Soil Dynamics and Earthquake Engineering 71 (2015) 88–99

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Seismic response of bridges with massive foundations

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ARTICLE INFO

Article history:
Received 5 July 2014
Received in revised form
16 January 2015
Accepted 18 January 2015
Available online 14 February 2015

Keywords:
Seismic-response
Massive foundation
Numerical model
Bridges

ABSTRACT

The dynamic response of vehicular overpasses with massive foundations built in highly populated earthquake prone regions is studied to assess the massive foundation potential of being a technically sound mean to reduce the structural response during major earthquakes. The study consists on numerical simulations using 3-D finite element models. Two typical supports of a major 23 km long vehicular overpass recently built in the north east part of Mexico City valley were considered in this research. This zone is characterized by the presence of stiff soils comprised by dense and very dense silty sands and sandy silts, randomly intercalated by stiff clays layers of variable thickness. Initially, a conventional raft foundation structurally connected to four precast closed-end concrete piles was considered. Then, the potential beneficial effect of a massive foundation of variable depth was assessed. Sets of 3-D finite element models were developed and the response of the systems was evaluated for a typical seismic scenario such as that prevailing at the zone, assuming a potential 8.1 M_w seismic event, and for a hypothetical 8.7 M_w extreme event. Important attenuations of about 39% to 48% at the upper deck spectral accelerations and of 21% to 30% in maximum lateral foundation displacements were achieved with the massive soil improvement for the cases analyzed. Thus, the massive foundations seem to be a convenient alternative to reduce the overall structural seismic response.

1. Introduction

Modern design of bridges and overpasses, and seismic retrofit of existing ones, has moved towards performance based evaluations (e.g. [1–5]). These evaluations usually include various seismic scenarios expressed in terms of uniform hazard spectra for a given return period (e.g. [6–8]), and time domain analyses to account for nonlinearities in the soil-foundation-structure system (e.g. [9–11]). Ground motion variability effects become crucial when the length of the overpass is significant, and thus, variability is not only due to rapid changes in local site conditions but also to (i) geometric incoherence caused by wave scattering in the heterogeneous ground, and (ii) wave passage effects. In particular, in highly populated areas, such as Mexico City, restrictions regarding allowable displacements both at the foundation and upper deck become more restrictive to avoid damage not only at the upper deck, caused by relative movements of the bridge supports, but also in nearby structures through waves radiating away from their foundation system which can interact with the incoming waves generated during a major earthquake, leading to beneficial or detrimental interaction.

This paper presents the seismic performance evaluation of massive foundations used as an alternative to positively modify the dynamic response of an urban overpass recently built in Mexico City. Sets of 3-D finite element models were developed using the program SASSI2000. Initially, a conventional raft foundation structurally tied to four precast closed-ended concrete piles was considered. Then, a massive foundation of variable depth was proposed as a technically sound alternative that presents interesting advantages over the conventional design, by providing confinement to the raft-pile foundation. The two foundation systems responses were computed for a typical seismic scenario such as that recommended by the Mexico City Building code, which approximately corresponds to a 8.1 M_w event, and for a hypothetical, but likely to occur, subduction 8.7 M_w extreme event, with the closest distance from the site to the rupture area of approximately 300 km. Although massive foundations have been used in long bridge structures (e.g. [12]), and some offshore structures (e.g. [13, 14]), to the best of the authors' knowledge, employing massive raft foundations for urban overpasses is a complete novel approach. The foundation improvement is conducted after completing the construction of the cast-in-place concrete piles. The foundation system is enhanced by excavating and filling with concrete a relative small square area around the piles, as shown in Fig. 1, up to the footing design elevation, where a reinforced concrete mat is built to receive the column footing. The piles pass through the pile cap and are post-tensed to improve even further

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http://dx.doi.org/10.1016/j.soildyn.2015.01.008
0267-7261/

