CALIFORNIA TOLL BRIDGES ANALYTICAL MODEL STRONG MOTION INSTRUMENTATION PROGRAM (CSMIP) CALIBRATION PROJECT

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ABSTRACT

Caltrans' Toll Bridge Seismic Retrofit Program involved performing vulnerability assessments and retrofit designs for the state-owned toll bridges. To determine bridge response and evaluate seismic performance, a finite element model of each toll bridge was created using the finite element program ADINA. Following recommendations of the Seismic Advisory Board the project main goals included the following: (a) update the existing models to conform to the current version of ADINA; (b) create a system to efficiently update the models for newer versions of ADINA; (c) create a standard system for model consistency; (d) create a system to convert Strong Motion Instrumentation Program (CSMIP) free-field motions to input ground motions for the ADINA model, and compare the analytical results with CSMIP instrumentation recordings; (e) use the ADINA models for post-earthquake evaluation of the bridges using input motions derived from the CSMIP, and direct maintenance crews to inspect the predicted regions of damage; (f) gain increased confidence in the existing and any future seismic retrofit work through the models. This paper will describe challenges the project team encountered during the implementation phases of this project.

Key words

Database – ADINA– Toll Bridges - Caltrans – CSMIP

Introduction

After the 1989 Loma Preita Earthquake, the California Department of Transportation (Caltrans) determined that the statewide toll bridges were of significant importance such that collapse during a seismic event would be detrimental to the safety and commerce of California residents and the region. Since then, Caltrans has implemented an extensive Toll Bridge Retrofit Program, performing vulnerability assessments and retrofit designs for each toll bridge. The Toll Bridge Retrofit Program used site-specific geological, geotechnical, and seismological data to predict

future major seismic events for each toll bridge. This, coupled with bridge-specific design criteria, which determined the maximum allowable structural response to a given event, served as a basis for the retrofit designs. To determine bridge response, a finite element model of each toll bridge was created using the finite element program ADINA [1]. Given that each toll bridge model was developed by different design teams using differing modeling assumptions and philosophies, there are likely many inconsistencies among these models. Therefore, it is vital to revisit all these models and update them so that Caltrans is able to:

a) Use the ADINA models for post-earthquake evaluation of the bridges using input motions derived from the Strong Motion Instrumentation Program CSMIP [2].
b) Use these models, with input CSMIP motions, to locate and evaluate predicted damage after future earthquakes.
c) Direct maintenance crews to inspect the predicted regions of damage.
d) Gain increased confidence in the existing and any future seismic retrofit work through the models.

Objectives and Scopes

In this project selected toll bridge models were converted to the latest ADINA version. The toll bridges that were chosen for this project are:

1. 1958 Carquinez Bridge
2. Vincent Thomas Bridge
3. Benicia-Martinez Bridge
4. San Francisco-Oakland Bay Bridge – West Span
5. San-Diego Coronado Bridge
6. Richmond San Rafael Bridge
7. San Mateo Hayward Bridge

The converted models were then translated into a neutral database-driven system that is independent of any structural analysis program. Once the data is saved in the format of database:

a) It can be exported in compliance with any ADINA version.
b) It can be exported with any new ground motions records, e.g. CSMIP record.
c) It can be exported as new input file with modification to the original data.

The new ground motions can be automatically generated from the recorded CSMIP free field record and be added to the database. With the new ADINA input file exported, further analyses will be performed and the results will be readily compared with the recorded bridge motions obtained from CSMIP program. The project was completed through seven milestones as summarized in Figure 1.

Methodology

The project was designed such that its product could allow the Caltrans engineers to start with CSMIP motions and obtain the response of any of the bridges of interest. As presented in Figure 2 the "*START*" point is CSMIP records which yield free-field ground motions serving as input

motions to the ADINA model. The "*END*" point in this figure is the predicted response of the bridge from the analysis that is used in the following manner:

a) The response parameters from the analysis are compared with the CSMIP recorded motions obtained from sensors that have been installed at selected locations on the bridge. This provides an excellent opportunity for the practicing engineers to compare the field measurements of the bridge with the analytical results. This provides better understanding of the seismic behavior of the bridge allowing the bridge engineering community to refine and improve the seismic design codes and modeling techniques.
b) For the immediate benefit, the predicted bridge response parameters are used to quickly identify potential damage locations and severity of the damage on the bridge since the bridge cannot be readily inspected for all damages immediately following a major earthquake. Repairs can be prioritized according to the degrees of damage indicated by the model.

