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Advances in Pavement Engineering and Ground Improvement

Edited by
Hadi Khabbaz, Ph.D.
Zahid Hossain, Ph.D.
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ADVANCES IN PAVEMENT ENGINEERING AND GROUND IMPROVEMENT

SELECTED PAPERS FROM THE PROCEEDINGS OF THE FOURTH GEO-CHINA INTERNATIONAL CONFERENCE

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Preface

This Geotechnical Special Publication (GSP) contains 18 papers that were accepted and presented at the 4th GeoChina International Conference on Sustainable Civil Infrastructures: Innovative Technologies for Severe Weathers and Climate Changes, held in Shandong, China on July 25-27, 2016. Major topics covered in this GSP are:

- Engineering Issues in Ground Subsidence
- Geophysical Testing in Civil and Geological Engineering
- Ground Improvement, and Chemical / Mechanical Stabilization for Pavement and Geotechnical Applications
- Asphalt Mix-Design, HMA Testing, & Material Property Characterization

The overall theme of the GSP is advances in pavement engineering and ground improvement and all papers address different research findings of this theme. It provides an effective means of shearing recent technological advances, engineering applications and research results among scientists, researchers and engineering practitioners.

Acknowledgements

The editors would like to thank the many individuals who assisted in reviewing the abstracts and papers. Without their efforts we would not have had high quality papers included in this publication.

Contents

Downdrag Behavior of Piled Foundations Caused by Deep Water Pumping: A Forensic Study of a Damaged HSR Viaduct

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Abstract: One of the viaducts of the High Speed Railway in Taiwan has suffered significant structural cracks in its piers. This has raised serious public concern. The damage was conjectured to have resulted from ground settlement due to regional water pumping. The paper proposed a practical methodology to investigate the downdrag behavior of the pile foundations of the viaduct. A fictitious settlement controlled layer beneath the pile foundation was used to control the ground surface settlement due to deep water pumping. A three-dimensional finite difference mesh including the soil profile and the pile foundation was established with the geotechnical investigation report and design data. By varying the ground surface settlement, the variations of the pile settlement, ground settlement, and downdrag force with depth for each pile can be reasonably simulated. The results show an obvious pile group effect, which shows the minimum downdrag force in the interior pile and maximum force in the corner pile. There also exists a critical surface ground settlement at which the drag force reaches the maximum value. The simulated differential settlement was close to the measured value, however this was not enough to have caused the structural cracks in the piers. The cracks are more likely caused by other engineering events.

INTRODUCTION

The Taiwan High Speed Railway (HSR) was constructed along Taiwan's western coastal alluvial plain in 2006 and began operating in 2007. Figure 1 shows its route and the site under study. Nowadays, it is a very important transportation artery. The western coastal plain has suffered from regional ground subsidence for many years owing to pumping water for use in agriculture irrigation and aquaculture fisheries. The most serious subsidence area is Yunlin County. Figure 2 shows the accumulated settlement contour of the county during 2002-2011 and the routes of HSR and the No. 78 highway.

