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Forces acting on bridge abutments over liquefied ground

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ABSTRACT

Large earthquake-induced displacements of a bridge abutment can occur, when the bridge is built on a floodplain or reclaimed area, i.e., liquefiable ground, and crosses a water channel. Seismic responses of a bridge abutment on liquefiable ground are the consequence of complex interactions between the abutment and surrounding soils. Therefore identification of the factors dominating the abutment response is important for the development of simplified seismic design methods. This paper presents the results of dynamic three-dimensional finite element analyses of bridge abutments adjacent to a river dike, including the effect of liquefaction of the underlying ground using earthquake motions widely used in Japan. The analysis shows that conventional design methods may underestimate the permanent abutment displacements unless the following two items are considered: (1) softening of the soil beneath the liquefiable layer, due to cyclic shearing of the soil surrounding the piles, and (2) the forces acting on the side faces of the abutment.

1. Introduction

Large earthquake-induced displacements of a bridge abutment can occur, when the bridge is built on a floodplain or reclaimed area, i.e., liquefiable ground, and crosses a water channel. When the abutment is located adjacent to a river dike or revetment (see Fig. 1), it is especially prone to movement toward the waterfront during an earthquake, when the underlying ground liquefies.

In conventional Japanese design methods, the seismic performance of bridge abutments on liquefiable soil is assessed by pushover analysis, i.e., by calculating the response of the abutment subjected to (1) the inertial force of the superstructure and the abutment, and (2) the seismic active earth pressure of the backfill. The kinematic load induced by interaction between the surrounding soil and structure has been neglected, for simplicity, because liquefaction of the foundation soil appears to cause a reduction of lateral soil resistance [1].

For structures subjected to lateral spread on level ground or gentle slopes, many procedures that account for effects of the lateral spreading on their performance have been proposed [2–5]. However, the existing procedures may not be directly applicable to bridge abutments since the seismic performance of abutments is also affected by many other factors, such as, (1) local deformation of the adjacent river dike, (2) deformation of foundation soils caused by the weight of a road embankment connected to the abutment, and (3) slumping of the road embankment itself. Because the seismic response of a bridge abutment on liquefiable ground is the consequence of complex interactions among all these factors, identifying the factors dominating the abutment response is critical when simplified seismic design is used.

In addition, the critical moment for the abutment during earthquakes has to be carefully chosen for such a simplified seismic design method: when the seismic performance of a pile-supported bridge abutment is assessed with the pushover analysis, the response coinciding with the arrival of the largest (principal) shock is generally assumed to represent the critical design condition for the abutment. However, the horizontal displacement of the abutment coinciding with the principal shock is not necessarily the maximum displacement the abutment will experience and the same is also true for the strength and ductility demands for the structural members that form the bridge abutment.

This paper presents the results of dynamic three-dimensional finite element analyses on bridge abutments built on liquefiable ground adjacent to river dikes, taking into account the effect of liquefaction on abutment response. Two configurations of the surrounding ground were modelled, and the seismic response of abutments both with and without piles is presented. Forces acting on the abutment as well as calculated responses of the abutment are described in detail to demonstrate (1) the critical moment assumed in the conventional design methods, i.e., pushover analyses, being not always appropriate and (2) marked contribution of the forces acting on the side faces of the abutment in the forces acting on the abutment. The results of the analyses are presented, including recommendations for revisions in the current conventional design methods employing the pushover analysis for bridge abutments.

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2. Numerical analysis overview

Highway bridge abutments constructed near a river channel were modelled and analyzed. Two configurations of the ground surrounding the abutment were considered; plan views and cross-sections of the models are illustrated in Fig. 2. The bridge crosses a river, with a distance between abutments of 70 m. For a fully coupled three-dimensional finite element analysis, limited computer resources did not permit the use of a fine mesh, so a relatively coarse mesh was employed (cf. Fig. 6 in the following section). Because of this limitation, the pile foundation was modelled by relatively small number of piles having large diameter.; The pile foundation was modelled with six $D=2\times L=20$ m cast-in-place concrete piles, arranged in 2×3 grids with 5 m spacing. The width of the bridge is 15 m, and the slope of the river dike and road embankment connected to the 10 m-high pile-supported abutment is $1V{:}2H$. The water level was set at 7.5 m below the crest of the dike. The original ground level is 5 m above riverbed for the cases illustrated in Fig. 2(a), and 10 m for the cases shown in Fig. 2(b). The thickness of the liquefiable layer (loose sand deposit) below the water table is 12.5 m, and the materials of the dike and embankment are assumed to be the same as that of the surface layer that lies above the water table. The piles are installed into a bottom non-liquefiable layer (dense sand deposit) through the liquefiable layer.

