80-55

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION

MATERIALS CONSIDERATIONS IN THE PLANNING, DESIGN, CONSTRUCTION, OPERATION, AND MAINTENANCE OF TRANSPORTATION FACILITIES

COURSE PRESENTED AT
TRANSPORTATION LABORATORY
5900 FOLSOM BLVD.
SACRAMENTO, CA. 95819

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Welcome to the Transportation Laboratory!

You have been invited to participate in a program designed both to disseminate and exchange information on materials, physical and environmental considerations in planning, design, construction, rehabilitation, operation and maintenance of transportation facilities. Since the primary purposes are to consider the materials and physical environmental aspects, the plan for guiding the discussion and outlining the general subject material is our responsibility. However, we are not assuming that the passing on of information will be a one-way proposition. It is important that you actively participate in the discussions. We hope in this manner to enrich everyone in attendance, not only with a knowledge of our functions and their significance, but also with your related experience.

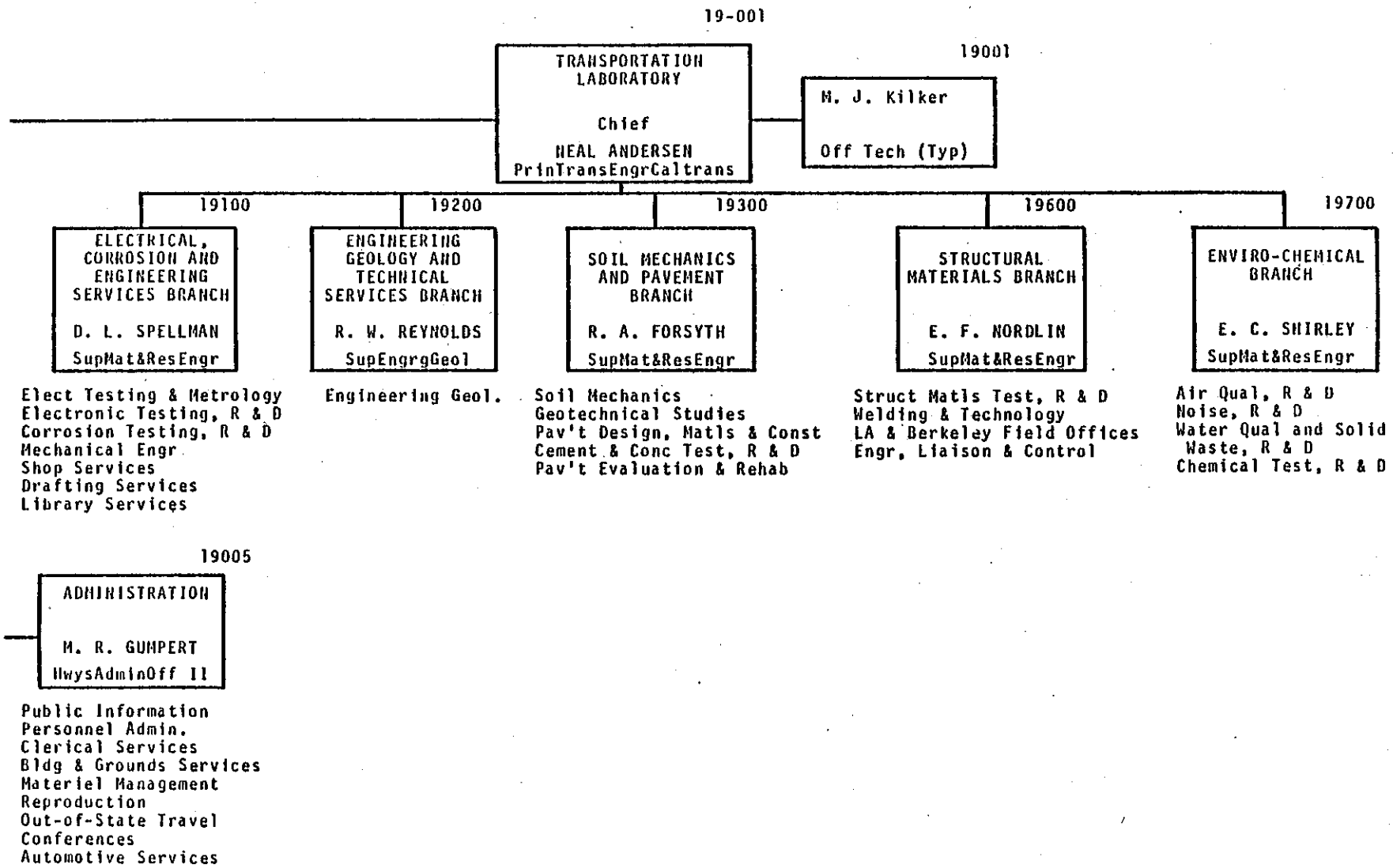
Please feel free at any time to ask questions and present ideas or comments that are relevant to the general subject.

More specifically, this training course has the following objectives:

1. To provide a more rounded appreciation of some of the problems facing Caltrans, contractors, materials producers, and manufacturers through an organized and coordinated program designed to exchange information and ideas between the TransLab staff and the engineers and those in other disciplines engaged in planning, design, construction, rehabilitation, operation, maintenance, and related activities.

2. To give you an opportunity to become acquainted with the personnel, facilities, and available services of the Transportation Laboratory.

NEAL ANDERSEN
Chief, Office of Transportation Laboratory


19-001
TRANSPORTATION LABORATORY
Chief
NEAL ANDERSEN
PrinTransEngrCaltrans
19001
M. J. Kilker
Off Tech (Typ)
19100
ELECTRICAL, CORROSION AND ENGINEERING SERVICES BRANCH
D. L. SPELLMAN
SupMat&ResEngr
Elect Testing & Metrology
Electronic Testing, R & D
Corrosion Testing, R & D
Mechanical Engr
Shop Services
Drafting Services
Library Services
19200
ENGINEERING GEOLOGY AND TECHNICAL SERVICES BRANCH
R. W. REYNOLDS
SupEngrgGeol
Engineering Geol.
19300
SOIL MECHANICS AND PAVEMENT BRANCH
R. A. FORSYTH
SupMat&ResEngr
Soil Mechanics
Geotechnical Studies
Pav't Design, Matls & Const
Cement & Conc Test, R & D
Pav't Evaluation & Rehab
19600
STRUCTURAL MATERIALS BRANCH
E. F. NORDLIN
SupMat&ResEngr
Struct Matls Test, R & D
Welding & Technology
LA & Berkeley Field Offices
Engr, Liaison & Control
19700
ENVIRO-CHEMICAL BRANCH
E. C. SHIRLEY
SupMat&ResEngr
Air Qual, R & D
Noise, R & D
Water Qual and Solid Waste, R & D
Chemical Test, R & D
19005
ADMINISTRATION
M. R. GUMPERT
HwysAdminOff II
Public Information
Personnel Admin.
Clerical Services
Bldg & Grounds Services
Materiel Management
Reproduction
Out-of-State Travel
Conferences
Automotive Services

January 1980

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

		Ext.
Chief, Transportation Laboratory	NEAL ANDERSEN	2403
Electrical, Corrosion & Engineering Services Branch, Chief -	Donald L. Spellman	2405
Engineering Geology & Technical Services Branch, Chief -	Robert W. Reynolds	2482
Soil Mechanics and Pavement Branch, Chief -	Raymond A. Forsyth	2361
Structural Materials Branch, Chief -	Eric F. Nordlin	2305
Enviro-Chemical Branch, Chief -	Earl C. Shirley	2476

For Information Concerning:	Please Contact:	Ext.
ADMINISTRATION	Myrna Gumpert	2409
AGGREGATES	Marv McCauley	2480
AGGREGATE BASES	Bob Doty	2363
AGGREGATE SUBBASES	Max Alexander	2356
AIR QUALITY STUDIES	Roy Bushey	2432
Instrumentation & Field Studies	Ken Pinkerman	2322
Microscale Modeling and Statistical Analysis	Paul Benson	2459
Mesoscale Analysis	Bennett Squires	2416
Energy	Paul Benson	2459
Mobile Emissions	Deane Coats	2420
ASBESTOS CEMENT PIPE	Bob Stoker	2304
	Rich Spring	2301
ASPHALT CONCRETE MIX DESIGN	Bob Doty	2363
	Tom Scrimsher	2473

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
ASPHALTIC EMULSIONS	Bob Doty	2363
	Glenn Kemp	2351
BARRIERS	Bob Stoker	2304
Dynamic Tests	Roger Stoughton	2308
Guard Rails		
Median Barriers		
Bridge Rails		
Energy Absorbers		
BEARING PADS	Bob Stoker	2304
	Rich Spring	2301
BITUMINOUS MIXTURES	Bob Doty	2363
	Tom Scrimsher	2473
BLEEDING PAVEMENTS	Bob Doty	2363
	Tom Scrimsher	2473
BOLTED JOINTS	Bob Stoker	2304
	Rich Spring	2301
CEMENT TREATED BASES	Bob Doty	2363
	Max Alexander	2356
CHEMISTRY	T. L. Shelly	2346
Adhesive for Raised Pavement Markers	T. L. Shelly	2346
Bridge Joint Sealers	R. W. Ford	2347
	T. L. Shelly	2346
Chemical Analysis and Contract Control Testing	R. W. Ford	2347
	R. Warness	2344
Epoxy Resins: Road and Bridge Repair	T. L. Shelly	2346
	Don Chatto	2343
Chemical Analysis of Cement Paints	R. W. Ford	2347
	Don Chatto	2343
	T. L. Shelly	2346
Pavement Marking Materials	Don Chatto	2343
	T. L. Shelly	2346
Structural Paints	T. L. Shelly	2346
	R. Warness	2344
CLAY PIPE MATERIALS	Bob Stoker	2304
	Rich Spring	2301

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
COMMODITIES	Bob Stoker	2304
	Richard Hickman	2303
CONCRETE		
Admixtures	Don Roberts	2338
Aggregates	" "	2338
Cements	" "	2338
Cylinder Breaks	Dave Wong	2337
Problems, General Repairs, Rehabilitation	Jim Woodstrom	2479
	Bill Neal	2324
	Don Roberts	2338
Specifications	Jim Woodstrom	2479
Testing	Don Roberts	2338
CONCRETE PAVING & COMPACTION	Bob Doty	2363
	Jim Cechetini	2357
CONCRETE PIPE	Bob Stoker	2304
	Rich Spring	2301
CORRELATION TESTING	Bob Doty	2363
	Max Alexander	2356
CORROSION	John Apostolos	2366
	Forrest Myhres	2342
	George Chang	2342
CORRUGATED METAL PIPE	Bob Stoker	2304
	Rich Spring	2301
DEFLECTION MEASUREMENTS	Jim Matthews	2364
	Paul Mason	2471
DRILLING	George Miller	2486
EARTHQUAKE ENGINEERING, SOIL DYNAMICS & LIQUEFACTION	Joe Hannon	2353
	Ken Jackura	2488
	Jerry Chang	2491
ELECTRICAL CALIBRATION & REPAIR	Bill Chow	2435
ELECTRICAL TESTING	Merle Wilson	2439

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
EMBANKMENTS	Rod Prysock	2474
	Joe Hannon	2353
ENGINEERING REPORT REVIEW	Bob Pieser	2412
EXPANSION JOIN SEALERS	Bob Stoker	2304
	Rich Spring	2301
EXPLOSIVES & BLASTING	Marv McCauley	2480
	Ted Beeston	2465
	Tom Hoover	2341
FENCING MATERIALS	Bob Stoker	2304
	Rich Spring	2301
FIBERGLASS	Bob Stoker	2304
	Richard Hickman	2303
FIELD INSTRUMENTATION	Joe Hannon	2353
	Bobby Lister	2490
	Rod Prysock	2474
FILTER FABRICS	Tom Hoover	2341
	Rod Prysock	2474
FINITE ELEMENT ANALYSIS	Chris Masklee	2340
	Tom Hoover	2341
	Rod Prysock	2474
FOUNDATIONS	Rod Prysock	2474
	Joe Hannon	2353
	Ken Jackura	2488
	Will Yee	2489
GEOLOGIC HAZARDS REPORT	Jim Gamble	2469
GEOLOGY	Marv McCauley	2480
	Duane Smith	2484
	Byron Works	2481
	Jim Gamble	2469
GEOPHYSICS	Ted Beeston	2465

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
GLARE SCREENS	Bob Stoker	2304
GRATES	Bob Stoker	2304
	Rich Spring	2301
GROUNDWATER	Bennett John	2332
	Rod Prysock	2474
	Joe Hannon	2353
	Marv McCauley	2480
GUIDE MARKERS	Richard Hickman	2303
HIGH STRENGTH STEELS	Bob Stoker	2304
	Rich Spring	2301
HORIZONTAL DRAINS	Duane Smith	2484
INFORMATION RETRIEVAL	Eva Caro	2452
INSTRUMENTATION	Bill Chow	2435
	Al Sequeira	2438
LABORATORY EQUIPMENT DESIGN	Wes Faist	2411
LABORATORY EQUIPMENT MAINTENANCE	Joe Langston	2445
LANDS & BUILDINGS	Myrna Gumpert	2409
LANDSLIDES	Joe Hannon	2353
	Rod Prysock	2474
	Marv McCauley	2480
	Byron Works	2481
	Duane Smith	2484
LIBRARY SCIENCE	Eva Caro	2452
LIME TREATED SUBBASES	Bob Doty	2363
	Max Alexander	2356
LIQUID ASPHALTS	Bob Doty	2363
	Glenn Kemp	2351

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
MACHINE SHOP	Geo. Oki	2446
MANHOLE COVERS	Bob Stoker	2304
MATERIALS MANUAL REVIEW	Bob Pieser	2412
MATERIALS RESEARCH REPORTS	Eva Caro	2452
MATERIALS TESTING REPORTS	Eva Caro	2452
METALLURGY	Rich Spring Bill Crozier Charles Kendrick	2301 2307 2312
MINERALS	Jim Gamble	2469
MOISTURE DETERMINATIONS OR NUCLEAR COMPACTION CONTROL	Joe Hannon Bobby Lister	2353 2490
NOISE STUDIES		
Quality Assurance (Calibration & Procedures)	Mas Hatano Rudy Hendriks	2413 2475
Prediction & Barrier Models	Mas Hatano	2413
Computer Application	Rudy Hendriks	2475
Report Review	Mas Hatano	2413
OVERLAY THICKNESS	Jim Matthews Paul Mason	2364 2471
PAVEMENT INTERLAYER FABRICS TO RETARD REFLECTION CRACKING	Jim Matthews	2364
PAVEMENT MANAGEMENT SYSTEM	Jim Matthews	2364
PAVEMENT MARKERS	Bob Stoker Richard Hickman	2304 2303
PAVING ASPHALT	Bob Doty Glenn Kemp	2363 2351

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
PERMEABLE MATERIAL	Rod Prysock	2474
	Bennett John	2332
PERSONNEL COORDINATION	Myrna Gumpert	2409
PLANT INSPECTION OF FABRICATED & MANUFACTURED MATERIALS	Jay Folsom	2314
	Bill Cook	2309
PLASTIC PIPE	Bob Stoker	2304
	Rich Spring	2301
PRESTRESSED CONCRETE MEMBERS	Bob Stoker	2304
	Rich Spring	2301
PROFILOGRAPH	Bill Neal	2324
QUALITY ASSURANCE	John Webster	2407
ROCK STRUCTURES	Marv McCauley	2480
	Byron Works	2481
RADIOGRAPHIC INSPECTION	Bill Crozier	2307
	Charles Kendrick	2312
RECORD SAMPLING	Bob Page	2359
	John Webster	2407
REINFORCED EARTH	Jerry Chang	2491
	Joe Hannon	2353
REFLECTORS	Bob Stoker	2304
	Richard Hickman	2303
RESEARCH COORDINATION	John Webster	2407
	Doug Howard	2408
RESEARCH PERIODICALS	Eva Caro	2452
RESILIENCE TESTING	Jim Matthews	2364
	Paul Mason	2471

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
R-VALUE PROCEDURES & EQUIPMENT	Bob Doty	2363
	Max Alexander	2356
SAND DRAINS	Rod Prysock	2474
	Joe Hannon	2353
SEAL COATS	Bob Doty	2363
	Glenn Kemp	2351
SEISMIC EXPLORATION	Ted Beeston	2465
SIGNS	Bob Stoker	2304
	Richard Hickman	2303
SKID TESTING	Bob Page	2359
	John Webster	2407
SLOPE PROTECTION OR SLOPE STABILIZATION	Marv McCauley	2480
	Joe Hannon	2353
	Rod Prysock	2474
	Tom Hoover	2341
SLURRY SEALS	Bob Doty	2363
	Tom Scrimsher	2473
SOIL & LAB SOIL TESTING	Rod Prysock	2474
	Joe Hannon	2353
	Will Yee	2489
SOIL COMPACTION	Joe Hannon	2353
	Bobby Lister	2490
SOILS RESEARCH	Joe Hannon	2353
	Rod Prysock	2474
	Jerry Chang	2491
	Will Yee	2489
	Bennett John	2332
SOIL TESTING, FIELD	Bennett John	2332
	Rod Prysock	2474
STORES	Bob Hale	2444
	Joe Perry	2443

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
STRUCTURAL RESEARCH	Bob Stoker John Dusel	2304 2315
STRUCTURAL SECTIONS CONSIDERATIONS	Bob Doty	2363
STRUCTURES & FOUNDATIONS	Ad Goldschmidt George Miller Rich Fox Dick Wilhelms Dick Hager	2336 2486 2339 2339 2485
TRAFFIC SAFETY DEVICES	Bob Stoker Richard Hickman	2304 2303
TRAFFIC SIGNALS & VEHICLE DETECTORS	Bob Donner	2436
TRB REPORTS	Eva Caro	2452
TUNNELS	Ad Goldschmidt Will Yee Jerry Chang	2336 2489 2491
ULTRASONIC INSPECTION	Bill Crozier Charles Kendrick	2307 2312
VALUE ENGINEERING	John Webster Wes Faist	2407 2411
WATER QUALITY SECTION	Richard Howell	2421
Soil Nutrient Test Kit	Doug Parks	2360
Fiberglass Roving Procedure/Nozzle		
Erosion and Revegetation		
PS & E Specifications		
Water Quality Surveys/Biology	Gary Winters	2477
Test Methods/QAP/Equipment		
Pavement Runoff Model		
Bioassay Tests		
Deicing Salt		
Percolation Tests (Roadside Rests)	Bill Grouttkau	2417
Reclaimed Water Useage/Permits		
Drip Irrigation		

INFORMATION: (916)739-2400
ATSS: 497+Ext.
Public No.: (916)739+Ext.

For Information Concerning:	Please Contact:	Ext.
WATERWELLS	Richard Wilhelms	2339
WELD DEFECTS	Bill Crozier Charles Kendrick	2307 2312
WELDED JOINTS	Bill Crozier Charles Kendrick	2307 2312
WELDING QUALIFICATION TESTS	Bill Crozier Charles Kendrick	2307 2312

Notes on

PROCEDURES, TESTING METHODS AND USE OF MATERIALS FOR TRANSPORTATION PURPOSES

Prepared by the

ELECTRICAL, CORROSION & TECHNICAL SERVICES BRANCH

Presented at

Transportation Laboratory
Sacramento, CA

ELECTRONIC SYSTEMS-DESIGN, TESTING & RESEARCH

The main function of this section is the testing of traffic control and detection equipment for compliance with contract specifications and the research and development of test methods and specifications for highway traffic control devices.

Testing

The testing for compliance to contract special provisions consists of traffic controller systems of digital, minicomputers and types utilizing microprocessors; ramp metering and telemetering equipment; electromechanical and modular changeable message signs; automatic sprinkler system controllers; magnetometer and inductive loop vehicle detectors; conflict monitors, flashing beacons, truck height indicators, traffic count summators, etc.

Research

A study has been completed which tested all available inductive loop vehicle detectors to compare the sensitivity and stability of these detectors with the loops that are presently used by the Department of Transportation. Experimentation is currently being done with new types of loops to provide greater sensitivity for detection of small motorcycles. The detection of small motorcycles has increasingly become a problem area as more and more of these are being licensed for use on the streets and highways.

A study is also being made of digital communication application to traffic control. We are looking into troubleshooting and maintenance procedures in digital communications equipment used to exchange information between local and master traffic controllers.

Developmental work is continuing on methods to obtain more reliable traffic control equipment. One test method that determines the powerline transient susceptibility of traffic control systems has been found very effective in assuring more reliable operation of solid state controllers and detection equipment.

Some of the accomplishments of this section to date include a Vehicle Classifying Counter which categorizes vehicles, on the basis of their wheelbase, into cars or trucks, then counts the number of axles of the vehicle and adds a count to one of the various classifications of vehicles (two-axle car, three-axle car, two-axle truck, three-axle truck, four-axle truck or five-through seven-axle trucks).

The section has been instrumental in promoting the application of minicomputers to act as a traffic signal controller at isolated intersections. The first installation of its kind was put into operation on March 15, 1971 and has exceeded the expectations of all concerned. The success of this installation has led the State into initiating purchase of 150 minicomputers to be used as traffic signal controllers and ramp metering controllers throughout the State Highway System. This study led to the application of microprocessors in traffic control which is the current 170 System Program.

Studies have been completed on a high-speed truck weighing system which will weigh trucks at speeds up to forty miles per hour. In addition a "Traffic Congestion Detector" has been developed which will detect if a line of traffic is moving more slowly than some predetermined speed and will illuminate a sign to warn approaching motorists who are unaware of the hazard. This system has application on blind curves, underpasses or overcrossings where oncoming vehicles have a restricted or no view of the roadway ahead.

Also, under development are improved methods of vehicle detection, an improved traffic counter and a "temporary loop" to be placed on the roadway to detect vehicles for short periods.

Systems Development and Implementation

This section is currently engaged in the development of a computer based Toll Audit Registration and Collection (TRAC) Project for toll bridges in California. We have designed and constructed a minicomputer-microprocessor prototype system to record all toll transactions on state-owned toll bridges in California. This prototype system has been in operation for two years in one lane of the San Francisco-Oakland Bay Bridge. The final installation will amount to approximately 3 million dollars worth of equipment throughout the State.

This section works closely with Headquarters Traffic and the districts in developing electronic equipment for highways use.

ELECTRICAL TESTING & RESEARCH INSTRUMENTATION

In keeping with the assigned function of the Transportation Laboratory this section is service oriented, both to the Laboratory and to the Department. Our work is roughly divided into three areas:

A) Measurements and Instrumentation
B) Instrument Calibration, Repairs and Maintenance
C) Quality Assurance of Electrical Materials

A. Measurements and Instrumentation

Engineering and research starts with design and basic to design is measurement. Measurement implies the "weighing" or comparison of a quantity, property or condition with a standard value of some kind. In instrumentation language this quantity, property, or condition is called the "measurand".

An instrument is a device for measuring and sometimes for recording and controlling the value of the measurand under observation. In our electrical-electronic context, the word "instrument" usually means a combination of an electrical meter or digital readout in combination with electronic circuits.

What does the word "instrumentation" mean? Oftentimes we not only want to measure a quantity but to automatically record, control, indicate or mathematically manipulate it. Seldom is one single instrument able to do this. Rather, a set of instruments is used, each a necessary part of the system. Hence, instrumentation is often the interconnection of many instruments to perform a complex measurement function.

What do we want to achieve with instrumentation? Or turning the question around, what do we want to achieve in research or testing of which instrumentation is a part? Some of the objectives may be:

1) Collect data for use in a new structural design.
2) Measure the adequacy of a structure, a design, or component part.
3) Refine a design (save money) with minimum component tolerance.
4) Evaluate how well a system works.
5) Uncover any design weakness at an early stage.
6) Increase the knowledge of how a structure works.
7) Confirm theoretical design and calculations.
8) Test for specification compliance.
9) Conduct engineering investigations.
10) Ultimately to improve the effectiveness, efficiency or economy of a highway related component or function.

Our instrumentation work "supports" the above objectives for the Laboratory and the Department. Over the years we have developed much instrumentation expertise and have acquired much "hardware" that can measure many different parameters. Here is a partial list of some engineering parameters we can measure and record:

strain	acceleration	time	humidity
temperature	force	displacement	light
velocity	distance	vibration	pressure

Because most of our work is in providing instrumentation services to the Department, the following describes some of the capabilities, types of work, and services we can provide:

1) Vibration Complaints

Districts occasionally receive complaints from people concerning alleged shaking or damage to their homes, buildings, or other facilities caused by highway construction or operation. Figure 1 shows our equipment to monitor very small earthborne vibrations. We have used this equipment to measure vibrations in and around: a movie studio, aerospace manufacturing plants, machine shops, an art museum, homes, grain silos, a pharmaceutical plant, and a cosmetic plant. Most often the vibrations have been found to be very small indicating that the feeling of significant movement is actually psychological rather than real. When the complainants are shown the small vibrations being recorded it generally aids in alleviating their concern. Comparison with findings of others on the effects of vibration is also helpful. Figure 2 shows two of the vibration sensors on the ground alongside of a railroad track to record train created earthborne vibrations.

2) Portable Scale

Figure 3 shows our portable weight scale. Each of the scales has a capacity of 100,000 pounds so that we can weigh up to a 200,000 pound axle load. The scale platform is 32" x 40". These scales are useful in weighing earth-moving vehicles to avoid damaging overloads on bridge or pavement structures or in weighing truck crane axle loads with crane boom loads at different angles, proposed for operation on a bridge deck under construction.

3) Tilt

An electronic level is available in this unit (Figure 4) that can measure tilt or levels to 1 second of arc. It has been used to measure culvert footing rotations. However, a more unique application was its use to measure the long-time tilt of a newspaper

press. A newspaper company complained that the dewatering operations for construction of a freeway near a river and their plant had caused their new million dollar newspaper press to tilt and malfunction. The press "tilt" was monitored with the level for several months to evaluate and assure its stability.

4) Rumble Strips

In this Office of Traffic rumble strip research project, a car was driven across several trial patterns of rumble strips to find the best pattern to give the most car noise, vibrations and front wheel bounce but at the same time to provide a safe warning to sleepy or careless motorists who may inadvertently wander onto the shoulder. Trial installations of the apparent optimum strip design were placed on selected highway shoulders on monotonous straightaway highways at right angles to the traveled way (Figure 5) so that the shake and sound would warn a driver when he is leaving the traveled way. Figure 6 shows the on-board recording instruments provided and installed by the Instrumentation Unit to measure car noise, vibration and wheel bounce.

5) Full Scale Dynamic Vehicular Crash Tests

Instrumentation is provided for the Structural Materials Branch's full scale dynamic crash tests. Retired Highway Patrol cars and other vehicles are instrumented to measure car and dummy decelerations under crash conditions. Sometimes the barrier system is also instrumented to measure strain, deflection or force on it from the vehicle crash. The car data is sent through a 1,000 foot long umbilical cable which connects the crash car and the trailermounted recording instruments. This data is ultimately used to evaluate design adequacy and effectiveness of the safety system being tested.

6) Earthquakes

Since the February 1971 San Fernando earthquake, the Office of Structures is continuing studies of earthquake effects on bridge structures. A part of this study involves recording seismic bridge motions, particularly those located on or near earthquake fault zones. The Instrumentation Unit selected and appropriated earthquake recorders, installed them on bridges, and had maintained them.* Figure 7 is an earthquake recorder made by Kinemetrics of Pasadena. Two of these recorders are installed in a bridge structure in San Fernando and two in a structure in San Francisco.

7) Measurement and Generation of Structural Motions

We have many instruments to measure frequency, displacement, velocity and accelerations. Typical uses for this class of instruments are in measuring bridge deflections and corresponding frequencies or similar parameters in the rumble strip tests.

Mechanical vibrations can be generated with a vertical shake table (Figure 9). It can shake a 150 pound object at a few cycles/sec. or a light object at 10 cycles/sec. or higher. This shake table was used extensively to vibrate and fatigue samples of bridge weldments for evaluation of orthotropic weld details.

*They are currently maintained by the California Division of Geology.

A field portable structural vibration shaker is shown in Figure 9A. It is a lowfrequency (0.1 to 30 cycles per second) shaker which can shake "small" structures at the above frequencies with a force of 30 force-pounds. In Figure 9A it is hung by a rope to the end of the mast arm. The up and down motion of the shaker in a "bootstrap" fashion sets the light standard into oscillation. Figure 9B shows the shaker attached to the light standard pole to push and pull it at its resonant frequency. At this resonant frequency (0.9 cycles per second), the luminare attached to the end of the mast arm moved up and down 1 foot for a total excursion of 2 feet.

8) Strains

There are many kinds of strain instruments available in the Instrumentation Unit for measuring strains in most engineering materials. As an example, a need for application of strain measurements was created when an overheight load on a truck struck the bottom of an overcrossing (Figure 8) on IS 80 near Dutch Flat. Concrete spalled out from the struck portion of the T beams and some of the rebars were bent out of shape. Bridge Maintenance wanted to splice new #10 rebars back into place with the assurance that the rebar would have an initial tensile load of 10,000 pounds. TransLab welding and instrumentation personnel worked out a procedure to lengthen the rebars by preheating and holding them to a precalculated temperature while simultaneously weld-splicing them into place. Upon cooling, the rebars then contract into a tensile state. Prior to initiating the above procedure, strain gages were cemented to the first several rebars. These gaged rebars were calibrated for load output in a tensile testing machine. Thereafter, when the rebars had been spliced into place and cooled, strain gage readings provided the assurance that the rebars had indeed developed the desired tensile stress.

9) Booster Axle Test

A booster axle is used to keep an otherwise overloaded truck within legal load limits by shifting a portion of the load to a booster axle. It is a trailing axle (Figure 10) which can be attached or detached from a truck as the need arises. Bridge Maintenance wanted to know how much the booster axle loads changed in crossing bridges and going up and down grades. Several makes of booster axles are on the market. One uses air bags and another uses a hydraulic cylinder to shift the overload onto the booster axle. On board pressure transducers (sensors) were installed by the Instrumentation Unit in the air and hydraulic lines to record pressure changes as a function of axle load changes. This provided the needed information to guide Bridge Maintenance in evaluating overload permit requests.

10) Structural Instrumentation

Large volumes of structural instrumentation work can be done by the Instrumentation Unit. This could be mainly for field projects in which transducers (measurement devices or sensors) are installed in or on the structure as it is being built. Data is usually collected concurrent with building of the structure. On bridge design evaluations, full scale dynamic load tests are made on the finished structure. For culvert studies, where long term fill settlement changes soil pressures, static data are collected over several years.

Structural instrumentation usually involves very large scale instrumentation including many transducers and a sophisticated data acquisition system. For example, in 1965 an orthotropic steel bridge was instrumented and tested (Figure 11) near Dublin on Route 680/580. On this bridge 1100 transducer circuits were installed to measure strains, deflections and loads. It took 30 miles of electrical

cable (Figure 12) to wire the 1100 transducers and to route their signals into a central recording trailer (Figure 13).

This project required a static load test in which a number of jacks were used (Figure 14) to load the bridge. Fast data recording speed was not essential so a lowspeed automatic data acquisition system (Figure 13), which recorded 5 data channels per second, was used. This bridge test produced 400,000 data points. All of it was recorded on computer magnetic tape for direct entry into a central computer for analysis.

Design evaluation testing of the Sacramento River Bridge (Figure 15), on IS 880 at Bryte Bend was completed in 1971. This unique composite steelbox girder-concrete deck bridge was dynamically loaded by driving two loaded trucks (Figures 16 and 17) across it many times. In this test a high-speed data acquisition system (Figure 18) was used to record dynamic bridge actions at a speed of 5000 data points a second. The system also includes a minicomputer which processes the incoming data into a predetermined format for recording on the system's magnetic tape recorder. This format is designed to be fed directly into the central computer for analysis. This project generated 338 million data points from 500 transducer circuits which required about 20 miles of cable for hookup. Needless to say not a single data point was hand collected.

Two large culvert instrumentation projects were completed in 1975 for the Office of Structures. One is an 8-foot diameter prestressed concrete culvert while the second is a #14 gage steel plate pipe culvert. On these two culverts TransLab installed about 1500 data circuits. Both of these projects are near Sunland on IS 210.

B. Instrument Calibration, Repairs and Maintenance

Measurements can be no better than the accuracy of the instrument used. Although electrical calibration is the Instrumentation Unit's prime capability, calibration of some nonelectrical parameters is also done. This service is primarily provided to the Laboratory but is also available to the Districts and Headquarters Departments on request.

Electrical calibration services are available for:

1) DC and AC voltmeters
2) DC and AC ammeters
3) DC and AC wattmeters
4) Ohmmeters

These can be calibrated in the "normal" ranges usually found in "normal" electrical work. However, 1000 AC amperes can be generated, if needed, to calibrate welding ammeters. Although not strictly calibration, a 0- 50,000 volt high-voltage test set is available. It is normally used to test breakdown of electrical insulation material. In addition, standards on ohms, henries and farads are available.

Physical calibration services are available for:

1) Force and Weight

Force calibration is provided by the six load cells shown in Figure 19. They are certified by the National Bureau of Standards. The cell capacities are 600, 1200, 6000, 24,000, 60,000, and 240,000 pounds. These cells are used to verify compression testing machines. In addition, three additional 240,000 pound cells identical to the

NBS 240,000 pound cell are available so that the four cells together can be used to measure 960,000 pounds.

A Gurley weight set (Figure 20), calibrated by the National Bureau of Standards, consisting of weights of 50, 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, and 0.01 pounds is available. This set is used primarily to calibrate scales sent in from District Construction and Materials Units for calibration.

2) Distance

Standardized 100, 200, and 300 foot surveying tapes, calibrated by the National Bureau of Standards, are available. Pedestals set at 50, 100, 200, and 300 foot intervals are available at the Laboratory (Figure 21) so that field surveying tapes can readily be calibrated with the NBS standardized tapes.

3) Pressure

Figure 22 shows the dead weight pressure calibrator. This device will generate oil pressures in the range of 100 to 10,000 psi and is used mainly to calibrate pressure transducers which are used to check contractor's prestressing jacks. It can also be used to calibrate pressure gages.

The repairs and maintenance functions are primarily in support of Laboratory work. However, if a local facility is not available to repair, adjust or calibrate an instrument for you, this unit may be able to do so, upon request.

C. Quality Assurance of Electrical Materials

The main function of this group is the quality assurance testing of all electrical and electronic materials used in highway facilities in compliance with Caltrans specifications or other nationally recognized specification.

The group performs routine and special tests on luminaires (isolux curves), sign lighting fixtures, ballasts, transformers, electrical conductors, photoelectric cells, signal heads, signal lamps and rubber gloves.

Typical Questions That May be Answered Through Instrumentation

Following are actual problems this unit assisted in solving that illustrates its capability range and perhaps how this capability may be helpful to you:

1. You are a bridge engineer with Bay Toll and you need to know the dynamic strains in some rebars embedded in the concrete deck pavement. What can you do?

2. Contractor wants to use unopened bridge for hauling earth fill with his off highway earthmovers or maybe put a crane on the unopened bridge. You have a weight measuring problem. What can you do?

3. During freeway construction a homeowner complains that earth movers or construction equipment is cracking his house. How can you evaluate the complaint?

4. You are to plan the repairs and increase the carrying capacity of an old reinforced concrete bridge but all design plans have been lost. How can you determine the rebar strains due to increased vehicle loads?

5. You have a problem with a hot-mixed plant and need to record temperatures of the aggregates and asphalt and the finished product. You obviously need rugged temperature devices. What is available?

6. A precision machine shop claims that the proposed routing of a freeway alignment would subject his shop to traffic-induced earthborne vibrations thereby ruining his operations. Can you answer his concern?

7. A drive-in movie owner has expressed concern that a proposed freeway alignment would subject his screen to auto lights from the freeway. Action on your part?

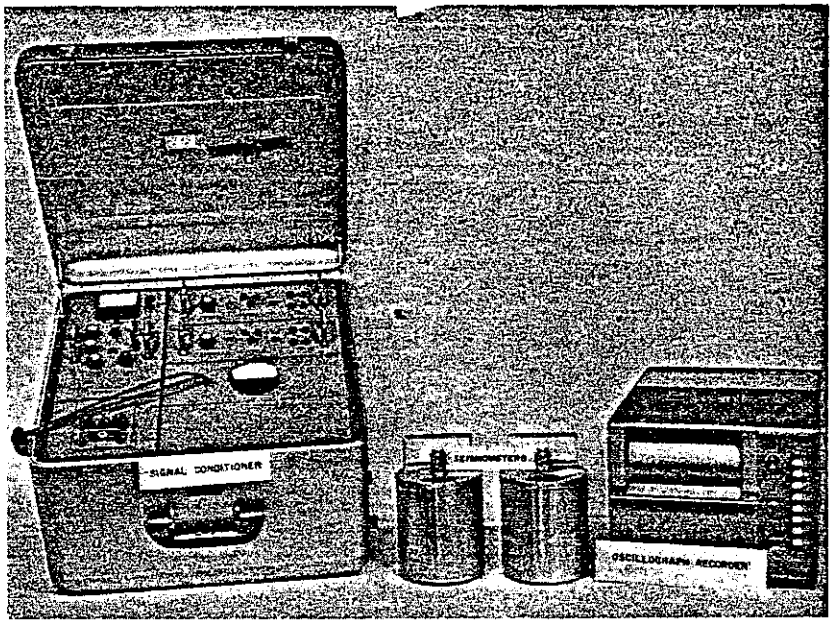


Figure 1. - Vibration equipment used to record shaking of houses, buildings or structures.

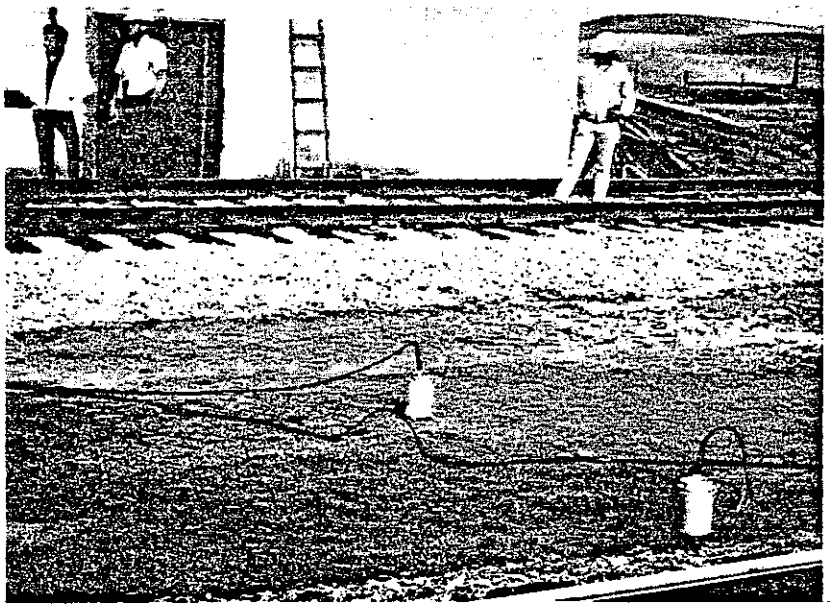


Figure 2. - Vibration sensors on the ground to record ground vibrations from train passages.

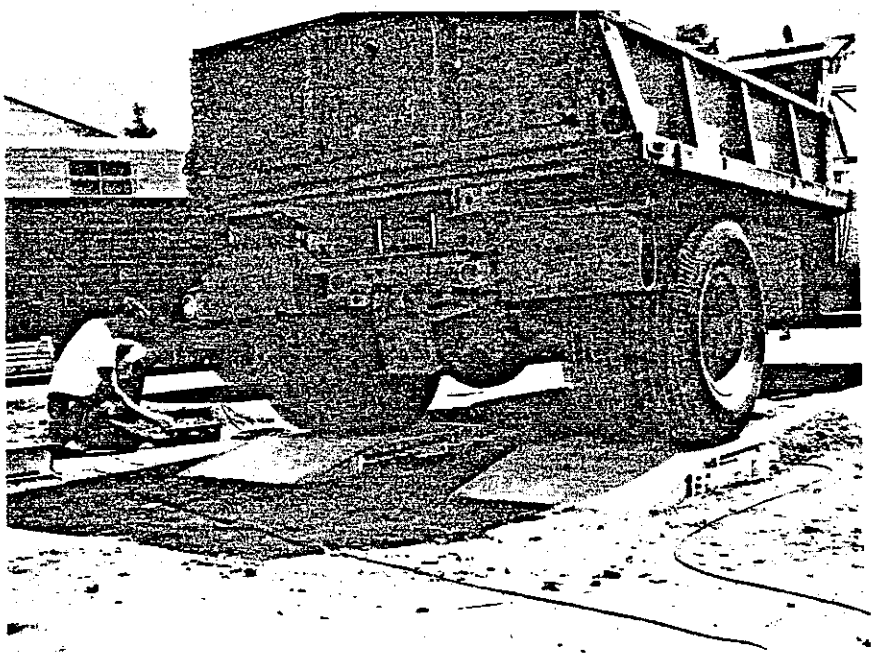


Figure 3. - Portable 200,000-pound capacity axial load scale.

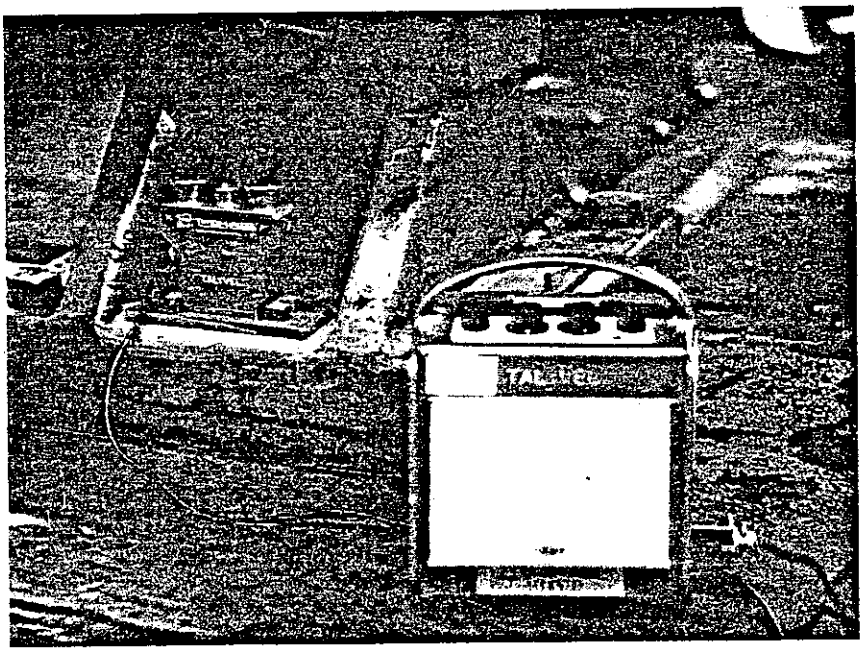


Figure 4. - Electronic level meter sensitive to 1 second of arc.

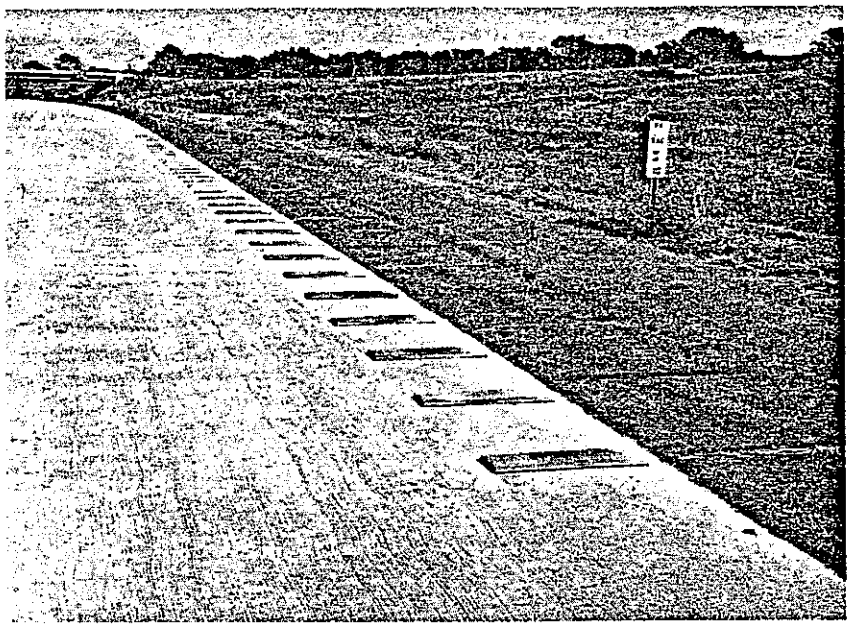


Figure 5. - *Test installation of rumble strips.

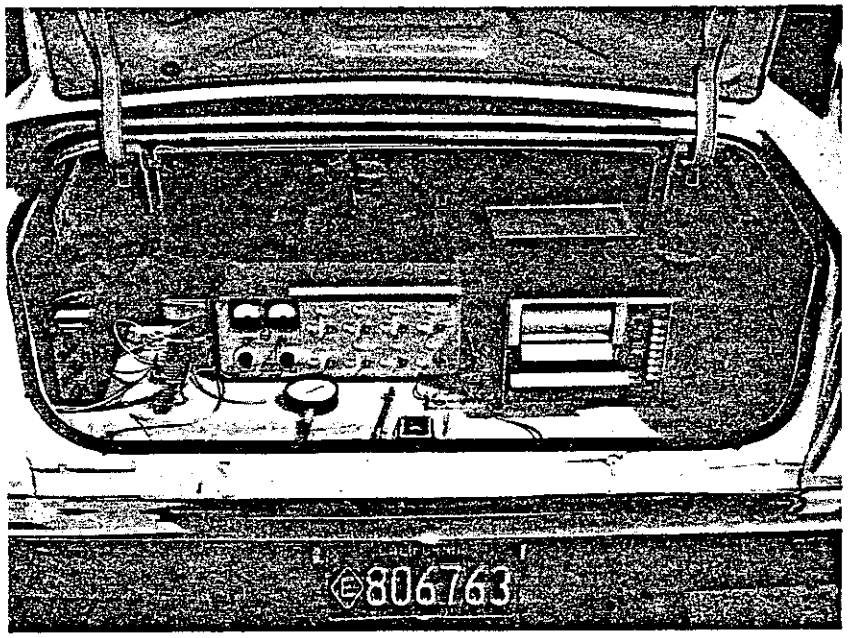


Figure 6. - Rumble strip recording instruments installed in trunk of test car.

*Test installation to determine best configuration and spacing only; trial installations will be placed on shoulder.

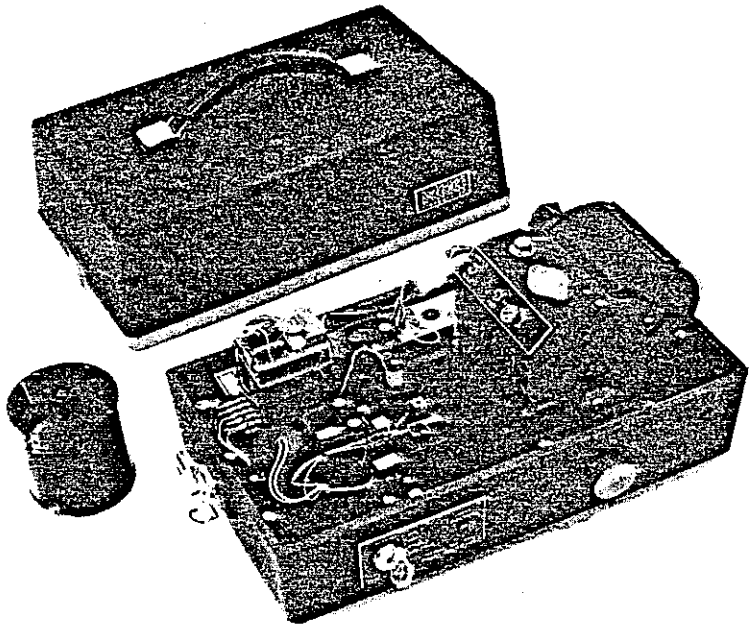


Figure 7. - Earthquake recorder.

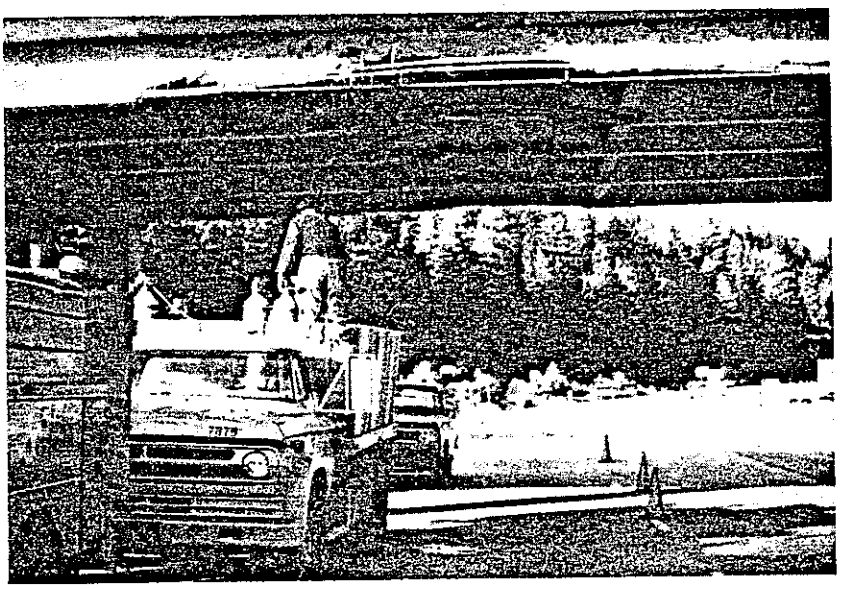
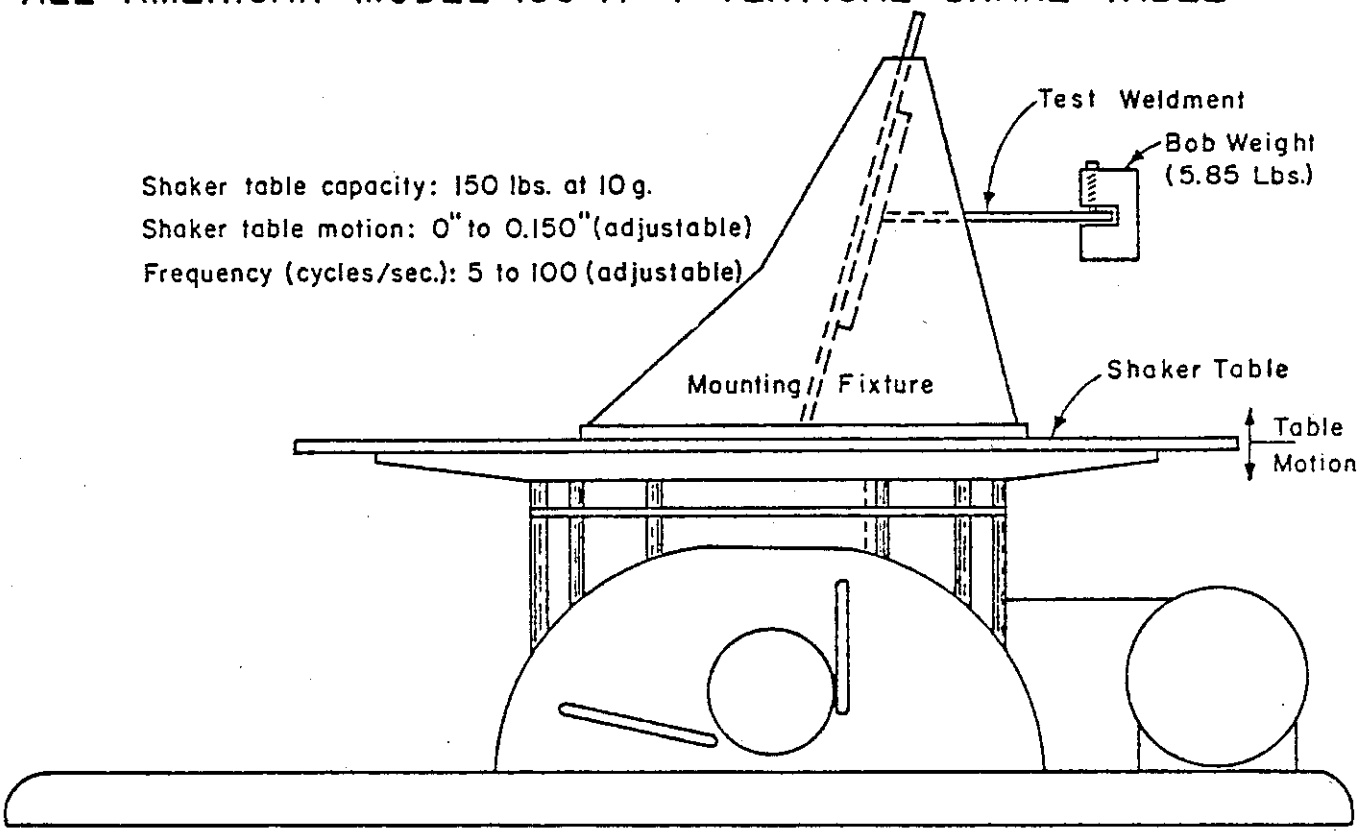


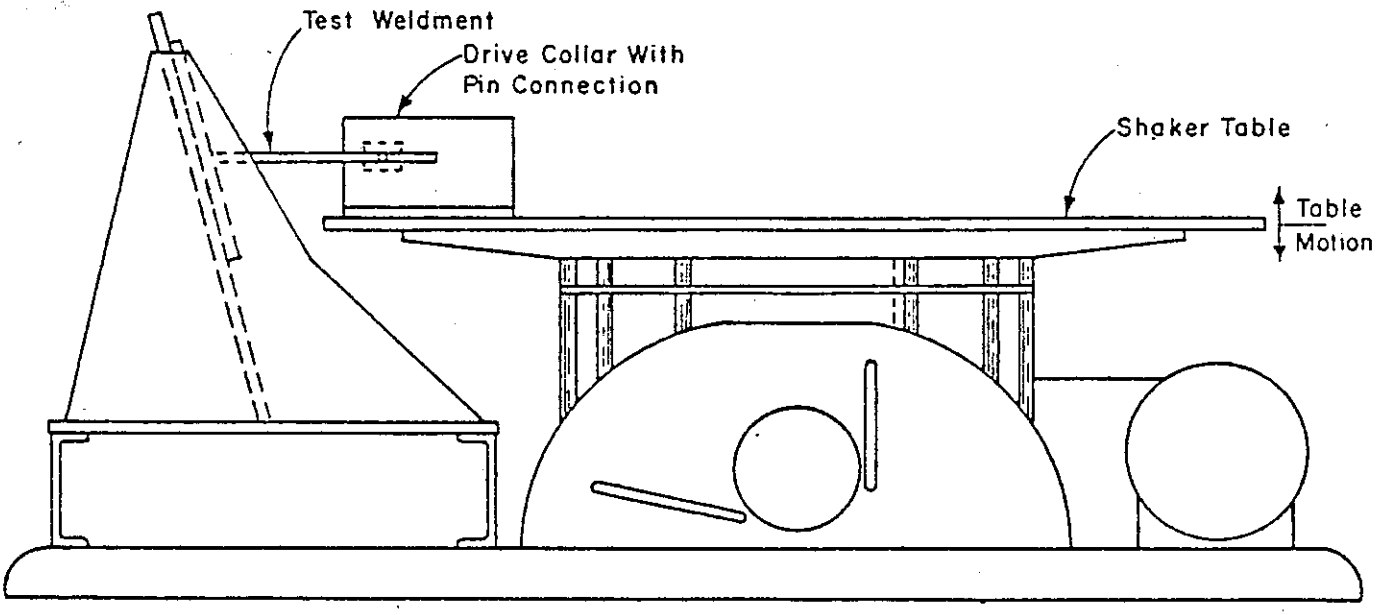
Figure 8. - OC structure damaged by an overheight load.

Figure 9

CALIF. DIV. OF HIGHWAYS
ALL AMERICAN MODEL 150 VP-T VERTICAL SHAKE TABLE



MOUNTING FOR FULL REVERSAL TESTING



ALTERNATE MOUNTING FOR ZERO-TENSION TESTING

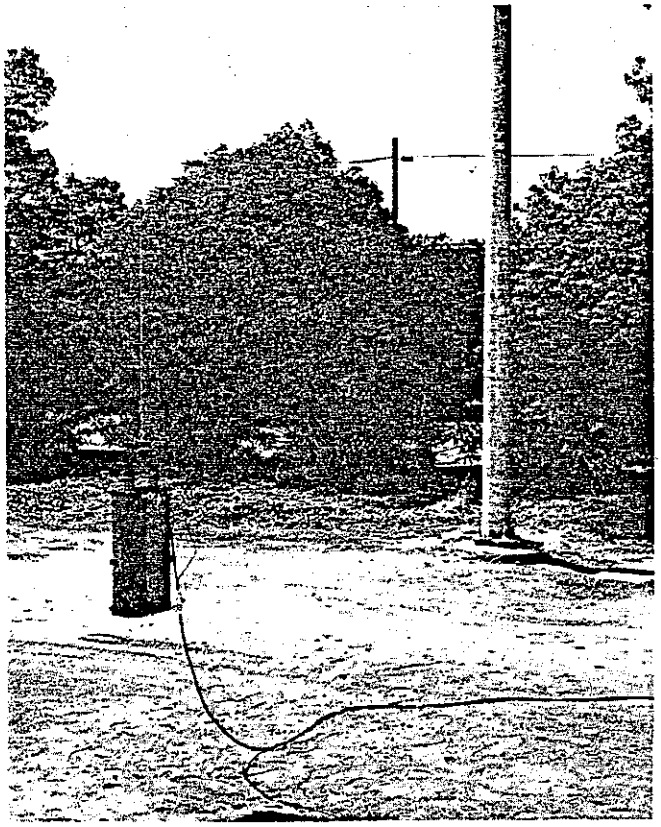


Figure 9A. Shaker hung by a rope to the end of a mast arm of a light standard. Up and down motions of the shaker sets the light standard into oscillations.

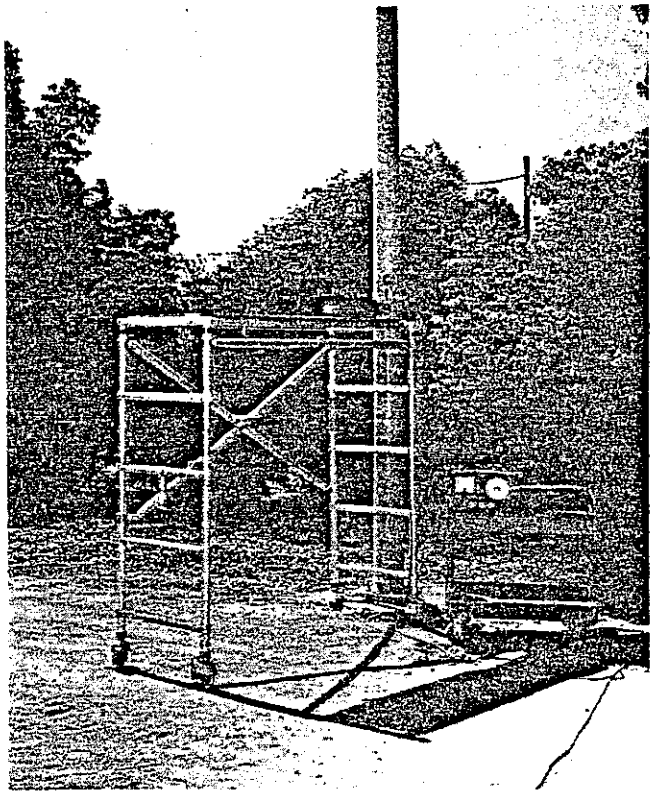


Figure 9B. - Shaker attached to light standard to push and pull the pole in its fundamental vibration mode.

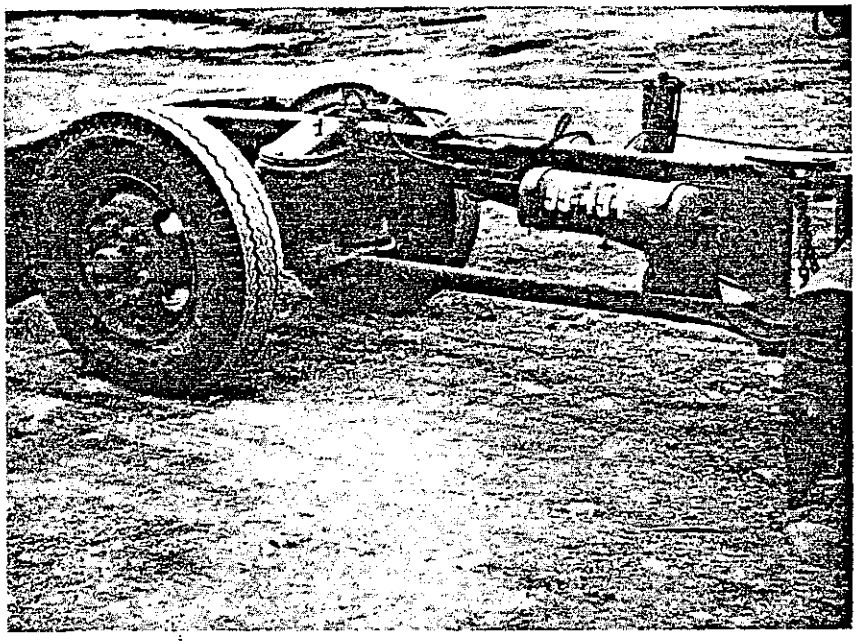


Figure 10. - Air bag type booster axle.

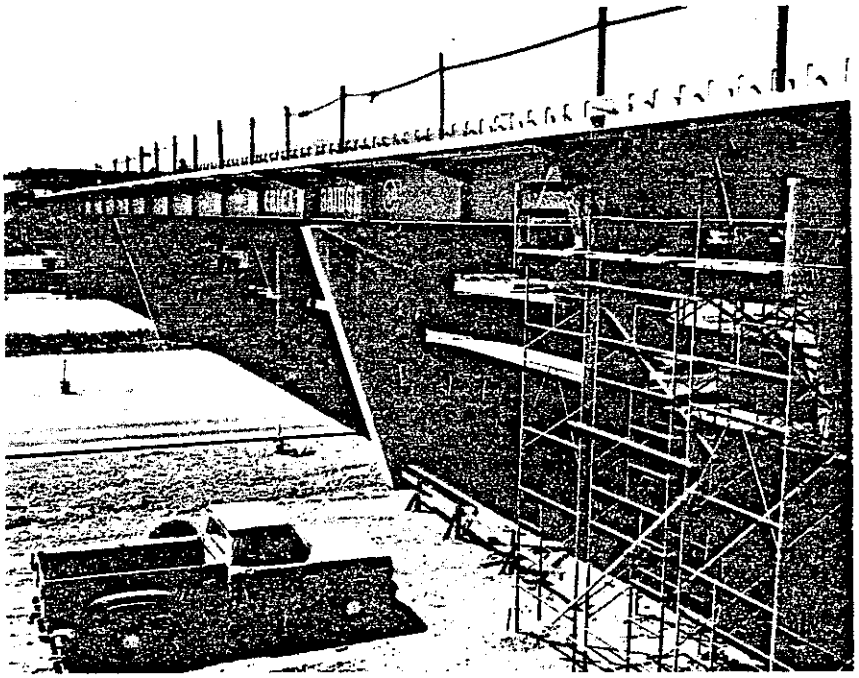


Figure 11. - Route 680/580 separation structure near Dublin, California.

Figure 12. - 30 miles of data cable.

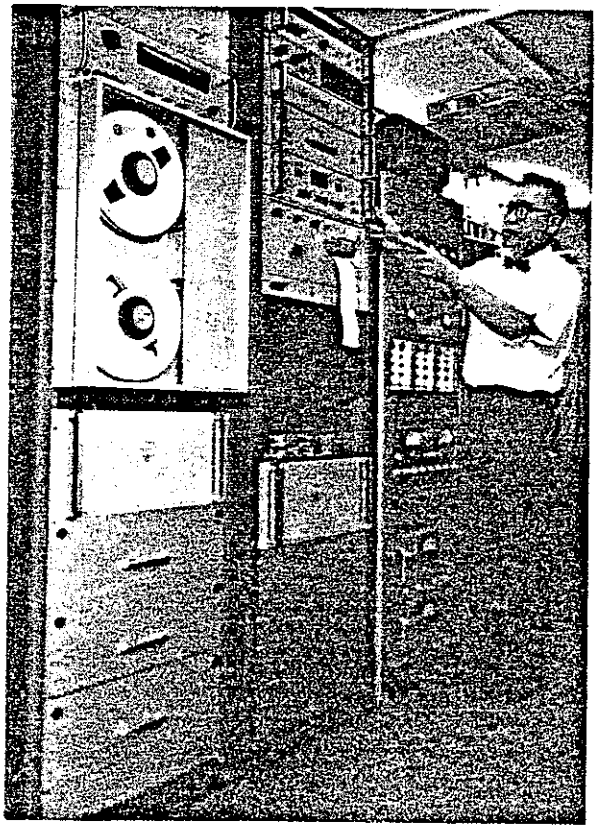


Figure 13. - Digital data acquisition system installed in central recording trailer.

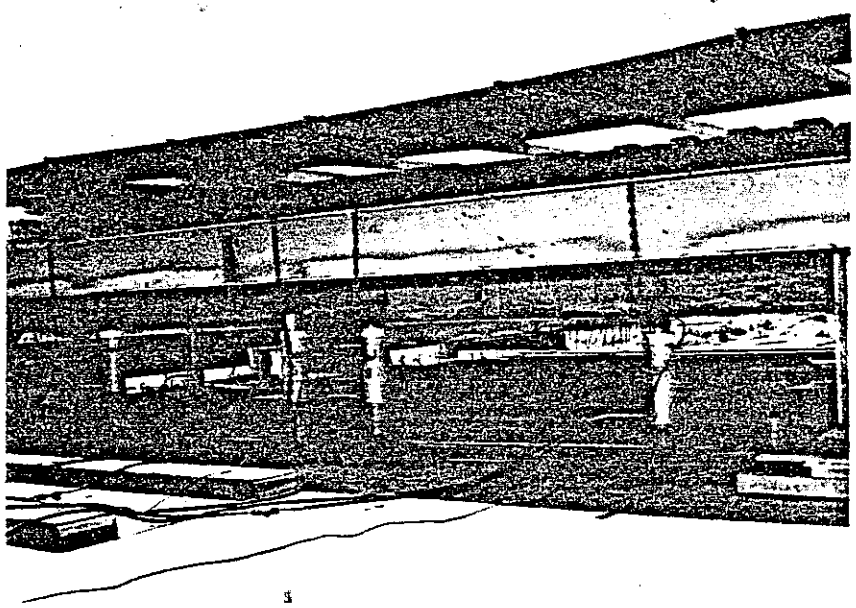


Figure 14. - Static loads applied to bridge deck with hydraulic jacks.

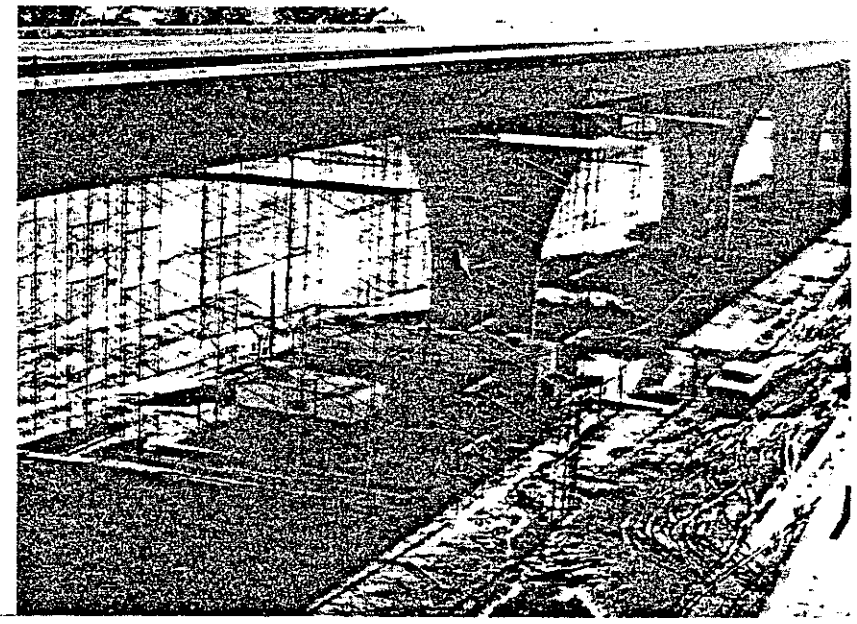


Figure 15. - Sacramento River Bridge on IS 880 near Bryte Bend, California showing instrumentation and service trailers.

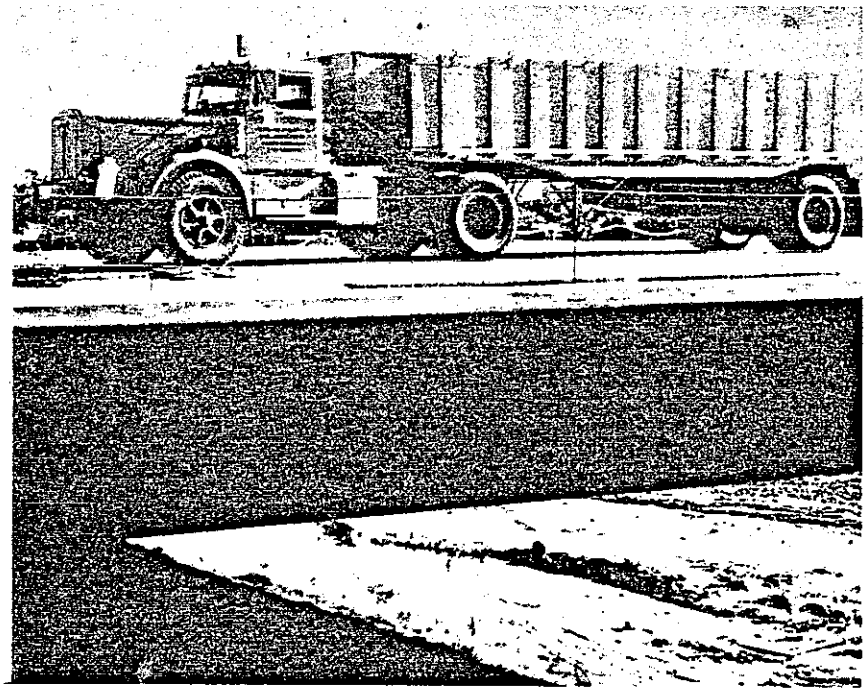


Figure 16. - AASHO HS-20 test truck with 8,000, 32,000 and 32,000 axial loads.

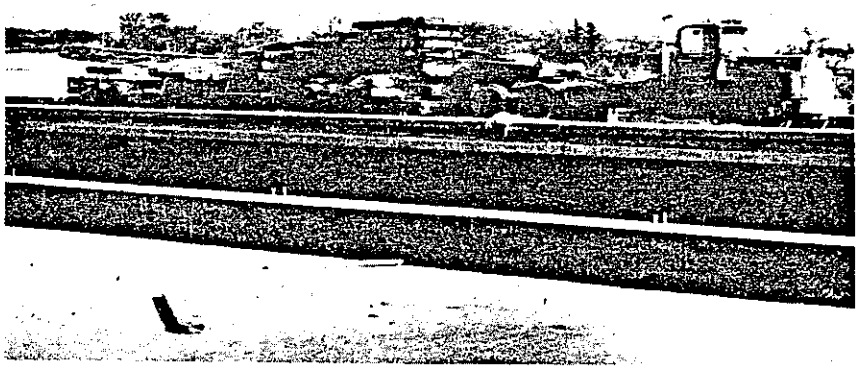


Figure 17. - 7 axle truck with heaviest axle weighing 44,190 pounds. Total truck weight is 220,530 pounds.

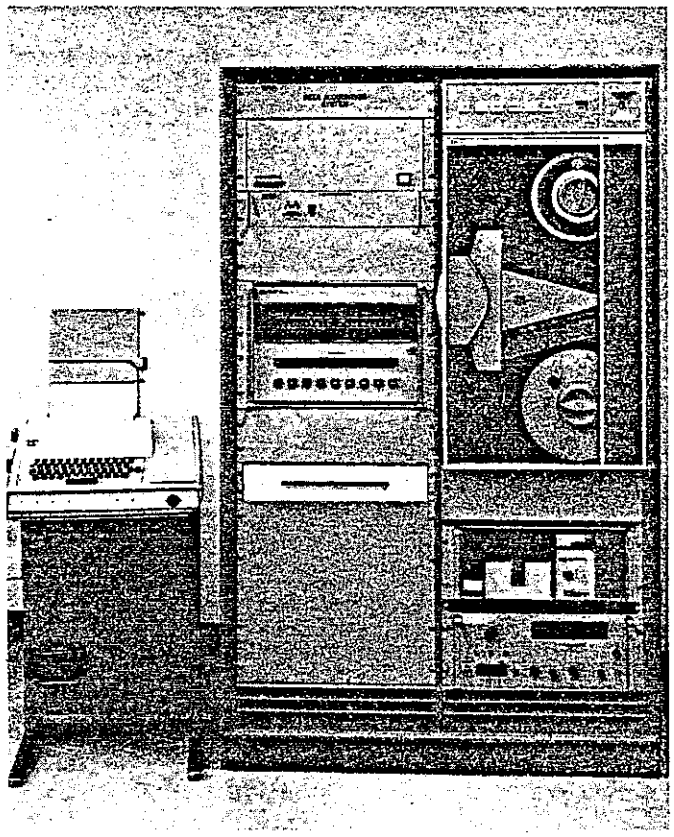


Figure 18. - High-speed digital data acquisition system.

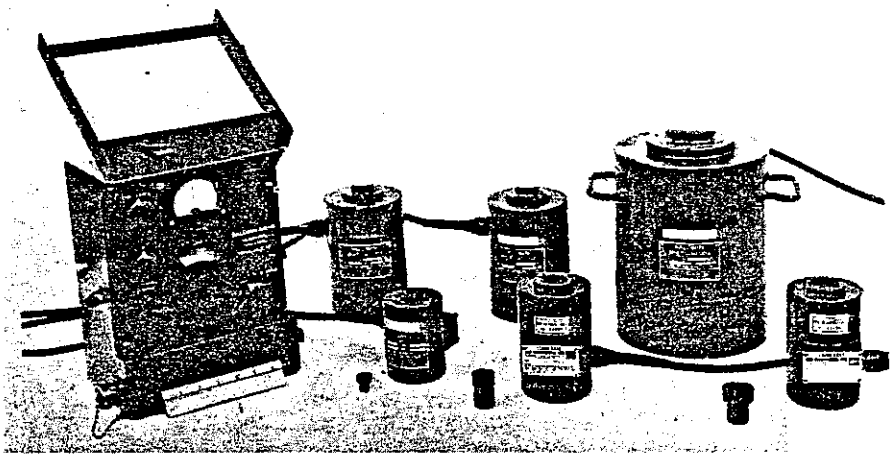


Figure 19. - National Bureau of Standards certified load cells.

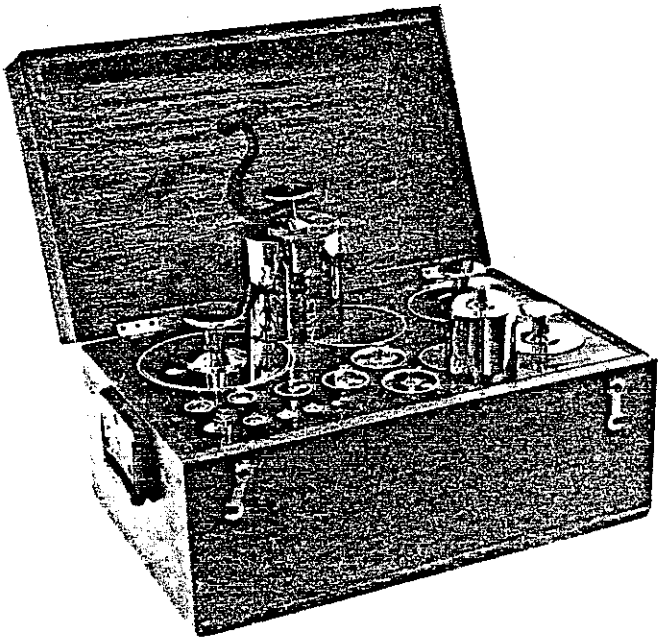


Figure 20. - Gurley weight set.

