Deformation Build Up in Soils and Damage to Viaduct Foundations

by

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1. INTRODUCTION

The conventional seismic design procedures are mostly based on scenarios in which ground accelerations and/or velocities are crucial factors. Actually, the intense ground motion of the Great Hanshin-Awaji Earthquake of 1995 caused serious damage to the Fukae viaduct of the Route 3, Hanshin expressway[1)]. An 18-span Pilz-decked section toppled over towards north, and turned out to symbolize the tragedy of Kobe. As contrasted with the collapsed viaduct, no clear sign of soil deformation was seemingly found on pavements in its vicinity. In reality, however, the earthquake has left signs of noticeable soil deformations. Tanaka (1995)[2)] measured the displacements remaining on the ground surface in Kobe by comparing aerial photographs taken before and after the earthquake. His study stirs up curiosities for the possible causes of the remaining soil displacements. Kobe city spreads over alluvial fans lined up along the Rokko Mountains, a typical configuration formed by continual faulting and flooding. The activated fault is thus hidden beneath the soils and other suspended matters that rivers have carried over centuries; and one possible interpretation for the remaining soil displacements is that the displacements are a faint projection on the ground surface of the fault dislocations. Konagai et al. (1998)[3), 4)], however, showed that some shallow sandy soils were subjected to quite large strains, far above a few percent, the fact evidenced by the observed dislocations of manhole rings. The displacements thus were responsible for damage to foundations and underground structures. This report examines the damage to pile foundations of the Route 3 viaduct piers, contrasting them with the surface soil deformations along the route.

2. DEFORMATION BUILDUP IN SOILS

Tanaka (1995) measured the displacements remaining on the ground surface in Kobe by comparing aerial photographs taken before and after the earthquake. Exact positioning of reference points for triangulation was made by utilizing GPS (Global Positioning System), a procedure, with erratic readings on 1/500 scale maps included, which may cause some 0.2 to 0.25 m errors in terms of standard deviation. **Figure 1** describes the distributions of the remaining soil displacement along the Route 3 of the Hanshin expressway. The observed

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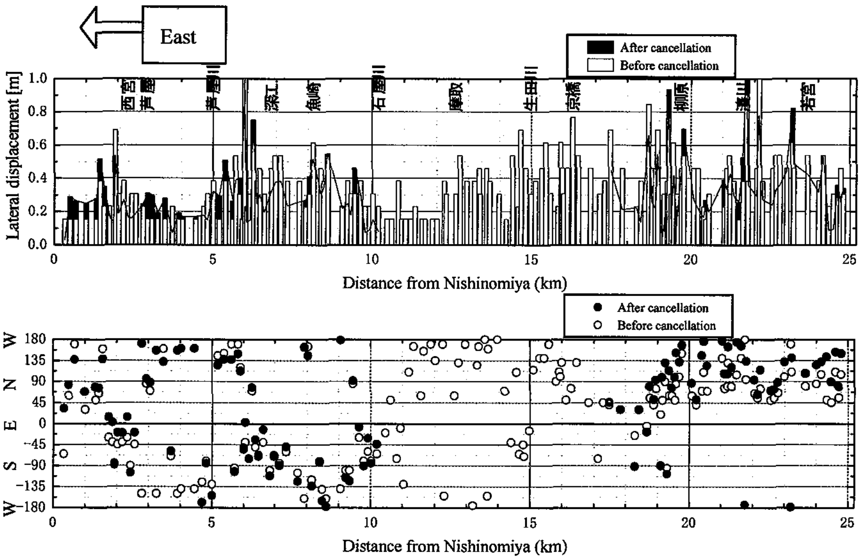


