NUMERICAL MODELING STRATEGIES FOR HIGH SPEED RAIL STRUCTURAL SYSTEMS

Quarterly Progress Report
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1 Background and Introduction

Bridges are key components of the high speed rail (HSR) infrastructure, while whole new construction of HSR bridges along a HSR line will take some tremendous cost and time. Utilizing the existing structure and foundation for HSR applications provides a good alternative to the challenge, but the methods for upgrading the existing substandard bridges to meet the HSR standards remain largely undeveloped in the engineering community.

2 Problem Statement

One of the transportation solutions that have been always considered in the past few decades is the high speed rail (HSR) where plans for the HSR date back to the High Speed Ground Transportation Act of 1965 (Public Law 89-220, 79 Stat. 893). However, full implementation of an inter-state HSR has never been accomplished. Only recently, California started to work on extending the first HSR line that connects the bay area to southern California. Although the construction for the HSR infrastructure started in California in 2017, the project is consistently getting delays and face several hurdles and challenges. Independent of the CA HSR progress, providing guidance on the modeling, analysis, and design of HSR infrastructure and structural systems could be very beneficial to inspire future national and local HSR projects within the United States.

Bridges are key components of the HSR infrastructure and both new construction as well as utilizing existing structure and foundation systems can be used for HSR. The inherent characteristics of HSR raise new problems beyond those found in typical highway construction, so comprehensive numerical approaches on the bridge structure modeling are needed. The focus of this project is to identify the modeling features and special characteristics of HSR bridges and provide guidance and demonstration examples on how to develop such models.

3 Research Approach and Methods

Our approach for this proposed study is twofold: (1) synthesis of existing literature on HSR bridge modeling and numerical simulation; (2) develop detailed finite element models to demonstrate HSR bridge simulation under service loads and extreme events such as earthquakes. OpenSees, an opens source framework developed by the Pacific Earthquake Engineering Center, will be adopted for the finite element computation. Component and system modeling and analysis will be conducted in a collaborative effort between FIU and UNR. The two teams will work together closely where the PI from FIU will be mostly in charge of the substructure modeling, i.e. foundation systems and soil-foundation interaction, and the team at UNR focuses on the superstructure. The specific research objectives include: (1) synergizing available national and international data on HSR bridge configurations and foundation systems; (2) develop numerical modeling guidelines based on previous studies; and (3) provide demonstration case studies for modeling and analysis of HSR bridges.

4 Description of Research Project Tasks

A summary of the proposed research tasks is as follows:

Task 1 – Literature search on HSR bridges and components.

Task 2 – Develop modeling guidelines for HSR bridges with focus on special features such as train-track-structure interaction.

Task 3 – Conduct demonstration analytical case studies of selected HSR bridge models.

Task 4 – Summarize the results in a final report

Task 1 – Update literature search on HSR bridge configurations and different components types and modeling

This task will perform extensive literature review to collect data on the different components and configurations of HSR using national and international studies and available design guidelines. The literature review is currently in progress with focus on collecting information on HSR infrastructure around the world. Table 1 summarizes the HSR in operation and under construction along with other statistics from around the world. At least 19 countries around the world are building or planning new high-speed rail lines. Few examples include:

- China invested in building the world's most extensive HSR system.
- Saudi Arabia began construction on 276-mile HSR line connecting holy cities of Medina and Mecca via Jeddah.
- Within the European Union, Spain is constructing about 1,500 miles of HSR lines.
- France is planning more than 2,500 miles of new HSR lines.
- England proposed second phase of its national high-speed rail network.

