ADVANCED ASSESSMENT OF COMPLEX BRIDGE SYSTEMS

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Abstract

Refined seismic design and assessment of complex structures pose stringent requirements on the quality of response parameters obtained from assessment studies. Such accurate response parameters enable controlling local and global damage and provide the tools by which effective design of new structures and retrofitting of the existing built environment. The latter argument is particularly relevant to special and complex structures, such as bridges, where foundations and soil characteristics influence significantly not only the response, but also the input motion. In this overview paper, recent and planned research in the Mid-America Earthquake (MAE) Center and the NEES@UIUC (MUST-SIM) facility at the University of Illinois is outlined in the context of analytical, experimental and hybrid simulations of complex bridge structures.

Introduction

Bridge structures are vital links in transportation systems. As such, protecting their integrity during and after damaging earthquakes is a priority objective, in order that emergency management and relief operations are not adversely affected. Due to their complex behavior, with distinct dynamic characteristics in the longitudinal and transverse directions, effect of curvature, multi-mode response, and structure-foundation-soil interaction, accurate assessment of bridges is one of the most challenging tasks in earthquake engineering. Highlights of two current investigations at the University of Illinois, focused on the behavior of bridges are presented below.

Analytical Assessment of Complex Bridges with Friction Bearings

One of the objectives of the ongoing investigation of complex bridges is to assess the significance of differences between design assumptions and assessment of the as-built structure. Amongst the most important and complex issues is modeling of expansion or expansion joints, and connections between the deck and abutments. The structure under investigation is carefully selected to represent multi-span complex bridges in a medium seismicity area. It consists of two units separated by an expansion joint: a four-span tangent unit and a five-span curved one with a 1300-foot radius, as shown in Figure 1. Whilst the two units act independently in the longitudinal direction, they are linked in

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transverse deformations at the intermediate expansion joint and pivoting at the abutments. The superstructure is composed of four steel girders with a composite cast-in-place concrete deck.

Various types of supports are employed including seat abutments as well as intermediate pinned and sliding bearings. Conventional pinned bearings at Piers 1, 2, 3, 6 and 7 (refer to Fig. 1) were assumed to resist the entire seismic forces in the longitudinal direction. The bearings at the abutments, the expansion joints and at Piers 5 and 8 are sliding supports providing restraint in the transverse direction only. Hence they accommodate significant motion in the longitudinal direction. Elastomeric bearings with a stainless steel sliding surface were suggested in the design for the movable bearings. The transverse resistance is provided via girder stops capable of transferring transverse forces to the abutments and Piers 4, 5 and 8.

