A STUDY ON COUNTERMEASURES AGAINST LIQUEFACTION-INDUCED GROUND FLOW BEHIND SEAWALLS

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ABSTRACT :

The purpose of the present study is to develop effective and economical measures for the reinforcement of existing seawalls and for the improvement of the ground behind the seawalls to prevent the occurrence of large ground displacement due to the flow of liquefied soil. The author proposed countermeasures, where steel sheet piles were driven behind the existing seawalls to prevent and to reduce the liquefaction-induced ground displacement. The effectiveness of the developed countermeasures was examined by model experiments under a centrifuge condition of 50g. Based on the experimental studies, the author proposed a method to estimate the external forces on countermeasure walls from the liquefied soil for the earthquake resistant design of the walls.

KEYWORDS: Liquefaction, Liquefaction-Induced Ground Flow, Countermeasure, Centrifuge Test, Numerical Analysis

1. INTRODUCTION

The 1995 Kobe earthquake caused large movements of seawalls in reclaimed islands in Kobe areas, which resulted in ground displacements of several meters in the horizontal direction. These ground displacements caused a large number of ruptures of foundation piles of buildings and bridges, and buried pipes of lifeline systems. A same phenomenon was observed during the 1964 Niigata earthquake. The liquefied ground along the river banks moved towards the river bed, resulting in the collapses of bridges and ruptures of buried pipes. Around the Tokyo Bay and Osaka Bay areas, there still exist old artificial islands reclaimed from the sea without any soil improvement and countermeasures of the seawalls against liquefaction. On these islands many industrial complexes have been constructed and operated. The storage tanks for combustible gas and petro-chemical products may be severely damaged and safety of the surrounding areas may be seriously threatened. The damage to these areas will affect the function of the metropolitan areas of Japan. Therefore, developments of effective countermeasures are strongly expected against future earthquakes. This paper presents a study on countermeasures against horizontal movement of liquefied ground based on model experiment in centrifuge condition.

2. SHAKING-TABLE EXPERIMENTS UNDER CENTRIFUGE CONDITIONS

Effectiveness of countermeasures, where steel sheet piles are driven behind the existing seawalls was examined by shaking table experiments under a centrifuge condition of 50g. The required stiffness of the steel sheet piles and the proper location of the driving of the piles were studied.

2.1. Experiment Method

Figure 1 shows the experiment models of three cases A, B, C, with variations of stiffness of the sheet piles and the locations. The model of sheet piles was made by steel flat plate, and the thickness of the plates was determined by a similarity rule of the bending stiffness between the prototype piles and the model type one.

Table 1 shows the model conditions and the similarity rule. The ground consists of three layers, saturated layer of thickness 12.0m with relative densities of 45~65%. Non-saturated surface layer has thickness of 2.0m and the relative density of 50%. The countermeasure walls were constructed by steel sheet piles with types of SP-Ⅲ and SP-Ⅵ.

