Flexural Beam Testing Requirements

June 30, 2015

Materials/QA & CIP Pavement Subtask Group

Concrete Task Group, Rock Product Committee

Disclaimer(s)

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Executive Summary

An evaluation of the Caltrans and ASTM flexural strength test methods was made (CT 523 and ASTM C 31, ASTM C78). A literature study of the history and development of the test methods was performed. A survey of Caltrans and Industry field personnel was done to help to understand the current application and variability of the Caltrans test method CT 523. A number of significant variables affecting flexural strength were identified in CT 523. These variables are found better controlled in the ASTM Standards.

Caltrans State Materials Engineer's policy is "Whenever possible, Caltrans will change its CTMs to reference appropriate national standards. This will ensure consistency and ease of project delivery amongst Local Agency, Caltrans, and Contractor stakeholders" (METS/GS Directive -05). It is the recommendation of the Flexural Beam Test Method Investigation Team that CT 523 be replaced by ASTM C31 and ASTM C78. Standard curing should be used for acceptance testing. Field curing should be used to determine strength for opening pavement to traffic. Minor costs to Caltrans may result from obsolete equipment replacement and training of personnel. The benefit of reduced claims and construction delays are anticipated. Impacts of these recommendations are considered in this report and should be addressed prior to implementation.

1.0 Introduction

Caltrans uses CT 523[1] to determine the flexural strength of concrete used in pavements. The results of CT 523 are used to determine the opening age to traffic and the acceptance of constructed concrete pavement. There have been discrepancies on CT 523 test results. For example, in some instances the later age strength tests have been less than the early age strength tests.

Industry expressed concern that the acceptance strength for concrete pavement is influenced by factors which are out of their control, such as environmental conditions, specimen fabrication, transportation, and storage. Also, Industry expressed concern that the certification and accreditation for third party labs and non-Caltrans personnel is inconsistently managed and enforced throughout the State. Industry requested the review of CT 523 and comparison to similar national standard testing (ASTM and AASHTO) pertaining to the material sampling, test specimen fabrication, curing, handling, and testing so a recommendation could be made as to the best test method or path forward to resolve existing issues.

The scope of this activity was focused on selecting the most appropriate test method and does not include implementation action including revision to the specification.

A joint Flexural Beam Test Method Investigation Team was formed comprised of 12 voting members from the Materials/QA Subtask Group and CIP Pavement Subtask Group to review the above stated issues and provide recommendations under the guidance of the Standard Project Work Plan and Rock Products Charter. The Project Work Plan is presented in Appendix 1.

[1] California Test 523 – Method of Test for Flexural Strength of Concrete

1.1 Purpose

The purpose of this document is to present the findings of the Flexural Beam Test Method Investigation Team and:

1. Recommend appropriate testing methods for acceptance testing of cast in place concrete pavement with the use of flexural beams.
2. Identify the current practices throughout the state in regards to CT 523 management and certification for all technicians performing these tests and the accreditation of Caltrans and third party laboratories.

1.2 Background

The earliest research on California's testing method for flexural strength (later to be named California Test 523 [CT 523]) appeared in a report published in January 1967. Caltrans sought to improve upon ASTM C31[2] and ASTM C78[3] that were already in place. The main focus of Caltrans' experimentation was to see if smaller test samples could be used and still provide accurate, reliable results. ASTM later followed Caltrans' lead and also allowed for smaller test sample sizes. At the time CT 523 was developed it was determined that this was the best method to determine the strength of in-place concrete pavement before opening the roadway to traffic. Today, many other states use either AASHTO or ASTM test methods. These test methods are commonly accredited and certified by AASHTO and ACI. These test methods are supported by national organizations that keep the test methods current and up to date. New Caltrans State Materials Engineer's policy is "Whenever possible, Caltrans will change its CTMs to reference appropriate national standards. This will ensure consistency and ease of project delivery amongst Local Agency, Caltrans, and Contractor stakeholders" (Appendix 2).

1.3 Definitions

As with most industries, the concrete industry has a variety of terms that have industry specific definitions. The following is a list of definitions for the industry specific vocabulary used within this document.

Acceptance Age – the time at which the pavement must comply with contractual obligations.
Opening Age – the time at which the pavement is ready for use.
Standard Cure – a single cure method for all specimens as defined by ASTM C31.
Field Cure – curing specimens in the field under a variety of methods as defined by ASTM C31.
3rd Point Loading – testing apparatus that applies a constant moment to the middle third of a beam.
Center Point Loading – testing apparatus that applies a point load to the center of a beam.
Caltrans – California Department of Transportation

[2] American Standard Test Method C31 – Standard Practice for Making and Curing Concrete Test Specimens in the Field
[3] American Standard Test Method C78 – Standard Test Method for Flexural Strength of Concrete

Industry – Concrete producers, contractors, and commercial testing laboratories
DOT – Department of Transportation

2.0 Objectives

The objectives of the flexural beam test method investigation were as follows:

1. Summarize current practices within Caltrans and other State DOTs (including testing, staff certification, lab certification, certification frequency, what accreditations are the labs obtaining, etc). Summary of current guidelines within Caltrans (and other State DOTs) including the IA Manual and Construction Manual.
2. Perform literature search for: a) Factors influencing performance of CT 523/ASTMs/Other State DOT Test methods. b) Any available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods. (Documents pertaining to CT 523 should be located in Caltrans files and/or archived records.) c) Details relating to the basis for the standard specification change, specifically Section 40. Section 40 of the standard specifications went from allowing 16% variance between two specimens to16% variance from the average of two specimens.
3. Prepare decision document that analyzes possible impacts to the Department and Industry (economic, logistical, etc.) Examples: Equipment, training, manual updates, design impacts, contract administration and specification updates. Analyze impacts: a) if the recommendation is made to switch to ASTM, b) if the recommendation is made to stay with CT 523.
4. Based on the decision document, gain consensus amongst the team to provide a recommendation to the Concrete Task Group as to which method is best. If a test method cannot be recommended, recommend a path forward. If a test method can be recommended, recommend to modify the specifications accordingly.

The approved Scoping Document established the specific information that was needed in order to make a recommendation on the testing requirements for flexural beams. The approved scoping document is presented in Appendix 3.

2.1 Methodology

In order to accomplish the above stated objectives, information was needed pertaining to the driving factors behind the creation and maintenance of CT 523, ASTM C31 and ASTM C78. Field data was needed to understand how CT 523 is being practiced in the field and its variability. Information from other DOTs on concrete pavement practices and acceptance testing was also needed for the comparative study. Four sub teams were formed and assigned to research and collect reasonable information within the stipulated timeframe and submit the following specific deliverables:

1. Summarize current practices within Caltrans and other DOTs.
2. Summary of investigation of factors influencing performance of CT 523, ASTMs and other DOT test methods.
3. Summary of available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods.

4. Explanation of details relating to the basis for the standard specification change, specifically Section 40 for determining difference of individual test results.

The following tasks were performed to gather pertaining information:

- Literature search on the individual test methods (CT 523, ASTM C31, ASTM C78, AASHTO T23, and AASHTO T97).
- Literature search on other DOT's pavement testing practices and acceptance requirements.
- Caltrans internal survey on pavement strength testing practices.
- Industry survey on the pavement strength practices on Caltrans projects and non-Caltrans projects.

3.0 Findings

3.1 Literature search on the development of CT 523

Over 1200 documents were reviewed but no documentation on the early development of CT 523 was found. However, the following information was found pertaining to the use of flexural strength for concrete pavement acceptance:

- A Caltrans (then Department of Public Works) technical report, Concrete Beam Breaker, December 1967 indicates recommendation of third point loading (TPL) and 18 inches span for field testing. Flexural strength results from third point loading were found relatively less than the single central point loading (SPL) strength. The report recommended using TPL strength of 400 psi equivalent to SPL strength of 450 psi.
- A Caltrans (then Department of Public Works) technical report, A Study of Flexural Strength vs. Indirect Tensile Strength, January 1967 suggested to utilize flexural strength instead of indirect tensile strength (IT) as reliability of IT testing was found relatively less than flexural strength.

3.2 Literature search on the development of ASTM C78

A literature investigation was done on the development of ASTM C78 and the factors influencing its performance. Given the national scope of ASTM, the long history of its test methods, and the support of its test methods by academia the information available on the development and performance of ASTM C78 was substantial. The key findings on factors influencing the performance of ASTM test methods are summarized below. A detailed summary of the investigation is presented in Appendix 4.

- Third point loading (ASTM C78) will produce lower strength result than the center point loading (ASTM C293). ASTM reports that beams tested under single point loading yield an average modulus of rupture approximately 14% higher than third point loading. The standard deviation of test results is lower for third point loading than center point loading.

- The within specimen coefficient of variation can be greater than 5%, with difference between two tests on the same specimen approaching 100psi. The average between-test standard deviation is less than the average within-test standard deviation (Greer, 1983).
- 1 to 2 days drying of initially moist cured specimen prior to loading can reduce the modulus of rupture by 200 psi or more (30%). Several studies show large reductions in flexural strength with non-standard curing (Meininger & Nelson, 1991). Drying of specimens is detrimental to early age strengths (less than 90 days). As drying becomes more thorough, a sharp reduction in strength is encountered when immersed in water before (24-48 hours) testing (Bloem & Walker)
- Concrete with larger maximum sized aggregate tend to develop slightly lower flexural strength than that with smaller sized aggregates when compared with identical cementitious contents and water to cementitious ratios.
- As with compressive strength, the apparent flexural strength of specimens increases with loading rate. A linear relationship between flexural strength and the logarithm of applied stress rate has been observed.
- ASTM C31 requires the use of consolidation with vibration of specimens molded with low slump (less than 1") concrete.

3.3 Literature search on other DOT's Practices

Specifications for 23 states were reviewed for their pavement strength testing requirements. The key findings are summarized below. A detailed summary report of other DOT's pavement strength practices is presented in Appendix 5.

- Most of the other states reviewed that utilize flexural beams use a "standard cure" method for acceptance and an "in-place/representative cure" method for opening-age strengths.
- Most of the states using flexural beams use either ASTM or AASHTO for sampling, fabrication, curing and testing.
- States use a variety of acceptance methods including compressive strength of cylinders, flexural strengths with beams or compressive strengths with cylinders correlated with beams/cores, or a combination of both flexural and compressive strengths.

3.4 CT 523 Practices - Caltrans Internal Survey

To discover the current practices within Caltrans, a survey was sent throughout the State to district construction. This survey focused on the application of CT 523 in the field by Caltrans, the certification and documentation of Caltrans personnel, and the certification and documentation of Caltrans testing facilities. The survey findings are summarized below. A comprehensive report is presented in Appendix 6.

- Uniform response that plastic molds are being used to fabricate beam specimens.
- Non-uniform response in regards of use of tamping rod or internal vibrator for fabrication of beams.
- Non-uniform response in regards to who is responsible for keeping sand/soil bed moist.

- Non-uniform response in regards to the number of beams fabricated per test.
- Most responses indicate that Method 2 (simple beam with third point loading) is being used.
- Non-uniform response in regards to what is done when two beam samples are tested and the results do not fall within the precision and bias range (i.e. resolution process).
- Samplers and testers appear to be certified though there is not a standard way of monitoring these certifications (e.g. database).
- Testing equipment appears to be properly certified, predominately by Caltrans.
- Multiple timeframes for notifying the resident engineer of the test results, up to 48 hours.
- Non-uniform response in regards to notifying the contractor of test results

3.5 CT 523 Practices - Industry Survey

To further understand the application and effectiveness of CT 523, a survey was sent throughout the State to the Industry. The intent of the survey was to gather as much information as possible from the Industry's experience. The questions were designed for the responder to evaluate CT 523 for a specific project(s) that they were involved in where CT 523 was used or required. The survey findings are summarized below. A comprehensive report is presented in Appendix 7.