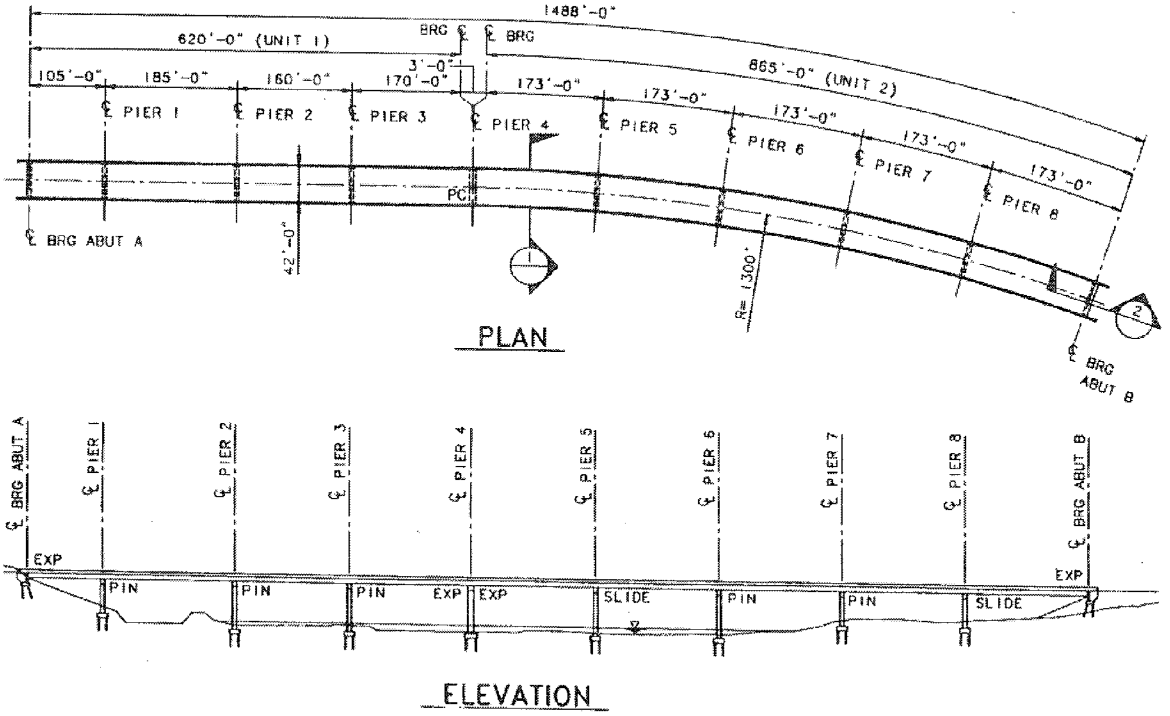
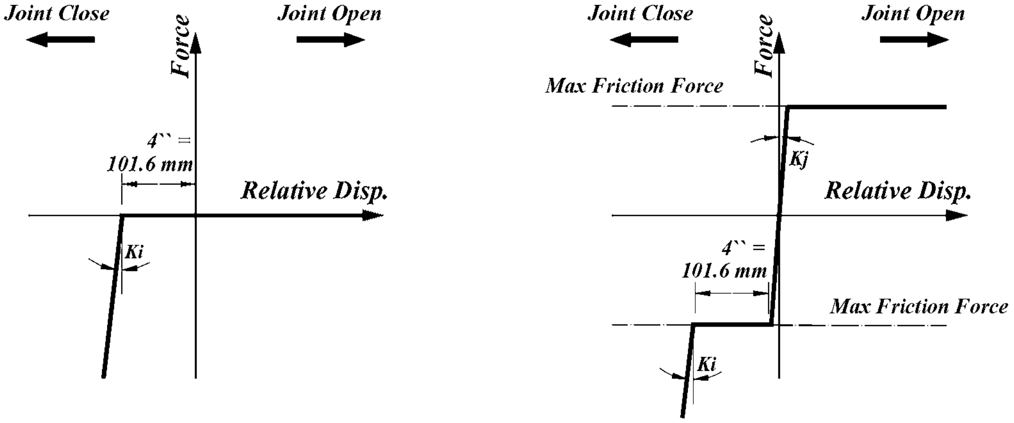


Figure 1. Plan and elevation of the nine-span viaduct steel-girder bridge

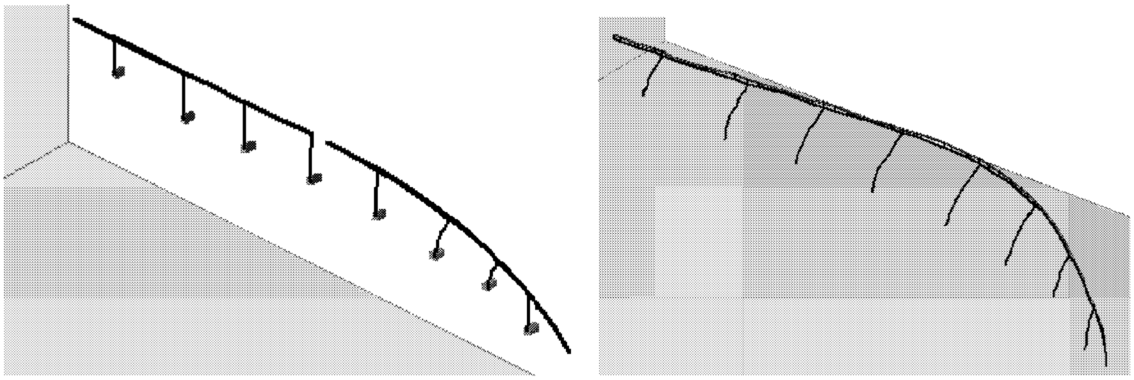
The gaps at the abutments and at the expansion joint are modeled in Zeus-NL (the MAE Center advanced analysis platform) using joint elements with a tri-linear asymmetric relationship capable of representing slippage and collision. Figure 2 shows the force versus relative displacement relationship of a typical joint employed at the abutments, the expansion joint and movable bearings. When the gap at the abutment and at the expansion joint undergoes a relative movement in the negative direction (joint closure) exceeding the gap width, the joint element begins resisting further displacement (collision). Two different joint elements are employed to model the movable bearings at the intermediate piers and at the abutments.