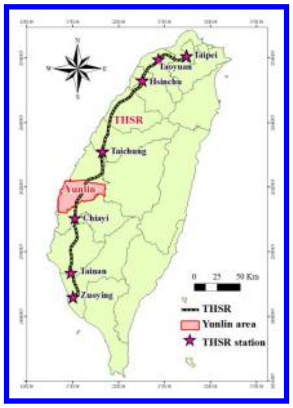

FIG. 1 The route of THSR and study site

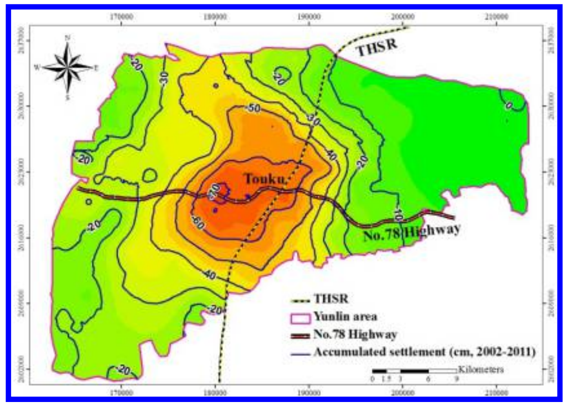

FIG. 2 Settlement contour of Yunlin County during 2002-2011

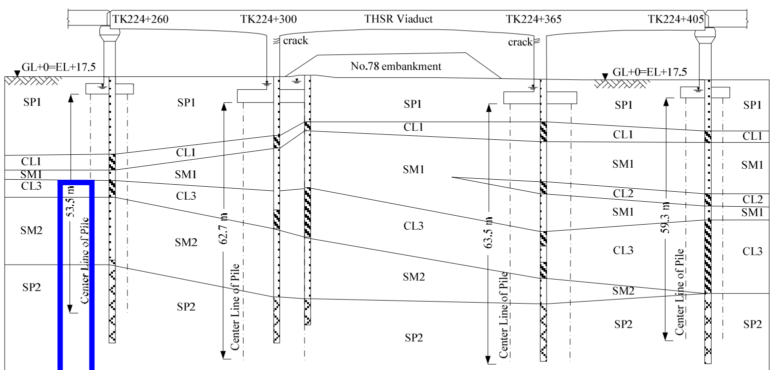

FIG. 3 The 3-span viaduct, the cracked piers, and the pile foundations

Two bridge piers of one HSR viaduct at the intersection of the HSR and No.78 highway have been found to have serious structural cracks at the top of the pier. Figure 3 shows the 3-span viaduct, the cracked piers, and the pile foundations. Figure 4 displays the cracks that occurred at the top of the damaged pier. Based on the settlement records during 2003-2010

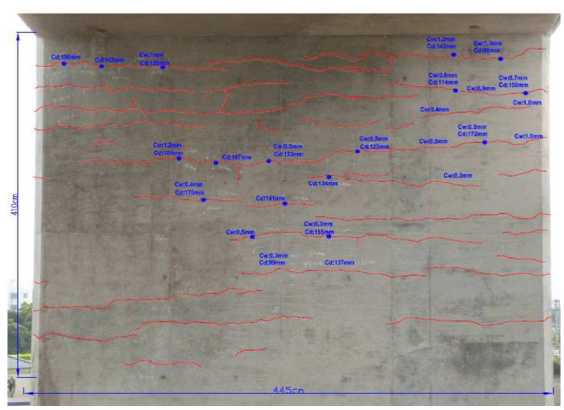

FIG.4 The cracks at the top of pier

(Sinotech 2012), the accumulated settlement at the intersection of the HSR and No. 78 Highway has reached a maximum of approximately 62 cm. Thus, the damage to the piers caused great concern in the public about the safety of the HSR. Most people attributed the damage to the settlement of the region due to pumping water. This background led to this study aiming to understand the influence of the regional settlement on the pile foundations of the HSR.

METHODOLOGY AND ANALYSIS MODEL

The purpose of this study is to investigate the effect of deep pumping water on the pile foundations of the HSR. The analysis procedure included (1) establishing an analysis model, (2) summarizing the parameters needed from the soil profile, (3) a simplified method to simulate deep water pumping, and (4) performing numerical simulations. Originally, the whole viaduct structure and foundation ground (full model) were included in the analysis model. However, the full model was unacceptable due to the following three factors. First, the element number was enormous, second was the very complicated soil profile, and the last was that the dewatering depth reached down to a depth of 300 m. All these made the analysis domain too large. The study finally selected one pile foundation and its surrounding ground as the analysis domain to save computational time and cost. The complicated soil layers were simplified into several horizontal soil layers. A novel idea was to use a controlled bottom layer to replace the large soil domain below the bottom of pile foundation. The settlement of the former was controlled to equal to that of the latter. Thus, the computational effort can be greatly reduced. Based on this idea, a practical methodology was successfully developed for analyzing the effect of deep water pumping on the pile foundation.