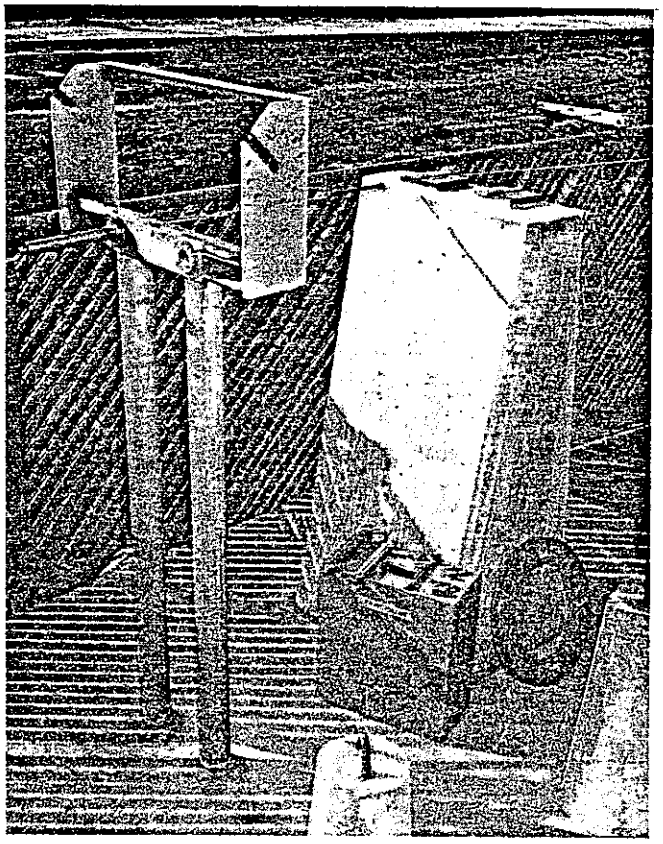


Figure 21. - Pedestal for surveying tape calibration.

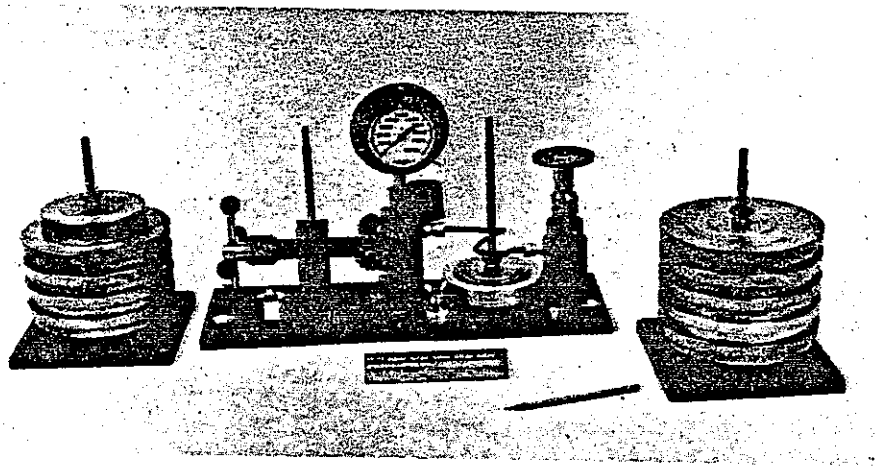


Figure 22. - Pressure calibrator.

CORROSION TESTING & RESEARCH SECTION

CORROSION AND ITS CONTROL

Introduction

"Corrosion" is defined as the deterioration of materials (usually metals) due to their reaction with the environment.

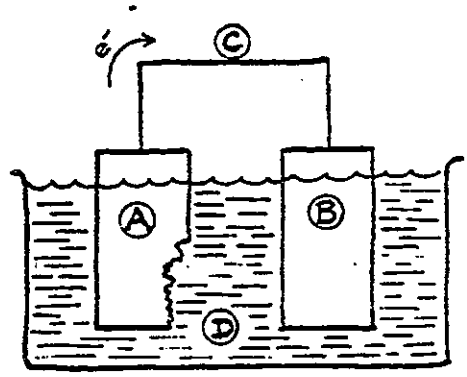
Metals are seldom found pure in nature. They are usually found as stable oxides, and energy input is required to refine them. These metals, now containing excess energy, are constantly trying to expel it and revert to their original stable oxide form. Thus, corrosion is a natural process, and affects most metals and other materials processed by man.

The cost of materials' corrosion, and corrosion control is staggering! Repair of corrosion-caused distress in California bridges alone will exceed $20,000,000. Replacement of the deck of the Golden Gate Bridge, deteriorated due to corrosion, will carry an even larger price tag. The Transportation Research Board has voiced concern for 200,000 bridges in the Unites States due to corrosion damage. The National Association of Corrosion Engineers has estimated the total economic damage to the U.S. This figure is $10 billion annually!!!

Corrosion Basics

Corrosion is an electro-chemical process. It involves electricity in the form of electrons flowing through a (metallic) conductor, and ions flowing in and through a liquid solution called an "electrolyte". A common battery is a typical corrosion cell; it contains the four distinct elements required for corrosion to occur:

A. The anode, or more active metal, which corrodes, giving off electrons to the metallic conductor and its ions to the electrolyte.



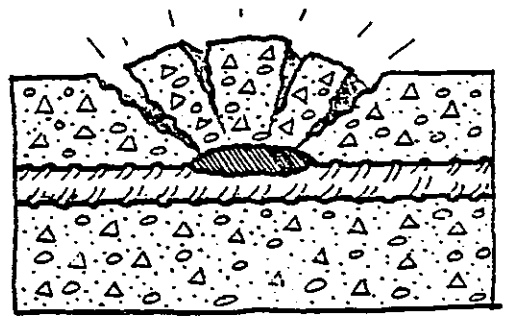
B. The cathode, or less active metal, which accepts the electrons, but does not corrode.

C. The metallic conductor, which transfers the electrons, e^-.

D. The electrolyte, or solution of ions which contacts both anode and cathode.

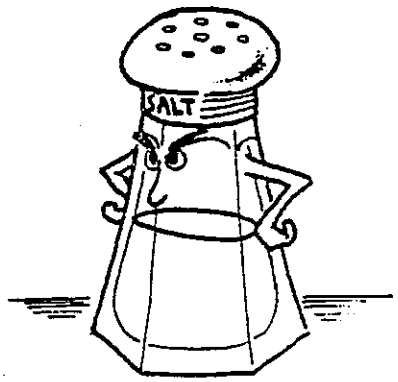
The metal ions entering into solution usually combine chemically with oxygen, and form the visible corrosion products we are familiar with, such as rust on steel, white powder on aluminum, and black "tarnish" on silver.

These corrosion products play an important part in the deterioration of reinforced concrete. The oxides of iron occupy 3 to 4 times greater volume than the original steel lost, and their strength of 4000 psi exceeds the tensile strength of concrete. This results in spalling bridge decks, long before the loss of section in the reinforcing creates any structural distress.



Environmental factors, and the nature of the metal oxides, play an important part in the rate of corrosion. Aluminum for example, is a very active metal, and combines quickly with oxygen -- however, its oxides are very stable, and form an ultrathin, transparent film over the base metal, halting further corrosion, by providing a barrier to the environment. Steel is also an active metal, and must be protected from the environment. Paint is one "barrier" used universally to protect metals, but no paint film is perfect, which may cause concentrated corrosion at the points of weakness such as pinholes, abrasions, etc. Steel corrosion products tend to be stable, and thus slow down the corrosion rate in alkaline environments. Concrete is highly alkaline, having a pH of 12.5, and thus tends to protect steel from corrosion.

One of the biggest enemies of steel is the chloride ion, usually denoted as Cl^-. It is usually encountered in the solution of common salt, NaCl, in water. Deicing operations and marine environments provide Cl^- in abundance. This ion enters into a complex reaction with corrosion products and prevents them from becoming stable, thus corrosion is allowed to continue at a rapid rate.



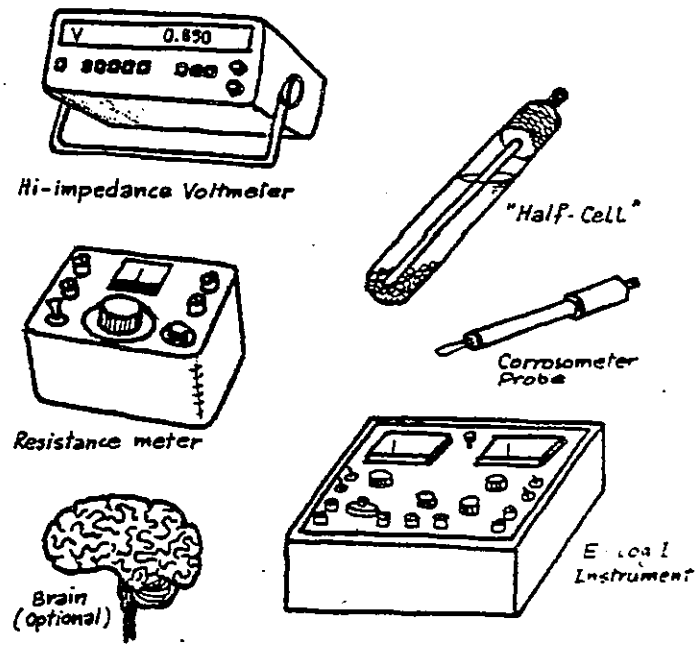
Detection of Corrosion

Visible detection is a simple matter of observing corrosion products on the surface of a metal, or rust stains appearing on the surface of concrete. To determine the actual loss of metal, the oxide layer must be removed by various abrasive and chemical methods. Not all

forms of corrosion are apparent through visual observation, however. The iron may have been corroded away from a cast iron pipe, for example, leaving only graphite, another constituent, which would conform to the original shape, and may even be capable of carrying low pressure liquids. Aluminum culverts tend to corrode from the soil side, thus an inspection of the inside may indicate a satisfactory condition, even though the pipe walls are actually corroding.

Electrical detection is the main tool of the Corrosion Engineer. Since corrosion is always associated with the flow of electrons in a D.C., or one specific direction, placing of instruments at strategic locations allows detection and measurement of corrosion. The principles of Direct Current instrumentation are simple, but the nature of the corrosion "cells" is such that highly specialized instruments and techniques are required in order that the effect of instrumentation does not influence the natural process under study. The strategic placement of appropriate instruments, and subsequent interpretation of test results in relation to the environment requires knowledge and experience, thus Corrosion Engineering is a combination of both art and science.

Some instruments commonly used in corrosion detection are ultrahigh impedance voltmeters, ammeters capable of detecting current flow in the order of picoamps, corrosometer probes which measure the rate of corrosion in given environments, special ohm and resistivity meters, standard reference electrodes (known as "half-cells" because they form 1/2 of a full battery



cell, with the metal being tested being the other half) as well as more common oscilloscopes and specialized "E-Log I" indicators.

Control of Corrosion

Corrosion can be controlled, or at least retarded, in a number of ways, depending on the actual conditions, some of which are discussed below:

1. Avoid contact between dissimilar metals. Copper, for example, in contact with steel or aluminum will act as the cathode and attack both the other metals.

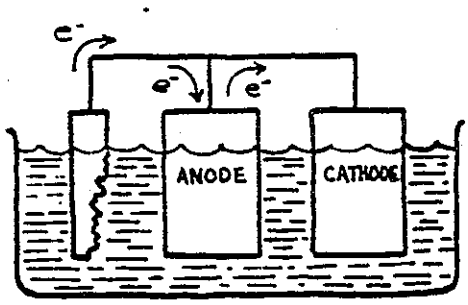
2. Provide a barrier between the metal to be protected and its environment; paint, galvanizing, metallurgical cladding, and asphalt dipping provide such barriers. Dense concrete, and additional concrete cover over reinforcing also help.

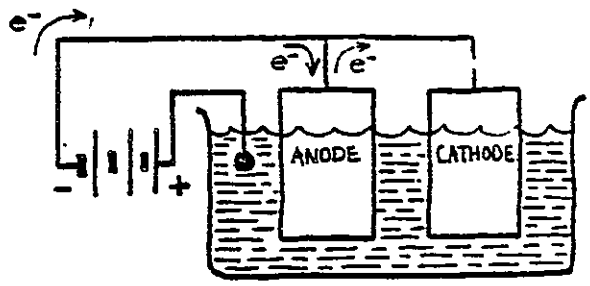
3. Introduce chemical "inhibitors" to the electrolitic environment; these chemicals, such as nitrites, ammonia, and many others have been routinely added to boiler water, car antifreeze, and other applications. We are now experimenting with their potential as concrete admixtures. Concrete itself is a good inhibitor.

4. Exclude salt, or chloride ions, and prevent its contact with most metals by every means possible. In recent experiments, Cl^- ions have been removed from salt-laden concrete through electrochemical techniques which take advantage of the (-) charge of these ions by attracting them to a (+) pole.

5. Cathodic protection; this is the only method capable of completely stopping the corrosion process. It basically amounts to replacing the electrons lost by the anode, thus turning it into a cathode --

hence the name of the process. These extra electrons are provided by another metal, called a "sacrificial anode" which corrodes -- zinc in galvanizing serves this purpose. Another source of electrons can be external, say from a battery, a solar cell, or from the utility company, which must be converted to D.C. prior to its use. Ships, storage tanks, pipelines, and recently experimental bridge decks are protected through the latter system, called "induced current" cathodic protection.





ELECTROMOTIVE FORCE SERIES

This is an abbreviated list of metals, presented in order of increasing energy, or tendency to corrode. At the top are metals such as gold, which tend to be cathodic and do not corrode. At the bottom are metals which tend to be anodic and generally do corrode.

When two dissimilar metals are connected electrically (i.e., come in contact, in an electrolyte, the more anodic metal will corrode, and the more cathodic will be protected. The theoretical voltage of such a "corrosion cell" will be the algebraic difference between their standard electrode potentials. Normally, the greater the voltage difference, the faster the anode will corrode.

Example: Zinc (Zn) and Iron (Fe) when connected would create a cell of -.763v-(-.440v) = 0.323 volts, and the zinc would corrode, protecting the iron. In an iron-copper cell, however, the iron would corrode at a theoretical potential of 0.78 volts.

	Metal		Std.Electr.Pot.,Volts
"Noble" end	Au	Gold	1.42
Usually are cathodes	Pt	Platinum	1.2
Do not corrode easily	Ag	Silver	.799
	Hg	Mercury	.798
	Cu	Copper	.34
	H	Hydrogen	.000 Reference
	Pb	Lead	- .126
	Ni	Nickel	- .23
	Cd	Cadmium	- .402
	Fe	Iron	- .44
	Cr	Chromium	- .71
	Zn	Zinc	- .763
Usually are anodes	Al	Aluminum	-1.66
Corrode readily	Mg	Magnesium	-2.38
"Active" end	K	Potassium	-2.92

It should be noted that this list is based on theoretical considerations. The purity of the metals, alloying, the nature of the electrolyte, temperature, and other factors can change the order of this list, as well as the potentials listed.

ENGINEERING & TECHNICAL SERVICES SECTION

The Engineering Services Section provides a number of engineering services such as mechanical engineering, drafting, machine shop and coordination of the research program. These services are needed in support of research and testing activities. The users are within TransLab.

Other engineering services provided by the section, such as the skid resistance unit and the library, support both TransLab and others' activities.

Final Record Sampling is required by the FHWA and is performed on construction projects on a statewide basis by crews assigned to the Engineering Services Section.

Following is a discussion of Engineering Services Section activities which are available to the Districts.

Skid Resistance

Skid testing in California may be either of two types.

The portable skid tester is used for contract acceptance of all new PCC surfaces and some research. The tester and the test procedure are described in Calif. Test 342 of the Manual of Test. Although the vehicle is stopped for a test, the friction values obtained by this method are from a correlation with a locked wheel, towed trailer, smooth tire and wet pavement at a test speed of 50 mph.

Towed trailer skid testers are used for all other work. Towed trailer skid testers are preferred because they perform at or near

existing traffic speeds and do not require lane closure. These units comply with ASTM E274* Standards. Values measured with these units are termed skid numbers and are defined in ASTM E274-77 as the tractive force between the tire and the pavement multiplied by 100 and divided by the dynamic vertical load on the test wheel. They are obtained with a locked wheel, ribbed tire (ASTM E501 or AASHTO M261) on a 0.022 inch thick water layer. The tractive force is obtained at a constant velocity and is averaged for a one-second interval. Subscripts are used with the symbol SN to denote the test speed. Skid numbers are usually measured at 40 mph or converted to equivalent 40 mph values and are designated SN_{40}.

The skid numbers reported by our towed trailer skid testers are correlated to National Bureau of Standards values as a result of one tester visiting the Central/Western States Calibration Center in Texas. The other testers are then correlated to the first tester on local pavement surfaces. Static calibration of the force transducers and calibration of the water flow rate is performed periodically.

A friction factor of 0.30 by the California portable skid tester is specified for all new PCC surfaces. This value corresponds to a skid number of approximately 40. Generally longitudinal tined textured surfaces have skid numbers in excess of 55. This same level of initial values was obtained on most finishes with a broomed texture.

*Except for terminology, ASTM E274 and AASHTO T242 standards are identical. In 1978 AASHTO changed the term skid number to friction number.

In addition to testing specific locations for Traffic, Maintenance, Materials and Construction personnel and for the Legal Division, an inventory is maintained for the whole state highway system.

In compliance with FHWA Instructional Memorandum 21-2-73, a statewide skid resistance inventory of California Highways was established and became operational prior to December 31, 1975. Using towed trailer skid testers, this program involves an initial testing frequency of one complete round each year for interstate routes, every other year for other freeway routes, and every fourth year for all other roadways. Ramps and interchanges will be tested only if District personnel make the request. Any roadways given a high priority by the Districts will be tested first.

The test data will be reported to the Office of Traffic to be evaluated with the wet pavement accident report; to the Office of Maintenance to be included in the Pavement Management System; to the Transportation Laboratory for wear factor determination and minimal skid number coordination; and to the Legal Division.

Library Services

The TransLab Library serves as an information center for Department employees in Districts and Headquarters Office as well as for TransLab staff.

TransLab generated reports and test methods, current ASTM standards and the latest Standard Specifications of all 50 State Departments of Transportation are all stored in the library.

TransLab Library is a specialized technical library covering such fields as portland cement, concrete, geotechnical engineering, physical environmental considerations.....etc. (e.g., the same fields covered by the Laboratory).

If you need a comprehensive list of our publications, please contact us. We have access to a wide variety of sources and will send you xerox excerpts, refer you to an expert or to another library if your request is outside of our subject areas.

If you need a specific publication, please let us know author, title and year of publication.

The library is open 7:30 a.m. to 4:15 p.m.
Telephone: Off-Net (916) 739-2452, ATSS 8-497-2452

Final Record Sampling

To comply with FHWA requirements, thickness measurements of the components of the structural sections of completed construction projects are made routinely by the Transportation Laboratory. Measurements are obtained for each lane mile of construction with a minimum of three per project.

For PCC pavements, it is cost effective to obtain the measurements of the structural elements prior to the PCC paving. For AC pavements, it is desirable to obtain thickness measurements prior to allowing public traffic on the roadway.

Therefore, the Laboratory should be notified by the Resident Engineer approximately two weeks prior to the completion of the AC paving or the placement of Lean Concrete Base or Cement Treated Base to permit the final record sampling to be scheduled.

Notes on

PROCEDURES, TESTING METHODS AND USE OF MATERIALS FOR TRANSPORTATION PURPOSES

Prepared by the

ENGINEERING GEOLOGY & TECHNICAL SERVICES BRANCH

Presented at
Transportation Laboratory
Sacramento, CA

ENGINEERING GEOLOGY AND TECHNICAL SERVICES BRANCH OF THE TRANSPORTATION LABORATORY

The Engineering Geology and Technical Services Branch of the Transportation Laboratory has been formed by combining the Engineering Geology Branch of Office of Structures - Design with the Engineering Geology Section of the Geotechnical Branch of the Laboratory. Personnel include engineering geologists, a geophysicist, technicians, and drillers. All of the engineering geologists are registered and four hold advanced degrees.

The Branch provides engineering geological services to all of the Transportation Districts and Headquarters Departments. The geological information is supplied for all phases of a project beginning with route location and continuing through problems that may develop during design, construction and maintenance. The Engineering Geology Branch regularly supplies the following services:

Drilling and Sampling

Three large vertical exploratory drill rigs, five Concore rotary rigs, a horizontal drill rig, and several compressor drive rigs are available for obtaining cores, soil samples, cuttings, groundwater information, and cone penetrometer information. The rigs provide capability for vertical drilling and coring to 2000 feet, horizontal drilling to 1000 feet, split spoon sampling to 250 feet, and undisturbed soil sampling to 500 feet. The equipment is commonly used in the following types of investigations.

Bridge and Freeway Structures
Tunnels
Retaining Walls
Sound Walls
Culverts
Embankment Foundations
Horizontal Drains
Water Well Locations
Slope Indicator Installation
Building Foundations (Maintenance Stations, Roadside Rests, etc.)
Sewage Disposal

Geologic Field Studies

Reports of geologic field studies have been prepared for the following purposes.

Geologic Hazards Report for an Environmental Impact Statement
Evaluation of Alternate Routes
Cut Slope Design
Materials Sources
Rockfall Evaluation
Assistance to Legal Department
Evaluation of Seismic Risk
Structure Foundations

Landslide Studies

Detection of Landslides
Evaluation of Present Activity
Monitoring Rate of Movement Using Various Methods Including Sub-Audible Rock Noise
Recommendations for Type of Repair for Landslide

Geophysical Studies

Equipment for conducting seismic refraction studies, shear wave studies, and electrical resistivity studies is available at the TransLab. Studies provide information for:

- Cut Slope Design
- Rippability of Material to be excavated
- Earthwork Factors
- Depth to Water Table
- Location of Large Subsurface Cavities
- Dynamic Modulus of Elasticity
- Poisson's Ratio
- Depth to Changes of Material

Laboratory Studies

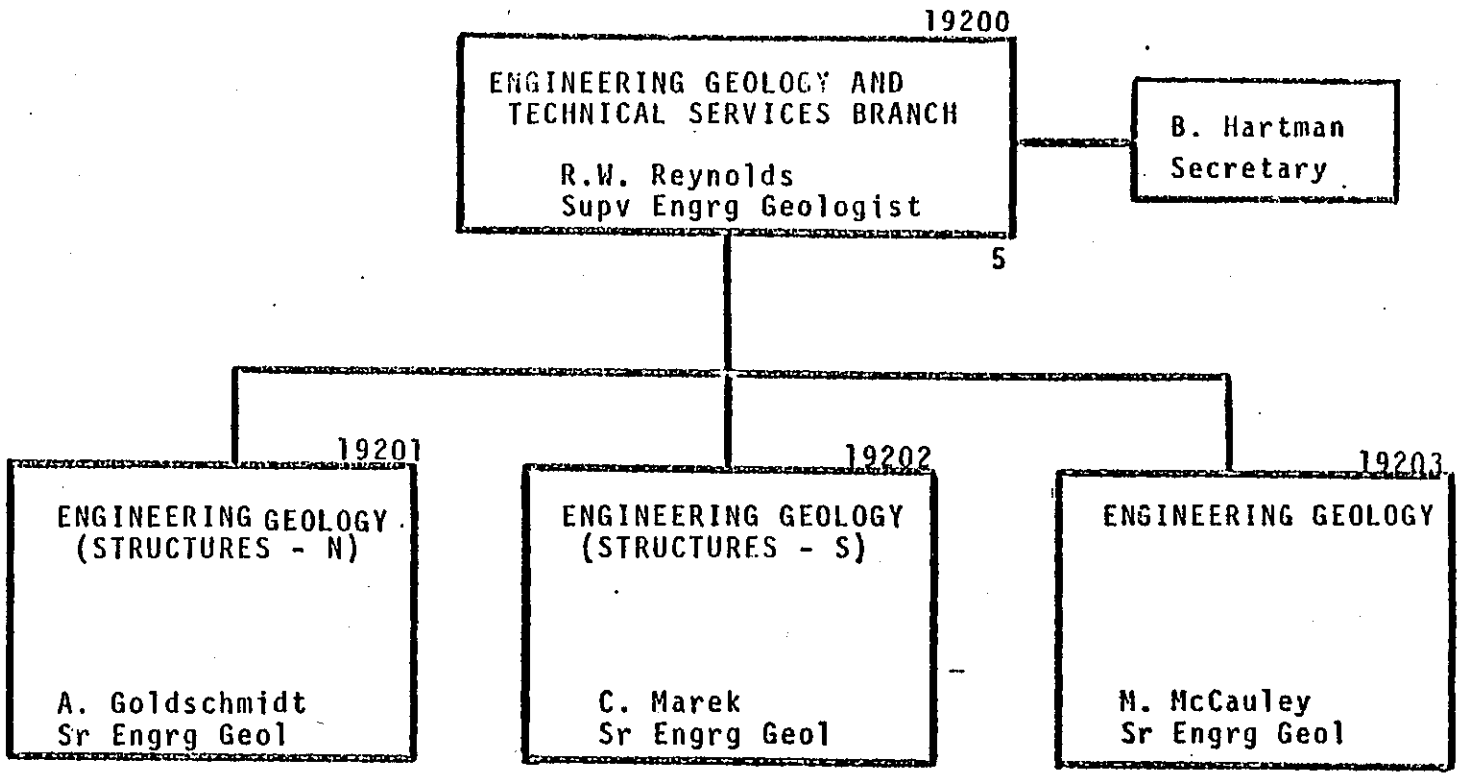
The geology laboratory is equipped with several microscopes, a differential thermal analyzer, and x-ray diffraction equipment. Studies can be made to:

- Identify Expansive Clay Minerals in Soil or Rock
- Identify Deleterious Minerals in Rock Slope Protection Material
- Classify Sands and Aggregates and Identify Deleterious Materials

Research

Current Studies Include:

- Procedures to Use for Evaluating Geologic Hazards
- Effectiveness of Horizontal Drains
- Rockfall Mitigation


19200
ENGINEERING GEOLOGY AND TECHNICAL SERVICES BRANCH
R.W. Reynolds
Supv Engrg Geologist
5
B. Hartman
Secretary
19201
ENGINEERING GEOLOGY (STRUCTURES - N)
A. Goldschmidt
Sr Engrg Geol
19202
ENGINEERING GEOLOGY (STRUCTURES - S)
C. Marek
Sr Engrg Geol
19203
ENGINEERING GEOLOGY
M. McCauley
Sr Engrg Geol

19201

ENGINEERING GEOLOGY
(STRUCTURES - N)

A. Goldschmidt
Sr Engrg Geol

18

EXPLORATION AND FOUNDATION STUDIES REVIEW

Assoc Engrg Geol
Fdn Drill Supv
Fdn Drill Supv
Fdn Drill Supv
Fdn Drill Supv
Fdn Driller
Fdn Driller
Fdn Driller
Fdn Driller
Fdn Driller
Fdn Driller
Fdn Driller
Fdn Driller

14

G. Miller
H. Williams
W. Hall
C. Lockhart
C. Keep
E. Brown
O. Braden
M. Sheaman
J. Dent
R. Teitzel
R. Dahlstrom
L. Reynolds
D. Johnson
J. Nunes

FOUNDATION STUDIES

Assoc Engrg Geol

1

R. Fox

FOUNDATION STUDIES

Assoc Engrg Geol

1

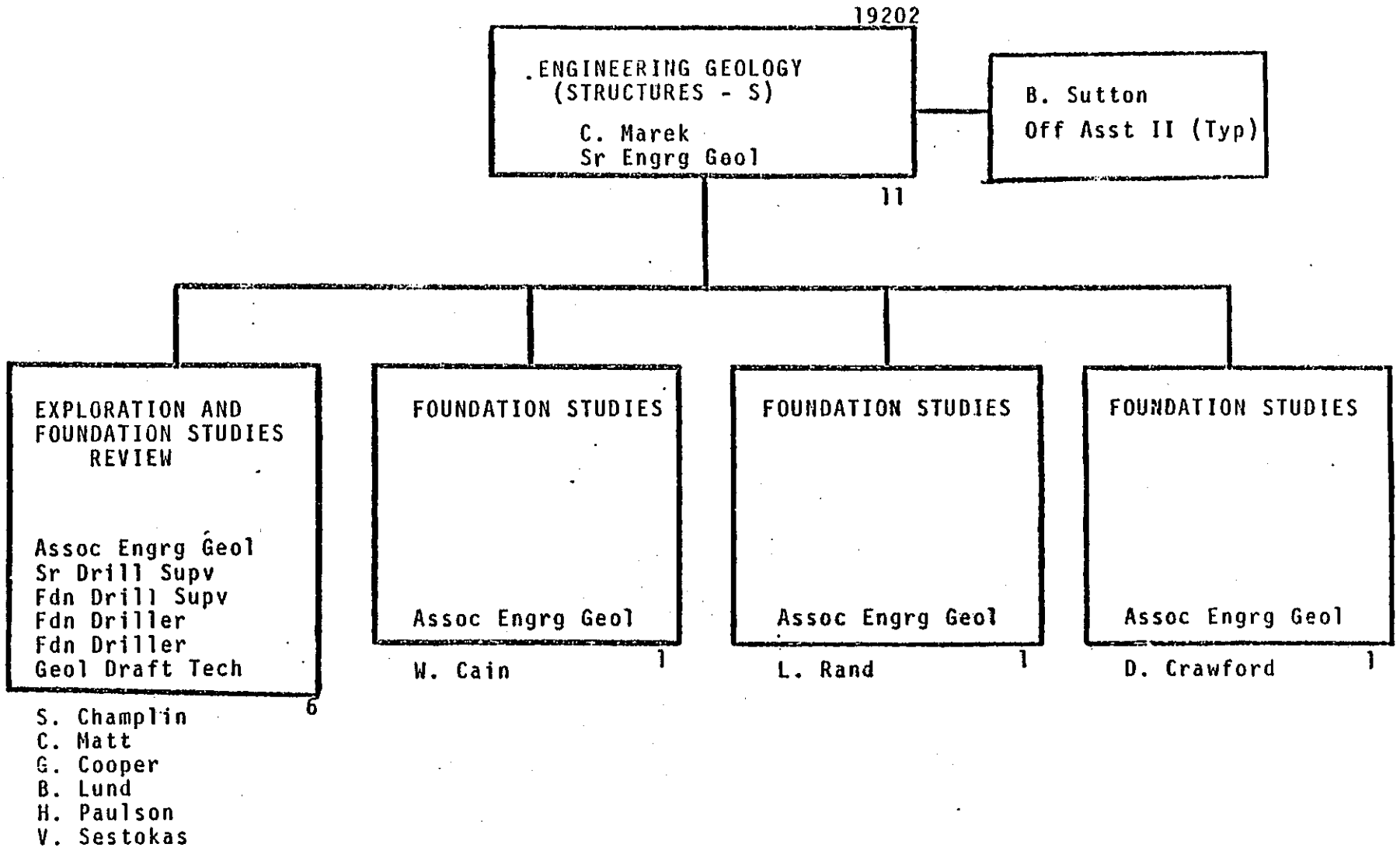
R. Wilhelms

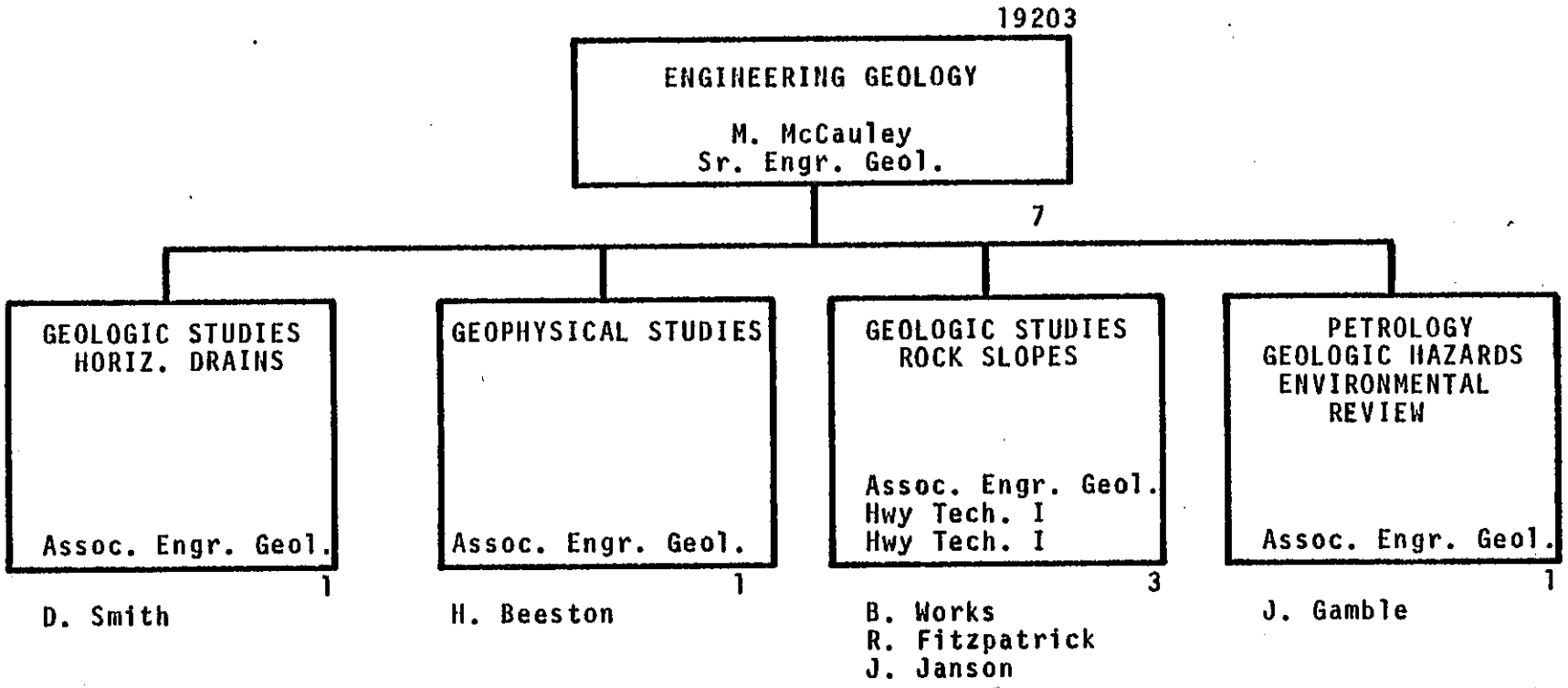
FOUNDATION STUDIES

Assoc Engrg Geol

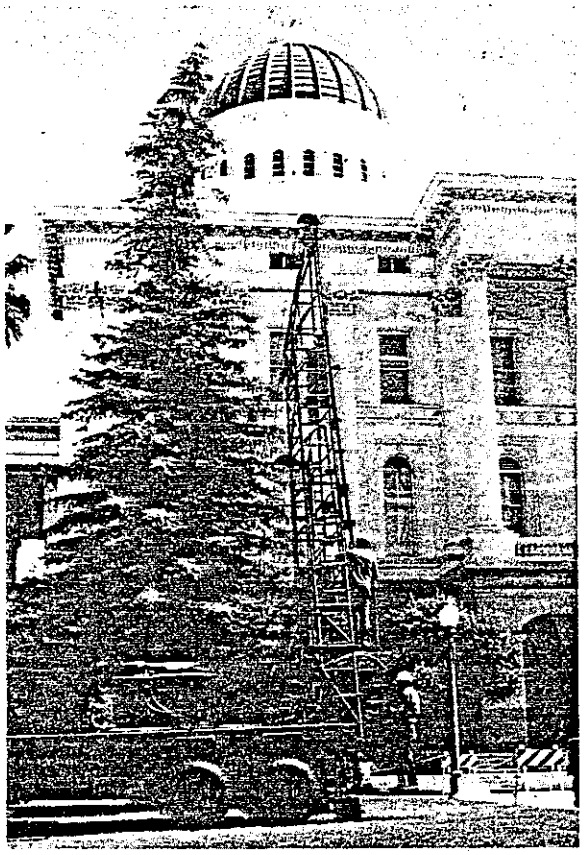
1

R. Hager

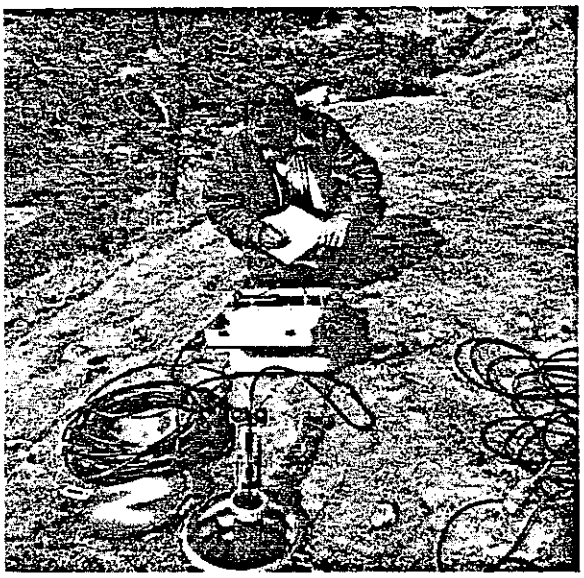

19202
ENGINEERING GEOLOGY
(STRUCTURES - S)
C. Marek
Sr Engrg Geol
11
B. Sutton
Off Asst II (Typ)
EXPLORATION AND
FOUNDATION STUDIES
REVIEW
Assoc Engrg Geol
Sr Drill Supv
Fdn Drill Supv
Fdn Driller
Fdn Driller
Geol Draft Tech
6
S. Champlin
C. Matt
G. Cooper
B. Lund
H. Paulson
V. Sestokas
FOUNDATION STUDIES
Assoc Engrg Geol
1
W. Cain
FOUNDATION STUDIES
Assoc Engrg Geol
1
L. Rand
FOUNDATION STUDIES
Assoc Engrg Geol
1
D. Crawford


19203
ENGINEERING GEOLOGY
M. McCauley
Sr. Engr. Geol.
7
GEOLOGIC STUDIES
HORIZ. DRAINS
Assoc. Engr. Geol.
1
D. Smith
GEOPHYSICAL STUDIES
Assoc. Engr. Geol.
1
H. Beeston
GEOLOGIC STUDIES
ROCK SLOPES
Assoc. Engr. Geol.
Hwy Tech. I
Hwy Tech. I
3
B. Works
R. Fitzpatrick
J. Janson
PETROLOGY
GEOLOGIC HAZARDS
ENVIRONMENTAL
REVIEW
Assoc. Engr. Geol.
1
J. Gamble

1/2/80



Setting up drill rig for exploration sampling at State Capitol



Monitoring earth movement with slope indicator.

Installing horizontal drains in slide area to remove excess ground water

Seismic equipment is packed into rugged terrain for geologic field exploration.

Differential thermal analysis with the x-ray diffractometer (above) identifies and quantifies soil and aggregate minerals.

Notes on

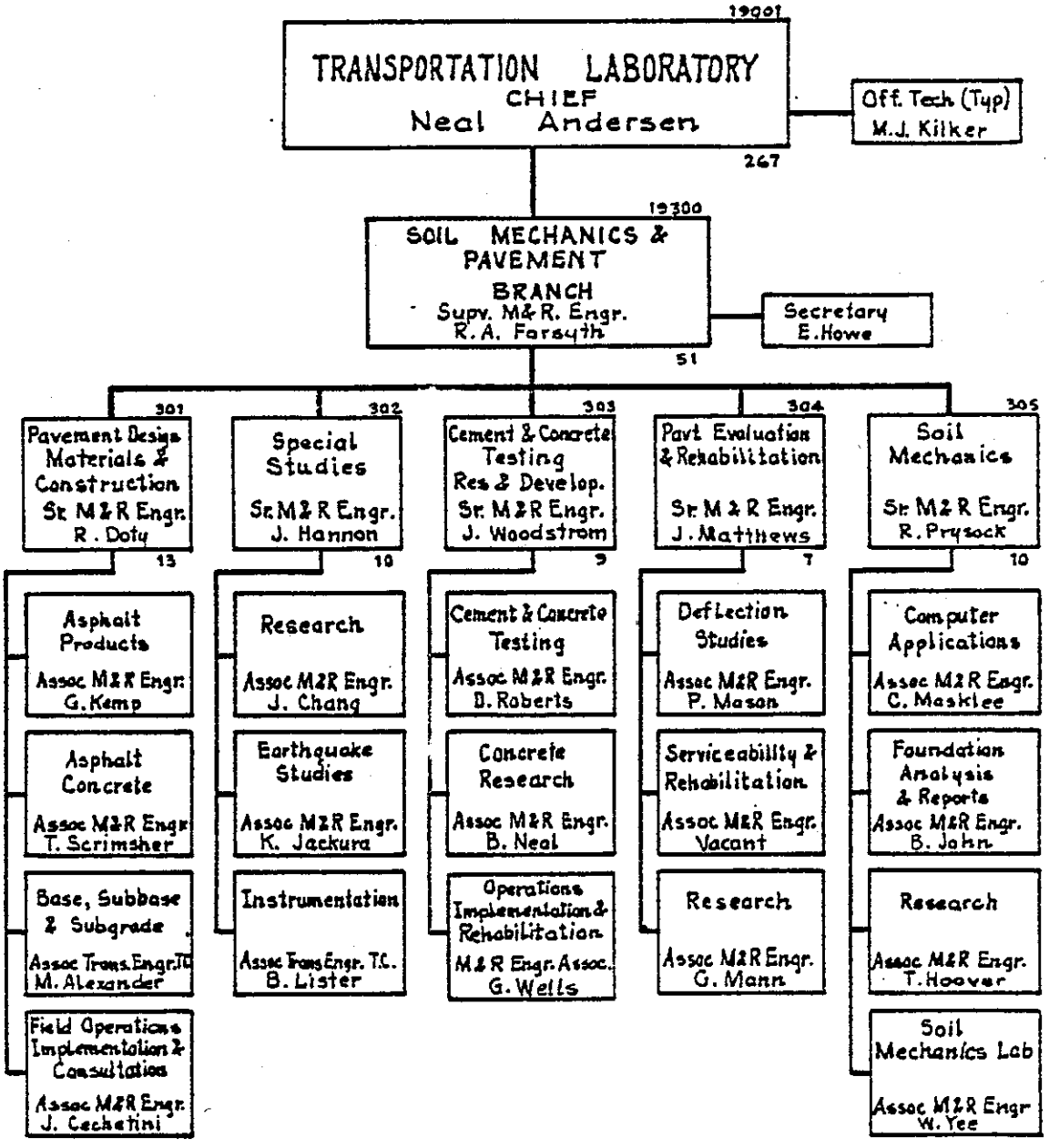
PROCEDURES, TESTING METHODS, AND USE OF MATERIALS FOR HIGHWAY PURPOSES

Prepared by the

SOIL MECHANICS & PAVEMENT BRANCH

Presented at

Office of Transportation Laboratory


19001
TRANSPORTATION LABORATORY
CHIEF
Neal Andersen
267
Off. Tech (Typ)
M.J. Kilker
19300
SOIL MECHANICS & PAVEMENT BRANCH
Supv. M&R. Engr.
R.A. Forsyth
51
Secretary
E. Howe
301
Pavement Design Materials & Construction
Sr. M&R Engr.
R. Doty
13
302
Special Studies
Sr. M&R Engr.
J. Hannon
10
303
Cement & Concrete Testing Res & Develop.
Sr. M&R Engr.
J. Woodstrom
9
304
Pavt Evaluation & Rehabilitation
Sr. M&R Engr.
J. Matthews
7
305
Soil Mechanics
Sr. M&R Engr.
R. Prysock
10
Asphalt Products
Assoc M&R Engr.
G. Kemp
Asphalt Concrete
Assoc M&R Engr.
T. Scrimsher
Base, Subbase & Subgrade
Assoc Trans Engr. TC
M. Alexander
Field Operations Implementation & Consultation
Assoc M&R Engr.
J. Cechetini
Research
Assoc M&R Engr.
J. Chang
Earthquake Studies
Assoc M&R Engr.
K. Jackura
Instrumentation
Assoc Trans Engr. TC.
B. Lister
Cement & Concrete Testing
Assoc M&R Engr.
D. Roberts
Concrete Research
Assoc M&R Engr.
B. Neal
Operations Implementation & Rehabilitation
M&R Engr. Assoc.
G. Wells
Deflection Studies
Assoc M&R Engr.
P. Mason
Serviceability & Rehabilitation
Assoc M&R Engr.
Vacant
Research
Assoc M&R Engr.
G. Mann
Computer Applications
Assoc M&R Engr.
C. Masklee
Foundation Analysis & Reports
Assoc M&R Engr.
B. John
Research
Assoc M&R Engr.
T. Hoover
Soil Mechanics Lab
Assoc M&R Engr
W. Yee

OPERATIONS OF THE SOIL MECHANICS AND PAVEMENT BRANCH OF THE THE TRANSPORTATION LABORATORY

The Soil Mechanics and Pavement Branch provides technical support to the planning, design, construction, and maintenance functions of the Department of Transportation in the following broad areas:

- Pavement design and quality control
- Embankment and foundation design
- Dewatering
- Dynamic (earthquake) analysis of earthworks
- Blasting
- Natural hazards (landslides, expansive soils, and subsidence)
- Earthwork reinforcement feasibility
- Earthwork instrumentation
- Pavement rehabilitation
- Pavement failure investigation

In addition to regular laboratory quality assurance testing, consultation, and the development of tests and specifications, the Branch conducts extensive research in all of the above areas.

The following are some of the Branch's specific capabilities in soil mechanics:

Analytical and Design Procedures

The following procedures include both static and dynamic conditions.

- Foundations - All types of shallow and deep pile foundations are analyzed for bearing capacity and settlement (total, differential, and rate).

- Stability - Slope and foundation stability for the project and adjacent structures can be analyzed both manually and by computer for a variety of soil conditions.

- Dewatering - Studies and recommendations are made for construction problems on the project and possible effects on adjoining structures.

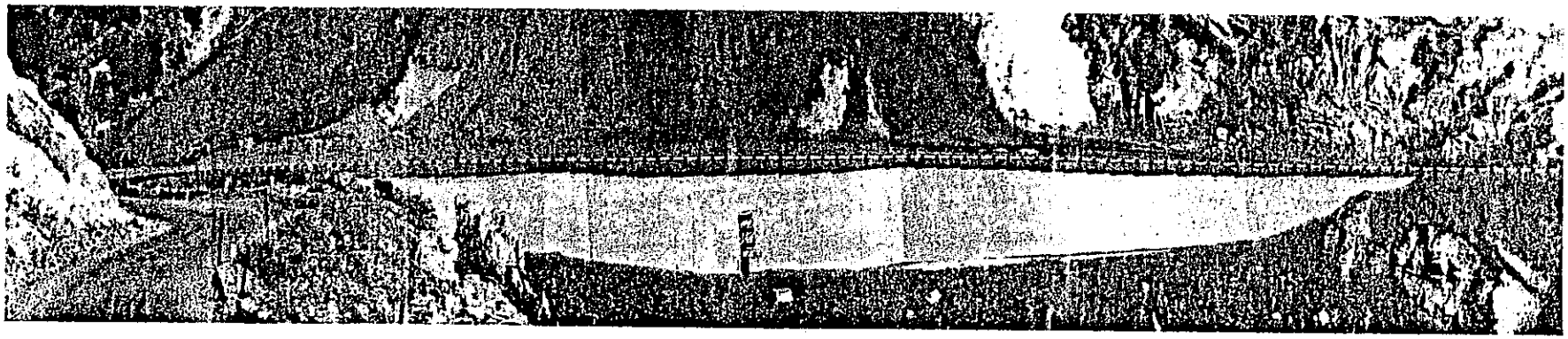
- Earth Retaining Structures - Earth pressure, stability studies and structural design of all types of temporary and permanent retaining structures.

- Machine Foundation Design - Dynamic studies to prevent damage due to vibration for both the machine and surrounding structures.

- Seismic Design - Complete facilities are available for computing design seismic motions of the site and design response spectra earthworks and structures.

- Explosive and Blasting - Consultation and recommendations for specifications, product stability, results evaluation, safety, suitability of application for various techniques, and damage criteria are provided.

- Finite Element Analysis - Modeling and investigation of soil and soil structure interactions to determine respective influences of various construction activities.



REINFORCED EARTH EMBANKMENT
07-LA-39

This structure combines soil and steel reinforcement to form a vertical gravity section capable of withstanding large lateral earth pressures.

Field Investigations

A. In situ Tests

1. Vane shear tests for cohesive soils
2. Standard penetration test for cohesionless soils
3. Permeability testing for silts and clays
4. Drawdown tests
5. Moisture content and density

B. Field Instrumentation

1. Slope indicators
2. Settlement platforms
3. Settlement profile gages
4. Soil pressure cells
5. Piezometers
6. Strain gages

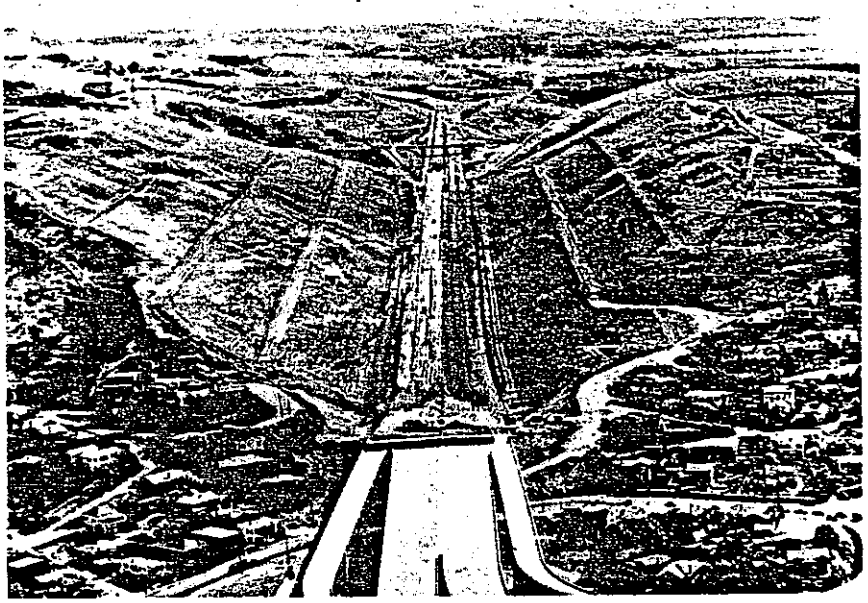
Laboratory Tests

A. Classification

1. Grain size determination
2. Specific gravity
3. Moisture content
4. Atterberg limits

B. Soil Mechanics

1. Triaxial compression on 2", 2.8", 4", 6", and 12" diameter specimens with pore pressure measurement
2. Direct shear
3. Unconfined compressive strength



Large benched highway cut south of Carquinez Bridge, Interstate 80, Contra Costa County.

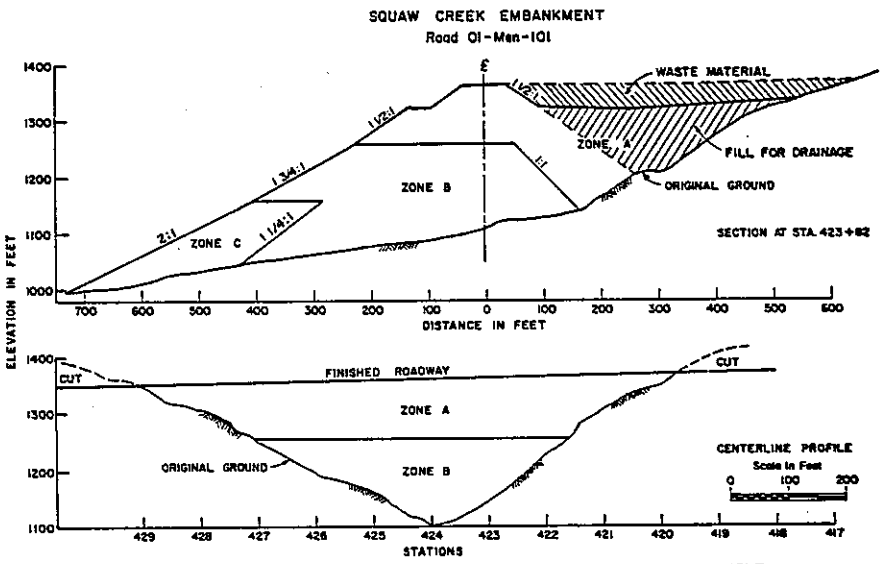


Figure SECTION AND CENTERLINE PROFILE THROUGH SQUAW CREEK EMBANKMENT

Representation of high, zoned embankment as constructed in 1967, on Route 101, Mendocino County.

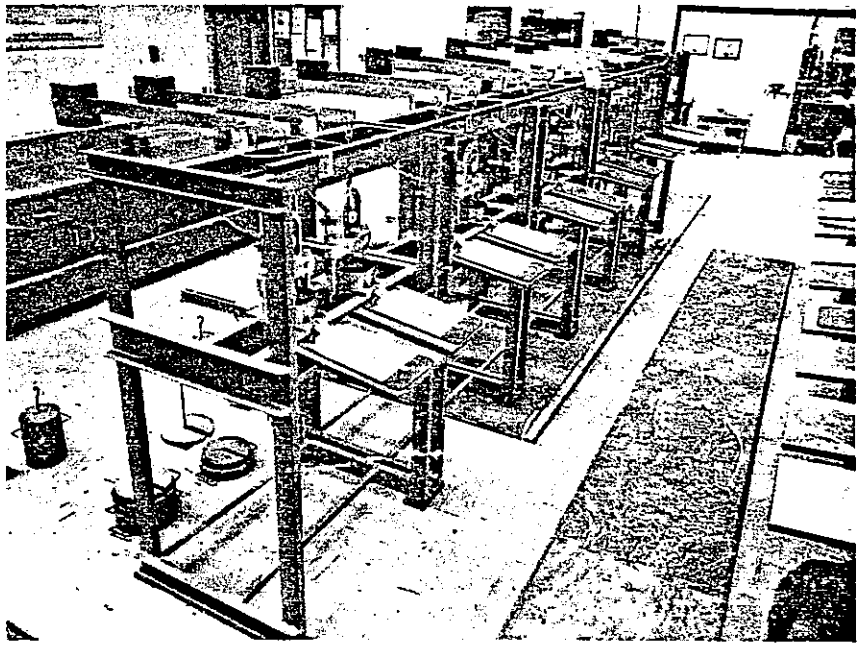
4. Vane shear
5. Consolidation
6. Permeability
   a. Constant head
   b. Falling head
7. Relative compaction
8. Relative density

C. Soil Dynamics

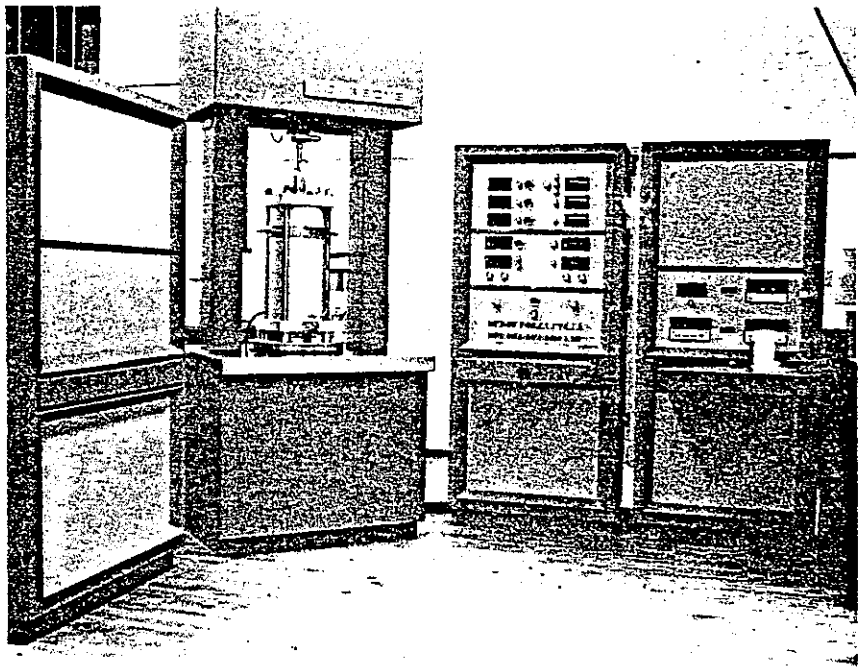
1. Resonant column for shear modulus and damping
2. Dynamic triaxial compression for determination of dynamic soil strength and liquefaction potential of cohensionless soils

Computer Capabilities

A. Dynamic finite element program for seismic design of earth structures.
B. Wave propagation program for analyzing earthquake ground motion and response spectra of earthquakes.
C. Two-dimensional finite element program for determining stresses and strains in earth structures, and deferring influences of various construction activities.
D. Slope stability programs for both the Fellenius and Modified Bishop methods.
E. Triaxial test data computation.
F. Consolidation test data computation.
G. Refraction seismic analysis and plotting.



View of consolidation test equipment,
Soil Mechanics Laboratory.



New Cox automated triaxial testing apparatus,
Soil Mechanics Laboratory.

The following are some of the Branch's capabilities in the pavement area:

A.C. Pavement Rehabilitation

The California Traveling Deflectometer, Benkelman Beam, and three Dynaflect units are utilized to perform nondestructive, in-place strength measurements of existing pavements. A complete method of design for overlays is provided which includes:

- Pavement condition surveys
- Deflection measurements and analyses
- Reflection cracking potential
- Effect of projected traffic loads
- Recommendations for design

Pavement Field Investigation

Complete coring and sampling equipment is available for sampling all layers of structural sections including PCC pavement, AC pavement, stabilized bases, untreated bases and subbases, as well as basement soils. Cores up to 12 inches in diameter can be obtained through pavements, including bridge decks, and stabilized bases. Special equipment for cutting sections is also available. Coring and sampling operations are normally performed for:

- Preliminary sampling for design purposes
- Investigations and evaluations
- Thickness measurements - all elements of the structural section
- Research studies

Cement and Concrete Testing

A completely equipped cement and concrete laboratory (regularly inspected by the Cement and Concrete Reference Laboratory of the National Bureau of Standards) for physical and chemical testing of portland cement, concrete and related materials and products. Examples include:

Portland Cement and Related

- Chemical and physical tests for compliance with ASTM Specifications and California Modifications
- Drying shrinkage (of portland cement mortar)
- Sand mortar strength
- Reactive aggregate tests

Concrete and Related

- Compressive and flexural strength
- Freeze-thaw durability
- Drying shrinkage (of concrete)
- Mix design (regular and lightweight concrete)
- Cement content of hardened concrete
- Creep and modulus of elasticity determinations
- Laboratory evaluation of the effect of admixtures on the properties of concrete
- Air content of hardened concrete
- Research studies dealing with the use of concrete in a transportation facility, for example:
  - Evaluation of concrete pavement performance
  - Skid resistant surfaces and textures
  - Smoothness evaluation
  - Mixer efficiency evaluation

- Experimental pavement features
- Field evaluation of admixtures, new construction methods and procedures
- Specifications and test method development

Treated and Untreated Soils and Aggregate Testing

Consultation and testing services are available regarding the testing of treated and untreated soils and aggregates. Although the most frequently used treatments consist of the addition of cement or lime to aggregate and soil, testing to determine the affect of other additives has been and can be provided. This Laboratory also subscribes to the laboratory inspection and the reference sample programs provided by the AASHTO Materials Reference Laboratory (AMRL).

Asphalt and Asphalt Concrete Testing

Two separate and completely equipped laboratories perform testing and conduct research of asphalt and asphaltic mixtures. (Some routine asphalt testing is also done at a branch laboratory located in Los Angeles.) All of the laboratories are inspected periodically by a team representing the AASHTO Materials Reference Laboratory (AMRL). The general areas of testing responsibility for each laboratory include:

A. Asphalt

1. Physical Testing

- Test for compliance with specifications

2. Research and Investigation

- Prepare and review specifications and test methods
- Study asphalt durability
- Study various surface treatments (new products, and various seals
- Study anti-strip agents - relative to reaction with various asphalts
- Recover and test asphalt for analysis

B. Asphalt Concrete

1. Physical Testing

- Test for compliance with specifications

2. Special Services

- Provide a team for equipment calibration and audit of laboratory testing. Provide a consultation and training service to all laboratories on design and testing of asphalt mixtures. Provide an AC compactor testing service.

3. Research and Investigation

- Prepare and review specifications and test methods
- Study cold emulsion mixtures
- Study recycled mixtures (surface, hot central plant and cold in-place operations)
- Study special mixes containing additives such as rubber, asbestos, various fibers, glass, light weight aggregate, slag, cinder, etc.

- Study slurry seal design and performance
- Conduct field investigation of pavement distress and performance
- Study hot plant performance including such items as dryer-drums and bag houses
- Study compaction and related density with reference to various rollers or compactors.

SPECIAL TOPICS

EARTHQUAKE ENGINEERING

Introduction

Development of a dynamic testing and analysis capability within our Soil Mechanics and Pavement Branch began soon after the San Fernando earthquake of 1971 made apparent the necessity of incorporating complete earthquake analysis into all transportation facility design work. Prior to the San Fernando disaster very little effort was expended in analyzing the effect of earthquake forces on highway embankments and foundations; but since then dynamic stability has received much greater emphasis. In view of the potential hazard in California, earthquake analyzation will be applied to earthwork considered susceptible to seismic damage on a routine basis in the future, with the aid of modern computer techniques which allow a rational design analysis to be performed economically and rapidly.

Earthquakes

Since there is probably some question as to what is meant by a dynamic analysis, let us first look at Figure 1.

This figure illustrates a typical seismic disturbance occurring along some active fault system. The mountain chain to the left is composed of bedrock developed by the thrusting action of the mantle during geologic time. The alluvium is an accumulation of decomposed and eroded material swept from the mountains by ages of wind and rain.

The earthquake to which the area is subjected is caused by the sudden release of internal stresses at a rupture point or "focus"

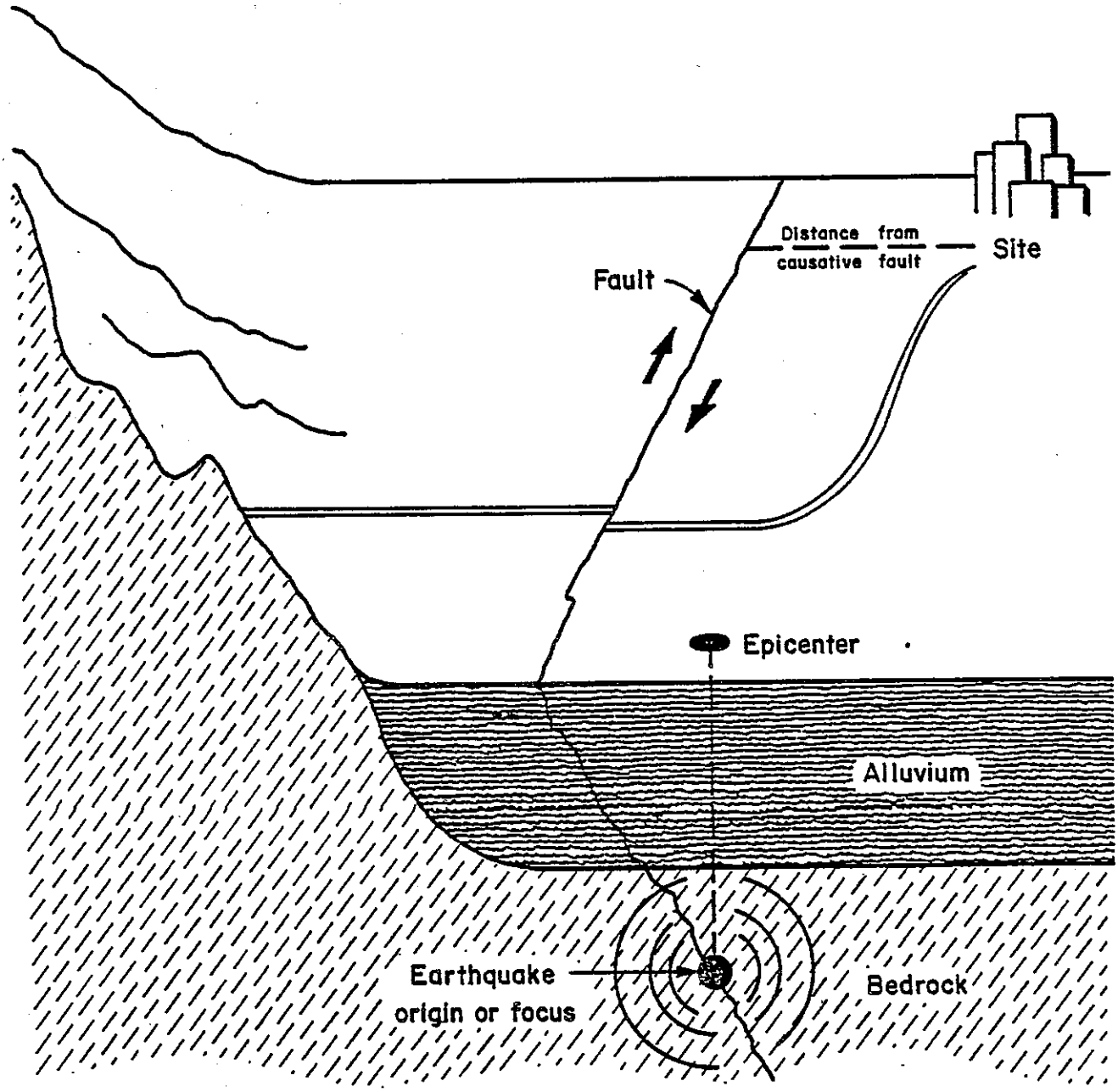


Fig. I CUT-AWAY SECTION OF EARTH ILLUSTRATING EARTHQUAKE MECHANISM

within bedrock. This point is not to be confused with the epicenter of the earthquake, which is the point on the ground surface directly above the focus. As a result of this sudden release of energy, relative movement along a segment of the fault is developed and, as a consequence, stress waves propagate outward in all directions along the fault rupture. The stress waves are transmitted through the various soil strata and are experienced at the earth's surface as ground shaking. The intensity of ground shaking at a given site, some distance from the epicenter of the earthquake, is dependent on three variables: the site - causative fault distance; the vibratory characteristics of the stress waves; and the geophysical properties of the soils underlying the site.

Earthquakes are a great concern to the engineering profession due to their tremendous damage potential and almost complete lack of predictability. Advances over the past decade in predicting seismic force transfer to man-made structures have resulted in a more thorough design analysis. The current dynamic evaluative technique, developed at the University of California, is extremely complex, requiring the use of computers to establish generated structural force levels for a given earthquake motion. Application of the technique, however, provides information essential to the selection of the most appropriate design or an estimate of the viability of some predetermined design.

Estimating Earthquake Forces

As the tremors or stress waves originating in bedrock characterize the earthquake's vibrational frequency and amplitude, they are an important part of the basic information needed for estimating seismic-generated force levels. Plotted records of these stress waves are called accelerograms as shown on Figure 2. Necessary additional information must include the dynamic characteristics of the overlying

alluvium obtained by field geophysical survey methods and laboratory testing techniques. The information describing the accelerogram and the alluvium's engineering characteristics is then fed into a computer and pertinent output data, such as maximum accelerations and shear stress-time histories of motions, are printed in numerical and graphical form.

Liquefaction of Sandy Soils

In addition to the maximum acceleration levels and shear stress values, another important consideration is that of liquefaction. Liquefaction is the inability of certain materials to resist shearing stresses when shaken by an earthquake. This condition exists where the material is saturated with water, fairly pervious, and generally in a loose state. The earthquakes repeated vibrations cause the particles to try to densify but, because of the water in the pores, they cannot. As a result, the material exhibits characteristics much like quicksand and soil supported structures collapse.

Earthquake Considerations

When, and in what way, do we utilize the engineering tools and analyses available to us for analyzing project sites located in active fault areas? The answer to the first part of this question, when, is not easily definable. Highly destructive earthquakes occur so infrequently at a specific location that expenditures to make a highway facility earthquake-proof are economically unrealistic. Consequently, in areas where seismic activity is probable, the Transportation Laboratory has developed guidelines to help the engineer decide when a study should be initiated.

These guidelines, "Earthquake Considerations", are set forth in Section 7-110.4 of the Highway Design Manual and Section 110, Materials

Reports (IX). They consider site location, embankment heights, depth of cuts, traffic use, and local soil, geologic, and groundwater conditions. The text and associated charts are the first step taken by this Department to develop rational criteria for initiation of dynamic investigations. These guidelines are presented in a subsequent section of the training manual. The question now arises, how is the analysis conducted?

Dynamic Evaluation - Resonant Column

Years ago earthquake generated force levels were simply estimated based on proximity to fault zones and their activity. Today, due to computers, seismic force levels are predicted with a little more assurance. Boring explorations delineate site subsurface conditions and geophysical surveys define field dynamic properties. For additional and supportive information, field soil samples should be obtained and submitted to the Transportation Laboratory for dynamic testing. A resonant column apparatus (Figure 3) is used for defining the soils shear modulus and damping characteristics during laboratory cyclic loading conditions. Shear modulus is the soils resistance to deformation and damping is the energy lost due to deformation. Since these values are strain dependent, both factors must be determined as functions of the induced soil strain.

The resonant column apparatus subjects a soil specimen to various torsional vibration modes or frequencies. The frequency is adjusted to produce resonance within the soil system at which time frequency and strain amplitude are measured. Shear modulus is then a measure of the slope line through the end points of the hysteresis loop stress-strain relation, while damping will be proportional to the area of the hysteresis loop stress-strain relation. Values so obtained are then used in a computer program for estimating ground motion for various input earthquakes.

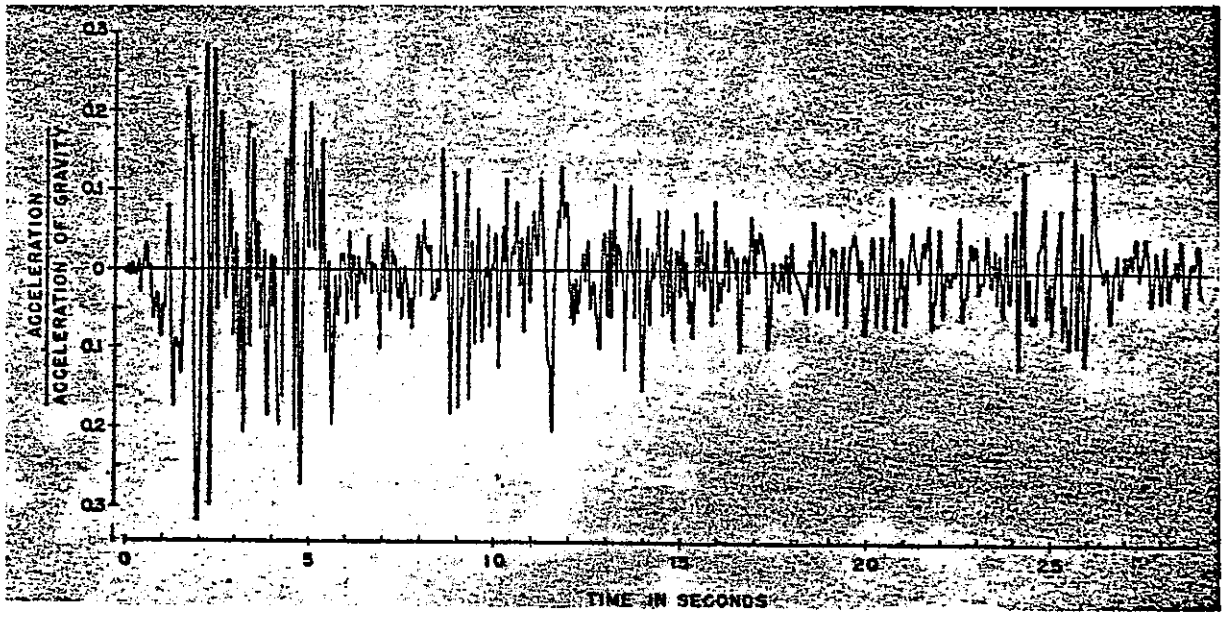


Fig. 2 Strong-motion Seismogram, El Centro, California, Earthquake, May 18, 1940 (N-S Component)

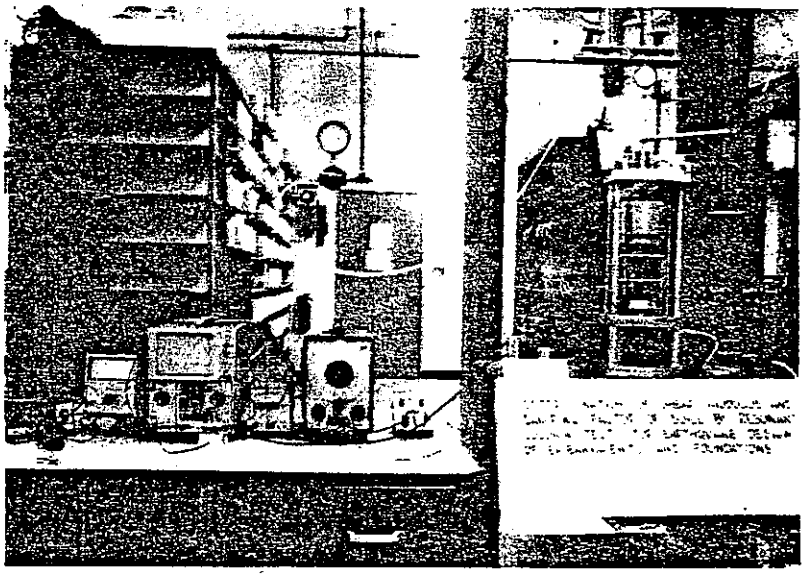


Fig. 3 Resonant column device used in dynamic testing of soils.

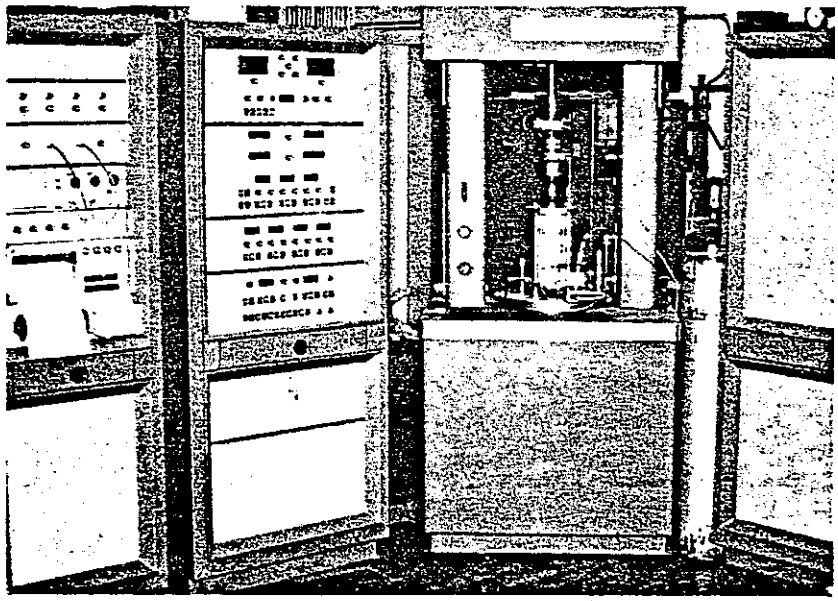
Cyclic Loading Device

The computed ground reaction or "earthquake" induced soil stresses will, for certain soil conditions, create soil liquefaction. Analysis of the soil to identify potential problem areas requires a stress-controllable, cyclic loading device, typical of the one that is operational at the Transportation Laboratory (Figure 4).