(a) Without Friction **(b) With Friction**

Figure 2. Force vs displacement relationship of the joint element at the abutments

Extensive investigations were undertaken using eigenvalue, static pushover and inelastic response history analyses on the bridge as-designed and as-built (Elnashai and Mwafy, 2004). From the large amount of results obtained, the effect of friction is selected as the focus for the current paper. The design was undertaken with what was considered as a conservative assumption of zero friction. Hereafter it is shown that assuming zero friction is not necessarily conservative, since it fundamentally affects the periods of vibration hence the demand imposed on the structure. Indeed, the demand increases in the case of the structural model with friction in spite of the load-sharing between the two segments of the bridge, as discussed below. In Figure 3, a sample of the no-friction mode shapes from Zeus-NL is shown.



(a) No-Friction T1 = 1.422 sec (b) Friction T1 = 0.796 sec

Figure 3: First two modes of the no-friction (design assumption) model

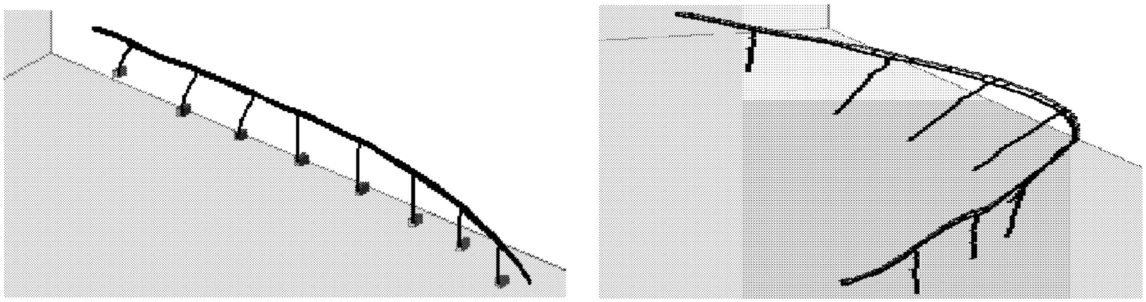


Figure 3 (continued): First two modes of the no-friction (design assumption) model

The fundamental mode is identified as totally independent vibrations of the two segments of the bridge without friction. Table 1 details the periods of various modes for different friction assumptions.

Table 1: Periods for no-friction and friction (designed and as-built bridges)

Period	***Sap2000*** (sec.)	***(a) Zeus-NL (Friction is neglectec & char. mat. str. is used)***		***(b) Zeus-NL (Friction is considered & mean values of material strengths)***					
				(b1) 5% Friction		***(b2) 10% Friction***		***(b3) 30% Friction***	
		Period (sec.)	*Diff* *(%)*	*Period* (sec.)	*Diff* *(%)*	*Period* (sec.)	*Diff* *(%)*	*Period* (sec.)	*Diff* *(%)*
T1	**1.518**	1.422	6.3	0.796	47.6	0.771	49.2	0.764	49.7
T2	**1.207**	1.130	6.4	0.763	36.8	0.728	39.7	0.709	41.3
T3	**0.802**	0.786	2.0	0.709	11.6	0.68	15.2	0.659	17.8
T4	**0.748**	0.732	2.1	0.651	13.0	0.631	15.6	0.608	18.7
T5	**0.748**	0.699	6.6	0.609	18.6	0.607	18.9	0.594	20.6
T6	**0.746**	0.699	6.3	0.607	18.6	0.565	24.3	0.560	24.9
T7	**0.745**	0.663	11.0	0.57	23.5	0.56	24.8	0.558	25.1
T8	**0.680**	0.615	9.6	0.559	17.8	0.555	18.4	0.486	28.5
T9	**0.655**	0.588	10.2	0.551	15.9	0.48	26.7	0.468	28.5
T10	**0.597**	0.565	5.4	0.437	26.8	0.436	27.0	0.466	21.9