To get to the "*END*" point the following "*Tasks*" (see Figure 2) need to be implemented.

Task 1:

The first step toward developing pier-specific input motions involves examining the CSMIP free-field records for need to perform baseline correction. Once satisfactory free-field motions are obtained, site response analysis and soil structure interaction analysis is performed at each pier location using the CSMIP motion as the input as depicted in Figure 3.

Site Response Analysis: Ground motions would impart loading along the pile foundation, and particle motions arriving at different soil layers would have different characteristics influenced by local soil conditions. Prescribing depth-varying ground motions at the ends of soil springs is often used to simulate the earthquake loading condition. For the current state of practice, the depth varying input motions prescribed along the pile are extracted from results of one-dimensional wave propagation analyses such as those using SHAKE program [3]. All one-dimensional site response programs assume that soils are horizontally layered and that shear waves propagate vertically.

Soil Structure Interaction: For a bridge superstructure, seismic shaking is transmitted from soil to structure throughout the embedded portion of the pile length. Once the depth varying free-field motions are obtained, a soil-structure interaction analysis is carried out to evaluate resultant shaking acting at the foundation level. This is undertaken by applying depth-varying motions at the end of soil springs that are attached to the pile foundation. In this soil-structure interaction analysis, the mass of structures is not included and only stiffness is considered. The resultant motion computed at the foundation level is termed "kinematic motion" that effectively drives the bridge superstructure. The method of computing the kinematic motion is based on a linear theory making use of the sub-structuring procedure. The approach utilizing kinematic soil-pile interaction has been fully implemented in the seismic retrofit as well as the new design for major toll bridges in California. Since the kinematic motion has been derived from the depth-varying near-field motions imparting seismic loads to the pile, it may be considered as 'weighted average' of the free field motions which consider soil and pile stiffnesses within the significant soil-pile interaction zone, normally defined by the characteristic length of the soil-pile system.

These kinematic motions along with foundation stiffness are implemented in the ADINA bridge model.

Task 2:
The Converter Link will automatically convert and assign the motions obtained in "*Task 1"* into ADINA format.

Task 3
The motions obtained in the previous task will be added to the bridge database. In order to facilitate this task and the database use, SC Solutions developed a Graphical User Interface that communicates with the database. This User Interface is called "Bridge Integrated Model Maintenance, Assessment, and Generation Environment" or "Bridge IMAGE". With this GUI, the new input motions can be readily appended to the existing database and viewed for comparison. Using the GUI, a new ADINA input file could be exported with the new ground motions in this task.

In order to start this task one needs to have a database of the bridge. Seven databases were developed for all the seven toll bridges in course of this project. The first step was to convert the old version of ADINA into the latest one. In that process it was necessary to put together a systematic description of the bridges that documents the details of the modeling approach such as nodes, elements, groups, materials (see Figure 4). Recommendations for improvements and/or modifications of the models were documented. However, the retrofit-basis design models were left unchanged.

For each bridge the validation of the converted models were carried out by comparing the original response quantities with the upgraded ones. Once the validation was completed the converted bridge models were imported into the neutral database-driven system using MS Access. This database is independent of any structural analysis program. This process, which is now a part of the "Bridge IMAGE" GUI, was developed during this project to import an ADINA input file into a new database interactively and to export it to any ADINA version with the new input ground motions. The database is then accessed using query language called SQL (Structured Query Language). SQL is an ANSI (American National Standards Institute) standard for accessing database systems including MS Access. The Carquinez 1958 Bridge database, as an example, contains the database tables listed in Table 1. All the database tables are filled using the information obtained from the ADINA input file. Descriptions of many of the components are provided consistent with the terminology obtained from drawings.

Task 4
At this stage the bridge model is analyzed using the latest ADINA input file. This new model was extracted interactively from the database using the GUI in the previous task. In this task the results from the analysis are obtained in a raw format.

Task5 and Task 6
The post-processing includes extracting the results and converting them into a proper format. All the needed post-processing script files were developed in this task. Also, it is necessary to convert CSMIP sensor motions of the superstructure to the proper format. These records along

with analytical response parameters are automatically imported into MS Excel files using macro commands. In this way the comparison of the analytical and measured motions could be done very quickly and efficiently. Also the response parameters are automatically imported into MS Excel files to be compared with the results obtained from the original retrofit-basis design models. This comparison will provide Caltrans engineers with regions of potential failure or hazard in the bridge in case of a seismic event.

