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Seismic behavior and capacity/demand analyses of three multi-span simply supported bridges

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Abstract

This paper presents the results of an analytical study on the seismic response of three Multi-Span-Simply-Supported (MSSS) bridges in New Jersey. The main goal is to determine the capacity/demand ratio for various components in order to evaluate the seismic vulnerability and to develop retrofit strategies. Another important objective is to investigate the effect of those response characteristics that are unique to this class of bridges on their seismic performance. Furthermore, the effect of modeling approach and appropriateness of pushover analysis using existing demand curve are also addressed considering the stiffening-interaction between the bridge and the abutments. The investigation includes detailed nonlinear time history analyses of three actual bridges as representatives of typical 2, 3, and 4 span bridges, which are common in New Jersey and the Eastern United States in general. Both 2-D and 3-D models were employed in order to evaluate the effect of modeling. Several parameters prove to have an important effect on the seismic response of MSSS bridges, such as soil–structure interaction, impact between adjacent spans, steel bearings, and plasticity at pier columns. Therefore, the seismic response of MSSS bridges is evaluated in light of a comprehensive parametric study based on these factors and quantified through capacity/demand (C/D) ratios for critical elements. Furthermore, the research needs related to the seismic evaluation, retrofit, and design of MSSS bridges are also discussed.

Keywords: Bridges; Seismic; Retrofit; Multi-span; Capacity; Demand

1. Introduction

A commonly used type of bridge in the Eastern United States, including New Jersey, is the Multi-Span-Simply-Supported (MSSS) system. In an MSSS bridge each span is simply supported with separation gaps between the adjacent spans and between the end spans and the abutments. The gap size is normally in the range of 25–76 mm (1–3 in.). Framing consists of slab-on-girder deck supported on pier bents (normally multi-columns) and seat-type abutment. Bridge columns in New Jersey are normally circular or square in cross section. The lateral reinforcement is different for circular and square columns. Generally, abutments are seat-type supported on footings although some are supported on piles. Steel bearings (fixed and expansion) are normally used as a means of load transfer from the superstructure to the substructure. Thus, in addition to better-understood seismic deficiencies common to all bridges, such as small seat width, inadequate transverse reinforcement in the columns/piers, and soil liquefaction hazard reported during past earthquakes around the world, for MSSS bridges there are other important sources of possible damage in the event of an earthquake. These are related to the steel bearings, impact between adjacent spans and between the end-span and the abutment, soil–structure interaction (especially at the abutments), and frictional characteristics following possible bearing failure. The latter parameter is important because even under low level of ground motion the impact forces can, at least theoretically, cause failure of the bearings in the form of shear failure at the anchor bolts and/or at the connection bolts between the girder and the bearing top sole plate. Therefore, post-bearing failure response of the bridge system should be considered using nonlinear models representing Coulomb friction. An equally important factor in the seismic response

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of MSSS bridges is the possibility of abutment backwall failure due to impact forces.

Due to concerns about the possibility of a damaging earthquake in the Central and Eastern states, the 1988 NEHRP maps have placed many areas including New Jersey into higher seismic risk categories. Consequently, based on AASHTO [2] seismic design guidelines, which adopted the NEHRP maps, the acceleration coefficient for northern New Jersey has increased to 0.18, and for the southern coastal areas to 0.1. Thus, the entire state is classified as SPC B. In addition to consideration to seismic load in the design of new bridges, the New Jersey Department of Transportation (NJDOT) also adopted the *Seismic Retrofitting Manual for Highway Bridges* [7] for seismic assessment and rehabilitation of existing bridges. Furthermore, as a part of its seismic retrofit and design efforts, NJDOT sponsored a research program to investigate the seismic response of MSSS bridges considering their unique behavioral characteristics. General issues related to seismic design and retrofit of MSSS bridges along with results of analyses on the effect of steel bearings on seismic performance of MSSS bridges, including detailed finite element analysis of critical components, have been reported by Saadeghvaziri and Rashidi [12,13]. This paper presents the results of a comprehensive nonlinear time history analysis of three actual bridges quantified through detailed capacity/demand ratios for key elements, and discusses design and modeling issues as well as the research needs related to MSSS bridges. Details of the work presented in this paper can be found in [15].

