Analytical Investigations and Design Implications of Seismic Response of a 2-Span ABC Bridge System

Quarterly Progress Report
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Submitted by:
PI- M. Saiidi and A. Itani
Graduate Student- Elmira Shoushtari

Affiliation: Department of Civil and Environmental Engineering
University of Nevada, Reno

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Background and Introduction

This quarterly report provides a summary of the progress of the project. Percentage of the completed work is listed as are a summary of the results when applicable.

1. Problem Statement

ABC relies heavily on prefabricated components. To maintain sufficient seismic resistance, these components must be properly connected and allow for development of full plastic moment and energy dissipation in bridge columns. Other bridge components including the connections need to remain capacity-protected and undergo no or little damage even under strong earthquakes.

Various connections and prefabricated components have been developed and investigated in the past few years. Substructure connections have included grouted ducts, mechanical bar splices, pocket or socket connections, among others. Superstructure connections have addressed simple for dead, continuous for live (SDCL) details of various configurations and connections for full depth or partial depth precast deck panels. The vast majority of the reported studies on ABC connections have been on components consisting of single or a subassembly of part of bridges. Component studies have been essential in understanding the local behavior of connections and have provided invaluable information that is beginning to help formulate seismic design guidelines for ABC connections. However, to determine the adequacy of connections in a realistic bridge, the connections along with prefabricated elements should be integrated in a bridge system and studied under realistic seismic loads. For example, it is not known how SDCL connections behave under biaxial seismic loading when the girders are integrated with precast cap beams and column pocket or grouted duct connections.

Through a current study at UNR funded by the ABC-UTC year 2 allocation, a two-span bridge system with steel superstructure, full-depth precast deck panels, and a two-column bent that integrates precast columns with pocket and grouted duct connections is under construction for testing on shake tables at UNR. The objective of the study to is to generate test data on interaction among various components and connections under biaxial simulated earthquake. The shake table motions include small, moderate, design level, and severe earthquakes to investigate the bridge model behavior at different limit states. Approximately 300 channels of data are collected on this bridge. Detailed analysis of the bridge, parametric studies, and design implications and recommendations are logical steps following the shake table tests. Extensive analytical studies of the bridge model are essential to maximize the benefits of the shake table study and translate the results into practical design guidelines. The purpose of the current project is to analyze the bridge model and several analytical variations of the bridge in detail and determine refinements that are necessary in the available design methods for seismic design of ABC bridges, their components, and connections.

2. Research Approach and Methods

The overall objective of the current proposal is to analyze in detail the two-span bridge model that is currently under construction at UNR and several analytical variations of the bridge. Other variations will include ground motion types such as near-fault and long-duration motions and unidirectional versus bidirectional earthquakes. The ultimate goal is to determine refinements that are necessary in the available design methods for seismic design of ABC bridges, their components, and connections. Figure 1 and 2 show the elevation and plan view of the bridge model, respectively. The bridge is a symmetric non-skewed, 0.35 scale of an assumed prototype and is the largest possible scale of a bridge system that could be tested without exceeding the capacity of the UNR shake tables. The extra mass shown in the figures help simulate realistic inertia forces and an axial load index (defined as the axial load divided by the gross cross sectional area and the specified concrete compressive strength) of 7% in the columns. The superstructure consists of steel girders and precast full-depth deck panels (Fig. 3). Details of deck connection to the girders and deck transverse joins are shown in Fig. 4. Straight deck bars extend in the deck joints, which are filled with ultra-high performance concrete (UHPC). The pier is a two-column bent with round columns (Fig. 5). Seat-type abutments with sacrificial shear keys are assumed. The connection between the superstructure and the bent is an integral type simulating SDCL (Fig. 6). This connection was developed at FIU and is being adopted in the bridge model to determine its system level seismic performance under horizontal bidirectional earthquakes. Various connection types are incorporated in the pier (Fig. 7). The columns are precast and identical. The column bases are rebar hinges that are connected to the footing through pocket connections. At the top, the columns are connected first to a partially precast cap beam through grouted ducts. The rest of the cap beam is cast-in-place after the placement of the steel girders.