- Many of the comments appear to be based on the Industry's observations of the department's sampling and testing.
- The Industry noted concerns that the beams were not being kept properly damp during curing and transportation.
- A uniform response was received that the Industry prefers ASTM test methods for flexural strength testing.
- Multiple responses stated that internal vibrators were not allowed, but then later stated that internal vibrators are used for fabrication of beams.
- Industry prefers the option to use internal vibrators for consolidation in lieu of tamping rods for fabrication of the beam samples.
- Multiple responses indicated that quality control testing is not being performed by the contractor.
- Multiple responses indicated that beam specimens were placed in curing tanks after the first 24-48 hours of fabrication.
- Multiple responses stated that change orders had to be issued to resolve disputes concerning flexural strength testing.

3.6 Section 40 Explanation Details

The existing procedure for determining the precision of test results in Section 40 is based on ASTM C78 and ASTM C293 test methods. Section 40 states that "Difference in the individual test results of beams aged 28 days must not exceed 12 percent when tested by Method 1, or 16 percent when tested by Method 2. The Engineer calculates the difference relative to the average of the 2 test results" (Section 40-1.01D(13)(c)(2). This is no longer a requirement in Section 40 and has been removed in the Revised

Standard Specifications. An example for calculating the precision of test results per Section 40 is presented in Appendix 8.

4.0 Review of Findings

The following section is a summary of the discussions that the team had on the key discoveries from the findings.

4.1 Current Practices within Caltrans

The following items were discussed in regards to the current practices within Caltrans:

- Caltrans internal survey results indicate inconsistency on the utilization of CT 523.
- Industry findings indicate many anomalies in beam fabrication, curing, handling, breaking of beam and acceptance of flexural strength testing.
- Some districts currently maintain a database of certified personnel, others do not. There is no statewide database to verify personnel or equipment has been certified to Caltrans standards.

4.2 Current Practice within Other DOTs

The use of national standards for acceptance testing was predominant in the states that were reviewed. The use of standard cure for acceptance testing by the vast majority of the states reviewed is noteworthy.

4.3 Factors Affecting Flexural Strength

The group discussed the following key testing items affecting the quality of the beams:

- **Consolidation:**
  Consolidation by rodding on low slump concrete can lead to poorly consolidated specimens, reducing flexural strength.
- **Curing**:
  A controlled curing environment produces more consistent results. Flexural strength is significantly affected by loss of moisture and uncontrolled environmental conditions.
- **Transportation and Handling:**
  Flexural beams are vulnerable to damage at early ages and must be transported with care. CT 523 requires the beams to be stripped within 24 hours before being transported to the curing location leaving the baseplate of the mold to support the specimen. This procedure can lead to moisture loss and physical damage of the specimen. ASTM C31 allows beams to be transported within 48 hours to the final curing location in the molds protecting the specimens from physical damage and moisture loss.

- **Testing Machines:**
  Loading rate and head configuration affect the strength of the specimen. Caltrans may have older machines that don't comply with ASTM requirements for loading rate and head configuration. However, if National (ASTM, AASHTO) test methods are adopted the older equipment that is mostly found in the field labs will no longer be necessary.

4.4 Development of CT 523 and ASTM Test Methods

An extensive amount of literature is available outlining the development, maintenance, and reliability of ASTM C31 and ASTM C78. The development and evaluation of ASTM test methods is continual and supported by many national and international government agencies, academia, and industries. Created over a half century ago, CT 523 has limited supporting data and limited ongoing development.

4.5 Basis for the Standard Specification 40 change

The procedure for determining the precision of test results is no longer a requirement in Section 40 and has been removed in the Revised Standard Specifications.

5.0 General Consensus

Based on the investigation outlined in this document, the Flexural Beam Test Method Investigation Team has reached consensus on the following items. As outlined in the approved Work Plan, the recommendations for flexural beam test method requirements are based on a general consensus obtained from a majority vote.

1. Use only 3rd point loading to determine flexural strength and to maintain the consistency of test results (ref: 12/5/2014 meeting minutes).
2. Use field cured beam specimens for the determination of flexural strength for early opening to traffic (ref: 12/5/2014 meeting minutes).
3. Use standard cured beam specimens for the determination of flexural strength for acceptance testing (ref: 3/10/2015 meeting minutes).
4. Allow vibrators as an alternative means of consolidation for beams (ref: 1/9/2015 meeting minutes).
5. Beams should be transported in their molds irrespective of mold types (ref: 1/9/2015 meeting minutes).
6. Contractor should be responsible to provide the suitable environment for initial curing (ref: 1/9/2015 meeting minutes).
7. Replace CT 523 with similar nationally supported standards ASTM C31 and ASTM C78 (ref: 3/10/2015 meeting minutes).

6.0 Impacts

In this section, the impacts of the recommendations are evaluated. The impacts of the recommendations affect both Caltrans and the Industry.

The requirement to use only third point loading would lead to the retirement of some older testing machines within Caltrans that do not have this capability. However, the older testing machines are found predominately in field offices. The Caltrans laboratories where beams would be tested for acceptance per the recommendation predominately have newer equipment capable of third point loading. Laboratories within the Department and Industry that do not have the capability of third point loading would have to update their equipment.

In order to provide standard cure conditions at the project site, an area would need to be provided to meet the specified conditions. Per the recommendation, this burden would fall on the contractor. This is already a common practice in other states. In Nevada, contractors supply portable sea containers equipped to manage the required conditions of a standard cure.

Additional equipment may be required to conform to the ASTM C31 fabrication standards. This equipment includes generators and vibrators for low slump concrete.

A specification adjustment in Section 40 may be required to clarify the consolidation method in the fabrication of the beams. ASTM C31 only refers to slump for the determination of method of consolidation.

The use of ASTM C31 and ASTM C78 may reduce the variability that is currently being experienced throughout the state with the use a CT 523. It will provide the State with a nationally recognized, supported, and developed standard. The movement from CT 523 to ASTM C78 will require the certification of personnel and equipment to ASTM standards. The QA/QC Structures Initiative has a roadmap that could be used to facilitate this shift.

Based on the research outlined in this document, the majority of flexural beam testing is being done with plastic molds. Steel molds are heavy, burdensome, expensive, and hard to obtain. Plastic molds are less expensive, easily available, and easier to use. Beams cast in plastic molds must be transported in the molds to avoid damaging the beams. If ASTM test methods are not adopted, either CT 523 will need to be revised to provide for the use of plastic molds or the state will need to replace all plastic molds with steel molds at a substantial cost.

Regardless of whether CT 523 or ASTM C78 is used, there is a need to address the precision or repeatability of contract related test results. Either contract language or test method procedure language would need to be written.

7.0 Recommendation

The Flexural Beam Test Method Investigation Team has reviewed the creation and supporting documentation of the CT and ASTM test methods for the flexural strength of concrete. The team has also reviewed the current practices within the state for testing the flexural strength of concrete. This

comprehensive investigation was very beneficial and yielded positive results. The research outlined in this document led the team to consensus on the key factors affecting flexural strength. Based on the consensus of these key factors it is the recommendation of the Flexural Beam Test Method Investigation Team that Caltrans should adopt ASTM C31 and ASTM C78 for both opening age and acceptance testing of flexural beams in lieu of CT 523. Acceptance testing should be based on standard cured specimens while opening age should be field cured.

References

AASHTO T177, Standard Test Method for Flexural Strength of Concrete (Using Beam with Center-Point Loading, American Association of State Highway and Transportation Officials (ASSHTO).

AASHTO T23, Standard Test Method for Making and Curing Concrete Test Specimens in the Field, American Association of State Highway and Transportation Officials (ASSHTO).

ASTM C192/C192M, Standard Practice for Making and Curing Test Specimen in the Laboratory, American Society for Testing and Materials (ASTM).

ASTM C293/C293M, Standard Test for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading), American Society for Testing and Materials (ASTM).

ASTM C31/C31M, Standard Practice for Making and Curing Test Specimen in the Field, American Society for Testing and Materials (ASTM).

ASTM C78/C78M, Standard Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), American Society for Testing and Materials International (ASTM).

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Appendix 1 - Work Plan

CALTRANS / INDUSTRY Rock Products Committee

Flexural Beam Test Method Investigation

Project Work Plan

July 1, 2014

Concrete Task Group

Cast-in-Place Pavement Subtask Group & Materials / QA Subtask Group

Flexural Beam Test Method Investigation
Work Plan
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Flexural Beam Test Method Investigation
Work Plan

This project work plan is for the development of *a consensus as to which test method is best after comparing California Test 523 and similar ASTM Tests.* The intent of this work plan is to document the project scope, schedule, roles and responsibilities, and expected outcomes so that the Department of Transportation (Caltrans) and Industry have the same understanding and expectations regarding this project. The work plan for this project is based upon the priorities developed between Caltrans and Industry through the Rock Products Committee – *Concrete* Task Group, and is intended to be a guide for the Sub Task Group for the development of deliverables. This work plan communicates to Task Group and RPC Co-Chairs the necessary project activities, resources required and timeline to complete the project.

Project Background

Industry has requested an analysis and comparison of ASTM vs CT requirements related to Flexural Test specimen curing and testing to see if CT 523 can be replaced with ASTM test methods.

Project Scope

The scope of the *Flexural Beam Test Method Investigation* project encompasses the following:

- *Summarize current practices within Caltrans and other State DOTs (including testing, staff certification, lab certification, certification frequency, what accreditations are the labs obtaining, etc.) Summary of current guidelines within Caltrans (and other State DOTs) including the IA Manual and Construction Manual.*
- *Investigate and summarize what disputes, claims, relevant RFIs, CCOs, or project delays have arisen that pertain to CT 523.*
- *Perform search for literature:*
    - *Investigate factors influencing performance of CT 523/ASTMs/Other State DOT Test methods.*
    - *Find any available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods. (Documents pertaining to CT 523 should be located in Caltrans files and/or archived records.)*
    - *Find details relating to the basis for the standard specification change, specifically Section 40. Section 40 of the standard specifications went from allowing 16% variance between two specimens to 16% variance from the average of two specimens.*

- *Prepare decision document that analyzes possible impacts to the Department and Industry (economic, logistical, etc.) Examples: Equipment, training, manual*

updates, design impacts, contract administration and specification updates. Analyze impacts:
  - *If the recommendation is made to switch to ASTM.*
  - *If the recommendation is made to stay with CT 523.*
- *Based on the decision document, gain consensus amongst the team to provide a recommendation to the Concrete Task Group as to which method is best. If a test method cannot be recommended, recommend a path forward.*

Changes to the project scope will be discussed with the RPC Co-Chairs and agreement will be obtained prior to carrying out any such change.

Guiding Principles

The Department policy is to start moving towards national standards and as such the following principles should guide the Sub Task Group in the development of *a recommendation as to which Flexural Beam Test Method Investigation method is best*:

- *The group recommendation will be based on a majority consensus.*
- *The members of the group may not all be in agreement. Once a general consensus, is reached members who disagree with the consensus will explain their position and that will be documented as part of the final report.*
- Development of *a recommendation as to which flexural beam test method is best* is a cooperative effort between Caltrans including Pavements, Construction, and METS, and the Construction Industry including materials suppliers.

Project Organization, Roles, and Responsibilities

A clear definition of the roles and responsibilities of each project team member and/or group helps to provide a better understanding of involvement, direction and accountability among participants in the project. The project's organizational structure is listed below and describes the roles and responsibilities of both groups and individuals who will participate in the project.

Project Sponsors, Mark Hill and Bruce Carter —Communicates the project vision, and the organization's role in supporting that vision. The Project Sponsor:

- Is the ultimate owner of the project deliverables and is responsible for fulfilling responsibilities as defined by the RPC *Concrete* Task Group;
- Has the authority to make decisions and responsibility for implementation of the (Insert title) within Caltrans;
- Promotes the project throughout Caltrans and is empowered to negotiate and provide solutions to Caltrans-level project issues.