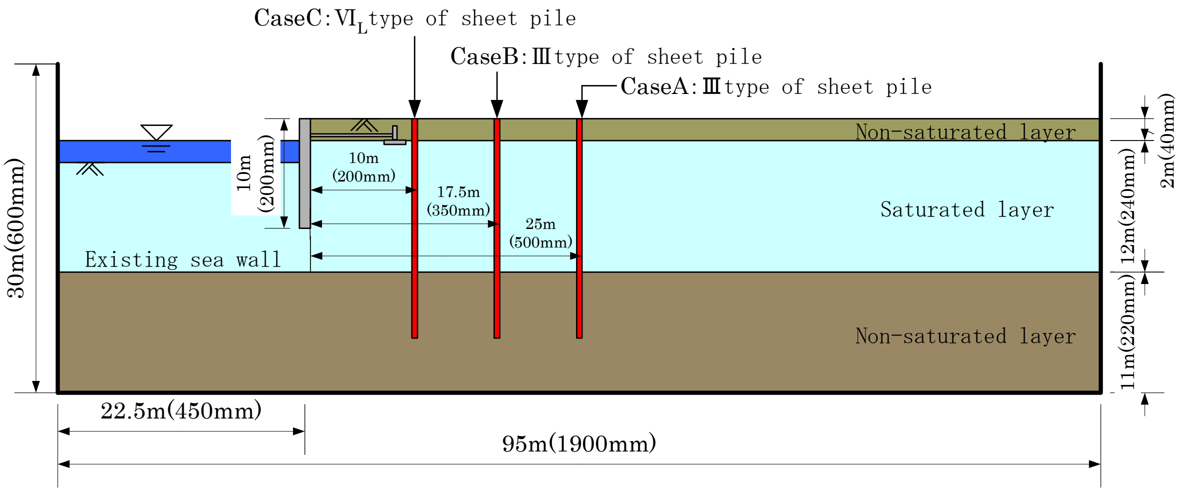


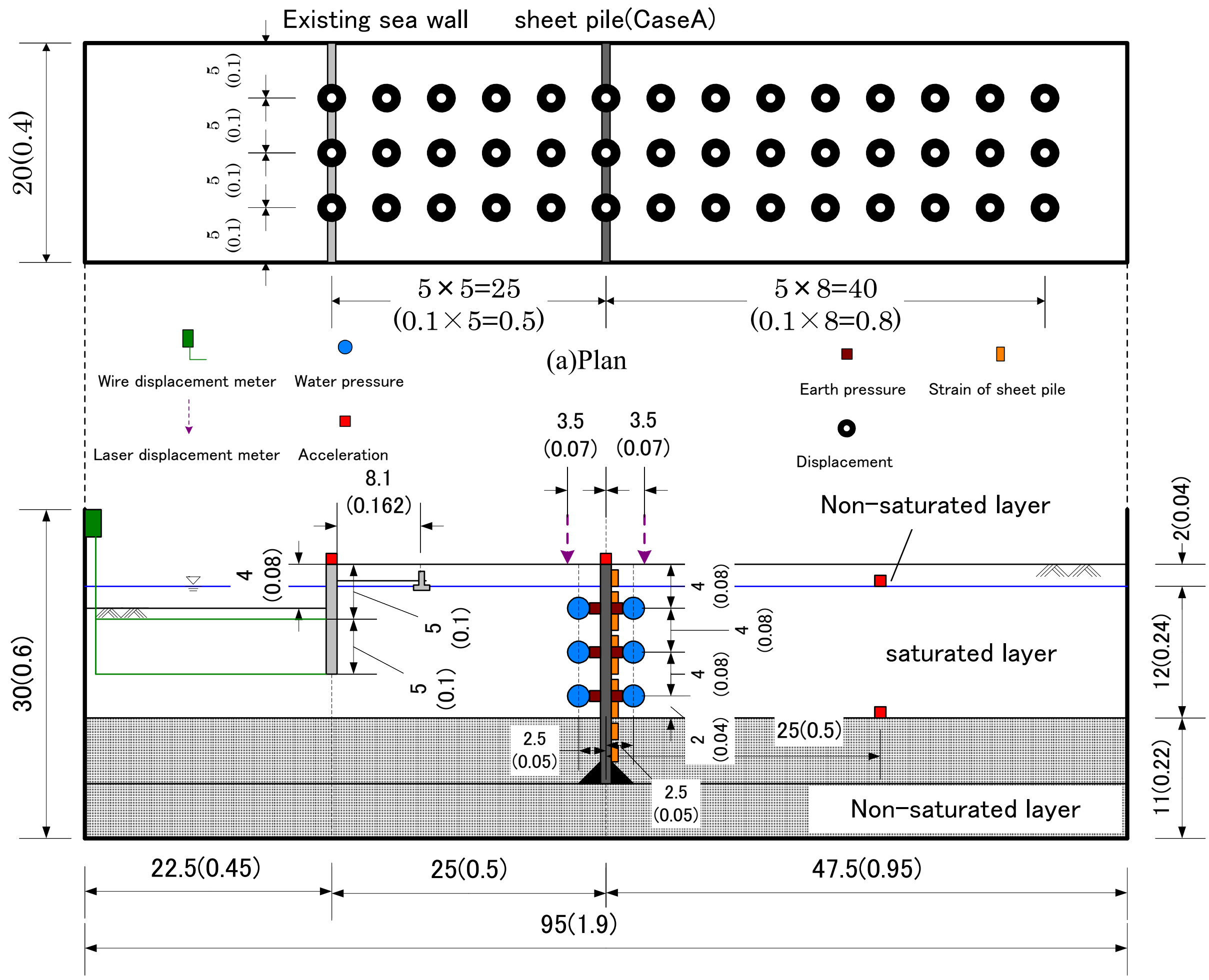
Figure 1 Configuration of experiment model

Table 1 Model conditions and similarity rule

Model Case	Saturated Ground		Non-Saturated Surface-Layer		Sheet Piles			
	Relative Density(%)	Thickness (m)	Relative Density(%)	Thickness (m)	Prototype Sheet Pile	Bending Stiffness of Actual Piles (KN/mm^2)	Thickness of steel plate of Model(mm)	Stiffness of Model Pile(KN/mm^2)
A	45	12.0	50	2.0	SP-Ⅲ	6.92×10^{11}	2.5	6.75×10^{11}
B	65	12.0	50	2.0	SP-Ⅲ	6.92×10^{11}	2.5	6.75×10^{11}
C	64	12.0	50	2.0	SP-Ⅵ	3.54×10^{12}	4.5	3.83×10^{12}

(centrifuge acceleration:50g)

Figure 2 shows the locations of instruments to measure pore-water pressure, earth pressure, strain of the sheet pile walls, ground displacement and acceleration. The time histories of ground displacements were also measured by the targets on the ground surface by using high speed camera.



