Seismic Retrofit of Bridge Steel Truss Pier Anchorage Connections

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ABSTRACT

The steel-concrete connection at the pier-to-foundation interface of steel truss bridges has been shown through simple analysis to be inadequate to resist seismic demands. This connection, having little to no ductility, may potentially be the weak link in the seismic load path. A picture of a typical anchorage connection is shown in Figure 1. While retrofitting to strengthen the existing connection to resist the full seismic demand is an option, this could also increase the demand on other, possibly vulnerable, members. Allowing failure or releasing the anchorage connection produces a rocking bridge pier system that may can effectively isolate the superstructure.

The proposed retrofit solution presented here uses a rocking system with added passive energy dissipation devices to force the damage caused by earthquake motions into easily replaceable, ductile structural “fuses”. The system has an inherent restoring force with a possible re-centering capability to limit or prevent residual displacements after an earthquake. A sketch of a retrofitted tower is shown in Figure 2. The retrofit strategy attempts to capacity protect all existing structural elements thus keeping the bridge in service after a seismic event.

BACKGROUND

The performance of existing steel bridges in past earthquakes has found certain details to be potentially vulnerable. These include the steel columns, joints and connections, steel tower bents, and steel superstructures. From an ultimate design standpoint steel bridges have performed well but significant damage in members and especially connections has been seen, leaving structures out of service until costly repairing can be done. This is unacceptable performance especially for bridges deemed critical for the response and recovery efforts following an earthquake.

A literature review revealed that the rocking bridge pier concept has been implemented into a few bridges including the Lions Gate Bridge (north approach) in Vancouver and the South Rangitikei Rail Bridge in New Zealand. Both use a steel yielding device at the foundation interface to dissipate energy.

OBJECTIVES

• To assess performance of existing steel/concrete anchorage details
• To produce a retrofit strategy that protects existing bridge elements and does not require strengthening of the foundation
• To verify that the retrofitted structure meets the performance objectives

METHODS

This research investigates the dynamic characteristics of the above proposed rocking/energy dissipation system including development of a design method of the energy dissipation devices. A tension/compression yielding brace (often called an “unbonded brace”) is selected as the energy dissipating “fuse” in this application. Testing has shown the brace able to withstand repeated cycling at high levels of axial strain (2.5-3.0%) (Iwata et al, 2000). A capacity design procedure is used and constraints are identified to protect all other elements. The constraints include limiting forces, impact energy to the foundation, and displacement ductility on “fuse” elements. The re-centering capability is also included as a design constraint; however optional.

The design procedure uses a graphical approach by which a pair of design parameters (A_u and L_u) are varied and solutions found that obey the design constraints. A sample design plot is shown with the solution area shaded in Figure 3.

METHODS (Cont.)

It was found that the system produces flag-shaped hysteretic behavior, as seen in Figure 4. The ultimate displacement response of this nonlinear hysteretic system is determined using a spectral capacity-demand procedure.

Nonlinear time history analysis is used to verify that the design methods are able to reasonably predict system response. A compression-only “gap” element and a hysteretic element are placed in parallel at the anchorage interface to model the rocking mechanism. A picture of the analytical model is shown in Figure 5.

The rocking bridge pier concept is applied to piers of varying aspect ratios under increasing seismic demands to determine its range of application. Key design parameters, on which the designer can operate, are identified and include increasing the stiffness of the existing pier, strengthening weak elements and using low-yield-point steels in the brace, among many possible.

RESULTS

The retrofit solution creates ductile response with limited retrofit effort. The design procedure appears to reasonably predict the response of the rocking/energy dissipation system described while satisfying the performance objectives. Various response parameters are shown in Figure 6.

CONCLUSIONS

Results (including many not presented here) suggest that the proposed retrofit strategy is a promising method to achieve ductile seismic response of bridge steel truss pier anchorage connections.

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Publications


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