Soil Dynamics and Earthquake Engineering 100 (2017) 1–15

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Vulnerability and recovery time evaluation of an enhanced urban overpass foundation

Juan M. Mayoral*, Adriana Badillo, Mauricio Alcaraz

Instituto de Ingeniería, Universidad Nacional Autonoma de Mexico, Mexico

ARTICLE INFO

Keywords:
Recovery time
Massive foundations
Vulnerability
Fragility curves

ABSTRACT

This paper presents a vulnerability assessment and recovery time evaluation of two critical supports of a 23.5 km long urban overpass built in stiff soil, in the northeast Mexico City area. The evaluations were carried out considering both normal and subduction fault events expressed in terms of uniform hazard spectra for several return periods. Probabilistic site response analyses, and site specific numerically-derived fragility curves were used to assess the critical supports probability of reaching or exceeding a given damage state, considering two foundation types: a conventional raft foundation structurally connected to four precast-end bearing concrete piles, and a so-called enhanced massive foundation. The seismic response of each foundation system was characterized using series of 3-D finite elements models developed with the program SASSI2000 for increasing seismic intensity levels. The effect of both soil conditions and ground motion characteristics on the soil-structure system response was accounted for in the analyses. The damage index was defined in terms of earthquake induced transversal and longitudinal pier displacements, which was associated with column cracking, and potential loss of support of the upper deck. The vulnerability and reduction on recovery times for the foundation alternative was established.

1. Introduction

Modern seismic design of strategic infrastructure such as metro lines, urban overpasses, life lines systems, or airports located in highly active earthquake areas, requires a proper seismic vulnerability assessment [1] to foreseen the capacity of the system to withstand very large to extreme events, ensuring earthquake preparedness, and reducing life losses or post-earthquake distress. In particular, the large number of failures in bridges, viaducts and overpasses during large to extreme seismic events reported in the technical literature [2–6] showed the importance of defining a proper approach to evaluate and, in turn, improve the seismic performance of this type of structures. As schematically represented in Fig. 1, seismic loading acting upon a soil-foundation system results from the interplay of earthquake incoming waves with the structure-swaying-produced waves, which in some cases may lead to an increase on the structural spectral ordinates in the foundation response with respect to those observed in the free field. The complex foundation vibration patterns that result from this interaction are difficult (if not impossible) to predict because they depend on many factors (that are interrelated) such as wave-path characteristics, bridge-foundation vibration patterns, soil-foundation interaction, soil behavior (elastic/inelastic), site geological and geotechnical characteristics, and pre-earthquake foundation conditions [7]. Furthermore, in dense urban zones, such as Mexico City, the incoming wave patterns can be modified as compared with commonly assumed isolated-single-foundation-structure conditions, due to their interaction with waves radiating away from nearby soil-foundation systems. Thus, modern urban bridge design has moved toward performance based concepts, requiring that any minor damage the system may undergo during the design earthquake occurs first within the superstructure rather than the foundation. Vulnerability evaluations require a proper seismic risk assessment, in which potential structural damage is established for several ground intensities. From this evaluation, design improvements can be implemented. A key step in seismic risk analyses is the definition of an appropriate fragility function that captures the most important seismic failure modes of the overpass [8,9]. A fragility function is a mathematical relationship that expresses the probability of reaching or exceeding a previously established limit or state of failure as a function of some measure of environmental excitation; usually a measure of acceleration, deformation, or force in an earthquake, hurricane or other extreme loading condition. Fragility curves can be developed for any intensity measurement, such as peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration (Sa), or spectral velocity (Sv). From the practical stand point, it is more convenient to

---

* Correspondence to: Coordinacion de Geotecnia, Instituto de Ingeniería, Universidad Nacional Autonoma de Mexico, Mexico City, Mexico.
E-mail address: jmayoralv@iingen.unam.mx (J.M. Mayoral).

http://dx.doi.org/10.1016/j.soildyn.2017.05.023
Received 5 July 2016; Received in revised form 5 May 2017; Accepted 8 May 2017