The response history analysis indicated clearly that assuming no friction at the bearings and joints is unconservative. 4. The base shear obtained from the six records used in the analysis is significantly higher (up to 100%) than that without friction. Moreover, for a number of piers the shear demand exceeds the design forces only under the ‘friction’ condition. It is therefore recommended that realistic, not idealized, assumptions are used in the assessment of actions and deformations for design.

Hybrid Simulation of Bridges with Soil-Structure Interaction

The MUST-SIM (NEES@UIUC) development group is at the forefront of developing simulation coordinators to perform multi-site (experimental, analytical or mixed) simulations (Hashash et al, 2004; Kwon et al, 2004). To illustrate the application of distributed mixed simulations, the ramp structure of the I-10 Santa Monica Freeway, referred to as Distributor-Collector 36, which suffered severe damage in the Northridge earthquake of 17 January 1994, is investigated. The structure is a prestressed concrete box girder deck supported cast-in-place piers. For multi-site PSD simulation, piers 6 and 7 are studied experimentally at the University of Illinois and Lehigh University. The deck and the rest of the piers are numerically simulated in computational module using dynamic analysis as illustrated in Figure 4, whilst the foundations are studied on the RPI geotechnical centrifuge. The ground motion input for this simulation is the NS Santa Monica City Hall record (~10km from the ramp structure) with peak ground acceleration of 0.370 g. The bridge deck and piers are modeled on Zeus-NL.

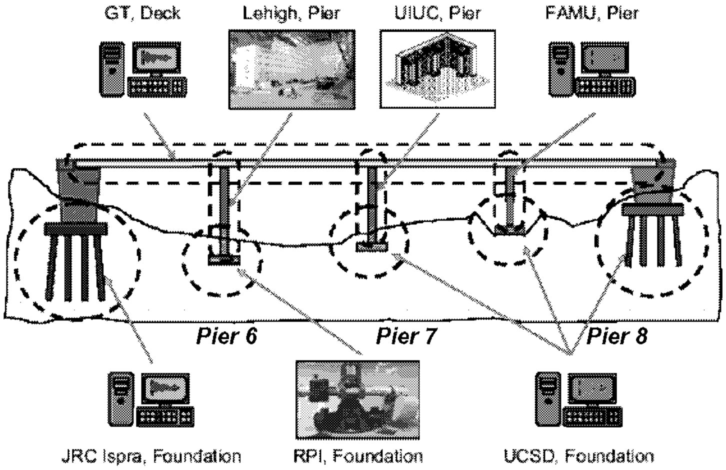


Figure 4: Plan for Multi-site Bridge Simulation

Pre-simulation analysis has given very good results when replacing the intended experimental sites with virtual sites (analytically represented at the collaborating institutions), thus proving the concept and the communications required for the actual test.