Table 1 - HSR in Operation and Under Construction Worldwide

	In Operation				Under Construction			Total		
Country	First year of operation	Miles	Percent of Total	Top Speed (mph)	Miles	Percent of Total	Top Speed (mph)	Miles	Percent of Total	Annual Ridership
China	2003	3,914	37.2	220	2,696	55.9	220	6,610	43.1	290,540,000
Japan	1964	1,655	15.7	190	235	4.9	230	1,890	12.3	288,836,000
Spain	1992	1,278	12.2	190	1,098	22.7	190	2,376	15.5	28,751,000
France	1981	1,178	11.2	200	130	2.7	200	1,309	8.5	114,395,000
Germany	1991	798	7.6	190	235	4.9	190	1,033	6.7	73,709,000
Italy	1981	574	5.5	190	—		—	574	3.7	33,377,000
South Korea	2004	256	2.4	190	116	2.4	190	372	2.4	37,477,000
USA	2000	362	2.1	150	—		—	362	1.5	3,200,000
Taiwan	2007	214	2.0	190	—		—	214	1.4	32,349,000
Turkey	2009	146	1.4	160	317	6.6	160	463	3.0	942,000
Belgium	1997	130	1.2	190	—		—	130	0.8	9,561,000
The Netherlands	2009	75	0.7	190	—		—	75	0.5	6,005,000
United Kingdom	2003	70	0.7	190	—		—	70	0.5	9,220,000
World Total	—	10,513	100.0	—	4,827	100.0	—	15,340	100.0	928,362,000

Notes: Data is sorted by miles in operation. China's annual ridership is an estimate based on various news reports. USA's annual ridership reflects FY 2010 ridership on Amtrak's Acela Express service on the Northeast Corridor.

Source: UIC (2011; 2009).

Several studies have been identified for this task and a comprehensive study recently completed in the United States is the one by Li & Conte (2018), which is summarized below as an example of synergizing existing literature. According to Lo and Conte (2018), the construction of high-speed rail bridges in highly seismic active areas (e.g., San Francisco and Los Angeles areas) calls for carrying out a detailed and comprehensive seismic analysis for these bridge types. Figure 1 shows an isotropic view of a California HSR (CHSR) prototype bridge, which was designed in collaboration with Parsons Brinckerhoff, Inc, an engineering firm assisting the CHSR Authority in developing the design criteria and technical standards. This prototype bridge is hypothetically located in downtown San Jose, California, for the study of the feasibility and optimality of seismic isolation in a CHSR prototype bridge. The bridge is a straight 9-span bridge, consisting of three 110.5-m- long and 14.6- m- tall frames with 3 spans of 33.5 m each and with 2 interior expansion joints between the central and 2 end frames, as well as 2 abutment expansion joints at the bridge ends and on top of the bridge deck is a typical ballast-less track system. A comprehensive 3D nonlinear FE model of the CHSR prototype bridge was developed using the nonlinear FE analysis software framework OpenSees.