(b)Longitudinal Profile

Figure 2 Locations of measurement instruments

2.2.Discussions on The Experimental Results

Figure 3 shows the ground displacement distribution behind the existing seawall. The sheet pile countermeasures can largely reduce the ground displacement behind the sheet pile, and in the case when the location of the sheet pile is far from the existing seawalls (case A) the effect on the reduction of the displacement is much larger. Therefore, the experimental results indicate the countermeasure walls for the production of the foundation of structures against ground displacements should be driven as far as possible from the exiting walls, namely just in front of the structures.

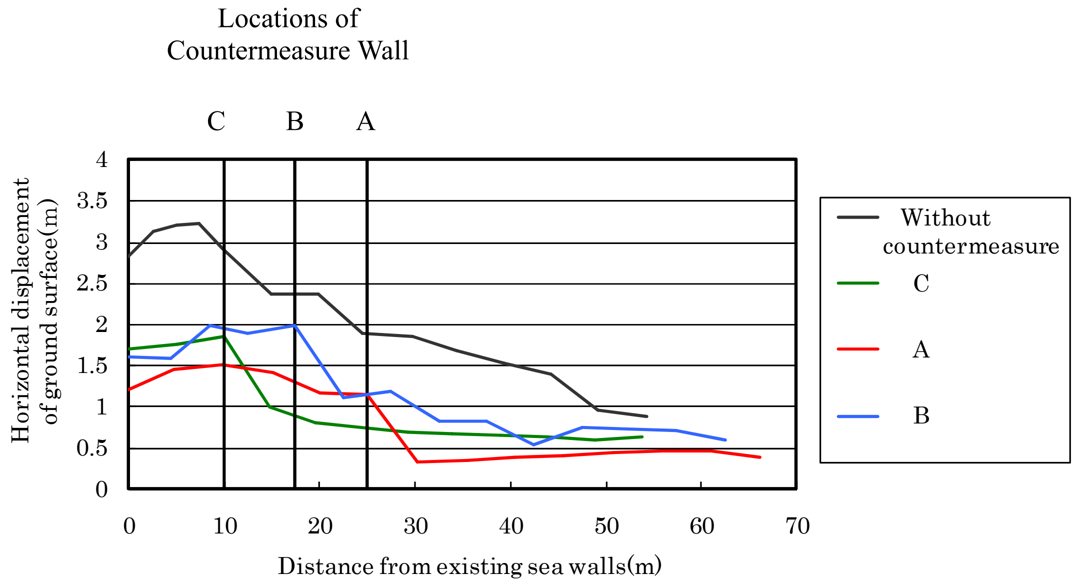
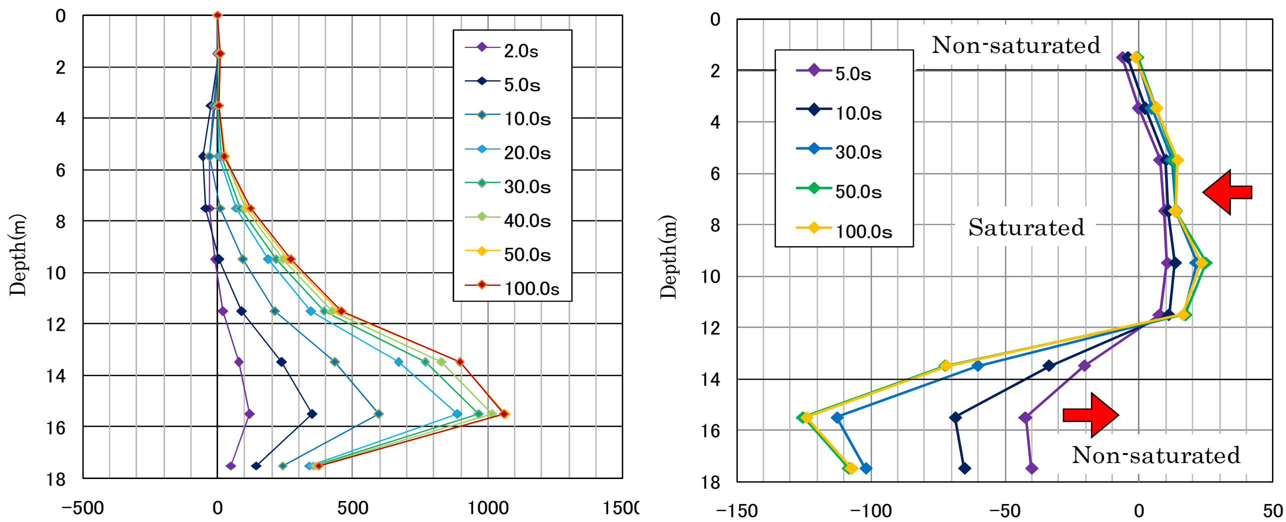