The machine is capable of exerting controlled rates of cyclic stress in a number of wave shapes, i.e., saw-tooth, square and sine. Samples of potential liquefiable material are tested by subjecting them to cyclic pulsating loads without allowing drainage. Ambient stress states existing in the field are duplicated in the laboratory to obtain stress compatible conditions. Pertinent information derived from laboratory testing consists of the soil samples consolidation and cyclic stress states, axial strain and number of pulses prior to onset of liquefaction. Failure occurs when the sample is unable to resist the applied cyclic loads. Comparison of the computed earthquake force levels with the average number of expected cycles before failure in the test specimen will indicate the liquefaction hazard for a particular field site.

In summary, important progress has been made in the analysis of soil behavior during earthquakes, and it is hoped that the preceding information serves to illustrate the variety of foundation problems confronting the transportation engineer working in seismically active areas. Careful consideration of the soil conditions and competent analysis can determine the consequences of potentially hazardous seismic events and provide a rationale for decisions involving rerouting, or the economics of reconstruction.

FIGURE 4



CYCLIC LOADING DEVICE

March 1975

GUIDELINES FOR DETERMINING WHEN SEISMIC INVESTIGATIONS AND DYNAMIC ANALYSES WOULD BE ADVISABLE

(TENTATIVE)

HIGHWAY DESIGN MANUAL

7-110.4 Earthquake Considerations March 3, 1975

Major destructive earthquakes occur so infrequently at a specific location that the expenditure to make a highway facility completely earthquake proof would not be reasonable, even if possible.

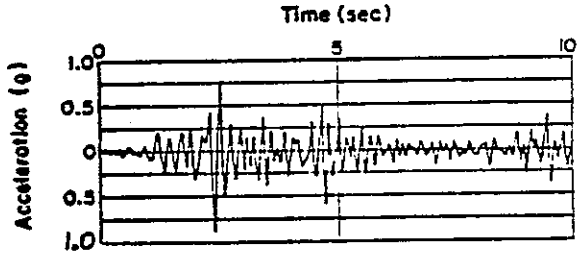
However, there are certain measures that should be considered when a project is to be constructed in a known active zone of faulting.

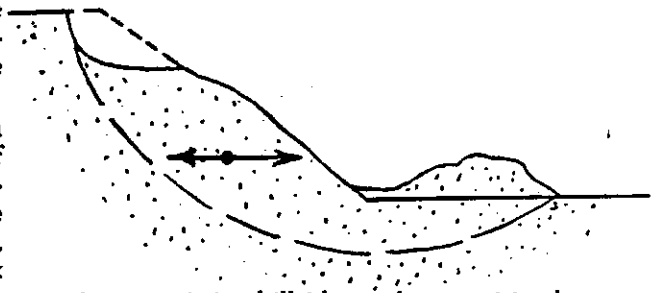
Early in the route location process, active and inactive faults should be mapped by engineering geologists. A general assessment of the seismic risk of various areas within the study zone should then be prepared. The Division of Structures and the Transportation Laboratory are available to assist in the assessment of seismic risk.

Strong consideration must be given to the location of major interchanges. They must be sited outside of heavily faulted areas unless there are exceptional circumstances that make it impractical to do so. Where seismic activity is highly probable and unavoidable, consideration should be given to avoiding complex multilevel interchanges in favor of simple designs with low skew, short span structures close to the original ground and maximum use of embankment. Single span bridges which can tolerate large movements are desirable.

Early recognition of seismic risk might lead the designer to modify alignment or grade in order to minimize high cuts, fills, and bridge structures in a given area. Slopes should be made as flat as possible both for embankment stability and to reduce slide potential in cuts. Buttress fills can be constructed to improve cut stability. The Division of Structures and the Transportation Laboratory should be consulted early when considering various alternatives to obtain recommendations for mitigating earthquake damage.

When subjected to an earthquake, fills may crack, slump, and settle. In areas of high water table, liquefaction may cause large settlement of the roadway. It is not economically feasible to entirely prevent this damage. The contract Special Provisions should provide for removal of loose and compressible material from fill foundation areas, particularly in canyons, sidehill fills, and ravines, and for foundation preparation on existing hillsides at the transition between cut and fill.





No modification is necessary in the design of the structural sections for the purpose of reducing damage due to future earthquakes. There is no pavement and base design which will reduce damage, since the structural section cannot be insulated from movements of the ground on which it rests. In active fault areas, consideration should be given to the use of flexible pipes or pipes with flexible couplings for both cross drains and roadway drainage.

Additional expenditure for right of way and construction to make highways and freeways more earthquake resistant in a known active fault area will have to be kept in balance with the amount of impact on the traveling public, if the facility may be put out of service following a disastrous earthquake. Also, the probable rate of recurrence at a specific location is often so infrequent as to make the value of a significant additional expenditure questionable. A major interchange, however, not only has a tremendous influence on traffic flow but presents a hazardous condition to the motorist during an earthquake. Because of the life-safety aspect, some additional expenditure is justified at such locations.

IX. Earthquake Considerations

A. The following criteria will serve as guidelines for determining when seismic investigations and dynamic analyses would be advisable. The criteria are divided into two categories; expected bedrock acceleration level on a state-wide basis, and roadway geometric and soil conditions at specific sites.

B. Bedrock Accelerations

The state map shown in Figure I depicts by means of contours the maximum expected bedrock accelerations from earthquakes in California. This base map was prepared in 1972 by the Division of Mines and Geology for use as a guide by engineers and planners. For purposes of highway planning and design, the three zones denoted as A, B, and C have been added. Zone A includes that portion of the state for which maximum expected bedrock accelerations will equal or exceed 0.4 times the force of gravity. Zone B is that portion for which maximum expected bedrock accelerations will be equal to or greater than 0.1 g but less than 0.4 g. Zone C is that portion for which maximum expected bedrock accelerations will be less than 0.1 g. These zones are not intended to correlate with any prior zoning from building codes or technical publications.

For highway projects located within Zone A, seismic investigations and dynamic analyses should be performed in accordance with the criteria outlined in the next section.

For highway projects located within Zone C, seismic investigations and dynamic analyses would not be necessary except for extreme local soil, geologic, or groundwater conditions as determined from normal materials investigations.

For highway projects located within Zone B, seismic investigations and dynamic analyses would not normally be necessary if such action can be justified by properly considering the criteria of the following section and local soil conditions.

C. Seismic Criteria

1. Embankments and Their Foundations

Embankments 150 feet or more in height, as measured vertically between downhill toe and hinge point, should be designed based on a dynamic analysis regardless of type or quality of foundation materials. Due consideration must be given the foundation in the dynamic analysis, however, since it constitutes part of the embankment-foundation system.

Embankments less than 150 feet in height should be considered for dynamic analyses according to a relationship between embankment height and predicted settlement within the foundation. This relationship is shown in Figure II and is based on the premise that greater foundation settlements for any given embankment height indicate increasing susceptibility to strength loss during a seismic event.

All approach embankments that support bridges or separation structures on spread footings should be analyzed dynamically to ensure

2. Cut Slopes

Cut slopes for two-lane undivided roads should be designed based on dynamic analyses when the height of slope, as measured by the vertical distance between the toe and top of cut, is equal to or greater than $\frac{20W}{TI}$, where W is the width between roadway hinge points and TI is the Traffic Index.

Cut slopes for multilane divided roads should be designed based on dynamic analyses when the height of slope is equal to or greater than $\frac{10W}{TI}$, where W and TI are as previously defined.

3. Special Conditions

In addition to the geometric criteria listed in 1 and 2 above, special soil and geologic conditions, when encountered, should be taken into account through dynamic analyses.

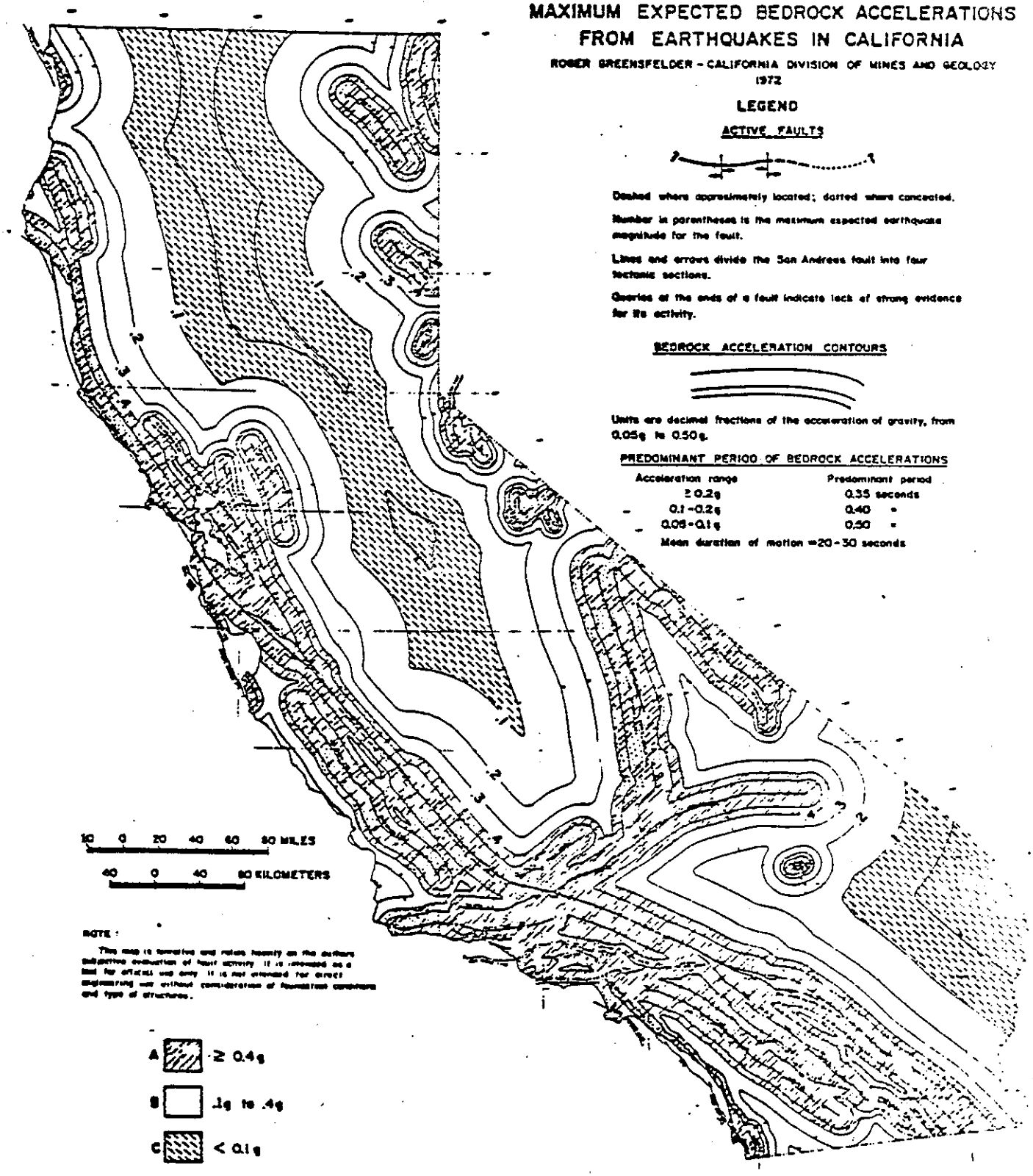
These conditions include liquefaction potential of loose cohesionless deposits with groundwater within 40 feet of ground surface; old landslides uphill from new route locations, and old landslides to be crossed by proposed roadways.

FIGURE 1

Figure 1

MAXIMUM EXPECTED BEDROCK ACCELERATIONS FROM EARTHQUAKES IN CALIFORNIA

ROGER GREENSFELDER - CALIFORNIA DIVISION OF MINES AND GEOLOGY
1972



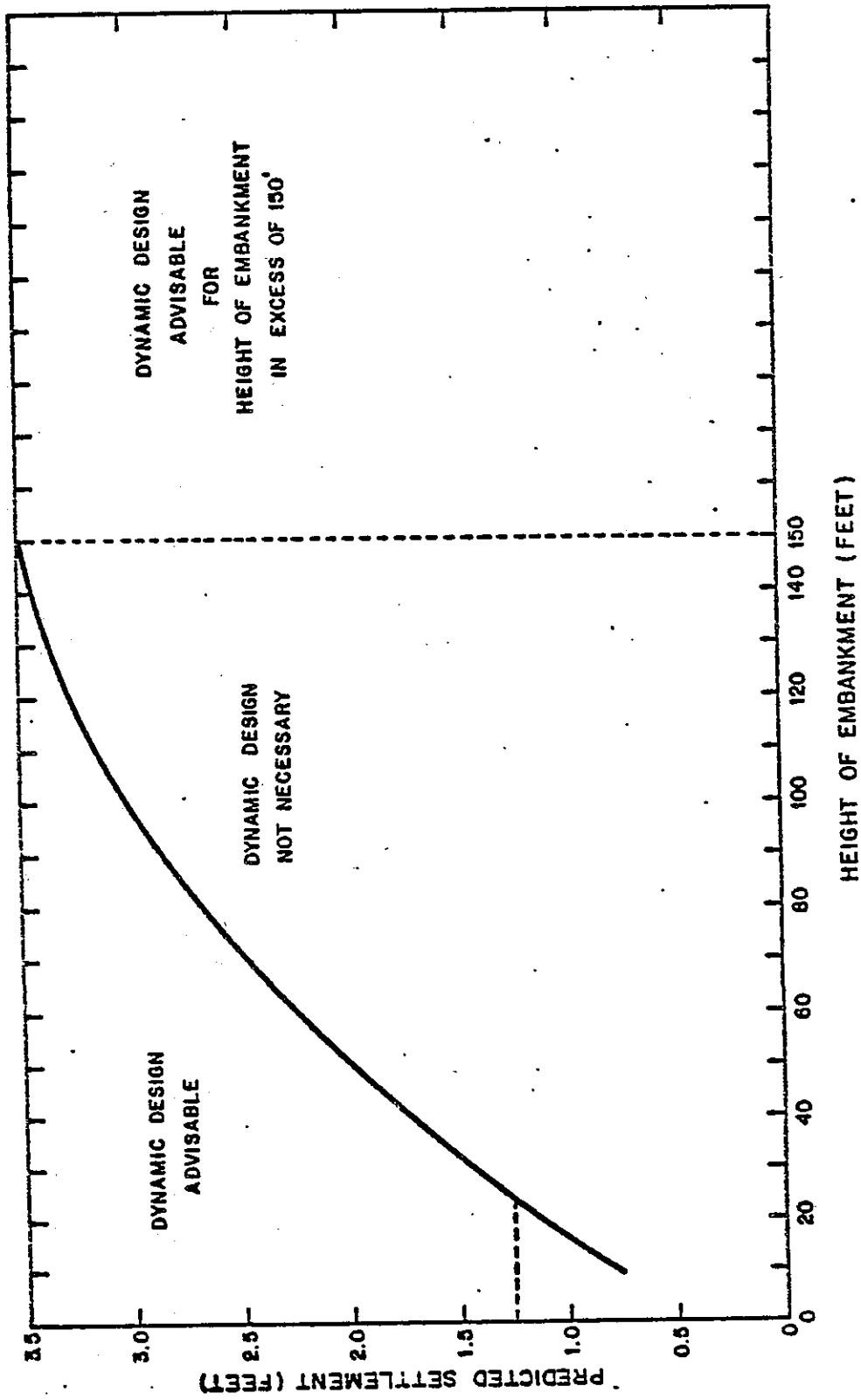


Fig.II EMBANKMENT HEIGHT AND SETTLEMENT CRITERIA FOR DYNAMIC ANALYSES

REINFORCED EARTH AND MECHANICALLY STABILIZED EMBANKMENTS

Introduction

Reinforced earth is a system involving the use of reinforcing elements in soil to increase its shear strength and thus permit construction of earthworks with vertical side slopes (Figure 1). The use of reinforcing materials to strengthen soil has been practiced since Roman times, when early fortifications were built by Gauls using logs and earth(1). Dikes of earth and tree branches have also been used in China for at least one thousand years. The concept of using wooden beams as reinforcement and concrete members as facing for constructing vertical retaining walls was proposed in 1925 by Andreas Munster, who patented this process in 1930(2). In 1969, Henri Vidal of France first reported on Reinforced Earth(3), and obtained a U.S. patent in the same year(4). His work prompted the first rational design system based upon the reinforced earth principle.

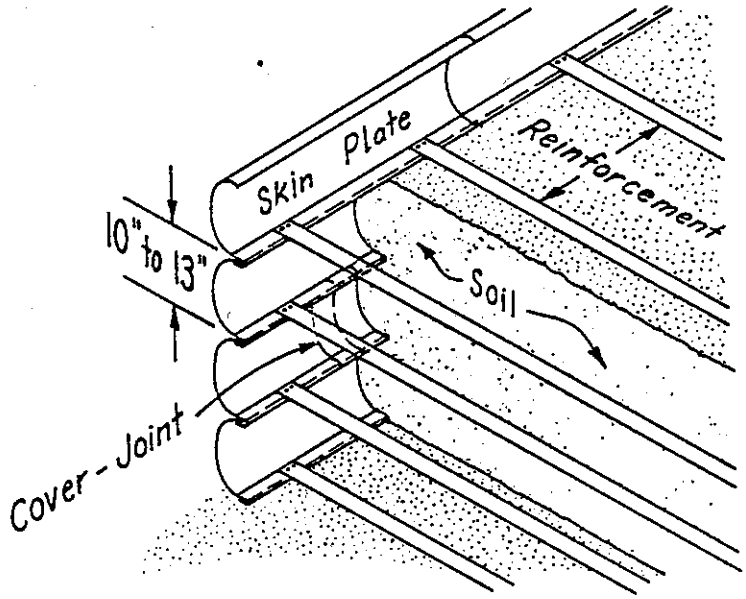


Figure 1 SCHEMATIC OF REINFORCED EARTH FILL

The California Department of Transportation built the first reinforced earth wall in the United States in 1972 using the Vidal System. This wall was constructed on Highway 39 in Los Angeles County and consisted of steel strip reinforcements with steel plate facing (Photos 1-a and 1-b). A second reinforced earth wall using the patented French system was constructed 1974. This wall, utilizing concrete facing and steel strip reinforcement, was constructed on Interstate Highway 5 near Dunsmuir (Photos 2-a and 2-b).

In September, 1971, the Caltrans Transportation Laboratory first recommended the use of welded wire mesh reinforcement and redwood plank facing for the construction of a parking area along Highway 89, near Lake Tahoe. The name, "Mechanically Stabilized Fill", was assigned by Caltrans to this type of construction. Subsequently, a mechanically stabilized fill with bar-mesh reinforcements and concrete facing was recommended for a realignment construction on Highway 96 near Hoopa. More recently two mechanically stabilized fills were designed for a frontage road along Interstate Highway 5 at Dunsmuir. These walls were constructed during the period 1974-76. (Photos 3-a and 3-b). Various sites have since been evaluated for possible application of these systems.

Mechanically Stabilized Embankments

A license agreement between the Reinforced Earth Company of Washington, D.C. and Caltrans covers future construction of Mechanically Stabilized Embankments (referred to as State Design) by Caltrans. The following are the terms and conditions contained in the license agreement:

(1) A royalty payment of ten ($10) dollars per structure will be made to the Reinforced Earth Company.

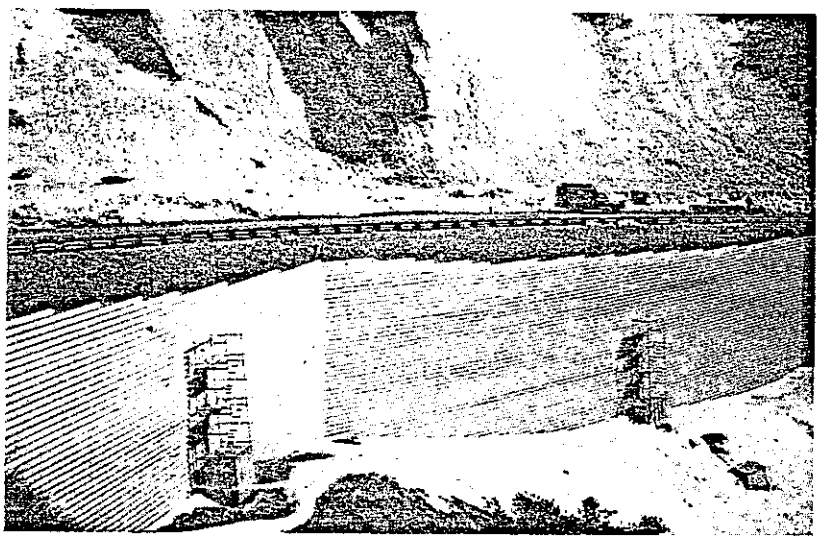


Photo 1-a: Complete View of the Reinforced Earth Wall on California Highway 39, Los Angeles County

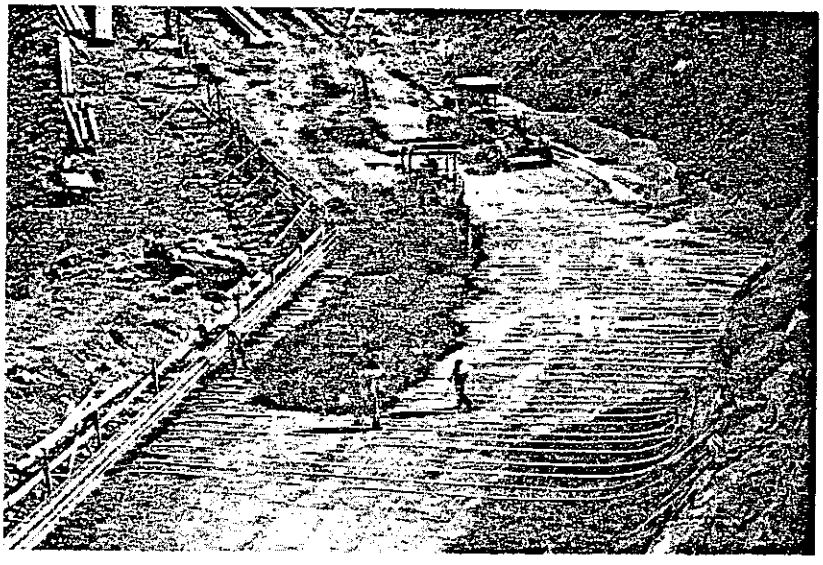


Photo 1-b: Construction of the Reinforced Earth Wall on California Highway 39, Los Angeles County

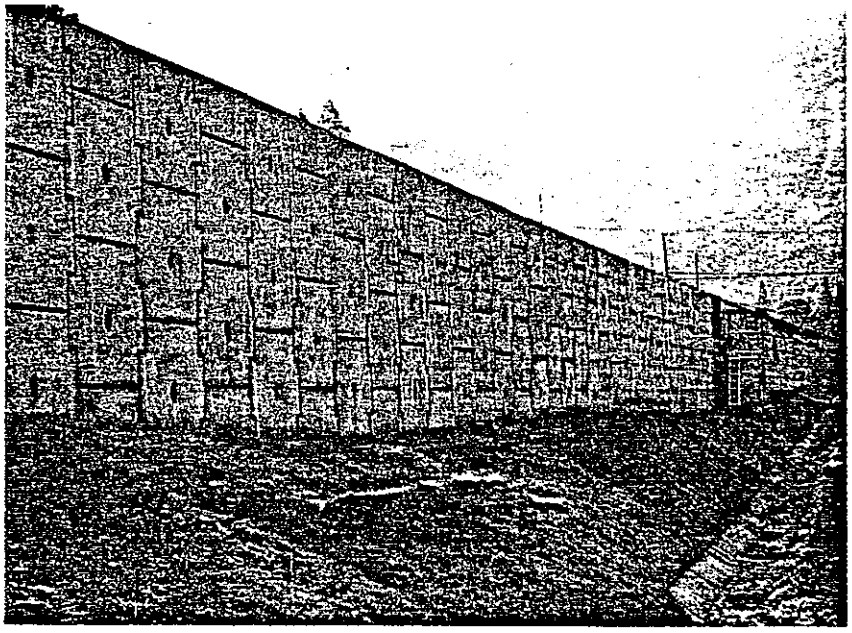


Photo 2-a: Concrete Facing of the Reinforced Earth Wall on Interstate Highway 5 at Dunsmuir

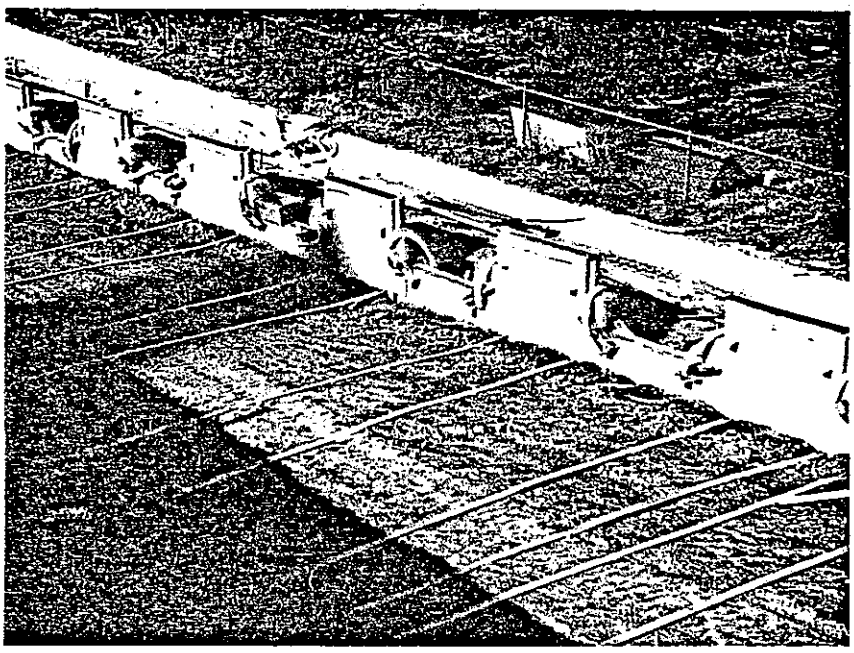


Photo 2-b: Concrete Facing and Reinforcing Strips of the Reinforced Earth Wall on Interstate Highway 5 at Dunsmuir

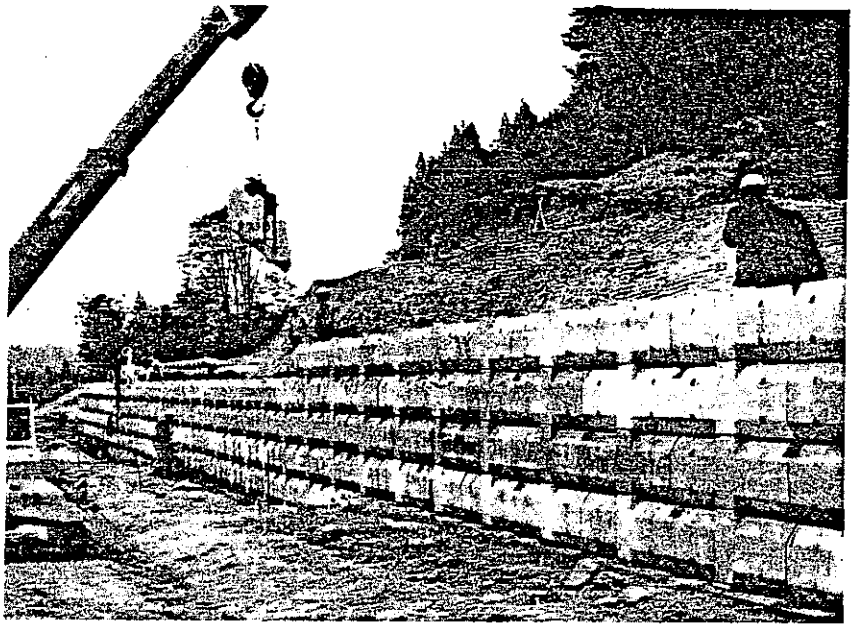


Photo 3-a: Concrete Beam Facing of the Mechanically Stabilized Embankment on Interstate Highway 5 at Dunsmuir, California.

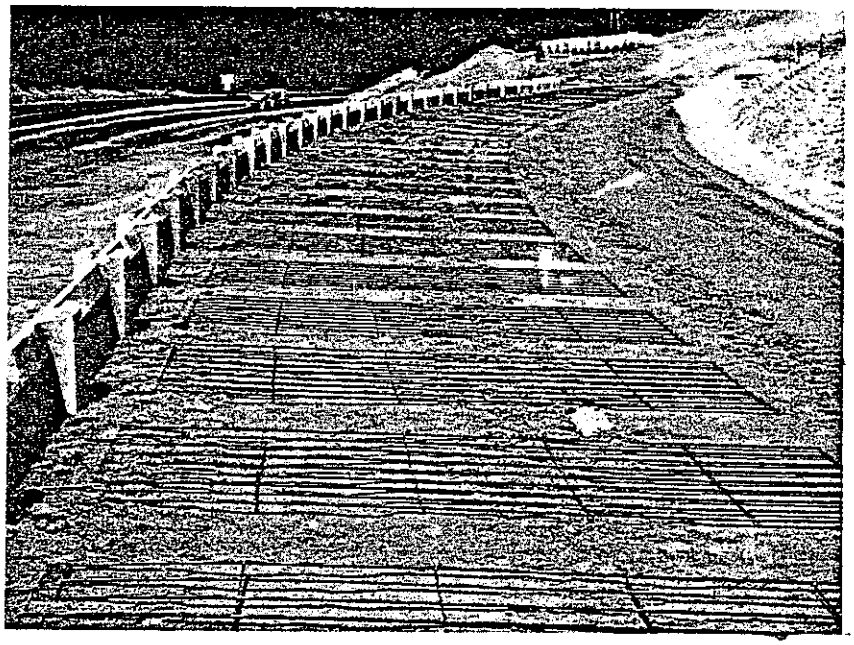


Photo 3-b: Reinforcing Bar-mat in the Mechanically Stabilized Embankment on Interstate Highway 5 at Dunsmuir, California.

(2) The State Design will be designated as "Experimental" for all projects advertised or offered for bid prior to April 1, 1981. DOT shall make all related research information available to the Reinforced Earth Company.

(3) The Reinforced Earth Company shall be given the opportunity to develop an alternate design and specifications for a structure using the patented reinforced earth construction on all projects where a mechanically stabilized embankment is proposed.

(4) All bid and solicitation documents, specifications, prime construction contracts and other published materials relating to the State Design shall contain a clearly readable notation that the State Design is under license from the Reinforced Earth Company.

(5) DOT agrees to include in the specifications for all projects where the State Design is given as an acceptable alternate, a provision that DOT, not Reinforced Earth Company, shall be held solely responsible for the State Design, its suitability, workmanship, and other characteristics except insofar as Reinforced Earth Company has supplied materials therefor.

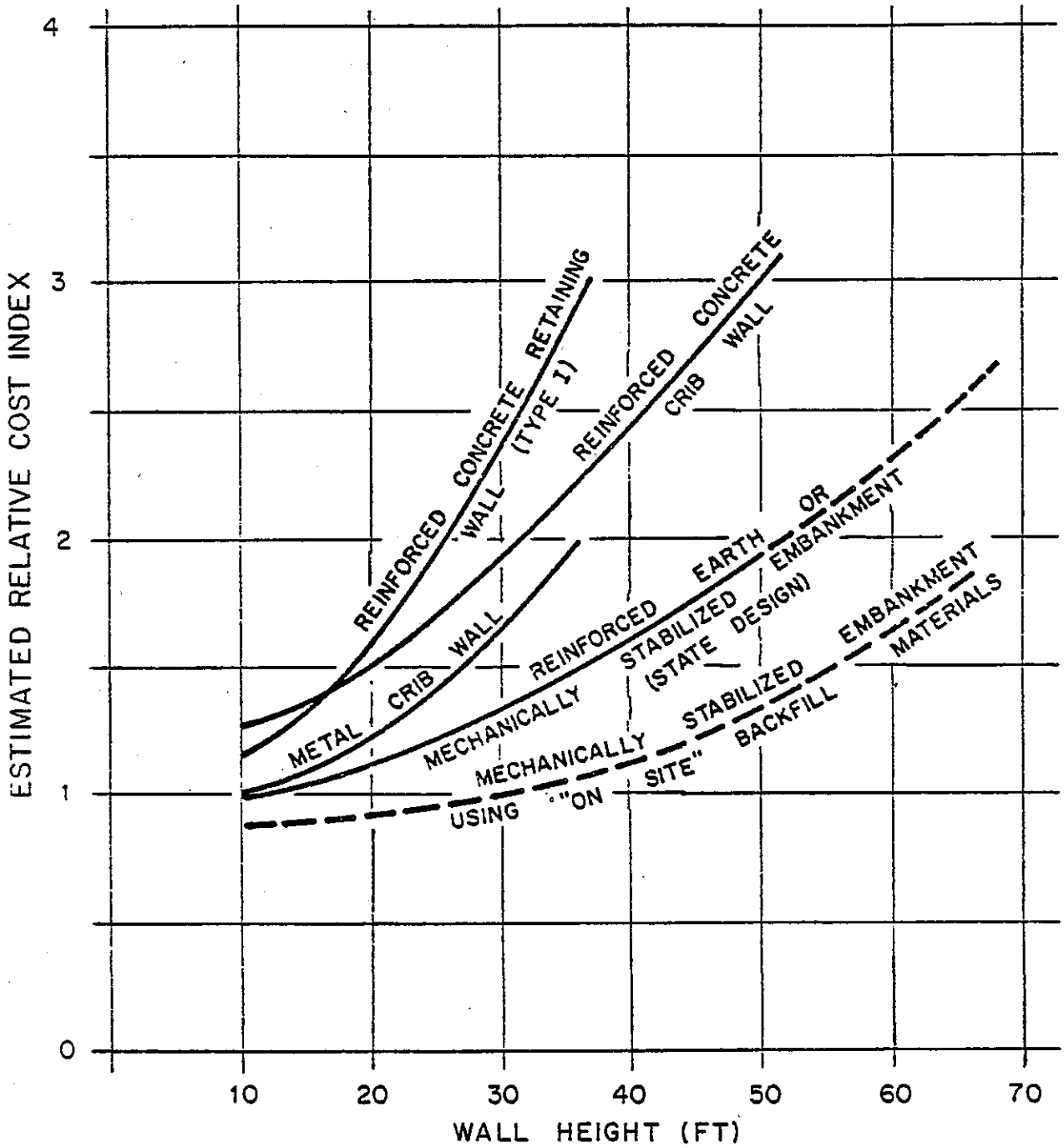
(6) Dissemination by DOT of information or of test data concerning the State Design shall be restricted to requested reports and information and to articles in technical journals and shall clearly indicate that the State Design is licensed by the Reinforced Earth Company.

(7) DOT shall not disseminate any proprietary data with respect to the patented Reinforced Earth Design, except that required for proposed contractors from whom bids or proposals are being sought with respect to a specific construction. DOT shall indicate the proprietary nature of such information with the appropriate legend according to Page 5 of the agreement.

(8) This agreement shall expire August 29, 1989, the expiration date of the Reinforced Earth Patent.

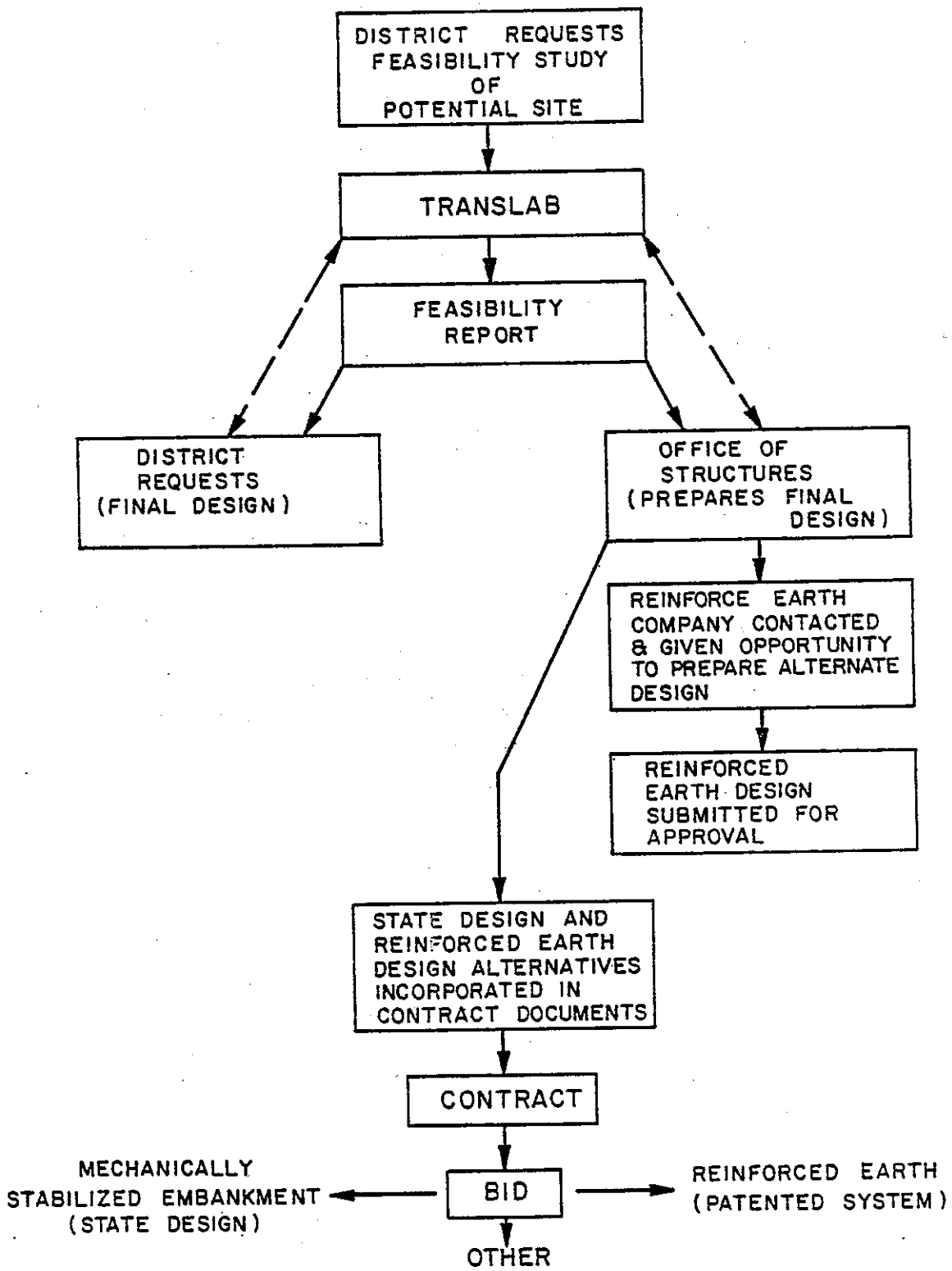
In summary, this agreement allows DOT to continue with research in the development of improved soil reinforcement techniques and to utilize mechanically stabilized embankments on future DOT contracts. Both the reinforced earth and the mechanically stabilized embankments can be substantially lower in cost than conventional earth retaining structures. The main advantages of mechanically stabilized embankment construction compared to the patented Reinforced Earth System are its potential use with poor quality backfill materials and the need for less excavation for lower height walls. The shape of the steel cross-sectional area also plays a significant role in extending the corrosion life of the reinforcing members. The mechanically stabilized embankment design utilizes round steel bar-mat with less surface area subject to corrosion, therefore, a longer service life is suggested. Mechanically stabilized embankment construction can also provide a temporary solution to traffic handling on some projects. A recent example is the construction of a temporary bulkhead at Delhi on Route 99 in District 10. This wood faced wall which was about 1300 feet in length, with a maximum height of 24 feet was constructed in twenty days. It eliminated the need for a detour by allowing construction of half an embankment and partial utilization of the existing roadbed. Considerable savings were derived as a result of this system. Figure 2 shows a relative cost comparison for mechanically stabilized embankment and reinforced earth relative to other retaining wall systems.

Various sites are proposed for construction of either mechanically stabilized embankment or reinforced earth within the near future. Figure 3 is a flow chart illustrating the design procedure.



RELATIVE COST COMPARISON
OF VARIOUS RETAINING WALLS

FIGURE 2



DESIGN PROCEDURE FOR
MECHANICALLY STABILIZED EMBANKMENT

FIGURE 3

Basic Theory

The basic mechanism of a reinforced earth embankment can be explained by Rankine's State-of-Stress theory. Assuming that an element of cohesionless soil mass in a fill is acted on by vertical and lateral stresses, the element of soil mass will be compressed (Figure 4a). If the lateral stresses are smaller than the vertical stresses, lateral expansion and vertical compression will occur (Figure 4b). When the lateral strain reaches a critical value, the element of soil mass will fail by shearing along a failure plane. A triaxial compression test indicates the same mechanism as described above. The state-of-stress at an imminent failure condition can be described by a Mohr diagram (Figure 5) in which Point A represents the state-of-stress shown by Figure 4a where σ_1 equals σ_3. In order to hold the soil element without failure the lateral stress (σ_3) must be increased. By providing reinforcement in a soil element (Figure 6), the skin friction of the reinforcement will supply additional lateral strain. This additional lateral resistance acts as an imaginary plate fixed at each end of the soil element to prevent failure. The state-of-stress at a stable condition is shown by Figure 7.

The state-of-stress developed in a reinforced earth embankment may vary from an "at rest" state in the inner portion of the embankment to the "active" state near the outer face of the embankment. However, the maximum frictional force required to prevent the soil mass from failure can be assumed to be equal to the active earth pressure as shown in Figure 5. The frictional force developed along the surface of the reinforcement is then resisted by its tensile strength.

Referring to Figures 1 and 4 through 8, the frictional forces along the surfaces of the reinforcing strips will create a soil arching

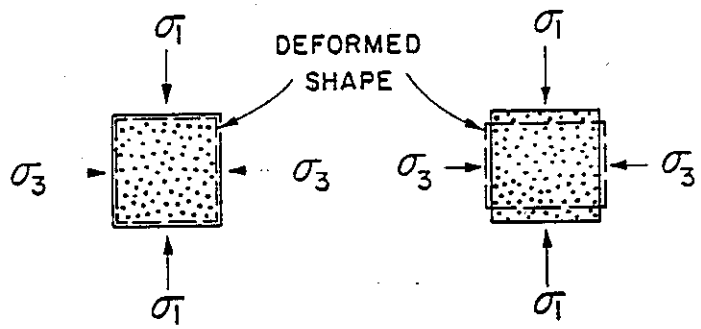


Figure 4a SAND CUBE ($\sigma_1 = \sigma_3$)

Figure 4b SAND CUBE ($\sigma_1 > \sigma_3$)

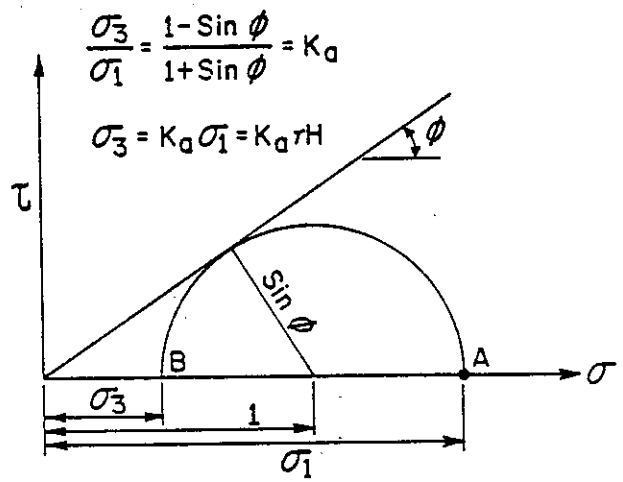


Figure 5 MOHR CIRCLE

(AT IMMINENT FAILURE)

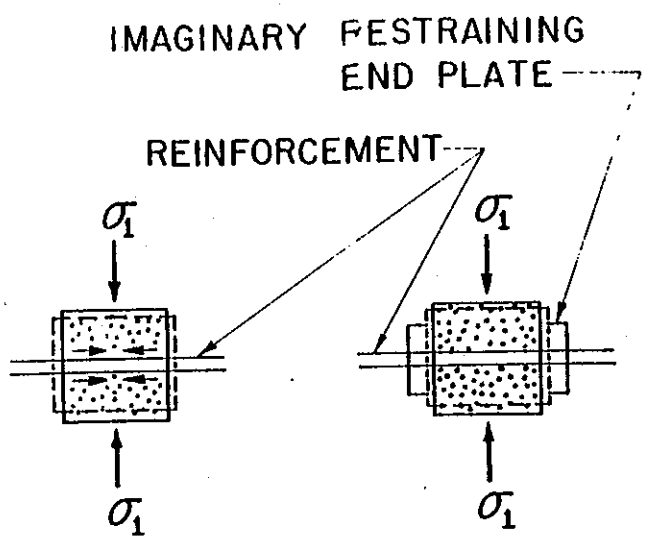


Figure 6 REINFORCED SOIL ELEMENT

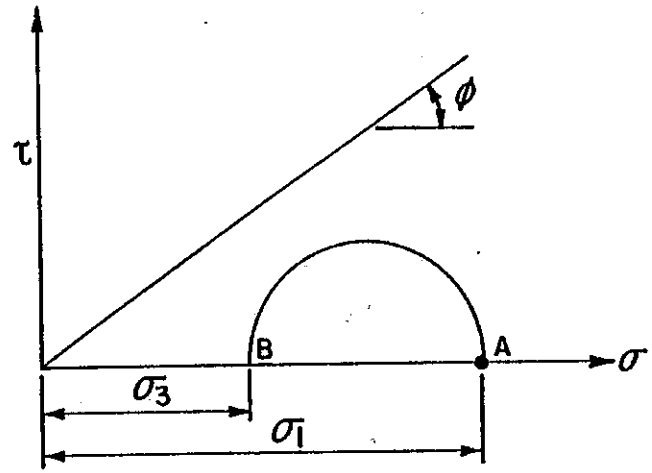


Figure 7

MOHR CIRCLE (WITHOUT IMMINENT FAILURE)

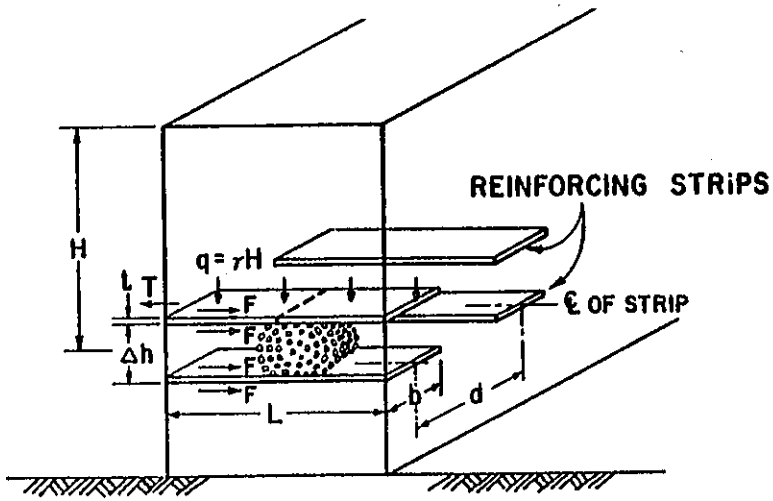


Figure 8

SCHEMATIC OF REINFORCED EARTH BLOCK

action in the vertical plane which, in effect, causes the soil particles to link together to form a series of vertical counterfort walls or reinforcing wedges which provide internal stability of the soil mass in a reinforced earth fill.

The determination of the maximum allowable vertical and horizontal spacing of the reinforcements is still uncertain. However, it can be assumed that the reinforcements must be closely spaced so that an arch action within the soil mass can be developed between reinforcements. This arch action, which causes the soil particles to link together without separation, may depend upon the size of soil particles, the skin friction between the soil and reinforcements, the internal frictional angle of the soil, and the stress developed within the soil mass.

Design of Strip Reinforcement

Based on the theory and principle discussed in the previous paragraph, the basic equations for designing the reinforcement are presented as follows:

Referring to Figures 5 and 8, following are the notations to be used in developing the basic design equations:

p = active earth pressure in pounds per square foot
f_s = steel tensile stress, in psi
K_a = Rankine active earth pressure coefficient
b = steel strip width, in inches
t = steel strip thickness, in inches
γ = soil density, in pounds per cubic foot
H = overburden height, in feet
d = horizontal steel strip spacing, in feet
Δh = vertical steel strip spacing, in feet

T = tensile force in steel strip, in pounds
F = frictional resistance, in pounds
L = length of steel strip, in feet
δ = friction angle between steel and soil

It is believed that the wall face may rotate slightly outward after compaction. A Rankine's active earth pressure may develop on the inner face of the skin plate, (Figure 9) as

$$p = \sigma_3 = K_a \gamma H \tag{1}$$

The total earth pressure acting on the inner face of the skin plate will tend to either pull out or break the steel strips. The pull force, T, developed in each steel strip will be then

$$T = K_a \gamma H d \Delta h, \tag{2}$$

and $T = f_s b t,$ (3)

or $$f_s = \frac{K_a \gamma H d \Delta h}{bt} \tag{4}$$

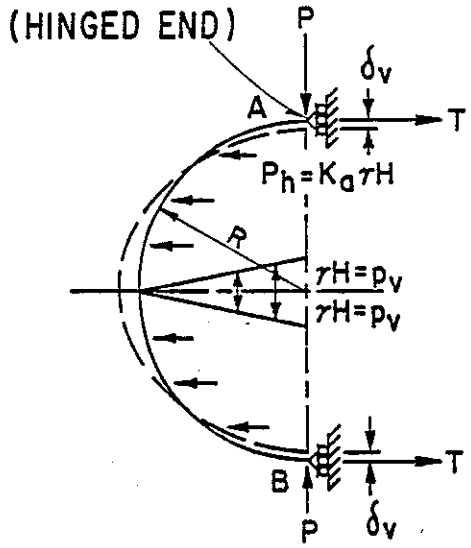
The friction force developed on each face of the reinforcing plate will be then

$$F = \frac{\gamma H b L \tan}{12} \tag{5}$$

Therefore, the factor of safety against slippage can be expressed as

$$F.S. = \frac{2F}{T} = \frac{2 \gamma H b L \tan}{12 K_a \gamma H d \Delta h} = \frac{b L \tan \delta}{6 K_a d \Delta h} \tag{6}$$

Equations 4 and 6 are the basic equation for the design of reinforcing strips.



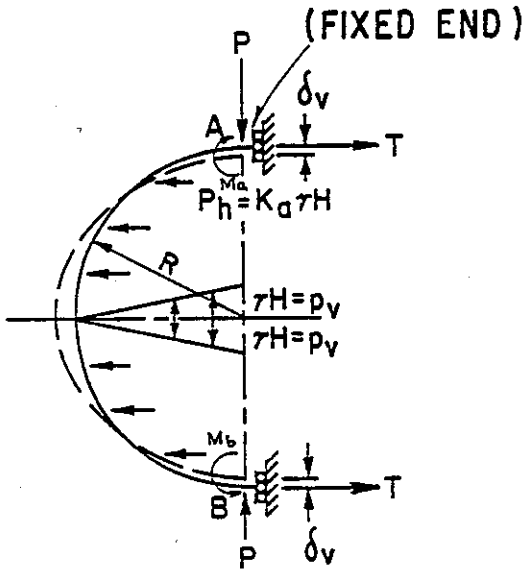


Figure 9

LOADING DIAGRAM ON SKIN PLATE

Design of Bar-Mat

The advantage of utilizing bar-mat for reinforcement is the increased pull out resistance provided by the cross members which mobilize the passive resistance of the soil in addition to the friction and cohesive strength. Based on large scale laboratory test results, for the same surface area, bar-mat develops nearly six times the pull out resistance of steel strips (Table 1). Therefore, the design of the bar-mat is only governed by the tensile strength of the longitudinal bars, the stability requirements and corrosion. The basic design equation is shown below.

$$N = \frac{K_a \gamma H w h}{A_s f_s} \tag{7}$$

where: N = number of the longitudinal bars required per facing member.

A_s = cross-sectional area of each longitudinal bar

f_s = allowable tensile strength of steel bar

w = width of each facing member

h = height of each facing member

K_a = Rankine active earth pressure coefficient

γ = soil density

H = overburden height

Stability

The overall stability of a reinforced earth or mechanically stabilized embankment under all expected loading conditions should be analyzed by considering the reinforced mass as a solid block or a gravity type of concrete retaining wall. Sliding instability and earth pressure developed within the backfill behind the reinforced mass, and the potential sliding or bearing failure of the foundation should be investigated in the same manner as is ordinarily done for design of embankments and retaining walls. As a

TABLE 4
COMPARISON OF PULL RESISTANCE FOR DIFFERENT TYPES OF REINFORCEMENT
(EMBEDDED IN GRAVELLY SAND SOIL FROM DUNSMUIR, UNDER NORMAL
PRESSURE OF 10 POUNDS PER SQUARE INCH)

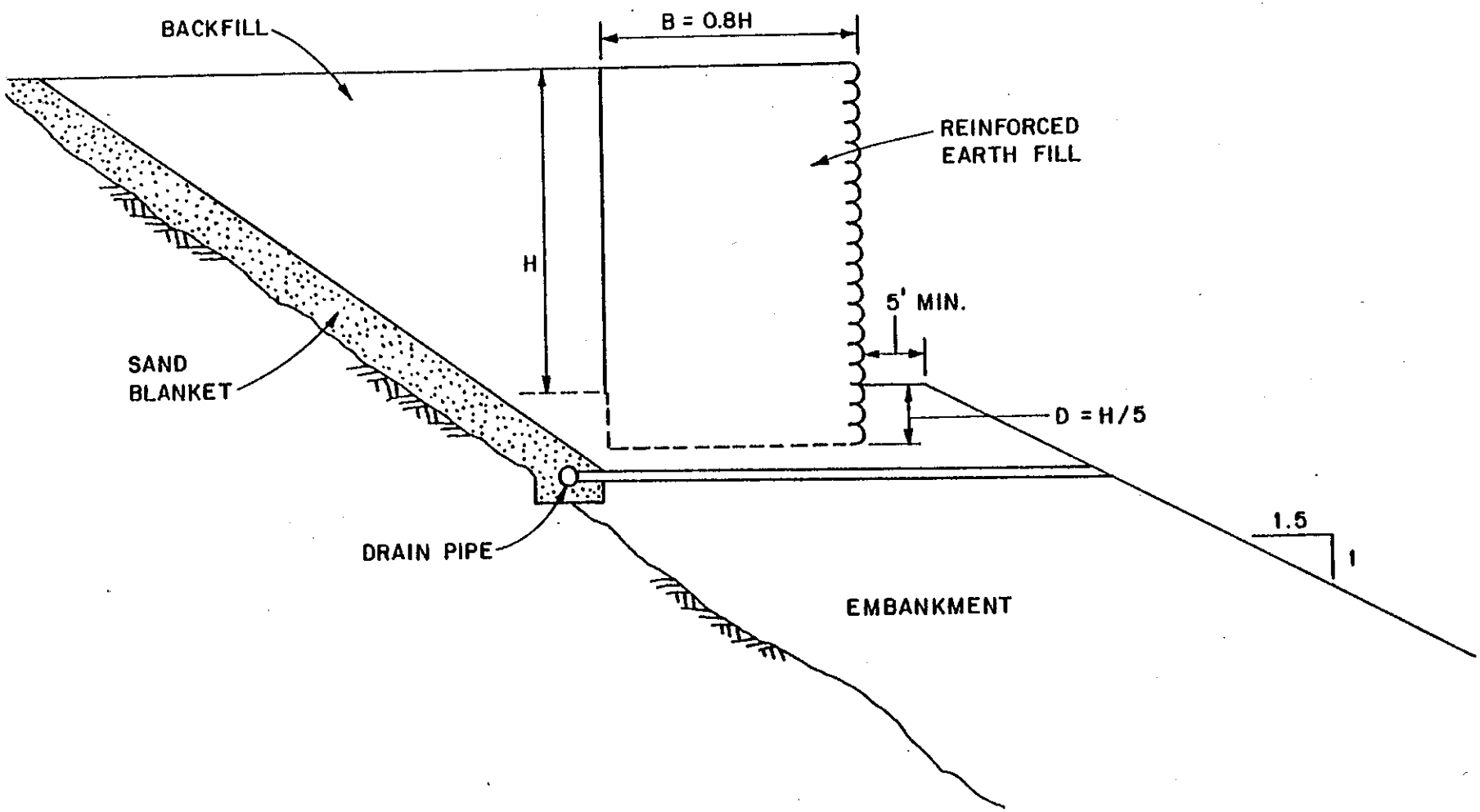
Type of Reinforcement	Description	Tot. Surf Area in % of Bar-mesh Rein.	Yielding Load (Kips)	Peak Load (Kips)	Residual Load (Kips)
Bar-mesh	Bar mesh with 8-3/8" Øx54" longitudinal bars and 7-3/8" Ø x 27" cross bars to form mesh opening of 4" x 8". (Test No. 2)	100	17.3	37.5	25.7
Longitudinal bars	8-3/8" Ø x 54" longitudinal bars, no cross bars. (Test No. 5)	69	2.5	3.4	2.8
Longitudinal bars	8-3/8" Ø x 54" longitudinal bars and 4-3/8" Ø x 50" longitudinal bars, no cross bars. (Test No. 6)	100	5.7	6.8	4.5
Solid steel plate	28" x 54" x 1/8" thick solid steel plate. (Test No. 7)	409	14.5	17.7	17.5
Steel strip	One metal strip 2.3" x 54" x 1/8" thick. (Test No. 8)	34	2.0	2.6	2.6
Steel strip	Two metal strips 2.3" x 54" x 1/8" thick. (Test No. 9)	67	4.4	5.3	5.3
Steel strip	Three metal strips 2.3" x 54" x 1/8" thick. (Test No. 10)	100	4.5	6.7	6.7

rule of thumb (suggested by the Reinforced Earth Company for stability considerations) the ratio of depth to clear height of a reinforced earth embankment is suggested to be at least 0.8. It is also suggested that the footing of the reinforced earth embankment be embedded in an excavated or backfill berm to one-fifth of the clear height of the reinforced earth embankment; the width of the berm should be at least 5 feet and the outer slope of the berm should be not steeper than 1.5 feet horizontal on 1 foot vertical (Figure 10).

Corrosion

The Transportation Laboratory developed a method for estimating relative soil corrosivity by combining the relative influences of the hydrogen-ion concentration (pH) and the minimum resistivity of the soil(5). Figure 11 is a chart developed for estimating underground corrosion rate of steel pipe. This chart shows the relationship between corrosion rate, minimum soil resistivity (ohm/cm^3) and pH values for acid soils and alkaline soils. A thorough investigation of soil samples and corrosive environment for a given construction site is recommended. Laboratory and field soil test should be conducted to determine various factors which affect corrosion.

Figure 11 can be used for estimating the rate of metal loss, and to establish the required thickness (corrosion allowance) of steel reinforcement for the design life.



STABILITY REQUIREMENTS
(RULE OF THUMB)

Figure 10

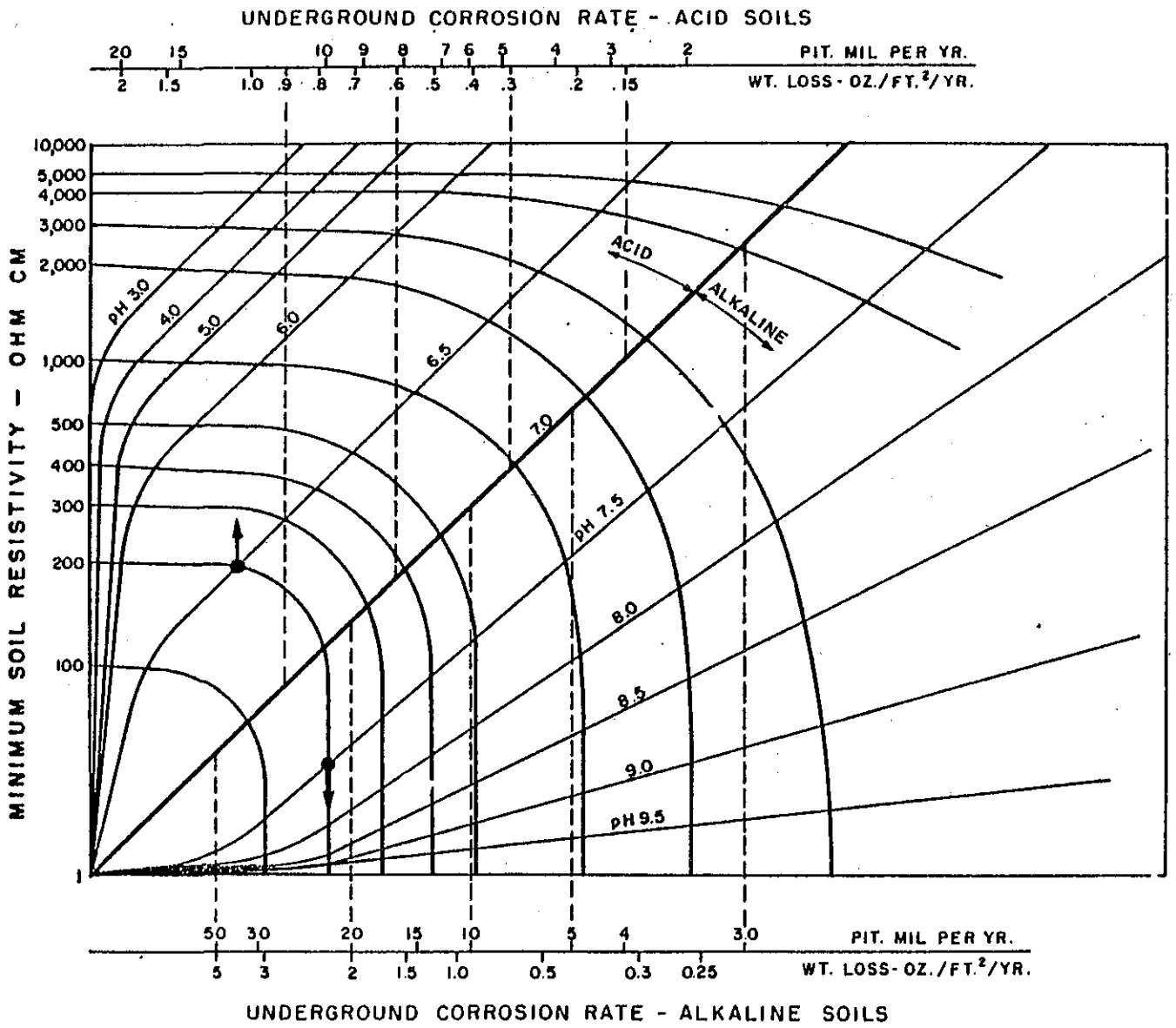


Figure 11 —Chart for estimating corrosion rate of steel pipe. Example 1: with pH of 6.5 and resistivity of 200 ohm cm, the underground pipe loss is about 1.0 oz sq ft/yr and the pitting rate about 0.013 ipy. Example 2: with pH of 7.5 and resistivity of 200 ohm cm, the underground pipe loss is about 2.2 oz; sq ft yr and the pitting rate is about 0.022 ipy.

REFERENCES

1. Caesar, Vol. 1, Translated by William Duncan, Harper Bros., New York, 1855, p 201.

2. Munster, Andreas, United States Patent No. 1762343, June 10, 1930.

3. Vidal, Henri, The Principle of Reinforced Earth, Highway Research Record, No. 282, pp 1-16, Washington, D.C., 1969.

4. Vidal, Henri, U.S. Patent No. 3421326, January 14, 1969 and 3686873 August 29, 1972.

5. Stratfull, R. F., A New Test for Estimating Soil Corrosivity Based on Investigation of Metal Highway Culverts, Corrosion National Association of Concrete Engineers, April, 1961, pp 115-118.

ASPHALT MATERIALS

FOR TRAINING PURPOSES ONLY

Transportation Laboratory
Laboratory Training Course
Sacramento, California

ASPHALTS

Paving Asphalt

Since about 1900, when engineers actually determined the consistency of paving grade asphalts by chewing, the grading of paving asphalt has been based on the consistency of the original material. Obviously the chewing technique was not very scientific. It was replaced by the penetration test in the early years of this century. Although the original test required the use of a No. 2 sewing machine needle, it has since developed into a scientific method of measuring the consistency of paving asphalts. The test has normally been performed at 77°F to determine the grade of the original asphalt. The penetration is the depth of needle penetration in one-tenth millimeters.

In May 1965, the Transportation Laboratory submitted to the conferees of the Sixth Pacific Coast Conference on Asphalt Specifications a new concept for grading asphalt. This concept consisted of grading the asphalt on the basis of viscosity after a treatment called the "Rolling Thin Film Test". The Rolling Thin Film Test simulates the pugmill action of hot mix batching plants relative to asphalt hardening and results in the asphalt having about the same viscosity as the asphalt in the mix delivered to the street. The viscosity of the asphalt residue test specimen is then measured at 140°F and designated in fundamental viscosity terms (poises).

Residue viscosity graded asphalt specifications became effective January 1, 1974, and utilize this concept of grading the asphalt after the simulated mixing phase. They were adopted to minimize the wide differences encountered during construction between some Santa Maria and Bakersfield asphalts. Better compaction control, savings in construction time, and probably an extended life for our asphalt concrete pavements should result from implementation of this specification.

The specifications included five grades, with an AR prefix that designates aged residue (Table A). The number following the AR designates the grade, with the higher values being the more viscous, or harder asphalts. The AR-4000 grade is being used for most of the hot-mix AC on Caltrans jobs. The Flash Point and Solubility in Trichlorethylene tests are performed on the original asphalt. The Flash Point is a safety test and the solubility designates purity in that it is a measure of the dirt or inert material in the asphalt. Temperature susceptibility (change in consistency with temperature) is controlled by the Viscosity at 275°F and the penetration at 77°F on the residue. Asphalt durability is controlled to some extent by the percent of original penetration requirement after the RTFC procedure. Ductility will continue to be controlled at 77°F with a minimum requirement.

Suggested uses are shown in Appendix I . These usages are a guide prepared by a committee of consumer and producer representatives.

TABLE A

STEAM-REFINED PAVING ASPHALT CEMENTS

Specification Designation	AASHTO Test Method	Viscosity Grade AR 1000	AR 2000	AR 4000	AR 8000	AR 16000
Tests on Residue from RTFC Procedure-Calif. Method 346*						
Absolute Viscosity at 140°F., poise	T-202	750-1250	1500-2500	3000-5000	6000-10000	12000-20000
Kinematic Viscosity at 275°F., cs, min.	T-201	140	200	275	400	550
Pen. at 77°F.100g/5sec.min.	T-49	65	40	25	20	20
% of orig. pen. at 77°F., min.	***	---	40	45	50	52
Ductility at 77°F., cm., min.	T-51	100**	100**	75	75	75
Tests on Orig. Asphalt						
Flash Point, Cl.O.C. °F., min.	T-48	400	425	440	450	460
Solubility in Trichloroethylene %, min.	T-44	99	99	99	99	99

*TFO may be used but the RTFC shall be the referee method.

**If the ductility at 77°F is less than 100 cm., the material will be acceptable if its ductility at 60°F is more then 100 cm.

***Original penetration as well as penetration after the RTFC loss will be determined by AASHTO Test Method T-49.

APPENDIX I

SUGGESTED USES OF PAVING ASPHALTS

The selection of the grade of asphalt for a particular use is influenced by:

1. Type of construction.

2. Aggregates with which the asphalt will be used (gradation, soundness, absorptiveness, surface texture).

3. Method of construction and equipment available (mixing, spraying, machine or hand-placing).

4. Climatic conditions during construction (temperature, humidity, wind).

In general, softer, more fluid paving asphalts are preferable in colder climatic areas. Workability is improved and thermal cracking reduced. In hot areas, higher viscosity, harder asphalts are preferable to provide increased tensile strength and hence tougher mixes. The preferred asphalt grade is also influenced by the amount of fine particles in the aggregates used. For example, aggregate deficient in fine particle sizes will require more viscous asphalts. Because of these considerations, it is proper to use different grades of asphalt in different areas for the same type of work.

Following is a brief discussion of the most common types of construction using paving asphalt. The grade of asphalt suggested for use is given.

Asphalt Concrete Base (ACB)

Asphalt concrete base is mixed in a central plant using heated aggregate or sand and paving asphalt. The prepared mix is laid with a paving machine or spreaders and compacted. Grades AR-8000, AR-4000, and AR-2000 are suggested. The AR-8000 and AR-4000 are preferable in hot climates while AR-4000 and AR-2000 are suggested for colder areas.

Parking Areas

For parking lots and driveways in hot climatic areas AR-8000 is usually the preferred grade In cooler climates AR-4000 should be used.

Highways

With good quality rough, textured aggregate and in hot climates AR-4000 is generally the best selection. With the same type of aggregate in cool climates, AR-2000 should generally be used.

In areas where sub-zero temperatures occur, AR-2000 or AR-1000 should be used.

Borderline quality aggregates require a higher viscosity asphalt. AR-8000 or AR-4000 is recommended.

Airports

Airports require good quality rough, textured aggregates. This is needed to withstand the high impact loads of heavy aircraft. In airport paving AR-8000 or AR-4000 is recommended in hot climatic areas. In cooler climates AR-4000 or AR-2000 should be used.

Open Graded Surface Courses

For open graded (porous) paving mixes used as surface courses, AR-8000 or AR-4000 is recommended.

Surface Treatments (Chip Seals)

Occasionally paving asphalt is used for chip seals. If proper construction practices are followed, paving asphalt of the AR-2000 grade may be used in hot climatic areas.

Curbs

For asphalt concrete to be used for curb construction, AR-8000 is recommended. The aggregate should have sufficient dust to insure a dense, tough curb.

Industrial Floors

Asphalt concrete made with AR-16000 or AR-8000 and a good quality aggregate having a rough surface texture is recommended for industrial floors.

SUGGESTED TEMPERATURES FOR USE OF PAVING ASPHALTS

Grade of Paving Asphalt	Distributor Spraying Temp., °F.		Pugmill Mixing Temperature of Aggregates, °F.	
	Min.	Max.	Min.	Max.
AR-16000	*	*	300	350
AR- 8000	295	350	275	325
AR- 4000	290	350	275	325
AR- 2000	285	350	275	325
AR- 1000	275	325	225	275

Pugmill mixing temperatures for open graded mixes should be between 225°F. and 250°F.

CAUTION: Suitable safety precautions are mandatory at all times when handling asphalt. These safety precautions include, but are not limited to, the following:

1. Do not permit open flames or sparks of any kind close to these materials except in heating kettles, mixers, distributors or other equipment properly designed and approved for handling and applying them.

2. Do not use an open flame to inspect or examine drums, tank cars or other containers in which these materials may be stored.

3. Properly vent and ground all vehicles transporting these materials.

4. Permit only experienced personnel to supervise the handling of these materials.

5. Comply with all applicable intra and interstate commerce requirements.

Liquid Asphalts

Liquid Asphalts, or "cutbacks", are asphalt products in which a "paving asphalt" is diluted by the addition of solvent such as cutter stock, kerosene, or naptha to produce a material which is liquid at normal temperatures. Specifications for these products are found in Section 93 of the Standard Specifications. Table B outlines how these products have been used by the State and which products are used predominantly. The use of Liquid Asphalts is decreasing due to environmental considerations and they may eventually be replaced by Emulsified Asphalts.

TABLE B

LIQUID ASPHALT USES ON STATE CONTRACTS

TREATMENT	Slow Curing				Medium Curing				Rapid Curing			
	SC-70	SC-250	SC-800	SC-3000	MC-70	MC-250	MC-800	MC-3000	RC-70	RC-250	RC-800	RC-3000
Prime Coat	x*	x*			x*	x						
Penetration Treatment	x	x										
Shoulder Seal									x*			
Sand Seal		x					x*					
Curing Seal						x*						
Chip Seal							x*					
Patching Mix			x*				x					
Plant Mix Base								x*				

* Predominant use of this product by State.

Emulsified Asphalts

Emulsified Asphalts, or "Emulsions", are produced in a process in which paving asphalt (approximately 60%), water (approximately 40%), and emulsifying agent (a soap or detergent) are blended. The product is a material which is liquid at normal temperatures and can be used for a variety of purposes where spraying is desirous. Table C shows how the various grades can be used in a variety of applications. Due to the adverse environmental effects of some of the other asphalt products, it is anticipated that there will be much wider usage of emulsified asphalts in the future. Section 94 of the Standard Specifications contains the Emulsified Asphalt specifications.

TABLE C

EMULSIFIED ASPHALT USES

	ANIONIC							CATIONIC					
USE	*RS-1	RS-2	MS-1	MS-2	*SS-1	SS-1h		CRS-1	CRS-2	CMS-2S	CMS-2	CSS-1	CSS-1h
Chip Seals	x	x			x			x	x			x	
Sand Seals	x				x	x		x				x	x
Slurey Seal					x	x						x	x
Fog Seal					x[1]	x[1]						x[1]	x[1]
Tack Coat	x				x[1]	x[1]		x				x[1]	x[1]
Dust Binder					x[1]							x[1]	
Patching Mix (Stockpile)										x	x		
Plant Mix Cold laid					x							x	x
Road Mix (Open graded)				x							x		
(Dense graded)				x						x		x	
(Clean sand)						x						x	x
(Sandy soil)					x					x		x	x

1 Diluted with water.

* Emulsions used most by State of California

BITUMINOUS MIXES

DESIGN OF BITUMINOUS PAVING MIXTURES

1. Prime requisites of a good asphalt paving mixture.

   A. Remain stable under imposed traffic loadings.

   B. Contain sufficient asphalt to provide durability without flushing to the surface.

   C. Resist the destructive forces of the elements.

Following is a brief presentation of the factors and considerations which enter into the laboratory design of asphalt paving mixtures.

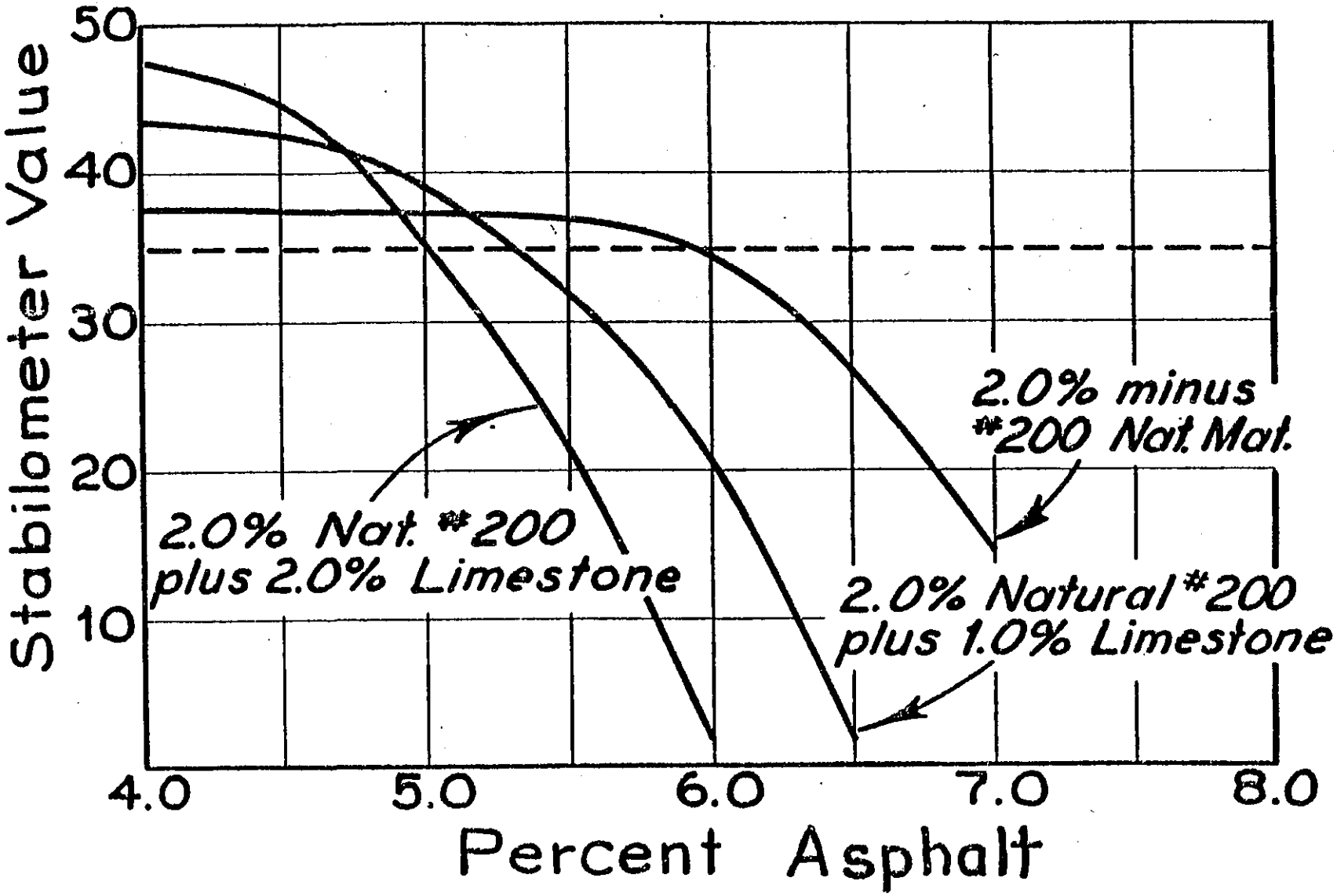
Aggregate Gradation (Sieve Analysis)

Aggregate gradation is probably one of the first characteristics which come to mind when the engineer considers the design of a bituminous paving mixture. If we are to provide for a stable and durable paving mixture, we must understand some of the things which affect the mixture, both beneficially and adversely, with regard to gradation.