RPC *Concrete* Task Group—Caltrans management and Industry representatives who can make decisions regarding acceptability of deliverables. The role of the Task Group includes the following activities:

- Provide high-level direction and oversight over the project;
- Build consensus and provide leadership for the project;

- Communicate project objectives and status to peers, colleagues, and staff;
- Monitor Sub Task Group performance and assure quality of deliverable;
- Assist the Sub Task Group Co-Chairs in resolving issues and removing obstacles;
- Identify and provide subject matter experts and any additional resources necessary for the project.

Caltrans Sub Task Group Co-Chairs, Deepak Maskey/Cornelis Hakim (Team Leader) and Keith Hoffman —The Caltrans Sub Task Group Co-Chair will provide overall leadership and direction to the project. The responsibilities of the Caltrans Sub Task Group Co-Chair include:

- Make or evaluate key project-related decisions;
- Share/provide operational knowledge;
- Identify project risks/issues and determine which should be elevated to the Task Group;
- Attend Task Group meetings to provide project status and solicit feedback and guidance;
- Assisting the Sub Task Group in identifying and gaining access to key subject matters experts or other stakeholders;
- Serving as primary contact to the Sub Task Group;
- Schedule meetings with Caltrans subject matter experts and stakeholders;
- Participating in project status/issue meetings as required;
- Reviewing all project deliverables;
- Coordinating and consolidating review comments on interim and final deliverables;
- Recommending for approval project deliverables in a timely and complete manner;

Industry Sub Task Group Co-chairs, Mark Hill and Bruce Carter—The responsibilities of the Industry Sub Task Group Co-Chair include:

- Review all project deliverables prior to submission to the Task Group;
- Plan and coordinate project activities as it pertains to Industry participation;
- Maintain open communication with the Project Sponsor and Caltrans Sub Task Group Co-Chair;
- Identify and/or validate project risks or issues that require escalation to the Task Group;
- Conduct meetings with Industry subject matter experts and stakeholders and document findings;

Caltrans Sub Task Group Members—Responsibilities of the Caltrans Sub Task Group members include:

- Provide program area expertise, input, guidance, thought leadership, and feedback to the Sub Task Group;
- Provide validation or additional information for Sub Task Group's findings;
- Actively participate in work sessions throughout the life of the project;
- Remain accessible to the Sub Task Group as a resource for information validation;
- Review project deliverables and provide comments to the Caltrans Sub Task Group Co-Chair in a timely manner, as necessary.

Caltrans' representatives on this Sub Task Group are:

CIP Pavement Subtask Group

Doran Glauz *Deepak Maskey/Cornelis Hakim* *Mehdi Parvini / OE*

Materials/QA Subtask Group

Jim Sagar *Keith Hoffman* *Ken Darby*

Industry Sub Task Group Members—Responsibilities of the Industry Sub Task Group members include:

- Provide program area expertise, input, guidance, thought leadership, and feedback to the Sub Task Group;
- Provide validation or additional information for Sub Task Group's findings;
- Actively participate in work sessions throughout the life of the project;
- Remain accessible to the Sub Task Group as a resource for information validation;
- Review project deliverables and provide comments to the Industry Sub Task Co-Chair in a timely manner, as necessary.

Industry's representatives on this Sub Task Group are:

CIP Pavement Subtask Group

Bruce Carter *George Butrovich* *Tom Carter*

Materials/QA Subtask Group

Mark Hill *Marc Robert* *Robert Hightower*

Project Resource Requirements

To deliver the project efficiently and timely the following estimated resources are necessary:

Caltrans:	
Pavement:	0.25 PYE
DES METS:	0.10 PYE
Construction:	0.10 PYE
District:	0.02 PYE
OE	0.02 PYE
Legal	0.02 PYE
Other:	
Industry:	0.50 PYE
FHWA:	0.05 PYE

Project Work Plan

This section describes each phase of the *Flexural Beam Test Method Investigation* project, the expected outcome of each phase, the methods of completing each phase, and the work products produced. The table below also identifies the necessary participants in order to complete the project phases.

Phase	Expected Outcome	Deliverables	Method	Participants
Develop project scope	The objective of this phase is to define the project scope, and develop a detailed project plan to accomplish the agreed on objectives.	• Scope • Guiding Principles • Roles & Responsibilities • Project Work Plan • Project Schedule • List of Project Deliverables	• Identify key stakeholders • Develop plan that outlines resources, project timelines and key milestones • Present scope and plan to Foundations Task Group for approval	• Project Sponsor • Caltrans Sub Task Group Co-Chair • Task Group
Develop Draft Deliverables	The purpose of this phase is the development of draft deliverables by the Sub Task Group. The deliverable must be complete and have Sub Task Group consensus.	• Scoping Document • Summary of Current Practices • Summary of Background Literature • Summary of Recommendations	• Interview Subject Matter Experts • Determine best practices • Determine requirements • Develop draft documents	• Sub Task Group • Caltrans Subject Matter Experts • Industry Subject Matter Experts
Stakeholder Input	The purpose of this phase is to submit draft deliverables for review and comment to stakeholders.	• Documentation of comments received and resolution • Final Document	• Circulation of documents to targeted stakeholders and subject-matter experts for review and comments. • Resolution of comments received by the Sub Task Group. • Documentation of comments and resolutions.	• Sub Task Group • Caltrans Subject Matter Experts • Industry Subject Matter Experts • Stakeholders • Task Group • Project Sponsor

Phase	Expected Outcome	Deliverables	Method	Participants
Pilot Implementation	The purpose of this phase is to reduce risk for both Caltrans and Industry while fine tuning new requirements in documents.	• Revised documents based on pilot results	• Try specification or test method on a limited number of pilot projects • Analyze pilot project results. If major revisions to the draft specification are needed prepare new draft document and then repeat process until no major revisions are needed.	• Sub Task Group • Project Sponsor
Final Deliverables	Ready for publication specifications, standard plans, test methods and guidance documents.		• Present deliverables to Task Group for recommendation to Sponsor	• Sub Task Group • Caltrans Subject Matter Experts • Industry Subject Matter Experts • Task Group • Project Sponsor

Deliverables and Delivery Dates

The project deliverables for *Flexural Beam Test Method Investigation* are described in the table below, with the anticipate date the documents will be delivered.

Deliverable	Anticipated Completion
Summarize current practices within Caltrans and other State DOTs (including testing, staff certification, lab certification, certification frequency, what accreditations are the labs obtaining, etc.) Summary of current guidelines within Caltrans (and other State DOTs) including the IA Manual and Construction Manual.	October 1, 2014
Summary of disputes, claims, relevant RFIs, CCOs or project delays have arisen that pertain to CT 523.	November 3, 2014
Summary of investigation of factors influencing performance of CT 523/ASTMs/Other State DOT Test methods.	November 3, 2014
Summary of any available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods.	December 5, 2014
Explanation of details relating to the basis for the standard specification change, specifically Section 40.	December 23, 2014
Prepare decision document weighing pros and cons of making switch.	March 31, 2015
Provide written recommendation if possible. If recommendation on test method cannot be made, recommend a path forward.	June 30, 2015

Quality Control

Caltrans will use internal quality reviews to verify the quality of project deliverables.

Communications and Reporting

The Sub Task Group will make use of the following communications mechanisms:

- **Status Meetings**—The Sub Task Group will meet as necessary to status progress and resolve issues;

- **Status Reports**—Caltrans will provide a written monthly status report to the Caltrans Project Sponsor that identifies activities completed during the period and issues tracked in the Issues Log;
- **Task Group Meetings**—Throughout the project, the Sub Task Group will communicate with the Task Group to provide information, obtain perspective, and gain approval for project direction.

Assumptions

The following assumptions were made in the development of this Project Work Plan:

1. Caltrans will be responsible for the development of the deliverables described in this document.
2. The Sub Task Group will have support from Caltrans and Industry leadership, management and employees.

Recommendation and Approval

This work plan for *Flexural Beam Test Method Investigation* was prepared based on Rock Products Committee scoping document approved on (still being developed). The resources necessary and timeline for completing the deliverables are based on reasonable assumptions and the scope of the work presented.

Work plan recommended for approval by:

_____
Cornelis Hakim
Caltrans Sub Task Group Co-Chair

_____
Keith Hoffman
Caltrans Sub Task Group Co-Chair

Work plan approved by:

_____
Dan Speer
Concrete Task Group Co-Chair

_____
Chuck Suszko
Concrete Task Group Co-Chair

_____
Nesar Formoli
Concrete Task Group Co-Chair

Approval Date: _____

Appendix 2 - METS/GS Directive-05

METS/GS Directive

Materials Engineering and Testing Services and Geotechnical Services

Number:	METS/GS-05
Effective Date:	April 23, 2014
Supersedes:	NEW

TITLE METS/GS Strategic Direction Towards Use of National Testing Standards

PURPOSE

The purpose of this Directive is to outline the METS/GS policy towards the greater use of national testing standards for the California Department of Transportation's (Caltrans) specifications.

BACKGROUND

Since 1912, Caltrans' Transportation Laboratory (Translab) has been at the forefront in developing innovative testing methods and other practices to improve product quality on our Transportation facilities. In many cases, the California Test Methods (CTMs) developed by Caltrans have served as the foundation for the comparable national testing standards subsequently developed by various organizations.

Over the past several decades, we have seen many other State Departments of Transportation (DOTs) and local California Implementing Agencies transition toward the greater use of national testing standards. Testing and accreditation standards from organizations such as ASTM International, the American Association of State Highway and Transportation Officials (AASHTO), the International Organization for Standardization (ISO), the American Association for Laboratory Accreditation (A2LA), and the National Ready Mixed Concrete Association (NRMCA) have been tried, tested, and proven on various public works projects.

The sampling and testing standards produced by these organizations are regularly evaluated and maintained by testing experts and academia, providing additional assurance that material quality can be accurately bench-marked and compared across various agencies and DOTs. In addition, these standards receive proficiency test data from thousands of laboratories across the nation, helping to deliver inter-laboratory variations that can be used in verification testing and QA programs.

Furthermore, independent laboratories, Industry organizations and other DOTs have also developed greater familiarity with these national testing procedures. As more transportation agencies chose to perform construction administration activities themselves, and as Caltrans streamlines its oversight of local project delivery in accordance with the 2014 Caltrans Program

Review, the use of national testing standards allows for a more consistent level of Quality Control (QC), QA, and IQA, regardless of the procurement mechanism or the implementing agency.

POLICY

Whenever possible, Caltrans will change its CTMs to reference appropriate national standards. This will ensure consistency and ease of project delivery amongst Local Agency, Caltrans, and Contractor stakeholders.

PROCEDURE

In all cases where Caltrans staff are involved in the development or refinement of test methods, both through functional unit responsibility or through committee involvement, these employees are to implement the use of quality standards from nationally-recognized organizations. When a national standard is being considered, the procedures needed to certify testers to the national standards must be evaluated to determine any impacts to Caltrans internal procedures to certify testers to materials testing procedures.

When updating any CTM, all staff are to modify the CTM to refer to its corresponding national standard where appropriate.

If a stakeholder or CTM reviewer feels that a transition to a national testing standard is not warranted for a certain activity, then it is the responsibility of that activity stakeholder to provide justification as to why the CTM is the more feasible alternative. The stakeholder must present technical justification and material quality benefits as part of this reasoning. This justification should be incorporated into the revision documents, once approved by the State Materials Engineer.

RESPONSIBILITES

<u>METS/GS Deputy Division Chief</u>
Ensures all METS/GS managers and supervisors are aware of this Directive and any revisions to this Directive. Acts as the State Materials Engineer and has the authority to modify CTMs. Only the State Materials Engineer or his designees may modify existing CTMs where necessary.

<u>METS/GS Managers</u>
Ensures all METS employees are aware of this Directive and any revisions to this Directive. Monitors and assesses the need for any additional changes to CTMs and specifications based on feedback from Caltrans stakeholders, Industry organizations, and partner DOTs.

