CALTRANS/CSMIP BRIDGE STRONG MOTION INSTRUMENTATION

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Abstract

Accurately monitoring bridge movements during a large earthquake is necessary to advance our knowledge of how these large structures are affected by seismic shaking. Different structure types react differently to the same seismic wave patterns. Dynamic soil-structure interaction can be studied and theories proven or disproven from the actual readings. Geotechnical downhole arrays are also needed to analyze the soil column movements from a deep source to better predict the surface motions from various events. The ground motion will vary from site to site and a large data base is needed before we can correlate our soil and structural models.

In July 1994, Caltrans began an aggressive program to instrument many bridges across California for strong motion. This program is a cooperative effort between Caltrans and the California Division of Mines and Geology's Strong Motion Instrumentation Program (CSMIP). Anthony Shakal and James Davis head the program from the Division of Mines and Geology side, and James Gates and James Roberts formulated the project from Caltrans end. The program is funded by Caltrans through an interagency agreement with the Department of Conservation.

Objectives Of Bridge Instrumentation

The sensors are force-balance accelerometers that are designed to give readings up to 4g and relative displacement sensors. The range of the sensors is wide enough to capture low level shaking as well as large amplitude motions. This data in turn can be used for predicting the movements that will be caused by strong shaking. The recorders store the data digitally and the data can be quickly downloaded over the phone line and processed. A displacement time history plot can be given to the bridge owner within minutes after an earthquake. This data can be used to make assessments as to whether the structure can be open to traffic immediately after a large event. The Caltrans/CSMIP project includes 15 bridges set-up for this near-real time processing of triggered sensors and has more planned for the near future.

For large structures, the quickly processed data can be used to pin-point the inspection efforts to the piers with the most damaging movements. The freefield sensors near Caltrans bridges will provide data for all agencies to build strong ground shaking intensity maps. These maps are to be used by emergency response groups such as FEMA. Each government agency will have the general locations of damaging motions to concentrate the critical first efforts to these locations.

The sensors are placed on the bridges to capture seismic movements as they relate to structural dynamic modeling. Sufficient number of sensors, if viable, are placed to determine the transverse mode shapes of the structures and to record the longitudinal motions of each frame. A tri-axial sensor package is placed at a freefield site to record the input ground motion to the structure. The freefield is placed as best as possible away from the influence of any structure such as the bridge, a building, the approach embankment, etc. to avoid anomalous inputs. The freefield is placed on a rock outcrop if one is available.

Selection Of Bridges For Instrumentation

There are more than 12,000 Caltrans bridges in California and it is not possible to instrument every structure. The bridge sites chosen are throughout California to take advantage of the probability of having a structure at a near source location. Many of the recent earthquakes are on

Figure 1 Locations of bridges instrumented with strong-motion sensors under the Caltrans/CSMIP bridge instrumentation project

newly discovered faults, so having a widely dispersed array of sites takes advantage of the shotgun approach of capturing large structural seismic motions. Many of the Caltrans strong motion sites are in the large metropolitan areas. These areas happen to be in the highest seismic regions. Most of the people, thus a majority of the largest interchanges, are in the big cities. Since life safety is the primary goal of the seismic retrofit program, a great effort is placed on understanding ground motions in these regions. An examination of the Caltrans bridge sites having strong motion sensors, as shown in Figure 1, will reflect these two philosophies by displaying a widely spread network with concentrations in Los Angeles and near San Francisco.

Another criteria for bridge site determination is the use of the Division of Mines and Geology's and the United States Geological Survey's studies that include mapping of earthquake faults in California. Bridges are chosen to be as near to the major faults as possible. Some locations along the faults have a higher probability of experiencing a large quake.

Various structure types are chosen for instrumentation to learn about all Caltrans bridges. The most common bridge type in California is the concrete box girder structure. Most of the bridges chosen for instrumentation are of this type. There are many box girder bridges to choose from in each region. Steel girder, truss structure, pre-cast concrete girder, etc. are also instrumented. Various substructure types are selected for strong motion studies. Pier wall, multi-column bent and single column bent bridges are all monitored. In the large metropolitan areas, various bridge types are chosen at the same interchange to study different structures having similar seismic