Conclusions

In this project we were able to achieve all of the stated objectives (see Figure 1), namely:

1. Conversion of the existing ADINA models of the seven toll bridges to the latest ADINA input files.
2. Development of neutral databases for all the converted models of the seven toll bridges.
3. Development of a prototype GUI to facilitate accessing the database and updating it with new ground motions, in this case CSMIP records. This GUI could be easily used to export the new ADINA input file in any ADINA version.
4. Development of the computer algorithms to obtain pier specific input motions. The entire process of processing CSMIP free-field motion through generating the kinematic motions has been automated.
5. Development of all the post-processing tools needed to extract response parameters from the new ADINA analysis. These response parameters can then be compared with the CSMIP records on the superstructure or with the original retrofit-basis design to estimate performance of the bridge during a seismic event.
6. Prepare reports for each of the seven toll bridges that describe the retrofit-basis design models in detail. Provide recommendations for improvements when needed.
7. Prepare a user manual for the Bridge Image GUI.
8. Prepare a report that describes the process of obtaining pier-specific input motion.
9. Prepare a quick user manual for the entire procedure from "START" to "END" (see Figure 2). This quick user manual could be used during normal operation or emergency situations.

Acknowledgements

This paper summarized the "CALIFORNIA TOLL BRIDGES ANALYTICAL MODEL MAINTENANCE AND STONG MOTION INSTRUMENTATION PROGRAM (CSMIP) CALIBRATION PROJECT", which was sponsored by the State of California, Department of Transportation Research Program. The authors would like to express their gratitude to Mike Keever (Caltrans) for his support. Thanks to Patrick Hipley (Caltrans) who provided interface with CSMIP in this project. Thanks also to Anoosh Shamsabadi (Caltrans) for his valuable technical recommendations and feedback.

References

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Milestone 1:
- ✓Model Review
- ✓SSI Review

Milestone 2:
- ✓Model Conversion
- ✓Verification Software Development
- ✓Model Documentation
- ✓Model Refinement/Recommendation
- ✓Model Validation

Milestone 3:
- ✓Ground Motion Processing

Milestone 4:
- ✓Instrumentation Plan Review
- ✓CSMIP Results Definition
- ✓Extraction of Motions at Sensors

Milestone 5:
- ✓Prototype User Interface Development (Bridge IMAGE)
- ✓Prototype Model Database Development