CTM Coordinator
Responsible for documentation and routing of all CTM changes for approval. Makes determination of future CTM updates needed. Maintains a record of all changes to CTMs, as well as reasoning or justification for changes. Records and uploads information into the appropriate METS/GS database, and also records changes on appropriate routing documents.
Records and uploads information into the appropriate METS/GS database, and also records changes on appropriate routing documents.

IHS Coordinator
The IHS Coordinator within the METS New Products Group is responsible for ensuring that all Caltrans employees have access to national standards. These standards can be found at the following website:
http://specs4.ihserc.com/?PROD=SPECS4&sess=672515910&workFlow=1

METS/GS Staff
Ensures compliance with all requirements of this Directive. Monitors and assesses the need for any additional changes to CTMs and specifications based on feedback from Caltrans stakeholders and Industry organizations, and reports recommendations to Managers. Staff members are also responsible for seeking supervisor approval prior to specialty testing work.

APPROVED

Philip J. Stolarski

PHILIP J. STOLARSKI, P.E.
State Materials Engineer
Deputy Division Chief
Materials Engineering and Testing Services and
Geotechnical Services
Division of Engineering Services

4-23-14
Date Signed

Appendix 3 - Scoping Document

Rock Products Committee
SCOPING DOCUMENT
Flexural Beam Testing Requirements
July 1, 2014

Task Group

Concrete Task Group

Problem Process

☒ Annual
☐ Expedited
☐ Emerging Initiative

Title

Flexural Beam Testing Requirements in Section 40

Issue/Problem Statement

Industry is concerned that the acceptance criteria for their product is based on factors out of their control, such as ambient temperature, weather conditions, specimen fabrication, transportation and storage.

Industry believes that California Test 523 certification and accreditation for third party labs and non- Caltrans personnel has been, and continues to be, inconsistently managed and enforced throughout the State.

Background

The earliest research on California's testing method for flexural strength (later to be named California Test 523 [CT 523]) appeared in a report published in January 1967. Caltrans sought to improve upon the ASTM C78 that was already in place. The main focus of Caltrans' experimentation was to see if smaller test samples could be used and still provide accurate, reliable results. ASTM later followed Caltrans' lead and also allowed for smaller test sample sizes. At the time CT 523 was developed it was determined that this was the best method to determine the strength of in-place concrete pavement before opening the roadway to traffic.

Most other states use either AASHTO or ASTM test methods. These test methods are commonly accredited and certified by AASHTO and ACI. These test methods are supported by national organizations that keep the test methods current and up to date. New Department policy is to start moving towards national standards where national test is the same as the California Test method.

Industry feels that the ASTM C31 and ASTM C78 test methods would be better methods for determining acceptance of concrete used for pavement due to the fact that it minimizes variables in curing, fabrication and storage of test specimens that are inherent to CT 523.

CT 523 only allows rodding of test specimens because at the time it was written, rodding was the only option as field electric generators and vibratory equipment was not readily available. Industry believes that rodding is not adequate for consolidation of low-slump concrete paving mixes. The current AASHTO and ASTM test methods allows for vibration of low-slump concrete pavement specimens.

Purpose

To come to an agreement as to which of the test methods previously identified will satisfy both Caltrans and industry with regard to acceptance testing.

Identify current practices throughout the state in regards to CT 523 management and certification for all technicians performing these tests and the accreditation of Caltrans and third party testing laboratories.

Objectives/Deliverables

This objective of this activity is to provide additional clarity to the flexural strength testing requirements found in the Standard Specification.

1) Summarize current practices within Caltrans and other State DOTs (including testing, staff certification, lab certification, certification frequency, what accreditations are the labs obtaining, etc). Summary of current guidelines within Caltrans (and other State DOTs) including the IA Manual and Construction Manual.

2) Perform literature search for:
   a) Factors influencing performance of CT 523/ASTMs/Other State DOT Test methods.
   b) Any available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods. (Documents pertaining to CT 523 should be located in Caltrans files and/or archived records.)
   c) Details relating to the basis for the standard specification change, specifically Section 40. Section 40 of the standard specifications went from allowing 16% variance between two specimens to16% variance from the average of two specimens.

3) Prepare decision document that analyzes possible impacts to the Department and Industry (economic, logistical, etc.) Examples: Equipment, training, manual updates, design impacts, contract administration and specification updates. Analyze impacts:
   a) If the recommendation is made to switch to ASTM.
   b) If the recommendation is made to stay with CT 523.

4) Based on the decision document, gain consensus amongst the team to provide a recommendation to the Concrete Task Group as to which method is best. If a test method cannot be recommended, recommend a path forward. If a test method can be recommended, modify the specifications accordingly.

Timeline/Resources

Deliverable	**Anticipated Completion**
Summarize current practices within Caltrans and other State DOTs (including testing, staff certification, lab certification, certification frequency, what accreditations are the labs obtaining, etc.) Summary of current guidelines within Caltrans (and other State DOTs) including the IA Manual and Construction Manual.	October 1, 2014
Summary of investigation of factors influencing performance of CT 523/ASTMs/Other State DOT Test methods.	November 3, 2014
Summary of any available data supporting the development or subsequent research related to CT 523 and similar ASTM test methods.	December 5, 2014
Explanation of details relating to the basis for the standard specification change, specifically Section 40.	December 23, 2014
Prepare decision document weighing pros and cons of making switch.	March 31, 2015
Provide written recommendation if possible. If recommendation on test method cannot be made, recommend a path forward.	June 30, 2015

Team Members

Team listed below represents that there will be 12 voting members and no more.

	CIP Pavement Subtask Group	Materials/QA Subtask Group
Caltrans Team Members:	Cornelis Hakim (Team Leader)	Keith Hoffman
	Mehdi Parvini / OE**	Jim Sagar
	Doran Glauz	Ken Darby
Industry Team Members:	Bruce Carter	Mark Hill
	George Butorvich	Marc Robert
	Tom Carter	Robert Hightower

** Represents one individual at any given time. If specifications need revising, replace Mehdi Parvini with someone from OE.

Team will be guided by Standard Project Workplan and Rock Products Charter.

Benefits

Relieves Industry's concern that the acceptance criteria for their product is based on factors out of their control, such as ambient temperature, weather conditions, specimen fabrication, transportation and storage.

If switch is made, certification and accreditation for third party labs and non-Caltrans personnel will be consistently managed and enforced throughout the State by using accepted ACI certification.

Has potential to reduce disputes on projects with regard to flexural strength testing method, therefore reducing litigation costs.

If switch is made, will eliminate the resources needed to update and maintain CT 523.

Will also know if improvements could be made to current practices within Caltrans.

Will gain knowledge on how or if the CT 523 can be improved.

Possible Impacts

If switch is made to ASTMs:

- Specifications, with the concurrence of all mandatory stakeholders, would have to be changed.
- Acceptance for opening to traffic will be determined by testing field cured samples.

Acceptance for 28 day strength (or more) will be determined by testing standard cured samples.

- Raising the specified flexural strength value to 625 psi for 28 days (standard-cured samples), 600 psi for 10 days (field-cured samples) and revise the specification that requires "pavement temperature (be kept) at not less than 40 degrees F for the initial 72 hours" to 50 degrees F in accordance with ACI 306.
- IA would need to begin certifying to ASTM instead of CT 523.
- May eliminate field laboratories.

If we stay with CT 523:

- Status quo is maintained.
- Better understanding from Industry on why CT 523 is used.

Resource Requirements

Caltrans:

Pavement:	0.25 PY
DES METS:	0.10 PY
Construction:	0.10 PY
District:	0.02 PY
OE	0.02 PY
Legal	0.02 PY

Other:

Industry:	0.50 PY
FHWA:	0.05 PY

Impediments to Completion of Deliverables

1. Lack of coordination and contribution of task group members
2. Lack of human and material resources
3. Lack of support by managers, functional units, and staff
4. Lack of staff to provide adequate training for implementation
5. New procedures may require more resources and time to complete. If this is the case, need to document conclusions in a report and propose a new Scoping Document with an updated resource estimate.

Recommendation and Approval

This scoping document for Flexural Beam Testing Requirements was prepared by the Concrete Task Group to address a priority issue that has Statewide significance and is within the Rock Products Committee mission. The Task Group Co-Chairs have determined the scope, resources required and timeline for delivery of this project to ensure that the deliverables are achievable in a timely manner.

Scoping Document Recommended for Approval by:

Dan Speer
Concrete Task Group Co-Chair

Chuck Suszko
Concrete Task Group Co-Chair

Nick Burmas
Concrete Task Group Co-Chair

Scoping Document Approved by:

Amarjeet Benipal
Caltrans RPC Co-Chair

Phil Stolarski
Caltrans RPC Co-Chair

John Stayton
Caltrans RPC Co-Chair

Approval Date: 6/23/14

Appendix 4 - ASTM Investigation

Summary of investigation of factors influencing performance of ASTM Test methods

Center Point Loading (ASTM C 293) Vs. Thrid Point Loading (ASTM C 78)

- **Third point loading (ASTM C 78) will produce lower results than center point loading (ASTM C 293).** Third point loading is much more likely to produce failure at the weakest section of concrete should this section occur within the middle third of beam - where center point loading provides maximum bending moment in just one section.

- **Beams tested per center point loading yield and average modulus of rupture approximately 14% higher than third point loading.**

- **The standard deviation of tests results is lower for third point loading than center point loading.** However, the coefficient of variation of the two methods is similar

Standard Deviation and Coefficient of Variation – ASTM C 78

- **The within specimen coefficient of variation can be greater that 5%, with differences between two tests on the same specimen approaching 100 PSI.** However, under careful laboratory control, the variability of flexural strength is no greater between batches than between tests.

- **The average between-test standard deviation is less than the average within-test standard deviation.**
  "This is because of the use of averages for the between test calculations and indicates that a significant portion of the variation in flexural-strength tests are a result of inherent variation in the test procedure." - Greer, CCAGDP Vol 5, No. 2

Effects of Moisture and Curing – ASTM C 78

- **1 to 2 days drying of initially moist cured specimens prior to loading reduces MOR by 200 PSI or more (30%)**

- **Several studies show large reductions in flexural strength with non-standard curing.**
  "Drying of specimens causes shrinkage (and presumably tension and micro cracking) near the surface. In flexure, the element near the surface on the bottom of the beam must carry the highest tensile stress and if disrupted by drying, large losses in indicated modulus of rupture result. On the other hand, in a pavement the bottom surface is not exposed to drying, in most environments, throughout the life of the pavement." – NRMCA 178

- **Drying of specimens is detrimental to early age strengths (less than 90 days). As drying becomes more through, a sharp reduction in strength is encountered when immersed in water before (24- 48 hours) testing.**
  "With regard to the meticulous attention required to secure accurate flexural strength results, it should be noted that, in the latter tests, drying for only 30 min caused an average reduction of 8 percent in measured modulus of rupture. Thus, the apparently minor lapse of permitting a slight amount of drying to occur before testing could easily result in apparent failure to meet strength requirements." - NRMCA 75

Miscellaneous

- **Concrete with larger maximum sized aggregates tend to develop slightly lower flexural strengths than that with smaller sized aggregates when compared with identical cementitious contents and water to cementitious ratios.**

- **As with compressive strength, the apparent flexural strength of specimens increases with loading rate. A linear relationship between flexural strength and the logarithm of applied stress rate has been observed.**

- **Specimens molded with stiff, slip-form concrete should be consolidated with vibration, not rodding.** ASTM C 31 requires vibration of concretes with a slump less than one inch and allows for vibration of all concretes. Studies have shown an increase in standard deviation and coefficient of variation for samples cast with low slump concrete consolidated by rodding.

Summary of any available data supporting the development or subsequent research related to ASTM test methods

- Goldbeck, A. T., “Apparatus for Flexural Tests of Concrete Beams,” *Proceedings*, Vol. 30, Part I, ASTM International, West Conshohocken, PA, 1930, pp. 591–597.
    - This paper and research data within is cited as a critical attempt to unify the flexural testing apparatus and details assumptions that are approximations when testing beams to failure and differences between center point and third point loading.