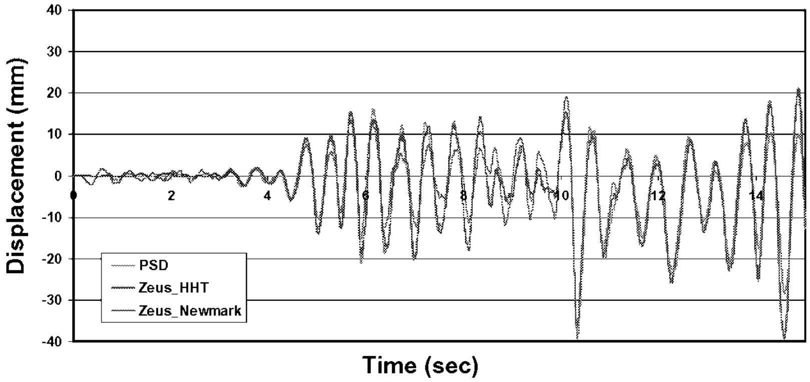


Figure 5: Comparison between integrated and distributed simulation results

Test preparations at the University of Illinois are underway, as indicated in Figure 6. The loading platform is attached to the top of the bridge pier, and lateral and vertical displacements, rotations and gravity forces are controlled simultaneously to represent the actions imposed on the pier by the foundation and deck.

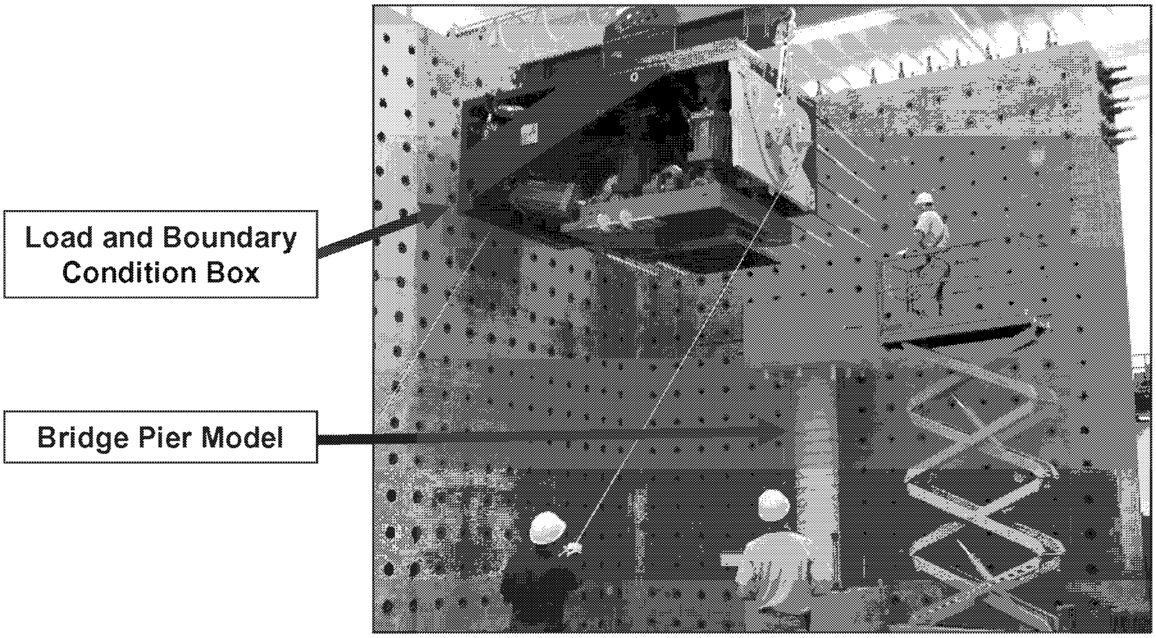


Figure 6: Test setup for pier testing and the University of Illinois (NEES@UIUC)

Once the test setup and communication, through NEESgrid, alongside SIMCOR performance are verified, the investigations will focus on the effect of axial force on the failure mode (axial-shear-flexure interaction) of circular RC piers. Since the deck plays an important role in determining the axial load in the piers, mainly due to its overturning effect and its vibration under the vertical component of earthquake ground motion, modeling the pier will be undertaken on ABAQUS or similar general purpose finite element analysis package, to include the box section properties in detail. The deck will remain in the elastic range. Foundations and underlying soil that are not represented at the RPI centrifuge will be modeled on Opensees. The ultimate object is to derive advanced vulnerability functions for RC bridges with soil-structure interaction effects.

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