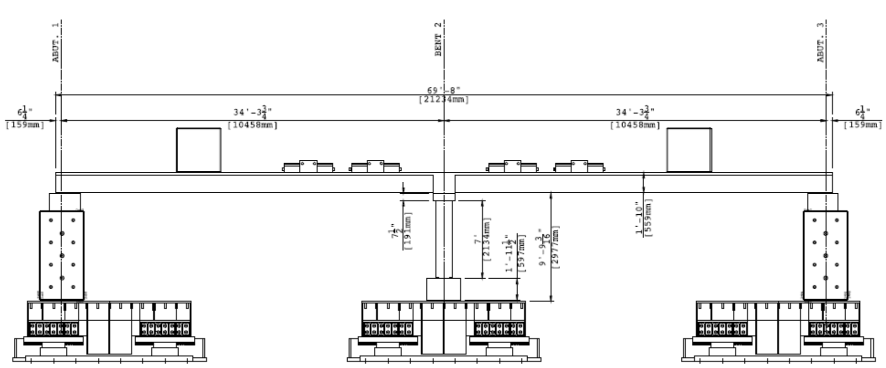

Fig. 1 - Elevation view and position of shake tables for the bridge model

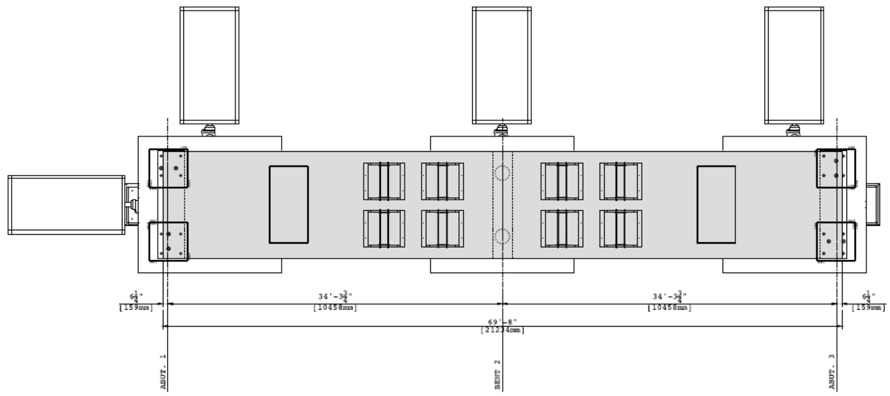

Fig. 2 - Plan view and position of shake tables for the bridge model

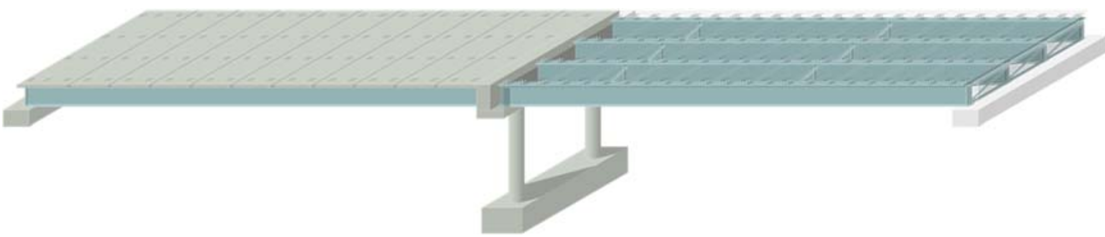

Fig. 3 - Isometric view of the bridge model

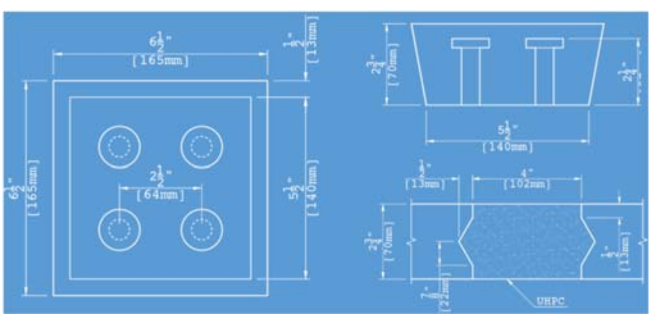

Fig. 4 - Deck panel girder connections and deck joints

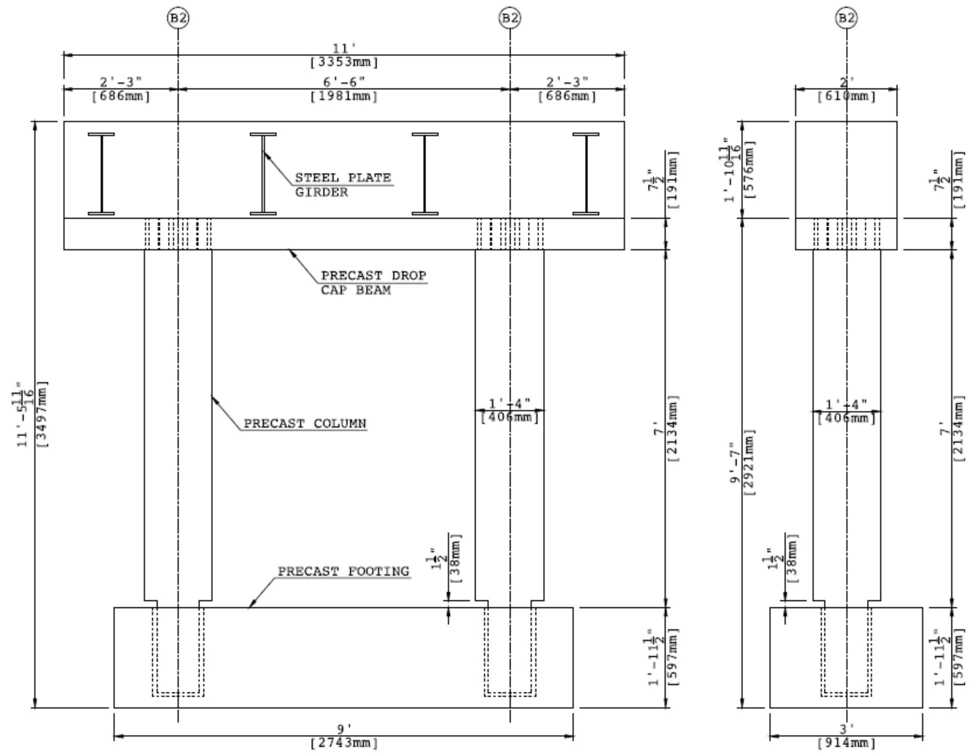

Fig. 5 - Elevation view of the pier

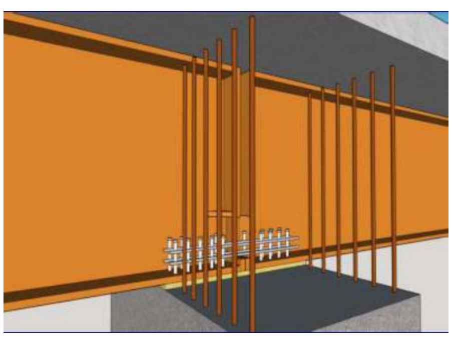

Fig. 6 - FIU SDCL steel girder connection

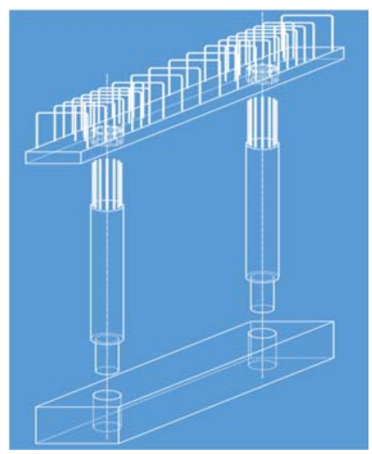

Fig. 7 - Pier connection details

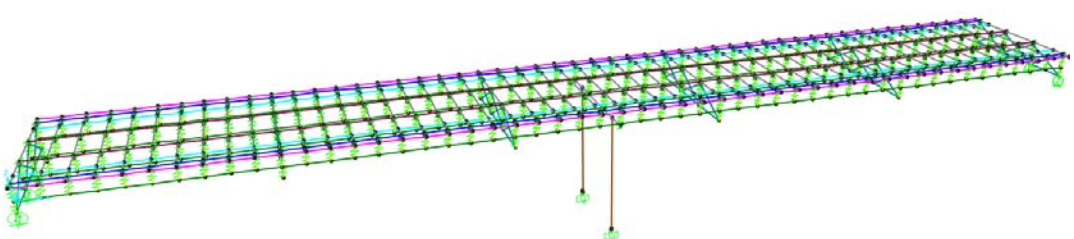

Fig. 8 - Preliminary OpenSEES model of test bridge

The bridge model is subjected to biaxial horizontal motions in the middle shake table with earthquakes of different amplitude until failure. White noise tests are also conducted in between the earthquake runs to determine changes in the effective period and damping as inelastic deformations develop. An OpenSEES model of the bridge model is developed using the actual material properties following the completion of the shake table tests. This model is used to calculate the macroscopic and microscopic inelastic seismic response of the bridge model using the actual shake table accelerations records for different earthquake intensities. Depending on the correlation between the calculated and measured data, the analytical model is refined and re-evaluated. Once the correlation is determined to be satisfactory, the model is used used for parametric studies of variance of the bridge model and input motions that could yield useful results to provide more insight and information for the seismic design of ABC bridges.***

3. Description of Research Project Tasks