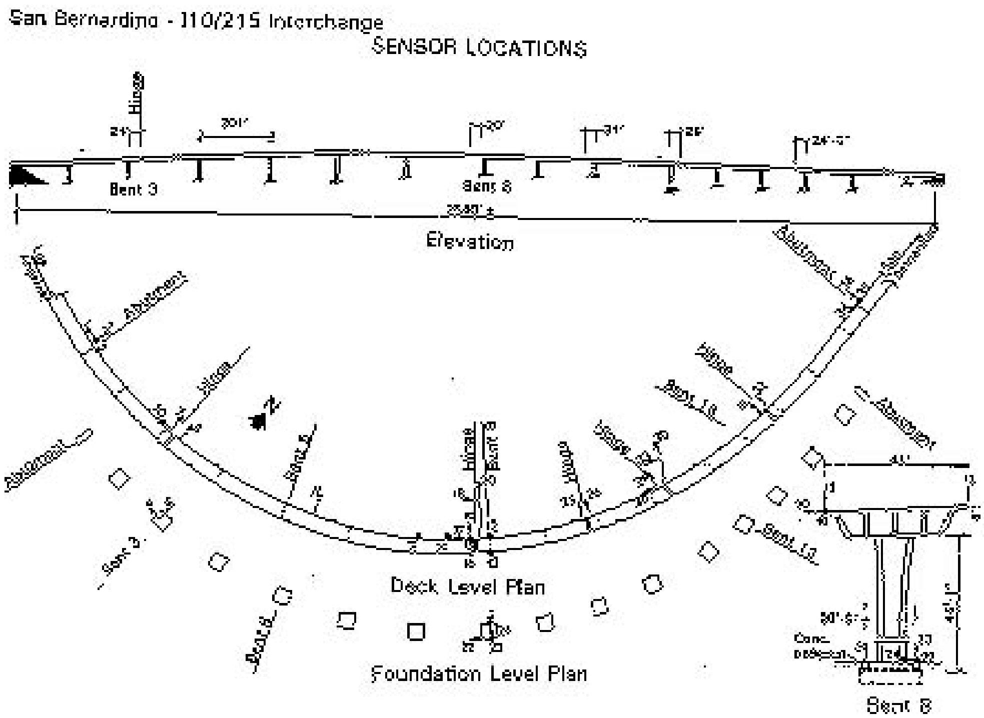

Figure 2 Plan & elevation views of the I10/215 interchange bridge near San Bernandino.

input.

In addition to understanding the structural mode shapes for the global bridge model, studies of different components of the bridge are also important. These studies include the opening and closing of in-span hinges, the movements over abutments, the top and bottom relative movement of the columns, and so on. For example, the I10/215 Interchange in San Berardino, shown in Figure 2, instrumented for the purpose of these studies.

Downhole Instrumentation

Geotechnical downhole arrays are placed throughout California to study the soil column motion amplification from the "rock like" material, e. g., the La Cienega Geotechnical Array shown in Figure 3. These installations are imperative because very little actual readings are available to correlate the geotechnical models. At these downhole sites, the soil is characterized very intensively by using P-S suspension logs, soil sampling, E-logs, cross-hole, etc. to gain a full understanding of the site. The real time data from the suspension logs is used to determine the exact depth of the downhole sensor packages. Downholes up to 900 feet are underway for strong motion instrumentation. Shallow arrays to study liquefaction are also planned. Some downhole tri-axial packages are being placed in concrete piles to study the soil-structure interaction at depth.

