Seismic Vulnerability Assessment and Retrofit Design of New York State Thruway Bridges

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Summary

After New York State's Schoharie Creek Bridge collapse in 1987, a comprehensive Bridge Safety Assurance program was developed to supplement the condition-based evaluation obtained from a traditional bridge inspection program and to provide a more systematic method of reducing the failure vulnerability of the state's 17,360 bridges. The intent was to assess and rate the degree of risk that is associated with certain design details and circumstances. As a result of this effort, New York State categorized risk factors according to six potential modes of failure: hydraulic, overload, steel details, collision, concrete details, and seismic (earthquakes). This paper summarizes the methodology in performing the seismic vulnerability assessment of 457 routine bridges spanning over or carrying the New York State Thruway and performing Structural Integrity Evaluation (SIE) for the representative structures with deficient and inadequate seismic performance. Response spectrum and pushover methods of analysis were performed for a 500 year and 2500 year return periods. The vulnerability modes for the critical structural elements were identified and recommendations for retrofit were also provided.

Keywords: Seismic Vulnerability; Routine Highway Bridges; Screening and Ratings; Structural Integrity Evaluation (SIE), Response Spectrum Method, Pushover Method

1. Introduction

This project was initiated by NYSTA to address the seismic vulnerability assessment of all their existing bridges as mandated by their overall BSA program. The assessment was intended to identify bridges that are seismically deficient and establish an order of priorities for corrective actions, either retrofit or replacement based upon the degree of vulnerability and the likelihood and consequences of failure. The project involved seismic vulnerability assessments of 457 bridges and ramps spanning over or carrying the New York State Thruway system.

2. Seismic Vulnerability Assessment Procedure and Results

The process comprises of three steps: screening, classifying and rating. The process is common to all six identified BSA failure modes and is intended to provide a uniform measure of a structure's vulnerability to failure. The seismic vulnerability rating is calculated by first assigning a likelihood of failure score using the vulnerability class to the bridge and then adding to it a consequence score. This latter score is based on an estimation of the failure type and an exposure score. All bridges receive one of the six possible vulnerability ratings 1 through 6. These ratings indicate the degree of vulnerability to seismic event, with rating of "1" being the most vulnerable. The ratings also indicate type of corrective action needed to reduce the failure vulnerability of a bridge and the urgency in which these actions should be implemented. The vulnerability assessment efforts resulted in 55 bridges with rating of "1", 41 bridges rated "2", 174 bridges rated "3", 170 bridges rated "4" and 17 bridges rated "5".

3. Seismic Integrity Evaluation (SIE)

16 rated "1" bridges were selected by NYSTA for SIE analysis based on the superstructure type, span lengths, substructure type, pier height, foundation type, soil borings, approximate period, etc.

Analysis Methods: In general, three methods are used to evaluate the seismic performance of the bridges: Response Spectrum method, Push-Over method, and the Time-History method. The 2006 FHWA Seismic Retrofit Manual published by Multidisciplinary Center for Earthquake Engineering

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Research (MCEER) for the Federal Highway Administration (FHWA) identifies these three methods of analysis as Methods C, D2, and E respectively. The response spectrum method is generally used to find out the elastic demand and capacity/demand ratios for all the major structural components. The non-linear static push-over method is used to establish the nonlinear plastic capacity of the structure and the time-history analysis method is performed to further assess their seismic performance in detail. For this conceptual design study, it was decided to use the Response Spectrum Analysis and Push-Over Analysis methods to complete the SIE study.

Sample Bridge: Results of one sample bridge evaluated with rating "1", were presented to demonstrate application of this approach for both analyses methods noted. The bridge selected was built in 1956 and rehabilitated in 1992, is located in the Westchester County, New York, and carries I-95 crossing MNRR NH Line with an Annual Average Daily Traffic (AADT) of about 92,000. The bridge was a five-span simply-supported rolled steel structure, 127m long, 16m wide and supported four lanes of traffic.

Loading and loading combinations: The seismic analysis was performed for the Extreme Event 1 load combination as per AASHTO. Response spectra curves were generated using the provisions of the AASHTO Guide Specifications for LRFD Seismic Bridge Design with assumed damping value of 5%. The bridges were analyzed for two earthquake levels: a lower level event having return period of 500 years and an upper level event having return period of 2500 years. A three-dimensional finite-element model of the bridge was created using SAP2000, version 14.2 software.

Response spectrum and pushover analyses were performed for both earthquake levels. The Capacity/Demand (C/D) ratios for the structural displacements; cap-beam, column and footing shears; and top/bottom column moments and column P-M-M interaction ratios were computed.

3.2 Discussion and Retrofit Recommendations

The displacement capacity for Pier 1 was greater than the displacement demand for the 500-year and 2500-year return earthquakes in the transverse direction. However, in the longitudinal direction, the displacement capacity was less than displacement demand for the 2500-year return earthquakes. The columns, in this instance, will show signs of yielding and some reparable damage may occur. The Capacity/Demand ratios were greater than 1.0 for the moment at the top and bottom of columns; however, all the columns are deficient in biaxial bending strength (P-M-M interaction). Confinement may be required to prevent rapid crushing extending into the core and to avoid strength degradation.

Based on the above analysis and all the existing information for this bridge, the recommended retrofit included installation of hinge joint restrainers or replacement of bearings, column casing (steel jacketing, concrete casing or composite casing) at all the piers. Since this bridge had insufficient information with regard to boring logs, pile sizes, pile lengths, and/or detail pile layout, it was recommended that before proceeding with any retrofit design noted above, detailed geotechnical investigation and reanalysis of this bridge with a more accurate soil-structure interaction model should be implemented.

4. Conclusions

- A multi-step assessment procedure for establishing seismic vulnerability rating scores for large portfolio of highway bridges was successfully applied to the 457 bridges carrying or over the New York State Thruway system. The bridge population from these numeric groups was then be prioritized for appropriate corrective action through additional evaluations.
- 16 bridges were selected for detailed SIE involving response spectrum and pushover analyses to determine the C/D ratios and recommended retrofit measures to address the deficiencies identified by C/D ratios.
- Conceptual retrofit solutions were provided considering the exiting geotechnical data, inspection reports and this detailed SIE analysis.
- This approach represents a cost-effective solution for seismic evaluation of large inventory of bridges.