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SIMPLIFIED METHOD FOR SEISMIC ANALYSIS OF MOTORWAY BRIDGES

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ABSTRACT: The paper develops a simplified method to analyze the seismic performance of motorway bridges. An actual bridge is used as an illustrative example. Detailed 3D model of a typical overpass bridge is developed and used to assess the effectiveness of the simplified method. Both longitudinal and transverse shaking is considered. The contribution of key structural components and the effect of soil structure interaction (SSI) are properly taken into account. The simplified models compare well with the full 3D model of the bridge–abutment–foundation–soil system, and are therefore proposed as a reasonable approximation.

KEY WORDS: Seismic vulnerability; bridge pier; nonlinear analysis; soil-structure interaction; Attiki Odos highway.

1 INTRODUCTION

Bridges tend to be most vulnerable during strong seismic shaking. The large number and complexity of bridges encountered along motorways in operation worldwide, present a particular challenge to engineers. The development of detailed 3D models of the bridge–foundation–abutment–soil system is the most comprehensive way to simulate their seismic performance. However, in order to cover a wide range of strong motion characteristics, a large number of seismic excitations are necessary. Conducting such analysis with full 3D models of the bridge–foundation–abutment–soil system would require quite a substantial computational effort, rendering the use of simplified models a practical necessity. To this end, a simplified method for seismic vulnerability assessment of typical motorway bridges is introduced herein using as an illustrative example a characteristic bridge of Attiki Odos, in the Athens metropolitan area.

2 PROBLEM DEFINITION, ANALYSIS METHODOLOGY

2.1 Case study

A typical overpass bridge (A01-TE20) of the Attiki Odos Motorway has been selected. Besides its simplicity, the selected bridge system is representative of about 30% of the bridges of the specific motorway, and is also considered quite common for other metropolitan motorways in the world. As shown in Fig. 1a, the selected system is a symmetric 3-span bridge with a continuous pre-stressed concrete box-girder deck, supported on two reinforced concrete (RC) cylindrical piers of diameter d = 2 m and height h = 8.8 m.

The piers are monolithically connected to the deck, which is supported by 4 elastomeric bearings at each abutment. Each bearing is 0.3 m x 0.5 m (longitudinal x transverse) in plan and has an elastomer height t_b = 63 mm. The piers are founded on B = 8 m square footings, while the abutments consist of retaining walls of 9 m height and 1.5 m thickness. The latter are connected to two side walls of 0.6 m thickness and founded on a rectangular 7 m x 10.4 m rectangular footing.

2.2 Finite element modelling

The seismic performance of the bridge is analyzed employing the FE method. The deck and the piers are modeled with elastic and inelastic beam elements, respectively. The reinforcement of the d = 2 m RC piers has been computed according to the provisions of the Greek Code for Reinforced Concrete (ΕΚΩΣ, 2000) for columns with large ductility demands. The inelastic behavior of the piers is simulated with a nonlinear model, calibrated against the results of RC section analysis using the USC-RC software [2001]. The result of such a calibration is shown in Fig. 1b. Linear elastic springs and dashpots are used to model the compression ($K_{c,b}$) and shear stiffness ($K_{s,b}$) and damping ($C_{c,b}$, $C_{s,b}$) of the bearings (Fig. 1b).

The footings and the abutments are modelled with elastic hexahedral continuum elements, assuming the properties of RC (E = 30 GPa). An idealised 20 m deep substratum of homogeneous stiff clay is considered, having an undrained shear strength S_u = 150 kPa (Fig. 1c). The latter is also modeled with hexahedral continuum elements. Nonlinear soil behaviour is modelled with a kinematic hardening model, having a Von Mises failure criterion and an associated flow rule [Anastasopoulos et al., 2011].

Appropriate *"free–field"* boundaries are used at the lateral boundaries of the model, while dashpots are installed at the base of the model to simulate the half-space underneath the 20 m of the soil that is included in the 3D model. Special contact elements are introduced at the soil–footing interfaces to model possible separation (uplifting) and sliding. A friction coefficient μ = 0.7 is assumed, which is considered realistic for the soil conditions investigated herein. The same applies to the interfaces between the abutment and the embankment soil.

A reinforced soil embankment is considered, which is quite common in such motorway bridges (due to space limitations). The latter is modeled in a simple manner, by “installing” appropriate kinematic constraints in the transverse direction.

