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Nonlinear dynamic analysis of Meloland Road Overpass using three-dimensional continuum modeling approach

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ABSTRACT

This paper presents a three-dimensional (3D) continuum nonlinear analysis of the Meloland Road Overpass (MRO) near El Centro, California. The modeling methodology and the computational tools are discussed in detail. The performance of the computational model is evaluated by comparing the computed responses with the responses recorded at the bridge site during the 1979 Imperial Valley and 2010 El Mayor-Cucapah earthquakes. Amongst the recorded earthquake events at the bridge site, these two events caused the strongest shaking. The comparison shows that the 3D model is potentially an effective tool for detailed analysis of a full bridge system including foundation soils, pile foundations, embankments, supporting columns, and the bridge structure itself in a unified system without relying on any ancillary models such as Winkler springs. Additional response parameters such as displacements, rockings, and bending moments are also evaluated although none of these was measured during the seismic events.

1. Introduction

The need for realistic numerical simulations in geotechnical earthquake engineering applications necessitates developing three-dimensional (3D) continuum models using a series of high fidelity geotechnical/structural models. Three-dimensional continuum models have been rarely used in practice since nonlinear dynamic analyses of large-scale models require major computational efforts that can be tedious, time consuming, and in some cases impractical. However, recent advances in high-performance computing software and hardware with the aid of parallel computing environments permit the analysis of large-scale problems such as bridge systems.

In recent decades, 3D continuum models have been widely used for simulating small-scale soil-structure problems such as retaining walls and pile foundations (e.g., [1–3]). Also a large database obtained from experimental tests (e.g., [4–7]) has facilitated the validation and application of these computational models. However, large-scale soil-interaction problems such as bridges have been rarely modeled using continuum modeling approach. A 3D analysis of an AASHTO model bridge was conducted by Finn [8] using an equivalent linear model and demonstrated the strong dependence of the response on the coupled inertial interaction of the superstructure. Elgamal et al. [9] developed a continuum model of the Humboldt Bay Middle Channel Bridge using a nonlinear model and studied the effects of permanent ground deformation on seismic response of the bridge. Kwon and Elnashai [10] modeled the Meloland Road Overpass (MRO) for which the geotechnical components, including the embankments, abutments, and pile groups, were modeled in one platform, and the structural components, including the bridge deck and the pier, were modeled in another platform. Nonlinear dynamic analysis was then performed by applying the outputs from one platform as the inputs to the other one [10]. Jeremić et al. [11] studied the influence of non-uniform soil conditions on a prototype concrete bridge. In their study, the whole bridge system was not simulated owing to computational limitations; the bridge deck was modeled with linear elastic beam-column elements, and the bridge abutments were not simulated under the assumption that the bridge deck was disconnected from the abutments. Lu et al. [12] showed that computational challenges of nonlinear dynamic analysis of large-scale models can be overcome using high-performance computing techniques. Using parallel computing environments, they reduced analysis execution time of the Humboldt Bay Middle Channel Bridge model, developed by Elgamal et al. [9], from 24 to 9 h.

In this study, the 3D continuum model of the MRO is developed within a single platform. The response of the bridge to the 1979 Imperial Valley and 2010 El Mayor-Cucapah earthquakes is evaluated using a finite element formulation with an implicit time integration scheme. Advanced nonlinear hysteretic models are used for constitutive modeling of the foundation soil and the

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bridge pier. Capabilities of the continuum model in simulating seismic response of the MRO are evaluated by comparing the computed motions at different locations of the bridge with the recorded motions from the two earthquakes. The study generally aims to: (a) provide baseline data for the authors' ongoing research in which the reliability of the current state of practice for dynamic analysis of bridge systems is assessed; and (b) illustrate the potential for further practical applications of the large-scale continuum models with the aid of recent advances in parallel computing environments.

2. Description of the MRO

The MRO is a two-span integral abutment bridge built in 1971 near El Centro, California, US, as part of the Highway 8. Below is a summary of the structural characteristics and instrumentations of this bridge. The bridge deck has a length of 64.0 m, width of 10.0 m and depth of 1.733 m (Fig. 1a). The deck section is box girder composed of four vertical webs with a thickness of 0.2 m. The pier at the center of the deck is 5.0 m in height above the ground surface with a diameter of 1.52 m (Fig. 1b). The pier is reinforced by a total of 18 longitudinal rebars with a diameter of 0.057 m. The pier foundation is composed of a 4.6 m by 4.6 m pile cap with a thickness of 2.0 m supported by 25 vertical timber piles (a 5 × 5 pile group) with lengths of 15.0 m and diameters of 0.32 m at the top and 0.20 m at the bottom. As shown in Fig. 1c, the abutment is of integral type with no deck joints and bearings. The height of the back walls is about 3.0 m with a thickness of 0.46 m, and each side of the abutment has two 6.0 m long wing walls with a thickness of 0.3 m. The abutments are supported by seven vertical timber piles (a 7 × 1 pile group) with lengths of 18.0 m and diameters of 0.32 m. The side slope of the embankment is 1 V:2 H, and the slope in front of the back walls is 1 V:1.5 H. The bridge is instrumented with 29 accelerometers on the structure and 3 accelerometers at a free-field site [13]. Fig. 1d depicts the location of the instruments.