A properly designed bituminous paving mixture is one having a balanced relationship between the coarse, intermediate, and fine particle sizes. An excess of fines will result in an overly dense mixture which will be critical because of its susceptibility to bleeding and instability with a slight excess of asphalt or moisture (see Figure 1). On the other hand, if the mixture has a deficiency in the finer or intermediate sizes, the pavement will be harsh and

Figure 1

EXAMPLE OF A BITUMINOUS MIXTURE BECOMING CRITICAL WITH ADDITION OF FINE DUST



open textured and permit the entrance of water and air, both of which have an adverse effect on the durability of the asphalt binder.

Mixtures containing aggregate that complies with our standard specifications normally provide a compacted mix having about 4 to 6 % air voids. Mixtures which give trouble due to over-densification usually have air voids of 3% or less when compacted in the laboratory. These mixtures approach zero air voids after several years of traffic, causing a bleeding condition.

Aggregate Quality

Aggregate impact resistance is determined by the Los Angeles Rattler Test. Specifications governing this quality of the aggregates are, of course, more restrictive for open graded mixes and seal coat screenings because the aggregates in this type of pavement are not protected and supported by the matrix as is the case in dense graded mixtures. Aggregates which show a high percentage loss in this test are susceptible to breakdown and degradation under traffic. This may result in raveling and ultimate failure of the mix from disintegration. A high percentage loss in this test, especially at 100 revolutions, usually is an indication that you are dealing with a soft and absorptive aggregate.

Asphalt Content

A durable mixture which will give satisfactory performance and have a long service life is the chief aim of the designer. Other things being equal, the one component which most affects the durability of the asphalt paving mixture is the amount of asphalt in the mixture.

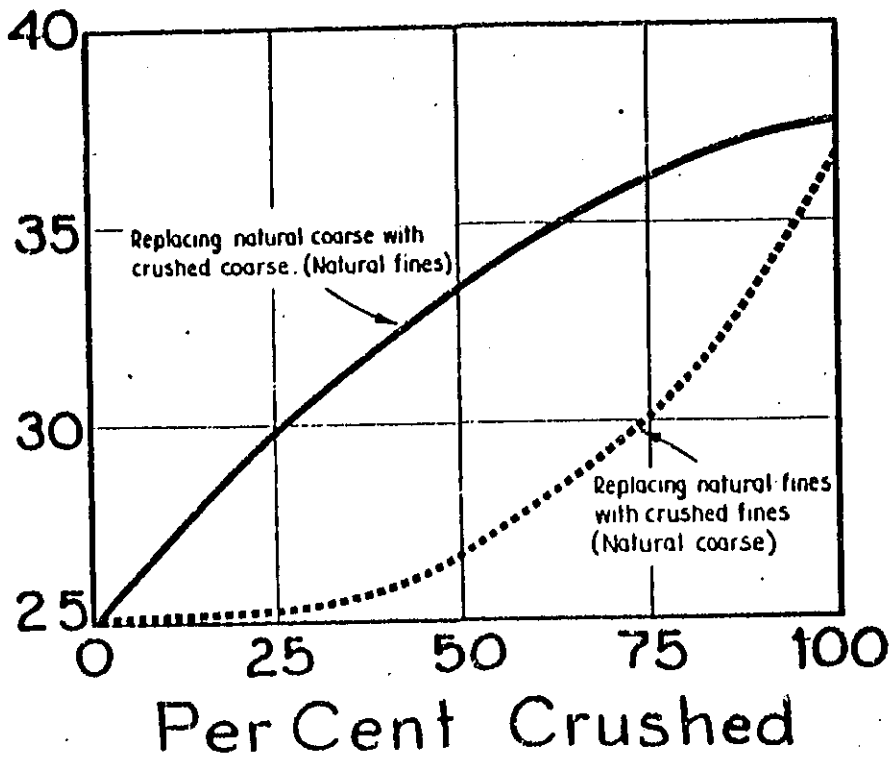
Asphalt in thin films deteriorates quite rapidly; therefore, a mix containing aggregate coated with a thick film of asphalt will provide a much more durable pavement than the same mix with thin asphalt films caused by a deficiency of asphalt.

Determining the proper asphalt content involves the use of the Centrifuge Kerosene Equivalent Test (C.K.E.) and is one of the steps of major importance in the design of bituminous mixtures. Aside from the results of the C.K.E. test, there are a number of other factors which must enter into the final recommended asphalt content for the mixture. Some of the factors which must be considered are the absorptive qualities of the aggregates, the stabilometer value and the density of the compacted mixture, and the tendency of the compacted mix to flush (bleed).

In addition to the amount of asphalt and fines in the mix, stability is governed by the particle shape and surface texture of the aggregate and is measured with the Stabilometer at a temperature of 140°F. It is a measure of the frictional resistance of the aggregate particles in contact with one another; therefore, surface texture of the aggregate has considerable effect on the values. As an example, a streambed gravel having a sandpaper-like surface texture will provide a better stabilometer value than an all-crushed ledge rock with a smooth glassy surface texture. As a general rule, however, crushed aggregates will provide higher stabilometer values than uncrushed aggregates (see Figure 2). As the stabilometer value is a measure of the mixture's ability to resist displacement under vertical loading, excessive fines or an excess of asphalt or moisture or any combination of these components may result in an unstable mixture with little resistance to deforation under load. Thus, the mix design procedure requires at least 4% voids in the laboratory-compacted specimen to allow for some variation in field density and prevent the development of a low void, bleeding pavement.

Resistance to Water

All of our asphalt pavements are, at some time or other, subjected to the action of water in some form; whether it be free water entering from the surface, water coming from the underlying materials by capillary action, or water in the form of vapors rising from a wet base as it dries during the summer months. In order to obtain a paving mixture which will resist these destructive forces, we must perform still other tests to determine this quality of the mixture. At present, three tests are performed to determine the water resistant qualities of the asphalt paving mixture: the Swell Test, Film Stripping Test, and Moisture Vapor Susceptibility Test. In addition, a fourth test that is becoming increasingly popular is the surface abrasion resistance test. All these tests are performed on the asphalt mix proposed for use, and the results of each test are evaluated independently. AC quality is controlled by maximum and/or minimum values in the specifications.


40
35
30
25
0
25
50
75
100
Per Cent Crushed
Replacing natural coarse with crushed coarse. (Natural fines)
Replacing natural fines with crushed fines (Natural coarse)

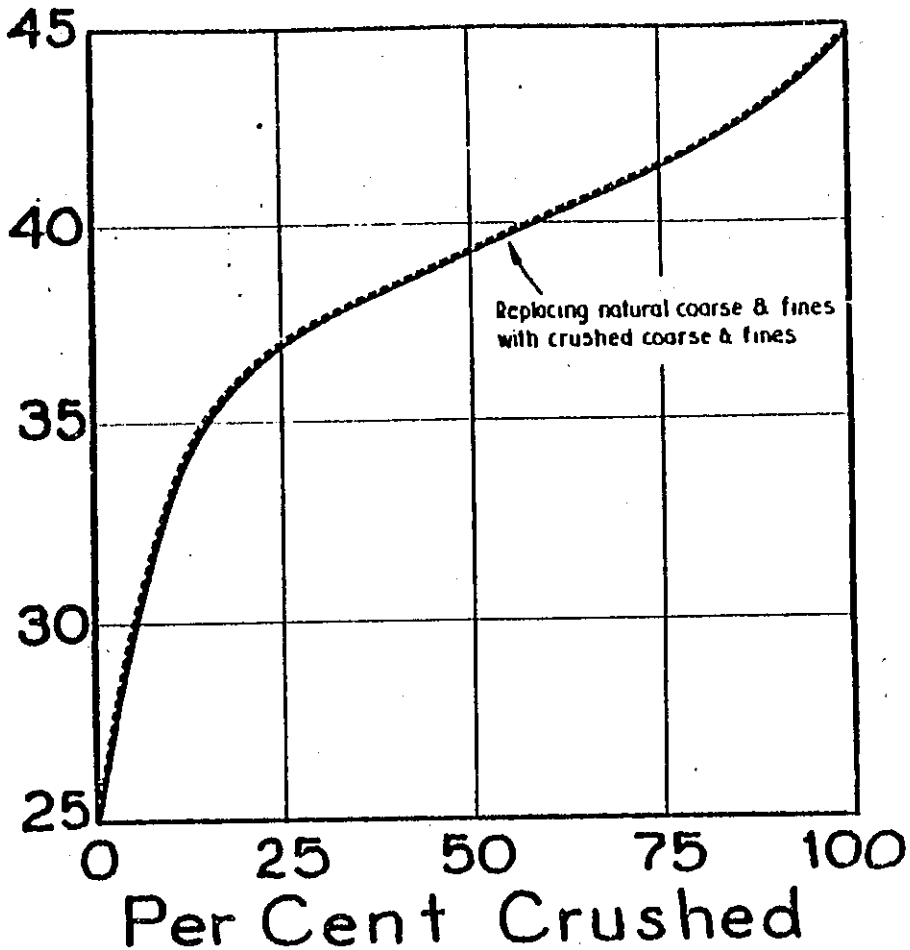

45
40
35
30
25
0
25
50
75
100
Per Cent Crushed
Replacing natural coarse & fines with crushed coarse & fines

Figure 2

CEMENT TREATED BASE

CEMENT TREATED BASE IN CALIFORNIA

Definition

Cement treated base is a uniform mixture of portland cement, graded aggregate and water. When properly mixed, compacted and cured, this aggregate can be transformed into a high quality, long lasting base. Under AC pavements, cement treatment is intended to provide an economical pavement foundation having slab strength. Under PCC pavements, CTB is intended primarily to provide an erosion resistant material to minimize pumping and, secondarily, to provide structural strength.

Construction Guidelines for Better CTB

Maximum Density. CTB compressive strength varies directly, though not proportionally, with density (Figure 1). High density and strength results in a better CTB. The magnified effect of low density on this property is not always appreciated.

Optimum moisture is the moisture content required to attain maximum density in the field. This moisture content can be estimated in the laboratory by the amount of water exuded from the material during fabrication of the test specimen. A sample from which one to six grams of water are exuded is considered to be at optimum moisture. The amount of water added to the CTB mixture in the field is usually higher than the laboratory determined optimum moisture content to allow for the evaporation that inevitably takes place during construction operations.

In the laboratory, density increases as the moisture content is increased above optimum because the excess water lubricates the aggregate and then drains out of the specimen (Figure 2). In the field, however, density decreases as the moisture content is increased above optimum because the excess water cannot drain away (Figure 2). Thus, excessive field moisture contents can result in densities (and compressive strengths) lower than desired.

Optimum Gradation. A well-graded material with approximately 50% passing the No. 4 sieve will generally give the highest compressive strength (Figure 3).

Loose Curing Time . The attainable compressive strength of CTB decreases as the elapsed time between mixing and compaction is increased (Figure 4). For this reason, it is imperative to compact CTB as soon as possible.

Trimming. Figure 5 shows the results of excessive trimming and over-rolling of CTB. The density of the CTB is decreased after each trimming operation and the CTB is permanently damaged if the trimming is delayed too long after mixing. Normally, over-rolling is not a serious problem, but if the CTB is placed over a resilient subgrade the density of the CTB can be drastically reduced by over-rolling.

Figure 1

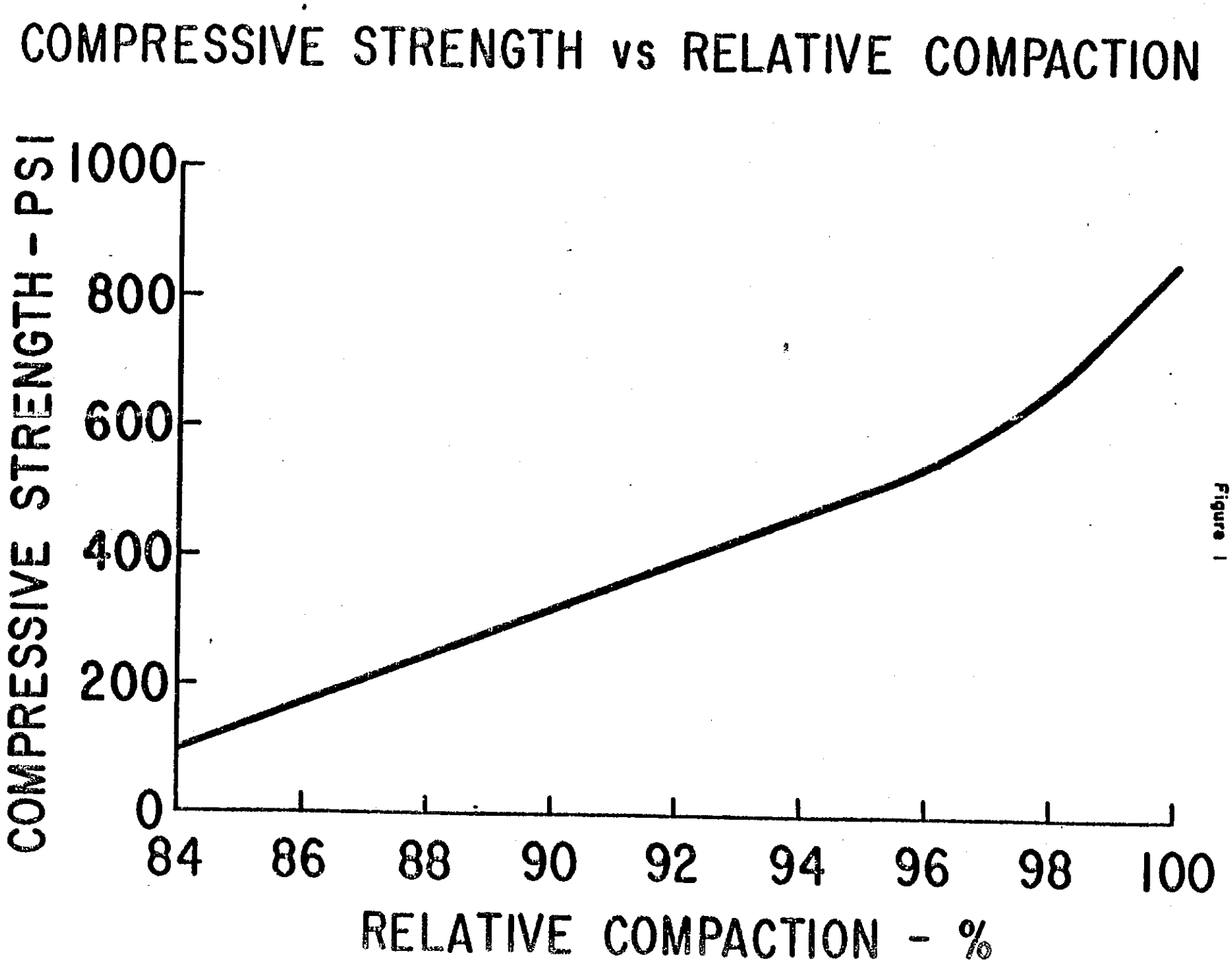

COMPRESSIVE STRENGTH vs RELATIVE COMPACTION
COMPRESSIVE STRENGTH - PSI
1000
800
600
400
200
0
84
86
88
90
92
94
96
98
100
RELATIVE COMPACTION - %

Figure 2

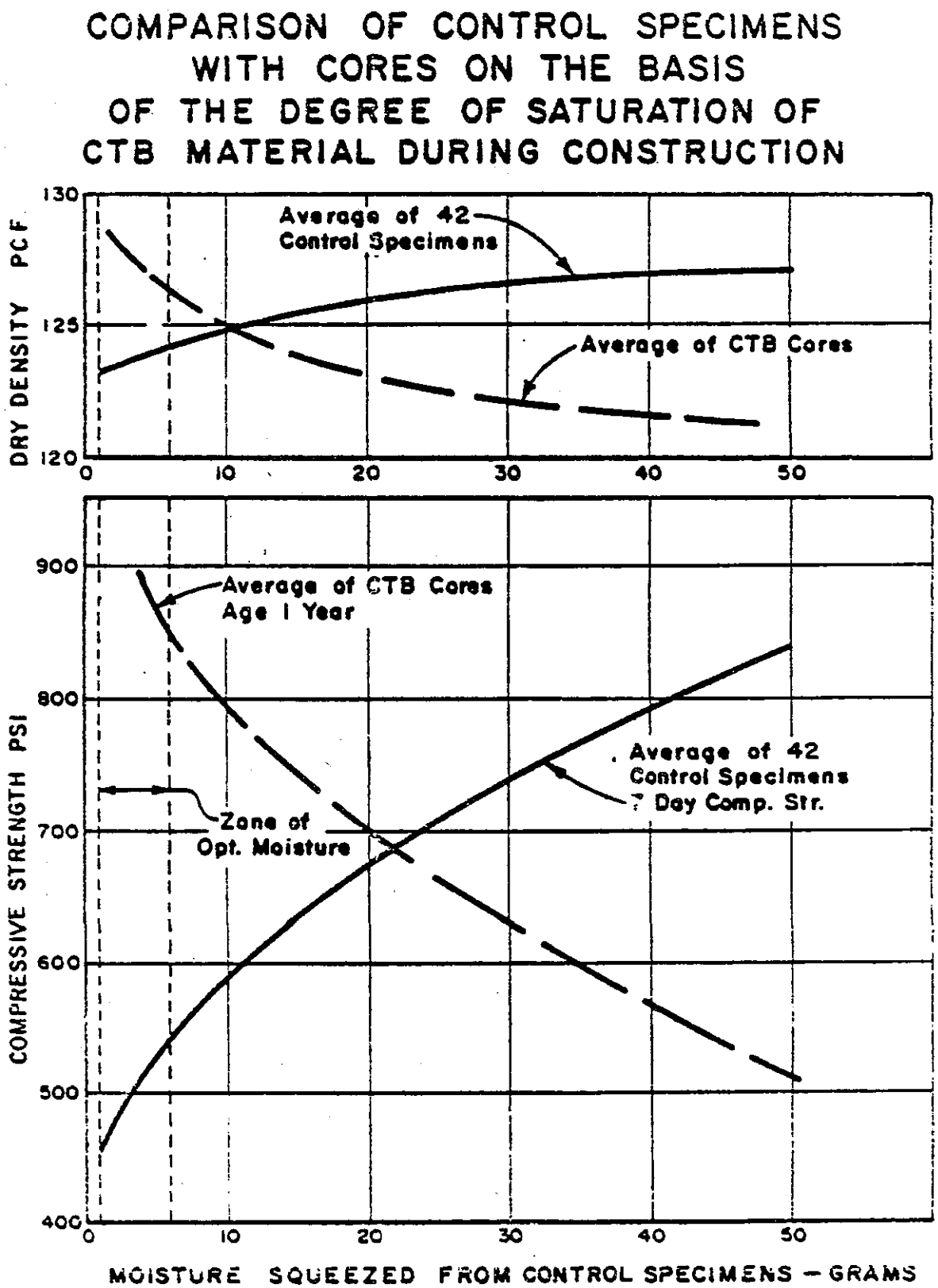
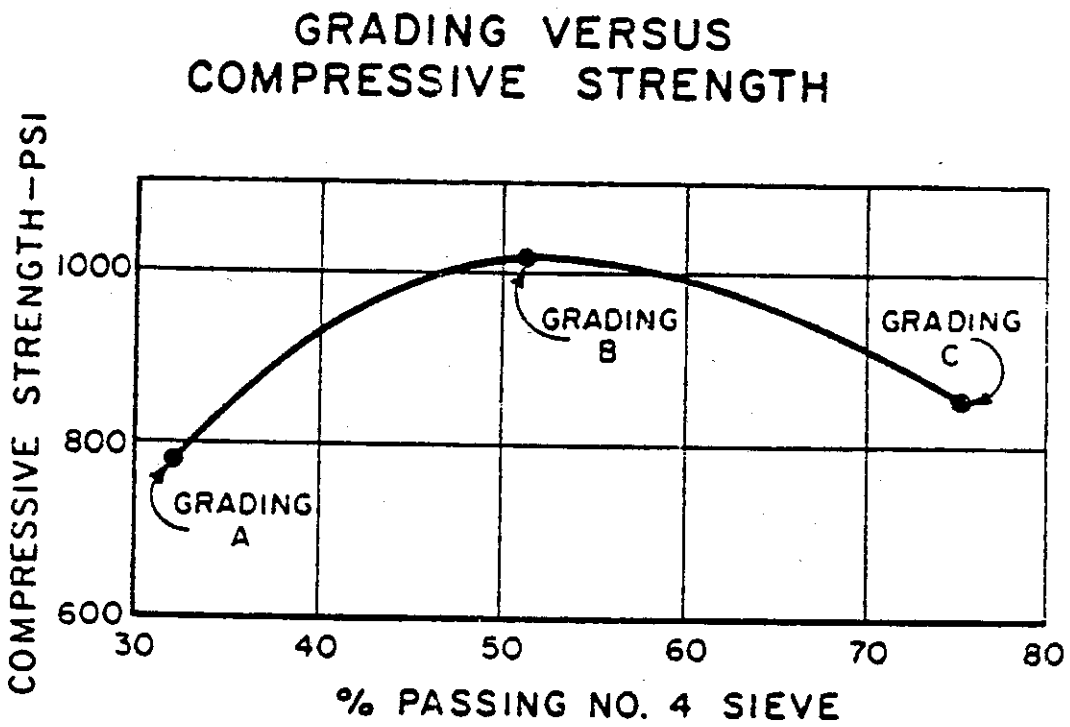

COMPARISON OF CONTROL SPECIMENS
WITH CORES ON THE BASIS
OF THE DEGREE OF SATURATION OF
CTB MATERIAL DURING CONSTRUCTION
DRY DENSITY PCF
130
125
120
Average of 42
Control Specimens
Average of CTB Cores
0
10
20
30
40
50
COMPRESSIVE STRENGTH PSI
900
800
700
600
500
400
Average of CTB Cores
Age 1 Year
Average of 42
Control Specimens
7 Day Comp. Str.
Zone of
Opt. Moisture
MOISTURE SQUEEZED FROM CONTROL SPECIMENS — GRAMS

Figure 3


GRADING VERSUS
COMPRESSIVE STRENGTH
COMPRESSIVE STRENGTH—PSI
1000
800
600
30
40
50
60
70
80
% PASSING NO. 4 SIEVE
GRADING
A
GRADING
B
GRADING
C

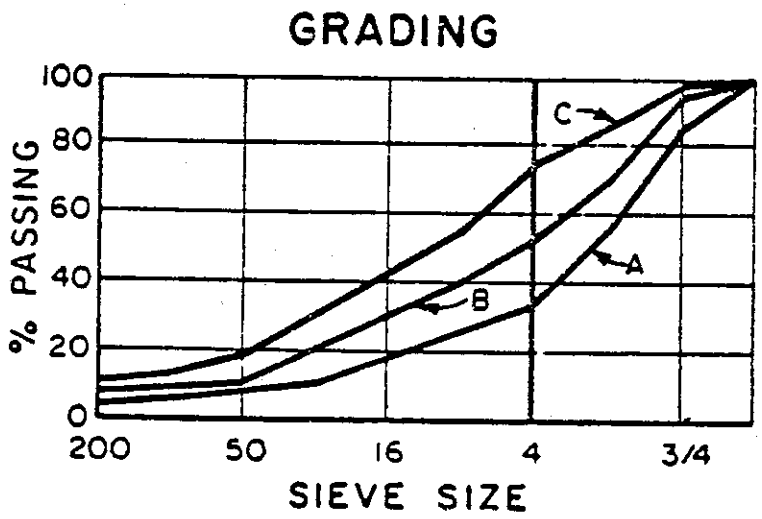

GRADING
% PASSING
100
80
60
40
20
0
200
50
16
4
3/4
SIEVE SIZE
C
B
A

Figure 4

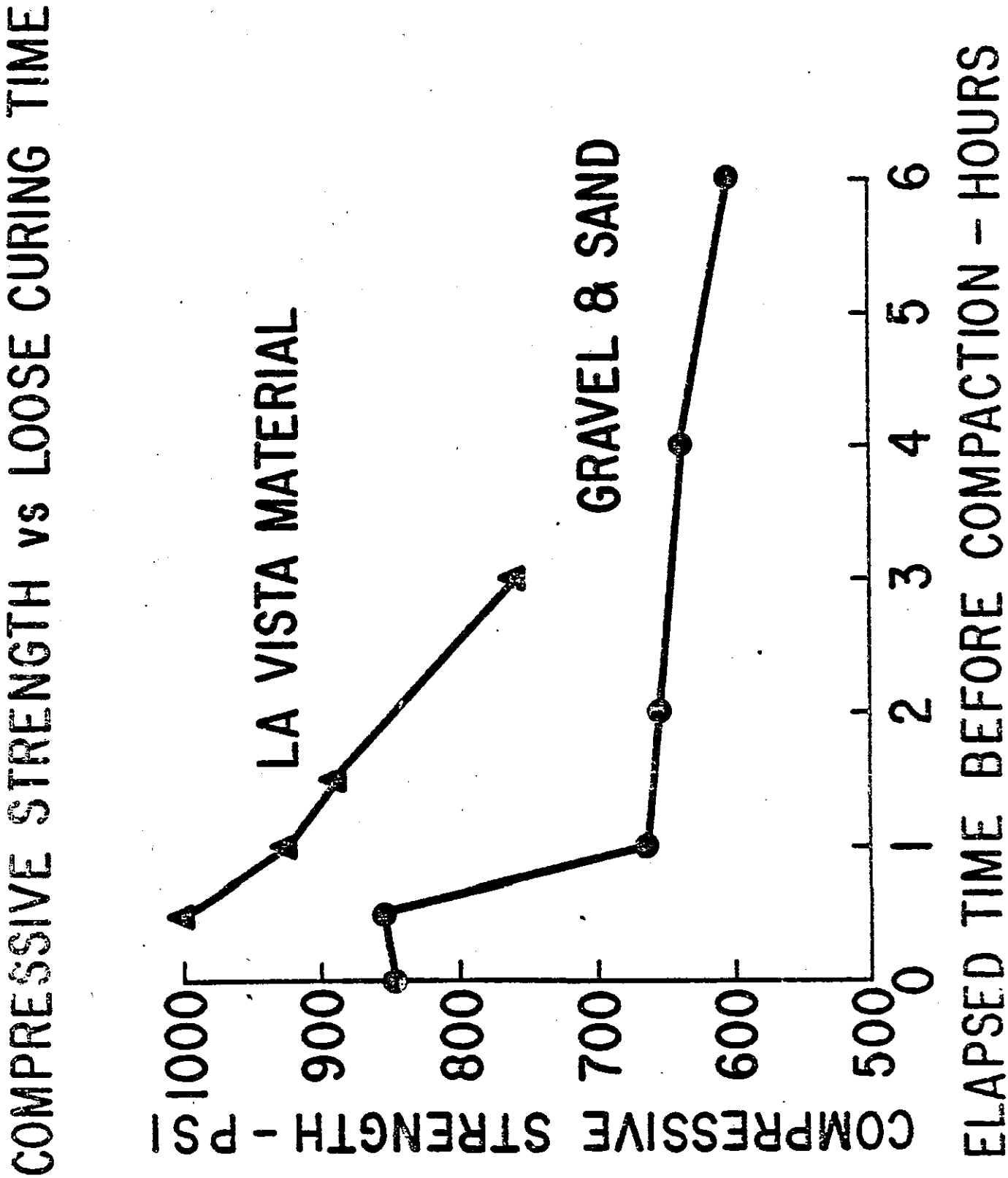
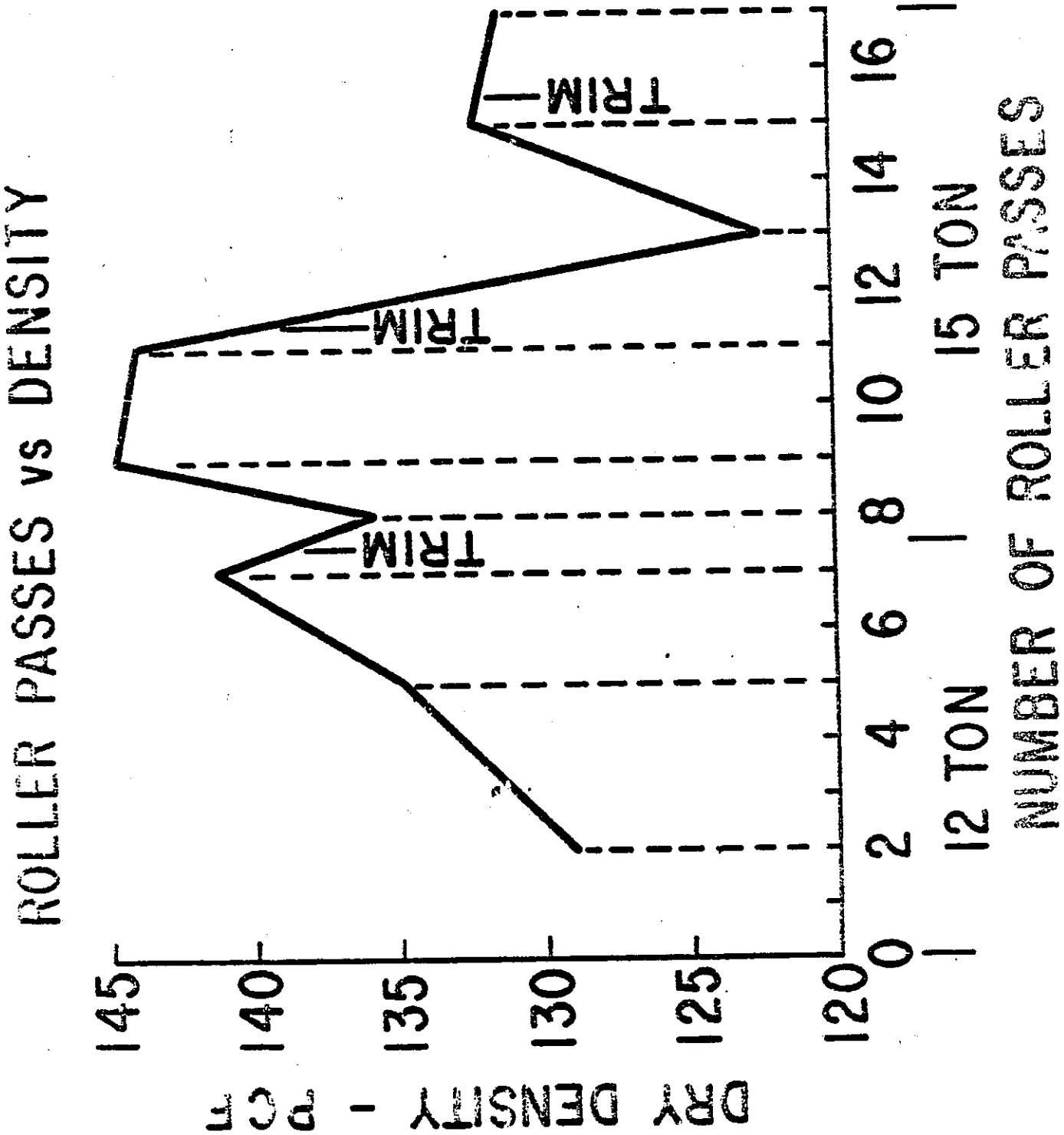

COMPRESSIVE STRENGTH vs LOOSE CURING TIME
LA VISTA MATERIAL
GRAVEL & SAND
COMPRESSIVE STRENGTH - PSI
1000
900
800
700
600
500
0
1
2
3
4
5
6
ELAPSED TIME BEFORE COMPACTION - HOURS

Figure 5


ROLLER PASSES vs DENSITY
DRY DENSITY - PCF
145
140
135
130
125
120
0
2
4
6
8
10
12
14
16
TRIM
TRIM
TRIM
12 TON
15 TON
NUMBER OF ROLLER PASSES

LIME TREATMENT IN CALIFORNIA

Definition

Lime treatment generally consists of mixing lime and water with in-place materials to improve the load bearing capacity of the material. When properly treated, compacted and cured, low quality or unsuitable materials can be incorporated into the structural section. When upgrading low quality material, this can make it possible to reduce the required thickness of the structural section.

Benefits and Accomplishments of Lime Treatment

Treatment with lime has resulted in savings by making in-place or locally available materials suitable for highway construction purposes. It has also resulted in structural improvements which should help to increase the service life of the road. Some specific benefits and accomplishments include:

1. Transformation of highly plastic, low R-value clayey soil into a cemented slab having a compressive strength of several hundred pounds per square inch.

2. Reduction or elimination of the expansion potential of the treated soil.

3. Creation of an impervious layer to prevent surface water from reaching underlying expansive soils.

4. Improvement of the stability and provision of slab strength in otherwise borderline or below standard base and subbase materials.

Evaluation of Lime Treatment of Specific Materials

Not all materials are suitable for treatment with lime. Since lime is not a cementing agent in itself, it can only provide benefits when the materials being treated contain the other necessary components.

Improvements in the stability of a material through treatment with lime are reflected in increases in R-value and sand equivalent and decreases in the plasticity index. Each of these indicated improvements in quality are the result of changes in the physical characteristics of the soil caused by complex chemical reactions. In addition, a cementing often occurs that provides slab strength and bonds the material together into an impervious layer. If this cementing does not occur, it is questionable whether any other changes in characteristics will be permanent.

Construction Guidelines

A basic knowledge of the various types of lime and the possible problems that may be encountered when treating soils is important to the engineer or his assistants assigned to inspect the work.

Three types of lime are commonly available and accepted by Caltrans for stabilization work. These are described briefly below.

1. Hydrated, high calcium lime is distributed in dry powder form. Because of its dry fluffy nature, this type of lime is often difficult to distribute uniformly and airborne dust can become a serious problem. Approximately 1/3 of the weight of dry hydrated lime is water that has combined with the calcium oxide (quicklime) to form calcium hydroxide (hydrated lime).

2. High calcium quicklime has two primary characteristics that have contributed to its rapid gain in popularity. Because the water of hydration is added on the roadway, less quicklime is required to accomplish the same results that can be accomplished with hydrated lime. Also, quicklime is normally supplied in a granular form which makes it easier to distribute and greatly reduces the dust problem. However, considerable heat is generated during the hydration of the quicklime. Construction personnel should be aware of this and ensure that the necessary precautions are taken to prevent burns due to this reaction.

3. Dolomitic quicklime is also a granular product and provides the same dust free distribution advantages as calcium quicklime. Dolomitic lime, however, contains only about 60% calcium oxide with the remainder being mainly magnesium oxide. Currently available test data indicate that Dolomite quicklime may not react with the soil as rapidly as other types of lime but the ultimate results will be comparable.

Any laboratory testing of material proposed for lime treatment on a particular job should be accomplished using the type of lime to be used on that job.

CALIFORNIA'S RESILIENCE DESIGN METHOD

Soil Resilience

The R-value pavement design method is concerned primarily with the design thickness formula and the three properties of a soil which are considered therein. These include:

1. R-value or stability
2. Cohesion
3. Expansiveness

We will now consider a fourth variable which, though not yet a part of the design thickness formula, is a separate and distinct property of soil which has a definite effect on the performance of the pavement structural section.

The fourth variable, resilience, is an indicator of the elastic or compression and rebound characteristics of soils under a dynamic load. This property, to a large extent, determines the magnitude of transient pavement deflection which, if excessive or repeated enough times, will result in fatigue cracking of bituminous surfacing or a cement treated base within its design life.

The characteristic condition of asphaltic concrete surfacing which has been fatigued is the predominance of "alligator" or "chicken wire" cracking. In the case of cement treated bases, block cracking will be evident. Fatigue cracking, however, is not generally associated with permanent deformation or displacement of the surfacing.

A laboratory testing procedure was developed by the Transportation Laboratory to incorporate the resilience factor into pavement design by providing a volumetric measure of the compression and rebound of

a soil specimen under dynamic loading. Since, for a given load and specimen size, this measurement is directly related to the recoverable stress energy of a deformed body when the load causing stress is removed, the testing instrument has been designated the "Resiliometer".

The Resiliometer, Figures 1 and 2, is an apparatus which measures the volumetric displacement resulting from a cyclic dynamic load applied to a 4 inch diameter by 4 inch high soil specimen. The load is applied by a rubber diaphragm containing ethylene glycol solution, the fluid being acted upon by air pressures of from 0 to 50 psi. Volumetric displacement is measured by a manometer tube. Lateral pressures are applied and measured by a Hveem Stabilometer.

Resilience studies were performed to determine the effects of specimen height, density, gradation, moisture content and repetitions of loadings which lead to the following general conclusions:

1. Resilience (internal compression and rebound) increases rapidly with moisture content and, to a lesser extent, void ratio.

2. Although individual clay specimens have been found to be extremely resilient at elevated moisture contents, the greatest sensitivity to moisture, i.e., the largest variations in resilience for a given increase in moisture content, are consistently found in the silt range.

3. Sands and gravels are generally low in resilience. The resilience-moisture content plots, Figure 3, illustrate fairly typical behavior of various types of soil.

The accumulation of these resilience data have proven beneficial in the study of qualitative appraisals of roadway materials for special projects and distress investigations. In order to introduce

the resilience factor into pavement design, a tie between laboratory resilience and field performance, i.e., pavement deflection, was required.

Thus, in 1960 the Transportation Laboratory initiated a study to establish a correlation between soil resilience and field deflection. In-place soils were sampled from 20 roadways throughout California and tested in the Resiliometer. Resilience values were determined for each of the material layers below the roadway surface, a.e., aggregate base, aggregate subbase and basement soil. A total resilience value was determined for each structural section. In the field, average pavement deflections were obtained at locations where the in-place soils were sampled. When total resilience values were plotted versus field deflections, a valid relationship was shown between soil resilience and pavement deflection. From this study emerged a method to predict pavement deflections from resilience test data. In 1966, the Transportation Laboratory published a report describing the development of the resilience design procedure.

In 1967, a comprehensive follow-up study was initiated to determine if the resilience design procedure would have application in preliminary design situations. District materials personnel were requested to obtain preliminary soil samples for resilience testing immediately after submission of materials reports for projects which:

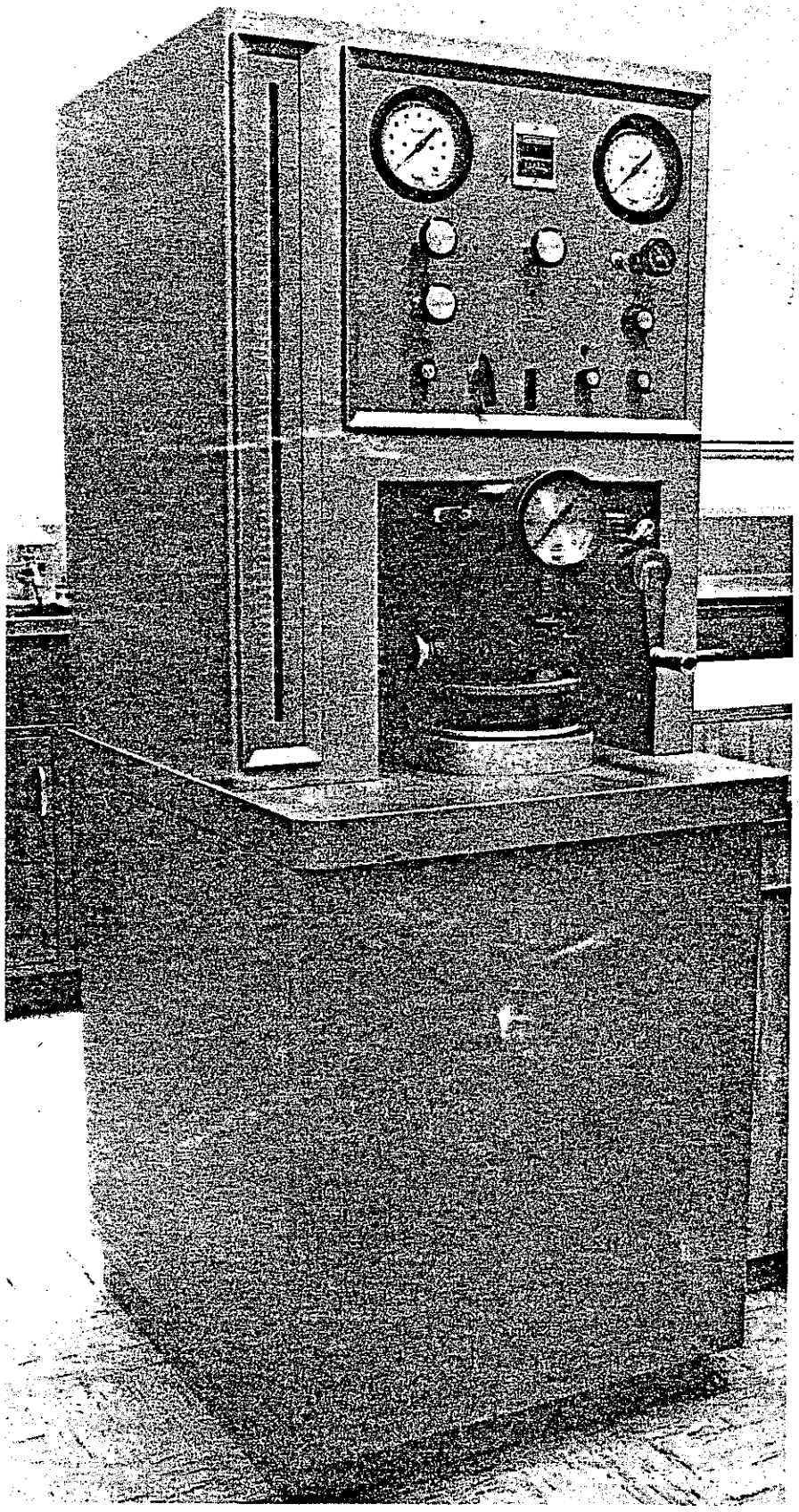
(a) Were greater than one mile in length.
(b) Did not utilize PCC or CTB in the structural section.
(c) Consisted of new alignment.

Soil samples from over 35 roadways were sent to the Transportation Laboratory and tested in the Resiliometer. Based on the summation of resilience for the proposed structural sections, predicted pavement deflections were determined. After the roadways were constructed, actual pavement deflections were measured.

The correlation between predicted and measured deflections was acceptable and it was concluded that the resilience design procedure would have merit in preliminary design. As a result of the follow-up study, several refinements were made to the initial resilience design procedure.

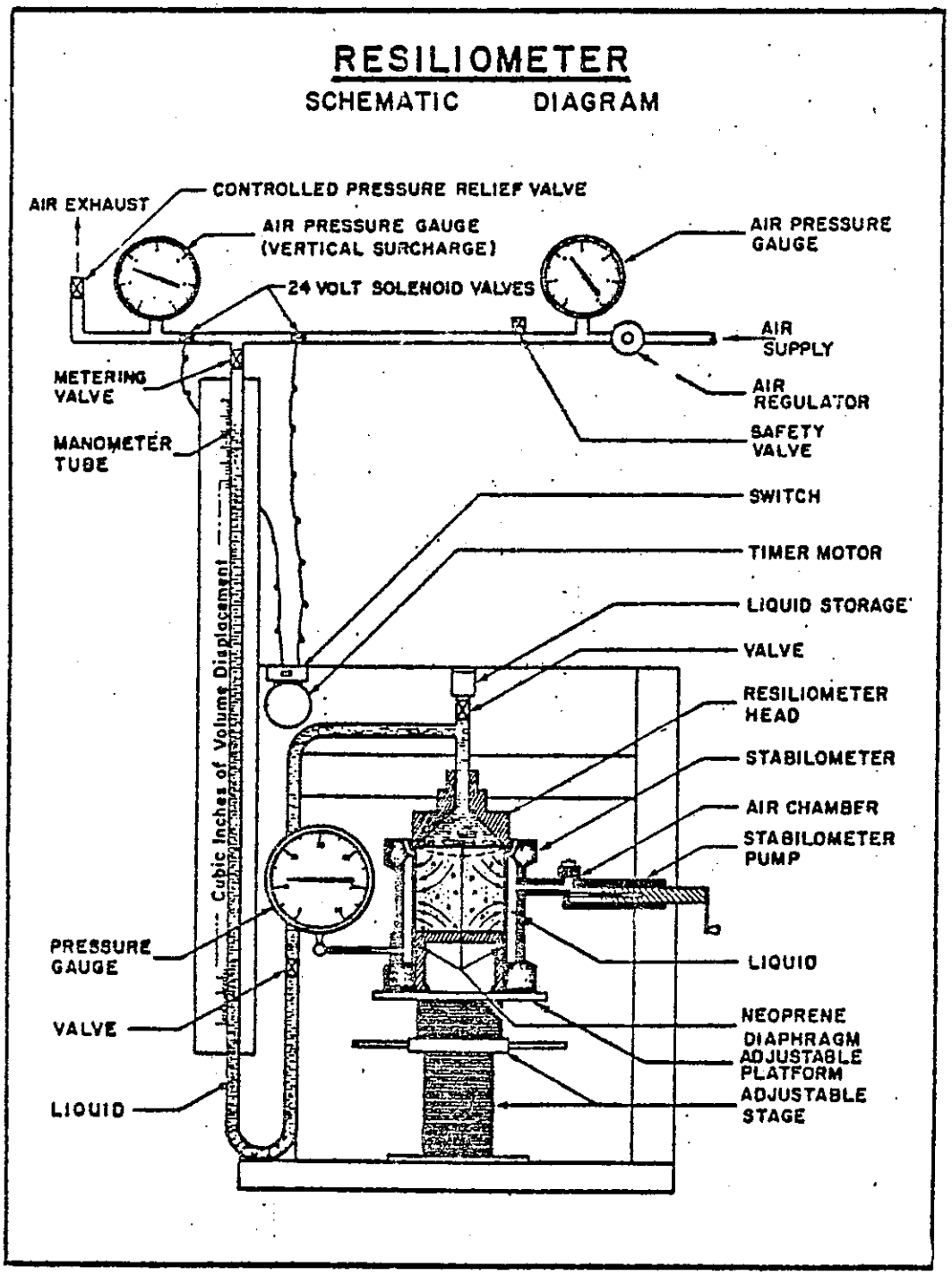
It is expected that California will soon add the resilience design method to its Manual of Test in order to guard against fatigue failures. Test Calif. No. 361 has been developed for this purpose.

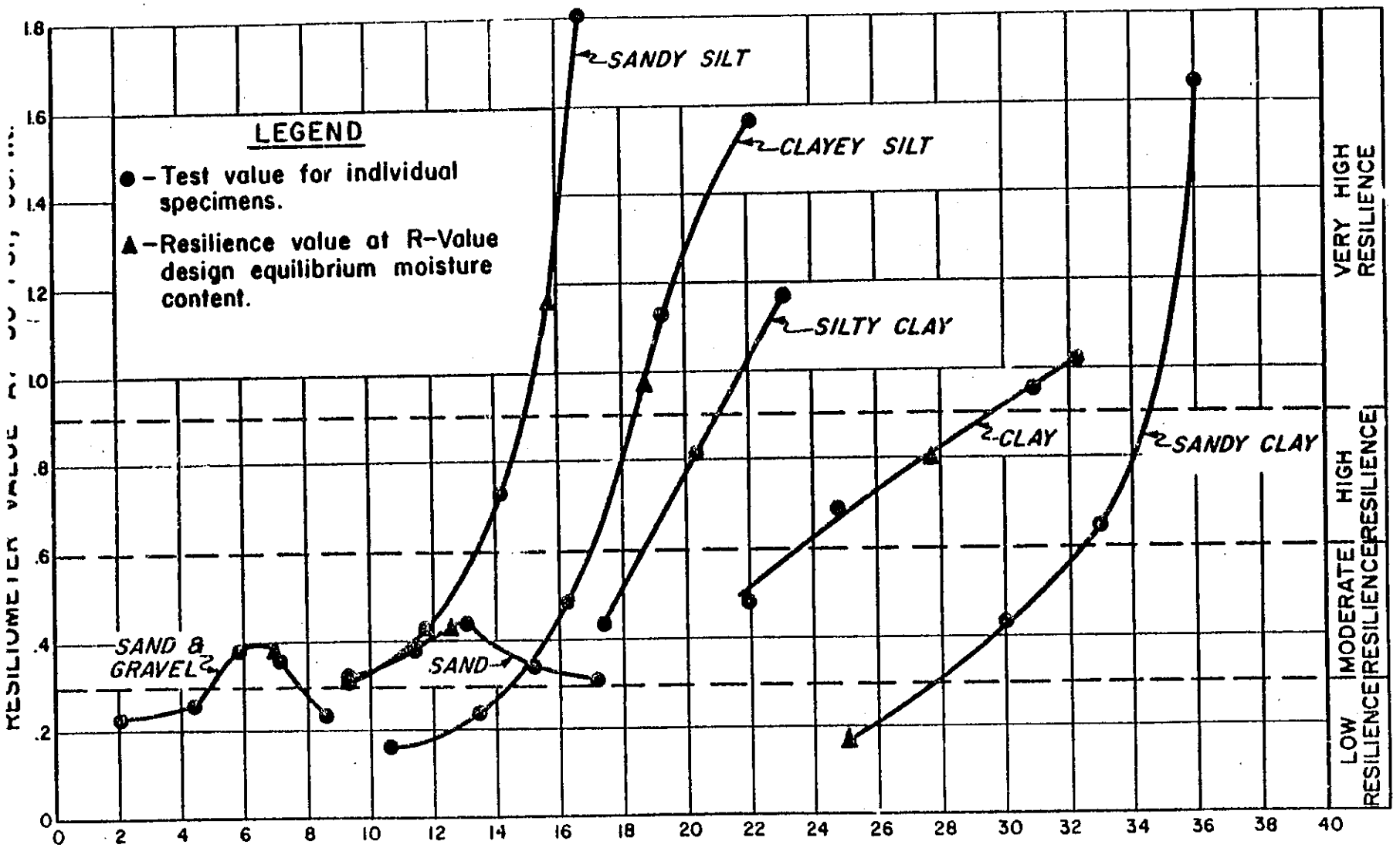
Figure 1



RESILIOMETER

Figure 2


RESILIOMETER
SCHEMATIC DIAGRAM
AIR EXHAUST
CONTROLLED PRESSURE RELIEF VALVE
AIR PRESSURE GAUGE (VERTICAL SURCHARGE)
24 VOLT SOLENOID VALVES
AIR PRESSURE GAUGE
AIR SUPPLY
AIR REGULATOR
SAFETY VALVE
METERING VALVE
MANOMETER TUBE
Cubic Inches of Volume Displacement
SWITCH
TIMER MOTOR
LIQUID STORAGE
VALVE
RESILIOMETER HEAD
STABILOMETER
AIR CHAMBER
STABILOMETER PUMP
PRESSURE GAUGE
VALVE
LIQUID
LIQUID
NEOPRENE DIAPHRAGM
ADJUSTABLE PLATFORM
ADJUSTABLE STAGE



Note: 1 in^3 = 16.4 cm^3
1 psi = 6.89 kN/m^2

TYPICAL RESILIENCE-MOISTURE CURVES

Figure 3

RECENT RESEARCH ACTIVITIES

PCC Pavement Performance

A considerable amount of research effort has been conducted on this subject with the generally accepted conclusion that faulting or step-off at joints is an inherent performance characteristic in the type of pavement construction used in California. Step-off is created by the migration of fines beneath the concrete slabs at transverse joints resulting in a build-up of these fines on the approach side of the joint. The thickness of the accumulation of fines coincides with the measured step-off on the pavement surface. The sources of fines are: (1) untreated shoulder materials adjacent to the slab; (2) erodible fines on the surface of cement treated base; and (3) foreign material entering through the joint opening. For faulting to occur the following conditions must exist: (1) a slightly curled pavement slab; (2) free water; (3) heavy wheel loads traversing the joint; and (4) the presence of pumpable fines.

Proposed solutions have involved experimental sections to achieve one or more of the following: (1) seal off the untreated shoulder material from the pavement slab; (2) install a low-cost drainage system to remove the free water from beneath the pavement slab; and (3) use a nonerodible base referred to as lean concrete base, in lieu of cement-treated base.

Lean concrete base is a cement-stabilized base using 8-9% cement and aggregates of CTB quality and sufficient water to make a plastic mix. It is mixed and placed with the same mixing and placing equipment used for concrete paving and receives the same cure as concrete. Two large-scale sections have been constructed to date. A standard special provision has been prepared allowing its use as an alternate to cement-treated base at the Contractors option.

Polymer Materials in Concrete

The field of plastics has become somewhat enmeshed with that of concrete with the result of significantly improving certain properties of the latter. We have been primarily interested in two applications of polymer materials, that of Polymer Impregnated Concrete (PIC) and that of Polymer Concrete (PC).

The application of PIC is primarily directed at sealing bridge decks from the intrusion of deicing salts. The treatment consists of: (1) drying out the upper surface of the deck at a temperature of 200°F to a depth of one inch; (2) allowing the deck to cool to 100°F; (3) soaking the surface with liquid monomers for 10-12 hours to allow penetration of one inch or more; and (4) applying steam heat in order to polymerize the entrapped plastic material. The result is a concrete surface that is virtually impermeable and whose strength is increased considerably.

After gaining experience with polymers in the laboratory, a complete bridge deck on Highway 395 in District 02 received the PIC treatment in the summer of 1976. The process is quite expensive and the chemicals must be stored and handled by people knowledgeable of the potential hazards. The monomers used were methyl methacrylate (MMA) and trimethylolpropane trimethacrylate (TMPTMA) in a ratio of 9:1. A catalyst is added shortly before application. Several states have conducted similar experiments, and it is our feeling that the PIC technique will not become a viable approach as a deck seal because of cost and complexity.

Polymer Concrete (PC) is another use of the above materials, which with the addition of a promoter becomes the lubricant and cementing agent to be combined with dry aggregates to produce concrete. The promoter is a chemical added to speed up and control the polymerization process. PC has been used as a repair material in structures and pavements. Properties can be controlled to cause the concrete to set in a half hour. Cylinder specimens of this type of concrete have yielded strengths of 6,000 to 10,000 psi in four hours.

Internally Sealed Concrete

Another approach at solving the problem of durable bridge decks involves the use of small wax beads as an ingredient in the concrete. After the concrete is mature, say 28 days, the surface of the concrete is heated to melt the entrapped wax particles. As they melt, the wax diffuses into the pores of the concrete creating a layer that is impervious to water.

The wax formulation was developed by Monsanto Research Corp. working under an FHWA grant. It consists of 75% paraffin and 25% montan wax, which is obtained from lignite deposits near Ione, California. Beads are formed by spraying the melted blend through a nozzle into a cooling tower. The resulting spherical beads are of a size range between the #80 and #20 sieves. Wax comprises about 7% by volume of the concrete, which amounts to about 105# per cubic yard.

Results of lab work and the construction of a bridge deck on Highway 395 in District 02 indicate that the concept has great potential in actually providing an internally sealed concrete. Cost of the wax beads is currently about $0.40 per pound which calculates to slightly over $1.00 per square foot for an 8" deck. Heating techniques still need development. Both propane fired infrared heaters and electric heating blankets have been used successfully to melt the wax beads to depths of 1-1/2 inches into the concrete.

PORTLAND CEMENT

Types of Cement

The specifications of the ASTM and AASHTO describe five types of portland cement. Types II, III, IV, and V are designed to produce certain specific properties in concrete which would not necessarily be obtained when Type I cement was used. The specific properties mentioned are obtained by varying the potential compound composition of the cement clinker, by proper adjustment of the gypsum content of the cement, and by fineness of grinding.

In November 1955, the Division of Highways decided that a cement conforming in nearly all respects to the Type II requirements would prove to be the best and most economical product for use in our work. In addition to the Type II requirements, the Division also requires that all portland cement must contain less than 0.60 percent alkalies.

Reasons for Specifying Type II, Low-alkali Cement, or Type II Prestress Cement

Type II modified low-alkali cement is specified for all of our portland cement concrete work except for steam cured or precast, prestressed concrete because:

1. It inhibits the alkali-aggregate reaction
2. It is superior to Type I cement in its resistance to sulfate attack
3. It has, in general, lower volume change characteristics

Type II Prestress cement is permitted for use in steam cured or precast, prestressed products. This cement is finer ground than Type II modified although its chemical composition is essentially the same. It develops higher early strength, but may have slightly higher drying shrinkage when fog cured than Type II Modified cement. However, the drying shrinkage of steam cured products is less than that of moist cured concrete. Increasing the fineness of grinding exposes more cement for reaction and requires a larger amount of SO_3 (gypsum) to produce maximum strength and minimum volume changes. The maximum SO_3 content permitted in Type II Prestress cement has been raised from 2.5% (ASTM limit for Type II cement) to 3.0% so that cement manufacturers can add enough SO_3 to produce the optimum conditions for strength and volume change.

Hot Cement

In addition to the heat of the clinker coming from the kiln, the mechanical work of grinding clinker liberates considerable heat with the result that the finished cement as it leaves the grinding mill nearly always has a temperature in excess of 200°F. Cement in bulk storage loses its heat slowly. Unless the cement has been in storage for months, its temperature on arrival at the work probably will be above that of the atmosphere.

The fact that cement is hot to the touch does not necessarily mean that it is inferior to cool cement. On the other hand, the heat of the cement does contribute to the final temperature of the mixed concrete and high concrete temperatures are undesirable in hot weather. The contribution of the cement to the temperature of the concrete is relatively small, however, because of its low specific heat. For example, if the temperature of any one of the ingredients

in a typical 5-sack mix were raised 30°F, the temperature of the mixed concrete would be raised approximately as follows:

An increase of 30°F in:	Produces an increase in concrete temperature of:
Cement	2.8°F
Water	8.6°F
Aggregates	19.0°F

A requirement that the cement be below a certain temperature at the time of use could increase its cost measurably. It is evident that the concrete mixture can be kept relatively cool more economically by steps that will result in cooler mixing water or cooler aggregates.

False Set

False set is a property of some cements which causes concrete to stiffen prematurely. It is not the same as flash set. False set can be destroyed by additional mixing or manipulation. Flash set cannot. False set is also called premature stiffening, rubber set, gum set, hesitation set, or plaster set.

A common cause of false set in cement is allowing the temperature during grinding to become too high. If the temperature exceeds about 230°F, the gypsum which is added to clinker is converted into plaster of paris. When mixing water comes in contact with the cement, the plaster of paris is converted back into gypsum, but in this process, the growth of gypsum crystals produces a structure that results in a stiffened condition of the concrete. The structure is rather weak however, while troublesome, can be broken down by reworking, thus restoring the concrete to its original consistency. Once this is accomplished, the concrete sets

and hardens in a normal manner. Reworking can be accomplished by remixing, vibration tamping, screeding, etc. Such steps add to the contractor's cost and lead to a desire to make the concrete of higher slump initially.

Some cements will develop false set if given sufficient aeration. Since even under the most careful handling cement samples are exposed to some aeration, laboratory tests for false set may be misleading with respect to job performance. For this reason, our specifications do not at present contain test requirements against false set.

When a contractor encounters a stiff concrete mix resulting from the use of a false setting cement, he may be inclined to add more water to produce the desired plasticity. The addition of water to such a mix unnecessarily lowers the strength of the concrete. Abnormal stiffening usually does not occur until about one minute after the concrete is discharged from the mixer and does not ordinarily occur in transit mix concrete because of the relatively long mixing time. A test for slump, by the Kelly Ball method, if performed immediately after discharge, can be completed before the false set occurs. If the Kelly Ball test should indicate a proper slump, the loss of consistency due to false set can be corrected by additional mixing of the concrete (in lieu of adding water) to restore plasticity.

The Alkali-aggregate Reaction (Internal)

The alkali-aggregate reaction is a chemical reaction which occurs between the alkalies (Na_2O and K_2O) in the cement, and certain aggregates, or some of the mineral composing these aggregates. When the percentage of the alkalies in the cement exceeds 0.60% and reactive constituents are present in the aggregate, serious volume change and cracking may occur in the concrete or mortar.

The mechanism of the reaction is ascribed by some to be due to osmotic pressure, while other investigators consider that it is caused by the absorption of water and consequent swelling of colloidal gels.

The alkali-aggregate reaction and means for inhibiting it were discovered by the Materials and Research Department under the direction of T. E. Stanton, a former Materials and Research Engineer.

Examination of many pavements and structures has indicated that if low-alkali cement is used with the commonly occurring aggregates in California, the results are entirely satisfactory. Only one exception has been found and that is with work containing an aggregate from the vicinity of Bishop. In this case, it is indicated that the alkali content of the cement should be held at a maximum value of less than 0.30%.

Sulfate Attack of Concrete

Sulfates occur in sea water and in those soils and groundwaters that are popularly described as "alkali" soils and waters. The compounds in "alkali" soils and waters that are harmful to concrete are the water-soluble sulfates. These sulfates which are sometimes referred to as "alkali" should not be confused with alkali in cement which are sodium and potassium oxides.

The so-called "alkali" attack occurs from external sources and should not be confused with alkali-aggregate reaction which arises internally from components present in the concrete as mixed.

Sulfates react with tricalcium aluminate (C_3A) in cement giving rise to new compounds of greater volume. The increase in volume and resulting pressure is responsible for the disruption of hardened concrete. Those cements that are lower in C_3A are the

least susceptible to attack. Type II cement, specified to contain not more than 8% C_3A, gives adequate protection against the sulfates in sea water and against moderately strong sulfates in soils or waters, if the concrete is of good quality. For high concentrations of sulfates, Type V cement, specified to contain not more than 5% C_3A, is indicated.

Since the rate of permeability of sulfates into concrete is an important factor, denser concretes are more resistant to attack. Density is achieved by a low water-cement ratio and good consolidation. Well graded aggregates and rich mixes make dense concrete easier to obtain. Air entrainment in some cases has been found to increase resistance to sulfate attack.

Volume Change of Portland Cement Concrete

Portland cement concrete is subject to many kinds of volume change. Some of them are due to the following:

- Thermal changes
- Loss and gain of water
- Characteristics of aggregates and cements
- Alkali-aggregates reaction
- Sulfate attack
- Freezing and thawing

Portland cement paste is a continuous phase in concrete, and it surrounds all aggregate particles. Volume change of concrete is a function of both the paste and the aggregates. In thermal changes, the aggregates play the most important part. In other changes, the paste plays a partnership role. Lower volume change can be obtained by proper regulation of the character of the cement paste.

The principal product of the reaction between cement and water is an amorphous gel which is formed from the water and the dissolved constituents of the cement. The process continues until the supply of cement is exhausted or until the space in the paste is filled with the hydration products. In 5 and 6-sack mixes, the amount of cement is the limiting factor. In rich mixes, such as are used in prestressed concrete, the space available in the paste may limit the amount of hydration.

If the paste is not kept in a saturated condition, the hydration of the cement is retarded or arrested. Hence, the importance of curing.

An increase in temperature increases the rate of hydration. Under steam curing, microscopically crystalline products, rather than amorphous gel, tend to be formed. High steam temperatures tend to decrease drying shrinkage, but they also lower ultimate strength.

Concrete that is not kept continuously wet is subject to shrinkage due to loss of water and subsequent expansion if it takes on water. On changing from a saturated state to a dry state at 50% relative humidity, average concrete, if unrestrained, shrinks at the rate of about 3/4-inch per 100 feet. This is about the amount caused by a drop in temperature of 100°F.

The more porous the paste (the higher the water-cement ratio), the greater is its shrinkage. With the same paste, the higher the paste content of the concrete, the greater is its shrinkage. Finely powdered additions to concrete usually produce greater shrinkage. Many, but not all, admixtures increase shrinkage. There is a correlation between the total amount of water, including water absorbed by the aggregates and drying shrinkage.

Different cements produce varying degrees of shrinkage in concrete as it dries. With the same cement, the percentage of gypsum that it contains is an important factor in its volume change. The gypsum component in cement is determined chemically and is expressed as SO_3. The percentage of SO_3 in gypsum is roughly about 40. For each cement, there is a particular percentage of SO_3 that produces minimum expansion in water and contraction or shrinkage in air. This percentage is called "optimum".

Low volume change is of great importance in the performance of concrete. Among cements, each with optimum SO_3, Type II, low-alkali cements produce less volume change than do most Type I or Type III cements.

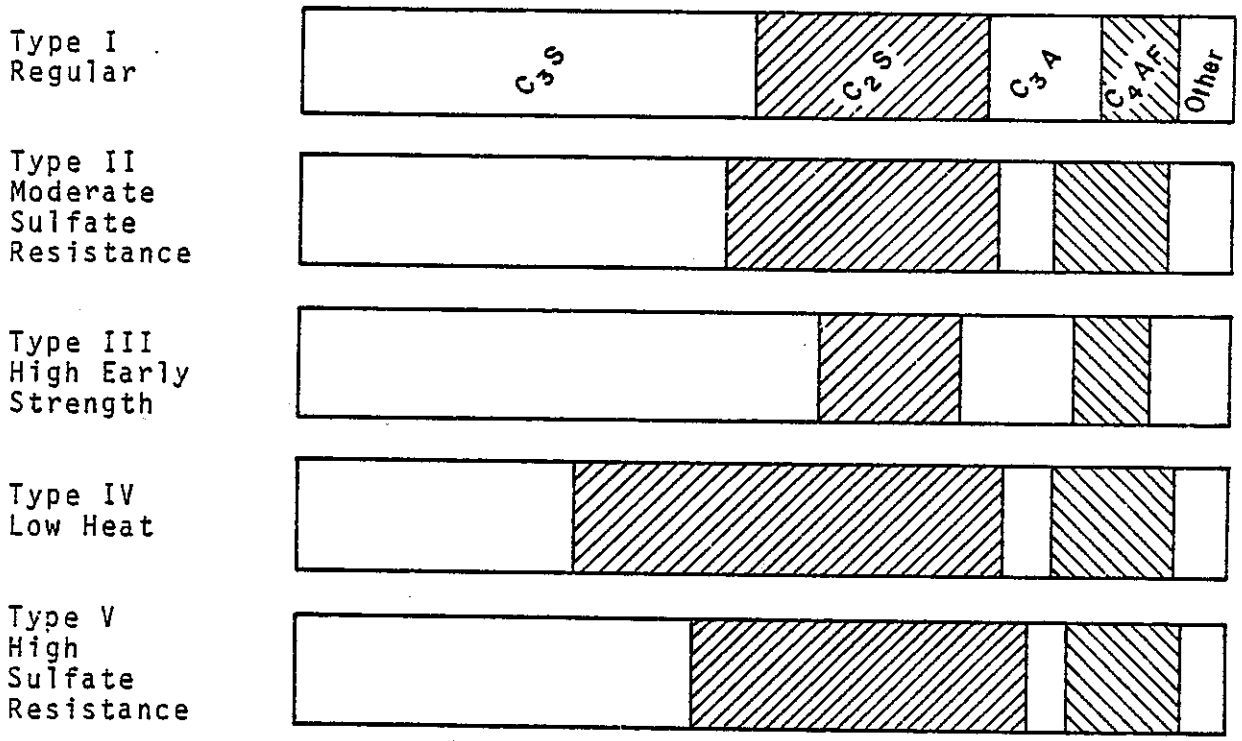
The California Standard Specifications currently set limitations on the maximum expansion and contraction of portland cement, when tested in accordance with Test Method No. Calif. 527. This, in effect, requires cement manufacturers to control the gypsum content at approximately the optimum value.

THE FIVE TYPES OF PORTLAND CEMENT According to ASTM Designation C-150

Type I	For use in general concrete construction when the special properties specified for Types II, III, IV, and V are not required.
Type II	For use in general concrete construction exposed to moderate sulfate action, or where moderate heat of hydration is required.
Type III	For use when high early strength is required.
Type IV	For use when a low heat of hydration is required.
Type V	For use when high sulfate resistance is required.

Note: We specify low-alkali for all five types. Type II specification is further modified by our specifications as mentioned earlier in this discussion.

Type and Typical Composition of Cement



C_3S Tricalcium Silicate C_2S Dicalcium Silicate	Compounds that contribute most to strength.
C_3A Tricalcium Aluminate	Responsible for most undesirable characteristics in cement.
C_4AF Tetracalcium Alumino-ferrite	An adulterant which serves to lessen amount of C_3A.

Other compounds, calcium sulfate, magnesium oxide and a small amount of other materials are also present in cement.

Under California Specifications, Type II cement must also be low in alkali, and meet test requirements for expansion in water and contraction in air.

POZZOLANS

The use of Pozzolans in highway concrete has been very limited in California. There are some advantages and also disadvantages to be gained from the use of these materials.

Pozzolans are siliceous or siliceous and aluminous materials, which in themselves, possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

While the primary purpose for using pozzolans has been to lower heat of hydration of mass concrete, they may be used to improve the workability of concrete, or to inhibit alkali-aggregate reaction. In addition to improving workability of concrete, most pozzolans will reduce heat generation, thermal volume change, bleeding, and permeability of the concrete. Some pozzolans, particularly calcined clay and shales, require more water than portland cements. When additional water is required, additional cement is also required to maintain a specified water-cement ratio and to assure that the concrete will meet design strengths. The additional water increases drying shrinkage which may result in increased cracking or other problems.

It has been reported that pozzolan combines with the free lime in the concrete reducing or eliminating efflorescence which may be

important esthetically, especially when using colored concrete. Pozzolans are currently being used as a cement replacement in an amount up to 15-20% of the specified cement content.

AGGREGATE

An important ingredient affecting the manufacture and performance of concrete is that of the aggregate, which comprises from 56% to 80% of its volume. It is evident that the many properties of this relatively inert material will have a big influence on the strength and durability of the mix. Since the selection of the aggregate is usually limited to local sources, it is necessary to have a good understanding of how the various aggregate properties might affect the final product. Therefore, the different properties will be discussed individually.

The basic shape of most aggregate varies from well rounded to flat and elongated to angular. The rounded aggregates are usually found in naturally occurring deposits such as inactive or old stream beds. Rough and angular particles usually are the product of crushing or manufacturing of aggregate from rock ledges or large cobbles. The rounded particles make a more workable concrete mix with a minimum of water and fine aggregate. The angular particles usually take more sand and water to produce a plastic concrete of the same workability as the concrete made from rounded particles. The water demand is even greater if crushed sand is used. Flat and elongated particles occurring in a natural deposit have the same effect on the concrete workability as the angular shaped particles. Aggregates with undesirable shapes have been used to produce good concrete by proper mix design and handling techniques. However, there are other cases where certain properties of the finished concrete may be difficult or impossible to attain with a given aggregate.

Surface texture can also be very important since smooth aggregates make a concrete mix more workable, and rough surfaces cause the aggregates to interlock causing reduced workability. These surface textures also affect the water demand of the concrete, the rougher aggregates requiring more water. The surface texture has an effect on the aggregate cement bond - the rougher surface providing the better bond. Surface texture is usually a product of an aggregate's origin, the natural aggregate being smoother than the crushed.

It is very desirable to have hard aggregate available for use in concrete. The property of aggregate hardness determines the extent of the concrete's resistance to abrasion and impact. The hardness requirement for good concrete makes aggregates such as shales undesirable.

Strength of the aggregate is one of the most critical properties since the strength of the aggregate particles will limit the potential strength of the concrete. As in any conglomeration of materials, the combination strength is limited by its weakest element. The only effective means of evaluating the strength-producing characteristics of an aggregate is to evaluate the material in controlled concrete.

A concrete's resistance to weathering, freezing and thawing is called its soundness. This property is affected by another aggregate property - porosity. The porosity of the aggregate determines the amount of water that enters the aggregate. An aggregate with small, deep pores usually allows moisture to enter the aggregate readily and makes it vulnerable to wetting and drying, or freezing and thawing. This causes the aggregate to fracture and the concrete to crack and scale. Aggregates that have very few or large pores are usually not affected by moisture, and are, therefore, sound or durable. Aggregates that are internally weak, soft, and friable, or laminated, are usually not sound.

Bond between cement paste and aggregates, concrete strength, and durability of concrete are all affected by the cleanness of the aggregate. Coatings of clay or organic material may inhibit the bond between the paste and aggregates; this lack of bond is detrimental to the ultimate concrete strength. Clay balls and soft particles are extremely susceptible to weathering forces, therefore causing a good concrete aggregate to appear not to be sound. Any clays or unsound fine material in the aggregate will be worked to the surface in normal concrete finishing operations, and will reduce the abrasion resistance of the concrete. Excessive fines ancrease the water demand which in turn reduces the potential strength of the concrete.

The concrete aggregate must also be inert so that it will not react with the cement paste or chemicals in the mix water. Reactions of this type have, in the past, caused serious disruptions of concrete.

One of the most important aspects of aggregates from one source with respect to mix design, is uniformity. If the type and sizes of aggregates are changing, the water demand in particular, will fluctuate. This will have a marked effect on workability and strength of the concrete. To quote a statement on this subject "The design of a concrete mix is worthless if uniformity is not present". One of the more important goals while concrete production is underway is to control uniformity of the concrete, and uniformity of the aggregate going into the mixer cannot be overemphasized.

The specific gravity of the aggregate is important because it relates the weight to a given volume of the material. This factor is usually determined in a saturated surface dry condition. The specific gravity will vary according to the mineral character, porosity, and other variables. Good concretes can be produced from aggregates having widely different specific gravities. We

should keep in mind, however, that when separate fractions of the aggregate differ in specific gravity, the aggregates tend to segregate both in handling during batching and while the concrete is being placed and consolidated. Also since the volume varies with specific gravity, the weigh batch proportions must be changed if the aggregate specific gravity changes, to maintain the desired cement content.

Sizing of aggregate particles and the arrangement of these sizes is known as "grading". The aggregate grading contributes to the workability and uniformity of the concrete. Proper grading will give a maximum density of concrete with a minimum of cement paste. Grading refers to both the coarse aggregate and the sand, and also the proportions at which the sand and coarse aggregate are combined. Relatively close control should be maintained over the grading since a large change in grading would have a distinct effect on the concrete; however, a small change in grading would probably never be noticed. There is a large range of aggregate gradings that will give a good concrete mix. The important thing is to maintain the same grading for which the concrete mix is designed, provided the aggregate grading meets specifications.

The volume stability of the aggregate is also a very important property. An aggregate that swells and shrinks during wetting and drying will cause the concrete to have high drying shrinkage. Aggregates that deform under the stresses set up by the drying action of the cement paste will also cause concrete to have high shrinkage.

Shrinkage is determined from fabricating concrete bars and measuring the length change of the bar as the concrete dries out. Each concrete source is compared with a standard source known to contain aggregates with average shrinkage properties.

Thermal properties of aggregates are also important considerations since aggregates that are very susceptible to thermal expansion and contraction can cause disruption in concrete. Aggregates normally used in concrete result in a concrete having thermal characteristics similar to steel and cases of incompatibility are rare.

In addition to the tests already mentioned to evaluate aggregate properties, there are several others used by this Department.

Grading tests are conducted by sieving the aggregate. The gradings are expressed in percentage of material passing each size sieve. There are wide ranges of gradings using three different maximum size aggregates permitted by the Standard Specifications. This permits the use of many local sources which is important from an economic standpoint.