Milestone 6:
- ✓Training Development
- ✓Training

Milestone 7:
- ✓Report

Figure 1: Millstones

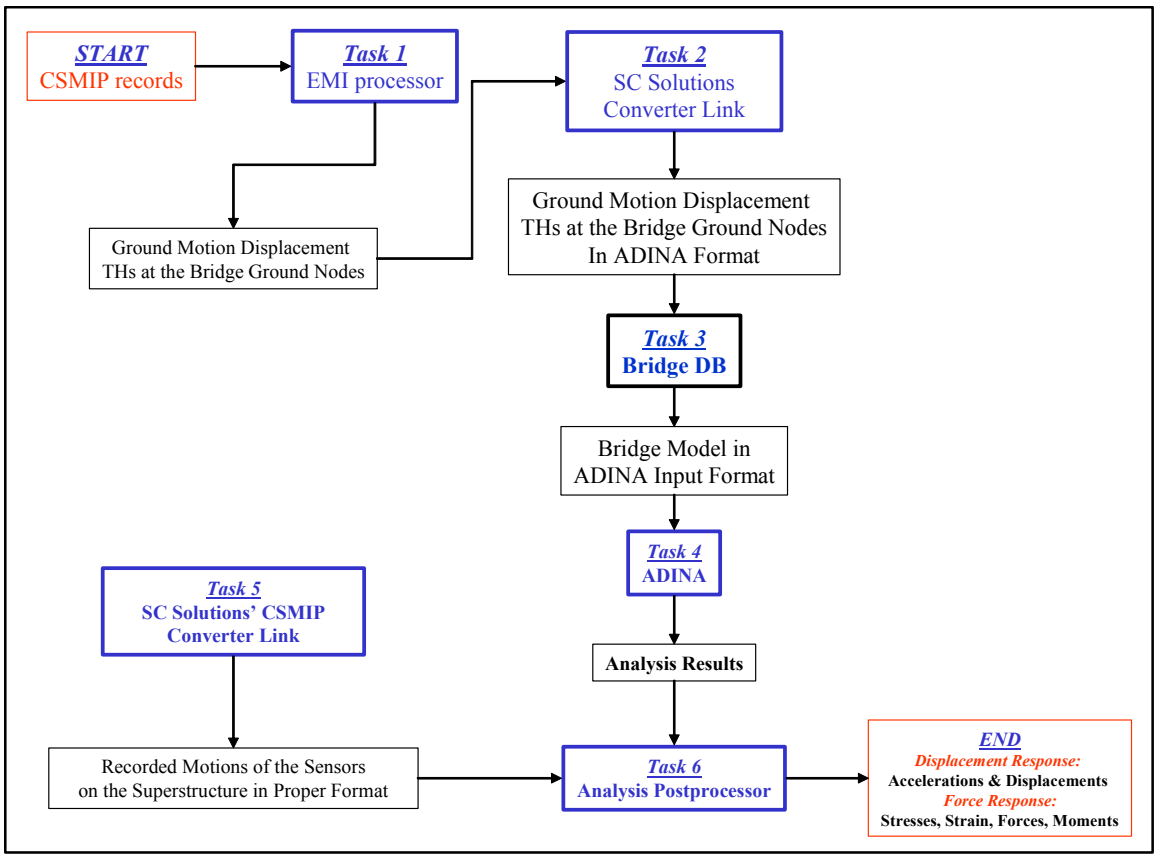

Figure 2: Methodology - Summary of the Procedure

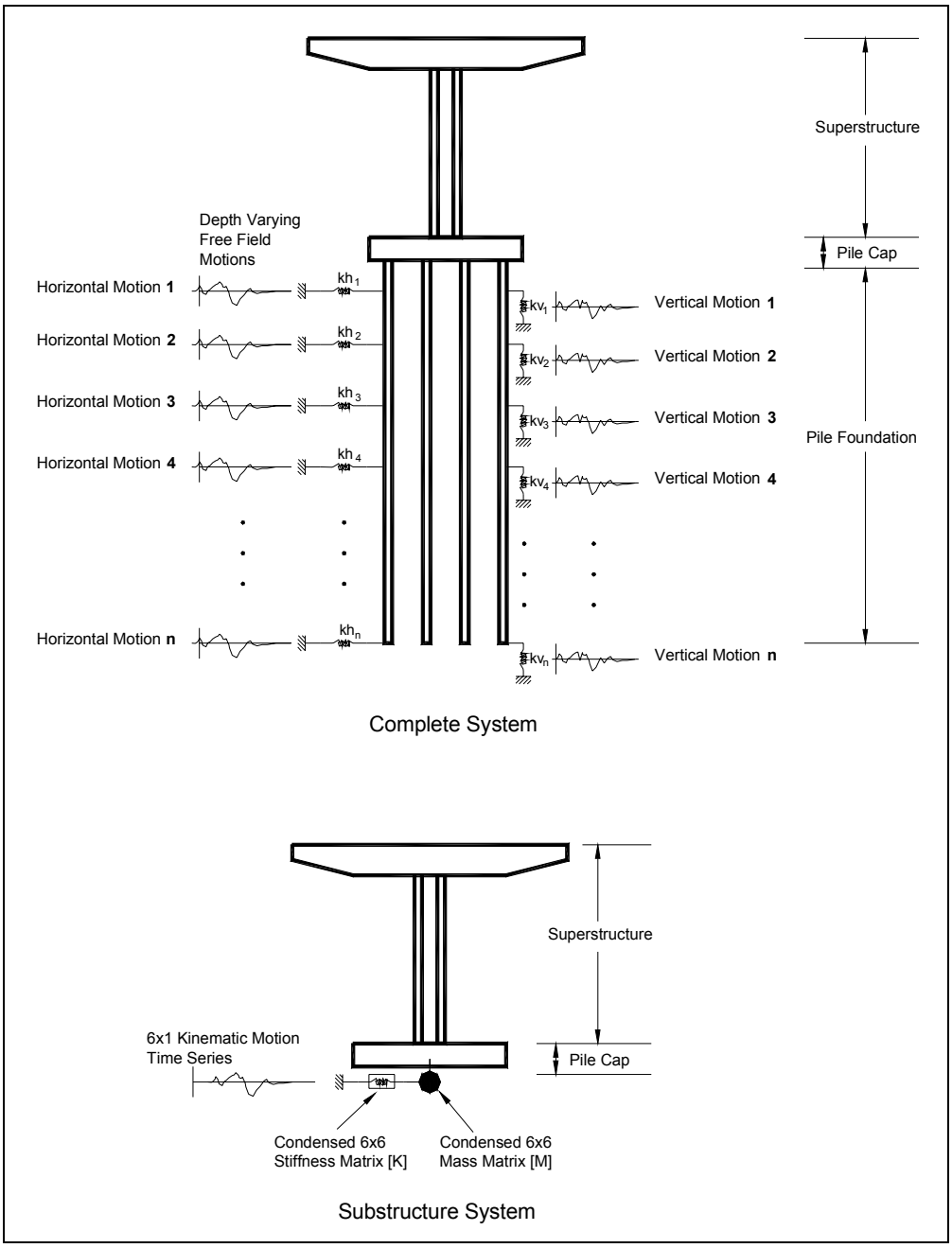

Figure 3: Schematic of Site Response and Soil-Structure Interaction

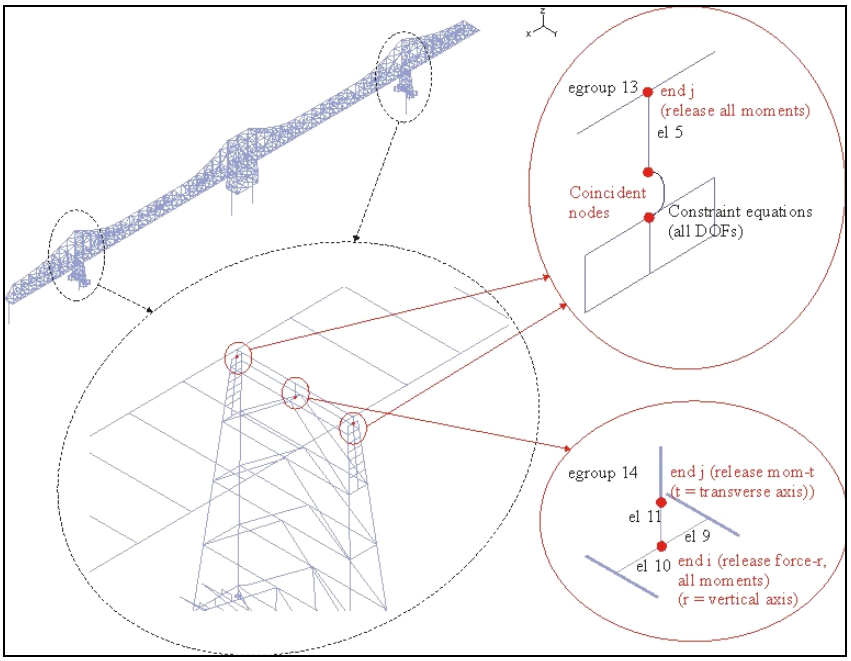

Figure 4: Tower-to deck Connection at Tower 2 and Tower 4

Table 1: Partial List of Tables in Carquinez 1958 Bridge Database

##	MS Access DB tables	Data Description
1	AppliedConcentratedLoads	Nodal concentrated loads
2	AppliedlDisplacements	Imposed nodal displacements
3	AppliedLoads	Mass proportional load application
4	AppliedTemperatures	Imposed nodal temperatures
5	AxesNodes	3D element orthotropic material axes' orientation
6	BeamGroups	Beam element groups
7	BeamLoads	Beam distributed loads
8	Beams	Beam element connectivity and property data
9	Boundaries	Nodal boundary conditions
10	ConstraintCoef	Constraint equation master node IDs and coefficients
11	Constraints	Constraint equation slave node IDs
12	ContactGroup3	3D contact groups
13	CrossSections	Beam element cross-section IDs
14	CurvMomentData	"Moment-curvature" curve data of the Beam MC rigidities
15	Dampings	Rayleigh damping coefficients
16	ElasticMaterials	Properties of Elastic type materials
17	Endreleases	Beam element end release data
18	ForceStrainData	"Force-strain" curve data of the Beam MC rigidities
19	GeneralGroups	General element groups
20	GeneralNodes	General element connectivities
21	Generals	General element property data
22	Groups	All element groups
23	GroupTypes	Element group types available
24	InitialTemperatures	Initial nodal temperatures
25	Links	Rigid links between node pairs
26	LoadMassProportional	Mass-proportional loads
27	Materials	Materials
28	MaterialType	Material types available
29	Matrices	General element property matrices
30	MatrixData	General element matrix elements
31	MatrixSets	General element matrix sets
32	MCForceData	"Moment-curvature" curve IDs been referenced to the axial force values of the Beam MC rigidities
33	MCrigidities	Beam plastic multilinear Moment-Curvature rigidities
34	MTForceData	"Torsional moment-twist" curve IDs been referenced to the axial force values of the Beam MC rigidities
35	NKDisplForce	"Force-displacement" curve data of the Spring element nonlinear properties