- Carrasquillo, P. M. and Carrasquillo, R. L., “Improved Concrete Quality Control Procedures Using Third Point Loading,” Research Report 1119-1F, Center for Transportation Research, University of Texas at Austin, Nov. 1987
    - This document is referenced in the precision statement of ASTM C 78 (10.1). Research conducted on more than 700 flexural specimens. Research identifies variables affecting the magnitude and uniformity of flexural strength test results, and provides sufficient data to form the basis of precision statements for the various test methods

- Greer, W. C., Jr. , "Variation of Laboratory Concrete Flexural Strength Tests," *Cement, Concrete, and Aggregates,* CCAGDP, Vol. 5, No.2, Winter 1983, pp. 111-122
    - This document is cited as key document in the development of the precision statement in ASTM C 78. An analysis of 145 laboratory flexural-strength concrete mixes. Typical values for within-test (within-batch) and between-test (between-batch) standard deviations are presented and compared with data published by others.

- “Concrete Mixture Evaluation and Acceptance for Air Field Pavements” Richard C. Meininger and Norm Nelson, NRMCA Publication 178, September 1991, NRMCA, Silver Spring, MD
    - This document presents case studies which detail the effect of different specification strategies and quality control procedures to minimize inherent testing variability.

- “Studies of Flexural Strength of Concrete, Part 2, Effects of Curing and Moisture Distribution ,” Stanton Walker and D. L. Bloem, NRMCA Publication No. 75, NRMCA, Silver Spring, MD
    - This document details a study conducted in several parts involving 384 tests for flexural strength, the data within demonstrates the importance of moisture distribution and adequacy of curing to the reliability of tests for flexural strength of concrete.

- “Studies of Flexural Strength of Concrete, Part 3, Effects of Variations in Testing Procedures,” Stanton Walker and D. L. Bloem, NRMCA Publication No. 75, NRMCA, Silver Spring, MD
    - This document provides data on modulus of rupture for: different positions of beams as molded; five methods of applying load; beams of different cross sections; sawed *versus* molded beams; and different moisture conditions of specimens and ages at test. Data is also presented on reproducibility of duplicate tests on the same beam and comparisons between flexural and compressive strength.

- Wright, P. J. F. and Garwood, F., “The Effect of the Method of Test on the Flexural Strength of Concrete,” *Magazine of Concrete Research*, No. 11, Oct. 1952, pp. 67–76.

Appendix 5 - Other DOT Practices

Other DOT Practices

State DOT	Spec. Reference	Prequal/Mix Design Process	Traffic Opening (Strength) Processes	Production Quality Assurance Processes (Strength)	Key Acceptance Differences
Texas	2004 Standard Specs.	Offers 4 options for design mix strength (min. 570 psi MOR @ 7 days, min. 3500 psi comp. @ 7 days, min. 680 psi MOR @ 28 days, or min. 4400 psi comp. @ 28 days). Specifies TEX-448-A for MOR & TEX-418-A for compressive. Note that TEX-418-A's procedure is ASTM C39 and TEX-448-A's procedure is ASTM C78 with supplemental information.	For opening to traffic strengths - Either 7 days old or minimum 2 days with either min 450 psi MOR or min 2800 psi comp. Test specimens are kept under same conditions (field cured - AASHTO T23/ASTM C31) as represented pavement. Also offers maturity method (TEX-426-A)for estimating concrete strength for traffic opening.	Job control testing personnel certification requirements. Engineer has opportunity to witness all tests. Contractor tests upon the Engineer's direction. 3000 SQYD lot size. Verification testing (1 to 10) using contractor's certified testing equipment. Complicated acceptance - Either MOR or compressive. MOR - 7 day of 520 psi min or lower if a 28 day of 680 psi min is correlated by TEX-427-A. Compressive - 7 day of 3200 psi min or lower if a 28 day of 4400 psi min is correlated by TEX-427-A. If results are 10% below requires corrective action. If results are 15% below, subject to rejection. If verification test differs from avg of 10 job control test by more than 10% (compressive) or 19% (MOR) requires corrective action. Appears that acceptance tests require "standard cure" under AASHTO T23/ASTM C31)	1) QC tests used as part of the acceptance decision with verification tests performed by the department. 2) Can use MOR or compressive strength testing for acceptance depending on qualification results. 3) Use State methods that modify ASTM procedures [ASTM C39 and ASTM C78]. 4) Use "standard cure" under AASHTO T23/ASTM C31 for acceptance testing.
North Carolina	2012 Standard Specs.	Trial batch - 1, 3, 7, 14, 28 day age tested. 28 day compressive (4500 psi min.) and MOR (650 psi min.) criteria. If both criteria are met with trial, acceptance is based on compressive only. If not, MOR is used. AASHTO R39, AASHTO T22 & AASHTO T97	Maturity Method (ASTM C1074) requires 3500 psi min. compressive strength for opening. Strength-maturity relationship is established using compressive strength results at 1, 3, 7, 14 and 28 days in accordance with AASHTO T22. The strength-maturity relationship must be verified every 10 calendar days.	Contractor personnel are certified by the department for PCC pavement tests (Article 1000-3). Department performs acceptance sampling and testing. A lot is defined as 1333.3 SQYD. One test consists of the average of 2 - 6"x12" cylinders at 28 day strength. Samples made and cured in accordance with AASHTO T23. Appears the acceptance tests require "standard cure". Specimens tested by the Engineer in accordance with AASHTO T22. Contracts include an item for the Engineer's field office and curing tanks (Section 725). 28 day compressive strengths less than 3500 psi are rejected, between 3500 and 4500 psi are pay adjusted, and greater than 4500 psi receive full payment. 28 day MOR strengths between 600 and 650 psi are pay adjusted and those greater than 650 psi receive full payment.	1) Department personnel use compressive strength if both MOR and compressive strength requirements are met in qualification. If not, MOR is used. 2) Samples are made and cured in accordance with AASHTO T23 [standard cure].
Ohio	2013 Construction & Material Specifications	Concrete mix designated by class (min. cementitious content, max. permeability, and min. 28 day compressive strength). JMF required. ACI 301 mix design process. Appears that 4000 or 4500 psi compressive strength is common requirement.	Requires 600 psi min. MOR for opening to traffic or other loads. Ohio supplement 1023 for making and testing concrete beams by department. 2 - 6" x 6" x 40" beams for opening age. Spading instead of rodding. Cure beams as nearly as possible in the same manner as the concrete it represents. Center loading hydraulic beam breaker. Represent 7500 SQYD	Two different potential pavement bid items 1) w/ QC/QA & 2) w/out QC/QA. QC/QA method uses compressive strength performed on cores (ASTM C42) tested by AMRL laboratory. 10 quality control tests for every 1 acceptance/verification test. Utilized for pay factors. W/out QC/QA department performs compressive strength testing w/ cores provided by the contractor. Strength pay factor is the project average strength/project required strength. The project required strength is the designated strength (e.g. 4500 psi) plus 1.65(project standard deviation).	1) Acceptance is determined based on cores taken from the concrete pavement (ASTM C42).
Florida	2014 Standard Specs.	Appears that the concrete mix design is approved through the Department's Material group. Does not really describe the mix design process for approval other than min 28-day compressive strength of 3000 psi, min. 470 lb/CY cementitious material and max w/c of 0.50 for pavement concrete.	Uses separate cylinders for compressive strength determination in accordance with ASTM C39. Cylinders are to be cured in a manner identical to the represented pavement. Must obtain 2200 psi minimum prior to traffic opening.	Specifies making and curing test specimens in the field conform to ASTM C31 (AKA AASHTO T23). Appears "standard cure" is required for acceptance. Compressive strength of cylindrical concrete specimens in accordance with ASTM C39. Specifies ASTM C42 for obtaining and testing drilled cores and sawed beams of concrete when concerns arise. Initial sampling of concrete from revolving drum mixer or agitators done in conformance with FM 5-501. Sampling of freshly mixed concrete in accordance with ASTM C172. Contractor required to provide curing facilities that have capacity to store all QC, verification and "hold" cylinders for initial curing. A "lot" is defined as 2000 SQYD or one day's production, whichever is less. Engineer verifies 1 in 4 QC tests. Verification from same load but different sample. Each "result" appears to be the average of three cylinder breaks. Allows for the average of two if one cylinder is lost or damaged. Prescribes a paymend deduction for the lost or damaged cylinder. If more than one cylinder is lost or damaged, requires cores. If results are 500 psi less than design strength requires investigation process. Has comparison criteria table to validate QC/verification results or trigger "hold" cylinder testing.	1) Acceptance is based on compressive strength (ASTM C39) based on specimens "standard cured" pursuant to ASTM C31/AASHTO T23. 2) Appear to use QC tests as part of the acceptance decision with verification tests. 3) Each test result is the average of three cylinder breaks, but allows for average of two if one is lost or damaged. 4) Requires cores if more than one cylinder is lost or damaged.

Washington	2014 Standard Specifications	ACI 211.1 is the process described for the concrete mix design. Requires a minimum MOR at 14 days of 650 psi. Requires 5 beams made under WSDOT T808 and tested under WSDOT 802. Note that WSDOT T808 has a laboratory method of storage and handling for determining acceptability of concrete paving mix and a field method for determining in-place flex strength. Appears beams can be either rodded or vibrated by the test method. Also requires 5 sets of 2 cylinders (4x8 for aggregate 1" or less - 6x12 for aggregate greater than 1") for 28 day compressive strength. These are to follow WSDOT FOP for AASHTO T23 and WSDOT FOP for AASHTO T22.		Acceptance appears to be based on 28 day compressive strength evaluated using WSDOT FOP's for AASHTO T23 and T22. Appears standard cure is used for acceptance. Two types of acceptance 1) statistical for 1500 CY or more of material and 2) non statisitical for less than 1500 CY.	1) Appears to use compressive strength for acceptance though qualification uses both MOR and compressive strength. 2) Use WDOT FOP on AASHTO T23 and T22 [modifies AASHTO for use]. 3) Use "standard cure" for acceptance.
Kansas	2007 Standard Specifications	Mix design process requires one set of three cylinders to break more than 2 standard deviations above 4000 psi if historical data exists. If no historical data the cylinders must break more than 1000 psi above 4000 psi.	There is some discussion of opening strength requirements and a reference to 5.16.22 KT-22, which describes how compression and flexural test specimens are made and cured in the field. Concrete with slumps greater than 3" must be rodded, while concrete with slumps between 1" and 3" may be rodded or vibrated. For opening type strengths, the specimens are cured near the representive concrete.	They have QC/QA and non-QC/QA methods of pavement. It appears that acceptance is based on compressive strength testing on 4" cores that are taken 21 days after placement and moist cured (KT-49) then tested at 28 days.	1) Appears to use compressive strength on cores taken from concrete pavement for acceptance. 2) Use a state standard [KT-49] for the curing process between 21 days [coring] and 28 days [testing].
New York			Cylinders	C 31 & C 39	
Iowa			Beams or Maturity	C 31 & C78 (modified)	
Maryland			Cylinders	T 22 (C39)	
Delaware			Cylinders	C 39	
Lousiana			Cylinders	DOTD TR 226 T 23 [C31] &DOTD TR 230 [T 22]	
Colorado			Cylinders	C 31 & C39	
Connecticut			Cylinders	ASTM C 31 (AASHTO T 22) & C 39	
Washington		Beams & cylinders	Cylinders	T 22 & T 23	
North Dakota			Beams, cylinders or cores	Cured as per pavement	
Michigan			Beams	T 97 & SC-T-42 [C31 & C 78]	
Indiana			Beams	T 97	
Missouri			Cores	Cores	
Nebraska			Cores	Cores	
Tennessee			Cylinders	C39	
Oregon			Cylinders	T 23 & T 22	
Nevada			Beams	T225F, T428F & T442G	Sim. To ASTM's, provision to sample at plant
Utah			Cylinders	T 23 & T 22	In front of paver

