PERFORMANCE EVALUATION OF STRUCTURAL SYSTEMS FOR HIGH-SPEED RAIL IN SEISMIC REGIONS

Quarterly Progress Report

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1. Problem Statement

High Speed Rail (HSR) imposes demands on the supporting structure that differ significantly from those imposed on highway bridges. Furthermore, the CA_HSR project travels through several very different physical environments, each of which creates its own demands. For example, the section passing through the Central Valley (flat and hot, easy construction access) faces construction challenges that differ from the sections that traverse the mountainous regions closer to the coast (widely varying column lengths, more difficult construction access, etc.) Thus any work aimed at developing an optimal system must start by understanding the design criteria and knowledge gaps perceived by the CAHSR design team. Only then can research be targeted and effective.

The structural systems to be used for the bridges along the line presently focus on large, stiff structures that are intended to minimize displacements and that do not rely on the development of ductile response to the same extent that highway bridges typically do. However, such stiff structures induce large forces in the substructures, and they are consequently expensive. CAHSR has identified cost containment as a critical issue, so the "strong" approach faces budgetary constraints.

At the other end of the stiffness spectrum, seismic isolation offers reduced forces (and potentially lower cost), but the displacements at the track level are likely to be much larger (Li and Conte 2017), and may exceed levels for safe vehicle operation. Thus, careful concept design will be necessary to resolve the conflicts between these two requirements (low forces and low displacements). Selection of a suitable concept must precede any detailed design considerations.

The research will investigate the connection and HSR system response using advanced, nonlinear analysis methods. A thorough literature review will identify types of connections and document their structural response; the UW team will work with the HSR team to identify one or more connections for further study. Using high-resolution finite element modeling, salient parameters of selected connections, including materials, geometry, and soil-structure interaction, will be studied. Those results will be used to develop spring and line-element nonlinear models of the components and connections as a function of the important connection parameters. The final research task will investigate the seismic response of a prototype HSR CFT system using these nonlinear models. Connection design details, seismic performance objectives, seismic hazard levels, and soils will be varied to study their impact. The results will provide important initial guidelines for the connection design and seismic performance which will found a future experimental research study to validate the work.

2. Research Approach and Methods

The overall goals of the proposed research are to:

- Evaluate the structural systems presently under consideration by CAHSR.

- Develop alternative concepts, and to obtain feedback from CAHSR to guide their further development.

- To develop preliminary calculations and drawings for selected Conceptual Designs, so that CASHR can evaluate their expected structural performance, their speed of construction and cost.

3. Description of Research Project Tasks, (*with reported progress*)

Task 1 – Literature Review and Agency Discussions.

The first task is to find out what agencies in other parts of the world have done in developing High Speed Rail. This will be achieved by a review of the literature and by contacting rail authorities, such as those in Japan, China, Taiwan, Germany, France and Spain. Learning from the experiences of others is an essential starting point, but it should be noted that their findings may not be usable directly in the USA, because the environments may be different (e.g. different seismicity, construction cost profiles).

This task has essentially been completed, and, at the request of the UTC Director, an interim report has been prepared and submitted to the UTC. As the project progesses, we will continue to seek additional in formation to add to that already found.

Japan built the first HSR system, but China now has by far the greatest number of installed track miles. Japan and Italy face the highest seismic hazards and so are of particular interest. The systems installed worldwide display a very wide range of structural systems, and it is clear that fundamental characteristics of them, such as how to accommodate thermal effects in addition to seismic ones, require overall planning prior to starting on detailed design. For example, distribution and orientation of shear keys and bearings needs to be addressed at the start of the design, because they influence so strongly the loads resisted by the various elements. Furthermore, allowing bridge expansion without inducing large compressive stresses in the rails imposes design constraints on the track fixation system.

For medium span bridges (i.e. up to 50 meters), box girders are perhaps the most widely used. It is believed that this choice is made because a closed box offers high torsional resistance, and so helps to limit deflections when a train passes on one of the two tracks supported, necessarily eccentrically, on the structure.

Task 2 – Meet with Personnel from CAHSR to Determine Design Criteria.

The team will meet with technical personnel from the CAHSR Authority to determine the design criteria for the rail infrastructure in the different regions in which it will be built. They may differ in the different regions of the planned route, such as the Central Valley and more mountainous regions. We will also seek information about the present approaches to project

delivery (Design-build, Design-bid-build, etc.) and the structural concepts on which the present design approaches are based.

No progress has been made on this task. We were asked by the UTC not to meet with, or even contact, the CA HSR Authority. Accordingly, we compiled a first list of questions, developed with input from other groups studying HSR. On 2 Nov 2018 sent the list to the UTC with a request that they forward it on to the CA HSR Authority. We are awaiting a response. When we receive responses from CA HSR, we expect further questions to arise.

Task 3 – Performance Evaluation of System Presently Under Consideration.

We will conduct structural evaluations of the present design approaches, using relatively simple computational models, to determine their ability to satisfy the design criteria obtained in Task 1. The use of highly detail models is not warranted at this stage, because it is the overall behavioral trends that are sought, rather than the behavior of a local detail. It is likely that the various loadings will impose competing constraints on the design, and these will have to be evaluated. For example, the limitation of seismic displacements may require a stiff, strong structure, whereas environmental loadings, such as thermal and shrinkage, may require a flexible one.

No progress. We are awaiting information on the structural systems described in Task 2.

Task 4 – Identification and Performance Evaluation of Alternative Systems

Alternative system concepts will be developed, guided by CAHSR's design criteria and the concepts in use elsewhere in the world. Their ability to meet the design criteria will be established through the use of simple mechanistic models, so that their first-level evaluation can be conducted in a reasonable amount of time. Then we will meet with CAHSR personnel to discuss the alternative approaches, and to obtain feedback with which to refine the underlying structural concepts. The feedback will be used to select the most promising concepts and to conduct more detailed evaluations on them. Again, loadings will include gravity, vehicular, seismic and environmental, and the goal will be to determine how well they meet the design criteria. The team has a long history of developing innovative structural systems (Stanton et al. 1997; Pang et al. 2010; Thonstad et al. 2016) and those past successes will be used to advantage in this task.

No progress.

Task 5 – Design Calculations and Drawings for Selected Conceptual Designs.

For each of the selected Conceptual Designs, we will provide preliminary calculations, approximate member sizes and connection details, and drawings. The purpose is to provide a basis for evaluating the expected structural performance, the methods of construction, the time

needed and the cost. The research team will provide a written evaluation of the expected structural performance. For the construction-related characteristics (methods, time, cost), the team will provide ideas, but the CAHSR staff will themselves need to develop reliable estimates, because those tasks lie outside the primary experience of the researchers. However, the calculations and drawings will provide the basis needed for CAHSR to develop preliminary estimates.

No progress.

Task 6 – Final Report.

A Final Report will be written that summarizes the methods used and the findings reached during the project. The Design calculations and drawings for the alternative systems will be included in appendices.