Analysis Model

The 3-span (40m-65m-40m) damaged viaduct has four pile foundations. The inner pile foundations with cracked piers were used to set up the analysis model. The analyzed pile foundation had a cap with dimensions of 18 m × 18 m × 3 m, and 12 bored piles (all casing piles) with 2 m diameters and 62 m of length. The ultimate axial bearing capacity of each single pile is about 52.4MN with a frictional capacity of 43MN (82%). The plan layout of the pile foundation and the pier is shown in Figure 5. The pile was meshed by hexadecagonal solid elastic elements. The ground was meshed by hexagonal solid elasto-plastic elements with finer mesh sizes in the foundation area and gradually coarser mesh sizes from the foundation edge towards the boundaries. The ground water table has been lowered down to a depth of 300 m. Thus, a large numerical model with a depth of 300 m was required to simulate the real conditions. However, the computational time was unacceptable for such a model. To overcome the problem, a 10 m thick controlled soil layer was used to replace the 230 m thick one below the bottom of the pile foundation by requiring the settlement of the former layer to be equal to that of the latter layer. Thus, the original model size of 112 m × 112 m × 300 m was reduced to a 112 m × 112 m × 80 m concept of the settlement-controlled layer. The final mesh of the analysis model had 1,920,000 elements, as shown in Figure 6.

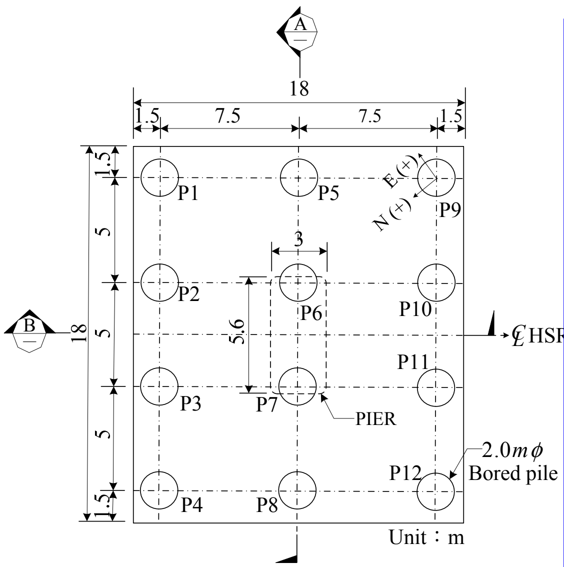

FIG. 5 The plan layout of pile foundation

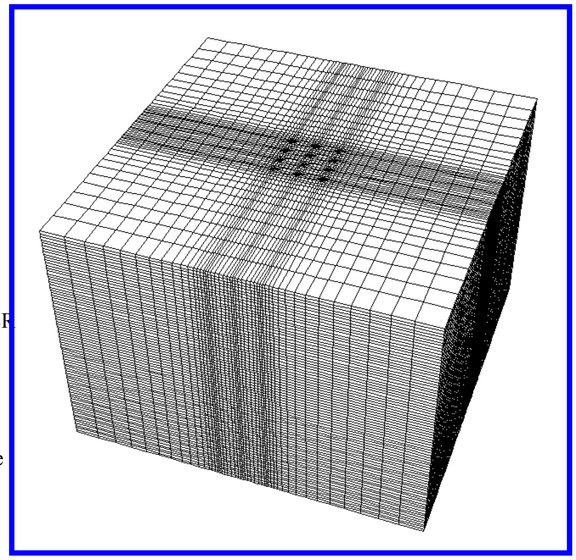

FIG. 6 The mesh of analysis model

Geotechnical Parameters

Based on the geotechnical investigation report for this site, there were data from one borehole at the position of each pier in the design stage. An additional boring hole was performed at a position near to the interior pier. The borehole depths ranged from 65 m to 69 m and the ground water tables ranged from 1.7 m to 2.7 m. The site consists of interbedded sandy and clayey soils down to at least 1000 m. The soil formation is very complicated. The simplified soil profile and the geotechnical parameters for analysis are summarized in Table 1. It consists of three sandy soils and two clayey soil layers. The pile bottom is located in the last sandy layer. Below that is the settlement-controlled layer for modelling the effect of deep soil formation beneath the pile foundation. The ground water table was assumed to be at a 2 m depth for the analysis. The pile is assumed to be an elastic material. The soils are elastic-perfectly plastic materials that follow the Mohr-Coulomb failure criterion.