Note: AASHTO T 22 = ASTM C 39 (Testing)
AASHTO T 23 = ASTM C 31 (Fabrication & curing)
AASHTO T 97 = ASTM C 78 (third-point loading)

Appendix 6 - Caltrans Survey

Caltrans Survey

Project #	1	2	3	4	5	6	7*	8	9	10
1. Who samples the concrete for the beam specimens on projects in your region/district (Contractor/Caltrans Construction Employee/Caltrans Materials Employee/Caltrans Consultant)?	CalTrans Construction Employee	Caltrans Consultant	CT inspector/Tester	Caltrans Materials Employee/Caltrans Consultant	Caltrans Material Employee and Caltrans Consultants	____	____	Caltrans Consultant	Caltrans Construction Employee	
2. In the case of Caltrans employee or consultant, is this individual assigned to the project or assigned to support many different projects? _____	project specific	many different projects	assigned to the project	different projects	many different projects	many projects	many projects	many projects	many different projects	
3. Is the sampler certified for sampling fresh concrete (CT 539) (Y or N)?	Yes	Y	Y	Y	Y	Yes	Yes	Yes	Y	
4. If the sampler is certified, who performs this certification (functional group)? _____	Independent Assuranct for CT District	district lab	CT M&R	Caltrans SRL IA	Independent Assurance	Independent assurance	Independent assurance	Caltrans certifying lab	IA	
5. How long is the certification valid for California Test 539? _____	1 year	two years	1 yr.	1-2 years depending on the testers experience	1 to 2 years based on the employee's experience and the IA's records	one year	one year	one year from date of issue	1-2 yrs	
6. What size beam molds are typically used in your district/region? _____	6"x6"x21"	6"x6"x18"	6"x6"x20"	6"x6"x21"	6"x6"x21"	6"x6"x18"	6"x6"x18"	6"x6"x20"	6"x6"x21"	
7. What type of beam molds are used (i.e. mold material type – plastic, steel, etc.)?_____	plastic	plastic	plastic	plastic	plastic	plastic	plastic	hard plastic	Plastic	
8. How often are beam molds evaluated for suitable use? _____	everytime they are used	daily	yearly	before use, if bad replace with new	before each use	daily	daily	monthly	Daily during testing	
9. How many beams are cast for each test?_____	minimum of 4 beams	6	3	JPCP, PCCP, CRCP typically 5 (2 for 10 day and 2 for 28 day and one for reserve if not w/in 16%)	2	6 beams	6 beams	6 min for every 1000 CY placed (2 for 10-day, 2 for 28-day & 2 spares)	Varies but at least 6	
10. Who fabricates the beam specimens on projects in your region/district (Contractor/Caltrans Construction Employee/Caltrans Materials Employee/Caltrans Consultant)?	CalTrans Construction employee	Caltrans Consultant or Caltrans Materials Employee	CT tester	Caltrans Materials Employee/Caltrans Consultant	Caltrans Material Employee and Caltrans Consultants	Caltrans employee/Caltrans consultants	Caltrans employee/Caltrans consultants	Caltrans Consultant	Caltrans Construction Employee	
11. Is the beam fabricator certified for fabrication under California Test 523 (Y or N)?	yes	Y	Y	Y	Y	Yes	Yes	Yes	Y	
12. If the fabricator is certified, who performs this certification (functional group)? _____	Independent Assuranct of CT District	district lab	CT M&R	Caltrans SRL IA	Independent Assurance	Independent assurance	Independent assurance	Caltrans certifying lab	IA	
13. How long is the certification valid for California Test 523? _____	1 year	1 year	1 yr.	1-2 years depending on the testers experience	1 to 2 years based on the employee's experience and the IA's records	one year	one year	one year from date of issue	1-2 yrs	
14. Do the beam fabricators screen off 1-1/2 inch aggregate? (Y/N)	No	Y	Y	Y	Y	depends on mix design	depends on mix design	did not have to perform this so far	Y	
15. Are beams for CT 523 testing always fabricated with a tamping rod or are alternative means (e.g. vibrator, spade, etc.) sometimes used? (Y/N) If yes, when are the alternate means allowed? _____	tamping rod only	Y, vibrator	N	N, vibrator on RSC (CT 524)	Yes when a change order has been issued by the RE	N	N	Yes, rubber mallets are used in addition to tamping rods (tap sides).	Tamping rod only	
16. Do the beam fabricators fabricate more than one set per shift? (Y/N) If so, at what frequency?_____	yes, 1 set for age reqd, 2nd set for 7-day breaks and 3rd set for opening	Y, 2 to 4 hours	Y, opening age dependent	not typically	Y, based on the frequency outlined in the Special Provisions	Yes, 1 per day	Yes, 1 per day	Yes. One set of beams (six beams) for every 1,000 CY of concrete placed in the shift.	Y, 1000 CY	
17. Are beams fabricated where they can be cured for the first 24 hours without being moved? (Y/N)	Yes	Y	Y	Y	Y	Y	Y	Yes. Usually away from construction traffic and in spots where there is not vibration from nearby moving equipment.	Y	

18. How are the sides and ends of beams protected initially?_____ _____. Who performs this work? _____ Are they certified under CT 523? (Y/N)	tarped & backfilled w/ sand, CT employee, yes	with sand, employee, Y	Thermal blanket, CT tester, Y	Native earth or base material on the jobsite, Caltrans Matls. Tester, Y	Damp sand, tester, Y	sand pit, Caltrans, Yes	sand pit, Caltrans, Yes	Sides and ends of beams are initially protected with sand/dirt. The Caltrans consultant performs this work. Yes.	Yes with sand or dirt, Caltrans, Y	
19. How is the top surface treated? _____ __. Who performs this work? _____ Are they certified under CT 523? (Y/N)	sprayed with the same curing compound as contract damp towels placed on top then tarped, CT employee, yes	cured, employee, Y	curing compound, CT tester, Y	Curing compound, Caltrans Matls. Tester, Y	same cure as used for the placement of the concrete, testers or contractor's laborers supervised by the tester, ___	finished and cured, don't know, ___	finished and cured, don't know, ___	No surface treatment is being used. In the future, we will direct contractor to spray the top surface of beams with cure.	With cure, Caltrans field lab, Y	
20. When are the beam specimens transported to the curing location? _____ Who performs this work? _____ How many people are used? _____. Are they certified under CT 523? (Y/N) Are the beams transported on the base plate of the molds to the curing location? (Y/N)	after 24 hours, ___, 1, yes, yes	next day, ___, 2, Y, Y	24 hours, CT tester, 1, Y, Y	Fabricated in curing location and then transported to sand pit at Lab after 24 hours, Caltrans Matls. Tester, 1 person, Y, Y	24 hours after fabrication, tester, 2, Y, Y	20 hours plus or minus 4 hours, tester, 1 or 2, ___, yes	20 hours plus or minus 4 hours, tester, 1 or 2, ___, yes	The beams specimens are transported to the curing location after 24 hours in the field. Caltrans consultant performs this work, usually two lab personnel perform the task of transportation, Yes. Yes.	24 hrs, Caltrans, 1-2, Y, Y	
21. Who is charged with keeping the earth or sand surrounding the beam specimens damp at all times during the curing period? _____ Do they utilize contractor resources to accomplish this? (Y/N)	CT employee, No	Contractor, Y	Contractor or CT Tester, Y	Contractor at jobsite, Caltrans at the lab, Y	Testers, Y and N	Caltrans and contractor as discussed at pre-paving meeting, don't know	Caltrans and contractor as discussed at pre-paving meeting, don't know	No one is performing this task for QC or QA. We will discuss this with QA Consultant and Contractor	Contractor, Y	
22. What precautions are taken when transporting the beams from the field to the lime bath? _____ _____	a moving tarp is placed under the beams and the beams are covered	keep next to the beam curing area	keep damp with wet cloths and plastic	Use of cart at the lab to limit lifting	Beams are placed on a cart and moved from the sand pit to the Lab about 50 feet	Done by Caltrans certified staff	Done by Caltrans certified staff	Flat bedding; ensuring that beams don't slide and hit each other.	Cover with wet burlap	
23. Who transports these beams from the field to the lime bath? _____ Are they certified under CT 523? (Y/N)	CT employee, Yes	CT employee, Y	CT tester, Y	Caltrans Matls. Tester, Y	Testers, Y and N	Caltrans, Y	Caltrans, Y	Consultant, Yes	Caltrans Field Lab, Y	
24. Is the equipment used to break the beam specimens brought to the project location or are the beam specimens brought to an established laboratory location? _____	equipment is brought to beams	project location	yes	CT 523 @ lab, CT 524 in field	For high early strength concrete or rapid set the equipment is brought to the field, for regular concrete the beams are transported to the lab.	don't know	don't know	beams are sent to lab	laboratory	
25. Who certifies the testing equipment? _____	Independent Assurance - CT District	district lab	CT M&R	private scale company	IA, Lab personnel and private testing firms	Independent assurance	Independent assurance	district certifying lab	IA	
26. How often is the equipment certified? _____	Yearly or project to project	yearly	yearly	1 - 2 times yearly	Yearly	one year	one year	one year from date of issue	yearly	
27. Is Method 1 or Method 2 typically used in your district/region? _____	Method 1	method 1	method 2	Method 2	2	2	2	method 2	2	
28. Is the equipment operator certified under CT 523? (Y/N)	Yes	Y	Y	Y	Y	Yes	Yes	yes	Y	
29. Who certifies the equipment operator (functional group)? _____	Independent Assurance - CT District	district lab	CT M&R	Caltrans SRL IA	Independent Assurance	Independent assurance	Independent assurance	district certifying lab	IA	
30. How long is this certification valid? _____	1 year	one year	1 yr.	1-2 years depending on the testers experience	1 to 2 years based on the employee's experience and the IA's records	one year	one year	one year	1-2 yrs	

31. Is the RE provided hardcopies of all certifications (personnel, equipment, etc.) for filing in the project records (Y/N)?	Yes	Y	Y	Y	Y	No	No	Yes	Y	
32. Who is charged with ensuring employees have valid certifications for the sampling or testing procedures they are performing in your district/region? _____	Independent Assurance	district lab	area construction engineer	CT lab senior	the employee	Independent assurance	Independent assurance	consultant lab manager and dispatcher	IA	
33. Does your district maintain a database of these certifications (Y/N)?	Yes	Y	Y	Y	Y	No	No	Yes. Consultant maintains a database of certifications.	Y	
34. Is there an established process to ensure employee certifications are renewed prior to expiration (Y/N)?	Yes	Y	Y	Y	N - employee's responsibility	No	No	Yes. Consultant has a spreadsheet and reminder process.	Y	
35. Are beam specimens evaluated for defects before testing (Y/N)?	Yes	Y	Y	Y	Y	Yes	Yes	Yes.	Y	
36. Are beam specimens examined for defects after testing (Y/N)?	Yes	Y	Y	Y	Y	Yes	Yes	Yes.	Y	
37. If individual beam test results exceed the precision and bias of the test method, what is typically done? _____ _____	a re-test with another beam is performed	N/A	disregard results	3rd beam is tested for 28 day strength if not w/in 16%	Results are checked by other compentent lab personnel, IA, or Lab manager.	Break whole beam	Break whole beam	Reported as anomaly; beam result discarded from average.	Break another set	
38. Are additional beam specimens tested when the variance between breaks is greater than the test's precision? (Y/N)	Yes	Y	Y	Y	Y if there are beams available	don't know	don't know	Y	Y	
39. How are test results transmitted to the RE? (e-mail, hard copy by mail, electronic materials management system, etc.) _____ _____	e-mail and hardcopy	hard copy	e-mail or hardcopy	e-mail, database entry then a pdf copy sent by e-mail	e-mail or fax	e-mail	e-mail	E-mail and hard copy.	Hand delivered	
40. How long does it take typically to provide the test results to the RE from time of beam break? _____	Immediately	same day	2 hours	Results to RE w/in 24 hours	1 hr or less	48 hrs	48 hrs	Next day.	10 minutes	
41. Are acceptance test results transmitted to the contractor (Y/N)? If so, how long does it take typically to provide the test results to the Contractor from time of beam break? _____	Yes, Immediately	Y, same day	Y, 1 day	N, RE sends results to Contractor	N, unless requested by RE	No	No	Usually no, however, non-conforming results are reported to contractor. Non-conforming results are reported the next day (once consultant lab informs RE).	Y, Not sure - RE's responsibility	