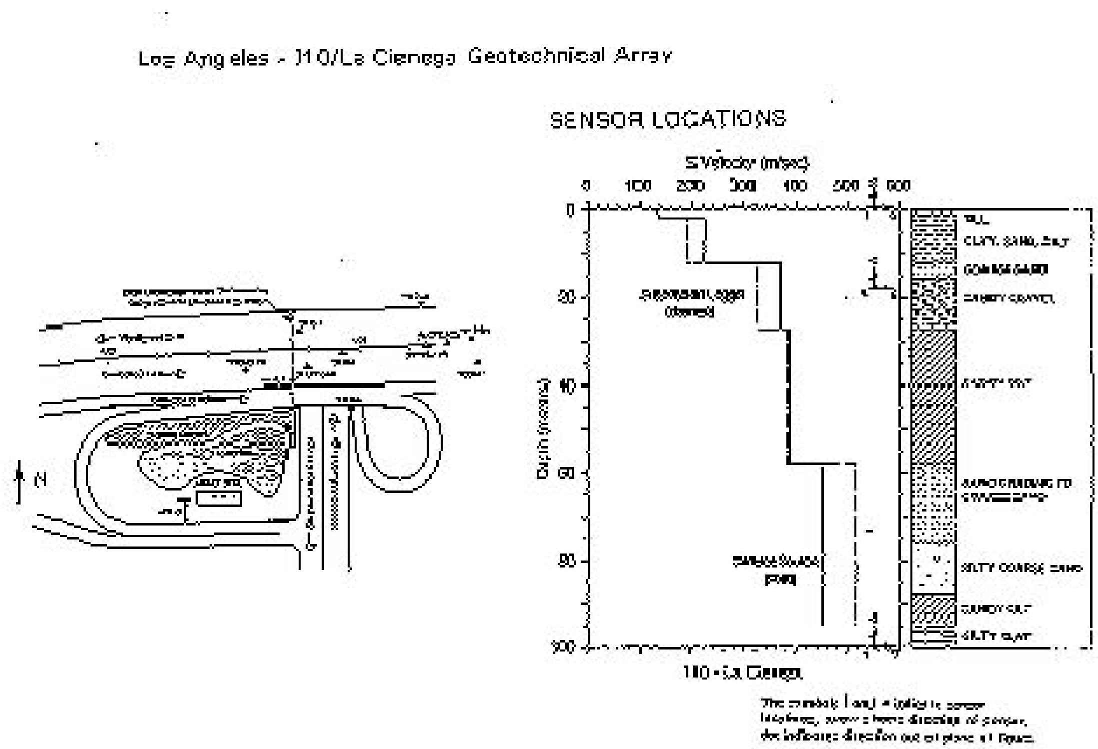

Figure 3 Schematic drawing showing the sensor locations and S-wave velocities at the cooperative Caltrans/CSMIP La Cienega Geotechnical Array in Los Angeles.

Toll Bridge Instrumentation

Some of California's toll bridges have been instrumented for strong motion previously, but full instrumentation of many others is underway, see Table-1 below. These critical structures are an important investment to the people of California and need to be closely monitored. Some of the structures would cost over a billion dollars to replace. All of Caltrans toll bridges have included as part of the retrofit effort a plan to instrument the bridge. As many as 115 sensors will be placed on each structure to capture motions in a large event. These readings will be used to verify the complex dynamic models. Each bridge location will include freefield and downhole arrays. If new piles are added to the foundations, downhole sensors will be placed in selected locations to record the input motion at the base of the pile.

Name of Bridge	Type & Length of Main Structure	Total Length (Miles)	Year of Completion	Estimated No. of Sensors
Benicia-Martinez Bridge	Steel Truss, 4884'	1.2	1962	90
Carquinez Strait Bridge (West)	Steel Truss, 3350'	1.0	1958	72
Richmond-San Rafael Bridge	Steel Truss & Plate Girder, 18483'	4.0	1956	90
San Francisco-Oakland Bay Bridge	Steel Suspension, 10051'	2.0	1936	75
San Mateo-Hayward	Steel Box Girder, 9650'	6.8	1967	115
Vincent Thomas Bridge	Steel Suspension, 2512'	1.1	1964	33 (Downhole)
San Diego-Coronado Bridge	Steel Girder & Box Girder, 7423'	1.6	1969	96

Table-1: Caltrans/CSMIP Toll Bridge Instrumentation

Other Instrumentation

Underwater transportation tubes that connect the cities of Oakland and Alameda will be instrumented with strong motion sensors as part of the retrofit effort. These tubes are being retrofitted for liquefaction utilizing stone columns and pressure grout injection. The strong motion sensoring project includes a shallow downhole array to study liquefaction. The tubes will use the strong motion sensors to trigger a warning sign that will stop cars from entering the tubes after a large earthquake.

Other purposes for strong motion instrumentation are to close vulnerable structures in remote areas. These structures will use common railroad crossing gates that are triggered by strong shaking and will stop the public from entering a possible damaged structure. In some locations, the probability is low that a car will be on a bridge during an earthquake, but the probability is higher that a car will drive onto a damaged or collapsed structure after an earthquake. These seismic gates will prevent this.

CSMIP also has portable strong motion sensor systems that can be quickly deployed to sites that have experienced a large earthquake. These systems will record strong aftershocks at the bridges that were not instrumented during the main shock. This allows more structures to be monitored in the local epicentral region on a temporary basis.

Instrumentation Maintenance

For any installation to be complete, a long term commitment is needed for maintaining the equipment (batteries, sensors, recorders, etc.) and a facility must be in-place to download and process the data. By having a phone link to the site, CDMG is able to dial up the recordering system and verify that all the sensors are up. This reduces the maintenance cost by having site visits only when there is a problem or to add new batteries.

Conclusion

Caltrans and CDMG/CSMIP continue to instrument bridges for strong motion in order to advance our knowledge of how these massive structures move in earthquakes. This information will be shared with other states and countries to improve the life safety of bridge structures throughout the world. Bridge and soil dynamic modeling techniques will be improved by correlating the computed responses from these models with the actual time history readings recorded from these structures.