Soundness of aggregate is determined by the sodium sulfate soundness test, Test Method No. Calif. 214, which consists of alternately soaking the aggregates in a saturated sodium sulfate solution and drying them out for five cycles. The salt forms crystals in the pores and micro-cracks of the aggregate which causes unsound aggregates to spall and fracture. The decrease in aggregate size resulting from fracture is determined and limits are established to distinguish a sound aggregate from an unsound one.

The test to determine the abrasion and impact resistance of coarse aggregate is the Los Angeles Rattler Test, Test Method No. Calif. 211. In this test, an aggregate sample is rotated in a steel cylinder together with a charge of steel spheres. The amount of fines generated are determined by the use of a No. 12 sieve, the percent passing being the "loss" in the rattler test. A maximum loss of 45% is the specification limit for concrete aggregate.

The Cleanness Value, Test Method No. Calif. 227, provides a relative indication of the presence of clay-like material in coarse aggregate, either in the form of coatings or separate particles. The sample is washed with demineralized water and the wash water is handled in a prescribed manner. The sediment in the wash waster provides the basis for establishing the "Cleanness Value".

Organic impurities, Test Method No. Calif. 213, in sand may appreciably affect the set and strength gain of concrete. The test for determining the presence of organic impurities involves soaking a sand sample in a sodium hydroxide solution. The color of the solution is compared to a standard to determine the presence of organic material.

The acceptability of sand for use in concrete from a strength standpoint is determined from a test of mortar strength relative to Ottawa sand, Test Method No. Calif. 515. Like mortar specimens are made from the sand sample and Ottawa sand. The specimens are tested for compressive strength. The sand specimen must attain a strength of 95% or more of the strength of the Ottawa sand samples.

The relative proportions of detrimental dust or clay-like material an a sand sample is determined by the sand equivalent (S.E.) test, Test Method No. Calif. 217. The S.E. value is determined by measuring the "sand height" and "clay height" of material when treated in a prescribed manner together with the proper test equipment.

<u>Freeze-Thaw Test</u> Test Method No. Calif. 528

The freeze-thaw resistance is determined for any aggregate which will be used in an area where it will be subjected to a wet freezing and thawing environment. Test specimens are fabricated from air-entrained concrete. The specimens are subjected to 40 cycles of alternate freezing and thawing. Criteria used to evaluate the resistance of the aggregate to freeze-thaw action are (1) permanent length change of the specimen, and (2) dilation that occurs during freezing.

The freeze-thaw test requires four months to complete, so advance testing of aggregate sources is almost a necessity. The sampling of sources for freeze-thaw acceptance testing has been handled primarily by District Materials Engineers who are familiar with both the future use of aggregate sources and the climatic conditions in the areas where these aggregates will be used.

CEMENT CONTENT TEST FOR CONCRETE PAVEMENT

In an attempt to produce concrete pavements having more nearly uniform strengths throughout the State, the cement content of the concrete is varied based on the strength producing qualities of the aggregate. A test program was initiated to test all PCC aggregate sources in concrete in the laboratory, establishing strength characteristics of the test aggregate at different cement contents. These tests are made in accordance with Test Method No. Calif. 536.

Since pavement performance is dependent on flexural strength, the beam flexure test is used as a basis in determining the desired cement factor. If, after the contract is let, aggregate samples indicate the need for an increase or decrease in the cement content shown in the Special Provisions, this change must be made by change order, as cement is not paid for as a specific item, but is included in the concrete paving item, on a price per square yard basis.

The general procedure for establishing a cement content for a given aggregate source is as follows:

1. When notice of materials is received, the sampling of the aggregates designated is scheduled by Lab forces. It is important that we be notified of the intended source of aggregate at least 60 days prior to the start of paving as provided in Section 40-1.01

of the specifications. This will allow enough time for sampling, processing and performing all necessary tests. If the aggregate is from a source on our list of previously tested sources which has been tested recently, we may not make the flexure tests but will make a cement content recommendation based on previous tests. Regular aggregate tests will be compared to see if there has been any significant change in the aggregate character.

2. After the aggregates are received in the laboratory, they are processed and concrete is made in accordance with Test Method No. Calif. 536. On each of three different days, concrete is made using job aggregates in 5, 5-1/2, and 6 sack mixes and also our standard aggregate in a 5 sack mix only, as a control of testing procedures and facilities.

3. From each batch, concrete is cast into beams (6 x 6 x 20 inches) for flexural strength tests and cylinders (6 x 12 inches) for compressive strength tests. Strength tests are all made at age 14 days and the results reported for each source or combination of sources tested.

Shown on the test report are the flexural and compressive strength, water cement ratio, and the recommended cement content, designated as 5.0, 5-1/2 or 6.0 sacks per cubic yard. The flexural strength is the most important factor used in determining the recommended cement content.

Considered in making the recommendation for cement content are the requirements that the concrete under test shall have a flexural strength of 550 psi at 14 days (3rd point loading), and a water cement ratio not exceeding 52 pounds per sack. The cement content designated will be the lowest that will meet these two requirements; however, it shall not be less than 5.0 sacks per cubic yard.

To the present time, over 130 sources or combinations have been tested: The recommended cement contents so far are as follows:

5.0 sacks per cubic yard -	52%	of the	combinations	tested
5.5 sacks per cubic yard -	26%	"	"	"	"
6.0 sacks per cubic yard -	22%	"	"	"	"

The quality of economically available aggregates appears to be going downward. We can go only so far in compensating for low quality aggregates by increasing the cement content. Alternatives are more processing to upgrade present sources, or longer hauls to better sources.

ADMIXTURES

An admixture is usually defined as any ingredient in concrete other than water, cement, and aggregates. The ASTM classifies admixtures into categories. These are:

1. Air-entraining agents
2. Water-reducers
3. Retarders
4. Water-reducing retarders
5. Accelerators

Many admixtures are manufactured for multi-purpose use. Since most accelerators contain a high concentration of chloride-ion or other undesirable chemicals and all those tested have been found to greatly increase drying shrinkage and promote corrosion of imbedded steel, they are normally not permitted in State work. Those more generally used are classified as air-entraining agents, water-reducers and retarders. The latter two are usually furnished in combination as water-reducing retarders.

Air-entraining Agents

Air entrainment of a properly designed concrete mix results in several advantages over a non-air-entrained mix. Among these are:

1. Greatly increases freeze-thaw resistance of hardened concrete and increases salt scale resistance
2. Increases impermeability of hardened concrete
3. Improves workability and uniformity
4. Reduces bleeding of the fresh concrete
5. Increases cohesiveness resulting in less segregation of the plastic concrete
6. Reduces water requirement

Primarily the entrained air protects the cement paste from detrimental freeze-thaw action. Millions of closely spaced microscopic air bubbles are spread throughout the paste portion of air-entrained concrete. These bubbles provide reservoirs that relieve the pressure as excess water is forced into them during expansion caused by freezing action, thus preventing damage to the concrete. Blocking or reduction of capillaries and water reduction results in less bleeding of the fresh concrete and greater impermeability of the hardened concrete. Other advantages are also gained from the microscopic bubbles which act as "ball bearings" and impart a lubricating effect.

It must be realized, if you are to obtain the maximum advantage from an air-entrained mix, the basic non-air-entrained concrete mix design must be properly adjusted. In an average mix design, this generally permits a water reduction of 6% or more and a sand reduction of 2% to 3%.

Not all concrete properties affected by air entrainment are desirable. Normally, the use of air entrainment is accompanied by some loss in strength. The compressive strength of 6 sack concrete containing 1-1/2 inch maximum sized aggregate and 5.5% air, for instance, would be about 80% of that of a comparable non-air-entrained concrete. Flexural strength is affected to a lesser degree. For this reason, concrete containing entrained air requires additional cement if it is desired to compensate for the loss in strength. Many concrete authorities agree that the loss of strength resulting from the use of air entrainment is nearly always outweighed by the advantages gained. Strength is often not the most important consideration in determining the adequacy of a given concrete mix. For instance, a high strength concrete without air entrainment will probably perform poorly in a wet freeze-thaw environment.

When concrete is to be subjected to freezing and thawing conditions, the total air content in the freshly mixed concrete should conform to the following:

Maximum Sized Aggregate	Total Air Content
1-1/2 inch	5.5%±1%
3/4 inch or 1 inch	6.5%±1%
Mortar or pea gravel mix	8.0%±1%

Since only the mortar portion of a concrete mix is protected by air entrainment, any increase in the amount of mortar per unit volume of concrete, such as results when the maximum sized aggregate is reduced, requires additional air to provide equivalent protection. It should be kept in mind that the coarse aggregate too may be frost susceptible and its ability to resist freeze-thaw action must also be considered. If it is shown to be frost susceptible, the use of an alternate aggregate may be required.

Formulations of the agents have sometimes changed without any notification from the manufacturer. Therefore, none except those agents certified to be neutralized Vinsol resins should be used before testing by the Laboratory. Often this requires only a brief identification test to determine if the material furnished is the same as that tested previously for all specification requirements. The concentrations of these agents are not all the same; therefore, the manufacturer's recommendations should be used as a guide for determining the dosage needed, at least until air tests are completed. Trial batches of concrete with air determinations are desirable. During use, frequent air meter checks are necessary to maintain the proper amount of air. The temperature of the mix may cause fluctuations of the air content, and it will quite often be found that as temperatures rise, more agent is needed to maintain the desired air content. More frequent testing should be done at the start of concrete delivery until records show the process is under control. The plant should be inspected to assure that the agent dispenser is operating properly. A sudden change in the slump or appearance of the concrete is cause for immediate investigation by the inspector.

Although air entrainment is not a cure-all for whatever distress concrete may suffer, it does greatly improve the durability and other characteristics of concrete, and its use should not be undervalued. It cannot, however, take the place of good materials and competent workmanship. These comprise the foundation of sound concrete construction.

Water-Reducing Retarders

During hot and/or dry weather and under difficult placing and finishing conditions, the Engineer or Contractor may wish to

delay the setting time of at least part of the concrete so that finishing procedures can be better coordinated. To accomplish this, a water-reducing, set-retarding admixture can be used. These products also may impart improved workability to the concrete to some degree.

The most commonly used water-reducing retarders can be grouped into two general categories: lignosulfonates, which are made from by-products of the pulp industry, and hydroxylated carboxylic acids. Since the lignins generally increase drying shrinkage of concrete, the dosage must be limited in order to conform to our current specifications. The acid types have very little effect on shrinkage, but are more expensive.

General

There are innumerable products proposed for use as concrete admixtures. Unfortunately, a number of these are being promoted without supporting data by people without a technical background. You should be suspicious when a brochure tells about a "miracle product" and makes fantastic claims without showing any test data. Reputable products are usually backed by evidence of extensive developmental work and laboratory testing, as well as a record of its performance in the field. This does not, however, eliminate the necessity of laboratory checking for substantiation of the manufacturer's claims and conformance to our specifications.

Only those admixtures actually proposed for use on a specific project are normally tested by the Laboratory. Tests are made to determine the effects of an admixture on shrinkage, setting time, and compressive strength. Sometimes other tests may be performed. Once an admixture is tested for specification compliance and is found to comply, rapid identification tests by infrared reflectance are made on subsequent shipments of the admixture to a project.

The Laboratory test report on admixtures approved for use lists the recommended maximum dosages for specific work. These dosages are based on tests performed by the Laboratory and conform to the requirements of the Standard Specifications. Although retardation tests are made in the Laboratory, the data may not be directly applicable to field use. The effects of admixtures on concrete are dependent to some degree on the cement, aggregates, concrete temperature, and atmospheric conditions. Therefore, it may be desirable to vary the dosage, even during the pour, as conditions change.

At times, it may be desirable to add both an air-entraining agent and a water-reducing, set-retarding agent to a concrete mix. Care must be exercised to determine the compatibility of the two when mixed together. Some combinations of admixtures react chemically to form a jelly-like substance. This would nullify or severely reduce the effectiveness of either admixture and might produce other detrimental effects. The Laboratory will provide background information, advice, and field assistance upon request. Most of the time the safe way would be to introduce the two admixtures to the mix separately.

The Standard Specifications now give the Engineer general control over the use of admixtures. He should, therefore, become familiar with the purposes and limitations thereof so he can use them discriminately to overcome or minimize some of the problems encountered in concrete construction and performance.

MIX DESIGN

Concrete mix design is the selection of the most economical and practical combination of materials to produce the necessary workability in the fresh concrete and the required qualities in the hardened concrete.

In designing a concrete mix, several factors must be considered. These are the strength, either compressive or flexural, that is required in the hardened concrete, the maximum size aggregate to use, whether the concrete will contain entrained air or not, and what workability will be necessary to get the concrete properly compacted and finished.

There are several good guides that can be used in making a mix design for a trial batch. These include the Construction Manual, Concrete Manual of Bureau of Reclamation, and pamphlets published by the Portland Cement Association and the American Concrete Institute.

In California highway practice, the minimum amount of cement to be used for any specific type of concrete is normally specified in the Standard Specifications or Special Provisions. The amount of cement per cubic yard of concrete may vary from 4 to 8 sacks depending on the class of concrete to be used, or the requirements for a particular structure or portion thereof.

The maximum size of aggregate is selected after considering the use that is to be made of the concrete and the most economical maximum sized aggregate available. The minimum dimension of the concrete member, or the spacing of the reinforcing steel may control the maximum aggregate size. In most highway concrete, the size used is referred to as "1-1/2 inch maximum". A smaller size may be used at times depending on job requirements. It is normally advantageous to use the largest maximum size possible as an increase in density, a decrease in total water, and an economical use of cement can be realized. For any given cement content and aggregate combination, there is a maximum size of aggregate at which highest compressive strengths may be obtained.

Water demand of the aggregates and cement will control the amount of water to be added. The amount of water should not exceed the minimum amount necessary to produce suitable concrete. The actual amount will depend on the use to be made of the concrete and the slump desired at the time of placement. It cannot be emphasized too strongly that excess water in the mix and lack of it in curing are concrete's two greatest enemies.

If the concrete is to be air-entrained for freeze-thaw protection or increased workability, adjustments to the mix should be made accordingly. Normally, the use of air will allow a reduction in water content and advantage should be taken of this reduction. Also, the volume of sand in the mix should be reduced. Since air entrainment reduces compressive strength, it may be necessary to add cement to compensate for the strength loss.

The mix designer must decide on the proportions of fine and coarse aggregate. The references mentioned give good suggested percentages for the trial batch relating to the amount of cement, maximum size aggregate, and desired air content. The amount of sand may need to be increased slightly if the aggregates are crushed products. Proportions must be selected to give a combined gradation within the limits set forth in the specifications.

All the ingredients are then combined into what is commonly referred to as a trial batch. Tests are made to determine the consistency, air content, and unit weight of the plastic concrete. Adjustments are made to the mix design, if necessary, so that the designed cement content and volume are achieved in the plastic concrete. The Unit Weight of Fresh Concrete, Test Method No. Calif. 518, is most useful for this purpose. Appropriate specimens, such as cylinders or beams, may be fabricated to evaluate the properties of the hardened concrete.

READY-MIXED CONCRETE

Specifications covering ready-mixed concrete are quite detailed because there are many factors involved. If not controlled, they can adversely affect the product.

One variable is the mixer itself. A report of tests of 12 makes of truck mixers states that each could be so operated as to produce poorly mixed concrete. Adequacy of mixing is sometimes specified in terms of variation in slump between the first and last portions of the discharge. Concrete can be both overmixed and undermixed. Overmixing results in the generation of fines and heat, requiring the addition of more mixing water to maintain the slump. Undermixing results in the materials not being thoroughly intermingled or dispersed. Both the minimum and maximum number of revolutions of the drum during haul are specified and should be checked systematically.

Most mixers have two capacities; one as a mixer and one as an agitator. Plates are usually attached to mixer trucks showing rated capacities. The capacity as an agitator is larger and concrete cannot be mixed properly when loaded to agitator capacity. When concrete is only partially mixed at a central plant (shrink mixed), the conveying truck is required to be loaded only to its capacity as a mixer. Other difficulties arising from ready-mix operations are:

1. Adequate inspection at plant not always possible.

2. Some trucks are not able to discharge low slump concrete fast enough to suit Contractor.

3. With several units operating, control of mixing time is difficult. The use of a recording revolution counter is now required and is of great help in this respect.

4. Worn equipment or equipment in poor condition (worn blades, leaky water valves, inoperative revolution counters, etc.) require more attention to detect and maintain.

5. Delays in the work (forms not ready, etc.). The specifications state the time limit for concrete once any mixing water has been added.

6. Variation in total water due to failure to remove wash water completely before introducing a new batch.

CENTRAL MIXING OF CONCRETE AND NON-AGITATED HAULING

Central mixing of concrete coupled with non-agitated hauling offers some advantages over on-site mixing. In recent years, several paving projects throughout the State have employed the central-mix procedure with good results. Mixer tests and tests of concrete hauled in non-agitating truck bodies have been made on several projects. Tests were made with both rounded and crushed aggregates. Results show that air-entrained concrete made with rounded aggregates and having a slump of about 2 inches can be hauled comparatively long distances without serious segregation. A test series on concrete made with crushed aggregate indicates that serious compaction or "locking up" may occur on short hauls of one or two miles, even though the concrete may not be unduly segregated. This problem may be encountered whether or not the concrete is air-entrained.

Based on field investigation and tests, specifications covering central-mixed concrete and non-agitated hauling of concrete have been included in the Standard Specifications. Tests for uniformity, both after mixing and after hauling, may be required.

Uniformity is measured by distribution of coarse aggregate and slump. Samples for uniformity tests come from different parts of the same batch being tested. It is difficult to secure good test samples and close attention to this detail is necessary.

VIBRATION OF CONCRETE

Vibration of concrete is another very important phase in the production of quality concrete. A person can be very careful in quality control of materials, mix design, mixing, and curing, and still come up with a "5000 psi void".

The Standard Specifications require all structure concrete to be compacted by means of high frequency internal vibrators except on miscellaneous work, such as pipe culvert headwalls, slope paving, curb and gutter, and concrete placed under water. Concrete pavement specifications for side form construction require the use of surface vibrators over the full paving width and internal vibrators along the longitudinal edges or an equivalent means of consolidation, and for slipform construction, require internal vibrators over the full paving width.

Generally experience will tell you if a vibrator is working properly by visual inspection of what it is doing to the concrete. However, vibrators can be checked easily ahead of time with a pocket tachometer. The frequency of vibration is the most important factor in the effectiveness of a vibrator. The specifications require a minimum of 3500 vpm for surface vibrators and 5000 vpm for internal vibrators. Lower frequency than those required seriously impairs effectiveness of vibration and increases the time required to obtain consolidation.

Uniformity of concrete is reduced and chances are the contractor will want to add more water if his vibrators are not working properly, thereby further impairing strength.

Pneumatic vibrators may have a tendency to ice up in cool or cold weather work, even in 40° and 50° temperatures. This can be overcome by proper maintenance and the use of anti-freeze in the air line. Problems such as this are the contractor's, but knowing something of remedial procedures may help when the need arises.

Electric-powered vibrators are generally smaller than the pneumatic type, and are quite often more desirable to use in thin walls and other "tight" situations.

When vibrators break down altogether, and it happens occasionally, other methods may be used just to consolidate materials already in place. Spades, straight hoes, shovels, and "jitterbugs" can do a pretty fair job in a "pinch", but should not be used except in emergencies.

The main thing in assuring proper vibration of concrete is to talk it over with the contractor ahead of time, be sure he has adequate equipment on hand (in proper operating condition), and then be sure all concrete is vibrated systematically.

MIXER PERFORMANCE

In 1959, and again in 1966, the Bureau of Public Roads requested the State of California to assist in evaluating the performance of paving concrete mixers. In 1959, the 34E paving mixer was evaluated and later central plant mixers were evaluated.

The first study was concerned with mixing time and overloading of the mixers. Tests were made to determine variations in slump, air content, unit weight of air-free mortar, weight of coarse aggregate per unit volume of concrete, and compressive strength of concrete sampled from different portions of a batch.

The second study was concerned with methods of charging concrete ingredients into the mixer and their effects on the finished product. In this study the same tests were made as in the first study except: (1) variation in the unit weight of air-free mortar was not included; and (2) variation in weight of coarse aggregate per unit volume was determined for both primary sizes of coarse aggregates.

These studies indicated that under certain conditions satisfactorily mixed concrete can be obtained with as little as 30 seconds of mixing time; and that under some conditions it cannot be obtained with as much as three minutes of mixing time. The key to obtaining uniformity lies in the method of charging ingredients into the mixer. If all materials are ribboned into the mixer in their proper proportions, a short mixing period may be adequate. However, if an ingredient, particularly cement, enters the mixer ahead of or behind the other batch ingredients, it may not be possible to achieve thorough mixing in as much as three minutes.

Other things to be considered in mixer performance are: condition of the equipment, such as the blades in the mixers, and action of valves and gates.

In addition to initially evaluating mixing in all untested setups, it should also be investigated if there is any reason to suspect that uniformly mixed concrete is not being obtained with either central mix plants, ready mix plants, or truck mixers. A significant variation in any of the previously listed factors

between the first one-sixth of the batch, the center of the batch, and/or the last one-sixth of the batch may indicate charging or mixing problems.

WORKABILITY

Workability is a property of concrete that is difficult to define and is even more difficult to measure. Many attempts have been made by the Lab and other people to develop a test to measure this property, but to date, a consistent reproducible test has not been developed.

One individual will tell you that large, round aggregate in your mix will give you good workability; another will tell you a 3/4 inch mix is more workable than a 1-1/2 inch mix, or vice versa; the contractor's labor foreman may tell you it takes water for good workability; and so on. To a certain degree, they may all be right; as there are so many variables involved that what is true for one source of material may not be true for another, even if they are close together geographically. Concrete considered to have good workability for a footing pour may not have adequate workability for placing a thin wall.

The main objectives in obtaining good workability are to be able to place the concrete with a minimum of effort, the least segregation, and the greatest density. The best test for workability is the actual concrete placing. However, problems can be avoided before coming to this point by careful attention to proper mix design and job control. Make adjustments to your mix if it appears to lack workability on initial pours. Encourage the contractor to use trial mixes on small pours first.

There have been some cases where workability was sacrificed just to use the same mix that was being used out of a particular plant on another nearby highway job. Do not sacrifice good workability on your job just because someone made a mistake on another job and stuck with it. A specific example of this was observed where a 33-33-33 "unproportioned" mix was used on a machine-finished bridge deck. To make matters worse, the aggregate was crushed rock. So by using a particular mix just to avoid redesign and accommodate the batch plant supplying the same mix to a nearby job, good workability was sacrificed making it difficult to place and next to impossible to finish. This left the Resident Engineer with "ulcers", the contractor very unhappy, a very poor looking deck, but a very happy batch plant operator.

We cannot blame all consolidation problems on poor workability. Quite often a contractor complains about poor workability when in reality the problem is his lack of utilizing proper placing methods, finishing methods, or equipment, or just insufficient manpower.

There just isn't any formula to assure good workability. Since there are so many variables involved, some experimentation is nearly always required to attain optimum conditions.

FINISHING

Finishing of the surface is perhaps the most important step in pavement and bridge deck construction. The riding public is entitled to expect a smooth-riding, skid resistant surface for their comfort and safety. Properly constructed joints, uniform texture of the final finish, the freedom from irregularities are all important in obtaining good riding qualities. These people

who pay the bills for our highway don't see the results of all the subgrade preparation, etc., going into a section of highway, but judge the entire job on the basis of the riding surface of the pavement.

After the concrete is deposited on the subgrade and spread to the desired thickness, it must be consolidated and finished. A uniformly maintained pattern of distribution in discharging concrete on the subgrade ahead of the spreading equipment is necessary for efficient spreading and finishing. Dumping while the bucket is stopped results in large piles of concrete instead of the partially spread concrete that results from discharging the bucket while it is still in motion. The pattern for distribution should be shifted for changes in cross slope and superelevation to deposit greater amounts of concrete at the higher side of the section.

Finishing of Unformed Surfaces

For the most durable result in any finished, unformed concrete surface, the following procedures should be carefully followed. The concrete used should be of the lowest slump that can be properly consolidated. Preferably consolidation should be by means of vibration or some equally effective type of mechanical equipment. With such equipment or vibration, slump should be less than 2 inches. Following consolidation, the operations of screeding, floating, and first troweling should be performed in such a manner that the concrete will be worked and manipulated as little as possible in obtaining the desired result. Overmanipulation brings inferior fines and water to the top and this impairs the quality of the finished surface; it is a direct cause of checking, crazing, and loss of surface mortar. For the same reason, each step in the finishing operation, from the first floating to the final floating or troweling should be delayed as long as possible and yet permit the desired result to be

obtained. Free water is unlikely to appear and accumulate between finishing operations if proper mix proportions and consistency are used. If water does accumulate, it should be removed so the surface can lose its water sheen before the next finishing operation is performed. Under no circumstances should any finishing tool be used in any area before accumulated water has been removed. Neither should neat cement be worked into the surface to dry such areas.

Except under rare conditions, water should not be applied to the surfaces of concrete slabs to facilitate the finishing operation. This can be avoided by proper timing of the finishing operation. Water added as a finishing expedient results in a low quality product susceptible to abrasion and scaling. Precautions and good construction practices during the placing and finishing operations can produce a well-consolidated and well-finished pavement.

CURING OF CONCRETE

Curing of concrete is too often considered an "unnecessary evil" by Contractors and apparently by some of our own inspection personnel. Much material is available apart from our own experience, indicating the great benefits derived from curing, and it would be well for all of us to review this information occasionally. Quite often a person is very careful to make sure the aggregate gradings are not out by one point, the CV and SE are in specs, and everything else is done "according to the book", and after proper placing and finishing, the concrete curing is all but forgotten. Then later, we wonder what went wrong when excessive cracking occurs, the surface scales, and durability in general is not what it should be. Our records show good strength and evidence that all materials used were in accordance with the

specifications. Of course, our records don't show the difference in curing between our test specimens that we guarded so carefully and the in-place concrete that may or may not have been cured properly.

Realizing the importance of proper curing, this operation should be discussed in detail with the Contractor prior to placing any concrete. An understanding should be reached on exactly how the curing is to be done and all necessary equipment and materials should be on hand before giving permission to proceed. Equipment should be checked out for proper operation and an ample supply of water should be available. Spray equipment should be provided with a wind shield to prevent blowing of curing compound and promote even application. Mixing apparatus should be checked out to assure proper mixing of pigmented compounds. Quite often pigmented compounds are rendered ineffective because of inadequate mixing.

Close attention to curing during concrete placing is important to prevent plastic cracking. Particularly in windy or hot weather, a fog water spray should be used until the pigmented compound or other curing medium is placed. Plastic shrinkage cracking can be expected if the rate of evaporation from the concrete surface exceeds 0.2-lb. per square foot per hour. This condition can be predicted quickly from a graph that appears in PCA Bulletin ST-95, knowing or estimating air temperature, relative humidity, concrete temperature, and wind velocity. It is generally always necessary on bridge decks and sometimes on pavement to do some fog spray curing to minimize plastic cracking unless weather is cool and humid, and the final cure is placed at the optimum time.

No matter how you look at it, curing is <u>no</u> minor part of producing quality concrete, and it should be a matter of concern to all of us to see that it is done properly.

HOT AND COLD WEATHER CONCRETE

As the water demand for concrete of equal slump increases with the temperature of the concrete when it is mixed, the potential shrinkage also increases. Special steps should be taken to produce cooler concrete when the atmospheric temperature reaches 80°.

Any means of producing cooler concrete during hot weather are definitely worthwhile as they reduce temperature differential during the cooler evening hours as well as the amount of mixing water required. Some of the aids in producing cooler concrete are:

1. Cool the mixing water by such means as shading or adding ice.

2. Cool aggregates by shading or sprinkling the stockpiles.

3. Sprinkle subgrade, side forms and area adjacent to forms just prior to placing concrete. On small jobs, shading the forms and reinforcing steel prior to placing concrete will help.

4. Be prepared for concrete. Have forms and reinforcing steel ready and have a large enough crew available to place concrete without delay.

5. Proper curing in duration, continuity and degree are especially important during hot weather. Curing entails proper temperature as well as moisture control. If possible, prevent sun from beating directly on fresh concrete. The period immediately following placement is the most critical and curing should start as soon as the surface of the concrete will resist damage, or as soon as bleeding water has disappeared. Apply a fog spray to the curing membrane after it has set hard enough to withstand the water.

Concrete placed in the early morning should be given extra protection as it has longer exposure to the sun and thus a greater temperature differential may occur at night. An investigation was made as to causes of erratic cracking in concrete pavements, and the data indicates that most of this cracking occurred near the morning joint and went from 200 to 800 feet into the day's run before gradually fading out. Curing is usually delayed longest on this section.

6. Wind protection often figures heavily in proper curing. A gentle wind of 10 mph will cause about 4 times as much evaporation from a concrete slab as still air at the same temperature.

Cold Weather

During cold weather, concrete has a lower water demand and the possibility of shrinkage damage due to temperature differential is greatly reduced. However, some disadvantages also arise during cold weather operations. Bleeding water does not evaporate from surface of the concrete and there is danger of surface damage due to over working during the longer setting period. Air entrainment will reduce bleeding and make earlier finishing possible in most cases.

Proper curing of the hardened concrete during cold weather is often neglected. Adequate moisture must be supplied to the concrete for proper curing as the cold dry air tends to dry the surface. The introduction of dry heat to the curing area to prevent freezing only aggravates this situation, so special attention must be given to the areas around salamanders to see that moisture is available.

Heating the various ingredients of the mix will increase the concrete temperature until heat from hydration is available. Water temperature is easiest to control since water is easiest to heat. For best results, temperature of concrete should be about 50-60° when placed during cold weather.

The main problem of cold weather concrete work is the slow gain of strength, so care should be taken to see that work is scheduled to allow time for the concrete to reach the required strength.

HIGH EARLY STRENGTH CONCRETE

On almost every project, there is a time when it is either desirable or necessary to increase the early strength of the concrete for one purpose or another. This may be for any one of various reasons; from form removal to special traffic conditions requiring the early use of a new concrete pavement.

One of the first things to be considered when faced with the problem of obtaining high early strength concrete is deciding exactly what is needed and what qualities of the concrete can be sacrificed in getting it. There are several methods available by which high early strength can be obtained. Some of these, however, sacrifice qualities of concrete to the point where they may not be feasible.

Method for achieving early strength:

1. Increased cement factor
2. Use of high early strength cement (Type III)
3. Steam curing
4. Use of an accelerator (usually calcium chloride)
5. Combinations of these methods

The selection of the method to be used in a particular case will depend mainly on two variables. These are the minimum strength required at an early age, and how much increase in drying shrinkage can be tolerated. In general, the various methods listed will give the following results.

1. Increased Cement Factor

The use of extra cement in a properly adjusted concrete mix will increase strength without increasing drying shrinkage.

When extra cement is used, a properly adjusted mix is one in which the sand content has been reduced about 2 or 3% for each additional sack of cement. This will prevent a sticky mix, and also take advantage of the higher cement factor by reducing the required W/C ratio.

As a general rule, drying shrinkage does not increase if this adjustment in the sand content is made for increases in cement factor.

2. Use of Type III Cement

The use of Type III cement increases the early strength of concrete, but other things being equal, also increases the drying shrinkage.

3. Steam Curing

Steam curing has been used effectively in the prestressing industry where high early strength is necessary for early form removal and for the transfer of prestressing. This method can be used for bridge members, but such a method is not practical for pavements.

4. The Use of an Accelerator

The accelerator used for high early strength is usually calcium chloride. When calcium chloride is used not in excess of 2% by weight of cement, it will increase the early strength of concrete; however, it also increases drying shrinkage up to 75%. When calcium chloride is used in pavements, the curling is 50% greater than that of plain concrete. Because of this tendency to increase shrinkage and curling, and also its detrimental effects on reinforcing steel, no reference to calcium chloride is made in the specifications and its further use is discouraged.

5. Combination of Methods

In order to provide more information on the relative effects of various combinations on early strength and drying shrinkage, a study was made employing 10 different combinations of cement types, cement factors and accelerators. From this study is was found that:

1. Highest 6-hour and 3-day compressive strength was obtained with the 6-sack, Type III cement mix with 2% calcium chloride. However, this combination also produced the largest drying shrinkage; 154% of a 5-sack, Type II mix.

2. The 7-sack, Type II cement mix gave 3-day compressive strengths of 91% of the 14-day, 5-sack, Type II concrete. At the same time, the shrinkage was only 83% of the 5-sack mix.

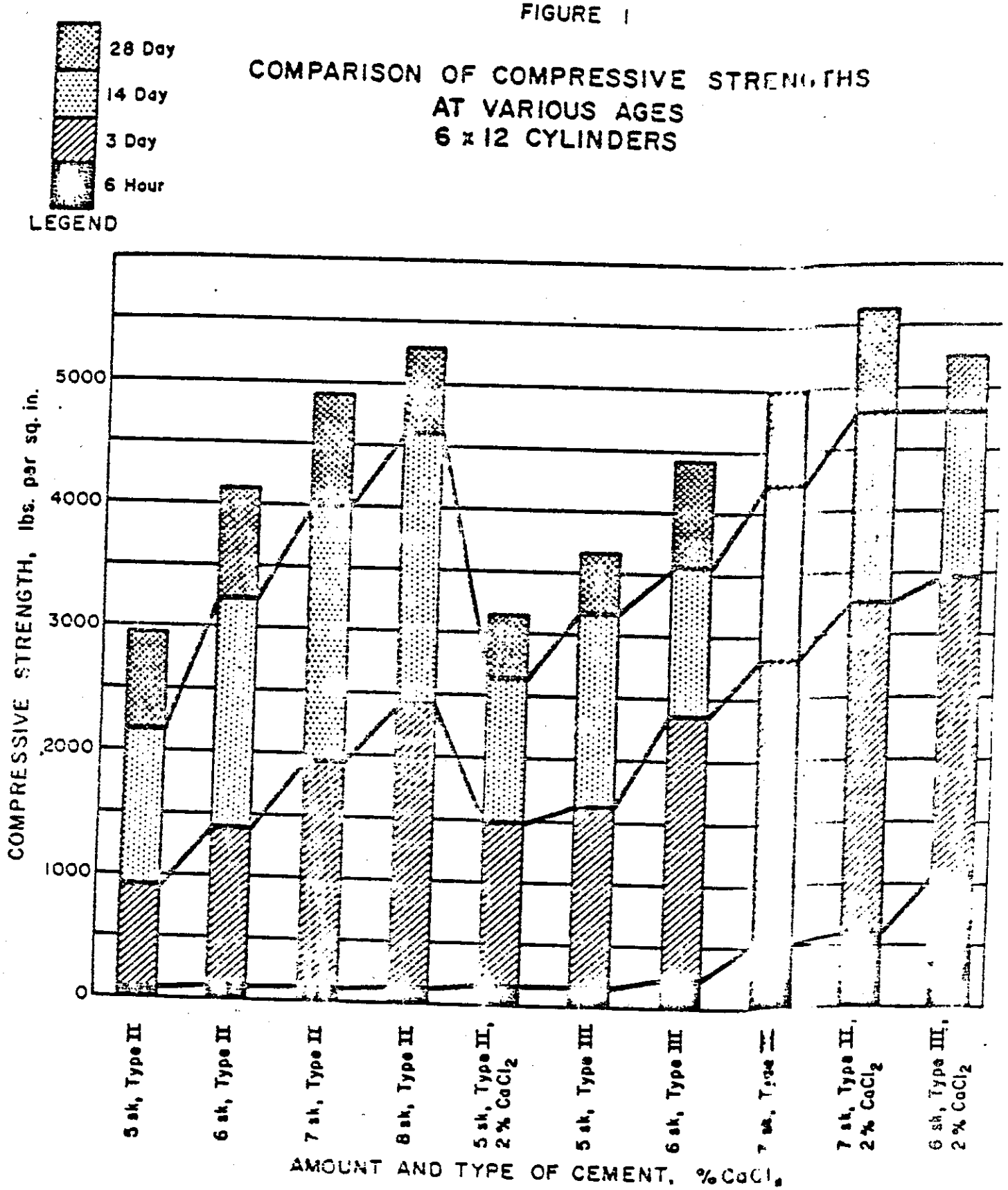
3. Various other combinations of cement factor, cement type and accelerators gave results similar to the two just mentioned. The method and combination to be used should depend on how badly the strength increase is needed and how much shrinkage can be tolerated.

It is stressed that the figures shown on the following graphs are applicable to the tests made in our laboratory study only. The relative values obtained in our study should apply to concretes made with other materials under various conditions.

As mentioned earlier, the sand content of our test mixes was reduced 2 or 3% for each additional sack of cement. This adjustment reduced the water-cement ratio for the rich mixes and maintained the total water in the mix nearly constant, varying only 7 lbs. per cubic yard for the 5 to 8-sack mixes.

FIGURE 1

COMPARISON OF COMPRESSIVE STRENGTHS
AT VARIOUS AGES
6 x 12 CYLINDERS



EXPERIMENTAL WORK TO MINIMIZE REFLECTION CRACKING

In California, research to minimize reflection cracking in asphalt concrete overlays has been in progress for many years. An evaluation of various methods and systems to reduce reflection cracking in bituminous overlays is being made to determine their relative effectiveness.

Reflection cracks develop from the movement of slabs or fractured pieces under the overlay layer. They can be caused by differential vertical movements due to wheel loads and lack of load transfer at a crack; by horizontal movements as a result of temperature or moisture changes in the base layer; or by early fatigue due to flexural stress concentrations. Cracking of this type may allow the entry of water and soil into the pavement, which leads to crack widening and spalling, increased maintenance costs, and decreased service life.

The potential problem of reflection cracking may be the controlling factor in the design thickness of an asphalt concrete (AC) overlay for existing asphalt concrete or Portland cement concrete (PCC) pavements. At present, rule-of-thumb procedures are used to determine AC overlay thicknesses when the governing criteria is control of reflection cracking. The thicknesses required are substantial and usually range from 0.25 foot, upward, for California climatic conditions. (Refer to Calif. Test No. 356 for further information.)

Early efforts on preventing reflection cracking were mainly concerned with paving over PCC surfaces, and a number of methods have been field-tested. These include: welded wire fabric reinforcement; breaking the concrete slab into small pieces; increasing thickness of overlay; placement of a gravel base course over the concrete; and various bond-breaking agents.

In recent years, increasing numbers of pavement overlays are being placed over failed asphalt concrete pavements. Various forms of failure are represented. In the case of AC pavements overlying high-strength cement-treated bases, transverse cracks are in the same general form as found for PCC pavements, except that they are at random spacing. This type of cracking is similar to thermal cracking of AC over an untreated base. The chief difference is that cracks in AC over PCC or CTB become wider with age; often even wider than the crack that originally existed in the PCC or CTB. One reason: the crack, fills with fines when the pavement is cool and contracts, thus causing the AC to "ridge and spall as the pavement expands from heating. Thermal cracking is normally greater on older pavement because the temperature range through which the AC can accommodate volume changes has narrowed due to asphalt hardening. Some projects have been overlaid with an AC utilizing softer asphalt, and less thermal cracking has been noted.

Other types of failure include block cracking patterns in the wheel tracks, and the familiar forms of alligator cracking caused by fatigue. It has been found in a number of instances that, even with relatively low deflections, serious cracking has occurred requiring overlays. This indicates that one of the prime functions of the overlay is to prevent reflection cracking. When structural adequacy is not a factor, any system that will reduce the thickness of the overlay required to control reflection cracking would be more economical.

Further, it has been noted on multilane roadways that most of the fatigued and failed pavements are in the outer traffic lane, with the inner lanes still in satisfactory condition for traffic use. Any reduction in thickness of the overlay in the outer traffic lane aids in reduction of the overlay on adjacent lanes and the shoulder where it is not needed. Such reductions of overlay thickness used to prevent reflection-cracking will provide substantial savings in expenditures and conserve resources.

The following information is from our recent research on various experimental field projects to evaluate the ability of several proposed systems and methods to prevent reflection cracking. Some of the field installations were placed by the TransLab while others were initiated by Transportation Districts.

SYSTEMS AND METHODS

Systems proposed for preventing reflection cracking in overlays have been placed over various forms of cracking encountered in PCC and AC pavements. Most of these systems are in the form of a strain-relieving material. However, other methods involving partial or full treatment of the existing cracked AC pavement are also being studied.

The following products and systems are presently being evaluated:

Dense-Graded AC Overlays

AC overlays of variable thicknesses are placed to serve as the control sections. In most cases, at least 0.1 foot additional AC can be placed for the same cost as a stress-relieving interlayer such as Petromat, or the rubberized slurry or chip seals.

Open-Graded Under Dense-Graded AC Overlay

A layer of open-graded AC base course is placed prior to laying a dense-graded AC surface course. The assumption is that this system will add flexibility to the overlay and provide a stress-relieving layer between the old pavement and the dense-graded surface course.

Rubberized Slurry Seal (SRI)

The SRI (Stress-Relieving Interlayer) is a rubberized slurry seal consisting of ground tire rubber, sand aggregate, and SS-1 emulsion mixed in equal parts by volume. The SRI, which is spread on the existing roadway with a conventional slurry seal truck, is assumed to act as a stress-relieving layer under the asphalt concrete to alleviate stresses causing reflection cracks.

Conventional Slurry Seal

An emulsion slurry seal of sand aggregate and an asphalt emulsion is placed just prior to the AC overlay.

Petrolastic

This air-refined asphalt is used to seal cracks in a roadway before resurfacing.

Stone Dust

Stone dust is placed on the pavement over transverse and longitudinal joints and cracks after the application of a tack coat. The stone dust is spread immediately prior to placing the overlay.

Tapes

Both 3M thermoplastic tapes and rubberized asphalt tapes have been placed directly on PCC pavement joints and cracks prior to their being overlayed with AC.

Fabrics

Fabrics have been used between both AC and PCC existing pavements and their overlays. On AC pavements, the cracks are filled and a heavy tack coat of asphalt cement applied prior to placing the fabric. On PCC pavements, fabrics have been placed either directly on the PCC pavement or, preferably, following placement of an AC leveling course. Generally, AR2000 or AR4000 paving asphalt is used as the tack coat. Some of the fabrics which have been tried in California are as follows:

PETROMAT - Nonwoven needle-punched polypropylene fabric.
BIDIM - Nonwoven polyester fabric mechanically interlocked by needle-punching.
CEREX - Spun-bonded nylon fabric.
MIRAFI - Nonwoven polypropylene homofilaments and polypropylene/nylon hetrofilaments heat bonded together.
FIBERTEX - Nonwoven needle-punched spun-bonded polypropylene fabric.
TRUTEX - Nonwoven, needle-punched polyester fabric.

Rubberized Chip Seal

The hot rubberized asphalt chip seal is composed of ground tire rubber, asphalt, and 3/8 inch aggregate. The hot asphalt-rubber mixture is sprayed onto the roadway surface and is followed by the application of 3/8 inch chips, which are preferably preheated and precoated.

Heater Remix

The existing AC pavement is heated, scarified, remixed, and rolled to a depth of approximately three quarters (3/4) of an inch before placing an overlay. Frequently, an asphalt emulsion or rejuvenating agent is added to the heater remixed layer of AC.

PETROSET "AT"

This product is used for "rubberizing" a new asphalt concrete pavement. The rubberized emulsion is sprayed on the pavement surface directly after the AC has been placed and compacted.

RECLAMITE

RECLAMITE is an asphalt rejuvenating agent used on both new and old AC surfaces. It can also be used in conjunction with the heater remix operation mentioned earlier.

EVALUATION TO DATE

Experimental overlays have been constructed on numerous projects since 1972, utilizing the materials previously mentioned. Table 1 summarizes some of the locations, and the systems and/or materials tried. Several of the projects have only one or two experimental materials placed; but nearly all have a control section for comparison purposes. Detailed crack surveys were made on most projects before overlays were placed.

The evaluation of projects constructed in 1972 provides some indication of which products show the most promise. However, it is still too early to evaluate the performance of the more recent projects.

Significant differences on most test sections have not developed because of the short test period, but the following findings appear warranted at this time:

1. An additional 0.12 foot AC placed in conjunction with a 0.08 foot maintenance blanket is performing better than the experimental test sections on a 02-Las-395 project, which exhibited thermal cracking prior to the overlay. It has extended the life of the overlay by more than two years.

2. Based on performance to date, the life of a 0.08 foot AC overlay has been extended at least three years on projects 08-Riv-15 and 11-SD-78 by placing PETROMAT with the overlay on pavements that exhibited hairline alligator cracks and pumping.

3. Asphalt cement (AR2000 or AR4000 viscosity grade) is best suited for a tack coat when installing fabrics to avoid a time delay caused by waiting for an emulsion to break; especially during cool weather and during the early morning.

4. The time (approximately 5 hours depending on weather) required for the rubberized slurry seal to cure using an SS-1 emulsion may prohibit its use on many overlay projects.

5. Problems were encountered during construction with CEREX, and rubber slurry seals when the overlay was placed by windrowing the AC material. The heat of the stockpiled material, equipment pushing and shoving, and paver pickup caused problems in keeping the materials in place.

6. CEREX, a spun-bonded nylon manufactured by Monsanto, Inc., could not be satisfactorily placed with a windrow paver operation and an RS-2 emulsion (02-Las-395 project).

7. Test installation of fabric on each of seven project locations in California show that the test sections are thus far performing better than the adjacent control sections of equal AC overlay thickness without fabric. The seven projects are located as follows:

a) 02-Las-395
b) 03-Pla-80
c) 07-LA-1
d) 08-Riv-395 (Temp. I-15)
e) 10-Sol-12
f) 11-SD-78
g) 11-Imp-115

8. The fabrics that demonstrate higher elongation per load are more easily placed in a wrinkle-free condition. Other states have reported these types are more effective in retarding thermal cracking.

The following tentative criteria appear to contribute significantly to the performance of fabrics when used in conjunction with AC overlays.

a) Perform crack sealing on all cracks over 1/4-inch width. Poor performance was noted when cracks 1/4-inch or greater in width were not sealed prior to placement of a tack coat and fabric.

b) About 0.25 gallon minimum per square yard of AR2000 or AR4000 paving grade asphalt should be placed as a tack coat prior to PETROMAT installation. Our experience to date has revealed that poorer performance was obtained when application rates of about 0.20 gallon per square yard or less were used with PETROMAT.

c) While some minor wrinkling of the fabric is unavoidable, folding of the fabric should be avoided during placement. It appears that excess fabric in one fold (three layers of material) tends to allow rapid development of a crack immediately over a fold, especially in thinner AC overlays.

d) PETROMAT installations in moderate or warm climates appear to perform better than those in the colder environments.

e) Our experience to date indicates that PETROMAT is, in general, more effective in retarding fatigue cracking (load associated) than it is in retarding thermal cracking (nonload associated).

f) An AC leveling course be placed over existing PCC pavements prior to placing the fabric. This then being followed by the overlay.

TABLE 1

TEST SECTIONS

PROJECT NO	DIST., CO., RT.	GENERAL LOCATION	CNSTR. DATE	TYPE OF EXIST. SURF. & CRACKING PATTERN	CONTROL SECTIONS		REFLECTION CRACKING RETARDING METHOD OR SYSTEM									
1	02-Los-395 29.8/31.8 50.6/51.2 02-Los-36 SUSANVILLE	DOYLE	AUG. 1972	AC SURF SEVERE MAP & BLOCK CRACKING	0.08' AC	0.20 AC	0.08' AC + STRESS RELIEVING INTERLAYER (SRI)	0.08' AC + EMULS SLURRY SEAL (ESS)	PETROSET "AT" EMULS. ON 0.08' AC	0.08' AC + PETROMAT	0.08' AC + PETROLASTIC CRACK SEALER ON 0.30 GP/SY RS-2	"RECLAMITE" EMULS. ON 0.08' AC				
2	03-Pla-80 31.3/33.2	COLFAX	JUL 1974	AC SURF LONG. & TRANS. CRACKS (CTB BASE)	0.20' AC	0.30' AC			PETROSET "AT" EMULS. ON 0.20' AC	0.20' AC + PETROMAT			INVERT OVERLAY 0.1' OG.AC + 0.1' DG.AC	INVERT OVERLAY 0.1' OG.AC + 0.2' DG.AC		
3	05-Sla-101 8.0/12.2	ARROYO GRANDE	SUMMER 1972	AC AND PCC PVTS. LONG. & TRANS. CRACKS									INVERT OVERLAY ON AC & PCC 0.60' OG.AC + 0.30' DG.AC			
4	06-Ker-43 0.1/8.0	BAKERSFIELD	FALL 1972	AC SURF. "ALLIGATOR" CRACKING										HEATER REMIXING & RECLAMITE + AC BLANKET		
5	07-LA-1 3.4/8.3	LONG BEACH	JAN 1973	AC. SURF. "ALLIGATOR" CRACKING PCC TRANS. & LONGI. CRACKS	0.15' AC	0.20' AC				0.10', 0.15', 0.20' AC OVER PETROMAT					STONE DUST BOND BREAKER	
6	08-Riv-15 28.0/28.5	RIVERSIDE	SEPT 1972	AC SURF. "ALLIGATOR" CRACKING	0.08' AC	0.35' AC				(0.08' AC + PETROMAT) (0.35 AC + PETROMAT)						
7	11-SD-78 7.5/15.6	VISTA	DEC 1972	AC SURF. "ALLIGATOR" CRACKING	0.08' AC				PETROSET "AT" EMULS ON 0.08 AC	(0.08' AC + PETROMAT) (1 SECTION PETROMAT + PETROSET ON AC)		"RECLAMITE" EMULS. ON 0.08' AC				
8	11-Imp-115 22.0/23.9	BRAWLEY	SPRING 1974	AC SURF BADLY "ALLIGATOR" CRACKED	0.20' AC	0.35' AC				(0.10' AC + PETROMAT) (0.20' AC + PETROMAT)						RUBBERIZED CHIP SEAL

CALIFORNIA'S FLEXIBLE PAVEMENT OVERLAY DESIGN METHOD

The California Department of Transportation has utilized deflection measurements for the evaluation of flexible pavements since 1938. In 1951, a series of comprehensive deflection research studies were initiated by the Transportation Laboratory in an effort to establish a tie between pavement deflection levels and pavement performance. Since the first formal study began in 1951 several projects have been completed and reports made. The results and conclusions of the first study were published in 1955. An evaluation of the data with respect to pavement deflections versus pavement conditions permitted the establishment of the concept of "tolerable deflection" criteria for a variety of structural sections. The term "tolerable deflection" as first used and shown in Table 1 is that level beyond which repeated deflections of that magnitude will produce fatigue cracking in the surface.

TABLE 1

Thickness of Pavement	Type of Pavement	Max. Permissible Deflection
8 in.	Portland Cement Concrete	0.012 in.
6 in.	Cement Treated Base (Surfaced with Bituminous Pavement)	0.012 in.
6 in.	Asphalt Concrete	0.012 in.
4 in.	Asphalt Concrete	0.017 in.
3 in.	Asphalt Concrete	0.020 in.
2 in.	Asphalt Concrete	0.025 in.
1 in.	Road Mixed Asphalt Surfacing	0.036 in.
1/2 in.	Surface Treatment	0.050 in.

These measurements were obtained using a 15,000 pound axle load and have been applied as guide criteria since 1955 for planning the reconstruction of existing roadways. The above deflection levels have since been related to the level of traffic load repetitions as will be discussed later. The Transportation Laboratory has completed additional research work to evaluate deflection criteria.

Continued evaluation of the deflection data resulted in two additional revisions to the California overlay design method during the period from 1970 to 1974. Deflection reduction characteristics and tolerable deflection levels of asphalt concrete were revised based on the performance of highway projects under review since 1960. An AC overlay design guide was developed which simplified the procedure for determining overlay thicknesses. This was first published in July 1976.

The overlay design guide was established to be used with untreated bases or treated bases which have deteriorated to the point where little slab strength remains. In these cases a structural overlay would virtually act independent of the old "cracked" pavement. For treated bases (CTB) with residual in-place strength, it is necessary to design the overlay using the "percent deflection reduction" curve.

SUMMARY STATEMENTS FROM RECENT RESEARCH

Pavement deflection measurements provide a reliable indication of in-place strength of the total pavement structural section.

Reasonable tolerable deflection values have been determined for various AC thicknesses and estimated traffic volumes.

When a given thickness of AC is placed over an existing roadway, the percent reduction in deflection is dependent on the initial deflection prior to placement of the overlay.

Using the above principles, California developed an overlay design method to determine overlay requirements utilizing pavement deflection levels, tolerable deflection criteria and estimated traffic volumes to determine structural adequacy.

Measured deflections can either increase, decrease or remain the same with time. Therefore pavement deflection measurements alone cannot be used to predict when an overlay would be required. They do indicate a present condition for which an overlay would be appropriate.

The California overlay design method at the present time does not provide for adjustments for temperature. Deflection differences caused by moisture changes in the base and subgrade throughout the year completely overshadow the magnitude of temperature adjustments that might be made. Our method attempts to determine pavement deflections during the worst condition (by testing in the spring or early summer) when the moisture content is at the highest level.

For 22 projects investigated for nearly 15 years, a relationship was found between fatigue cracking and tolerable deflection levels previously determined for various thicknesses of AC and traffic volumes. Seventy-three percent of the pavements that exceeded tolerable deflection levels had fatigue cracking in excess of 10 percent of their area regardless of asphalt properties.

The following general observations were noted regarding asphalt properties and pavement performance:

(a) Ductility values usually drop from 70 to 100+ (new AC) to less than 30 when AC pavements reach 10 percent fatigue cracking, regardless of the time period to reach 10 percent cracking. Pavements that exhibited 10 percent fatigue cracking approximately 6 to 8 years after construction had ductility values nearly 50 percent lower (from construction to failure) than pavements reaching 10 percent fatigue cracking approximately 13 to 15 years after construction.

(b) Penetration values of asphalt used for new AC (usually greater than 40) generally have dropped to less than 15 by the time 10 percent fatigue cracking occurs. No appreciable penetration differences were noted for good and poor performing pavements.

(c) Modulus of rupture, softening point and cohesion values generally tend to increase throughout the pavement life. Pavements with slightly higher modulus of rupture, softening point and cohesion values were quicker to reach 10 percent fatigue cracking than pavements with lower values.

Of the 22 projects investigated in a recent study, one percent fatigue cracking was reached an average of 9.2 years after construction. Ten percent fatigue cracking occurred an average of 11.7 years after construction. This marked increase in fatigue cracking over a short interval confirms results found on the Zaca-Wigmore Test Road, and indicates that failure is not directly proportional to time.

DEFLECTION MEASURING EQUIPMENT

The development of the Benkelman beam (Figure 1) during the WASHO Road Test in 1953 greatly simplified transient pavement deflections. This apparatus was adopted for use by California in 1954.

An automatic deflection measuring device known as the California Deflectometer was later developed by the Transportation Laboratory, and put into operation in 1960. A newer version was introduced in 1967 (Figure 2).

The Deflectometer is based on the Benkelman beam principle. It combines a tractor-trailer unit which carries an 18,000 pound single axle load on the rear tires and a carriage to support probes for measuring pavement deflections under both wheels simultaneously. It is an electro-mechanical instrument which measures pavement deflections at 20 foot intervals while the vehicle moves steadily along the roadway at 1/2 mile per hour. Pavement deflections are measured to the nearest 0.001 inch by means of probe arms resting on the pavement surface between each dual wheel assembly and are permanently recorded on chart paper. Between 1,500 and 2,000 individual deflection measurements are possible per day as opposed to about 300 measurements using the manually operated Benkelman beam.

Another device which is presently used by the Transportation Laboratory is of commercial manufacture and is known as the Dynaflect (Figure 3). California has three of these units currently. The Dynaflect is an electro-mechanical system for measuring the dynamic deflection of a roadway surface produced by an oscillatory load. This device consists of a dynamic force generator together with a motion measuring instrument, a calibration unit and five motion sensing geophones mounted on a small trailer. The trailer, in a stopped position, exerts a 1,000 pound peak to peak, 8 cps oscillatory load onto the pavement

surface through two rigid, rubber covered steel test wheels. The resulting amplitude of pavement deflection is picked up by the geophones and read as a deflection measurement on a meter located in the tow vehicle. Approximately 800 individual deflection measurements are possible per day with one of these units. The Dynaflect has been used on deflection research and special investigation work and has been correlated with the Deflectometer.

Another deflection measuring system of recent commercial manufacture, known as the Road Rater (Figure 4), has been subjected to a limited amount of evaluation. Although this evaluation was of limited scope it tends to indicate that this system has much promise. It operates on a principle similar to the Dynaflect but its operation is somewhat more flexible since the frequency of load application can be varied from 10 to 60 cps. There is a basic difference in the method of load application between the two devices. The Road Rater loading is applied through two pads attached to a steel plate whereas the Dynaflect utilizes two rubber covered steel wheels.

DETERMINING OVERLAY REQUIREMENTS FOR STRUCTURAL ADEQUACY

There are two basic procedures used by the State of California to determine overlay requirements for structural adequacy. The first procedure utilizes an overlay design guide proposed for roadways with untreated bases or treated bases having little residual slab strength. The second procedure utilizes (1) a tolerable deflection chart, (2) a deflection reduction curve, and (3) gravel equivalents primarily for roadways with treated bases having good slab strength.

(1) How to Determine Overlay Requirements for Structural Adequacy (For Roadways with Untreated Bases or Treated Bases with Little Residual Slab Strength).

Utilizing the deflection map, Figure 5, the first step is to examine the 80th percentile deflection levels and determine limits of similar levels. In selecting areas of similar deflections, an effort should be made to keep deflections within 0.010 inch increments. The next step is to obtain a representative deflection level for each deflection area. To do this, 80th percentile deflections are usually averaged. These deflections are then compared to the tolerable deflection values (Figure 6).* If evaluated deflection values are greater than the tolerable amount, an AC overlay is warranted for structural adequacy. Using Figure 7, California's asphalt concrete overlay design guide, overlay requirements are obtained utilizing Traffic Index values and 80th percentile deflection levels.

Example

Given the following data determine AC overlay requirements for structural adequacy only (roadways with untreated bases or treated bases having little residual slab strength).

Location	Representative 80th Percentile Deflection
P.M. 59.6 to P.M. 62.7	0.029 inch
P.M. 62.7 to P.M. 66.0	0.015 inch
Traffic Index$_{(10\text{-year})}$ = 9.0	
Existing Structural Section:	0.30 foot AC, 0.50 foot AB

*The Imperial Valley is in an environment where asphalt aging and embrittlement occur at a more rapid rate than other areas in the State. Hence, the tolerable deflection chart, Figure 6, should be tempered with judgment for projects situated in this area.

Solution:

From Figure 6, the tolerable deflection for 0.30 foot AC (T.I. = 9.0) is 0.019 inch. This indicates that the section of roadway from P.M. 59.6 to P.M. 62.7 requires an overlay for structural adequacy and the section of roadway from P.M. 62.7 to P.M. 66.0 is structurally adequate.

Using Figure 7, locate the vertical line representing a Traffic Index of 9.0 on the absissa. On this line interpolate the 80th percentile deflection of 0.029 inch. From this point, travel horizontally to the left to determine the needed asphalt concrete overlay. An overlay thickness of 0.18 foot AC is indicated from Figure 7. Asphalt concrete overlays are generally rounded off to the nearest 0.05 foot, therefore a 0.20 foot AC overlay is recommended for structural adequacy from P.M. 59.6 to P.M. 62.7. From P.M. 62.7 to P.M. 66.0, the average 80th percentile deflection level is 0.015 inch. Figure 7 also shows that this section of roadway appears structurally adequate. A roadway with a Traffic Index of 9.0 would require an eightieth percentile deflection value of 0.023 inch before a 0.10 foot AC overlay would be warranted. We, therefore, can consider a different strategy for this section of pavement, depending on whether or not there may be low skid resistance, whether or not we want to do something about cracks or other defects, etc.

(2) How to Determine Overlay Requirements for Structural Adequacy (For Roadways with Treated Bases Having Good Slab Strength).

The deflection map is utilized to determine representative deflection levels and limits of deflection variations. Once these values are obtained, determine the tolerable deflection levels for the treated base sections using Figure 6. Since treated bases for most structural sections are 0.50 foot or greater in depth, use the 0.50 foot CTB line in Figure 6 to represent all treated base thicknesses. If the 80th percentile deflection is less than the tolerable value, no corrective

repair is normally necessary other than perhaps a seal coat or thin AC blanket to seal cracks, improve appearance or provide a better riding quality. If the 80th percentile deflection is greater than the tolerable value, determine the required percent reduction in deflection using the tolerable deflection for the thickness of surfacing proposed for the repairs as follows:

Percent Reduction in Deflection =

$$\left(\frac{\text{80th percentile deflection} - \text{tolerable deflection}}{\text{80th percentile deflection}}\right) 100$$

Utilizing the calculated deflection reduction value and Figure 8, the required increase in gravel equivalent value is determined. Figure 9 is used to obtain the required AC overlay thickness. As a final check, the overlay requirement obtained using Figure 9 is then compared to the overlay requirement obtained using the untreated base method using Figure 7. If the overlay thickness from Figure 9 is greater, this indicates that the treated base section has poor slab strength and for design purposes is evaluated as an untreated base section.

Example

Given the following data, determine AC overlay requirements for structural adequacy only.

Location	Representative 80th Percentile Deflection	Existing Structural Section
P.M. 1.00 to P.M. 3.50	0.015 inch	0.30 foot AC 0.50 foot CTB 1.00 foot Base

Traffic Index$_{(10\text{-year})}$ = 11.0

Solution:

Using Figure 6, locate the sloping line representing 0.50 foot CTB and the vertical line representing a Traffic Index of 11.0. From the intersection of these lines, travel horizontally to the left to obtain the tolerable deflection level (0.009 inch) for the existing roadway. Since the measured 80th percentile deflection value is higher than the tolerable value, an AC overlay is indicated.

$$\text{Deflection Reduction Needed} = \left(\frac{0.015 - 0.009}{0.015}\right) 100 = 40 \text{ percent}$$

Therefore, a 40 percent deflection reduction is required. Using Figure 8, a 0.40 foot gravel equivalent is needed to obtain a 40 percent reduction in deflection. Figure 9 shows for a Traffic Index of 11.0 that a 0.20 foot AC has a gravel equivalent of 0.34 and 0.25 foot AC has a gravel equivalent of 0.43. Therefore, a 0.25 foot AC overlay is recommended for structural adequacy.

DETERMINING OVERLAY REQUIREMENTS TO MINIMIZE REFLECTION CRACKING

Determining an adequate overlay to minimize reflection cracking requires a great deal of engineering judgment. The type, size and amount of surface cracks, the extent of localized failures, the existing structural section and when it was placed, the thickness and performance of previous overlays, ride quality, environmental factors and anticipated traffic loadings all have some influence on the decision.

At present, there is no set method to determine corrective treatment to guard against reflection cracking. A discussion of strategies that have worked effectively for many years on California highways follows:

1. Shrinkage and Thermal Cracking

Shrinkage and thermal cracking are nonload-associated type failures. Thus, evaluated pavement deflections are quite often within tolerable values. Age hardening, overheated mixes, insufficient asphalt content and normal thermal conditions are some of the chief causes of shrinkage cracking.

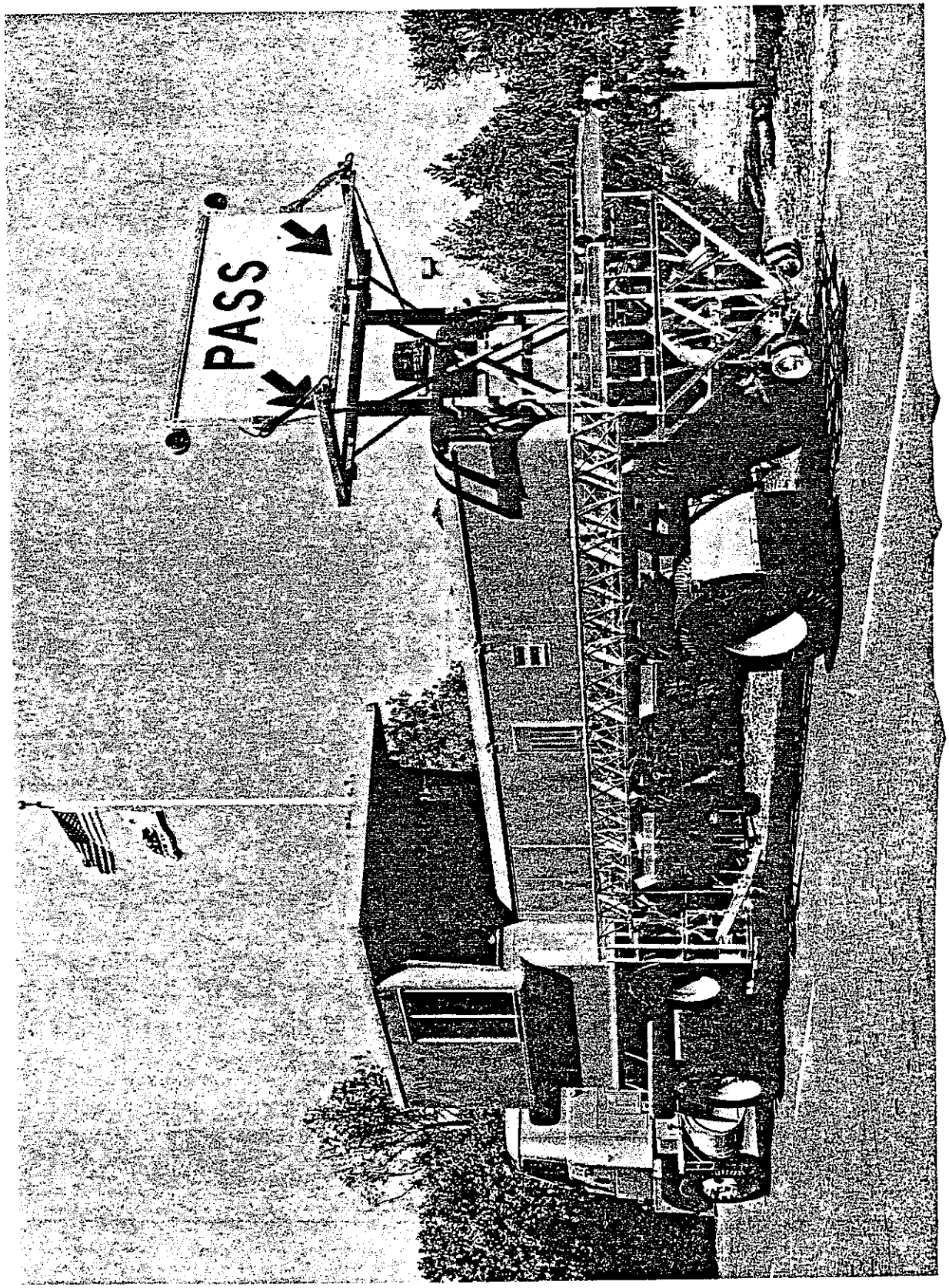
In moderate to high rainfall areas, one of the prime objectives is to seal surface cracks and maintain the seal to prevent water from entering the structural section and causing roadbed deterioration. Conventional chip seals and thin blankets oftentimes are ineffective since surface cracks usually "reflect" through within a short period. A 0.15 foot AC overlay should provide adequate cover to minimize reflection cracking on roadways with shrinkage cracks less than 1/8-inch wide. Roadways with shrinkage cracks 1/8- to 1/4-inch wide would require a thicker overlay to retard reflection cracking.

In areas of low rainfall, structural section deterioration due to moisture entering the roadbed may not be a major problem. The prime objective is to provide good skid resistance and ride quality if deflection measurements indicate the structural strength to be adequate. A thin OGAC overlay is often used to provide a good skid resistant surface. A leveling course plus a thin blanket may be needed to restore good riding qualities. In cases of shrinkage cracking or thermal cracking where (1) traffic loads are light (2) rainfall is low (3) pavement ride quality and skid resistance are acceptable, and (4) pavement deflections indicate adequate structural strength, the most cost-effective strategy is "do nothing". This is mentioned because the natural urge is to "do something" about a cracked pavement when basically it is in good condition and will provide adequate service for many years without any corrective treatment. Because many such roads exist, a "do nothing" strategy is valid.