Appendix 7 - Industry Survey

Question/Responses	A	B	C	D
1. Was this project State administered or externally administered?	State	State	State	State
2. Where was the project located? (City, county, district, state route, etc.)	Solano County/I-80	Route 5 – Elk Grove #03-SAC-5-0.0117.2	Route 80 - #03-Yol, Sac 80-R.10.91117	Wildomar, Riverside County, District 08, I-15/Clinton Keith Overpass Widening
3. Who was the Resident Engineer?	Martin Mercado	Mesnak Okpala	Rizwan Tanvir	Saleh, Zouheir
4. What was the project number?	#04-0A5354	#03-0F5904	#03-3797UF	CT 08-0F5804/RCTD A2-0264
5. Who has been/is performing the tests for beam flexural strength for concrete pavement on behalf of the Contractor? a. The Prime Contractor b. Sub Contractor c. Other d. Typically do not perform testing and rely on State QA testing	other.	Typically do not perform testing and rely on State Quality Assurance testing	Typically do not perform testing and rely on State Quality Assurance testing	Typically do not perform testing and rely on State Quality Assurance testing RELY ON STATE QA TESTING
6. Do you know what test method is being used to **fabricate** the flexural strength concrete test specimens? a. ASTM C31 b. CTM 523 c. Not sure d. Other method_____	CTM 523	CTM 523	CTM 523	CTM 523
7. Do you know what test method is being used to **test/break** the flexural strength concrete test specimens? a. ASTM C78	CTM 523	CTM 523	CTM 523	CTM 523

b. ASTM C293 c. CTM 523 d. Not Sure e. Other method_____				
8. Is the person **fabricating** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are made on behalf of Contractor	Yes	No specimens are made on behalf of Contractor	No specimens are made on behalf of Contractor	No specimens are made on behalf of Contractor
9. Is the person **testing/breaking** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are tested on behalf of the Contractor	Yes	No specimens are tested on behalf of the Contractor	No specimens are made on behalf of Contractor	No specimens are tested on behalf of the Contractor
10. Is the laboratory that is **testing/breaking** the specimens on behalf of the Contractor an accredited laboratory? a. Yes (list accreditation_____) b. No c. Not sure d. No specimens are tested on behalf on the Contractor	Yes –CTM 523 + others	No specimens are tested on behalf of the Contractor	No specimens are tested on behalf of the Contractor	No specimens are tested on behalf of the Contractor
11. Are the testing records maintained? (Please explain) a. Yes	No			YES, by us as the State QA tester, no Contractor testing or records being

b. No				performed/generated
12. If so, where are the test records maintained?				In the office of the resident engineer and QA testing laboratory
13. If so, how long are the test records maintained for?				As required by project document, information is contained in our Laboratory Information Management System (LIMS) and testing results are available for many years beyond project requirements.
14. Describe the testing frequency for tests performed on behalf of the Contractor.	Once every 300 cubic yards or once daily			N/A
15. Describe the testing frequency for tests performed on behalf of the State/EIA.	Once every 1000 cubic yards	1 set per 1000 cy	1 set for every 1000 CY	2 sets of 3 per shift. 1 each generally broke at 7, 10 and 28 days of cure per set cast.
16. Have there been any issues or Change Orders as a result of flexural strength testing issues?	Dispute re the State's testing. State testing indicated 65% of test failed to meet contract requirements. Contractor's testing indicated ALL test met contract requirements.	There was a change order to allow acceptance of the pavement to be based on tensil strength from drilled cores in lieu of flexural testing. This was due to the fact that all CT 523 results on concrete placed during the month of Feb. 2013 failed.	Concrete placed on 5/17/2013 showed CT 523 results at 12 days of 620 PSI flex. At 28 days, the results were 380 PSI flex. Because acceptance is at 28 days an investigation took place to verify concrete was acceptable to Caltrans. On this problem, the 2-28 day samples were greater than 16% apart as required by the test method.	Issues with large difference in test results on samples tested. Have noticed samples where early breaks are higher than breaks at later days of cure. (more results at each age of break would help)
17. If CTM 523 is used, are there any	State's QA testing –	No leather shims used	No leather shims used	None

deviations from the test method that occur that you can think of?	specimens not initially cured per test method, sand pit not kept moist, no shims or leather used during testing of specimens.	when breaking the beam. Beams were not kept continually wet during the testing process.	when breaking the beam. Beams were not kept continually wet during the testing process.	
18. Which test method do you think is best for determining flexural strength?	ASTM C 78	ASTM C 78 ASTM C 31	ASTM C 78 ASTM C 31	ASTM, due to procedure inspections by AASHTO which most contractor and independent labs undergo and the large pool of CCRL reference samples submitted and reported for review.
19. What brand of beam breaker do you have?	Forney	Forney	Forney	Tinius Olson with Humboldt apparatus/attachment
20. Is it (the beam breaker) independently certified/calibrated?	Yes	Yes	Yes	Yes
21. How old is the beam breaker?	2 years	2 years	2 years	25 plus years, calibrated at least annually
22. Please explain how the specimens are cured after the initial 24 hours or 48 hours? (Sand Bed? Curing tanks?)	Both sand pits and lime saturated water tanks.	We use curing tanks.	We use curing tanks	Sand bed
23. When are the specimens transported to the curing location?	State's – first thing next morning Contactor's – not before 22 hours nor after 26 hours.	Usually next day	Usually next day.	Next day
24. What precautions are taken to protect the specimens during transportation?	State – none Contractor – thick rubber mats and wet	Beam left in mold and wrapped in wet blankets to insure they are not allowed to dry out.	Beam left in mold and wrapped in wet blankets to insure they are not allowed to dry out	Keep beams in mold during transportation and use of a cushioning material (foam rubber)

	burlap			
25. Do you use the plastic “break away” molds? If using CTM 523, how is the base plate left in place while using the “break away” molds?	Yes – beams are transported in molds and “stripped” at the lab	Yes.	Yes	No, metal molds generally used, plastic molds would be much easier due to weight and cost of molds, also less likely to be stolen and scrapped.
26. What are some of the challenges you have faced associated with CTM 523?	Initial field curing requirements. Sand pit moisture conditions/temperature at laboratory.	Vibrators are not allowed Wideswing of temperatures during the whole curing process Beam transportation	Vibrators are not allowed Wideswing of temperatures during the whole curing process Beam transportation	Reliability of test results on same set of beam breaks at different age of cure
27. Where is the sampling being performed? Plant or jobsite?	Both plant & Jobsite.	Jobsite/lab	Jobsite/lab	Jobsite
28. Do you use internal vibrators for beam fabrication?	Occasionally, but never for compliance testing.	Yes	Yes	Generally no, we do have vibrators available.
29. Do you use a tamping rod for beam fabrication?	When specifications require.	No	No	Yes
30. Business type	Material supplier	Material supplier	Material supplier	Laboratory

Question/Responses	E	F	G	H
1. Was this project State administered or externally administered?		State	State	state
2. Where was the project located? (City, county, district, state route, etc.)	Santa Clarita, LA County, 07 - I-5	Los Angeles, 07 CA I-5	Bakersfield, Kern County, District #6 06-Ker-99-R28/R44.3	Cities of Rancho Cucamonga, Fontana and Rialto in San Bernardino County, District 08, Route 15
3. Who was the Resident Engineer?	Arsoul El Jamal	Emile Eid	Sam Dhaliwal	Fereydoon Alipanah
4. What was the project number?	#07-2332A4	07-1219U4	06-0L6404	Contract No. 08-472224
5. Who has been/is performing the tests for beam flexural strength for concrete pavement on behalf of the Contractor? a. The Prime Contractor b. Sub Contractor c. Other d. Typically do not perform testing and rely on State Quality Assurance testing	Outside lab	Outside lab	Outside Lab	Outside lab w/ Caltrans cert
6. Do you know what test method is being used to **fabricate** the flexural strength concrete test specimens? a. ASTM C31 b. CTM 523 c. Not sure d. Other	CTM 523	CT 523	CT 523	CTM 523

method_____				
7. Do you know what test method is being used to **test/break** the flexural strength concrete test specimens? a. ASTM C78 b. ASTM C293 c. CTM 523 d. Not Sure e. Other method_____	CTM 523	CT 523	CT 523	CTM 523
8. Is the person **fabricating** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are made on behalf of Contractor	Yes	Yes	Yes	Yes
9. Is the person **testing/breaking** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are tested on behalf of the Contractor	Yes	Yes	Yes	Yes
10. Is the laboratory that is **testing/breaking** the specimens on behalf of the Contractor an accredited laboratory? a. Yes (list accreditation_____) b. No c. Not sure	Yes	Yes	Yes – Caltrans - AASHTO	Yes - ARML

d. No specimens are tested on behalf on the Contractor				
11. Are the testing records maintained? (Please explain) a. Yes b. No	Yes	Yes	Yes. Lab has copies. Contractor has copies. State has Copies.	Yes - Test records are maintained by both the independent lab performing the test and by the contractor
12. If so, where are the test records maintained?	Computer	On a computer spreadsheet	Contractor keeps paper and electronic files at the corporate office.	At the lab's and contractor's main offices
13. If so, how long are the test records maintained for?			3 years	Not sure of the independent lab. Contractor for 7 years.
14. Describe the testing frequency for tests performed on behalf of the Contractor.	Parallel w/Caltans testers	Parallel w Caltrans tests	Every 500 cy / placed	It depends on the contract. On this contract, the contractor was not required to perform strength testing. However, due to erratic and suspect testing by Caltrans, we chose to have the independent lab test alongside Caltrans which was one set per 1000cy. We were also required to perform plastic property testing (penetration, air, unit wt, temp, etc. once per 4 hours).
15. Describe the testing frequency for tests performed on behalf of the State/EIA.	Usually once per production shift.	Usually once per production shift	Every 1000 cy / placed	The State was required to test for strength and plastic properties once per 1000 cy. However, there were many times when we would place up to 3500 cy and the State would only test twice when there should have been 4 testing periods. There have also been instances where two samples were required due to the yardage exceeding 1000 cy and Caltrans

				technicians obtained samples within 100 yards of each other so that they would have the proper number of samples and then could leave the job early.
16. Have there been any issues or Change Orders as a result of flexural strength testing issues?	Caltrans strengths were less than the independent lab's most of the time. There were some bad breaks, and Caltrans would not accept The independent labs data for strength acceptance. We performed split tensile testing and the concrete was accepted.	Yes. Caltrans issued a change order to reimburse us $430,000 for costs caused by improper handling and testing of beams.	Yes. Inconsistency on the States beam results. Typically lower than QC. Photos indicated fabrication and curing issues with State Beams.	MANY!!! It has been noted that Caltrans personnel do not protect beams from drying during transport. They have been observed tossing the beams into trucks and not securing them from movement. When side-by-side testing has been done, where samples have been fabricated by both an independent lab and Caltrans, Caltrans breaks are consistently lower than the independent lab. We have even had two labs test alongside Caltrans on a number of occasions. The independent labs had identical results and Caltrans was 50 to 100 psi lower (flexural strength).
17. If CTM 523 is used, are there any deviations from the test method that occur that you can think of?	Lack of protection of the beams. Transported too soon. Not tripped from molds before transportation.	Caltrans deviates by not protecting the beams, transporting the beams mionerally (sic) and still in their molds.	Not properly burying the beams in sand properly and maintaining the sand in a moistened state. Demolding the specimens prior to transport. Specimens not secured while in transport	For Contract 08-472224 the only deviation observed was the lack of protection during transport. However, we have noted the following issues on one or more projects by Caltrans technicians: Improper curing in the sand

				bed (sand was not kept wet or the layer of sand was not at least 4 inches) Improper curing in lime saturated water prior to testing (beams have been pulled directly from sand bed and tested, beams have been cured in water with no lime, beams have been stored in water bath at 56°F during winter months – method requires water to be at 73 ± 9°F). Deviations from the test method during testing (sample dimensions were not measured – 6” x 6” was assumed, full contact with the loading blocks was not checked, leather shims were not used when they should have been – shims had mysteriously disappeared, beams were loaded into the load apparatus at an angle and tested, beams were tested with one side of the beam hanging out over the edge of the loading block)
18. Which test method do you think is best for determining flexural strength?	Casting - ASTM C 31 Breaking – ASTM C 78	Casting - ASTM C 31 Breaking – ASTM C 78	ASTM C293 CT 523 is good if followed properly	We feel that ASTM C31 should be used for fabrication and curing and ASTM C78 should be used to test the beams.
19. What brand of beam breaker do you have?	N/A	N/A		We have two compression machines. One is a Forney Model FT (250,000 pound capacity) and the other is a Test Mark Model CM-2500