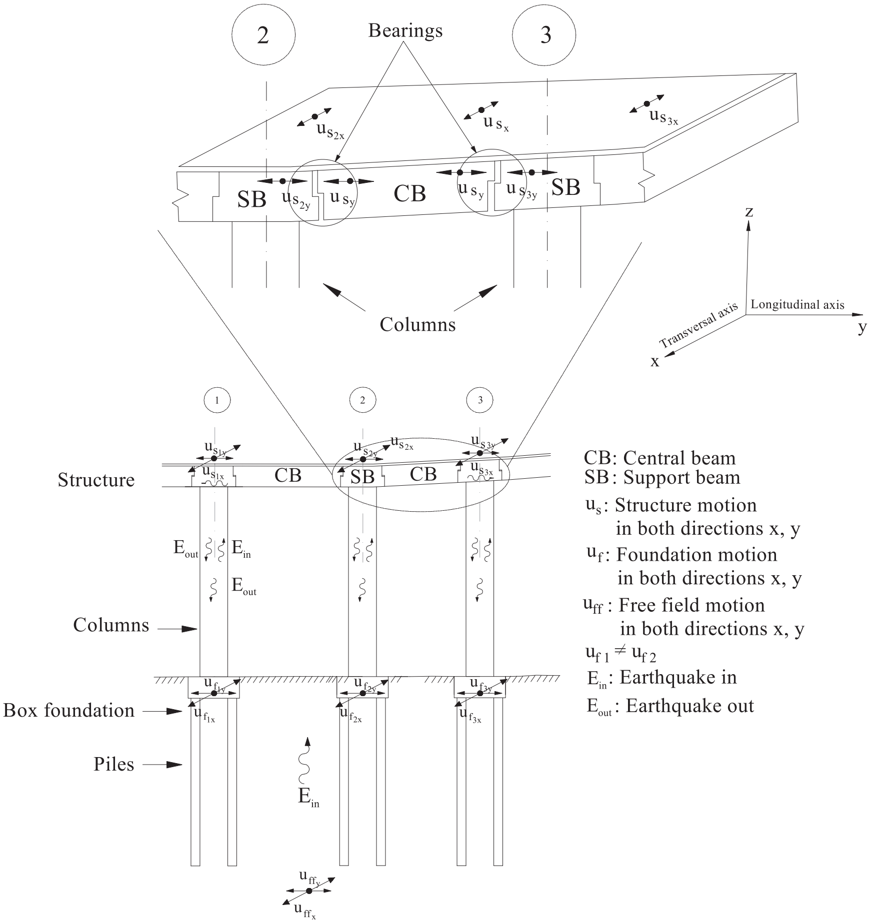

Fig. 1. Effect of relative movements of the bridge supports on upper deck.

relate the probability of reaching or exceeding a given state of damage, with the peak ground acceleration in the free field (PGA_{ff}). Thus, local codes can be used directly to estimate the probability of failure. Inhere, PGA_{ff} is related to lateral support column displacement, and, in turn, to the damage index. Fragility functions are required elements in the vulnerability and risk assessment of overpasses and associated infrastructures and networks.

In this paper, a vulnerability assessment and recovery time evaluation were carried out for a conventional and an enhanced foundation, aiming at enhancing its seismic performance. Similar approaches have been followed by other authors for specific cases such as retrofitted [10], or isolated [11] bridges. As a case study, a vulnerability assessment and recovery time evaluation of two critical supports of a 23.5 km long urban overpass built in Mexico City is carried out. The location of supports S-1 and S-2 within the overpass is presented in Fig. 2. These are separated approximately 1.1 km away from each other. Site specific fragility curves were obtained for two foundation alternatives: a) a 3.6 by 4.6 m^2 conventional raft foundation structurally connected to four 0.8 m-diameter cast in-situ concrete piles. The foundation is 1.70 m thick as shown in Fig. 3, and b) an enhanced massive foundation, formed by adding concrete fill around the piles, down to a 6 m depth (Fig. 3b). A depth of 6.0 m was deemed appropriated based on the reduction of the expected spectral accelerations and the required relatively shallow excavation without support, which must be performed to place the massive enhancement. Considering the average undrained shear strength, s_u, of 40 kPa to 50 kPa, detected along the project, the critical excavation depth is about 7 m, using a factor safety of 2. Only those supports located in the critical zones, where number of blows corrected by energy and overburdening, $(N_1)_{60}$, are less than 15 in the upper 10 m, are to be strengthening. Since this technique requires only to excavate a relatively narrow area around the pile cap foundation, prior placing the poor concrete filling, it represents a cost-effective alternative to be used to improve the seismic performance of both new and existing structures.

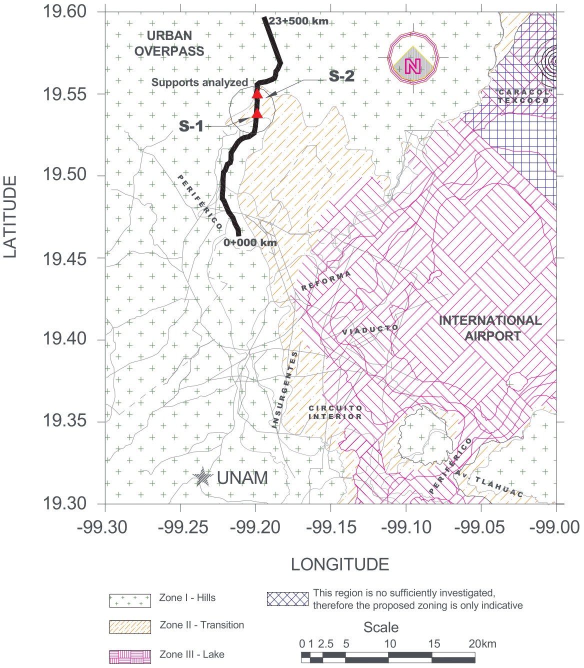

Fig. 2. Urban overpass and studied supports locations.