The following is a description of tasks carried out to date.

Task 1 – Update literature search on analytical studies of seismic performance of prefabricated bridge components, connections, and systems

An in-depth literature search will be conducted to identify the most recent analytical modeling methods and results on dynamic load studies of prefabricated bridge elements and their connections. The search will include any analyses of ABC bridge systems subjected to seismic loading. Included will be precast deck panels and their connections to girders and to other panels.

Under Task 1 of the proposed study, the literature search will be updated and expanded to identify any new information that could potentially enhance the menu of analytical models for different earthquake-resistant ABC elements and connections.

Updating the literature search has begun. This task will continue until after the completion of the two-span bridge test.

Task 2 – Identify critical macroscopic and microscopic bridge model response parameters and extract measured data for use in analytical studies

The accuracy and acceptability of analytical modeling methods may be assessed at two levels: global response simulation and local response simulation. The global seismic response consist of forces and displacements and relationship between these parameters that define stiffness and its variation as inelastic deformation in steel and concrete develop. Other important global parameters consist of the effective stiffness and damping factor of the bridge. These two parameters will be determined based on the white-noise tests that will be conducted in between shake table runs. Local responses of importance are curvature and rotations in addition to strains in superstructure steel girders, steel reinforcement, and concrete at various critical sections of elements and connections. The curvature and rotation data indicate the extent of section nonlinearity, while the strain data will help explain some of the visible damage that will be documented in the shake table tests. Although SDCL, the cap beam, the superstructure, and the footing are designed to be capacity protected, the measured data will be streamlined for correlation studies with the analytical model and determine if these elements were indeed capacity protected and, if so, the margin against being damaged.

This task will be conducted after the completion and preliminary analysis of the two-span bridge tests.

Task 3- Conduct analytical studies of the bridge model

The most likely analytical tool to be used will be OpenSEES, which is a proven software package for earthquake analysis of structures including bridges. Fig. 8 shows a preliminary sketch of the OpenSEES model of the bridge. The adequacy of analytical modeling methods to capture the inelastic response history of the bridge models will be evaluated under this task with respect to correlation between the measured and calculated data. The correlation studies will address both global and local response data. Based on experience of the PIs, reasonably detailed analytical models developed in OpenSEES are able to capture the global response of bridge columns and piers tested in the in-plane direction. The work of Task 3 will determine if the same holds true for bridge systems with multiple components that are subjected to biaxial earthquake excitations. Correlation studies at the local level will determine if standard element models incorporated in OpenSEES are able to replicate the measured response and the extent of any discrepancies between the measured and calculated results.