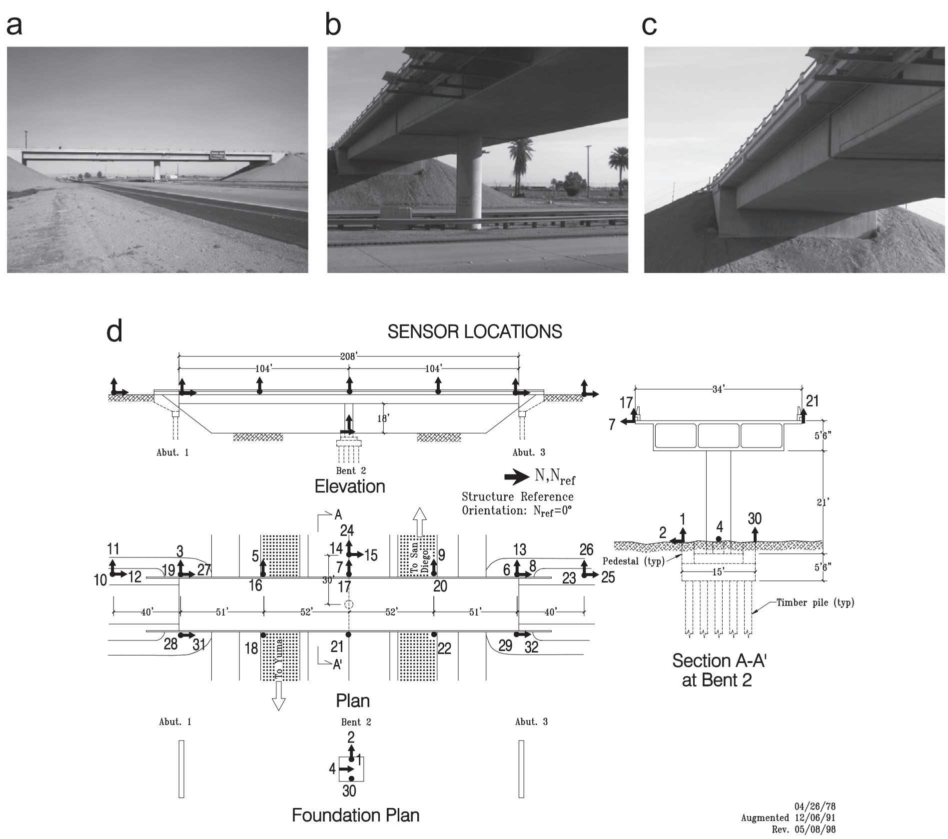

Fig. 1. Meloland Road Overpass (MRO): (a) closeup photo, (b) the pier, (c) the abutment, and (d) configuration of the accelerometers [13].

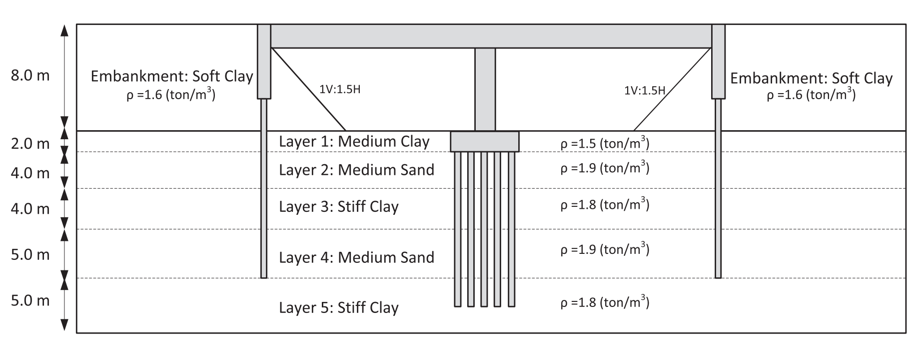

Fig. 2. Schematic representation of soil layers at the MRO site (dimensions are not to scale).