Figure 1 Displacements remaining on ground surfaces

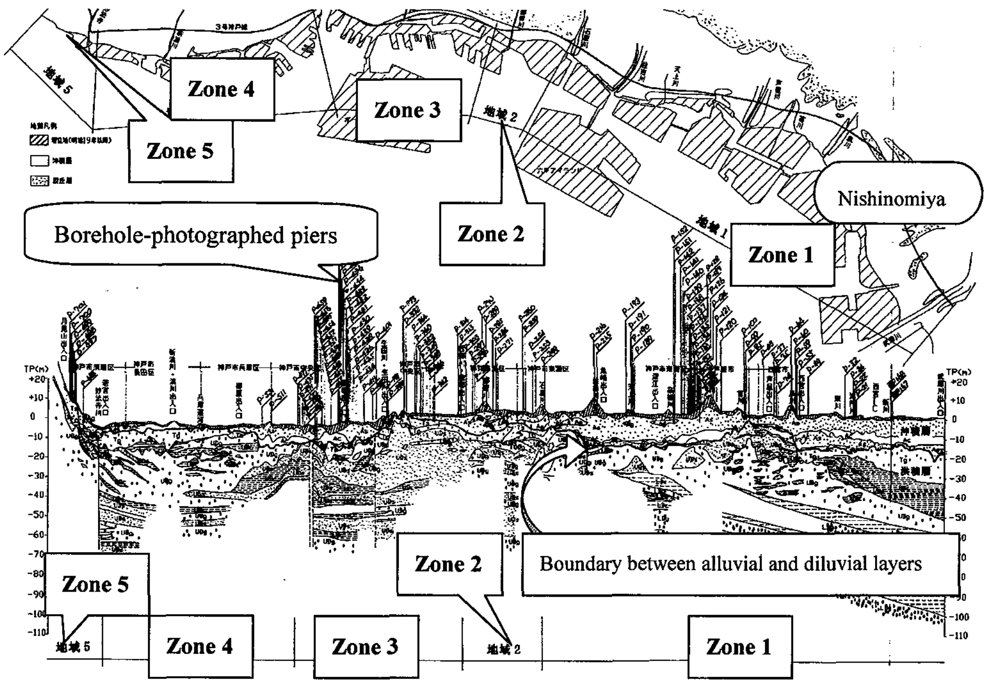


Figure 2 Zones along Route 3, Hanshin Expressway

distribution of the displacements can retain some certain components of bedrock movements that were directly caused by the fault dislocation. Cancellation of these components is essentially impossible as far as no reliable indication of bedrock movements is available. Nevertheless some thick and stiff caisson foundations of the Route 5 running roughly parallel to the Route 3 were considered to reflect the motions of bedrocks as their bottom ends touched firmly the bedrocks. The displacements of these foundations and triangulation points on stiff soils were used for the cancellation of the bedrock displacements, though the cancellation yielded only slight change in the overall pattern of the displacement distribution as shown in **Figure 1**. The entire extent of the Route 3 was divided into 5 zones (**Figure 2**) based on a rough categorization of subsoil conditions. Zone 1 extends from Nishinomiya to Ishiyagawa over a widely spread alluvial soil deposit of about 10 to 15 m thick. The soils and other suspended matters that rivers have carried over centuries from the Rokko mountains are mostly from weathered granite. In Zone 2 (from Ishiyagawa to Maya), the Route 3 runs along the boundaries between alluvial fans and the terraces at the base of the Rokko Mountains, whereas in Zone 3 (from Maya to Naka-Futo), it runs along an old coast of the Stone and Earthenware Age of Japan (Jomon Age). Zone 4 extends over a deposit of coarse sandy and gravelly soils with some isolated clayey soil layers sandwiched. The Route 3, like the other major routes in Kobe, goes from east to west through the long-spread city. It however changes its direction towards north in Zone 5 (from Wakamiya to Tsukimiyama) where diluvial terraces feature some undulating configuration.

Except for Zone 1, a clear general ground movement in the north direction is recognized (**Figure 1**).

3. DAMAGE TO PILES

The Route 3 of the Hanshin expressway, a long viaduct with the entire extent of about 25 km through Kobe, has total 718 piers, and 84% of the piers are pile-supported. Among them, 91% are bored cast-in-place piles. Three plots in **Figure 3** show, from the top respectively, types of foundations, numbers of grouped piles and pile lengths with respect to the distance along Route 3. The lengths of the piles vary in accordance with the thickness of the alluvial soil deposit (**Figure 4**). Borehole pictures of cracks on the piles were taken at 122 piers. The piers investigated are shown in **Figure 2**. Average crack openings per pier were then categorized into 10 ranks (**Figure 5a**), and were compared with the embedment depths of the piles (**Figure 5b**) and the absolute values of ground surface displacements as well (**Figure 5c**). In **Figure 5b**, hatched bars show the locations of the clayey layers that exhibit some flexible natures. The extent of damage indicated with the crack openings seems to be consistent with the spatial distribution of the displacements remaining on the ground surfaces. This tendency becomes