Figure 1

BENKELMAN BEAM WITH TEST TRUCK

Figure 2



CALIFORNIA TRAVELING DEFLECTOMETER

Figure 3

DYNAFLECT IN TEST POSITION WITH FORCE WHEELS AND GEOPHONES DOWN

Figure 4

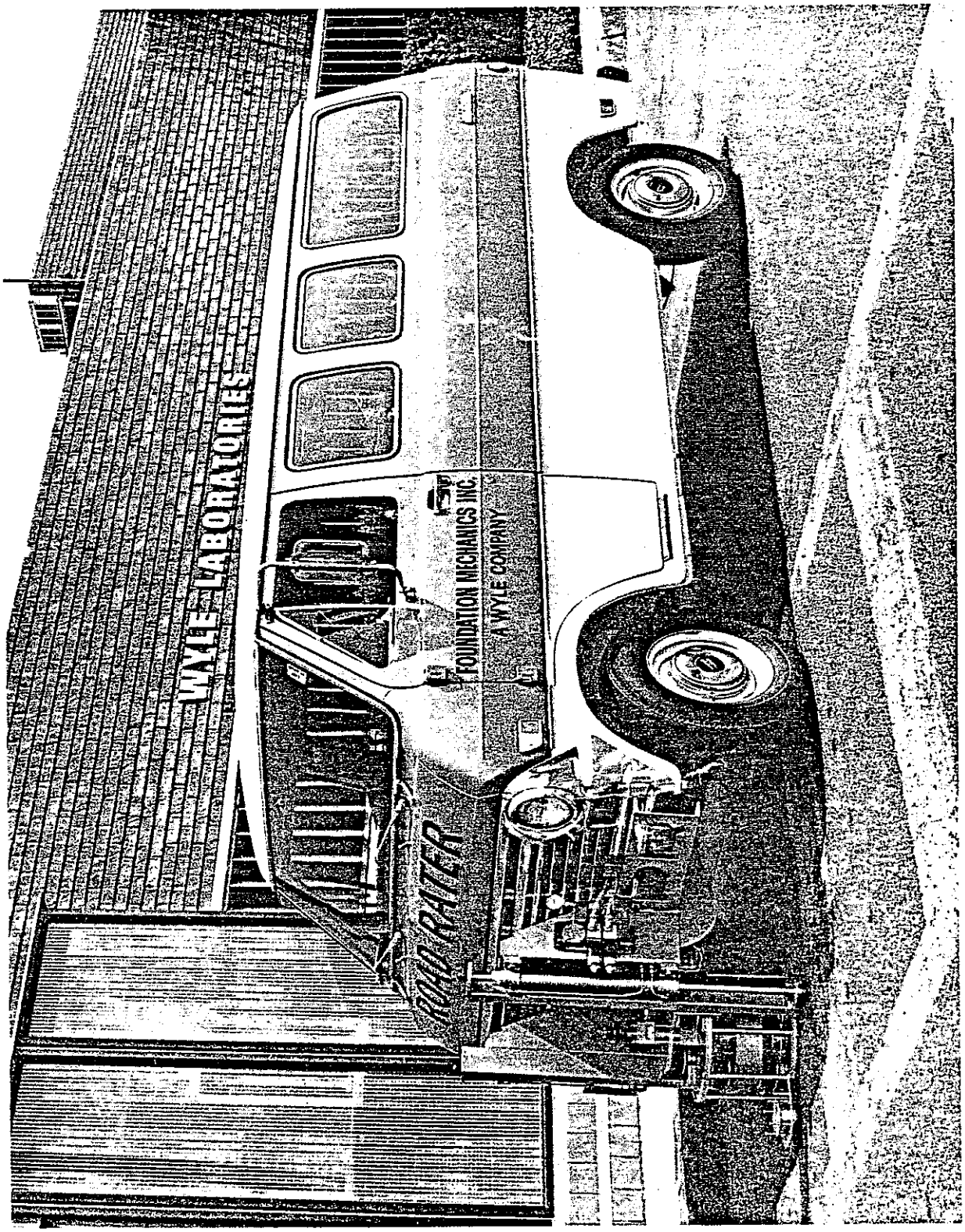

WYLE LABORATORIES
FOUNDATION MECHANICS INC.
A WYLE COMPANY
ROAD RATER

Figure 5

DEFLECTION MAP OF 09-Iny-395-59.6/66.0

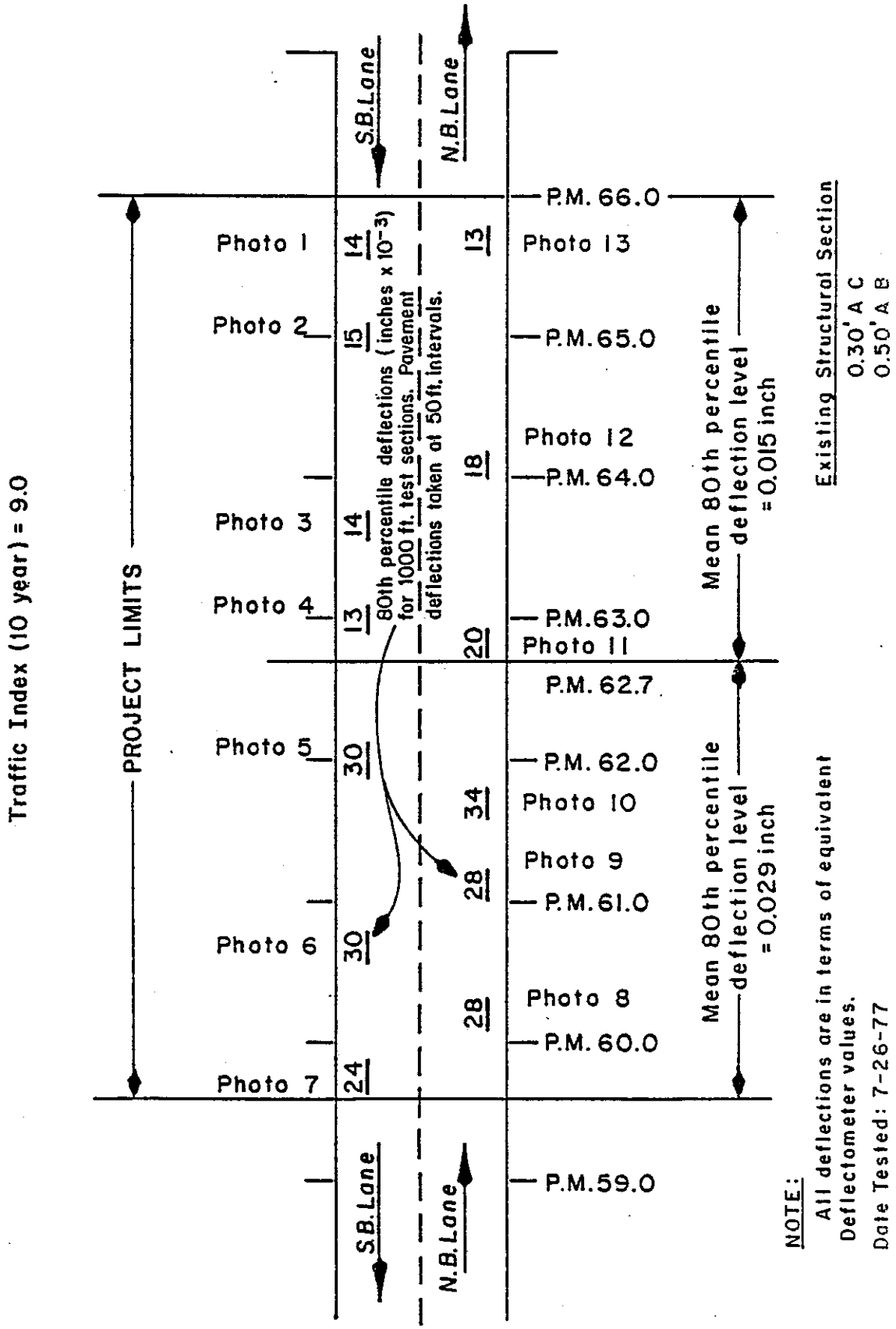
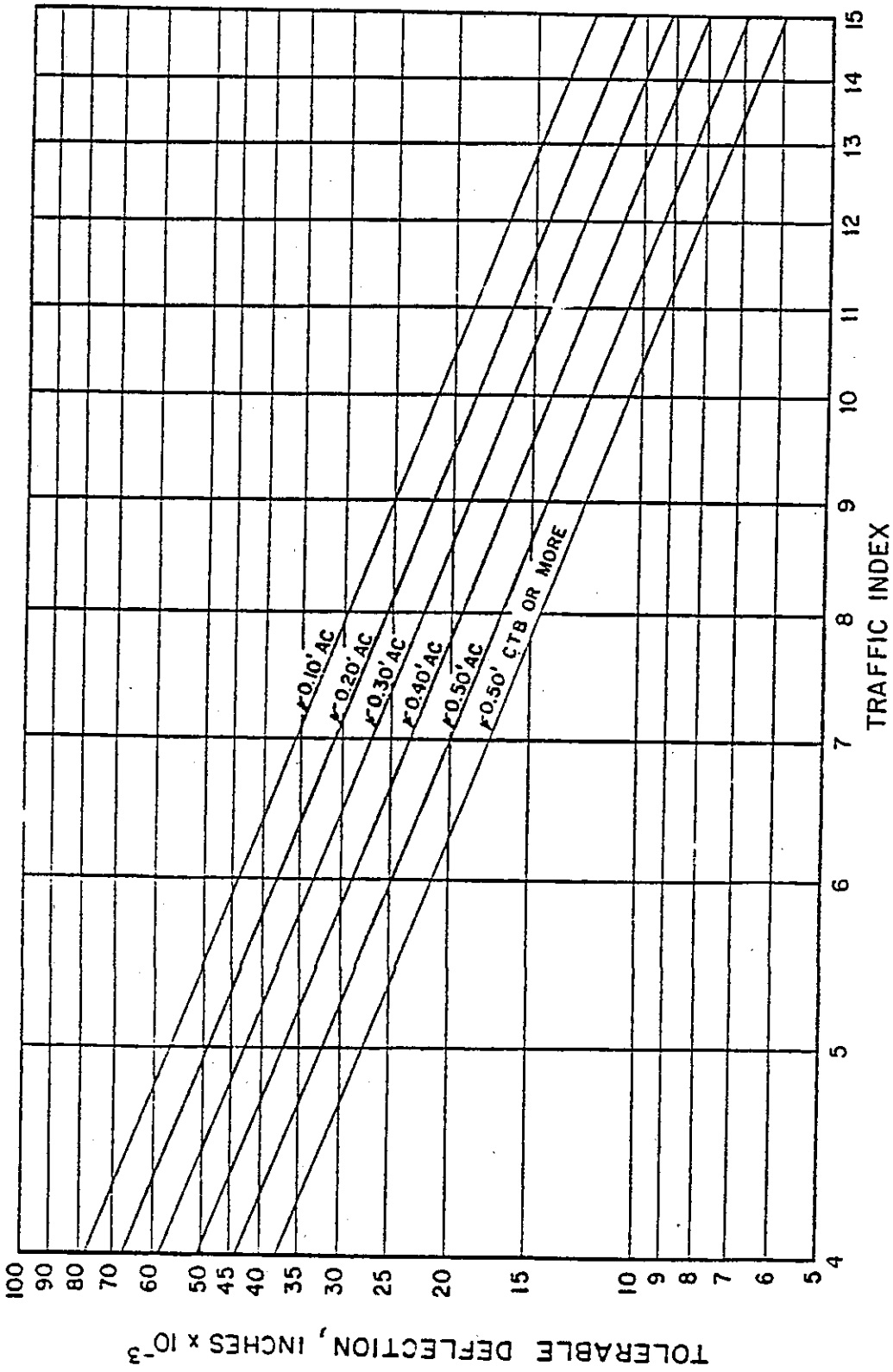


Figure 6



TOLERABLE DEFLECTION CHART

Figure 7

ASPHALT CONCRETE OVERLAY DESIGN GUIDE

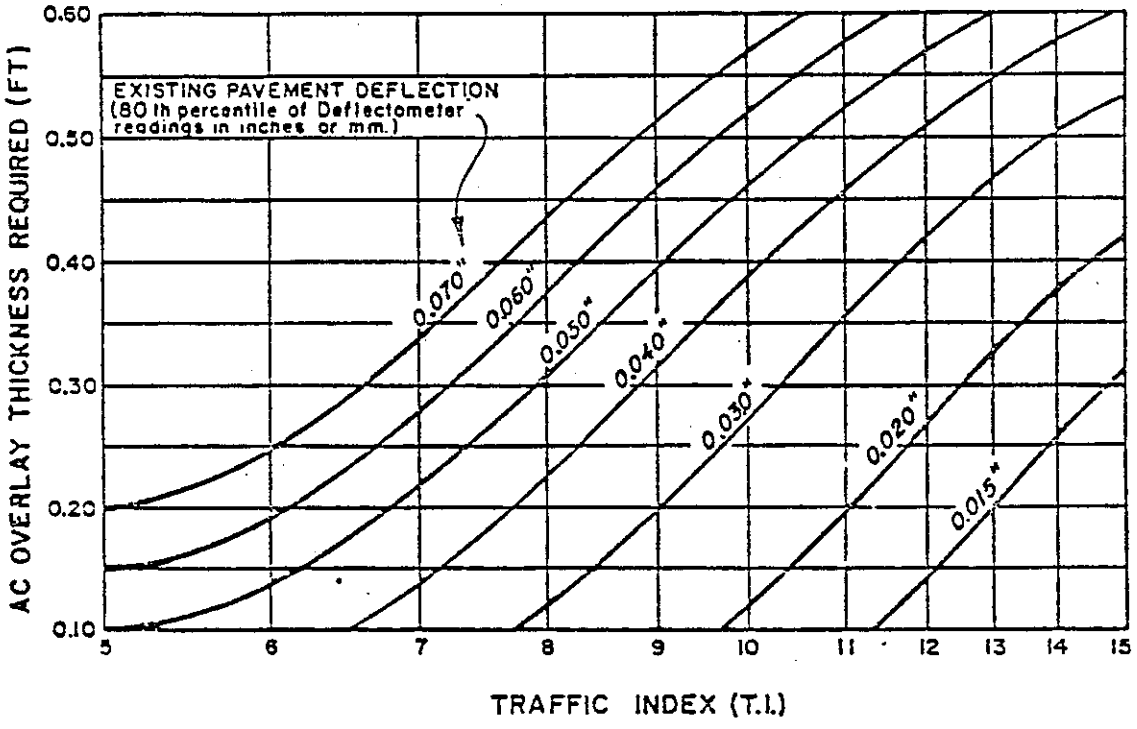


Figure 8

REDUCTION IN DEFLECTION RESULTING FROM PAVEMENT OVERLAYS

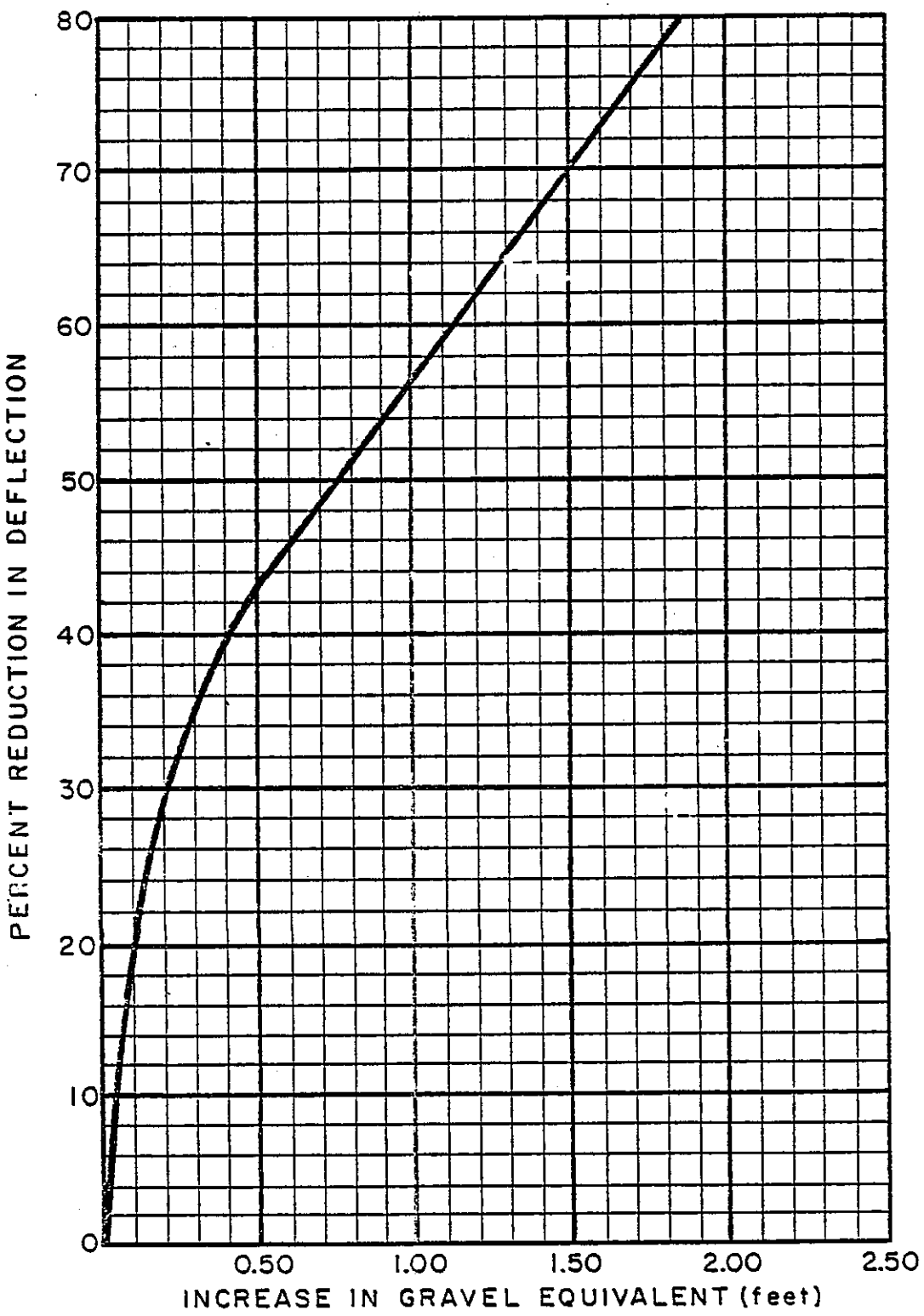


Figure 9

GRAVEL EQUIVALENTS FOR VARIOUS AC THICKNESSES & TRAFFIC INDICES

Actual Thickness of AC Overlay, in feet	Traffic Index (TI)										
	5 and below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	14.5 15.0 & up
	Gravel Equivalent Factor (Gf)										
	2.50	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.50
0.10	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.15
0.15	0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.22
0.20	0.50	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.30
0.25	0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.37
0.30	0.75	0.70	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.46	0.45
0.35	0.88	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.52
0.40	1.00	0.93	0.86	0.80	0.76	0.72	0.68	0.66	0.63	0.61	0.60
0.45	----	1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.67
0.50	----	1.16	1.07	1.01	0.95	0.90	0.86	0.82	0.79	0.76	0.75
0.55	----	----	1.18	1.11	1.04	0.98	0.94	0.90	0.86	0.84	0.82
0.60	----	----	----	1.21	1.13	1.07	1.03	0.98	0.94	0.91	0.90
0.65	----	----	----	1.31	1.23	1.16	1.11	1.07	1.02	0.99	0.97
0.70	----	----	----	----	1.32	1.25	1.20	1.15	1.10	1.06	1.05
0.75	----	----	----	----	----	1.34	1.28	1.23	1.18	1.14	1.12
0.80	----	----	----	----	----	1.43	1.37	1.31	1.26	1.22	1.20
0.85	----	----	----	----	----	1.52	1.45	1.39	1.33	1.29	1.27
0.90	----	----	----	----	----	----	1.54	1.48	1.41	1.37	1.35
0.95	----	----	----	----	----	----	----	1.56	1.49	1.44	1.42
1.00	----	----	----	----	----	----	----	1.64	1.57	1.52	1.50
1.05	----	----	----	----	----	----	----	----	1.65	1.60	1.57

PAVEMENT MANAGEMENT SYSTEM

A Pavement Management System (PMS) has been developed by the California Department of Transportation to monitor deteriorating pavement, to disseminate repair strategy information, to substantiate cost-effective rehabilitation strategies, and to be used as a basis for managing existing pavements in the State highway system. PMS begins with a statewide pavement condition field survey taken every two years. This survey identifies the location, nature, severity, and extent of pavement problems so data from the survey together with costs, rehabilitation strategies, traffic data, highway classification data, and other information has been computerized. The computer follows an engineering logic process to identify an appropriate level of repair for pavement. Because of the characteristic differences in flexible and rigid pavement problems and remedies, each pavement type is treated separately in the PMS. The end product is a series of reports describing pavement condition, rehabilitation strategy, and cost; candidate projects for various highway programs; and alternative repair strategies. This information will be used as a basis for establishing the magnitude and character of the various highway programs, the priority of repair work, and the funding to provide a designated level of service for California.

The Transportation Laboratory assisted the Division of Maintenance in the development of PMS through a research effort to establish criteria for rehabilitation of California pavements. A research project having this title was published in February 1979 by the Transportation Laboratory.

As the performance criteria were developed, they were immediately implemented into California's Pavement Management System which was simultaneously being developed. The performance criteria utilized pavement condition information obtained from past biennial pavement

evaluation surveys. The experience gained in utilizing this pavement condition information was fed back, along with information from the Pavement Management Group, into modifying the type of information recorded in future biennial pavement evaluation surveys.

The findings from this project have been incorporated into the California Pavement Management System.

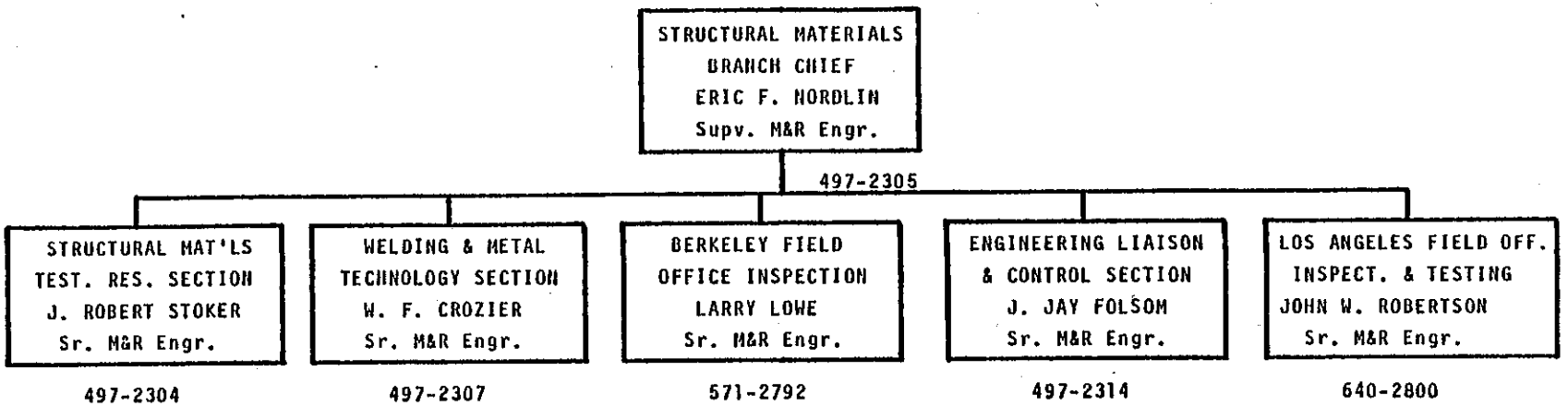
Notes on

PROCEDURES, TESTING METHODS AND USE OF MATERIALS FOR TRANSPORTATION PURPOSES

Prepared by the

STRUCTURAL MATERIALS BRANCH

Presented at
Transportation Laboratory
Sacramento, CA



The Structural Materials Section is responsible for inspection, testing, analysis, investigation, and research of metals, woods, and other structural materials or fabricated and manufactured products.

The Structural Materials Testing and Research Section is divided into four units as follows:

	Unit Supervisor
1. The Structural Materials Test and Specification Unit operates the structural mechanics laboratory. This unit performs static load tests on samples of structural materials submitted by the districts and the field offices. It also performs investigational studies and develops new laboratory tests for the structural materials. This unit serves as advisor to construction projects relative to prestressed concrete tendons and stressing operations.	Rich Spring 497-2301
2. The Structural Materials Research Unit performs research on structural designs such as bridge members, sign structures, culvert pipe, bearing pads, etc.	John Dusel 497-2315
3. The Safety Systems Tests and Specification Unit performs routine tests and research on signs, markers, and other delineation materials. It also performs routine tests on various commodities and develops new specifications and tests for these materials as required.	Dick Hickman 497-2303
4. The Safety Systems Research Unit conducts research, including full scale dynamic tests, into various transportation safety systems such as bridge railings, guardrails, median barriers, energy absorbing barriers, breakaway sign supports and light poles, etc.	Roger Stoughton 497-2308

The Welding and Metal Technology Section performs special services, investigations and research in welding in the broad field of metallurgy. This group performs the welding inspection for all welded field splices on structural steel members on construction projects.

The engineer in charge of the Engineering Liaison and Control Section coordinates the in-state and out-of-state source inspection of fabricated and manufactured materials and acts as Office Engineer and administrative assistant to the Section Chief.

The Berkeley and Los Angeles Field Offices make inspections and sample structural materials or fabricated and manufactured products at the source of manufacture or supply. For products such as prestressed concrete or welded structural steel members, the inspection is continuous. Samples are forwarded to the Sacramento laboratory of the Los Angeles Field Office for analysis and testing as required. Final record sampling and measurements on highway construction projects in the Southern Area are performed by Los Angeles Field Office crews.

Note: All phone numbers shown are ATSS

10/25/79

STRUCTURAL MATERIALS BRANCH

The Structural Materials Branch, including Los Angeles and Berkeley Field Offices, provides complete inspection, testing, consultation and research services with regard to structural materials and manufactured items being incorporated into transportation facilities and other appurtenant structures.

INSPECTION SERVICES

The Structural Materials Branch provides expert source inspection service for virtually any material used in Caltrans construction and maintenance projects. With the backup support of the various TransLab facilities and the instrument and fabrication shop, it is possible to provide a complete inspection package and to determine compliance with all specification requirements. Regardless of size or complexity of the project, qualified field and plant inspectors are available for structural steel fabrication and prestressed concrete construction.

Source inspection in California is handled through the Los Angeles Field Office, the Berkeley Field Office, the Sacramento Inspection Office and by the various Caltrans Transportation District Offices except Districts 04, 07, and 09. This source inspection quality assurance effort is coordinated by the Structural Materials Branch in Sacramento which also arranges for inspections as necessary at out-of-state sources.

TESTING CAPABILITIES AND FACILITIES

The STRUCTURAL MECHANICS LABORATORY is equipped to perform physical and performance tests on all materials which include reinforcing steel, prestressing steel, structural steel, bolts, neoprene bearing pads, joint sealing materials, plastics and wood products.

Equipment includes physical testing machines capable of applying tensile and compressive loads ranging from one to one million pounds. Two of the testing machines (the 75,000 lb. and the 1,000,000 lb.) have dynamic capabilities for fatigue testing and sustained loading tests that can be computer programmed.

In addition to the conventional equipment, the Structural Mechanics Lab is also equipped with many specialty equipment items which include:

- Fatigue testing machine for bearing pads
- Impact testers for testing plastic pipe as well as metallic materials
- Full line of load cells for field use to measure forces up to 1-1/2 million pounds
- Environmental chambers for high and low temperature tests

This testing lab is supported by a complete machine shop capable of preparing any type of test specimen or designing and constructing special testing equipment and fixtures.

The SAFETY SYSTEMS LABORATORY is equipped to perform testing and research on all types of signing and delineation materials as well as other commodities such as pencils, paper, textbooks, typewriter ribbons, thermometers, survey tapes, safety belts, flagging material and many other commonly used items.

The following list is an example of just a few of the many items of specialized equipment located at the Sacramento Laboratory:

- Two artificial weathering chambers to measure the durability and weathering properties of materials
- A 100-foot light tunnel to determine retro-reflective values
- Equitorial tracking rack to accelerate weathering of samples being evaluated
- Controlled environmental room
- Colorimeter used to determine color coordinates of paint, retro-reflective sheeting, etc.

In addition to equipment used at TransLab to evaluate the durability of materials, exposure racks are located in six climatic zones throughout California.

The WELDING & METALLURGICAL LABORATORY is fully equipped to provide the following support services:

- Routine testing for welder qualifications and procedure qualifications
- Metallurgical, failure analysis and fracture mechanics through the utilization of metallographic and metallurgical equipment
- Non-destructive testing in radiography, ultrasonic, magnetic particle and dye penetrant
- Research to investigate the applicability of all metals, ferrous and nonferrous for use in structures and to establish specifications for their use and fabrication control
- Perform all current welding processes on ferrous and nonferrous metals

The LOS ANGELES FIELD OFFICE also includes a testing laboratory to process routine check samples of materials being incorporated into on-going construction and maintenance projects in Southern California. Their facilities include:

- Complete testing equipment for asphalt products
- Electronic testing equipment to check for specification compliance and operational performance of all types of electronic control devices
- Complete facilities for testing concrete products
- Facilities to perform all routine tests on steel products
- Mobile drilling equipment for determining specification compliance in pavement structural sections

RESEARCH

The Structural Materials Branch has complete capabilities to perform research and investigations to resolve structural materials problems which arise during the design or construction of any transportation facilities. Major areas of research include:

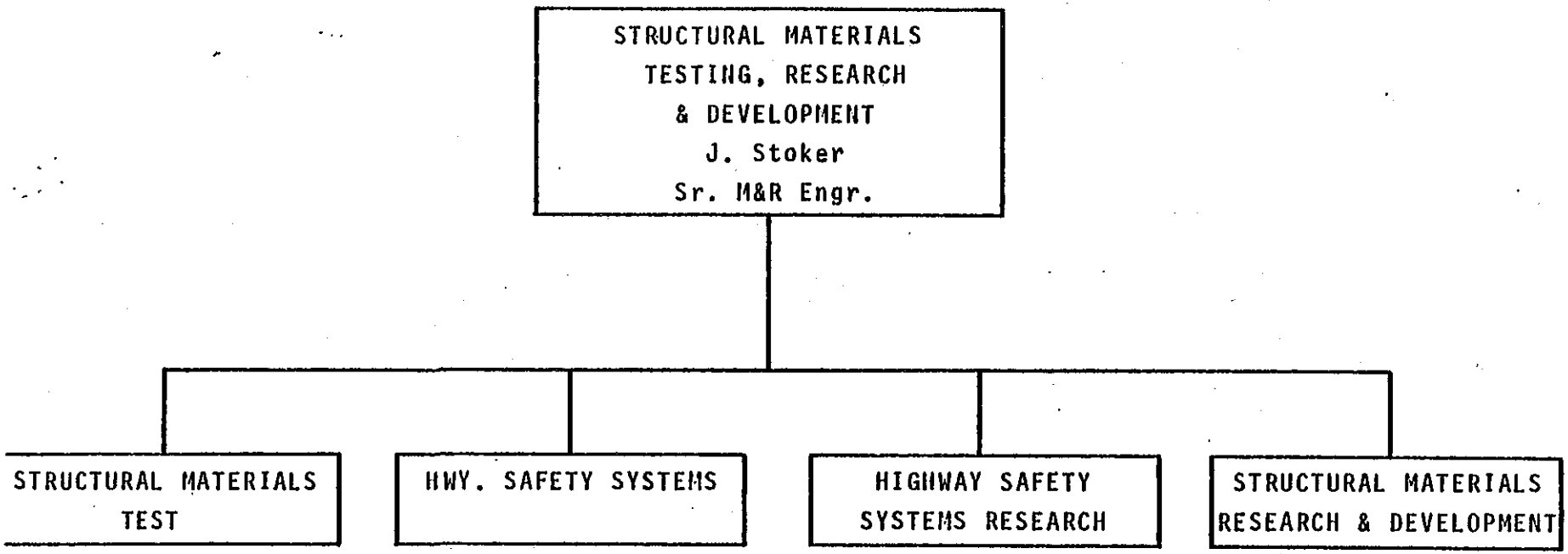
- Signing and delineation research on a continuous basis in an effort to develop new systems and upgrade existing facilities in the field of signing and delineation of transportation systems
- Full scale vehicle crash testing research on various highway safety systems such as guardrails, median barriers, bridge rails, crash cushions, and breakaway sign and luminaire support designs used in the California Transportation System. A 2,200-foot long runway is available to conduct these or any other type of dynamic vehicle impact tests

- Welding research to evaluate the use of new welding processes or new welding materials proposed for use in steel structures and to investigate current problems that could lead to serious structural failure without corrective action
- Metallurgical research and investigation, concerned with such properties as weldability, strength, corrosion resistance, fracture toughness and fatigue crack resistance, are going on continuously to evaluate new materials and older metals for new applications
- Nondestructive testing research to evaluate and measure the effectiveness in the inspection of raw and fabricated metals used in structures.

MISCELLANEOUS SUPPORT

Miscellaneous services performed on a continuing basis include the following:

- Review plans and specifications for design units to assure proper use of materials and fabrication methods
- Act as a consulting agency for continuous updating of specifications and plans as materials and manufacturing techniques and processes change
- Develop test methods and inspection procedure manuals
- Through participation in various technical societies, the Branch regularly provides input into these national organizations including assistance in writing and revising specifications.


STRUCTURAL MATERIALS
TESTING, RESEARCH
& DEVELOPMENT
J. Stoker
Sr. M&R Engr.
STRUCTURAL MATERIALS
TEST
HWY. SAFETY SYSTEMS
HIGHWAY SAFETY
SYSTEMS RESEARCH
STRUCTURAL MATERIALS
RESEARCH & DEVELOPMENT

9/1/79

STRUCTURAL MATERIALS TESTS AND SPECIFICATIONS UNIT

INTRODUCTION

The primary function of this unit, also known as the Physical Testing Laboratory, is to perform physical tests on samples of manufactured materials destined for CALTRANS construction projects to assure that these materials comply with the appropriate specifications. For example, products such as reinforcing steel, prestressing steel, steel plates, aluminum sheet, elastomeric bearing pads, plastic waterstops, and hemp rope are tested to determine their physical properties such as yield and tensile strength, hardness, ductility, modulus of elasticity, and impact resistance. In performing this primary function which constitutes about 60% of the total effort, the unit personnel expertise and equipment capabilities have been developed such that the unit can perform many important secondary functions very effectively.

These secondary functions include: a program of prequalification testing and calibration of prestressing systems; evaluation of new products and procedures; materials testing for other government agencies; updating CALTRANS specifications and test methods; working with technical organizations such as ASTM and AASHTO to update their specifications and test methods; providing technical consultation for CALTRANS personnel, other agencies, and private industry; and performing research testing for other units.

EXAMPLES OF PRODUCTS TESTED

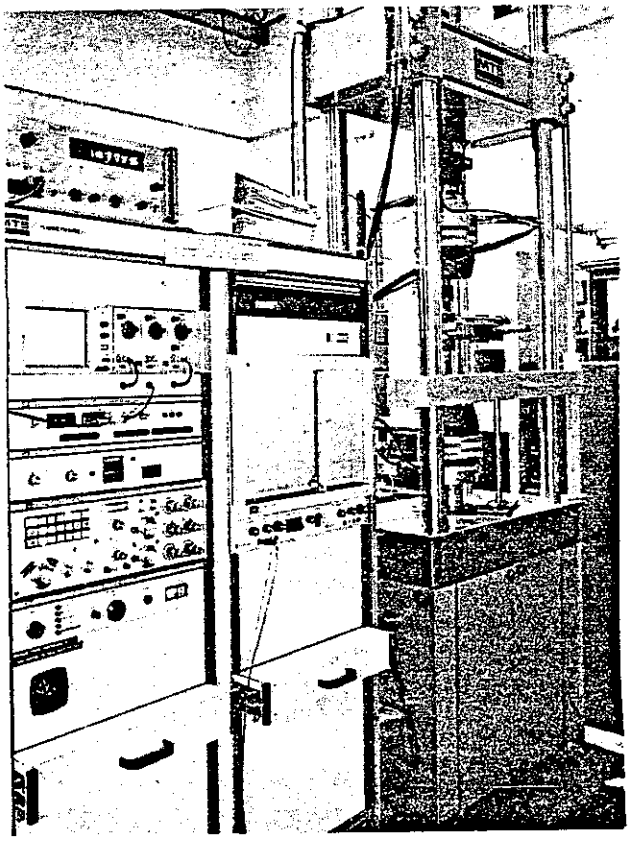
The following is a partial list of products tested for compliance with specifications:

Steel sheet and plate
Steel pipe and conduit
Plastic pipe, conduit, and fittings
Fence Fabric
Fence posts and hardware
Aluminum sheet
Nuts and bolts
Reinforcing bar
Prestressing strand, wire, bars
Prestressing hardware
Joint Seal
Elastomeric Bearing Pads
TFE (Teflon) Bridge Bearings
Waterstop
Plastic Foam
Expansion joint material
Nylon load binders
Compact tensile specimens
Fabric
Hemp rope
Synthetic Fiber Rope
Wire rope and fittings
Glare screen posts
Log bunks
Seat belts
Light poles
Culvert pipe
Culvert pipe couplers
Plastic pull boxes
Reinforcing bar couplers
Shovels
Wrenches
Sprinkler heads
Drip irrigation components

CAPABILITIES OF EQUIPMENT

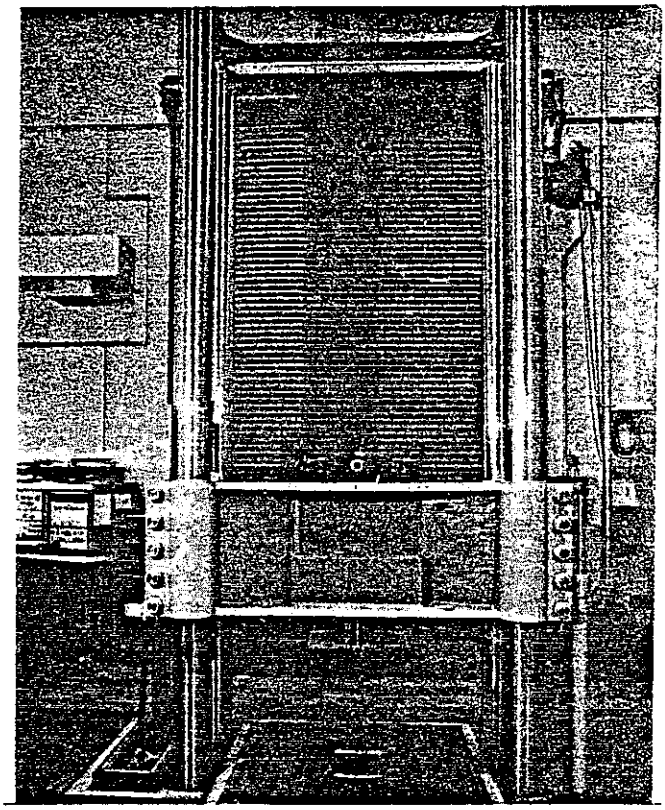
The unit equipment has the capability of accurately applying loads ranging from a few pounds to a million pounds to the various specimens under investigation. This wide range of testing equipment is required to handle the variety of materials received. Some of this equipment is illustrated below:

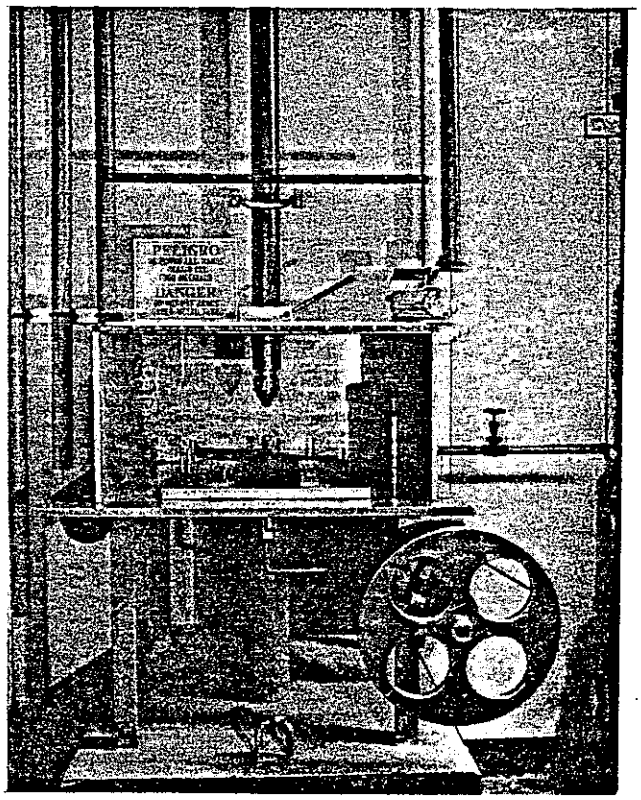
6 Kip Capacity Baldwin. Lowest range = 120 pounds. Used primarily for testing of rubber, plastic, and fabric tensile specimens, joint seal, paper, pavement markers, rubber tear specimens, seat belts. Test temperatures can range from -20°F to +350°F.



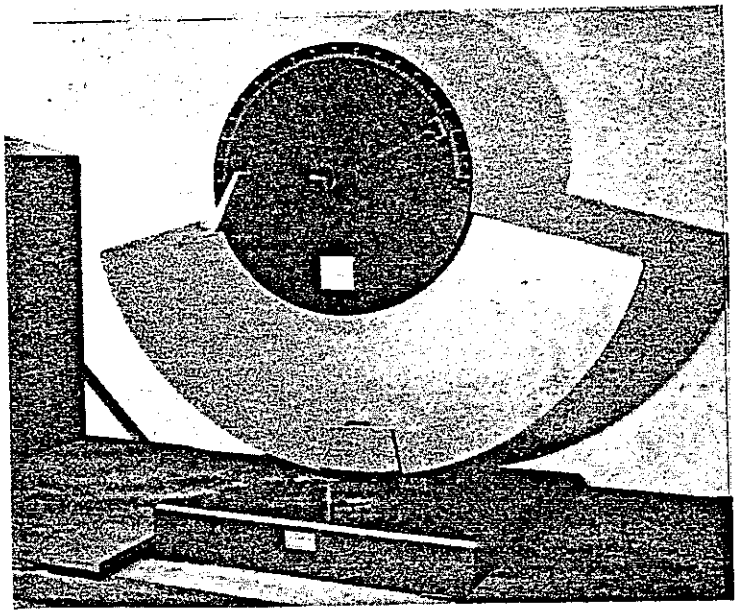
75 Kip Capacity MTS. Used primarily for tensile specimen stress/strain curves, creep tests, cyclic tests where relatively high frequency is desired.

1000 Kip Capacity MTS. Used primarily for large diameter reinforcing bar, large steel tensile specimens, calibration of prestressing load cells, research testing where high loads and/or large space is required, creep tests on large specimens, cyclic tests at high loads and low frequency.

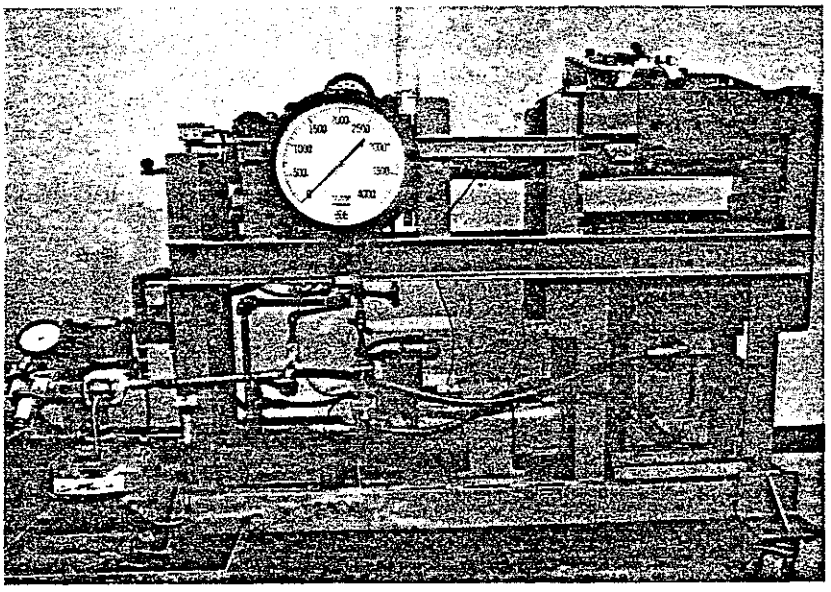




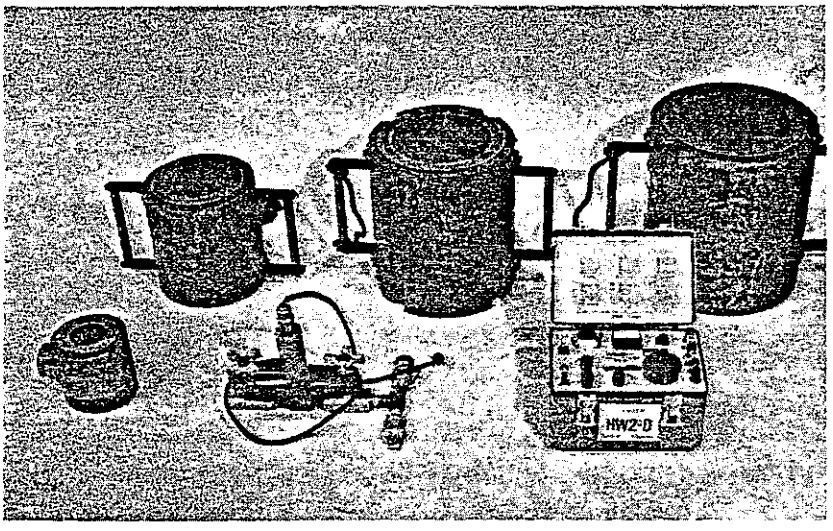
17 Foot Drop Impact Tester. Used primarily for impact test of plastic pipe, and any small specimens requiring impact tests.



Charpy Impact Tester.
Used to determine Charpy impact resistance of steels at various temperatures.



Fatigue Testing Machine. Used for combined compression and translation fatigue tests on bridge bearing systems. Designed and built specifically for this purpose.



Load Cells, Pressure Cell, and Readout Box. Load cell capacities ranging from 50 Kips to 1300 Kips.

The unit has developed an extensive array of loading fixtures designed for use with the various products and research specimens.

The unit works in cooperation with other units in the Transportation Laboratory in order to fully utilize the expertise and equipment available. For example the Machine Shop prepares many of the test specimens and loading fixtures; the Chemistry Laboratory performs chemical analyses and coating tests; and the Instrumentation Unit assists in automated data acquisition.

PRESTRESS SYSTEMS CALIBRATION AND PREQUALIFICATION

The unit is charged with the responsibility of assuring that Contractors' prestressing hardware is appropriate for the intended use and that the Contractor's jacking equipment is properly calibrated. In performing this function, the unit works in close cooperation with Office of Structures Design and Construction personnel who are responsible for design and jobsite inspection of post-tensioned concrete bridges. The information generated is also provided to several other States to assist them in assuring the quality of prestressing operations on their projects. The unit also investigates failures of prestressing systems and provides quality assurance through testing of prestressing steel and hardware samples.

Prior to using any prestressing system on a CALTRANS contract, the Contractor must obtain "approval" to use the particular system. The Contractor (usually a prestressing sub-contractor) must demonstrate (usually through tests) that the system is not hazardous and will not cause habitual construction or maintenance problems. The unit reviews Contractors' submittals, witnesses tests simulating jobsite conditions, and grants "approvals" when appropriate. Following "approval" of a given prestressing system, the unit monitors the jobsite performance of the system by way of "feedback" by Office of Structures Construction personnel.

Prior to using any prestressing jack and pressure gage on a CALTRANS project, the Contractor must have the jack/gage combination calibrated by this unit on an annual basis. The unit performs this function, at the Contractor's request, by establishing the relationship between gage pressure and jacking load which is determined from electro-mechanical load cells. The unit possesses a series of load cells ranging in capacity from 50 Kips to 1300 Kips. These cells were developed and built in cooperation with the Laboratory Instrumentation Unit and Machine Shop such that accuracy is maximized while the effect of eccentric loading is minimized. The calibration of the cells are checked periodically using this unit's testing machines.

Each Contractor's jack is also calibrated with respect to an electro-hydraulic cell commonly known as a pressure cell. Construction personnel from the Office of Structures Construction are equipped with pressure cells which are identical to the one used in the calibration procedure. Whenever a Contractor's jack is recalibrated, this unit transmits the revised pressure cell data to the Office of Structures Construction for use by construction personnel to assure that the proper loads are applied to prestress tendons. This revised data is also transmitted to several States who are equipped with the same type of pressure cell. The pressure cells are assembled, calibrated, and maintained by this unit with assistance from the Electronics Unit and the Machine Shop.

SPECIFICATIONS AND TEST METHODS

The specifications most commonly employed by this unit are ASTM, AASHTO, and the CALTRANS Standard Specifications and Standard Plans. Some of the other specifications used less frequently are SAE, AWS, Federal Specifications, UL, ANSI, Military Specifications, and Commercial Standards.

Through working with these specifications and related test methods on a daily basis, a substantial amount of expertise is developed which is often directed toward improving the existing standards. The unit proposes changes to existing standards, reviews and makes recommendations regarding changes proposed by others, participates in round robin testing performed to evaluate various test methods, and revises its own test methods when appropriate.

EVALUATION OF NEW PRODUCTS AND PROCEDURES

The unit performs evaluations of new products and procedures which are normally initiated by material vendors, other units within CALTRANS, or by the unit itself. Because of the ever increasing demand for improved or less costly materials, the need for new products is growing along with their evaluation. If the results of such evaluations are positive, changes in existing standards are recommended to allow the use of the new product or procedure. Some examples of recent evaluations are:

- Natural rubber bearing pads
- Ceramic coatings for guardrail
- Alternate coatings for fence posts
- Intermediate weight steel conduit
- Styrofoam for use under precast concrete barriers
- Alternate steels for prestressing hardware
- Alternate posts for headlight glare screen
- Alternate posts for chain link fence
- Mechanical galvanizing
- Culvert coatings

Findings of evaluations of commercial products are reported to AASHTO such that the information derived can be utilized by other States.

CONSULTATION

In performing the above functions, the unit maintains communications with CALTRANS personnel, other government agencies, material vendors, contractors, and technical organizations. Through this exchange of information, the unit possesses a high degree of expertise regarding the products and materials it deals with on a daily basis. Therefore, one of the important functions of this unit is to provide information to those involved with these products and materials.

STRUCTURAL MATERIALS RESEARCH UNIT

This unit conducts research on a variety of materials and products used in the construction of California's Transportation Systems. In the course of performing research, both innovative engineering design and new products are incorporated into the solution of problems encountered.

Besides performing research, the unit:

1. Reviews research of other organizations to avoid duplication of effort or to initiate implementation of such effort.

2. Evaluates new products and designs developed either within CALTRANS or by manufacturers.

3. Solves specific problems, and implements important research findings by developing and recommending new or modified test methods, specifications, or designs.

4. Serves in a consultive role for continuous updating of specifications, standard plans, and test methods, as materials and manufacturing techniques and processes change.

7. Works with manufacturers and contractors who might be affected by proposed changes in designs, specifications, or test methods, giving them an opportunity to provide pertinent input.

A list of some of the general subject areas in which research has been conducted fairly recently and a description of related findings follow:

Anchor Bolt/Fastener Research

1. Three different systems for determining the tension in high strength bolts as used for structural joints have been evaluated. One system known as Load Indicating Washers utilizes a special hardened washer having a series of protrusions circularly located on one surface of the washer. Depression of these protrusions as the nut is tightened indicates the tension in the bolt. A resulting gap caused by these protrusions of from 0.010-inches to 0.015-inches indicates that the bolt is properly tightened to its approximate proof load. The accuracy of bolt tension obtained by this method is excellent (coefficient of variation = ±6%).

A second system evaluated is known as the Tension Set Fastener. This system utilizes a bolt complying to either ASTM A325 or A490 specifications, but having a splined pig tail with an annular notch at the end of the threaded portion of the bolt. The special torque wrench engages the splined end as it turns the nut. When the preset torque is obtained, the splined end twists off. Inspection is extremely simple with this bolting system and the repeatability of torque and thus bolt tension is fairly accurate.

The third system evaluated is known as the Hi-Lok Nut. This nut has an extra long body with an annular groove toward the middle. When the design torque is reached when tightening the bolt, the outer portion of the nut twists off. The repeatability of this system was fair, not as good as the two forementioned systems, but better than the manual torque wrench method.

The Hi-Lok nut is a new system and is still under development for structural purposes, although it has been used extensively for smaller fasteners in the aircraft industry. This type of nut would appear to be applicable for small installations such as slip base lighting standards when a torque wrench often is not available.

2. There is no direct correlation between the pullout strength capacities of cast-in-place anchor bolts and friction-type anchors used in concrete structures because pullout strength of friction-type anchors is dependent on the rate at which the load is applied. Friction anchors tend to creep under sustained load.

3. Epoxied-in-place bolts and threaded rods, often used to temporarily attach railing to bridge decks, are satisfactory anchorage devices when subjected to rapidly applied axial loads. Under sustained load, however, epoxy will creep and release bolt preload or fail under a direct sustained dead load.

Bridge-Related Research

1. A satisfactory method of attaching Type 25 Replacement Barriers, using rebar dowels, to existing concrete bridge decks where older style balluster-type railing has been removed, has been developed. In an initial investigation, optimum dynamic pullout strengths of #5 and #6 rebar dowels bonded in shallow holes were determined by testing various combinations of bonding materials and rebar embedment depths.

Following the development of a satisfactory bonding procedure for anchoring rebar dowels using portland cement grout, six full-scale sections of bridge barrier were constructed on a simulated bridge deck. The full-scale barrier sections were tested by applying static horizontal loads to determine how

strengths of replacement barriers anchored using various configurations of grouted rebar compared with that of the conventional or standard Type 25 Concrete Bridge Barrier. It was found that all of the replacement barriers tested, which were anchored using rebar dowels and a "drill and grout" procedure, proved to be stronger than the standard Type 25 Concrete Bridge Barrier. A modified bridge barrier containing a hollow 6-inch-diameter steel duct was found to be weaker than the standard Type 25 Bridge Barrier.

2. A type of commercially available 1-inch-diameter hollow groutable rock bolt has been evaluated for attaching new or enlarged overhead signs, electroliers, and earthquake motion restrainers onto existing concrete bridges. The full tensile strength of these rock bolts installed in 12-inch-deep holes could be developed at a minimum 6-inch edge distance. Creep of these grouted rock bolts was found to be negligible. Steel specifications utilized by the manufacturer of these 1-inch-diameter rock bolts were found to be too general for structural applications where dynamic loads are of prime importance.

3. A protective coating of organic zinc-rich primer paint applied to contact surfaces of high-strength bolted connections was tested in this project. From this research, it was determined that a coating of organic zinc-rich primer, from 1 to 3 mils thick, provided adequate corrosion to structural joints without adversely affecting the performance of the joint under long-term creep or cyclic loading, provided that certain provisions, as outlined in the final report of this research project, are followed. Parameters found to significantly influence joint behavior in this project were (1) paint curing time and thickness, and (2) the type and magnitude of externally applied loads.

4. Improved installation methods and realistic design values for lateral load resistance of 1-inch and 2-inch-diameter anchor bolts cast in concrete abutments or columns at bridge super-to-substructure connections have been determined as a result of a recently completed research project. The most efficient method of anchor bolt installations tested utilized a metal cannister filled with mortar and reinforced with hairpin tiebacks. Design curves based on system yields occurring at 0.05 inch of bolt deflection were developed and presented for various parametric combinations.

5. Problems with excessive differential settlement at bridge hinges and abutments due to compression and excessive creep of the bearing pads can be remedied. This can be accomplished by changing the reinforcing fabric in elastomeric bearing pads from dacron to fiberglass. Fiberglass fabric does not exhibit the excessive elongation and creep under load that dacron does. The specifications have been revised to implement this finding.

6. An extensive testing program was conducted to determine if it would be possible to lessen the required embedment lengths of large reinforcing bars (#18, #14, and #11) used in columns of bridges. It was found that steel plates attached to the ends of large reinforcing bars embedded in concrete blocks significantly reduce required embedment length; however, this method also decreased system ductility at stress levels above the yield strength of the steel. It was also determined that approximately 90% of the load in a #18 rebar is transferred by bond to the concrete within the first two feet of embedment.

7. Tetrafluoroethylene (Teflon) is a satisfactory material for expansion bearing for bridges, however economic considerations normally limit the use of TFE to long span structures or structures with large horizontal movements.

8. A study to determine fatigue characteristics of different type of welded deck-to-rib connections for a box girder bridge with an orthotropic steel deck was undertaken at the request of the Toll Bridge Administration. It was determined that 80% partial penetration welds have an endurance limit from 13 to 23% less than do 100% penetration welds.

9. The Vibra-Tension unit, an electronic device for determining the force in prestressing strand, has been evaluated to determine its accuracy and to develop a proper operating procedure. The instrument is engineered to operate on the "vibrating string principle" and to measure the fundamental mode of vibration in an oscillating strand. A direct reading of force is obtained via a transducer held near the strand, while the strand is tapped with the palm of one's hand to initiate a vibration. The prestressing force can be measured within an accuracy of 2% following the procedures of the newly developed Test Method 677-A. The Vibra-Tension unit has replaced the Strand Stress Beam developed in 1968.

10. Steel creep loss in prestressing tendons increases as the "lock-off" force increases. No single quantitative value could be determined or adopted due to the variations in the stressing system now in use.

Culvert Pipe Research

1. Hot dipped asphalt coating of corrugated metal pipe has a number of drawbacks including handling and the effect on the environment from the application process. An evaluation has been performed on other coating systems which have the promise to be equally or more durable, easier to handle, cost competitive, and less polluting in their application. A specification has been prepared to allow the use of cold applied asphalt mastic and

polymeric coatings as alternatives to hot dipped asphalt for use on the outside of pipe where corrosion protection is the primary concern.

2. An evaluation of standard slotted CMP drains has resulted in improvements in the design and it was determined that this drainage system is capable of supporting occasional maximum legal truck loads imposed upon it. Use should be restricted to areas out of the traveled way until fatigue studies are conducted to determine an endurance limit under cortinual traffic.

3. A 10 1/2" CMP band coupler, known as the Hugger Band, proposed for helical pipe fabricated with cold formed re-rolled annular ends has exhibited excellent moment carrying ability, has provisions for an "O" ring seal where water tightness is required, and is considered an acceptable coupling band. A similar band with a width of 12 inches, known as the Wing Channel Band, has proven to be equally effective.

4. An evaluation of perforated, corrugated plastic pipe has indicated that this product would be an economical type of highway underdrain if not subjected to heavy wheel loads. It was found that the pipe could support the weight of soil overburden but could not support heavy construction loads when installed with shallow depths of cover, less than 5 feet.

Lighting Standard and Sign Research

1. Tests of a 60' long box beam "butterfly" type sign indicated that:

a. There was no structural difference between plug welds and Huck bolts for the web-to-flange connection.

b. A steel structure is capable of supporting twice the load of an aluminum structure containing a web of approximately equal thickness manufactured using an aluminum alloy having a yield point slightly higher than the steel yield point.

2. Dynamic shaking of a lighting standard to simulate wind excitation usually does not lead to base metal fatigue failure. Failure of lighting standard mast arm-to-pole connections and pole-to-base connections appears to be due to gross flaws in the welds or fatigue failure in the bolts.

3. Higher torques on clamping bolts of slip bases on large lighting standards are necessary to maintain contact between upper and lower slip base plates and thus avoid clamping bolt failures due to fatigue loading imposed by wind forces. These increased torques require that the thickness and steel quality of plate washers used on clamping bolts be improved to prevent yielding or excessive bending of these washers. Slightly higher initial tension in clamping bolts is necessary above that finally desired to compensate for creep of the zinc layers at each clamped joint.

Miscellaneous Research

1. An evaluation of load binder systems used by the trucking industry, including synthetic webbing material and metal hardware, showed that in general tensile strengths of the system were equal to or above the manufacturer's load ratings. Most synthetic webbing materials tested, however did show considerable elongation when subjected to high tensile loads.

2. As highway landscaping represents a significant program of the department, there is a need to develop an efficient and economical landscape irrigation system. Research has been conducted to develop specifications and test methods to assure the procurement

of an adequate and economical landscape irrigation system. New methods and new products are continuing to be evaluated toward this goal such as in depth investigation and evaluation of drip irrigation systems, a new technique for providing irrigation which is very economical from the standpoint of water usage and does not create soil erosion or water run-off. New equipment is also under evaluation such as water flow controllers, control valves, pressure regulators, pipe fittings, sprinkler heads, etc.

Research is currently in progress or pending on the following:

1. There have been a number of failures of high strength bolts connecting mast arms to lighting standards, and lighting standards to their bases. As a result of these failures, we have a project underway to develop design information relative to the fatigue strength of threaded fasteners. The goal of the project is to develop design stress limitations for fasteners subject to tensile fatigue stresses.

2. Research is currently being performed to evaluate the strength of slotted corrugated metal pipe drains under heavy truck loads to determine loading limitations of the pipe.

3. Various types of expansion anchors will be evaluated for tensile pullout strength and creep under sustained loading. Other parameters of interest will include concrete strength, expansion anchor size, embedment depth, and clear edge distance.

4. An effort will be made to develop improved specifications for neoprene and Teflon bridge bearing pads based on performance testing.

5. Two experimental 36-inch-diameter corrugated steel culverts have been installed near Woodfords, California, to determine wear qualities of various pipe coatings in mild to moderately abrasive conditions. The materials coating the inside of the pipes to be compared include: (1) hot-dipped asphalt, Nexon, asphalt paving, and two types of concrete paving.

TRANSPORTATION SAFETY SYSTEMS RESEARCH UNIT

This unit performs special investigations and research related primarily to highway safety.

The main accomplishment of this unit has been the conduction of more than 200 vehicle jump tests over curb and saw-tooth medians, and more than 150 vehicle crash tests of bridge barrier and approach rails, median barriers, guardrail, sign supports, lighting standards, and energy attenuating barriers.

Smaller studies have been conducted in such varied areas as:

1) testing scored concrete rumble strips, 2) evaluating several different headlight glare screen designs, 3) testing of spike barriers, such as those found at parking lot exits, as a possible deterrent to wrong way movements, 4) evaluating the advisability of using reflectorized license plates, 5) testing several construction zone traffic handling devices, 6) developing and testing lane control devices, 7) crash testing a truck mounted crash cushion, 8) crash testing small breakaway sign supports, and 9) crash testing a motorcycle into a solid barrier.

Following is a description of our general procedure for barrier tests, our research findings, current work, criteria for the selection of barriers and services provided by this unit.

Test Equipment and Procedure

Our tests are generally conducted in compliance with the Transportation Research Circular No. 191 "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", which is a national standard for vehicular impact testing.

Our vehicle tests are conducted at our Dynamic Test Facility which is located inside a high speed track at the new California Highway Patrol Academy. It is in Bryte, a small town on the western edge of Sacramento. From 1964 to 1974 we conducted our tests on an unused runway at the municipal airport of Lincoln, California.

Most of the barrier tests in the past have been conducted using full size automobiles weighing 3500 to 5000 lbs. For several years we have been using mainly retired CHP sedans weighing 4500 to 4900 lbs. which is near the upper weight range for passenger vehicles. This allows us to have identical vehicles for a given test series, and these cars are powerful enough that they can be self-powered and still accelerate to the desired impact speed in a relatively short distance. In some instances, smaller vehicles such as a Volkswagen or a Sprite have been used. A 40 passenger bus was also used for three barrier tests. With the increase in the small car population, tests with 2250 lb. vehicles are now required and have been used a few times.

Up until the end of 1972 the test vehicles were driven into the test installation by remote (radio) control. They were remotely steered and braked from a control car which followed closely behind the test car. Now we use a cable guidance system. The guidance cable passes through a pipe attached to a bracket which is connected to the spindle of the front wheel of the vehicle. Remote braking is possible through an electrical cable pulled behind the test vehicle which also transmits several channels of data from accelerometers and other transducers mounted on the vehicle and dummy. A trip bracket is placed near the test barrier in the path of the test vehicle and actuates a switch on the test vehicle bumper which cuts off the ignition so that the engine will not be running during impact. During the run-in before impact, the vehicle accelerates to the desired impact speed, and then is maintained at that speed with a speed control device mounted on the vehicle.

To obtain data on the motions and deceleration forces a human would be subjected to during impacts, an anthropomorphic dummy is placed in the driver's seat of the crash vehicle for all tests. The dummy, Willie Makit, is a 50th percentile male weighing 165 lbs. It is restrained during tests by a standard lap and shoulder belt.

The tests have been run at speeds of from 15 to 90 mph and at angles up to 36 degrees with the barrier. Vehicular and dummy decelerations are measured with electronic accelerometers for use in judging the severity of injuries to passengers. A photographic record of each test is obtained using eight to ten strategically located high speed 16mm cameras operating at speeds ranging from 300 to 500 frames per second. A normal speed 16mm camera, 35mm slide camera, and 70mm sequence camera are also used to record the test. This coverage is supplemented by 16mm documentary motion pictures and still photographs taken before and after each test.

Research Findings - Metal Beam Guardrail

Vehicle crash tests in 1964 resulted in recommendations that the top of "W-section" rail should be 27 inches above ground, the 8" x 8" D.F. timber posts should be spaced on 6'-3" centers, and the rail should be blocked out from the posts with 8" x 8" timber blocks to minimize the tendency of cars to snag on the posts.

Additional tests in 1965-1968 disclosed that the ends of all sections of guardrail should be securely restrained with a cable anchor system to develop the tensile strength of the rail during impact. Tests on an alternate sloping beam end anchorage design resulted in rollovers of the test vehicle, consequently, this design was not recommended for use. In this test series a transition guardrail design also was developed to gradually increase guardrail strength where it is tied into the end of a bridge rail, bridge pier or other rigid object.

In 1972 tests were conducted to verify that the 8" x 8" D.F. posts could be replaced either with 6" x 8" D.F. posts or W6 x 8.5 steel posts. Some additional modifications to the barrier were found to be needed with the steel post design as determined from this test series.

In 1974 the cable end anchor design was replaced with a breakaway cable terminal on some guardrail installations. This design was developed and tested by the Southwest Research Institute, and provided a less severe impact for vehicles striking the end of a guardrail installation headon.

Research Findings - Median Barriers

As a direct result of this testing, the following guidelines have been established for median barrier placed on California freeways:

1. Cable Barrier

The cable barrier design used for many years evolved in four test series from 1958 to 1963. In 1978, median barrier warrants were changed and cable barrier now may be installed only at special sites with Headquarters approval.

The cable type median barrier should not be placed in medians less than 22 feet in width. Narrower medians would not provide enough room for cable deflections during impact or for maintenance without closing lanes. In current practice in California, the cable barrier is not placed in medians less than 32 ft. wide. If a dike is absolutely necessary, it should be located within one foot, center to center, of the barrier. The dike should be no higher than six inches and preferably four inches high. If installed on a raised or flat (10:1 maximum) paved median, the

cable height should be 27 to 28 inches above the median surface. On unpaved flat medians, the cable height should be between 27 and 30 inches above the ground surface exclusive of any localized ditch surface.

Using a cable barrier system adjacent to bushes or plantings is generally considered to be a poor practice. This is primarily because of the earth berms that are often placed around the bushes to contain irrigation water. As with the dikes mentioned above, these berms could cause an approaching vehicle to vault over the cables. During routine grading there is also a buildup of earth berms adjacent to the bushes. However, if it is absolutely necessary to locate the cable near plantings, the median profile in the immediate vicinity of the barrier should be relatively flat.

Although not generally recommended, the cable barrier can be used in sawtooth medians having slopes flatter than 3:1. If the sawtooth step is over 6 inches or the slope is greater than 3:1, the cable barrier should not be used. When used on the flatter slopes, the barrier should be located at the top of the slope at the shoulder hinge point. The cable height should be held to between 27 and 28 inches above the shoulder surface.

Laboratory tests conducted in 1976 showed that:

a. When pipe posts are installed, special cable clamps are required to prevent clamp rotation and loosening. The U-bolts should be semicircular and the clamp plate fabricated to provide a groove on the inside face to fit the configuration of the cable.

b. Consolidated sand or asphalt AR-2000 may be used in place of asphalt AR-1000 as a filler material for Type B cable barrier post footing sockets.

2. Metal Beam Barrier

This design was first tested in 1958-59. Additional tests in 1964 confirmed the effectiveness of this barrier. Currently this barrier may be installed in medians 20 to 45 feet wide.

The blocked-out metal beam barrier is quite versatile. It can be used effectively in a median of almost any surface width and surface terrain. The barrier can be adjusted to sawtooth situations by vertically staggering the opposite beam members. The beams are deep enough and wide enough to redirect vehicles that have traversed very uneven median surface conditions. The amount of lateral deflection is such that the barrier can be placed in relatively narrow medians. Although more roughness in the surface terrain can be tolerated with this barrier, dikes, earth berms, curbs, and plantings should not be placed in front of it which might cause a vehicle to vault over the barrier.

In the 1977 Standard Plans a new metal beam median barrier design using thrie beam was added. Thrie beam is shaped like W-section beam except that it has three corrugations instead of two and is 20 inches wide instead of 12 1/4 inches. The top of the rail is mounted at a height of 32 inches instead of 30 inches. Steel or wood posts may be used. This design was tested successfully at the Southwest Research Institute. The greater beam width and height provides better protection for vehicles with a wide range of bumper heights, yet eliminates the need for a steel channel rubrail.

3. New York Box Beam Median Barrier

The minimum median width for the Box Beam Barrier is 10 feet. This will allow for the dynamic and permanent deflection that will occur when the barrier is impacted. This minimum width

should be increased if area is to be provided within the median for maintenance on one or both sides of the barrier without closing some lanes. Until more testing is performed on this design or until some operational experience is obtained that indicates otherwise, it is recommended that the median terrain restrictions listed above for cable type barrier also be applied to the box beam barrier. Very little of this type of barrier has been installed on California highways.

4. Concrete (New Jersey) Barrier - Type 50

This barrier is particularly applicable to narrow, flat medians. Currently it is allowed in medians 2-32 feet wide. Vehicles impacting at flat casual angles ride up on the sloping face and are tilted away from the barrier. For this reason the vehicles incur little damage. The vehicle also tends to hug the barrier rather than bouncing back into traffic. The barrier has sufficient strength to resist sharp angle impacts on the order of 25° but the amount of vehicle damage and rebound at these larger angles will usually be greater than for the beam type barrier. However, up to about a 10° impact angle, the New Jersey barrier is quite effective in minimizing vehicular damage.

Until more test data or operational information is available, this design should generally be restricted to relatively flat medians free of curbs, dikes, ditches, and plantings.

This barrier sustains very little damage except during severe impacts, hence maintenance costs are greatly reduced and there is less exposure to traffic for maintenance personnel. In recent years this barrier, when slipformed, has cost less than the blocked-out metal beam barrier.

In 1972 we completed a series of five tests on a Type 50 concrete barrier extruded on top of the ground. This barrier gained strength from four post-tensioned prestressing strands that were embedded in the concrete while it was being extruded. The developer of the barrier intended to extrude barrier sections about 400-450 feet long, in practice, with four foot maximum gaps between sections needed for the stressing operations. These gaps were then to be filled with reinforced concrete. Tests proved the barrier would withstand impacts by a 4900 lb. vehicle traveling at 65 mph and at a 25° angle with the barrier. One test conducted with the car impacting the barrier at an angle of 7° reaffirmed the effectiveness of the barrier when hit at low angles. At this time no barrier of this type has been placed on California highways.

In 1974 we conducted one proof test on a slipformed Concrete Barrier Type 50 which had no footing. It was placed on the pavement over cable barrier post stubs, 12 inches high, with one continuous cable clamped on them. The test was successful; there was no barrier movement or damage. This construction method has since been used extensively where cable barrier is being replaced with concrete barrier.

An 1976 we conducted a proof test on a continuous concrete median barrier Type 50 which was placed without a footing or other anchorage on top of asphalt concrete paving. The barrier had two #4 steel rebars placed 6 inches and 12 inches down from the top of the barrier. There was no barrier movement during impact; hence, this design was included in the 1977 Standard Plans. One #4 rebar was added on each side of the base of the barrier to replace any reserve strength for heavy vehicle impacts which might have been lost with elimination of the footing. Designs using the footing or a lowered cable barrier are still preferable in some cases depending on site conditions and economics.

In 1978 we conducted a severe crash test to determine the strength and stability of steel channel beams (gap beam design) spanning a 4-foot gap in a continuous CMB where a drop inlet would be located. It was concluded that the gap beam design and the adjoining concrete barrier end anchors (footings 2 ft. wide by 10 ft. long by 10 inches deep) were capable of withstanding impacts as severe as those for which the CMB was designed. This gap beam design has two advantages over the steel cover plate previously used: 1) the channel beams are much lighter and easier to remove for maintenance work on the drop inlet, and 2) the channel beams can be salvaged from rub rail on metal beam barrier that is being replaced with CMB.

Between 1972 and 1974 we conducted proof tests on three different unanchored precast concrete median barrier designs with pinned unanchored precast concrete median barrier (CMB) designs with pinned end connections. Barrier tilting and excessive lateral barrier movement contributed to vehicle vaulting and hazardous vehicle trajectories in two tests. The barriers used in these tests were extensively damaged. However, a limited survey of Caltrans construction personnel indicated that similar barrier designs used at construction sites had generally been very successful in redirecting impacting vehicles (probably because these impacts were less severe than our proof tests). It was recommended that barriers of this type be used only where moderate impacts are expected, and that further research on improved designs be conducted. Two tests in 1977 on another precast CMB design yielded results similar to those above. The use of expanded polystyrene pads and grout pads under the CMB segments plus a tensioned cable strung through them was not helpful. The current design for Temporary Railing - Type K was strengthened as a result of the various tests on precast CMB.

Research Findings - Bridge Rail

Most of the current California bridge rail designs have also been tested. An example of this is a test series completed on the Type 20 bridge barrier rail, a 39 inch high barrier containing a single 6" x 2" steel rail and a 27 inch high reinforced concrete parapet contoured very similarly to the New Jersey type concrete median barrier. As was the case with the New Jersey type concrete median barrier, very little damage was sustained by the vehicle at a 7° impact angle (66 mph) and the associated decelerations were relatively low.

Subsequently a series of full scale tests was conducted on a modified Type 20 bridge rail. This design was identical to the Type 20 design except that the concrete parapet height was decreased from 27 inches to 20 inches and lightweight PCC was substituted for standard weight PCC. This barrier is not recommended for use because vehicle damage was more severe than with the Type 20 design after low angle impacts. In addition the barrier failed structurally during the 25 degree impact "proof" test.

Following these tests the Bridge Department evaluated all previous tests and decided to adopt the Concrete Barrier - Type 25 as the standard bridge rail. The Type 25 barrier has the same 32 inch height and sloping face profile on the traffic side as the Concrete Barrier - Type 50.

Two tests were conducted in 1970 on the California Type 15 bridge barrier rail. This barrier consists of two 3-1/2 inch square structural tubular steel rails supported at 14 inch and 27 inch heights by 6WF 25 steel posts bolted to the outer edge of the bridge deck. As this barrier is intended for bridges no more than 32 feet wide, it was tested at a 15° impact angle. The test

results indicated that if an 8 foot post spacing is used, the barrier will retain and redirect 4500 pound passenger vehicles very effectively.

In 1977 the Type 15 bridge barrier rail was disqualified for use by the FHWA because it had not been designed to meet AASHTO specifications or crash tested at an angle of 25°. It was replaced with the Type 115 bridge barrier rail, a similar design which was designed by the Office of Structures to meet AASHTO specifications.

Research Findings - Breakaway Supports

1. Roadside Signs

Other research has involved the development of breakaway concepts such as wooden sign supports (1966-67 test series). In this case, the impact resistance of the support was reduced by drilling holes through the poles near ground level. This modification did not significantly alter the pole's ability to withstand moments induced by wind loadings but reduced the shear strength substantially, thus resulting in a decrease in the collision severity if and when these supports are impacted.

2. Lighting Standards

Another study in 1968 was concerned with determining the effectiveness of various breakaway lighting standard bases in reducing the severity of vehicular impacts. As a result of these tests, California is specifying slip base devices on new lighting standard installations as well as converting many of our existing standards to "breakaway" using a slightly modified slip base design.

In 1975 two tests were conducted on breakaway slip base lighting standards which were taller, heavier, and had longer mast arms (Calif. Type 31 Lighting Standard). A small car impacted this design at low speeds; the impacts were relatively mild and the slip base functioned properly. Some improvements in the slip base design were made, and torque-tension relationships in the slip base clamping bolts were clarified.

Questions about installation procedures frequently arise. The slip base bolts should receive the proper torque while the lighting pole is on the ground, or with the pole dead weight supported to eliminate base moments if the pole is upright. A detailed training film on installation procedures was completed in 1977 and is available for loan.

Research Findings - Impact Attenuators

Since about 1968 we have given high priority to the evaluation of various energy absorbing systems ("crash cushions") to protect errant vehicles from critical fixed object installations located in traffic gore separations and at other problem locations. To date we have completed 15 full scale tests of barriers incorporating water-filled plastic cells, empty 55-gallon drums, and frangible plastic cylinders containing sand. The results of these tests indicated that although all three barriers had some limitations and contained some features that required future modification, they were definitely preferable to the solid concrete deflector that had been in use in California. Consequently, the use of this concrete deflector has been discontinued.

In addition to conducting our own tests, we have witnessed numerous tests of crash cushion designs by private companies. By this method we have qualified three additional crash cushion systems for use in California. The Energite system of sand-filled plastic containers

is very similar to the Fitch modules. The Hi-Dri attenuator uses the same side panels, diaphragms, cable restraints, and back up structure as the water cell barrier but the water filled tubes are replaced with expendable cartridges containing several vermiculite concrete cells as the energy absorbing elements. These cartridges can be replaced very quickly when an attenuator is restored after an impact. The GREAT (Guard Rail Energy Absorbing Terminal) attenuator uses the vermiculite concrete cell cartridges for energy absorption, but has telescoping side panels made from short sections of thrie beam (a triple corrugation metal beam rail) and a set of slip off chain anchorages to replace the cable anchorage system used with the Hi-Dri attenuator. The GREAT attenuator can be used in very narrow locations and/or in front of narrow fixed objects such as the ends of concrete median barriers. Portable GREAT barriers and sand filled barrels are now approved for temporary use.

Over 500 installations of the six energy attenuator designs mentioned above are on California freeways. The attenuators have been hit over 500 times with many lives saved, and generally they seem to be very successful.

As of January 1976 there were about 1600 unprotected gores on California highways. In the gore improvement program which is underway, about 950 gores will be cleared of fixed objects and the remainder will be protected with crash cushions.

In 1972-1974 we conducted four vehicular crash tests on metal beam guardrail envelopes called "bullnose barriers". In addition to serving as guardrail flare envelopes, these barriers were designed to function as crash cushions. They consisted of two flared sides of W-section guardrail joined at one end by a curved section with about a five-foot radius. Extra cables, post connection hardware and concrete footings were used to enhance

the energy absorption function. By the third test, a barrier design had evolved which successfully cushioned the headon impact of a car. However, on the last test when the test vehicle impacted the nose of the barrier, offset and at an angle, the vehicle ramped up and vaulted over the barrier. This design would be satisfactory for moderate speed locations. It was planned to continue development and testing to improve the design for use at high speed locations, however, as a result of the blanket gore clearance program, there seems to be less need for this design.

Attempts were made to develop a crash cushion for the ends of Type 25 concrete bridge barriers using bulk vermiculite concrete. It was hoped this material could be molded into aesthetically pleasing shapes. The project was dropped because of the great difficulty in obtaining concrete strengths having a consistant narrow range of low values.

Many of the gores which will receive crash cushions in the current improvement program have existing six inch high Type B curbs. A series of eight professional driver "jump" tests were conducted with a large and small car. The trajectories of the vehicles passing over a test curb installation were plotted to determine whether the curbs would have an adverse effect on the functioning of impacted crash cushions mounted on top of the curb pads.

It was found that the maximum amount of vehicle rise (about 9-1/2 inches at a distance of 14.5 feet back of the gore curb nose) occurred when a lightweight car (2790 lbs.) impacted the curb at 40 mph. A typical sand barrel type crash cushion was placed on top of the raised gore surface five feet back of the gore curb nose and a lightweight car with dummy driver went over the curb and into the crash cushion at a speed of 40 mph. The curb had no

appreciable effect on the crash cushion performance. This study resulted in guidelines for the placement of sand barrel type crash cushions on raised gore surfaces, the main one of which was that the front barrel of the crash cushion should be placed within 0-5 feet of the gore curb nose. When any other types of crash cushion are used, the raised gore surface must be removed completely.

Research Findings - Edge of Paved Surface Drop-Offs

Fifty professional driver tests using small, medium, and large cars and a pickup truck were conducted in 1974. The driver steered the vehicles at small angles off the pavement, down over the drop-off edge, continued straight a few hundred feet, and then steered the vehicles back up over the drop-off edge. Drop-off heights ranged from 1-1/2 to 4-1/2 inches; vehicle speed was about 60 mph; shoulder surfaces of dirt and AC were used. For these test conditions, there was little effect on vehicle stability or controllability.

Current Work

1. "Vehicular Impact Tests of Breakaway Wood Post and Timber Pole Sign Supports." The FHWA had declared that with the exception of posts 4" x 6" or smaller, wood posts and timber poles used as breakaway supports for Roadside Signs are no longer acceptable unless qualified with vehicular impact tests to meet new standards. A research project is underway to conduct tests that will qualify the current designs or, if necessary, indicate whether modified designs can be qualified.

2. "Investigation of a Truck-Mounted Crash Attenuator and Roll Ahead of Impacted Vehicles." To date four vehicle impact tests have been conducted on a truck-mounted attenuator (TMA) which

uses vermiculite concrete cells, like those in the G-R-E-A-T and Hi-Dri attenuators, as the energy absorbing medium. The cells are mounted in a plywood box six feet long by eight feet wide by two feet high which can be attached quickly to the rear of the truck. The fourth test with a lightweight car resulted in a slight redesign of the steel gridwork frame supporting the attenuator box so the frame would be more crushable. Truck rollahead has varied from 2'-6" to 13'-10" depending on the car weight and whether the rear only or the rear and front truck wheels were braked. The next test will be conducted with a heavy car impacting the TMA at an angle. One additional test may be conducted after that, if needed. In all tests the truck is at rest and the car has an impact speed of 45 mph. Eighty TMA units are on order by Caltrans for use on trucks especially subject to rear end collisions.

3. We have provided consultation and witnessed a recent test of a MODCAN crash cushion being developed by the Jet Propulsion Laboratory (JPL) and sponsored by NASA's Technology Utilization office. This design uses aluminum beverage cans as the principal energy absorbing elements. Later live driver tests by JPL in 1978 were on a shortened version for use along side secondary highways in front of utility poles, etc. This design is not approved at present for use on California highways.

Future Work

In the next three years we hope to conduct impact tests to determine the effect of terrain on longitudinal barrier effectiveness; to test retrofit bridge rail designs for use in replacing unsafe old bridge rails; to develop a breakaway cable terminal design for use with thrie beam barriers; to begin testing highway safety appurtenances for use on secondary roads and highways; to test

lightweight lighting standard poles made of aluminum instead of steel; and to develop a lightweight truck mounted attenuator made from aluminum honeycomb material.

Service Requirements for Traffic Barriers

These are well summarized in the following quotes from NCHRP Report #118, "Location, Selection, and Maintenance of Highway Traffic Barriers":

"The purpose of a traffic barrier is to reduce the number of highway fatalities and to minimize personal injuries. It accomplishes this objective by reducing the severity of ran-off-the-road, hit-other-object type accidents. The design of traffic barriers is a complex task because of the sometimes conflicting performance requirements that necessitate compromise.