				(250,000 pound capacity).
20. Is it (the beam breaker) independently certified/calibrated?				Yes, the breakers are calibrated annually by an independent calibration company.
21. How old is the beam breaker?				It is unknown how old the Forney machine is. However, the load transducer and digital readout was upgraded three years ago. The Test Mark machine is two years old but has been in service for only one year.
22. Please explain how the specimens are cured after the initial 24 hours or 48 hours? (Sand Bed? Curing tanks?)	Sand bed	After 24 hours, sand bed.	Sand Bed. Moist sand needs to be checked periodically daily until ready to break specimens. The last 24 hrs the specimens are placed in a lime bath until ready to break for acceptance.	On the 08-472224 project, the independent lab transported the beams to their permanent lab location after and stored the beams in a sand bed. They were then moved to the water tank 24 hours prior to testing. On the 08-472224 project, we were not sure what the procedures were for Caltrans fabricated beams. The beams were typically transported to the Caltrans lab after 18 to 24 hours of field cure, but after that, we are not sure. We did request to witness testing on one occasion to see what the typical procedures were, but were given an exact time to witness and then the IAT representative was present to be sure that the Caltrans technician followed the proper test procedures. Unfortunately, we were not

				able to see what the typical methods used were due to the Caltrans technicians being worried that IAT would pull their certs. They followed all procedures to the letter – but then it took them 1.5 hours to test two beams.
23. When are the specimens transported to the curing location?			24 hrs upon completion of fabricating and placing them in the sand bed with moistened sand.	As noted above, both labs transported beams to the curing location within the specified time limits of the method.
24. What precautions are taken to protect the specimens during transportation?			Specimens are left in the molds until demolded at lab for placement in either lime water bath or moistened sand bed. Large coolers are also available if needed to transport demolded specimens.	The independent labs are usually very careful about transport. They have used a number of methods to pad the bed of trucks such as foam, sand or folded burlap. They also typically cover the beams with wet burlap and plastic sheeting to protect the specimens from drying. Caltrans technicians typically do not pad the bed of the truck and often do not cover the beams to prevent drying. We have also noted that the beams are allowed to slide around the bed of the Caltrans trucks.
25. Do you use the plastic “break away” molds? If using CTM 523, how is the base plate left in place while using the “break away” molds?			The whole mold is used to stay in place until complete demolding is taking place. Ensures no cracking or damaging the specimens.	Most independent labs and Caltrans labs now use the plastic molds. Because of their design, there is no “base plate” to leave in place during transport. The beams are usually transported in the full mold.

26. What are some of the challenges you have faced associated with CTM 523?	Preparation and handling issues. Lack of timely results.	Mishandling of beams from the point of casting through protection and transportation of their central lab for breaking. We never get timely results.	People not following the test method	Use of vibrators is not allowed for consolidating specimens. Paving mixes are typically batched at a penetration of ½" to 1" (1" to 2" slump). Because of the stiff consistency of paving mixes, rodding of beams often leaves voids or rock pockets and specimens do not represent the concrete being placed and consolidated using vibration. The initial curing of beams packed in wet sand works well during hot, dry weather to keep specimens cool and damp. However, during winter months when temperatures can be in the mid 40°F to low 50°F range, packing cold sand (observed as low as 48°F) around the specimens slows initial cure of the concrete. Specimens are then very susceptible to micro fracturing when transported at 18 to 24 hours. ASTM C31 requires that initial curing of specimens be done at 60° to 80°F, and 68° to 78°F for concrete at 6000 psi or greater in compressive strength (some paving mixes can actually reach 6000 psi in compressive strength). This can be easily accomplished by packing beams closely together and covering with plastic sheeting, followed by wet burlap and a cure blanket or cure box. As noted previously, rodding

				specimens fabricated from stiff paving mixes does not always represent the concrete being placed, as that concrete is being consolidated using vibrators. ASTM C31 requires that concrete with slumps less than 1" must be consolidated using vibration and concrete with slumps greater than or equal to 1" can be consolidated using either rodding or vibration. We have done studies on beams fabricated using rodding vs vibration and have found that specimens that were consolidated using vibration consistently attain higher strengths than those that were rodded. If the intent of testing of concrete is to determine if material placed is of sufficient quality, then the methods of consolidating specimens should replicate that of the concrete being placed, i.e. vibration. The new version of CTM523 (July 2012), requires that the dimensions of the specimens be measured and reported to the nearest 1/16 of an inch. Most labs use dial or digital calipers to measure dimensions. Calipers typically measure to decimals not fractions. Measuring and reporting in fractions from a caliper that has been read in decimals can create conversion and calculating errors. ASTM C78 requires

				that dimensions be measured to the nearest 0.05 inches and previous CTM 523 methods required 1mm (0.04”) both of which are more accurate than measuring to 1/16” (0.0625”). Additionally, rounding of three measurements taken to the nearest 1/16” is much more difficult than round of measurements determined in decimals.
27. Where is the sampling being performed? Plant or jobsite?	Plant mostly; some on-stie especially when using ready mix concrete.	Job site.	Plant – safety is main concern from jobsite. Jobsite if only behind k-rail and only if beams can be properly buried in sand and not damaged due to construction activities.	Location of sampling depends on safety issues and space on grade. If there is limited space at the point of placement, thus creating safety concerns, the location of sampling has often been moved to the plant site. However, arguments about not following CTM 523 always arise when sampling locations have been moved to the plant site. We have been required to hold material from being tested until the truck delivering the sampled material has arrived at the point of placement in order to replicate the travel time. There have also been projects where there is no safety concern but due to limited space it would be impossible to pick up samples the following day. Because sampling, testing, curing and sample pick up can be better

				controlled at the plant site, this is the location we prefer.
28. Do you use internal vibrators for beam fabrication?	No	No.	Yes if mutual agreed upon from the RE and the District lab prior to job commencement. Making a large number of specimens.	Only when testing “Rapid Strength” concrete per CTM 524. Also when we’ve done comparison studies on various methods of consolidation and curing.
29. Do you use a tamping rod for beam fabrication?	Yes	Yes.	Yes if sample numbers are relatively small or if there is something in the SSP’s that will not allow Vibratory use.	Yes, when testing per CTM 523. As noted previously, we do not feel this is method is representative of concrete being placed.
30. Type of business entity	Contractor	Contractor	Contractor	contractor

Question/Responses	**I**			
1. Was this project State administered or externally administered?	I don't have access to most of the requested data			
2. Where was the project located? (City, county, district, state route, etc.)				
3. Who was the Resident Engineer?				
4. What was the project number?				
5. Who has been/is performing the tests for beam flexural strength for concrete pavement on behalf of the Contractor? a. The Prime Contractor b. Sub Contractor c. Other d. Typically do not perform testing and rely on State Quality Assurance testing				
6. Do you know what test method is being used to **fabricate** the flexural strength concrete test specimens? a. ASTM C31 b. CTM 523 c. Not sure d. Other method_____				

7. Do you know what test method is being used to **test/break** the flexural strength concrete test specimens? a. ASTM C78 b. ASTM C293 c. CTM 523 d. Not Sure e. Other method_____				
8. Is the person **fabricating** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are made on behalf of Contractor				
9. Is the person **testing/breaking** the specimens for flexural strength on behalf of the Contractor currently certified to perform the test? a. Yes b. No c. Not sure d. No specimens are tested on behalf of the Contractor				
10. Is the laboratory that is **testing/breaking** the specimens on behalf of the Contractor an accredited laboratory? a. Yes (list accreditation_____) b. No c. Not sure d. No specimens are tested on behalf				

on the Contractor				
11. Are the testing records maintained? (Please explain) a. Yes b. No				
12. If so, where are the test records maintained?				
13. If so, how long are the test records maintained for?				
14. Describe the testing frequency for tests performed on behalf of the Contractor.				
15. Describe the testing frequency for tests performed on behalf of the State/EIA.				
16. Have there been any issues or Change Orders as a result of flexural strength testing issues?				
17. If CTM 523 is used, are there any deviations from the test method that occur that you can think of?	My only concern with the CT method for fabricating and testing beam samples has been with storage of the samples. The Caltrans method states the samples shall be stored in damp earth or sand which is a single method for storage that doesn't always work or apply.			

	Then Caltrans method also requires stripping and storing in damp earth or sand until age of break. Again, this is just one method for storage that doesn't always work or apply. If Caltrans adopts ASTM verbiage for storage, everything will be perfect. Caltrans requires using a tool to spade the concrete along the sides of the mold. This doesn't hurt anything if done properly but isn't necessary with the new molds.			
18. Which test method do you think is best for determining flexural strength?				
19. What brand of beam breaker do you have?				
20. Is it (the beam breaker) independently certified/calibrated?				
21. How old is the beam breaker?				
22. Please explain how the specimens are cured after the initial 24 hours or 48 hours? (Sand Bed? Curing tanks?)				
23. When are the specimens transported to the curing location?				
24. What precautions are taken to protect the specimens during transportation?				

25. Do you use the plastic “break away” molds? If using CTM 523, how is the base plate left in place while using the “break away” molds?				
26. What are some of the challenges you have faced associated with CTM 523?				
27. Where is the sampling being performed? Plant or jobsite?				
28. Do you use internal vibrators for beam fabrication?				
29. Do you use a tamping rod for beam fabrication?				
30. Type of business entity	Material supplier/contractor			

Appendix 8 - Section 40 Precision Example

CT 523 (July 2012)

J. PRECISION AND BIAS

Difference in the individual test results of beams aged 28 days, tested by the same operator, must not exceed 12 % of their average when tested by Method 1, or 16 % of their average when tested by Method 2. When tested at two different laboratories, the results must not exceed 15% of their average when tested by Method 1, or 19% of their average when tested by Method 2.

Equation: $\text{Diff (\%)} = \dfrac{A - B}{(A + B)/2} \times 100\%$

Example: Test A = 590 psi/in^2
Test B = 670 psi/in^2

$\text{Difference} = \dfrac{590 - 670}{(590 + 670)/2} \times 100\% = 12.7\%$

Section 40 (2010 Std. Specs.)

40-1.01D(13)(c)(2) Portland Cement Concrete

Concrete pavement is accepted for modulus of rupture on a lot basis. The minimum modulus of rupture for each lot is 570 psi at 28 days.

For modulus of rupture, a lot of concrete for concrete pavement must comply with the following:

1. Quantity must not exceed 1,000 cubic yards.
2. Department determines the modulus of rupture of test beams aged 10 days and 28 days.
3. Department calculates the modulus of rupture by averaging the individual test results of 2 beams aged for 28 days.
4. Difference in the individual test results of beams aged 28 days must not exceed 12 percent of their average when tested by Method 1, or 16 percent of their average when tested by Method 2~~. The Engineer calculates the difference relative to the average of the 2 test results.~~