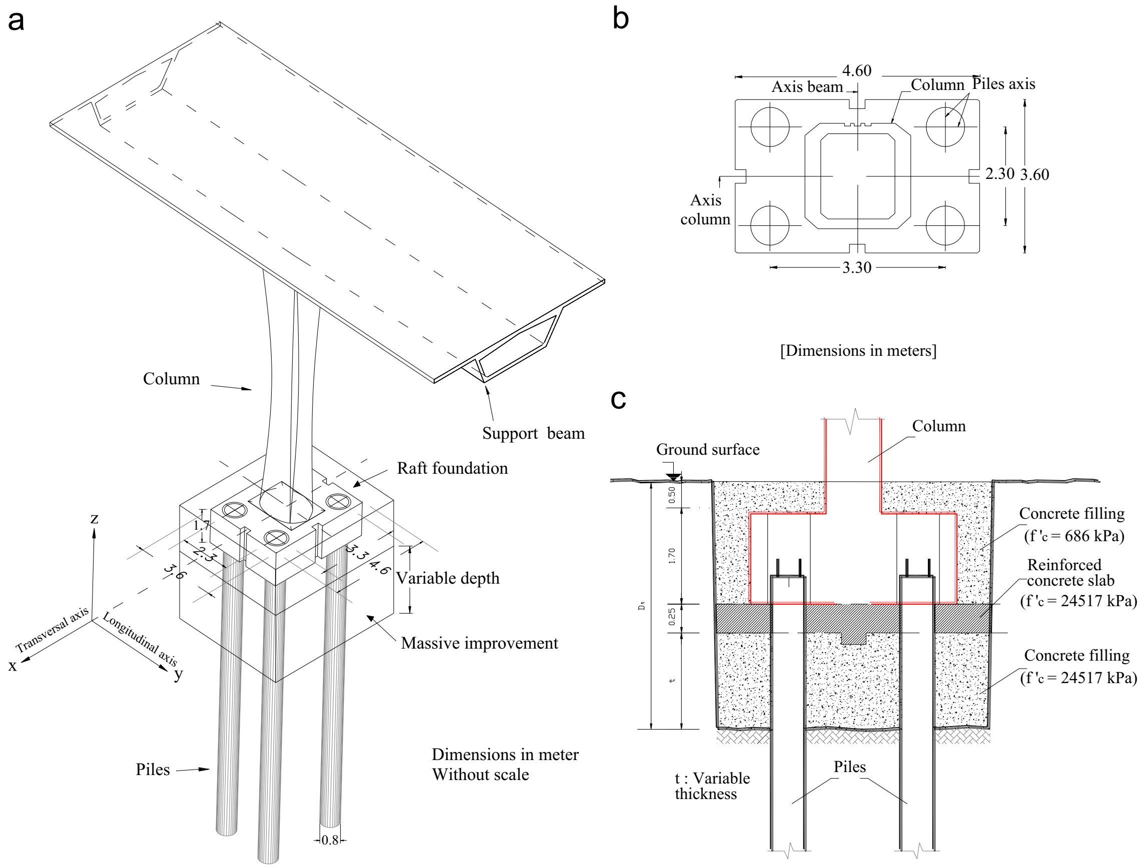

Fig. 1. Schematic representation of foundation supports for urban overpass.

the contact between the head piles and pile cap. Finally, the excavation is completely filled with a low strength poor concrete. Thus, due to the simplicity of the construction procedure, the cost of this seismic mitigation approach is very low with respect to using any seismic isolation device [e.g. [15–19]). Moreover, this technique can be applied in the foundation of each column of the overpass as needed, to fine tune the seismic response along the overpass, seeking to reduce upper beam excessive lateral displacements or vibration, which may preclude collapse, depending on a particular requirement. Other methods such as ground improvement (e.g. [20, 21]), or seismic barriers (e.g. [22–26]), will not be applicable due to the soil type (i.e. stiff silty sands and sandy silts), and the fact that the overpass was built in a very densely populated urban environment such as that prevailing in Mexico City. A potential shortcoming of this approach is the expected ground settlement that can be generated in some soil types exhibiting high compressibility and low shear strength, such as soft high plasticity clays, due to the actual weight of the massive foundation.

2. Seismic performance evaluation of a massive foundation

A numerical study was conducted to assess the effect that a massive foundation can have on the seismic response of two typical supports of an urban overpass recently built at the northwest area of Mexico City. Fig. 1 shows a schematic representation of the beam-support-foundation system. The overpass is comprised by an upper deck resting on top of central and support beams that are structurally tied to the columns, which, in turn, are monolithically attached to a rectangular foundation. The upper part of this foundation consists of a reinforced 1.7 m mat covered by concrete filling. This mat rests on top of a reinforced 0.25 m concrete slab, which, in turn, is underlain by a 3.6 by 4.6 m^2 massive un-reinforced concrete block of variable depth. The mat foundation is connected to four 0.8 m diameter, cast-in-place, concrete piles. The separation between piles is 2.30 m and 3.30 m in the transversal and longitudinal directions, respectively. Table 1 shows the concrete strengths at 28 days (f_c) of the concrete used in each structural member. The reinforcement steel yield strength, f_y, was 412,020 kPa. The unit weight was 23.5 kN/m^3. For the work presented herein, two critical supports, S-1 and S-2, of this overpass were modeled to study the potential beneficial effect of the massive foundation system on the overpass seismic response. Two seismic scenarios were considered, one corresponding to that represented by the Mexico City building code, RCDF [27], and one corresponding to a subduction extreme event with moment magnitude, M_w, of 8.7, and a closest distance from the site to the rupture area of approximately 300 km. 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. Both studied supports have the same basic geometry, changing only the column and pile lengths, as summarized in Table 2.

2.1. Subsoil conditions

To characterize the geotechnical subsoil conditions found at each site where supports S-1 and S-2 are located, one standard penetration test, SPT, boring was conducted along with selective undisturbed sampling. In addition, two piezometers were installed to obtain pore pressure distributions, and one cross-hole was performed to measure the shear wave velocity distribution with