"The order of emphasis for service requirements is first to safety, second to economics, and third to aesthetics.

"DYNAMIC PERFORMANCE"

"1. A longitudinal barrier must restrain a selected vehicle. (The selected vehicle is one that is representative of a large majority of the vehicle population.) This implies that when a vehicle of specified weight, dimensions, velocity, and approach angle strikes a barrier it will not climb over, break through, or wedge under the installation.

"2. A crash cushion must decelerate a selected vehicle impacting direct-on in such a manner that occupants restrained by seat belts can survive with little or no injury.

"3. A longitudinal or crash cushion barrier that is impacted by a selected vehicle along its length must either stop or redirect the vehicle in such a manner that passengers restrained by seat belts can survive, preferably uninjured.

"4. A longitudinal or crash cushion barrier should redirect or stop the selected vehicle in such a manner as to minimize hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier installation and not be directed back into the traffic stream.

"5. During impact, the longitudinal or crash cushion barrier must function in such a fashion that vehicle occupants and other traffic are not likely to be endangered by vehicle or barrier fragments or barrier elements that could intrude into the passenger compartment or be deposited on the traveled way.

"COST CONSIDERATIONS

"A longitudinal or crash cushion barrier should be economical in construction, installation, and maintenance; hence, in evaluating the relative merits of two or more systems, consideration should extend beyond the first cost to the least-annual-cost analysis. Design performance of traffic barriers should minimize damage to impacting vehicles; this consideration includes not only high-speed, high-angle impacts, but also the more frequent minor 'brush' accidents.

"OTHER CONSIDERATIONS

"To provide for maintenance crew safety, longitudinal and crash cushion barriers must be amenable to quick repair of crash damage; the design should not inhibit general maintenance operations at its location, particularly in narrow medians where high-speed traffic would be impeded and would endanger the crew.

"A traffic barrier must remain functional in all weather conditions present at the highway site throughout its expected life. Also, it should exhibit weather durability (i.e., against moisture, snow

and ice, salt, sunlight, and temperature excursions). A traffic barrier installation should be difficult to vandalize and should not be attractive to vandals.

"A final consideration is for the traffic barrier to have a pleasing and functional appearance."

Services Provided by this Unit

Questions, suggestions, and requests for assistance are welcome regarding special site problems, construction problems, impact attenuator design, changes in standard plans, specifications and special provisions, etc. Research reports documenting all traffic barrier test series are available upon request.

Movies of many of these test series are also available for loan. A training and public relations movie is available which describes our testing program with many scenes of crash tests from 1953 to 1972. This is a 20-minute color movie that is professionally narrated and is suitable for presentation on T.V. This movie may be borrowed for presentations to the public or orientation of employees. Several districts have a copy of the movie.

Caution

Over 25 years of crash test experience have taught us that seemingly minor changes in barrier dimensions or details can cause wide variations in barrier behavior. DO NOT DEVIATE FROM THE STANDARD PLANS UNLESS YOU ARE ABSOLUTELY SURE IT WILL HAVE A NEGLIGIBLE EFFECT ON BARRIER PERFORMANCE. We will be happy to answer your questions with background information and a "yes", "no", or "maybe" recommendation. We are sensitive in this area because we have assisted our Legal Division in an increasingly

large number of accident cases involving safety barriers. Invariably the question arises as to whether the subject barrier was built according to the standard plans. Any deviations from standard procedures are magnified by the plaintiff's attorneys.

TRANSPORTATION SAFETY SYSTEMS TESTS AND SPECIFICATIONS UNIT

I. INTRODUCTION

The primary function of this unit is to provide quality assurance for signing and delineation materials. A secondary function is the development of specifications and test methods for these materials and for the quality assurance of a wide variety of products, called commodities, which are sometimes but not necessarily directly used in highway construction work. The accomplishment of these functions involves a coordinated effort including research, product and material evaluations, specification and test method preparation, and compliance testing. Follow-up contact with the ultimate user of these products is a necessary step which often leads to revisions which tend to de-bug or refine the original specifications. In addition, specifications are reviewed and revised at regular intervals to meet changing needs and/or take advantage of improvements in the "state-of-the-art" of industrial technology.

Another important activity of this unit is to provide liaison among manufacturers, vendors, and user agencies. Direct communication and consultation with the representatives of these organizations is an essential step in the development or improvement of products purchased by the State. Every effort is made to encourage the growth of fair competition among suppliers.

II. SIGNING MATERIALS

A. General

Since the introduction of the Uniform Signing Regulations by AASHTO early in 1958, the expenditure for new construction signing and for upgrading existing freeway signing to interstate standards has increased to today's multi-million dollar annual expenditure.

The subsequent recognition of color coding, internationally uniform symbol signs, and the increased emphasis upon traffic safety, etc., have stimulated the development of a multitude of signing and delineation devices and materials. A necessary consequence of the stimulation of product development is the evaluation and selection of those devices and materials which best perform the intended function at the least cost.

In addition to laboratory testing, an important part of the evaluation procedure is to determine the durability of the proposed materials by exposing them to weathering. For this purpose, vertical south-facing exposure racks are located to provide data for the six distinctive climates and/or environments common to California. The sun exposure rack locations and their environments are (1) Sacramento - representing central valley area - high heat, low humidity, moderate cold, occasional smog and agricultural pollutants, (2) Eureka - representing north coastal area - natural dew cycle, mild salt-air, heavy rainfall, (3) Port Hueneme - representing south coastal area - severe salt-laden air, heat, and rainfall, (4) Los Angeles - representing heavy industrial area - smog, heat, industrial pollutants, (5) El Centro - representing desert areas - extreme heat, wind, and windblown sand, and (6) South Tahoe - representing mountain areas - severe cold, freeze-thaw cycling, high altitude radiation. In addition, a north-facing exposure rack has been installed at Palm Springs to evaluate the abrasive effects of blowing sand.

To supplement the stationary sun vertical racks, other exposure racks located at the Sacramento Lab track the sun and maintain sample surfaces normal to the sun. These are known as equitorial racks and provide accelerated weathering data (generally a factor of 2). Sometimes, samples are exposed under service contract at private testing facilities where special weathering

apparatus utilizing a concentration of sun rays (mirrors) and water spray cycling offer acceleration factors up to 8 or 10 times faster than that obtainable on the conventional vertical south-facing exposure racks.

An artificial weathering chamber in the Sacramento Lab known as a Weather-O-Meter has recently become prominent as a laboratory method of measuring the durability and related properties of various products. The Weather-O-Meter utilizes a selection of ultraviolet radiation sources, filters, temperature, and pH controlled water spray. Although artificial weathering is valuable, especially for comparative testing, the results must be correlated with actual exposure to provide meaningful data.

B. Sign Surfacing Materials

Signing systems usually consist of a surfacing material mounted on a signboard and supported by either wood or metal posts or an overhead sign support structure which may in turn be attached to a freeway structure. Nearly every material imaginable has been proposed for use for one of the components of a signing system. All of these materials have experienced varying degrees of success and failure.

Opaque surfacing materials are those which are nonreflective and nontranslucent and include paints of numerous generic composition, porcelain enamels which are primarily a glass-like surface fused to a metal substrate, plastic films of fairly recent development, fiberglass, and chemical conversion systems applied to aluminum substrates, to name just a few. Some of the problems encountered with the opaque surfacing materials are color stability, surface deterioration by erosion, brittleness, shrinkage, and loss of adherence.

Examples of retro-reflective sign surfacing materials would be the exposed lens materials utilizing glass beads partially imbedded in a binder, and enclosed lens materials commonly known as reflective sheeting. A new material which utilizes high density miniaturized cube corner retro-reflectors cast into a flexible vinyl sheet shows promise for temporary signing and delineation needs. Problems experienced with retro-reflective surfacing materials include dust retention, loss of reflectance, shrinkage, cracking, loss of adherence, color stability, damage by impact, and dew formation.

C. Sign Substrates

The most common sign substrate materials used today are aluminum, steel, wood (primarily high-density plywood), fiberglass, and a group of plastics (principally polycarbonates and ABS). Formica, commonly used for kitchen sink tops, is an example of a material proposed for use as a sign substrate. Considerations affecting the selection of a sign substrate material are corrosion resistance, weight, bulk, resistance to delamination, compatibility with surfacing material and support system, availability, resistance to vandalism, ease of repair, and cost.

The temporary signs used to direct traffic through construction and maintenance zones represent yet another signing system. Examples of this temporary signing system would be vinyl impregnated nylon fabric signs, knit signs and mesh signs utilizing tripod or quadpod telescoping sign supports. Visibility, legibility, and ability to spill wind are several of the properties requiring special investigations by this unit.

III. DELINEATION MATERIALS

Many hours of research, investigation, evaluation, and specification writing are spent on the development of delineation systems. Daytime as well as nighttime delineation is becoming increasingly more important with today's heavily traveled highways. Quality assurance testing of pavement markers (reflective, nonreflective, temporary, snow plowable, etc.), for instance, is needed to assure that the color, photometrics, bondability and durability, of these products meet the requirements of our specifications. Delineator posts, traffic cones, rumble strips, channelization markers, tripod and quadpod sign and delineation supports, temporary traffic striping, headlight glare shield, reflector buttons, and highway barricades are examples of delineation products which must be tested for compliance to assure reasonable and uniform standards of performance.

IV. COMMODITIES

Probably the least spectacular job in the laboratory is testing such commodities as pencils, paper, plumb bob string, and rags. However, the millions spent on these unglamorous items dictate the necessity of developing test methods and specifications for them that will assure the most for the taxpayer's dollar. Is a nonslip wax nonslip? How long does a certain typewriter ribbon retain its ink? These are typical of the questions answered routinely by the commodities unit.

The development of specifications and test methods for the quality assurance of this variety of products involves procedures similar to those used in the development of specifications and test methods for signing and delineation materials. Special investigations and research efforts are usually necessary to resolve problems and improve products for the benefit of the user agency. Although most of our research and test effort is

expended for highway oriented products, a substantial number of commodity investigation and testing is performed at the request of other State agencies, i.e., General Services, Correctional Industries, State Printing Plant, Department of Motor Vehicles, and the California Highway Patrol. A prime objective of the research effort related to commodities is to adequately define a product which will meet the needs of the user agency and, through specification writing, provide a fair basis for competitive bidding among prospective manufacturers or suppliers. An important step in the course of research and investigation of these products involves direct communication with manufacturer's representatives including the sales, technical, and administrative levels of a given company. The success of this communication effort often determines the degree of cooperation received from industry, which in turn, contributes to the improvement of existing products or the development of new products. The following list is offered to provide an example of the scope and variety of commodity items tested by this unit.

Hose; garden, weed-oil, high pressure, air	PVC pipe	Wood
	Rope and cord	Safety Belts
Textbooks		
	Waterproof membranes	Ceramic Tile
Paper		
		Floor Tile
Flagging Material; cloth, plastic	Plastic valve boxes	Mud Flaps
Thermometers	Survey Tapes	Safety Fuses
Water coolers	Drapery material	Carpet
Shoe soles and heels	Naugahyde upholstery material	

V. TYPICAL DEVELOPMENTS

A. Samples of reflective sheeting for signs from new manufacturing sources are being artificially weathered in the Weather-O-Meter in an attempt to correlate performance with similar samples that have been mounted on the field exposure racks. In addition new reflective sheeting products must exhibit long term durability as indicated by the satisfactory performance of samples exposed for at least two years on our sign weathering racks.

B. Specifications are under continual development to serve the needs of the Office of Traffic or Office of Maintenance for new or improved products like Flexible Guide Markers, High-level Flag-sign Warning Devices, Traffic Cones and others. Each specification requires special study.

C. Fiberglass sign material with a polystyrene core was evaluated and compared with porcelain enameled aluminum laminated sign panels. A specification was prepared to insure that fiberglass laminated sign panels would be both functionally adequate and comparable in service to the laminated aluminum panels. The bids received for a small contract indicated that the fiberglass signs are not economically feasible at this time.

D. We conduct many night viewings of a number of highway signs and safety devices composed of different brands of retro-reflective material. These night viewings are conducted in our Transportation Laboratory yard and on the roadways. Evaluations of observers as to adequacy of border, legend, background, angularity, and over-all suitability are utilized in the development of new specifications.

E. A color correlation testing program of reflective sheeting and opaque sign materials with our current suppliers and other major manufacturers is being made. A limited color study was conducted sometime ago in cooperation with the AASHTO-ARBA Task Force No. 7 Committee toward the development of a new color specification exclusively for reflective sheeting. This color specification which has since been adopted by AASHTO consists of a series of color coordinates that define the acceptable color tolerance for each color.

F. The drafting of a new "Specification for Reflective Sheeting on Aluminum Highway Signs" has been completed. This specification has been completely reorganized and the reflective intensity values have been changed to better reflect the optical characteristics of the reflective sheeting material. The new specification includes new color tolerance values which apply exclusively for reflective materials. Another major change in the specification is the addition of durability requirements after accelerated weathering for 1,000 hours in the Weather-O-Meter. Our present minimum requirement of two years of satisfactory use on highway signs has been retained.

G. A "Specification for Aluminum Single-Sheet Signs for Overhead Structures" was written to utilize new plastic films and a resin base enamel which have shown promise on our sign exposure racks as alternatives to porcelain enamel sign coatings. The overhead signs were separated from our regular porcelain enamel on aluminum sign contracts in order to provide a small contract in which porcelain enamel on aluminum can compete, on a bid basis, with Colovin (polyvinyl chloride), Tedlar (polyvinyl fluoride), exterior grade plastic film laminates, Kynar 500 (Polyvinylidene fluoride), a resin base enamel, and FPC 461 (trifluorochloroethylene copolymer) lacquer.

H. A study on screening pastes as used on reflective sheeting signs has been completed. This information was needed on the weatherability and compatibility of screening pastes when applied to the newly developed reflective sheetings.

I. "A Stability Evaluation on Portable Flasher Supports" was made for the Headquarters Traffic and Maintenance Departments to determine the relative stabilities of different flasher support designs. This evaluation was made due to complaints received that the standard barricade is often blown over by truck generated wind gusts. The portable flasher supports were evaluated by placing them on the shoulder, one foot from the edge of the traveled way, and observing and filming the results which occurred from wind gusts producted by passing trucks. From our evaluation we determined that:

(1) Portable flasher supports with the legs spread 50 inches apart were generally more stable than those with legs spread to 38 inches.

(2) A means to prevent portable flasher supports from sliding is needed.

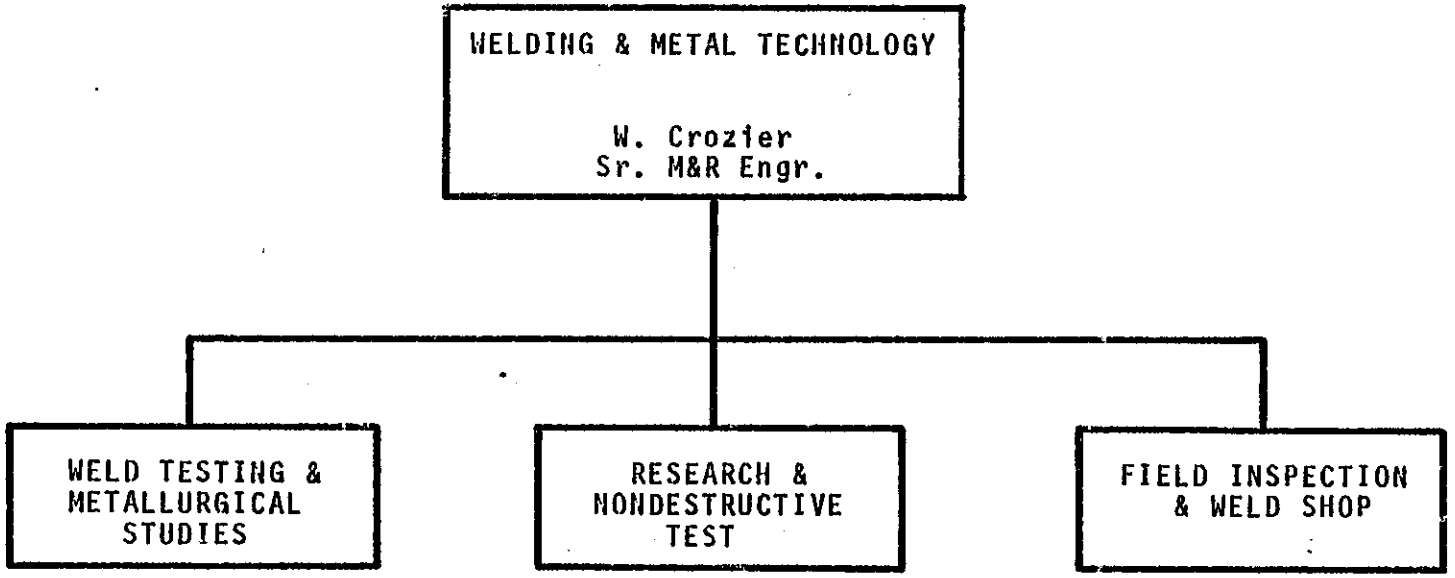
J. Barricades fabricated from discarded truck tires have been evaluated and found to have the unique property of being able to withstand 55 mph impacts with little, if any, damage to the vehicles or the barricade. The Office of Maintenance and Office of Traffic plan to install these barricades in areas where this feature is important.

K. An investigation of adhesion failure of temporary pavement striping tape was conducted at two locations. Interim recommendations including the use of softer aluminum foil, greater adhesion strength, and bristle roller application have been made.

L. An evaluation study is being made on samples of a new flexible reflective product. This material utilizes high density miniature cube corner retro-reflective lenses cast into a translucent vinyl sheet and backed with another vinyl sheet. The edges of the sheets are heat sealed together to prevent contamination by moisture vapor, dust, etc. The unique properties of this material, especially flexibility, warrant our continued evaluation of it as a delineation and signing material. Due to the flexibility of the material, it possesses superior abrasion and impact resistance. Thus this material may withstand the ravages of wind blown sand better than conventional signing materials. The impact resistance of the material makes it an ideal candidate as the reflective system for use on traffic cones and other flexible delineators in lieu of reflector buttons which are generally broken by vehicular impact. The reflectivity of the product is good to excellent.

M. Flexible plastic guide or clearance marker posts which can self-erect after being run over by vehicles are being evaluated as an alternative to the current metal post and paddle. Several types have been tested including those with circular, triangular, and "T" cross sections with wall thicknesses of 1/8" to 1/4". Most of these have sustained ten vehicle impacts at highway speeds without significant damage to either the delineator or the vehicle. One post being studied is rigid enough to be driven in place; the others are installed in predrilled holes.

The extent to which these delineators will be used will depend on how well manufacturers can develop weathering durability including ultraviolet light resistance and a durable reflective system for this application.


WELDING & METAL TECHNOLOGY
W. Crozier
Sr. M&R Engr.
WELD TESTING & METALLURGICAL STUDIES
RESEARCH & NONDESTRUCTIVE TEST
FIELD INSPECTION & WELD SHOP

9/1/79

STRUCTURAL MATERIALS WELDING AND METAL TECHNOLOGY SECTION

The Welding and Metal Technology Section controls the inspection of welding used on steel highway structures, and, when requested, on steel structures fabricated for state agencies other than the Department of Transportation, and for other public agencies (federal, other states, counties and cities). This control is direct by means of staff inspectors in many cases and indirect through specifications, interpretations, supervision, consultation, testing and/or reviews provided by Welding Unit personnel.

Support operations provided by the Welding Laboratory staff include:

1. A welding inspection capability which covers:

a. The drafting, updating and reviewing of welding and related material specifications.

b. The preliminary reviewing of project plans and specifications for welding capability.

c. The prefabrication reviewing of contract plans for specification compliance and the establishment of inspection requirements.

d. Scheduling, performing inspection and tests to maintain surveillance on fabrication in progress and reviewing the result of all such inspection and tests to specification compliance (including inspection performed by other units or assigned contracts).

e. Maintaining records of welder and weld procedure qualification to retain in active contracts.

f. Providing advice and consultation services on welding and metal problems to designers, specification writers, Resident Engineers, inspectors, maintenance engineers and others involved in metal fabrication for public agencies.

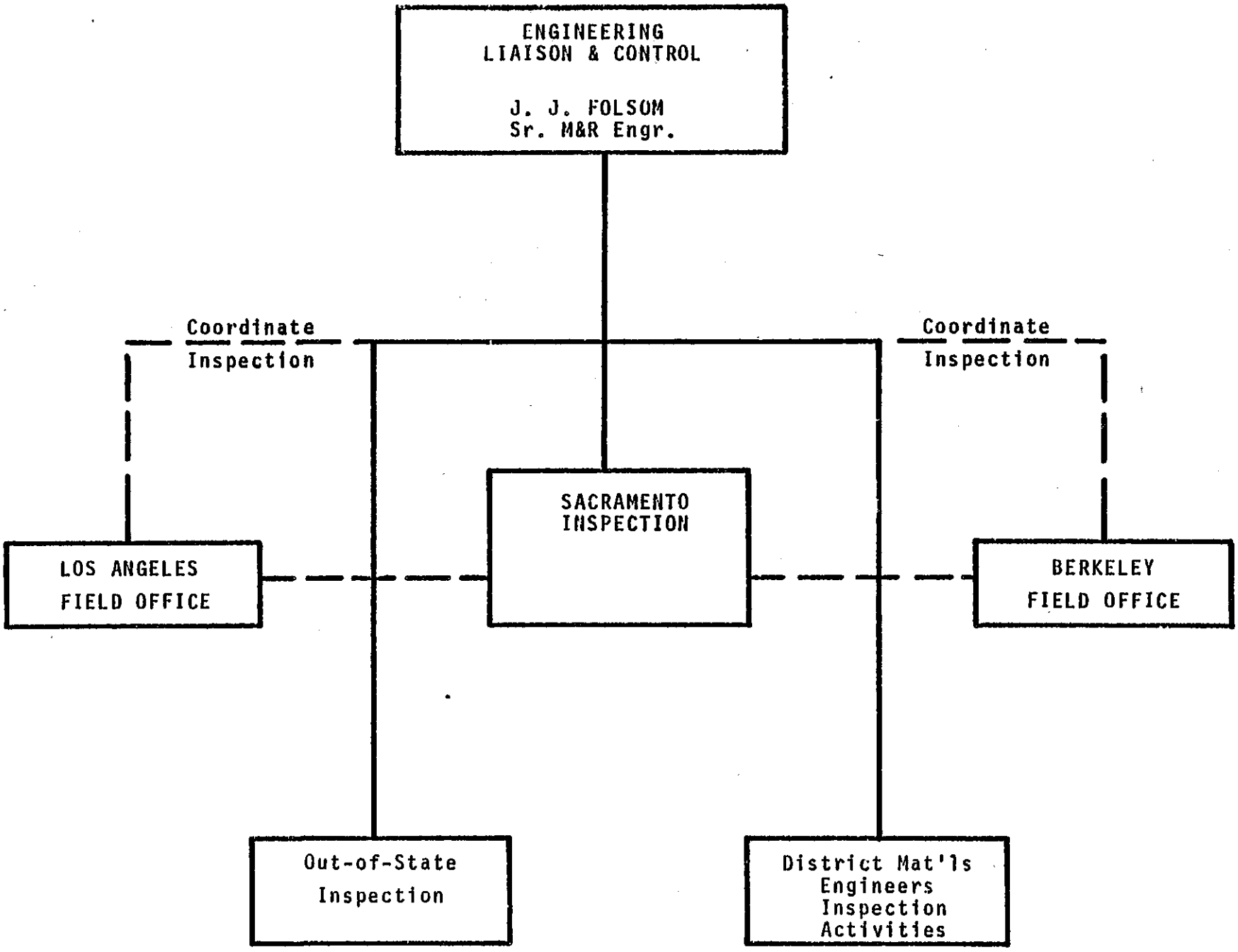
10/25/79

2. Non destructive testing capabilities in radiography (X-ray and gamma ray - stationary and mobile units with dark rooms), ultrasonic testing (4 portable units), magnetic particle testing (2 units) and dye penetrant testing.

3. A metallurgical, failure analysis and fracture mechanics capability through the utilization of metallographic and metallurgical testing equipment (polishing machines, a laboratory furnace, binocular and metallurgical microscopes, a 100x axial comparator, a microhardness tester, a charpy precracking machine, a charpy slow bend machine, and an instrumented precision impact test machine) within the welding unit and through the utilization of technical services available from other units of the Transportation Laboratory.

4. A research capability to investigate the applicability of new steels and welding processes to transportation structures and to establish the requirements that will have to be put into specifications for control.

5. In order to sustain the welding research capability, the welding unit has a thoroughly equipped weld shop to prepare experimental welds for investigation and testing. It is provided with machines to perform shielded metal arc, gas metal arc, submerged arc, flux cored arc and electroslag welds on steel, aluminum and assorted other metals. This shop also services the Transportation Laboratory Machine Shop.


ENGINEERING
LIAISON & CONTROL
J. J. FOLSOM
Sr. M&R Engr.
Coordinate
Inspection
Coordinate
Inspection
SACRAMENTO
INSPECTION
LOS ANGELES
FIELD OFFICE
BERKELEY
FIELD OFFICE
Out-of-State
Inspection
District Mat'ls
Engineers
Inspection
Activities

9/1/79

STRUCTURAL MATERIALS ENGINEERING LIAISON AND CONTROL SECTION

The primary objective of the Engineering Liaison and Control Section is to provide uniform, competent, and objective evaluation of the quality of materials going into our highways and bridges and insure that such materials comply with applicable contract specifications. This section coordinates and assigns the source inspection on miscellaneous items and fabricated products for Department of Transportation construction projects.

In addition to the coordination responsibilities this section also has a group of experienced inspectors, supported by a competent clerical staff, with full capabilities in all phases of miscellaneous and shop fabrication inspection.

All requests for inspection are funnelled through the inspection coordination office located in Sacramento. The associate in charge takes these requests and decides the best way to handle the inspection. If the materials source is in the San Francisco Bay area or the Los Angeles area, the inspection would be assigned to the appropriate field office in either Berkeley or Los Angeles. For other locations in California we may assign the inspection work to one of the District Materials Laboratories.

For sources of material from outside the State, service contracts are made with qualified commercial laboratories and testing agencies as well as service agreements with other State highway departments to perform inspection on our behalf. These agreements are negotiated on a yearly basis so assignments can be made immediately upon receipt of an inspection request.

These various agreements and contracts, in addition to Caltrans facilities and personnel, give the Transportation Laboratory the capability of providing reliable and complete inspection service anywhere in the country.

10/25/79

Operations in the past have been primarily oriented toward source inspection of materials used in highway and bridge construction projects, but the process applies equally well to materials for all types of projects.

The mechanics of the inspection process used by CALTRANS are as follows:

1. For a CALTRANS contract, the contractor will designate the source of material where the inspection can be made. This is done on a Notice of Materials to be Used Form which is provided to the contractor by the Resident Engineer.

2. The associate in charge of the Structural Branch Inspection Office receives these filled out forms and from this information determines the best way to handle the inspection. The usual method would be to assign the inspection to one of our field or district offices unless the source is located outside the State. For an out-of-state source, a decision is made whether the inspection will be performed by a commercial laboratory or by the highway department in the state where the material originates.

3. For inspection in California a Notice of Materials to be Sampled Form is issued to the appropriate field office or district informing them of the assignment. For out-of-state inspection assignments are made by letter.

4. Upon receiving notification that an inspection is to be made, our field office or district office notifies the vendor using a Notice of Materials to be Furnished Form. The commercial lab for out-of-state inspections usually notifies the vendor by letter or phone.

5. It is then up to the vendor to notify the appropriate office when his product is ready to be inspected.

6. The source inspection process involves the following:

a. Checking for compliance with material requirements (physical and chemical); this includes checking test reports and identifying materials to a test report in addition to sampling and testing as necessary.

b. Visual and dimensional inspection during and after fabrication.

c. Final check of workmanship and finish.

d. Tagging and Reporting.

7. Inspected material is identified by tags or other suitable marking. Tags are used whenever practical and they are given a lot number which also appears on the inspection report. The lot number is intended to identify the "lot" or shipment.

8. Inspection is then reported on a Report of Inspection of Material Form. This gives the identifying lot number and the description and quantity of the material released.

STRUCTURAL MATERIALS BERKELEY AND LOS ANGELES FIELD OFFICES

The Berkeley and Los Angeles Field Offices each have a group of experienced inspectors that handle the source inspection in the San Francisco Bay Area and Los Angeles Area. These inspectors have complete capabilities in all phases of miscellaneous and shop fabrication inspection.

The basic mechanism of source inspection includes a thorough evaluation of the manufacturer's own inspection and quality control procedures, his manufacturing techniques, visual inspection of finished workmanship, dimensional checking, evaluation of raw materials and finished goods by random sampling and testing to the required specifications, and packaging and load-out procedures.

The variety of expertise of the Field Office personnel is such that expert source inspection service can be provided for almost all materials and equipment utilized on public works projects. Particular expertise can be furnished in the inspection of structural steel fabrication and in the field of prestressed concrete construction.

The following list (which is far from complete) gives examples of the types of materials and fabrication inspections being performed on a routine basis.

Miscellaneous Manufactured Materials

1. Reinforcing Steel
2. Wire Mesh Reinforcing
3. Expansion Joint Filler
4. Waterstop
5. Elastomeric Bearing Pads
6. Bridge Deck Joint Seals
7. Prestressing Steel
8. Castings and Forgings

9. Miscellaneous Iron and Steel and Bridge Metal
10. Drop Inlet Grates and Frames
11. Treated Timber and Timber Products
12. Sealing and Waterproofing Products
13. Precast Concrete Products
14. Fencing
15. Guard Rail, Median Barriers, and Bridge Barrier Railing
16. Signal, Lighting, and Pumphouse Electrical Equipment
17. Signs, Markers, and Traffic Safety Devices
18. Corrugated Metal and Structural Plate Pipe

Structural Steel

1. Fabrication of Welded Structural Steel
2. Shop Painting of Structural Steel
3. Fabrication of Riveted and Bolted Structures

Prestressed Concrete

1. Prestressed Concrete Bridge Girders
2. Prestressed Concrete Piles

In addition to inspection capabilities, the Los Angeles Field Office also does a considerable amount of testing and has capabilities in the following areas:

1. A complete up to date asphalt testing facility.

2. Electronic testing equipment for specification and operational testing of traffic controllers.

3. Complete facilities for curing, capping, and determining compressive strength of concrete products.

4. Testing facilities for determining yield and tensile strengths of steel products such as reinforcing bar, plates, and shapes. Also specification testing of cable assemblies.

5. Testing of galvanized products for determining coating thicknesses.

6. Pavement marker testing excepting reflective qualities.

7. Welder qualification and procedure tests.

8. Mobile drilling equipment for determining thicknesses of materials in structural typical sections.

9. Portable skid resistance testing equipment for determining coefficients of friction.

INTRODUCTION

The functions and structure of the Enviro-Chemical Branch are best explained by examining the objectives of the Branch and a summary of the activities which support those objectives. The objectives of the Branch are to:

° Provide consultation and advisory services to Caltrans Districts and Headquarters Units and other Governmental agencies, in the field of air, noise, and water pollution, natural environmental hazards, natural environmental resources, energy, and chemistry of construction and maintenance materials.

° Develop methods and techniques for the investigation and reporting of:

a) environmental impacts in the areas of air, noise, and water pollution, natural environmental hazards and natural environmental resources.
b) energy requirements of transportation facilities
c) chemistry of construction and maintenance materials

° Provide a centralized testing capability for the more complex environmental and chemical tests used in materials control, research, and environmental analysis, by maintaining a staff of expert personnel and state-of-the-art equipment.

° Provide training and review services to ensure that Caltrans effort in the areas of environmental protection, energy conservation, chemical analysis, and usage of construction and maintenance materials is of a uniform high quality.

° Conduct research which will anticipate, and provide solutions to, the needs and problems of transportation facilities in the broad fields of environmental quality, energy conservation, and applied chemistry during planning, design, construction, operation, and maintenance.

° Promote an interdisciplinary approach to the optimization of Transportation Service by studying and maintaining awareness of the complex interrelationships between transportation, land use, and national, state, and local environmental and energy goals.

In a broad sense, the activities to support these objectives are involved either with research or with support for District and Headquarters operational units, and the consequent branch administrative duties. Further division of the two main categories appears below:

Support for District and HQ Operational Units

° Consultation and Advisory Services

Typical Tasks:

District project visits
Equipment calibration
Limited equipment maintenance
In-depth assistance on specific projects
Environmental data storage, retrieval, and processing
Outside consultant contact
Maintain current knowledge
Specifications preparation
Liaison with other agencies
Coordination with outside laboratories
Requests for proposals (RFP) preparation
Legal assistance
Proposal evaluation

- Development of Methods and Techniques

  Typical Tasks:

  Prepare test methods
  Write procedural manuals
  Develop the use of mathematical models
  Write and maintain EDP programs for noise evaluation, meteorological data reduction, etc.
  Design and fabricate special equipment
  Develop application techniques for paints, paint systems, and adhesives
  Develop bridge deck membranes
  Prepare quality control programs

- Complex or Special Data Analysis and Testing Services

  Typical Tasks:

  Steel analysis
  Fabrication of air sample bags
  Paint testing
  SO_2 and H_2S analysis

  Visibility (Nephelometer)
  New and experimental product evaluation
  Wind field analysis - balloon and Theodolite
  Joint sealant and adhesives analysis
  Bioassay
  X-ray (diffraction and emission) testing
  Toxicity testing
  Cement testing
  Noise spectral analysis
  Atomic absorption testing
  Water analysis

- Training and Review Services

  Typical Tasks:

  Air quality training (formal)
  Water quality training (formal)
  Noise training (formal)
  On-the-job training
  Statistical training (formal)
  Report review
  Study plan review
  Maintain information "Clearinghouse"
  Field review

Research

- Quantification of Highway Impact on the Environment

  Typical Tasks:

  Study methods and techniques
  Predictive models
  Equipment development
  Special test methods

- Impact Mitigation

  Typical Tasks:

  Noise barriers
  Sedimentation basins
  Revegetation
  Slope protection
  Highway configuration

- Application of Environmental Considerations

  Typical Tasks:

  Location guidelines
  Air and water quality "Hazards"
  Design guidelines
  Evaluation of contractors' erosion plans
  Evaluation and control during construction
  Maintenance guidelines
  Special provisions

- Evaluation of Implemented Environmental Research

  Typical Tasks:

  Accuracy of predictive methods
  Effectiveness of mitigation measures

- Development and Evaluation of Construction and Maintenance Materials

  Typical Tasks:

  Structural paints
  Traffic paints and marking systems
  Adhesives

- <u>Development and Evaluation of Usage Techniques for Construction and Maintenance Materials</u>

  Typical Tasks:

  Application of paint systems
  Application of epoxy resin and polyurethane systems

The remainder of this section of the training manual is devoted to presenting some specific information on environmental analysis and chemical testing.

AIR QUALITY CONSIDERATIONS FOR TRANSPORTATION PROJECTS

Prepared
by the
Air Quality Unit
ENVIRO-CHEMICAL BRANCH

For Training Purposes Only
Transportation Laboratory Training Course
Sacramento, California

AIR QUALITY

Air quality studies are concerned with the kind and amount of pollutants discharged into the atmosphere by man's activities. It is true that large quantities of pollutants that influence air quality are discharged into the air by natural activities. Over the ages these have not presented serious problems to the well being of plants and animals because the global distribution and dispersion of these pollutants result in low average concentration levels. It is unfortunate that man's activities have led to the building of concentrated complexes of industries and cities where large discharges of various pollutants occur in very limited regions. At times these regions have meteorological conditions that seriously delay the adequate mixing and dispersion of these pollutants with possible subsequent impairment of the air quality considered necessary for the health and welfare of man, animals, and plants.

Air quality is directly concerned with the term pollutant and to arrive at a definition one must look at the word contaminant. Scientists working in the field of air quality believe that any substance which is present in greater concentrations than it would be in normal clean air is a contaminant. When a contaminant is of such a nature that it is injurious to anything that is valued by man, it becomes a pollutant. The term pollutant is applied to any substance which has been or could be a pollutant without regard to the measured concentration of the substance.

Air pollution experts have divided the sources into stationary and mobile. Stationary sources, in turn, include point sources and area sources. Point sources are ordinarily the result of industrial operations. Area sources emanate from the collective

activities of man such as home use of fuels and agricultural use of pesticides. Of direct concern to transportation engineers are point sources resulting from production of highway materials involving aggregates, asphalt and portland cement mixtures and on-site contractor's operations. Also of concern are construction or maintenance operations that involve burning or dust formation.

Mobile sources include various types of vehicles that use the highway or city streets. These include all that use the gasoline or diesel internal combustion engine as the energy source. Although the highway or street per se is not a source of air pollutants, the transportation engineer has become involved in the concern over pollutants emitted by the vehicles operating on the roadway. Perhaps one should think of this aspect in the same concept that the transportation engineer plays a very important part in the safety of the motorist through the planning, design, and operation of the transportation system.

The following five primary pollutants are emitted in substantial amounts from various emission sources:

Carbon Monoxide	Sulfur Oxides
Hydrocarbons	Particulates
Nitrogen Oxides	

Table A shows the estimated nationwide man-made emissions of the five major pollutants for the year 1977. It will be noted that a substantial percentage of the carbon monoxide and hydrocarbons are derived from the motor vehicle. The nitrogen oxides are also contributed in large quantities by the motor vehicle, but in this case fuel combustion from stationary sources is also important. Sulfur oxides and particulates

TABLE A
ESTIMATED NATIONWIDE EMISSIONS IN MILLIONS OF METRIC TONS FOR FIVE MAJOR POLLUTANTS IN 1977

POLLUTANT	TRANSPORTATION	FUEL COMBUSTION IN STATIONARY SOURCES	INDUSTRIAL PROCESSES	SOLID WASTE DISPOSAL	OTHER	TOTAL	PERCENT OF TOTAL BY TRANSPORTATION
CARBON MONOXIDE	85.7	1.2	8.3	2.6	4.9	102.7	83
HYDROCARBONS	11.5	1.5	10.1	0.7	4.5	28.3	41
NITROGEN OXIDES	9.2	13.0	0.7	0.1	0.1	23.1	40
PARTICULATES	1.1	4.8	5.4	0.4	0.7	12.4	9
SULFUR OXIDES	0.8	22.4	4.2	—	—	27.4	3

are almost entirely contributed by stationary sources such as industrial processes and power plants. One should be aware of the differences in importance of these pollutants in various areas of the United States. In certain areas where meteorological and topographical constraints are present, the Los Angeles basin being a prime example, one may encounter secondary reactions. These reactions lead to the photochemical formation of oxidants collectively called "smog" (3). The compounds in "smog" may produce undesirable health effects in man and animals and damage to certain types of economically important plants.

On the other hand in areas where numerous industrial and thermal power plants exist, sulfur oxides along with nitrogen oxides and particulates from stationary sources may be of greatest importance.

Chemicals involved in the formation of photochemical smog include hydrocarbons and nitrogen oxides (commonly from automobile exhaust and stationary sources) and atmospheric oxygen. A "mixing bowl" in the form of a basin such as the Los Angeles area is provided when meteorological and topographical constraints combine to limit the horizontal and vertical dispersion of the primary pollutants. All that remains is to add ultraviolet radiation from the sun, and the reactions lead to the formation of photochemical smog. The smog results from a very complex series of chemical reactions.

In summary, we have primary emissions partly from man's activities and secondary pollutants generated under certain circumstances from those primary pollutants. Both primary and secondary compounds may have adverse effects and must be considered in assessing the problem of air pollution.

In order to control air quality, states have been divided into regions, so-called "basins", based on common topography and

meteorological conditions. As an example, Figure 1 shows the California basins. Each basin typically contains a number of cities and counties, and often parts of more than one state.

Some states and now the Federal Government have issued National Ambient Air Quality Standards. The Ambient Air Quality Standards applicable in California are compared with the National Ambient Air Quality Standards (NAAQS) in Table B. These standards are to protect the health and public welfare of the people. The National Standards are of great importance to the transportation engineer since laws passed by Congress require each state to provide an acceptable state implementation plan to the U.S. Environmental Protection Agency. The plan details methods for the attainment of ambient air quality equal to or better than the NAAQS.

A study of the NAAQS reveals two sets of requirements known as primary and secondary. The primary standards are for the purpose of protecting the public health with an adequate margin of safety, while the secondary standard is to "protect the public welfare from any known or anticipated adverse effects of a pollutant".

Section 109J of the Federal Highway Act states, in effect, that the construction of federal-aid highways must be consistent with any approved implementation plan for attaining the NAAQS. Federal instructions call for a finding of consistency between the implementation plans and any highway project, and must be documented in the project's environmental impact report.

Legal Aspects

It is important to understand the legal background for environmental studies since public law, in many cases, dictates the

FIGURE 1

CALIFORNIA AIR BASINS
NORTHEAST
PLATEAU
NORTH
COAST
SACRAMENTO
VALLEY
LAKE
CO.
MOUNTAIN
COUNTIES
LAKE
TAHOE
SCALE IN MILES
0
100
SAN
FRANCISCO
BAY AREA
NORTH
CENTRAL
COAST
SAN JOAQUIN
VALLEY
GREAT
BASIN
VALLEYS
SOUTH
CENTRAL
COAST
SOUTHEAST
DESERT
SOUTH
COAST
SAN
DIEGO

TABLE B

AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging Time	California Standards[1]		National Standards[2]		
		Concentration[3]	Method[4]	Primary[3,5]	Secondary[3,6]	Method[7]
Oxidant[10]	1 hour	0.10 ppm (200 ug/m³)	Ultraviolet Photometry	—	—	—
Ozone	1 hour	—	—	240 ug/m³ (0.12 ppm)	Same as Primary Standard	Chemiluminescent Method
Carbon Monoxide	12 hour	10 ppm (11 mg/m³)	Non-Dispersive Infrared Spectroscopy	—	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hour	—		10 mg/m³ (9 ppm)		
	1 hour	40 ppm (46 mg/m³)		40 mg/m³ (35 ppm)		
Nitrogen Dioxide	Annual Average	—	Saltzman Method	100 ug/m³ (0.05 ppm)	Same as Primary Standards	Gas Phase Chemiluminescence
	1 hour	0.25 ppm (470 ug/m³)		—		
Sulfur Dioxide	Annual Average	—	Conductimetric Method	80 ug/m³ (0.03 ppm)	—	Paraosanilne Method
	24 hour	0.05 ppm (131 ug/m³)[9]		365 ug/m³ (0.14 ppm)	—	
	3 hour	—		—	1300 ug/m³ (0.5 ppm)	
	1 hour	0.5 ppm (1310 ug/m³)		—	—	
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m³	High Volume Sampling	75 ug/m³	60 ug/m³	High Volume Sampling
	24 hour	100 ug/m³		260 ug/m³	150 ug/m³	
Sulfates	24 hour	25 ug/m³	AIHL Method No. 61	—	—	—
Lead	30 day Average	1.5 ug/m³	AIHL Method No. 54	—	—	—
	Calendar Quarter	—	—	1.5 ug/m³	1.5 ug/m³	Atomic Absorption
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m³)	Cadmium Hydroxide Stractan Method	—	—	—
Hydrocarbons (Corrected for Methane)	3 hour (6-9 a.m.)	—	—	160 ug/m³ (0.24 ppm)	Same as Primary Standards	Flame Ionization Detection Using Gas Chromatography
Vinyl Chloride (Chloroethene)	24 hour	0.010 ppm (26 ug/m³)	Gas Chromatography (ARB staff report 78-8-3)			
Ethylene	8 hour	0.1 ppm	—	—	—	—
	1 hour	0.5 ppm				
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 10 miles when the relative humidity is less than 70% (8)				
APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:						
Carbon Monoxide	8 hour	6 ppm (7 mg/m³)	NDIR	—	—	—
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 30 miles when the relative humidity is less than 70% (8)		—	—	—

(FOOTNOTES ON REVERSE SIDE)

NOTE:

1. California standards are values that are not to be equaled or exceeded.

2. National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

3. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

4. Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

5. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency.(EPA).

6. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.

7. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.

8. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

9. At locations where the state standards for oxidant and/or suspended particulate matter are violated. National standards apply elsewhere.

10. Measured as ozone.

manner in which certain aspects of an air quality study must be performed and, in general, dictates the questions which must be answered.

The first major law affecting the work of the transportation engineer with regard to air pollution was the National Environmental Policy Act of 1969. This act created the Council on Environmental Quality. Implementation of this act by the Federal Highway Administration occurred through instructions in the Federal-Aid Highway Program Manual (FAHPM). The purpose of the FAHPM is to provide guidelines to transportation departments to assure that the human environment is carefully considered and national environmental goals are met when developing federally financed highway improvements. The instructions reiterate that portion of the law requiring an environmental impact statement for each federally financed project.

Two other important federal laws were enacted in 1970. The first of these, the Clean Air Amendments of 1970, (since twice amended) empowered the Environmental Protection Agency (EPA), previously established by executive reorganization, to establish national ambient air quality standards and to require each state to submit a plan providing for implementation, maintenance, and enforcement of such standards in each air quality control region within the state. These plans, discussed earlier, are termed implementation plans.

A third national law, the Federal-Aid Highway Act of 1970 provides for the establishment of general guidelines to assure that possible adverse economic, social, and environmental effects relating to any proposed project on any federal-aid

system have been fully considered in developing the project. That act also calls for the development of guidelines to assure that highways constructed pursuant to that act are consistent with any approved plans for the implementation of any ambient air quality standard or any air quality control medium designated by the Clean Air Act.

The Clean Air Act Amendments of 1977 require states to submit implementation plans for attaining and maintaining the air quality standards as well as the prevention of any further deterioration of air quality in clean air regions. It further requires that the state implementation plans define the methods that would be utilized to attain the national ambient air quality standards by 1982. For those non-attainment areas unable to meet the 1982 deadline for certain pollutants, additional requirements and stategies must be included in the implementation plans for attainment by 1987. Those areas not meeting these deadlines face the possibility of losing further federal support of transportation related facilities.

Figure 2 illustrates the general relationship between these laws. The bibliography, references 5 through 14, lists references for additional reading in the area of environmental law.

Medical Aspects

The medical aspects of the various emissions are complex and a great deal of research has been completed on the subject. In addition, studies of many different kinds are scheduled to be performed in the future. A continuing problem is the consideration of short and long range effects of the individual emissions, and of more recent concern is the indication that some of the pollutants may have a more serious effect on health when acting in combinations of two or more than when acting alone.

MAJOR LAWS AND REGULATIONS GOVERNING AIR QUALITY IMPACT STUDIES FOR HIGHWAY PROJECTS

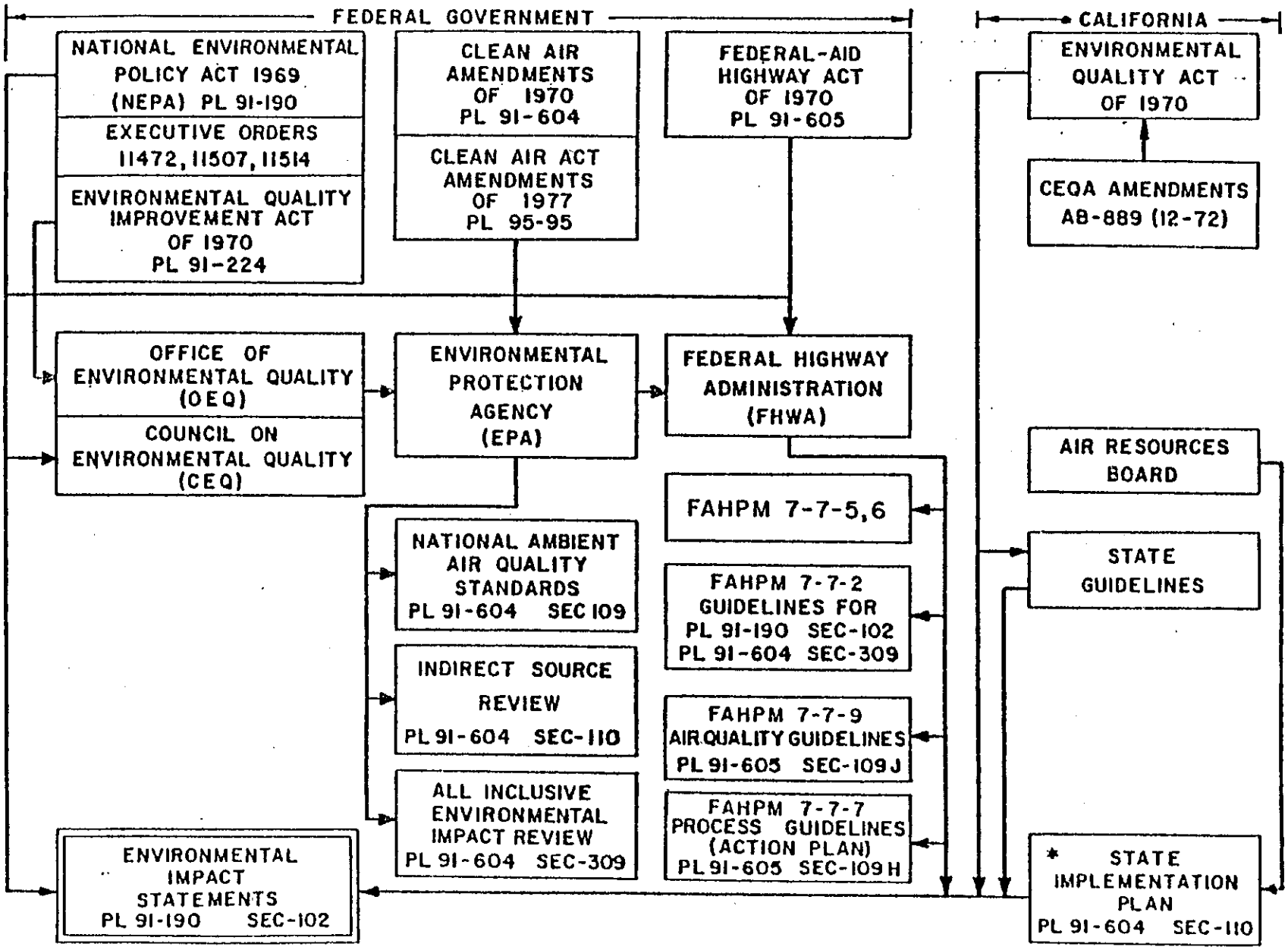


FIGURE 2

At the present time air quality standards are developed to protect those people who are especially susceptible to the effect of air pollutants. Scientific studies and clinical evidence has indicated that air pollution can be related to human sickness and premature death. Both sexes and all ages can be affected, but the greatest danger exists for the very old and very young, and those already suffering from certain chronic ailments. Both the upper and lower respiratory system is in direct contact with inhaled pollutants. Some pollutants pass through the lungs and into the blood. Carcinogens can enter the body through the skin as well as the lungs and be carried by the blood to any organ.

The transportation engineer cannot be expected to be familiar with all the complex problems involving the effects of the various emission on humans, animals, and plants. However, he should be cognizant that the primary and secondary federal standards are based on substantial amounts of evidence, some of which are controversial (4). For this reason we have listed references to a series of air quality criteria which should be studied for details on many aspects of each pollutant including medical details (15 through 20). These manuals are an excellent source of information and should be carefully studied by those in transportation engineering who are directly concerned with the preparation of air quality reports. Also Part III of reference 21 provides a series of well written papers on the effect of air pollution on human health, animal life, vegetation, and materials.

The Roadway (Line Source) and Air Quality

The primary emissions from the spark ignition internal combustion engine are: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x) and particulates. Lead compounds are

the most important particulates. Two of the primary gaseous omissions, oxides of nitrogen and hydrocarbons, together react in the presence of ultraviolet light to form secondary compounds (oxidants).

The route, whether it be a city street, a modern freeway, or rapid transit system, is a line source of emissions. The microscale analysis involves modeling the processes of mixing and dispersion of the emissions within the immediate area adjacent to the line source (Figure 3). This area is stated to be the corridor extending a certain distance on each side of the line source. The boundaries of the corridor are defined by that line which shows the reduction of emissions from the line source to ambient levels. This distance upwind and downwind from the line source may vary from day to day because of changes in micrometeorogical conditions and may very along the line source depending on topography. In most cases, only primary emissions are considered in the microscale corridor since photochemical changes require some period of time. However, when winds blow parallel to the line source there may be sufficient time for some photochemical reaction to take place. Also design, topography, and micrometeorological conditions all influence the degree of potential photochemical change.

The mesoscale (Figure 4) involves all of the area outside the corridor where there are effects either from the primary emissions from the specified line source or the photochemical products derived from these emissions. The mesoscale meteorologically is of the order of two to two hundred kilometers and encompasses areas of community size to air basin size. This is a very difficult area to delineate for analyzing the effects of emitted pollutants since the emission load from the line source becomes mixed downwind with all other sources from

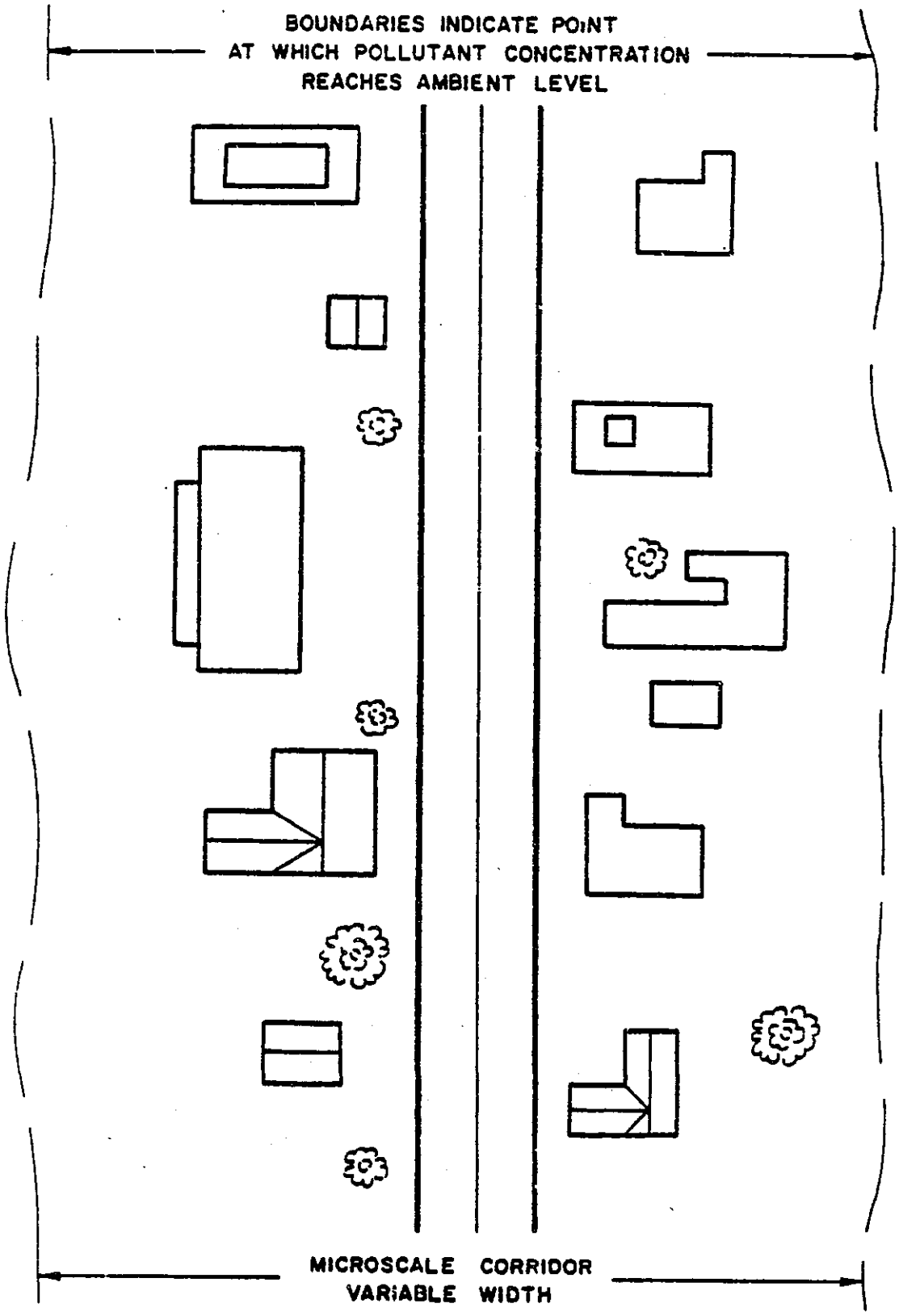


Figure 3 MICROSCALE ANALYSIS

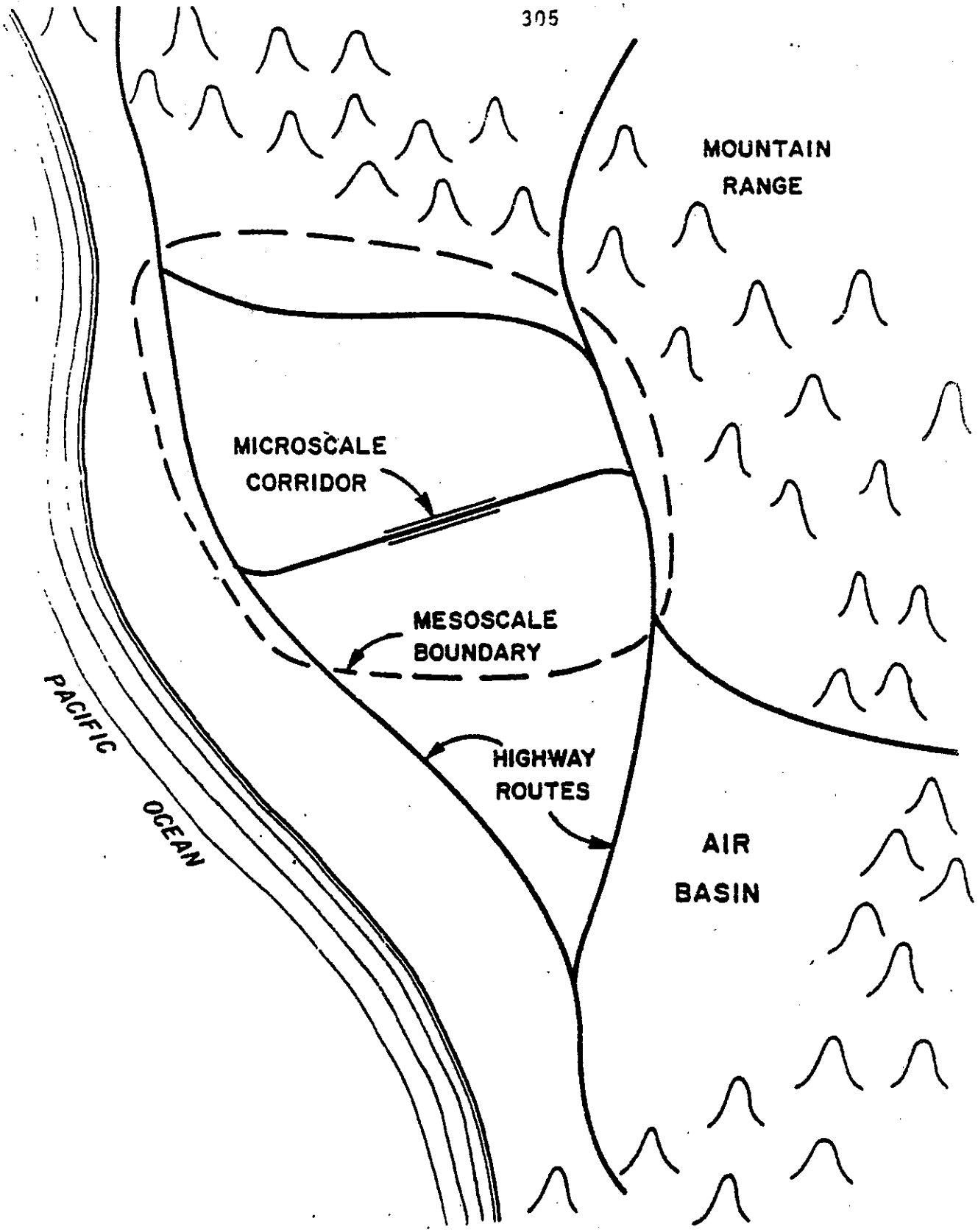


Figure 4 MESOSCALE ANALYSIS

within and outside the area. Currently, the best practical solution to this problem is to assume that the mesoenvironment encompasses that area in which there are significant modifications in the surface traffic pattern caused by the construction of the new facility.

The amount of vehicle emissions from a line source is influenced by many variables. Those being considered in predicting emissions from a line source are:

1. Volume of traffic
2. Vehicle mix in terms of model year
3. Vehicle speed
4. Vehicle type
5. Ambient temperature
6. Percentage cold starts
7. Percentage hot starts
8. Evaporative emissions
9. Crankcase emissions
10. Elevation

The influence of vehicle emissions on people, animals, and plants within the corridor (microscale) is governed by:

1. Mechanical mixing by traffic
2. Micrometeorology
3. Natural topography of the area adjacent to the roadway
4. Right of way widths and distance to receptor
5. Highway geometric configuration
6. Building configuration and kind of occupancy near the alignment
7. Patterns of agricultural land use within the corridor
8. Upwind pollutant concentrations (background levels)

The influence of vehicle emissions on the people, animals, and plants within the immediate areas beyond the corridor and within the basin (mesoscale) is influenced by:

1. Mesometeorology
2. Large scale topography
3. Distribution of sensitive receptors
4. Patterns of agricultural land use
5. Existing pollutant levels

Older, uncontrolled vehicles emit a greater amount of pollutants than newer vehicles having emission controls. As an example, the following table compares typical uncontrolled vehicles and the federal and state requirements for the 1974 and 1979 controlled vehicles:

PASSENGER CAR EXHAUST EMISSIONS
GRAMS/MILE

Pollutant	Typical Uncontrolled Vehicle, Pre '66	Calif. Std. 1974	Calif. Std. 1979*	Federal Requirements 1974	Federal Requirements 1979*
Carbon Monoxide	80	39	9.0	39	15
Hydrocarbons	11	3.2	0.41	3.4	1.5
Nitrogen Oxides	4	2.0	1.5	3.0	2.0

*Vehicles requiring catalytic exhaust systems.

The importance of continued improvement of emission control systems is apparent when one considers the improvements gained since controls became mandatory.

The following table, though developed several years ago with techniques different from today's, still serves to indicate that uniform traffic flow has many advantages. The table lists the percentage of each emission emitted per average mile traveled for each mode of operation. The importance of maintaining a cruise mode of operation is brought out by a study of this table. Therefore, features of the roadway which tend to reduce the use of deceleration and acceleration modes, such as reduced grades, ample radius curves, reduced congestion, etc., will tend to lower emissions.

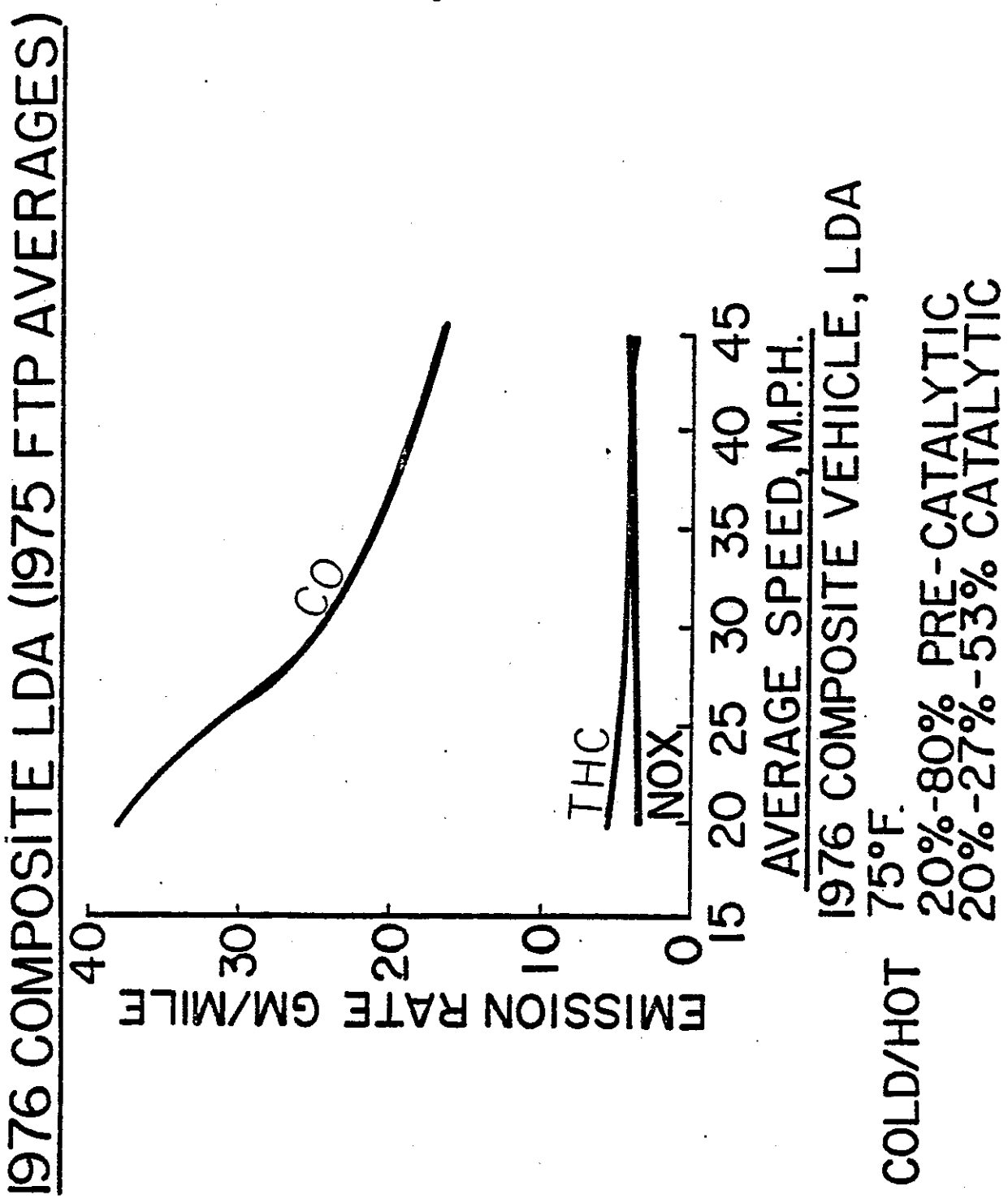
PERCENTAGE OF CONTAMINANT EMITTED IN EACH MODE PER AVERAGE MILE TRAVELED

Operation Mode	Gross Hydrocarbons	Carbon Monoxide	Nitrogen oxide
Idle	5.9%	7.5%	0.03%
Cruise	14.1%	14.3%	21.40%
Acceleration	56.2%	62.2%	78.50%
Deceleration	23.7%	16.1%	0.17%

Source: Rose, A. H., and Smith, R. "A Direct Measurement Technique for Automobile Exhaust" Archives of Environmental Health, Vol. 5, p. 95, 1962.

Emissions are also influenced by the average route speed of the vehicle. The average route speed takes into account the variations in speed caused by acceleration, deceleration, and idle modes in average city street driving. Such changes are mainly caused by traffic signals and vehicle congestion. Thus the average route speed on a city street may be 15-20 miles/hour; while on an expressway or freeway, with the majority of time being in the cruise mode, the average route speed may be in the range of 45-55 miles/hour. Figure 5 shows reductions in carbon monoxide and hydrocarbon emissions with increase in average route speed and the increase in NO_x emissions with increase in average route

Figure 5


1976 COMPOSITE LDA (1975 FTP AVERAGES)
EMISSION RATE GM/MILE
40
30
20
10
0
CO
THC
NOX
15
20
25
30
35
40
45
AVERAGE SPEED, M.P.H.
1976 COMPOSITE VEHICLE, LDA
75°F.
COLD/HOT
20%-80% PRE-CATALYTIC
20%-27%-53% CATALYTIC

speed. These curves are a plot of the speed corrected composite emission factors versus speed.

Current methodologies are presented in the EPA publication titled "Mobile Source Emission Factors" dated March 1978, (50). These data are revised for California conditions and are included in the California Air Resources Board's computer program EMFAC5, and its documentation "EMFAC5 User's Manual" by John Winston dated May 1978,(23). A Caltrans computer program titled "ENVØ28" is used in conjunction with EMFAC5 to summarize its many files into a usable format. The "User Manual-ENVØ28"(23A) has been prepared.

City street driving is generally involved with marked changes in speed of the vehicles including all four of the operating modes. Vehicles stopping at signals are closely grouped not only in their own lane but also in adjacent lanes. During the deceleration for stop signals, the waiting idle period, and the rapid acceleration following clearance, the emissions per vehicle are very high.

On the other hand the increase in route speed through use of more unrestricted roadways lowers emissions and allows operation in the cruise mode for a substantial part of the trip. Further, such increase in route speed accelerates the mixing of all the pollutants and prevents zones of intense concentration from forming. Studies indicate the presence of a "mixing zone" within the roadway prism where turbulent action of high speed vehicles actively promotes mixing of the pollutant. Such action lowers the level of emissions reaching the occupants of the vehicles. This type of mechanical mixing is greatly reduced when vehicles are slow moving or idling. In this connection it cannot be overstressed that congestion leading to stop and go operations on any roadway will not only increase the emission

load that must be dispersed but also will increase the concentrations of emission for occupants of the vehicles and nearby locations.

The emission factor computer programs EMFAC5 and ENVØ28 (23 and 23A) are used to calculate the emission rate for a given set of conditions. These emission factors are then used to calculate the tonnage of emissions from a given volume of traffic operating at an average route speed. This information is required for an assessment of the mixing and dispersion of the emissions from the line source and for an estimate of the mesoscale pollution levels in the immediate air basin surrounding the line source.

The total load of emissions from vehicles using the roadway must be effectively mixed and dispersed so that pollutant levels fall to existing or background levels as soon as possible downwind from the line source (microscale or corridor analysis). The following factors influence the mixing and dispersion operation with the corridor.

1. Traffic action within the "mixing cell"
2. Micrometeorology
3. Natural topography of the immediate area around the roadway
4. Building configuration
5. Highway geometric configuration

A. Q. Eschenroeder(24) first introduced the concept of the "mixing cell". In this concept the turbulence generated by moving vehicles especially at higher speeds mixes the emissions to produce an average concentration within the mixing cell. This concept has now been modified such that a "mixing zone" of uniform emissions and turbulence is said to exist, and that the pollutant residence

time within this zone controls the amount of initial vertical mixing that take place. Thus, concentrations are reduced as a result of the traffic turbulence within the mixing zone.

The most important factor is the micrometeorology of the line source. A clear understanding of the meteorological conditions existing along the corridor is essential in predicting the dispersion of the emissions. We cannot overstress the importance of on-site observations with sensitive meteorological instrumentation in order to characterize all essential parameters (2).

The natural topography of the immediate area will influence wind flow patterns and, therefore, the transport of emissions downwind. Certain topographic features may influence the concentration of air contaminants in certain areas. Meteorological data are necessary to allow construction of wind streamlines which are influenced by the topography.

Building configuration downwind of the line source may produce aerodynamic effects leading to distortion in wind direction with subsequent changes in emission concentrations. Highway configurations such as fills crossing canyons, etc., can influence wind direction and transport of the emissions. Other highway designs such as depressed and elevated structures produce different dispersion patterns for emissions. In the future it is possible that certain designs which aid in dispersion, or retention within the right of way, of pollutants may be required in critical areas where topographical and meteorological conditions lead to a concentration of air contaminants on or near roadways.

The concentration of carbon monoxide in the mixing zone compared to that in the exhaust indicates that exhaust emissions from moving automobiles are immediately diluted several hundredfold. It should be noted that this occurs within the traffic lanes themselves.

In the region that forms the mixing zone there is very rapid dispersion of emissions caused mainly by the movement of the vehicles. The turbulence of the mixing action generated by the vehicle inceases with speed. Freeway driving permits a maximum of such action because of the high route speed. Such action coupled with the prevailing wind is responsible for the rapid drop in concentration of emissions on each side of the freeway.

Bryan and Taylor (30) have reported that the concentration of contaminants at a monitoring station located 150' from the traffic lanes of a heavily used freeway was approximately equivalent to the average ambient levels measured at other monitoring stations in Los Angeles.

Brice and Roesler (31) made an investigation in a number of large cities on the exposure to carbon monoxide of occupants of vehicles moving in heavy traffic. In connection with this study they made a comparison of the difference in carbon monoxide and hydrocarbon concentrations near the driver in traffic, and at continuous air monitoring program (CAMP) stations located in the downtown areas of each city. These stations were positioned 50 to 70 feet from the street with the sample intake about 15 feet above the ground. The following table presents their findings:

City	Average Carbon Monoxide PPM In Traffic	Average Carbon Monoxide PPM CAMP Site	Ratio	Average Hydrocarbons PPM In Traffic	Average Hydrocarbons PPM CAMP Site	Ratio
Cincinnati	21	3.1	6.8	5.7	2.3	2.5
Denver	40	17	2.4	9.6	5.6	1.7
St. Louis	36	17	2.1	9.3	3.5	2.7
Washington	25	5.3	4.7	6.2	2.7	2.3
Chicago	37	29	1.3	4.8	3.4	1.4

The results clearly indicate the effect of rapid dispersion between the driver's location and the area adjacent to the city street, even though the downtown route was "boxed" in by tall buildings which reduces ventilation regardless of wind direction.

A comprehensive report, "CALINE3-A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets" (52), is a third generation California Line Source Disperson Model. This model can be used to predict carbon monoxide concentrations near highways and arterial streets given traffic emissions, site geometry and meteorology. The model has adjustments for averaging time and surface roughness and can handle up to 10 links and 20 receptors. The model also contains an algorithm for deposition and settling velocity so that particulate concentrations can be predicted.

The evidence presented therein indicates, in general, a rapid dispersion of emissions occurs from roadway systems, and that concentrations of emissions approach background levels at relatively short distances from the traffic lanes of highways or freeways.

The primary emissions from a line source may be lifted from the corridor and, coupled with other emission sources both stationary and mobile, move over relatively long distances depending upon wind flow patterns within the basin.

During periods of favorable meteorological conditions, the emission load within the basin is adequately mixed and dispersed and no excessive concentrations of pollutants are noted. However, a period of unsatisfactory meteorological conditions, such as an inversion coupled with relatively stagnant conditions, may lead to a build up of primary pollutants.

It is difficult to perform an analysis to determine the role played by the primary emissions from a specific line source in the photochemical changes leading to "smog" some miles downwind from the source. This will depend on the complex meteorology of the basin and the influence of topography on wind flow patterns. Again the building configuration, especially clusters of tall buildings, may influence wind flow patterns.

THE TRANSPORTATION ENGINEER AND AIR QUALITY

A. PLANNING AND DESIGN

The transportation engineer must consider air quality during planning, design, construction, and maintenance operations. He should be aware of the effect of traffic movement on air quality.

The requirement that the transportation engineer must furnish an Environmental Impact Statement for each of his projects during the planning and design stages requires a full discussion and disclosure of the various possible environmental impacts including air quality.

To assist the transportation engineer in properly evaluating the effect of a project on air quality, a series of manuals (34) has been prepared. For general reading on this phase, reference 34f of the manual series is recommended.

One of the purposes of the Air Quality Report is to present information that will allow the writer of the Environmental Impact Statement to answer certain questions stated in the

law. Some of these questions are concerned with the possible negative effects the project may have on the air environment. Also one must discuss the State Implementation Plan as related to the project. Another important consideration is the effect on air quality of not building the proposed project.

All of these questions require an understanding of the relationship between air quality and the project in terms of planning decisions and design criteria. Part of this has been presented in the previous discussion on the roadway and air quality.

References 35 through 43 should be studied for the various aspects of the problem in terms of planning and design. E. W. Hauser, et al(35) states, "Thus planners must have both long- and short-range views of emission problems due to transportation. The long-range view required involves two factors: the growth and changing patterns of transportation, and the changing nature of emission characteristics of transportation, especially motor vehicles. The first factor is the chief one that lies in the range of responsibility of transportation and urban planners. However, the second must be included in planning." These considerations are shown in the flow chart in Figure 6. (40)

A series of examples found in Bellomo's paper (43) illustrates an analysis for advanced planning in terms of air pollution. Existing urban systems may also be analyzed knowing the movement of traffic, average speed, and emission factors. From such data one may calculate the total tonnage of primary emissions into the region from the transportation network. Improvement of a highway with the resultant traffic facilitation can significantly lower concentrations of primary pollutants.