2. Description of the bridges

Three simple span and simply supported bridges, representative of typical bridges in New Jersey, are evaluated under this study. For these bridges the number of spans varies and is equal to two, three and four. They all have concrete slab decks on steel girders and reinforced concrete pier bents. The gap sizes between adjacent decks or end spans and abutments vary from 25 to 76 mm (1 to 3 in.). Pier columns and abutments have spread footings without piles. The pier columns are all circular with spiral or circular lateral reinforcements. The level of concrete confinement varies for each bridge. The lowest confinement belongs to Bridge #1 (3-span bridge) with #3 circular hoops at 305 mm (12″) spacing. On the other hand Bridges #2 and 3 (2 and 4 span bridges, respectively) both have well confinement details for their pier columns, which consist of spiral reinforcement at small pitch (89–57 mm, or 3.5″–2.25″).

Bridge #1 has three spans in lengths of 42.7, 29, and 42.7 m (140′, 95′, and 140′) with skewness equal to 33°. The width of the bridge is made of two separated symmetric half-decks and has a total width of 26.2 m (86′). Each half-deck has six 1626 mm (64″) high girders supporting a 241 mm (9.5″) thick concrete slab. Separate pier bents beneath each half-deck consist of two 1.22 m (4′) diameter circular columns and a 1.4 m (4.6′) high cap beam.

Bridge # 2 is a straight (only 3° skewness) bridge with two equal spans of 29.7 m (97′–4″). Each deck has fifteen 1143 mm (45″) high girders supporting a 222 mm (8.75″) thick concrete slab. The deck cross section has two unequal parts, namely part 1A (with 9 girders) and part 1B (with 6 girders) and it has total width equal to 34.1 m (112 feet). Correspondingly, the pier bent consists of two parts with a total of ten 0.91 m (3′) diameter circular columns.

Bridge # 3 has four spans in lengths of 12.8, 39.6, 36.6, and 26.8 m (42′, 130′, 120′ and 88′) with skewness equal to 45°. Each deck has 7 girders 2184 mm (86″) apart, supporting a 203 mm (8″) thick concrete slab. Each column bent consists of five 1.07 m (3.5′) diameter circular columns and a 1.37 m (4.5′) height cap beam. Since the details of steel girders were not available, typical and estimated dimensions, considering the previous two bridges, were assumed. Note that girder information is primarily needed in determination of the total mass and in light of its relatively small weight compared to the deck this assumption is quite adequate. With regard to stiffness, the deck-girder system is very rigid regardless of the exact values for area and moment of inertia for individual elements. The stiffness of the bridge system is controlled by the weaker elements (i.e., columns and abutments).

All three bridges use steel bearings to connect superstructure to the substructure. Typically four 22 mm (7/8″) diameter A325 steel bolts are used to connect the bearing to the girder, and two 38 mm (1.5″) diameter A615 steel anchor bolts are used to connect the bearings to the abutments and cap beams. These elements are the weak links in the load transfer from the superstructure to the substructure through the bearings. The edge distance or seat width is in the range of 178–254 mm (7–10 in.).

Plan and elevation for Bridge #1 is shown in Fig. 1. Cross sections for all three bridges are shown in Fig. 2.

3. Analytical modeling

Analysis of MSSS bridges under gravity loads is simple and straightforward and this is indeed the reason behind using this system. Under transverse seismic load for straight bridges the system can be easily analyzed as a series of independent simply supported beams with boundary springs representing soil–structure interaction. However, the response of MSSS bridges in the longitudinal direction is complicated by the impact between adjacent spans as well as soil–structure interaction [14]. If the displacements due to a design earthquake obtained from linear analysis exceed the expansion joint width then a nonlinear dynamic time history analysis that includes impact will be required. For straight bridges the fundamental concepts important to longitudinal motion can be captured with a two-dimensional (2-D) model. However, for skewed bridges there is an interaction between the longitudinal and transverse mode shapes and three-dimensional (3-D) models are required. Therefore, in this study both 2-D and 3-D models were employed to perform in-depth analyses of these three bridges. Note that the use of 2-D models is more efficient than performing unidirectional analysis as a special case of the 3-D models. Special emphasis was placed on detailed parametric studies under the longitudinal earthquake excitation because the study of the damage to MSSS bridges has shown that seismic waves in this direction have caused more damage than