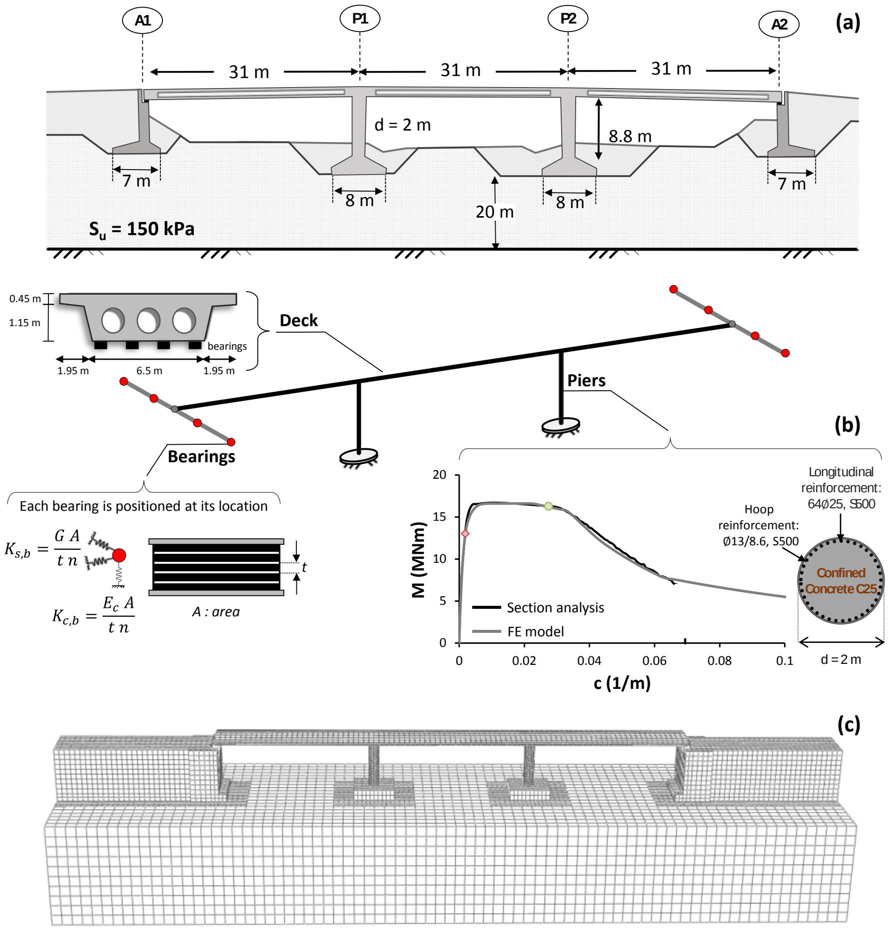

Figure 1. (a) Typical overpass bridge (A01-TE20) of the Attiki Odos motorway used as an example for the analyses (b) key attributes of the bridge and (c) full 3D model of the bridge, including the foundations, the abutments, and the subsoil.

3 SIMPLIFIED METHOD

3.1 Development of models

A simplified model is developed for the selected bridge. The simplified model is composed of a SDOF system of a pier with lateral and rotational springs and dashpots connected at the top, representing the deck and the abutment bearings. Its definition requires section analysis of the pier, and computation of spring and dashpot coefficients using simple formulas. The nonlinear soil–structure interaction is also considered replacing the soil–foundation system with horizontal, vertical, and rotational springs and dashpots. While the horizontal and vertical springs and dashpots are assumed elastic, the nonlinear rotational spring is defined on the basis of non–dimensional moment–rotation relations. The proposed models in both directions are presented in Fig. 2.

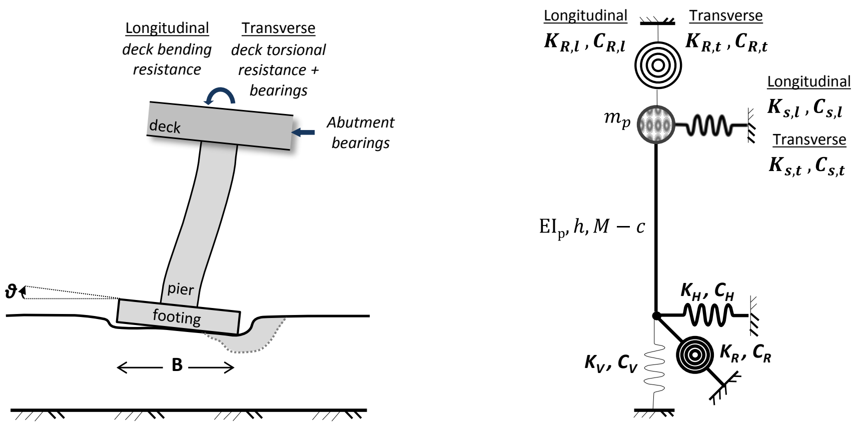

Figure 2. Proposed simplified models in longitudinal and transverse direction accounting for the contribution of the key structural components and SSI.