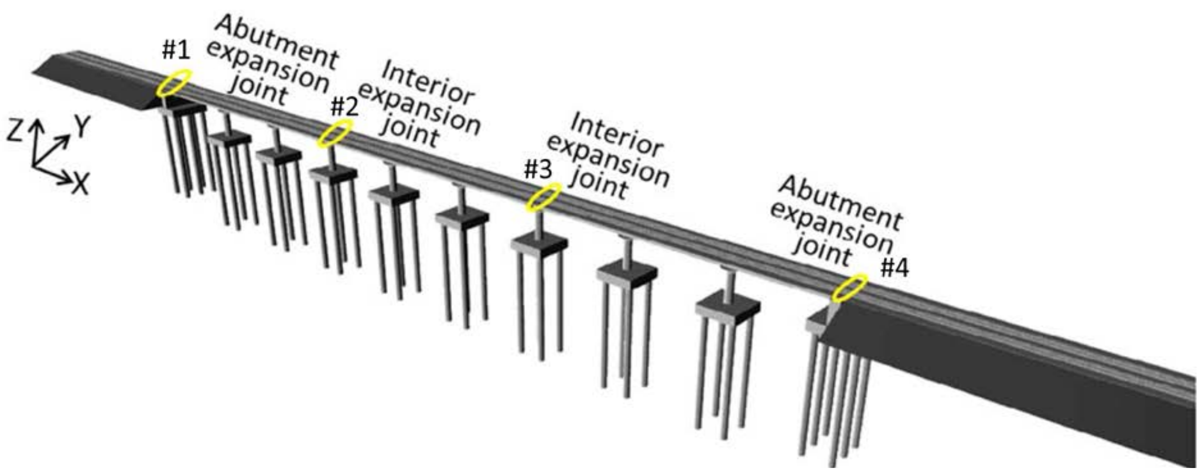

Figure 1. Isotropic view of a high-speed rail prototype bridge

The track-structure interaction was accounted for by explicit modeling of the rails (on both the bridge and the left and right extensions) using linear elastic beam-column elements with material and section properties specified in the AREMA manual for rail type 141RE. The connection between the rail and structure or subgrade was represented by a series of elastic-perfectly- plastic springs in the longitudinal direction and elastic springs in the transverse and vertical directions, respectively. The bridge deck, a posttensioned single-cell box girder (12.8 m wide at the top), was modeled using elastic beam-column elements, considering the fact that the bridge deck was designed to remain elastic as a capacity protected component. The bridge pier columns of circular cross-section with a diameter 2.44 m were modeled using displacement- based beam- column elements with nonlinear fiber sections. Realistic uniaxial nonlinear constitutive material models were assigned to the concrete (cover and core) and steel fibers. The connection between adjacent bridge decks, i.e., slotted hinge joint devices, was modeled using zero-length elements, each comprising a gap hook and a bilinear hysteretic spring in series in the longitudinal direction and bilinear hysteretic springs in the transverse and vertical directions, respectively. The abutment shear keys were modeled using a shear key model developed and calibrated based on experimental results. The connections between the bridge deck and pier columns, i.e., the seismic isolators, were modeled using zero-length elements with 2 uncoupled bilinear inelastic materials for the horizontal shear behavior.

Task 2 - Develop modeling guidelines for HSR bridges with focus on special features such as train-track-structure interaction.

As discussed above, one of the objectives of Task 1 is to collect sufficient information on HSR infrastructure, with focus on bridges, from published studies, report, or design codes and guidelines. The objective of Task 2 is to develop modeling guidelines for HSR bridges. HSR are different from highway bridges not only in design but dynamics response and behavior. Thus, special modeling features of HSR bridges such as train-track-structure interaction need to be considered in representative HSR bridge models that could be reliably used for informing HSR design. Given that HSR is commonly used in several countries as shown above in Table 1, such information on special modeling features of HSR bridges exist and will be compiled as part of developing the modeling guidelines for HSR bridges.

As previously mentioned, this project is collaborative with FIU for providing modeling guidelines of the full HSR bridge systems including foundation systems and substructure. The collaboration is extended to include University of Washington as well through an ABC-UTC initiative to provide design guidelines for HSR bridges as well as the modeling guidelines. So this task is liely to have parallel tasks at FIU and UW.

Task 3 - Conduct demonstration analytical case studies of selected HSR bridge models.

Using the body of literature and detailed modeling guidelines developed in Tasks 1 and 2, selected HSR bridge configurations and prototypes will be used to develop detailed FE models in Opensees and conduct series of nonlinear analysis under various types of loads including earthquakes. The objective of this task is to provide demonstration and step-by-step examples for developing HSR models and conducting numerical simulations.

Task 4 - Summarize the investigation results in the final report.

A final report describing the details of different tasks will be prepared and integrated into a larger report in collaboration with FIU and UW. The report will be used as basis to provide a short guideline on HSR bridge modeling and numerical simulation strategies.

5 Schedule

This project has been extensively delayed over the course of the last 1.5 years because of several major changes in the scope. While the scope and tasks presented herein are believd to be finalized, the expected end date for this project is June 2020,a nd the progress in the 4 tasks is as foolows:

- Task 1 → complete by Nov 2019

- Task 2 → complete by January 2020
- Task 3 → complete by April 2020
- Task 4 → complete by June 2020

The percentage of completion of this project is as follow:

Item	% Completed
Percentage of Completion of this project to Date	15

6 References

1 Y. Li and J. P. Conte, “Probabilistic performance-based optimum design of seismic isolation for a California high-speed rail prototype bridge,” Earthq. Eng. Struct. Dyn., vol. 47, no. 2, pp. 497–514, Feb. 2018.

2 California High-Speed Train Project, “Technical Memorandum: Design guidelines for High-Speed Train Aerial Structures TM 2.3.3.,” 2009.

3 Y. Li and J. P. Conte, “Effects of seismic isolation on the seismic response of a California high-speed rail prototype bridge with soil-structure and track-structure interactions,” Earthq. Eng. Struct. Dyn., vol. 45, no. 15, pp. 2415–2434, Dec. 2016.