This task will be conducted after the completion and preliminary analysis of the two-span bridge tests.

Task 4- Refine the analytical model and conduct parametric studies

Refinement of the analytical model will involve attempting different concrete and steel elements embedded in OpenSEES and identify those that lead to the best correlation between the measured and calculated results. Once an acceptable correlation is achieved, there will be sufficient confidence in the analytical modeling techniques, and the model will be ready for parametric studies. The parameters to be studies will be carefully selected to address issues that could be affected by a system response rather than component response. The ultimate target of the parameters to be studied will be to generate information that could be incorporated in ABC seismic design guidelines. An example of parameters to be studies in the effect of biaxial earthquake motions. Past experimental studies on bridge piers have focused on the in-plane response of the piers, and conclusions have been reached. One of the parameters to be studied will be to apply only transverse motion to the bridge and compare the results with those from biaxial motion studies. Stresses that will be developed in the cap beam, the columns, and the superstructure connections are expected to be different. To determine the effect of biaxial motion on SDCL connections, the bridge model will be analyzed only in the longitudinal direction of the bridge and again the strains at the connection will be compared to those from biaxial earthquake simulation. These are only a few examples of the extensive parametric studies that are envisioned under this task.

Preliminary work on parametric studies on the effect of near-fault earthquakes has begun. Two horizontal components of five near-fault and five far field motions selected from the PEER website were selected for earthquake magnitudes of 6 to 8 on soil with VS30 between 200 to 360 m/s (656 to 1181 ft/s). The distance to the fault was assumed to be between 0 and 15 km for near-fault motions and 15 to 30 km for far field motions. The records were normalized with respect to the design spectral acceleration.

Task 5- Summarize the investigation and the results in a draft final report

A final report describing the details of different tasks will be prepared and submitted to the ABC-UTC steering committee for review and comments. Upon addressing the review comments, the report will be finalized and made widely available for dissemination. This task will be done after the completion of all the other tasks.

4. Expected Results and Specific Deliverables

The deliverables from different tasks are as follows:

Task 1: A synthesis of the literature review providing a summary of the state-of-the-art on inelastic seismic response modeling of different prefabricated bridge components and connections.

Task 2: Key response parameters that are relevant to global and local seismic response of the bridge to assess the ABC components and connections of the bridge and interaction among them.

Task 3: An assessment of detailed analytical model of the 2-span bridge model in light of correlation between the analytical and experimental data.

Task 4: A reliable analytical model for inelastic dynamic response history analysis of bridges. In addition, identification of critical parameters affecting the seismic response of ABC bridges and the required changes in available design methods.

Task 5: A report summarizing the key steps and procedures used in the analytical parametric studies in addition to the most appropriate element models in OpenSEES to replicate the seismic response of bridge systems. The report will also present results regarding component versus system performance of different variations of the bridge model and the earthquake motions in addition to implication in seismic design of ABC bridges.

5. Schedule

To allow for the completion of all the project tasks, the study will be conducted over a period of 17 months following the schedule in Table 1. Note that Q2 in Year 2 is two-months long. The milestones are marked in the schedule, and the following notes explain the deliverables at these milestones.

- a- Critical response data to assess analytical model
- b- Inelastic dynamic analytical model
- c- Important design parameters
- d- Final project report.

Task	Year 1				Year 2	
	Q1	Q2	Q3	Q4	Q1	Q2
1. Literature search	X					
2. Critical response parameters		X[a]				
3. Analytical model development		X	X[b]			
4. Parametric studies and design				X	X	X[c]
5. Final report						X[d]

Completed Work   Remaining Work