3.2 Efficiency of the proposed method

The performance of the simplified models in both directions is assessed using as a benchmark the detailed 3D model of the bridge–abutment–foundation–soil system. The latter requires substantial computational effort, calling for careful selection of the seismic excitations. Hence, three characteristic records are selected: (a) Aegion, which is considered representative of moderate intensity shaking; (b) Lefkada-2003, which contains multiple strong motion cycles and can be considered representative of medium intensity shaking; and (c) the notorious Rinaldi-228 record (Northridge 1994), containing a very strong forward rupture directivity pulse, and being representative of very strong seismic shaking. The comparison is performed in terms of time histories of deck drift δ and moment–curvature (*M–c*) response of pier P1 (left column).

As depicted in Figs. 3, 4 indicatively for the Aegion record the simplified model compares well with the full 3D model in both directions of seismic loading and therefore can be considered a reasonable approximation of the seismic response of the bridge.

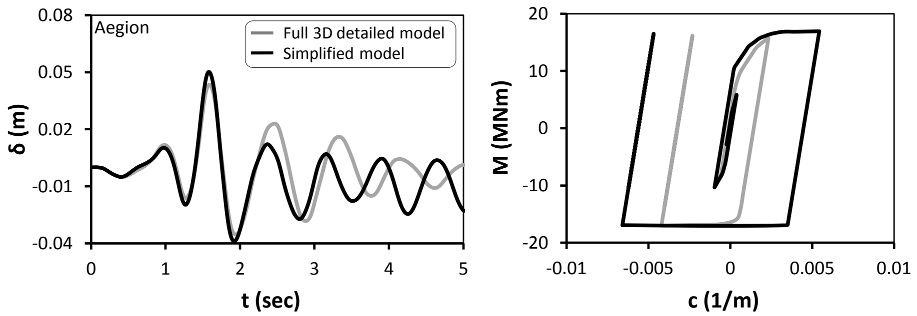

Figure 3. Comparison of the simplified model to the full 3D detailed model in the transverse direction. Time histories of deck drift δ (left column) and moment–curvature response of pier P1 (right column), using as seismic excitation the Aegion record.

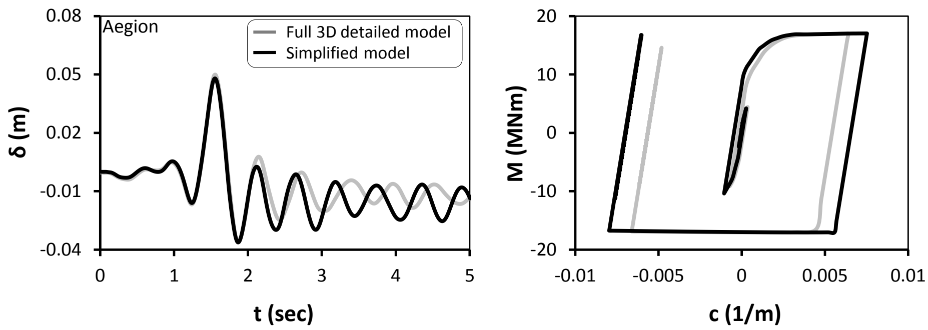

Figure 4. Comparison of the simplified model to the full 3D detailed model in the longitudinal direction. Time histories of deck drift δ (left column) and moment–curvature response of pier P1 (right column), using as seismic excitation the Aegion record.

4 CONCLUSIONS

Conducting dynamic analyses using detailed 3D models of bridge–abutment–foundation–soil systems requires substantial computational effort, rendering the use of simplified models indispensable. The present study introduced such a simplified method for seismic analysis of typical motorway bridges, accounting for the key structural components and the nonlinear soil–structure interaction (SSI).

For this purpose a typical overpass bridge of the Attiki Odos Motorway in Athens (Greece) is used as an illustrative example. A detailed 3D model of the bridge is developed to assess the effectiveness of the simplified method. The proposed model comprises an equivalent SDOF system of a single bridge pier, with lateral and rotational springs and dashpots connected at the top, representing the deck and the abutment bearings. The definition of the model requires cross-sectional analysis of the most vulnerable pier, and computation of spring and dashpot coefficients using simple formulas. The simplified models also account for nonlinear SSI.

Although the proposed models are based on a number of simplifying approximations, they have been found reasonably accurate, as was highlighted in the paper. Despite our focusing on a representative but specific bridge system, the results could perhaps be of more general validity.

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