Figure 6

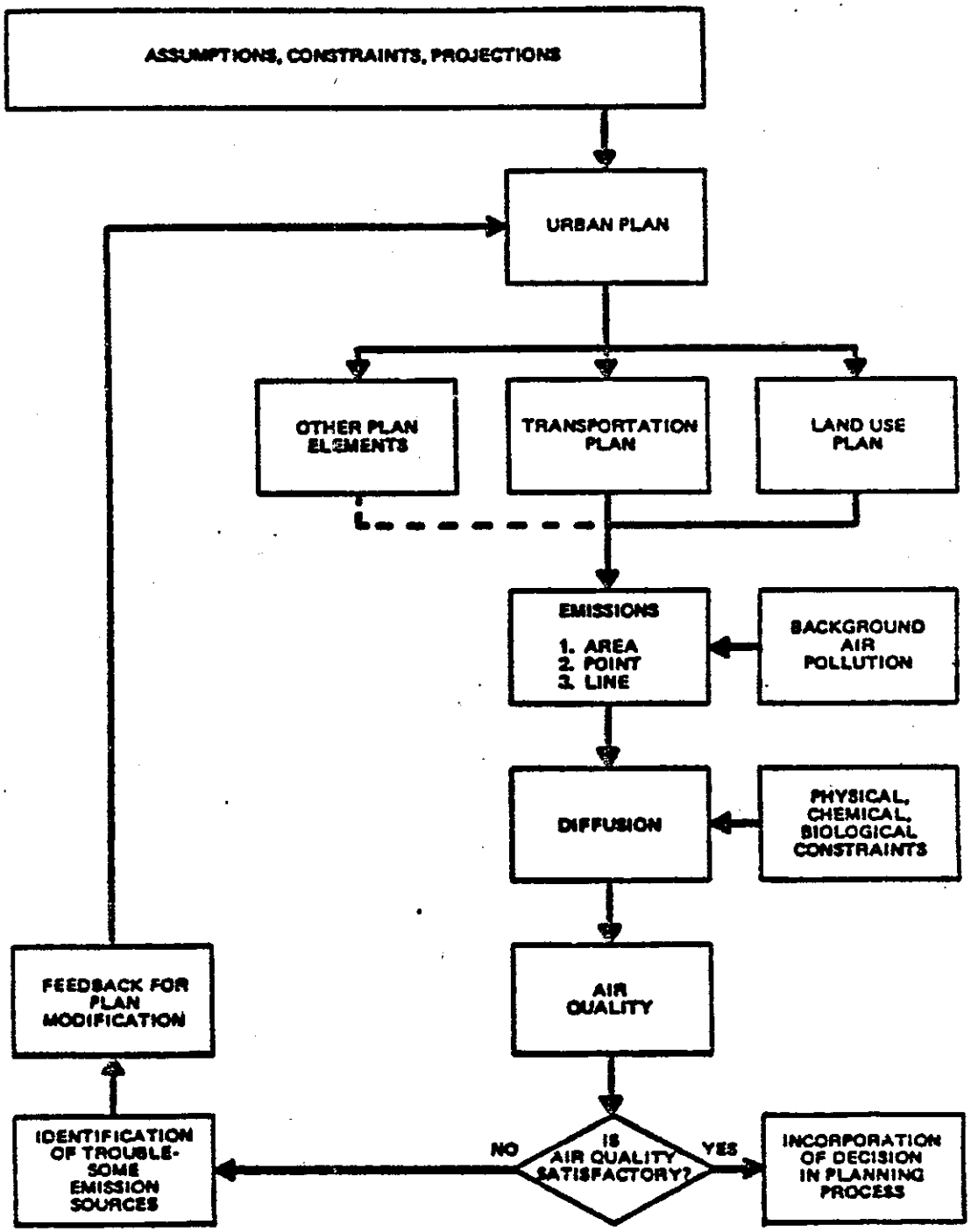


Figure AIR QUALITY CONSIDERATIONS IN THE PLANNING PROCESS

From Reference (41)

The oxidant changes are difficult to determine from such an analysis. The photochemical production depends on many factors, especially meteorological parameters. The use of photochemical models to calculate potential ozone concentrations is in its early stages. They presently require further study and verification. The kinetics of the photochemical mechanisms involved have been under investigation to aid in representing the reactions in modeling activities.

The modification of the traffic system in some specific areas may lead to an improvement in flow and a reduction in emissions for that area. Such a reduction in emissions is usually not very significant in the mesoscale picture since the meteorological and topographic parameters will control the movement of the primary emission load in the mesoscale area being considered. In this connection it is very important that the planner be thoroughly familiar with the meteorology and topography of the region involving the transportation system. This may be done either by consultation with air pollution specialists on the transportation department staff or by contracts with local, state, and federal air pollution experts.

As an example one may consider the proposed addition of a sizable length freeway to an existing system. The freeway will markedly change the existing street travel pattern for the specific area being considered in the planning process. As a first step, a complete traffic analysis must be prepared indicating all changes in volumes and average route speeds for the area influenced by the proposed freeway. Using emission factors and mix of vehicles, one may calculate the emission tonnage for the date of opening of the freeway. Now one must analyze the movement of this new emission load into other parts of the region if it is different than the existing emission load.

To make a comprehensive mesoscale analyses, the planner must also obtain from local or other air pollution agencies available data on the locations of, and emissions from stationary sources within the study resion. The concentrating of a large volume of previously dispersed area traffic onto a proposed line source located near a cluster of existing stationary sources may result in a high emission load. This change in pollutant level could conceivably increase the potential for secondary pollutants to form. The degree of severity will also be dependent on meteorological and topographic factors.

Another very important problem in the regional urban planner's consideration of air quality is the concept of multimodal analysis for the transportation needs of a specified corridor. An example of this type analysis is found in Bellomo's paper(43). In this analysis we have a very complex situation. One now must consider not only the freeway, but a number of other possible modes of travel either separately or in combination. The traffic analysis necessary for air quality studies must be comprehensive for each proposed mode or combination in order to prepare an air quality comparison within the corridor. As examples, a proposal for rapid transit within the corridor would require a detailed realignment of the traffic patterns within the corridor including the starts and movements in and around the parking lots at the commuter stations; or perhaps different travel patterns could develop for a freeway alone or in combination with bus movements. In all cases various emission factors are required together with a detailed analysis of volumes, average route speed, and mix of cars and trucks. This must be projected for the maximum design life of the proposed facility in order to satisfy the requirements of the Environmental Impact Statement.

Following the systemwide analysis and the evaluation of the influences of the proposals within any specific area on the air quality of the basin (mesoscale), one must consider the effects on air quality within the immediate area of the transportation corridor. This will involve a microscale analysis addressing such terms as meteorology and topography. As a design state example, the location of a large complex distribution structure with its movements of concentrated masses of traffic may alter air quality within the immediate area since meteorological and topographic features may not be conducive for adequate mixing.

The location of large parking lots at bus or rapid transit stations may markedly increase emission concentrations in the immediate area and downwind. Planning for these types of facilities requires a thorough analysis for site selection since the deceleration, acceleration, and idle traffic modes are quite frequent within and around such areas. Even embankment construction and cut excavation can significantly effect the micormeteorology.

In a recent paper, Middleton and Ott (36) discuss air pollution and highway design. They state, "The present state of knowledge is not adequate to permit us to establish priorities for the individual design approaches that would minimize the pollution problem in all cases." However, examples of possible steps are the following:

1. Provide the maximum distance between routes and nearby dwelling places.

2. Make dividing strips between opposing lanes as wide as possible.

B. CONSTRUCTION AND MAINTENANCE

Some construction and maintenance operations may alter air quality within the corridor and the immediate area. Dust and smoke are the two principal agents which may alter air quality during these operations. Transportation engineers should be familiar with regulations relative to burning within each air pollution district and also State laws in this connection. They should also be familiar with regulations regarding dust discharges not only from on-site operations, but from the contractor's other related activities such as aggregate processing plants and the preparation of asphalt and portland cement concrete paving mixtures.

In urban areas of some states, rigid control of smoke and dust is maintained by local agencies on many types of industrial operations including those producing construction materials. In other areas the transportation department may be required to issue their own specifications for control of dust and smoke emissions(44 and 45).

A number of alternatives to burning in connection with clearing operations are available(48) and should be studied by the engineer prior to start of construction. In fact, the control of dust and smoke should be discussed in the Environmental Impact Statement during the design stage and be covered in the specifications for the project.

There continues to be a need for further research in this field especially on test methods for determining dust emissions from various operations of the contractor on the jobsite.

C. Operations

We have previously discussed the differences in emission levels from vehicles in various operating modes (idle, acceleration, deceleration, and cruise) and the fact that an improvement in operational characteristics will reduce emissions at least for carbon monoxide and hydrocarbons. S. Bellomo(43) discusses this aspect of improvement of air quality as a side effect of improving operational characteristics on city streets through safety programs. Bellomo states, "Even though air pollution reduction is not one of the objectives of the program, it comes out as an important by-product of improved traffic flow. Such actions as synchronizing traffic signals and using computerized signal systems improves traffic flow up to 30% and more, and a comparable decline in air pollution (carbon monoxide and hydrocarbons) can be expected for the operating systems. Unlike the effects of pollution reduction through planning and design of new development and facilities, pollution reductions on the operating system can affect the whole area." An excellent review on this and other aspects of transportation control is found in reference 47. The application of such programs to freeways and expressways also shows promise of expediting traffic during high volume peaks by computerized ramp control and other methods. Such a system has been utilized on the freeway system in Los Angeles (48). These actions also reduce emissions by increasing time that traffic is in the cruise mode.

The Future

The many factors involved in the effects on air quality of transportation systems require a large scale future research effort. The present state of knowledge does not provide answers for many important questions. Emission factors for motor vehicles

are still open to improvement and are often being revised. Research continues on the development of accurate photochemical models. The proper deployment of meteorological equipment and analysis of data for the many line source situations encountered in the United States are the subjects of Caltrans research.

The transportation administrator should fully realize the complexity of the air quality problem and should work to foster the development of specialists within his own organization. He should be cognizant of other federal and state agencies involved in the field and establish working relationships with key personnel in these agencies.

REFERENCES

1. Ruckelshaus, W. D., The States and EPA, Journal of the Air Pollution Control Association, Vol. 22, p 80, 1972.

2. Legarra, J. A., The Highway Administrator's Role in Pollution Control, Highway Research Board Summer Meeting, Sacramento, California, August 1970.

3. Air Quality Criteria for Photochemical Oxidants, U. S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Washington, D. C., March 1970.

4. Heuss, J. M., Nebel, G. J. and Colucci, J. M., National Air Quality Standards for Automotive Pollutants - A Critical Review, Air Pollution Control Association Journal, Vol. 21, No. 9, p 535, 1971.

5. Federal Environmental Legislation and Regulations as Affecting Highways, National Cooperative Highway Research Program Research Results Digest #25, January 1971.

6. Shane, Jeffrey N., Environmental Litigation in 1971, Highway Research Circular No. 135, Legal Studies, May 1972, Highway Research Board.

7. Schneiderman, M., Cohn, C. K. and Paulson, G., Air Pollution and Urban Freeways: Making a Record on Hazards to Health and Property. Catholic University Law Review, Vol. 20, No. 5.

8. Davies, J. E., The Politics of Pollution, Pegasus, New York, 1970.

9. Grad, T. P., Rathjens, G. W. and Rosenthas, A. J., Environmental Control: Priorities, Policies, and the Law, Columbia University Press, New York, 1971.

10. The Environment and the Law, A Symposium, Suffolk University Law Review, Vol. 5, No. 3, 1971.

11. Control of Environmental Hazards, A Symposium, Michigan Law Review, Vol. 68, No. 6, 1970.

12. Henkin, H., Martin, M. and Staples, J., The Environment, The Establishment and the Law, Houghton Mifflin, New York, 1971.

13. Krier, J. E., Environmental Law and Policy, The Bobbs-Merrill Co., Indianapolis, Ind., 1971.

14. Meyers, C. J., and Tarlock, A. D., Legal Aspects of Environmental Pollution, The Foundation Press, Mineola, N.Y., 1971.

15. Air Quality Criteria for Carbon Monoxide AP-62, U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, March 1970.

16. Air Quality Criteria for Hydrocarbons AP-64, U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, March 1970.

17. Air Quality Criteria for Nitrogen Oxides AP-84, U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, January 1971.

18. The Oxides of Nitrogen in Air Pollution, 2nd Printing Nov. 1969, State of California, Air Resources Board, Sacramento, California.

19. Air Quality Criteria for Photochemical Oxidants AP-63, U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, March 1970.

20. Air Quality Criteria for Particulate Matter AP-49, U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, January 1969.

21. Air Pollution, Edited by Stern, A. C., Academic Press, New York, 1968, Vol. 1, Part III.

22. Rose, A. H., Jr., Smith, R., McMichael, W. F., and Kruse, R. E., Comparison of Auto Exhaust Emissions in Two Major Cities, Journal of the Air Pollution Control Association, Vol. 15, No. 8, 1965.

23. EMFAC5 User's Manual, John Winston, Planning Division, California Air Resources Board, May 1978.

23A. User Manual ENVØ28, - Motor Vehicle Emissions Rates Summary Program, John Winston, Deane Coats, California Department of Transportation, Transportation Laboratory, July 17, 1978.

24. Eschenroeder, A. Q., An Approach for Modeling the Effects of Carbon Monoxide on the Urban Freeway User, General Research Corporation, Santa Barbara, California, January 1970.

25. Beaton, J. L., Skog, J. B., Shirley, E. C., and Ranzieri, A. J., Mathematical Approach to Estimating Highway Impact on Air Quality, State of California, Department of Public Works, Materials and Research Department, Air Quality Manual No. CA-HWY-MR657082S-(4)-72-12, May 1972.

26. Beaton, J. L., Skog, J. B., Shirley, E. C., and Ranzieri, A. J., Meteorology and Its Influence on the Dispersion of Pollutants from Highway Line Sources, State of California, Department of Public Works, Materials and Research Department, Air Quality Manual No. CA-HWY-MR657082S-(1)-72-11, April 1972.

27. Reed, L. E., and Barrett, C. F., Air Pollution from Road Traffic, International Journal Air and Water Pollution, Vol. 9, p 357, 1965.

28. Analysis of Air Near Heavy Traffic Arteries, Air Pollution Foundation, Los Angeles Air Pollution Report No. 16, December 1956.

29. Maga, J. A., Vehicular Pollution Effects in Urban Development, American Society of Civil Engineers, Journal of the Urban Planning and Development Division, December 1967.

30. Bryan, R. J., and Taylor, J. R., An Air Sampling Study in Conjunction with the Exposure of Animals to Determine Biological Effects of Automotive Emissions as Air Pollutants, Air Pollution Control Association, 58th Annual Meeting, Toronto, Canada, June 1965.

31. Brice, R. M., and Roesler, J. F., The Exposure to Carbon Monoxide of Occupants of Vehicles Moving in Heavy Traffic, Journal of the Air Pollution Control Assoc., Vol. 16, p 597, 1966.

32. Colucci, J. M., and Begeman, C. E., Carbon Monoxide in Detroit, New York and Los Angeles Air, Environmental Science and Technology, Vol. 3, p 41, 1969.

33. General Electric Co., Final Report on Study of Air Pollution Aspects of Various Roadway Configurations, September 1, 1971.

34. Beaton, J. L., Skog, J. B., Shirley, E. C., and Ranzieri, A. J., California Division of Highways, Materials and Research Department:

a. Meteorology and Its Influence on the Dispersion of Pollutants from Highway Line Sources.

b. Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality.

c. Traffic Information Requirements for Estimates of Highway Impact on Air Quality.

d. Mathematical Approach to Estimating Highway Impact on Air Quality.

e. Analysis of Ambient Air Quality for Highway Projects.

f. A Method for Analyzing and Reporting Highway Impact on Air Quality.

35. Hauser, E. E., West, L. B., Jr., and Schleicher, A. R., Fundamental Air Pollution Considerations for Urban and Transportation Planners, Traffic Quarterly, Vol. 26, #1, p 71, 1972.

36. Middleton, J. T., and Ott, W., Air Pollution and Transportation Traffic Quarterly, Vol. 22, #2, p 175, 1968.

37. Croke, E. J., Croke, K. G., Kennedy, A. S., and Hoover, L. J., The Relationship Between Land Use and Environmental Protection, Center for Environmental Studies, Argonne National Laboratory, Argonne, Illinois, 1972.

38. Kennedy, A. S., et al, Air Pollution - Land Use Planning Project, Phase I Final Report, Center for Environmental Studies, Argonne National Laboratory, July 1971. NTIS No. ANL/ES-7. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22151.

39. Voorhees, Alan M., and Associates, Inc., and Ryckman, Edgerley, Tomlinson and Associates, Air Quality Considerations in Transportation and Urban Planning, A Five-Year Program Guide, Dec. 1971. NTIS No. PB207-111, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22151.

40. Voorhees, Alan M., and Associates, Inc., and Ryckman, Edgerley, Tomlinson and Associates, A Guide for Reducing Air Pollution Through Urban Planning. Dec. 1971. NTIS No. PB207-510, National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia, 22151.

41. Fensterstock, J. C., Kurtzweg, J. A. and Ozolins, G., Reduction of Air Pollution Potential Through Environmental Planning, Annual Environmental Planning Meeting of the Air Pollution Control Association, June 1970.

42. Noll, K. E., Transportation and Air Pollution Traffic Engineering, Vol. 42, No. 9, p 12, 1972.

43. Bellomo, S. J., and Edgerley, E., Jr., Ways to Reduce Air Pollution Through Planning Design and Operations. Highway Research Board No. 356, 1971. Highway Board.

44. Environmental Pollution Control at Hot-Mix Asphalt Plants, Information Series 27, The National Asphalt Pavement Association.

45. Burt, W. T., III, and Gueho, B. J., Air Pollution From Hot-Mix Plants. Louisiana Department of Highways Research and Development Section, October 1970.

46. Humphres, H. W., Impact of Ecology on Construction, Presented at the 50th Annual Meeting of WASHO, San Antonio, Texas, June 1971. Highway Focus, Vol. 4, #2, p 1, 1972.

47. Evaluating Transportation Controls to Reduce Motor Vehicle Emissions in Major Metropolitan Areas - An Interim Report, Institute of Public Administration and Teknekron, Inc., March 1972. Prepared for the Office of Land Use Planning, Environmental Protection Agency. National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia, 22151.

48. Los Angeles Area Freeway Surveillance and Control Project - First Annual Report, State of California, Business and Transportation Agency, Department of Public Works, January 1971.

49. The Highway Official and the Environment, Department of Transportation News, Federal Highway Administration, Washington, D. C., May 1972.

50. U.S. Environmental Protection Agency, Office of Air and Waste Management, Mobile Source Emission Factors, Final Document, EPA-40019-78-005, Washington, D.C. 20460, March 1975.

51. Ward, C. E., Ranzieri, A. J., and Shirley, E. C., CALINE2 - An Improved Microscale Model for the Diffusion of Air Pollutants from a Line Source, State of California, California Department of Transportation, No. CA-DOT-TL-7218-1-76-23, November 1976.

52. Benson, Paul E., CALINE3 - A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets, State of California, Department of Transportation, Transportation Laboratory, November 1979.

NOISE CONSIDERATIONS FOR TRANSPORTATION PROJECTS

Prepared
by the
Noise Research & Development Section
ENVIRO-CHEMICAL BRANCH

For Training Purposes Only
Transportation Laboratory Training Course
Sacramento, California

NOISE RESEARCH & DEVELOPMENT SECTION

Organization

Policies, procedures, and services related to noise are developed and provided for Caltrans by the following Headquarters offices in Sacramento.

Office of Planning and Design

It is responsible for policies and procedures as related to project development including Noise Reports. The Community Noise Program HB 311 and the School Noise Program HB 312 are assigned to this office.

Office of Environmental Planning

It is responsible for policies and procedures as related to Environmental Impact Statements (EIS), Environmental Impact Reports (EIR), Findings of No Significant Impact (FONSI) and Negative Declarations (ND).

Office of Structures and Design

It is responsible for developing structural design criteria, standard plans, special provisions, and designing sound walls not covered by standard plans. It also provides architectural assistance on projects.

Office of Transportation Laboratory

It is responsible for providing consultation and advisory services in environmental noise.
Developing methods and techniques for investigating, evaluating and reporting environmental noise impact.
Providing a centralized capability to do the more complex and difficult noise studies by maintaining a staff of experts and state of the art equipment.
Providing noise training and review services to ensure that District noise study efforts are of a uniform high quality.
Conducting noise research which will anticipate and provide solutions to the needs and problems of Caltrans during highway planning, design, construction operation and maintenance.
Evaluating implemented noise research.
Developing modifying and maintaining computer programs to facilitate project noise studies.
Performing Quality Assurance Audits on District's noise instrumentation and procedures.

Introduction

Noise is defined as any sound that is undesirable because it interferes with activities such as sleep, telephone usage, conversation, television programs, and enjoyment of a quiet environment. This definition is very subjective because people react differently to various sounds. A rock band is an example. Depending on the intensity of the noise, it can be merely annoying or even a health hazard.

The California Department of Transportation (Caltrans) has been involved with noise problems for a number of years. One of the first studies performed by the Transportation Laboratory was reported in September 1961(1). It concerned the determination of vehicular noise emanating from modern highways. Shortly after 1970, enactment of the National Environmental Policy Act (NEPA) and other federal and state laws led to organization of staffs to perform noise studies for environmental impact reports, school noise studies, and design of noise barriers.

Caltrans is mandated by law to become involved in all types of transportation but the current workload is still oriented towards highways. Mitigation of highway noise can take place in three major areas as follows:

1. Quiet the source (cars, trucks, motorcycles).

2. Land use planning, zoning ordinances, and building codes.

3. Design of highways.

The first two areas require law and enforcement and, unfortunately, the highway engineer does not exercise control over these items.

Definition of Sound

The measuring unit for describing sound intensity is the decibel. In a simple form, it is a logarithmic unit expressed as follows:

$$dB = 20 \log \frac{P_1}{P_2}$$

dB is the decibel

P_1 is the measured pressure

P_2 is the reference pressure (0.0002 microbars)

The decibel is commonly referenced to one of three frequency response schemes (A,B,C). These have been devised because the human ear does not respond equally to all frequencies. On a noise meter, different electronic networks are used for each scheme. For transportation related noise, the A scale is used since it is most representative of the ear's response. Noise measurements on this scale are denoted as dBA. The C scale essentially retains all the sound signals over the full frequency range and the B scale is between the A and C scales in terms of frequency weighted response. Figure I shows a general relationship between dBA and common indoor and outdoor noise levels.

Measurement of Sound

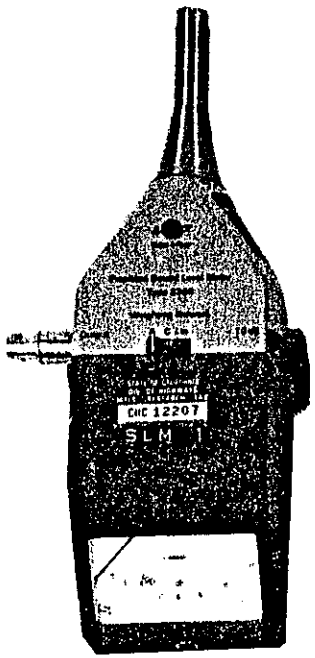
Basic sound measurement systems consist of a microphone, an amplifier or analyzer, and a readout. The components are all incorporated into a sound level meter for measuring sound (Figure II).

RELATIVE SCALE OF VARIOUS NOISE SOURCES AND EFFECT ON PEOPLE

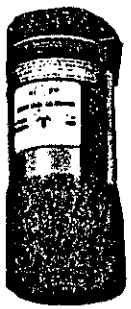
PUBLIC REACTION		NOISE LEVEL (dBA)	COMMON INDOOR NOISE LEVELS	COMMON OUTDOOR NOISE LEVELS
		110	Rock Band.	
				Jet Flyover at 1000 ft.
LOCAL COMMITTEE ACTIVITY WITH INFLUENTIAL OR LEGAL ACTION		100	Inside Subway Train (New York).	
	4 TIMES			Gas Lawn Mower at 3 ft.
LETTERS OF PROTEST	AS LOUD	90	Food Blender at 3 ft.	Diesel Truck at 50 ft.
COMPLAINTS LIKELY	TWICE AS LOUD	80	Garbage Disposal at 3 ft. Shouting at 3 ft.	Noisy Urban Daytime.
COMPLAINTS POSSIBLE	REFERENCE	70	Vacuum Cleaner at 10 ft.	Gas Lawn Mower at 100 ft.
			Normal Speech at 3 ft.	Commercial Area
COMPLAINTS RARE	$\frac{1}{2}$ AS LOUD	60		Heavy Traffic at 300 ft.
			Large Business Office.	
	$\frac{1}{4}$ AS LOUD	50	Dishwasher Next Room.	Quiet Urban Daytime.
ACCEPTANCE				
		40	Small Theatre, Large Conference Room (Background)	Quiet Urban Nighttime.
			Library	Quiet Suburban Nighttime.
		30	Bedroom at night Concert Hall (Background)	Quiet Rural Nighttime.
		20		
			Broadcast and Recording Studio	
		10		
		0	Threshold of Hearing	

Figure 1

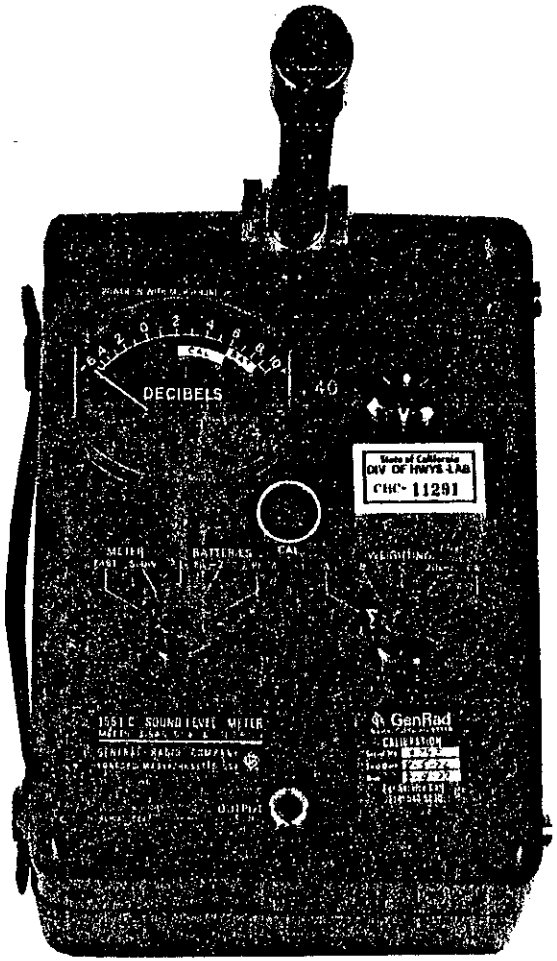
FIGURE II



SOUND LEVEL METER
B & K MODEL 2206



CALIBRATOR
B & K MODEL 4230



SOUND LEVEL METER
GEN RAD MODEL 1551C

CALIBRATOR
GEN RAD MODEL 1562A

In addition to the basic instruments, the more sophisticated systems use items such as graphic level recorders, tape recorders, octave band analyzers, statistical distribution analyzers, and computers for data analysis.

Sound level meters are classified into types based on the American National Standard (ANSI) specifications. The sound level meters used by Caltrans fall into the Type 1 or 2 category which provides a nominal accuracy of about ± 1 and 2 dBA respectively.

An important part of any measurement system is the calibration. This is accomplished by fitting a calibrator over the microphone. The calibrator is periodically checked with a standard which is traceable to the National Bureau of Standards.

For Caltrans purposes, sound measurements from highway traffic are generally taken at a height of 5 feet. Distances would vary depending on the particular situation. Procedures for field measurements are detailed in the FHWA publication entitled "Fundamentals and Abatement of Highway Traffic Noise"(2).

Descriptors

There are many descriptors of noise developed by various agencies for specific purposes. The following list shows the various descriptors used by Caltrans:

Descriptor	Used for	Parameter
Peak Method	School Noise Studies, Required by Calif. Streets and Highways Code Section 216	The loudest mean noise recorded during a Measurement period.
L_{10}	Highway Noise Studies, Required by FHWA	A statistical evaluation of noise that indicates the sound level which is exceeded 10 percent of the time. Measurements made during peak traffic periods.
L_{eq}	Highway Noise Studies, Required by FHWA, alternate to L_{10} descriptor	The amount of acoustic energy equivalent to that contained in the measured noise
L_{dn}	Highway Noise Contours used by cities and counties in their General Plan	This is an average 24 hour noise level. The day hours are from 7 A.M. to 10 P.M. The night hours are from 10 P.M. to 7 A.M. and are weighted with a 10 dBA addition
CNEL	Used as an alternate to L_{dn} and by the California Division of Aeronautics	Same parameter as L_{dn} except there is a 7 P.M. to 10 P.M. period with a 5 dBA addition

Highway Noise Sources

The major source of highway noise emissions is from diesel trucks(2,3,4,5). Noise from a heavy truck cruising at 45 mph produces around 86 dBA at 50 feet, although levels above 90 are not uncommon. Current laws require trucks sold in California after 1977 to emit less than 83 dBA.

Engine exhaust, cooling fan, engine and chassis, intake, and tire/pavement interaction are the dominant sources of truck noise. Quieting these sources, according to research studies by the White Motor Company, International Harvester and the Freightliner Corporation, reduced truck noise to 76, 78, and 75 dBA, respectively(6,7,8).

Passenger cars are relatively quiet at low speeds but the tire/pavement interaction becomes a significant factor above 35 mph. The noise at 55 mph is around 75 dBA(2,3,4,5).

Although cars are considerably quieter than trucks, the large proportion of cars in the total traffic mix makes their contribution to the overall noise a significant factor.

Traffic Noise Predictions

FHWA Report RD-77-108 (9) provides the accepted FHWA procedures for predicting traffic noise based on the L_{eq} descriptor. It became effective on December 31, 1979. The procedures prior to this date are based on the National Cooperative Highway Research Program (NCHRP) Reports No. 117 and 144 (4,5) using the L_{10} descriptor.

Charts, computation forms and nomographs are available to facilitate the calculations. A computer program is also available for the more sophisticated user.

The factors entering into the prediction procedure are as follows:

1. Traffic Parameters

    a. Vehicle volume
    b. Vehicle mix
    c. Vehicle average speed

2. Roadway Characteristics

    a. Pavement width and number of lanes
    b. Vertical configuration
    c. Gradient

3. Observer Characteristic

    a. Observer distance
    b. Element size
    c. Shielding
    d. Observer relative height
    e. Terrain characteristics

Noise Abatement

Abatement of highway traffic noise is generally accomplished by the following means:

1. Quiet the source.
2. Protect the receiver.
3. Intercept the path.

The Transportation Engineer is primarily involved in intercepting the path for abating traffic noise from highways. This is accomplished during the design of the facility or by retrofitting noise barriers after construction.

Noise from highway traffic generally follows four paths to the receiver where the facility is constructed with and without barriers.

1. A direct path (visualized by a line of sight).
2. Diffracted path (noise that bends over a barrier).
3. Transmitted path (noise that goes through a barrier).
4. Reflected path (noise that rebounds from an object to the receiver).

Barriers to mitigate traffic noise have been constructed of earth, plywood, concrete, cement blocks, steel and stucco. Studies to evaluate the various type barriers are limited. Some general criteria for barriers are that the material should weigh about 4 psf, be designed for wind load, and considered for aesthetics, cost, maintenance, and safety.

The practical limits for noise attenuation from barriers are estimated as follows:

1. Reduction of 5 dBA is simple
2. Reduction of 10 dBA is attainable
3. Reduction of 15 dBA is very difficult
4. Reduction of 20 dBA is nearly impossible.

Charts, computation forms, nomographs, and a computer method are available for designing noise barriers. FHWA Report RD-77-108 (9) provides the accepted FHWA procedures for designing barriers based on the L_{eq} descriptor. The optimum design is based on variables such as distance between source, barrier and receiver; height and length of barrier; traffic type; volume and lane distribution; and type of barrier.

Figure III shows illustrations of noise reductions due to various highway configurations. As a comparison, Figure IV shows three configurations shown in Figure III with sound barriers and reduced noise levels. These examples are not intended for design purposes.

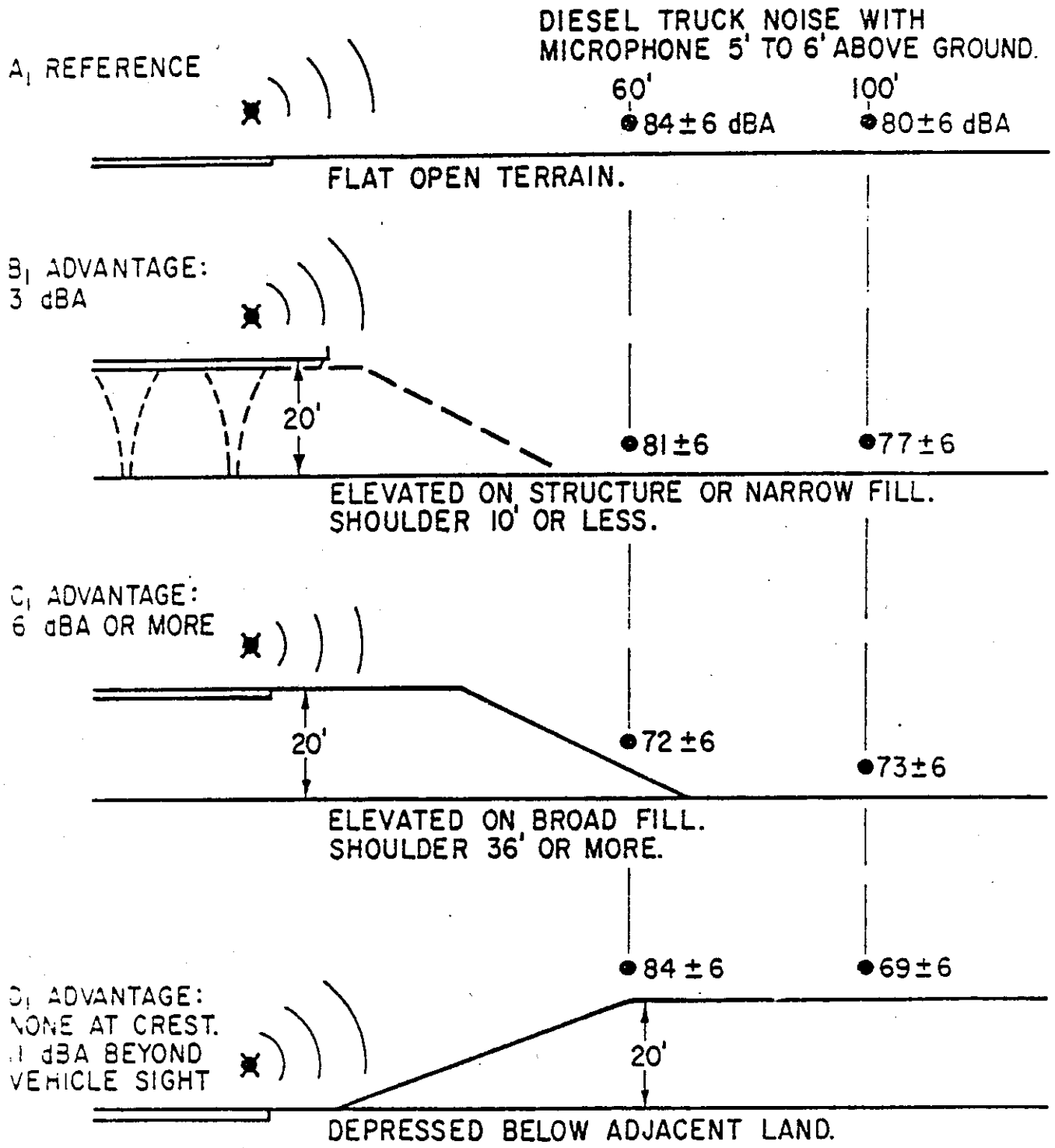
Plantings of trees and shrubs are generally of little value in attenuating noise. NCHRP Report No. 117(4) suggests the use of 5 dBA attenuation for a 100 foot depth of woods of sufficient density such that no direct visual path exists from one side of the woods to the other.

Environmental Impact Statements (EIS)

In general, the EIS should always report the existing level and the anticipated levels at the design year for the "no build" and "build" conditions. The noise level descriptors, measurement instruments, procedures, and analysis should be presented in a manner that enables the layman to understand the noise impact. The more technical information should be placed in the appendix or in a separate report.

Figure V shows the current FHWA guideline which indicates design noise levels for various activity categories. Mitigation measures should be recommended where predicted noise levels exceed the FHWA standards. Any alternatives and their consequent changes in noise levels should also be reported. Specific noise sensitive receptors such as schools, churches, libraries, hospitals, and similar facilities should be covered in the EIS. Other items of consideration are land use planning associated with or near the highway and construction noise.

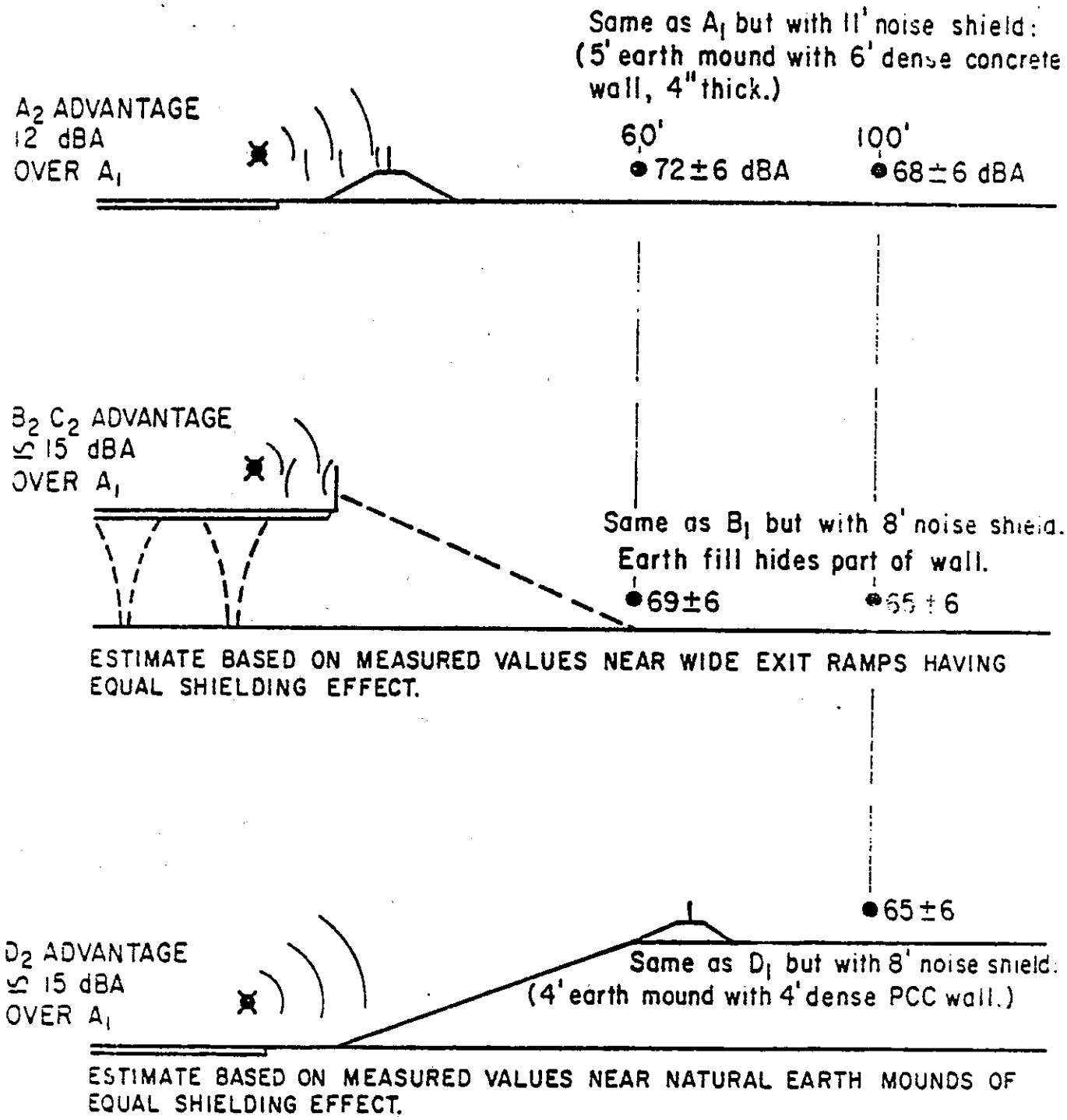
FIGURE III



UNMODIFIED HIGHWAY DESIGNS

NOISE RADIATION MEASURED FROM DIESEL TRUCKS

FIGURE IV



MODIFIED HIGHWAY DESIGNS
FOR BETTER NOISE REDUCTION

FIGURE V

ACTIVITY CATEGORY	DESIGN NOISE LEVELS NOISE DESCRIPTOR L_{eq}	L_{10}	DESCRIPTION OF ACTIVITY CATEGORY
A	57 (Exterior)	60 (Exterior)	Tracts of land in which serenity and quite are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or stages, or open spaces, or historical districts which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, and parks which are not included in category A and residences, motels, hotels, public meeting rooms, schools, churches, libraries and hospital
C	72 (Exterior)	75 (Exterior)	Developed lands, properties or activities not included in categories A or B above.
D	-------	-------	For requirements on undeveloped lands see Section 772.19(a) and (c).
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

SOURCE: Title 23-Highways, Chapter 1, U.S. DOT, FHWA, Part 772 Federal Register, Vol. 41, No. 80, April 23, 1976.

REFERENCES

Cited

1. Bourget, L., The Effects of Basic Highway Designs on Traffic Noise Attenuation, Materials and Research Laboratory, No. 100-R-6227 September 1961.

2. Fundamentals and Abatement of Highway Traffic Noise, No. FHWA-HH1-HEV-73-7976-1, June 1973.

3. Highway Noise Measurement, Simulation and Mixed Reactions, Report 78, 1969.

4. Highway Noise, A Design Guide for Highway Engineers, Report NCHRP No. 117, 1971.

5. Highway Noise, A Field Evaluation of Traffic Noise Reduction Measures, NCHRP Report No. 144, 1973.

6. Noise Reduction Tests and Development Performed on the White Motor Corporation Quieted Truck, Department of Transportation, No. DOT-TST-75-61 January 1975.

7. Seven Reports by the International Harvester Corporation, Department of Transportation, No. DOT-TST-74, 75, 76, May 1974 thru March 1976.

8. Eight Reports by the Freightliner Corporation, Department of Transportation, No. DOT-TST-73, 74, 75, 76, May 1973 thru January 1976.

9. FHWA Highway Traffic Noise Prediction Model, FHWA-RD-77-108, December 1978.

Project Development and Noise

Community Noise Program HB 311

In 1974, Caltrans undertook a Community Noise Program to reduce traffic noise impact by retrofitting noise barriers to existing highways. This program has since been formalized by Section 215.5 of the Streets and Highways Code. This is not a federally mandated program but the FHWA is providing matching funds where their criteria are met. An evaluation made in 1973 indicated around 350 million dollars would be needed for this program. Current level of funding is about 18 million dollars a year.

Initially, community noise projects in those areas developed prior to freeway route adoption (Category C1) are prioritized. Noise levels in this group exceed the FHWA design guideline of L_{eg} 67 dBA.

Within the C1 category, first priority is given to those projects with the highest noise index (NE) determined as follows:

$$NE = \frac{\text{dBA reduction} \times (\text{dBA level}-70)^2 \times \text{dwelling units}}{\text{cost (\$1,000)}}$$

dBA reduction = average achievable reduction at the first row of dwelling units

dBA level = measured or predicted level at the first row of dwelling units

Dwelling units = number of dwelling units in the first row adjacent to the freeway.

The C2 category affects those community projects in areas developed prior to freeway construction and the C3 category applies to those developed after the freeway is constructed . Priorities in these groups are established in the same manner as the Category C1 and the noise levels must be above the FHWA design guideline of L_{eg} 67 dBA.

At the present time, it appears that work will not begin on the C2 projects until 1982 or 1983 and on the C3 projects in subsequent years.

After prioritization, the District contacts the homeowners by mail and by the news media, and holds public hearings to determine if the residents want noise barriers. There have been comments by some residents that they do not want a noise barrier because it would result in things such as loss of view, the barrier is not aesthetically pleasing, it blocks the breeze and creates a shadow zone. If the community input is favorable, the designers finalize plans for the noise barrier.

The preliminary process is performed in conjunction with the Environmental Noise Section personnel who make the initial studies, noise measurements and write the noise report.

The Caltrans Headquarters offices provide various functions such as training, policies, procedures, computer programs and perform research studies to support the District's efforts.

School Noise Program HB 312

Section 216 of the Streets and Highways Code requires that freeway generated noise inside private or public elementary or secondary school classrooms be reduced to 50 dBA peak or to preconstruction noise levels from prior existing sources. Those schools constructed prior to award of the construction contract and prior to January 1, 1974 qualify for this program. This is estimated to be a 42 million dollar program with about 5 million budgeted each year until completion in 1983 or 84.

First priority is given to schools receiving the highest noise levels. However, the priorities may be modified for the following reasons:

1. Coordination with community noise projects.

2. Interest shown by school district and their ability to deliver plans if work is done on the school.

3. Desires of school to incorporate other features in a project at their expense.

4. Where more than one school is involved in a district, they may establish the priority for their district.

In most cases, the noise levels in schools are lowered by things such as building noise barriers, sealing windows, using double panes and solid core doors. Air conditioning or a ventilation system is needed where the classrooms are sealed. Sometimes noisier or quieter school activities can use different rooms.

Highway Design

The design of the highway may involve various considerations for minimizing noise as follows:

1. Highway alignment and grade.
2. Pavement surfacing.
3. Placing the roadway on fill or in a cut section.

Many of the above options are only available for new construction on new alignment and are not viable alternatives. Others need to be planned as part of the transportation system and studies performed to evaluate their effects.

Research

1. "Evaluation of Noise Barriers" (Est. Comp. July 81)

This project concerns validating barrier design models currently being used. It will also evaluate community acceptance of barriers.

2. "Effect of Freeway Noise on Hearing and Academic Achievement of Children" (Est. Comp. July 80)

The objective of this project is to develop an empirically based interior noise limit for schools.

3. "Insulation of Buildings to Attenuate Noise - Experimental Construction" (Est. Comp. July 83)

The objective is to insulate buildings and evaluate effectiveness from a noise and energy standpoint as an alternative to barriers for some situations.

Construction and Maintenance

There are more than 27 million people impacted by construction noise levels of L_{dn} 55 dB or greater according to recent estimates by the U.S. Environmental Protection Agency EPA), and over 2 million of these people are impacted severely by levels in excess of L_{dn} 65 dB. This places construction noise second only to transportation noise in the national ranking of sources contributing to community noise impact. These figures are only approximate, but they serve to illustrate the construction noise problem. Moreover, they do not include the large number of people who are impacted briefly but not insignificantly as they pass construction sites on their way to work or at other times.

Construction noise, in all its forms, possesses the characteristics to cause significant effects to either the operator or the community. The high noise levels produced by the equipment make the construction process one of the more annoying and irritating sources of noise.

In today's urbanized society most people are exposed to construction noise at some time or another, whether it be from a project in the community or merely passing a number of projects on the way to work or to the restaurant at lunchtime. Projects involving highway construction modification or repair, in the community or in rural areas, are especially annoying because the community is exposed to a new and unusual source of noise.

In the past, construction has been typically a transient activity, representing a nuisance of only limited duration. Today, large construction projects are spanning greater time periods. An increase in the numer of projects also means that there is nearly always some activity in most neighborhoods. The result is that, while construction noise as generated at a single site may exist for a limited time, the integrated effect when considering all construction sites in a community results in virtually a continuous noise intrusion as viewed by residents. This, in part, may have led to declining public tolerance of construction site noise.

Past surveys of significant noise sources at construction sites indicate that even when construction noise does not exceed the everyday background noise levels, concurrent attitudinal surveys often reveal that a majority of the community's residents close to the construction project are annoyed by it. Such friction between a community and a construction project can often be attributed to a lack of information or communication rather than

any one specific source of annoyance. Specific complaints concerning excessive noise may only be secondary symptoms of more generalized problems which the community may be ill-equipped to define. The combination of traffic congestion, dust, odor, litter, noise, night operations, lighting, site safety, etc., can be annoying, irritating, and even hazardous. Further, when a citizen is highly aggravated by some aspect of a construction project and is met with nonresponsive attitudes, he can devleop powers of sensory perception which potentially can result in costly delays or even project cancellation.

Another attitude that is an important variable in noise annoyance is that usually described as "preventability". Respondents in the community have been asked simply to indicate whether they considered that noise from the various construction sources could be reduced and, if so, by whom. The results indicate that the relationship between preventability and annoyance is stronger than that between preventability and actual exposure. The relationship between the preventability attitude and construction noise annoyance has been found to be such that an annoyed person was twice as likely as one not annoyed to feel that noise from construction sites could be prevented or reduced.

It is fairly clear that the noise from construction sites can be a significant annoyance to the local community, even though the absolute magnitude of the annoyance is difficult to specify. Moreover, there may be an increasing tendency for the public to object to the noise, due to the levels produced and its irritating quality, and that this tendency will most likely accelerate as construction activity becomes more widespread.

As a result of the growing national environmental awareness, the need for assessing and mitigating the impacts due to the

noise emitted from highway construction sites has been recognized by federal, state, and local agencies. It has been estimated that approximately 7,000,000 people are exposed to some part of about 1750 hours per year of federal and state highway construction noise. The noise levels reaching this population are high. FHWA estimates that indoor noise at residences at highway construction site boundaries often exceeds 65 dBA which precludes normal speech, interferes with sleep, and can be very annoying to most people.

The Federal Department of Transportation has the legal basis for action to mitigate this excessive noise. This legal basis can be found in Section 109(h) Title 23, Code of Federal Regulations.

To meet the requirements of Title 23, the Federal Highway Administration (FHWA) has promulgated the Federal Highway Procedure Manual (FHPM) 773 which requires construction noise to be addressed as follows:

1. Identify land uses or activities which may be affected by noise from construction of the highway. The identification is to be performed during the project development studies.

2. Determine the measures which are needed in the contract plans and specifications to minimize or eliminate adverse construction noise impacts to the community. This determination shall include a weighing of the benefits achieved and the overall adverse social, economic and environmental effects of the abatement measures.

3. Incorporate the needed abatement measures in the contract plans and specifications.

The FHWA has a legislative mandate to act to reduce or, if possible, eliminate adverse environmental effects of highway construction. They have an ongoing research study to develop procedures and standards for predicting and mitigating construction noise and it is anticipated these will become available in the future.

The California Standard Specifications (Section 7-1.01N) state that all internal combustion engines used on the job shall be equipped with a muffler of a type recommended by the manufacturer. Section 42-1.02 states that the noise level from grooving operations shall not exceed 86 dBA at a distance of 50 feet. Section 42-2.02 states that the noise level from grinding operations shall not exceed 86 dBA at a distance of 50 feet.

The Caltrans Special Provisions for a project may required limitations on work hours and/or noise levels.

Traffic/Operations

Noise pollution occurs as a result of vehicles traveling at relatively high speeds on highways.

A critical factor in noise prediction and ba rier design is an accurate count of autos, medium and heavy trucks. Their speeds and noise emission levels must also be known as well as other variables.

Strategies for minimizing noise through traffic control are:

1. Eliminate truck traffic on certain highways.

2. Place speed limits through certain areas.

3. Traffic control by restricting truck traffic during certain hours.

4. Strong enforcement program enforcing the vehicle codes.

5. Regulations controlling the noise source by requiring lower noise emission levels on new trucks.

6. Education of vehicle operators in operation and maintenance of vehicles as related to noise.

WATER QUALITY CONSIDERATIONS FOR TRANSPORTATION PROJECTS

Prepared
by the
Water Quality Section
ENVIRO-CHEMICAL BRANCH

For Training Purposes Only
Transportation Laboratory Training Course
Sacramento, California

Pollution of water by transportation activities is classified principally into three categories: 1) Physical, 2) Chemical, and 3) Biological. Each of these types of water pollution represents a potential impact on the environment. Understanding the nature of the "changed" environment resulting, for instance, from a highway activity assists in determining the probable water quality impact on downstream water users.

In the study of water quality, the watershed is taken as the unit of study. Within the watershed, many working systems exist, such as soil-plant-animal and water-atmosphere. The highway activity commonly traverses a watershed in some defined manner. It may affect conditions both above and below the crossing. Thus, it is desirable to study conditions throughout the watershed in order to understand system relationships. Once the "system" is defined, the impact caused by the "changed" environment can be ascertained. Water quality criteria help determine whether the impact is negative or positive. The criteria also point to the proper remedial measures required either to enhance the environment or decrease the adverse effects.

Physical Pollution

The major impact resulting from highway facilities generally is erosion and subsequent sedimentation. This impact is classified as physical pollution. Investigations have revealed erosion of highway slopes to be a significant contributor of sediment in streams and lakes.

Erosion of barren slopes occurs through rain-drop impact and by surface runoff. In some regions of the state, where annual precipitation is less than 10 inches, wind is the major erosive agent.

Gully and rill erosion are the most obvious types observed. This is so because they leave scars on the landscape. Sheet erosion, however, is also a predominant erosion type. It occurs uniformly over the surface of a slope and is thus more difficult to detect for the untrained eye.

Natural geologic erosion occurs over a long period of time and allows ecosystems to adapt to the slow changes in the environment. Accelerated erosion is attributed to the activities of man whereby drastic changes to the environment occur so rapidly that ecosystems find difficulty in adapting to the change.

The severity of slope erosion is controlled mainly by factors such as soil type, vegetative cover, precipitation (quantity and intensity), slope (angle and length), slope aspect, climatic conditions, and land use.

In California, severe to very severe erosion potential is found in the southeastern, southern and foothill region of the Sierra; and north and south coastal areas. The Sierra-Nevada and northeastern portions of the state are moderately erosive in nature and the valley area is classified as having low erosion potential. There are exceptions to these general classifications on a microenvironmental scale however.

Adverse effects of erosion and sedimentation include the addition of nutrient particles to streams and lakes. In some cases, the addition of nutrients can help to accelerate eutrophication (the natural aging process) of the water system. The principal nutrients leached from the eroded soil are nitrogen, phosphorus and carbon compounds.

Sediment deposits on the streambed are detrimental to the propagation of fish which rely on the clean gravel beds for spawning. Fish foods which thrive on the streambeds are also adversely affected by increased sediment deposits.

Deposits of eroded material in drainage systems also decrease the flow capacity of the facility. During periods of high flow, over-bank flooding could occur from the decreased conveyance capacity. Sediment bearing waters increase in "bulkiness" which means a larger volume per unit time is required versus that for relatively clean water.

Sediment build-up at down-slope areas periodically suppresses emerging vegetation. In some cases, it has also covered the aeration zone (located within the drip-line of trees) required for vigorous growth of larger vegetation species.

Maintenance costs required to remove sediment from drainage facilities and "repair" badly eroded slopes can be sharply reduced through a comprehensive erosion and sedimentation control plan.

An estimate of the probable amount of erosion on highway slopes for a specified period of time can be performed through a field survey. This information can be used in estimating potential environmental impacts and also in the design of mitigation measures such as sediment basins.

Translab conducts a 3-day training course in estimating slope erosion from road slopes. Methods discussed include the Universal Soil Loss Equation, Slope Transect Method, and Slope Trough Technique.

Actual sediment transport in streams can be determined so that comparisons can be made with estimated slope erosion rates. These measurements will include sediment from all sources upstream of the sampling site. Sediment is primarily transported in two modes: 1) suspended sediment and 2) bed load. The suspended sediment represents the "finer" material that is held in suspension by the turbulent forces of the water. The "coarser" material, called bed load, are particles that roll, slide and skip along the bottom of the stream. The interchange between suspended sediment and bed load is definable for each reach of the stream and is dependent upon the streamflow characteristics, physical configuration of the reach, the sediment properties, and the quantity of water available to serve as the transport agent.

To measure sediment transport, the streamflow must be known. Methods of determining streamflow include actual measurement, streamgage recorder, or synthesis.

Suspended sediment samples are obtained after selecting a good sampling site. Such a location would include a representative section of channel, fairly uniform streamflow lines, no flow impediments immediately upstream, such as a bridge pier, and accessibility.

Samples are obtained from uniform vertical sections of the stream. A US-DH-48 or US-DH-59 depth-integrating sampler is used to collect the sample in one-pint bottles.

Laboratory analysis of the sample can be made by filtering the suspended material and weighing the "dry" residue. The results are reported as mg/l concentration.

From determinations of the instantaneous sediment transport rate, a sediment rating curve can be developed to relate streamflow to suspended sediment discharge. An analysis of annual streamflow values can then be used to estimate the suspended sediment yield.

Bed material can be obtained by "grabbing" several representative samples across a stream width. A US BMH - 60 Hand-Line bed-material sampler or a US BMH - 53 Piston-type bed-material hand sampler are typical examples of equipment used for this purpose. Bed material is the sediment undergoing transport and not the in-place material of the channel bottom. A size analysis is performed on the material (in millimeters) and the Meyer-Peter, Muller Bedload function can be used to compute transport rates for gravel and Colby Method for sand sized particles.

For a sediment transport study over a long period of time, a sampling program must be developed that will yield comprehensive results. In these instances, more elaborate hydrologic equipment may be required to take into account diurnal flow characteristics and a detailed sampling plan formulated. Sediment rating curves combined with mean monthly flows will assist in determining annual transport quantities.

Chemical Pollution

Chemical pollution of water from highway sources occurs primarily through use of products for deicing, and weed, rodent, and insect control. Runoff from the highway facility may carry residue from these products into nearby streams or lakes. A constant build-up of chemicals in a defined aquatic life system may lead to adverse effects.

Certain species of vegetation may be sensitive to deicing salt whereas others may have a high salt tolerance. Biostimulation of undesirable phytoplankton or algae by trace elements in salt can occur. Research continues in this area to determine the biostimulatory nature of chemicals and recommend specifications for the use of salt.

Toxic materials are particularly of concern to prevent contamination of sources not intended for its use. Most of these materials are used during the operation and maintenance phases of the highway program. Hazardous spills also pose a threat to environmentally sensitive receptors such as domestic water supplies.

Chemical analysis of water samples and the common methods used follow approved testing procedures of the Environmental Protection Agency as outlined in the Federal Register of December 1976. Some of the Transportation District Laboratories have set up certified water testing labs. Translab operates a Quality Assurance Program to insure that results are accurate and reliable. District personnel attend a 3-day lab training session conducted by the Translab. Re-certification of the district labs is made every 3 years by Department of Health. Advanced testing methods are carried out at the Translab on atomic absorption and spectrophotometric equipment. Due to low holding times for testing some chemicals, the Districts may have to arrange for advanced testing by local laboratories nearer to their facilities.

Chemical tests include dissolved oxygen, conductivity, pH, hardness, chloride ion, alkalinity, and nutrients. Heavy metals, oil and grease may be tested for urban type highways.

The parameters that are selected for study are determined from knowing the scope of the project, water quality criteria of beneficial water users, and ecosystem relationships. A study

Paint Research (General)

This laboratory maintains extensive contact with raw materials companies through their technical representatives. We are thus able to keep abreast of the latest developments in the field of paints. We formulate many paints on the basis of our own experiments and suggestions from these raw materials suppliers. We also check proprietary samples of paint from various paint companies.

All paints used by the Department of Transportation have been reformulated so as to comply with the various air pollution requirements. The components of our specification paints are selected so as to guard against any toxic materials that might be injurious to the health of the workmen.

A recent model rule by the California Air Resources Board would require the development of high solids or water-based paints. A few specialized low solids, solvent-based paints such as traffic line paints and concrete curing compounds, which are now exempt under this guideline, will be required to conform by 1982, after adoption of rules by each air pollution control district. A great deal of research effort will be required to reformulate all our paints in order to conform to these newer regulations.

1. Traffic Paints

Through traffic paint research, the Chemical section has developed compositional specifications for rapid drying traffic paints, capable of bearing traffic in 30 seconds or less when heated to 160-180 degrees F. The paints were designed for use in Caltrans' heat striper, which uses no open flame or heat exchanger to heat the paint. The paint is heated by a high speed kinetic type heater which heats by friction.

abundance of bottom dwelling organisms in a stream (macroinvertebrates) will provide insight into the present condition, as well as past events. In polluted or disturbed (detrimentally impacted) aquatic environments the complexity of the macroinvertebrate community is reduced when compared to a "normal" and comparable stream community. The change in the community is reflected by changes in diversity and this can be computed from biological monitoring data. This information allows an interpretation of the degree of ecological impact on the organisms utilizing a particular aquatic ecosystem. In addition to the macroinvertebrate communities other assemblages of organisms such as plankton in lakes, periphyton on stream bottoms and fish populations can be used as sources of biological impact information.

The Biology Unit assists districts in performing environmental investigations, and provides ecologically and biologically oriented assistance when requested.

Summary

The principal categories of water pollution are 1) physical, 2) chemical, and 3) biological. Understanding the "system" in which the highway facility or activity will intrude is necessary to formulate an impact assessment.

An environmental study should be developed for a particular project that is fitted to the needs or conditions of the anticipated problem. Insufficient data or inadequate sampling can be eliminated by properly formulating the water quality survey in the early stages of a project study. Coordination of activities with affected agencies will assist in developing a comprehensive and acceptable plan.

Research by Translab Water Quality Section continues in the areas of:

- Revegetation
- Solid Waste Disposal
- Deicing Salts
- Ditch Linings for Erosion Control
- Pavement Runoff Contaminants
- Biostimulatory and Toxic Effects of Pavement Waters
- Ecological Considerations
- Treatment of Wastes at Roadside Reststops

Research reports are produced to assist districts in implementing the findings. Test Methods are produced and training manuals developed to assist in the on-going work in the districts. Special studies are conducted where needs arise. Training courses are offered in: 1) Basic Water Quality for Transportation Systems, 2) Slope Erosion Estimates, 3) Biology, and 4) Chemical Testing.

Rainfall Simulator

The TransLab Water Quality Section also has responsibility for a rainfall simulator. This apparatus is capable of generating high intensity, non-wind driven rainfall with large droplet sizes for testing samples as large as 4 ft by 8 ft.

This facility will be used to test erosion control products and techniques used on California's highways and to conduct erosion control research.

CHEMISTRY OF MATERIALS FOR TRANSPORTATION PROJECTS

Prepared
by the
Chemical Unit
ENVIRO-CHEMICAL BRANCH

For Training Purposes Only
Transportation Laboratory Training Course
Sacramento, California

CHEMICAL SECTION

PROJECT DEVELOPMENT/TRAFFIC/OPERATIONS

Decisions on types of materials to be used on projects are usually made during project development and often are carried to the final contract stage without adequate investigation as to the suitability of the material for a specific use.

At the project development stage, use of the Transportation Laboratory expertise could be a definite asset in the selection, use, and application of a particular material. Such an evaluation would also include the possible hazards in the use and handling of the particular material and its possible effect on the health and welfare of both the public and the project personnel.

The Chemical Section performs chemical analysis on almost any type of material used in highway construction, including bridges. Also water and air quality analyses are performed for determination of mineral content with potability determinations for water handled by state or local health departments.

Specifically, the Chemical Section does routine analysis on paints, portland cements, soils, steel, water, concrete, and various plastics, adhesives and rubbers.

Formulation of paints and adhesives has been a continuing federally financed research project for many years. The Chemical Section has developed, through research, a series of epoxy adhesives suitable for highway and bridge use.

Continued research in the field of paints, especially structural steel and traffic paints has led to a series of compositional formulas which are used extensively in a competitive bidding process for all traffic and structural paints.

HIGHWAY CONSTRUCTION/MAINTENANCE

During the actual construction of highways and related facilities and in the maintenance phase following construction, the Chemical Section is available both on an advisory basis and a service branch to check materials for compliance to specifications.

Routine Analysis

Following is a list of products commonly tested in the Chemical Section laboratory along with representative tests:

Paints

Paints from the factory and from the field are tested for the amount of pigment, pigment composition, vehicle composition, weight/gallon, viscosity, total solids, and application properties.

Cements

Cements are tested for oxides of calcium, iron, magnesium, silicon, aluminum, sulfur, sodium and potassium; insoluble residue and ignition loss. From these values, theoretical compositions are calculated which are used in determining the type of cement, and verifying conformance to specification.

Soils

Soils are sometimes tested for complete mineral content, but more often for pH, sulfate, and chloride, to determine the corrosive nature of soils for use against concrete or steel structures.

Steels

Galvanized steel products are tested for weight and uniformity of coating. Complete chemical analyses are performed on structural steels and alloys.

Waters for PCC and Corrosion Studies

Waters are usually analyzed for pH, sulfate, and chloride; however, complete mineral analyses are run when requested. We are not equipped to do bacteriological analyses on waters.

Cement Content

The cement content of a concrete is determined from the calcium oxide content of the concrete.

Adhesives

Adhesives used by the Department of Transportation for bonding raised traffic markers, making concrete repair, installing joint sealants, etc., are tested by this laboratory for conformance to specifications.

Joint Sealants (two component type)

Materials tested are for sealing bridge deck and pavement joints. Control of these materials is critical since the movement of bridge deck joints is so great that it is difficult to obtain a material which will perform satisfactorily in the field.

Environmental Samples

Because of public concern over the impact of the automobile on the environment, programs monitor particulates in air on and near freeways to measure changes in water quality in watercourses resulting from highway construction activities.

Samples are taken by Transportation Laboratory or District people under the direction of the Enviro-Chemical Branch. Chemical laboratory personnel perform tests which cannot be done in the field. At present, we analyze particulates in air samples for lead content and sulfur.

Water samples are tested or analyzed for the following:

Total Metals by Atomic Absorption

Cadmium	Manganese
Calcium	Mercury
Chromium	Molybdenum
Cobalt	Nickel
Copper	Potassium
Iron	Sodium
Lead	Zinc
	Magnesium

Other Determinations

Alkalinity	Nitrogen
Chloride	Fluoride
Conductivity	Total Hardness
Chemical Oxygen Demand	Total and Suspended Solids

Miscellaneous (Anti-freeze, Brake Fluid, Wood Preservatives, Etc.)

These are tested for conformance to specifications.

Paint Research (General)

This laboratory maintains extensive contact with raw materials companies through their technical representatives. We are thus able to keep abreast of the latest developments in the field of paints. We formulate many paints on the basis of our own experiments and suggestions from these raw materials suppliers. We also check proprietary samples of paint from various paint companies.

All paints used by the Department of Transportation have been reformulated so as to comply with the various air pollution requirements. The components of our specification paints are selected so as to guard against any toxic materials that might be injurious to the health of the workmen.

A recent model rule by the California Air Resources Board would require the development of high solids or water-based paints. A few specialized low solids, solvent-based paints such as traffic line paints and concrete curing compounds, which are now exempt under this guideline, will be required to conform by 1982, after adoption of rules by each air pollution control district. A great deal of research effort will be required to reformulate all our paints in order to conform to these newer regulations.

1. Traffic Paints

Through traffic paint research, the Chemical section has developed compositional specifications for rapid drying traffic paints, capable of bearing traffic in 30 seconds or less when heated to 160-180 degrees F. The paints were designed for use in Caltrans' heat striper, which uses no open flame or heat exchanger to heat the paint. The paint is heated by a high speed kinetic type heater which heats by friction.

This system allows traffic lines to be applied under traffic, with a minimum of delay and without the use of traffic cones. The system upgrades safety to both the striping crew and the public, since minimal traffic delay is caused during the stripinn operation. The system has been used in California since 1972 with 10 hot stripers in the state.

This rapid dry traffic paint has been tested against traffic paint from various states across the U.S. and has shown itself to be as good as the best that has been tested. Due to the compositional formula and strict attention to using the most economical materials while providing the optimum in wearability and application properties, this paint has consistently shown lower cost per gallon on a competitive bid basis than the majority of commercially available traffic paints. A conservative estimate of cost savings, using state specification paint would be at least $150,000 per year, based on about 500,000 gal/year usage.

The Chemical section has also developed a fast dry traffic paint for use in the older, conventional, air atomized striper units, which have no capability for heating the paint. This type of paint dries cold with no heat in about 5 minutes.

Both the rapid and fast dry types are used extensively by cities, counties, and out of state agencies. The latest research effort has affected a substantial cost savings in both the rapid and fast dry types. This savings in raw material costs would amount to about $0.40/gal or about $200,000 per year. Field tests on this material are currently in progress (1979).

In 1977, the California Air Resources Board (CARB) issued their model rule on the use of paints containing solvent, including

all architectural and traffic paints. This ruling so restricts the amount of solvents allowed that all our present paints, including traffic paints, would become obsolete. This rule is a model rule, to be adopted or altered by local air pollution districts. To date the trend for the local districts has been to accept the model rule essentially as written.

Since this CARB rule becomes effective September 1982, efforts have been made in the Chemical Section to investigate alternatives for the existing traffic paint systems. A federally financed project has been underway for about 1 year to assist in the investigation of these alternatives.

The possible alternatives to date are as follows:

1. Water-based traffice paints
2. Hot melt thermoplastic spray
3. Hot melt epoxy resin spray
4. Two component epoxy spray
5. Polyester spray

Water-Based Traffic Paint

The system requiring the least equipment change to existing striping units is the water-based system. The Chemical Section has been actively engaged in encouraging several California paint companies to provide their own water-based formulations for preliminary testing in our laboratory. To date we have applied water-based traffic paint from two vendors with encouraging results. Preliminary indications show that the water-based paint, when completely cured, does provide a satisfactory traffic line with acceptable wearability. To

date all water-based traffic paint has been applied with the hot striper. Heating to at least 130°F has been necessary to provide a good spray pattern, due to the high initial viscosity. Dry time at 130°F has been about 4 minutes which is certainly a vast improvement over the older water-based paints with dry times from 30 to 60 minutes or more.

The biggest problem with the water-based paint is that application cannot be made during rain periods, even when the road is dry before application. Subsequent rain or heavy fog before the paint has thoroughly dried will soften the film which is then easily removed by traffic.

Hot Melt Thermoplastic Spray

This system, using hot thermoplastic at 450-475°F, is sprayed thru an air atomizing paint gun, and has been applied under contract in California. Service life has been acceptable when applied at 60 mils thickness or more. This system requires specialized striping equipment and at the present time can only be applied on a contract basis by a limited number of companies in the USA. Smaller units for smaller application are being leased by our maintenance forces.

Hot Melt Epoxy Resin

This system was developed by Southwest Research Institute under federal grant. This system uses a solid epoxy resin plus fillers and simply melts the mass with agitation and then sprays it out thru an airless spray tip with about 40 lbs. of air pressure. No catalyst or hardner is used. Applications on I-80 near Donner Summit were satisfactory until the first snow storm when snow removal operations also removed about

60% of the line. A test area in Los Angeles, near Redondo Beach on SR1, has proved quite satisfactory after several months of service in a high traffic density location. This system also requires specialized equipment.

Two Component Epoxy Spray

This system uses a liquid epoxy resin and hardner and is applied by a highly sophisticated application unit. The cured traffic line is very tough and durable and has withstood service reasonably well in the Lake Arrowhead area during the winter of 1978-79. There is no question as to the superiod toughness of the epoxy traffic line but again the traffic line would have to be applied on a contract basis and at considerable expense. For some critical areas the expense might be justified.

Polyester Spray

A two component polyester system was tested in the laboratory and our initial reaction was not too favorable due to the high shrinkage rate of the cured material, its lack of adhesion to asphaltic concrete, and the use of a hazardous catalyst.

Thermoplastic Traffic Line Markings for Legends or Cross Walk

a) Hot Melt Type

This material is heated in an oil bath and applied to the road at 400°F at a thickness of from 3/32 inch to 1/8 inch. Time to bear traffic is 3 to 5 minutes. This thermoplastic traffic line is a mixture of a thermoplastic resin together with glass beads, titanium dioxide, and inert filler. The material is

applied where high traffic density gives a very short service life to traffic paint. Crosswalks and on and off ramps on freeways account for the major volume of this material. A thermoplastic line tends to become dirty on the surface due to skid marks, but these marks generally wear off in time.

b) Flame Spray Type

This is flame sprayed on the road surface to a 6 to 8 mils thickness and will bear traffic in 30 seconds or less. This is especially suitable for crosswalks or legends.

2. Bridge Paints

The coastal area around Cambria on US 101 is an extremely severe envrionment for bridge paints and provides ideal field conditions for a test section. Many paint systems have been tested in this area, and other areas along the coast, as well as in the laboratory Two general systems showed superior performance and have been used for many years.

a) A multiple vinyl system applied in 4 to 6 coats with 6 mils total thickness, gives service life two to three times that of a conventional red lead bridge paint. The cost is about 20% greater than for a red lead primer and finish coat.

b) A single component zinc-rich primer usinn a phenoxy binder, with either an alkyd or vinyl top coat.

Water-Based Bridge Paints

The solvent-based bridge paints do not comply with the volatile organic content restrictions of the California Air Resources

Board. Consequently, much emphasis is being placed on federally funded research to develop effective bridge paints which comply with the restrictions. In addition to the CARB restrictions, There is much concern over the use of pigments containing lead and chromium, due to their toxicity. These pigments have been the most effective for corrosion resistance in primers. With these restrictions in mind, the Chemical Section has done extensive testing of water-based paints using raw materials manufacturers' formulations and varying different parameters in their formulations. Our goal has been to develop a water-based system with performance at least equal to a red lead system which is still used by a majority of states. Accelerated laboratory test results are being correlated with results from panels exposed on a test underneath the Golden Gate Bridge in San Francisco. Some of the better paint systems, as determined by these tests, are currently being applied to several structures in the state on an experimental basis. Five additional structures are being scheduled for these systems in 1980. Accelerated lab tests do not always correlate with actual exposures, so these jobs are being closely monitored by lab personnel to evaluate various application problems which may not be apparent in the lab. Preliminary results are encouraging and accelerated tests appear to show some water-based systems much superior to red lead systems. As manufacturers develop new materials, we are confident that through continued research and testing we can adequately protect steel structures with environmentally acceptable coatings.

3. Epoxy Mortar or Concrete

The use of epoxy mortar or concrete has decreased considerably due to the success of other fast setting materials such as Set 45, a magnesium phosphate cement and Cement Fondu, a high alumina cement.

4. Bonding Raised Pavement Markers to the Roadway

A rapid set and a slower or standard set material are available for use. This is probably the largest and most successful use of epoxy resins.

Polyurethane Resins

a. A specification has been developed for a polyurethane resin. This material does not become brittle at low temperatures and can withstand impact better than epoxy resins. Its first use has been for headers and general patching. Again Set 45 may prove to be a cheaper more easily applied material.

Raised Pavement Markers, Research and Application

During periods of rainy weather, the painted stripe on the pavement becomes invisible, especially at night. For daytime visibility, a properly formulated raised nonreflective marker is adequate in both clear and rainy weather. For nighttime visibility, a reflectorized raised marker is required for proper visibility.

Both the reflective and nonreflective markers are stained badly by tires during hot dry weather. This reduces the visibility of the markers to the extent that some improvement is needed, especially during the late summer.

During winter months, the tire stain is quickly removed. The efficiency of old reflective markers is also much better during wet weather than during dry weather, because the water fills surface scratches. Thus the present marker system is at its best when it is needed most.

Environmental Water Quality Testing

Since the Districts are required to prepare environmental impact statements, TransLab assist them in establishing Water Quality Control Laboratories. Standard test methods were evaluated and published for their use and lists of required equipment and reagents were furnished to the Districts. Assistance is given to enable the Water Quality Control Laboratories to obtain certification from the California Department of Public Health.