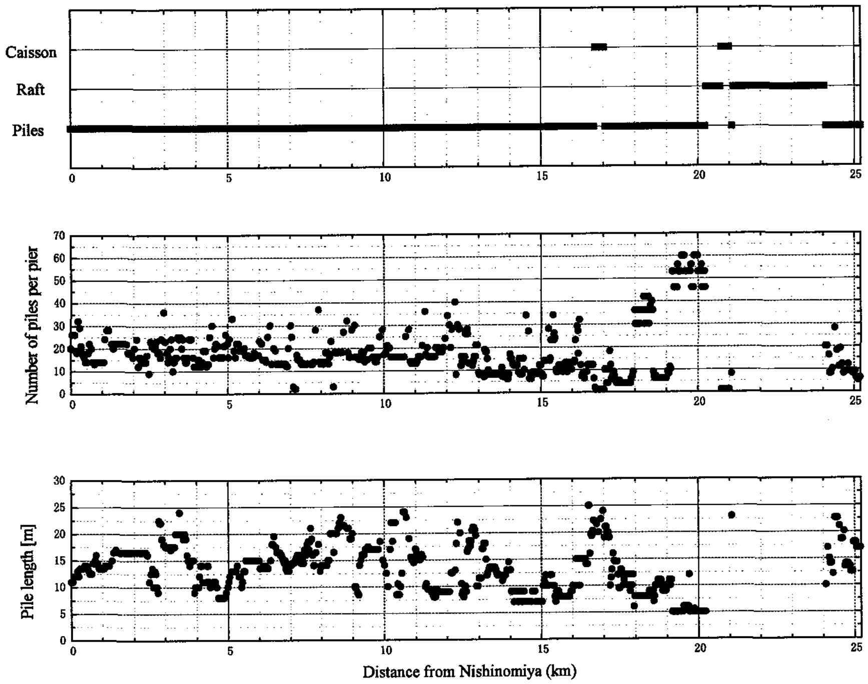


Figure 3 Types of foundation, number of grouped piles and pile lengths

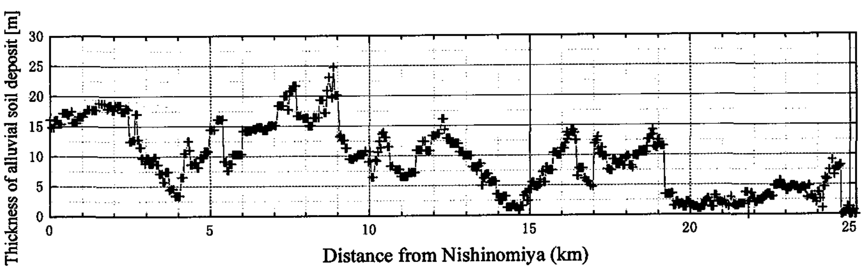
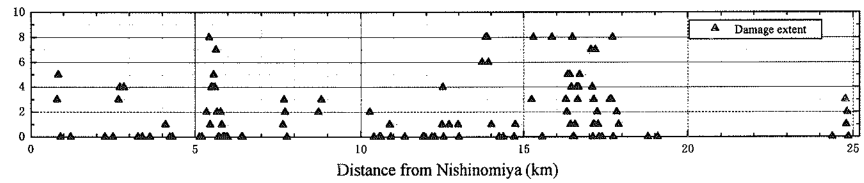
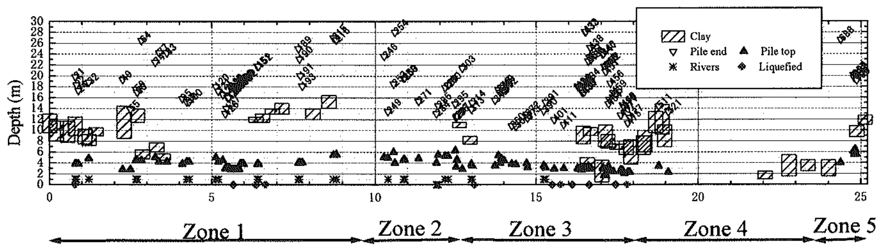


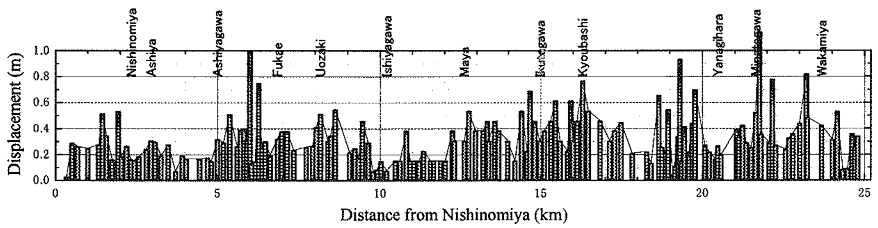
Figure 4 Thickness of alluvial soil deposit