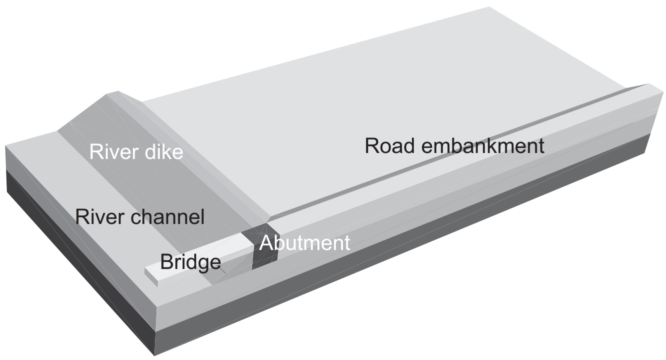

Fig. 1. Bird's eye view of abutment for river crossing bridge.

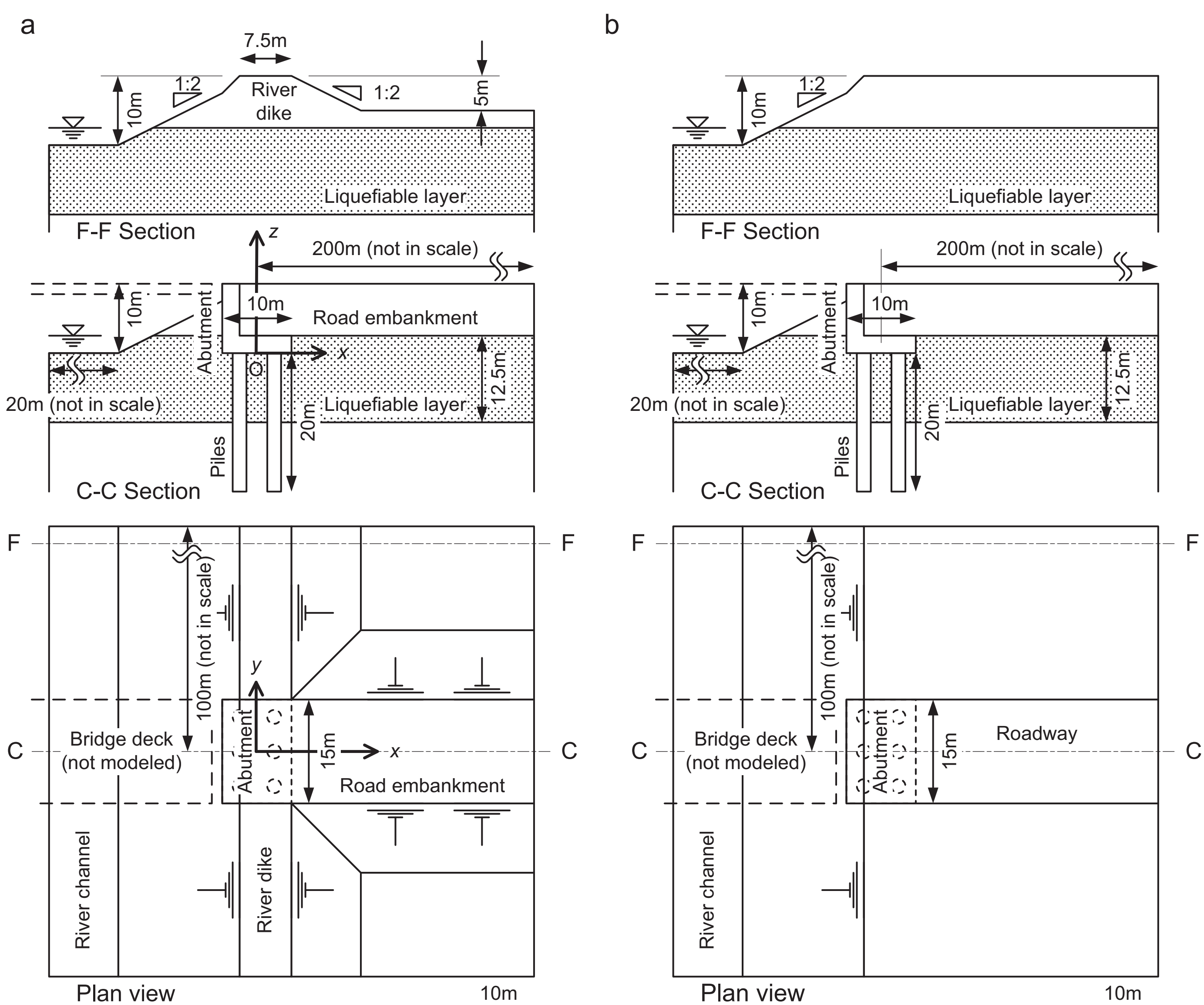

Fig. 2. Plan views and cross sections of target abutments. (a) Ground level is at a height of 5 m above riverbed (P-L). (b) Ground level is at a height of 10 m above riverbed (P-H).