(a) Distribution of damage to piles

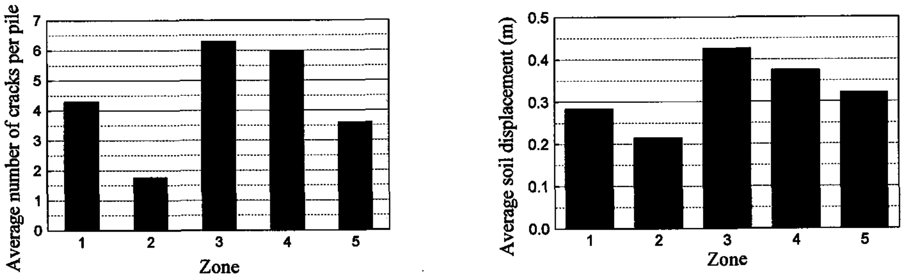


(b) Depths of pile ends and locations of clayey layers



(c) Displacements remaining on ground surface

Figure 5 Damage to piles and displacements remaining on ground surface



(a) Average number of cracks per pile

(b) Average displacement remaining on groundsurface

Figure 6 Soil deformations and damage to piles in different zones

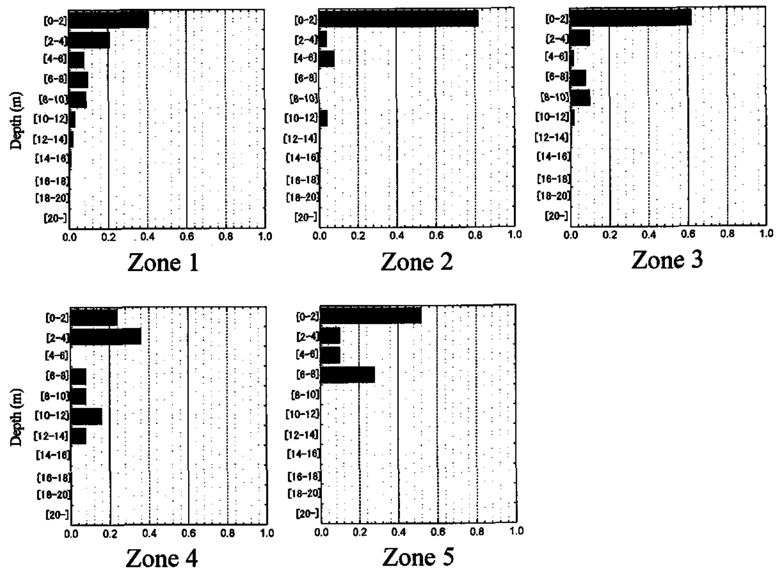


Figure 7 Crack distribution along depth

clearer when the average numbers of cracks per pier were summarized for the different zones (1-5) of the Route 3 (**Figure 6a**), and compared with the average surface ground displacements (**Figure 6b**).

There are two primary causes of cracking of piles beneath a viaduct pier; the dynamic response of the viaduct and the free-field ground motion that forcibly deforms the piles. The former is liable to cause the upper part of piles to be cracked, whereas the latter is responsible for the cracking of piles where the soil strain is the most pronounced. Crack distributions with respect to depth were summarized for the five zones of the Route 3 (**Figure 7**). In all these zones, piles were liable to be cracked at their top ends. In Zones 3-5, however, the second densest clusters of cracks are found at some deeper locations where clayey layers appear most frequently. This fact suggests that these clayey layers might have amplified the ground motion to a considerable extent, and the displacements remaining on the ground surface retain the displacements built up in these layers.

4. CONCLUSIONS

This paper described the distributions of the remaining soil displacements along a viaduct, the Route 3 of the Hanshin expressway, and discussed the correlation between the soil deformations and the spatial variation of damage to the pile foundations of the viaduct's piers. The entire extent of the Route 3 was divided into 5 zones based on a rough categorization of subsoil conditions. The extent of damage to pile foundations seems to be consistent with the spatial distribution of displacements remaining on the ground surfaces. This tendency becomes clearer when the average numbers of cracks per pier were summarized for the different zones. There are two primary causes of cracking of piles beneath a viaduct pier; the dynamic response of the viaduct and the free-field ground motion that forcibly deforms the piles. The former is liable to cause the upper part of piles to be cracked, whereas the latter is responsible for the cracking of piles where the soil strain is the most pronounced. Crack distributions with respect to depth were summarized for the five zones of the Route 3. In all these zones, piles were liable to be cracked at their top ends. In Sections 3-5, however, the second densest clusters of cracks are found at some deeper locations where clayey layers appear most frequently.

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