Figure 3 The Effectiveness of countermeasure walls to reduce the ground displacement in horizontal direction

Figure 4 shows the bending moment of the countermeasure wall (Case A) and the external force from the liquefied ground. The external force was estimated from the measured bending moments by a differentiation. From the saturated layer, most part of which was estimated to be liquefied, an external fore toward the sea (from the right to the left) was applied, while from the lower non-saturated soil external forces, toward the inland (from the left to the right) was applied on the countermeasure wall. The mechanism of the external force will be discussed as follows;



(a) Bending moment of countermeasure wall(kN･m/m)

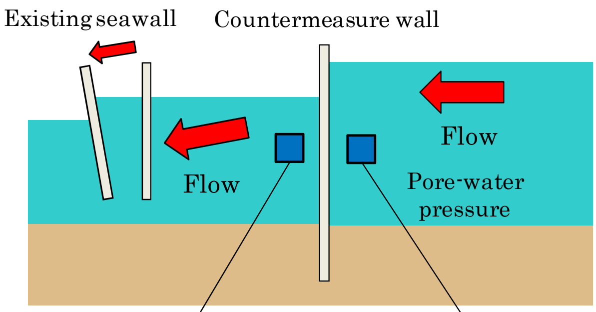
(b) External forces on the countermeasure wall(kN/m²)

Figure 4 Bending moment of the countermeasure wall and external forces (Case B)

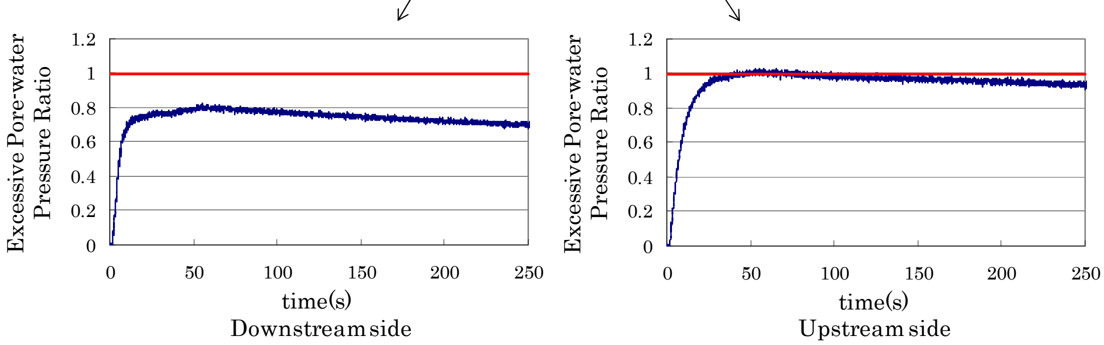
3. ESTIMATION OF EXTERNAL FORCES ON THE COUNTERMEASURE WALL

Figure 5 (a) shows the schematic sketch of the movement of the existing seawall and the ground surface due to liquefaction and flow. The existing wall moved horizontally towards the sea and also largely inclined. The ground surface on the downstream side (the sea side) of the ground flow largely subsided due to the flow away of liquefied sand to sea. The ground surface also subsided in the upstream side (the land side), but the magnitude of the subsidence was limited, which was caused only by the densification of the liquefied soil. Therefore difference in the ground surface elevation is one of the causes to generate the external forces on the countermeasure wall.

Figure 5 (b) is excessive pore-water pressure ratio in the both of upstream and downstream sides. The excessive pore-water pressure in the downstream side did not reach 1.0, which meant that the ground in the downstream side did not perfectly liquefied due to the flow of the liquefied soil towards the sea. On the contrary the ground in the upstream the excessive pore-water pressure reached 1.0 which meant the perfect liquefaction. The difference in the excessive pore-water pressure in the two sides of the countermeasure wall is another reason to generate the external force on the wall.



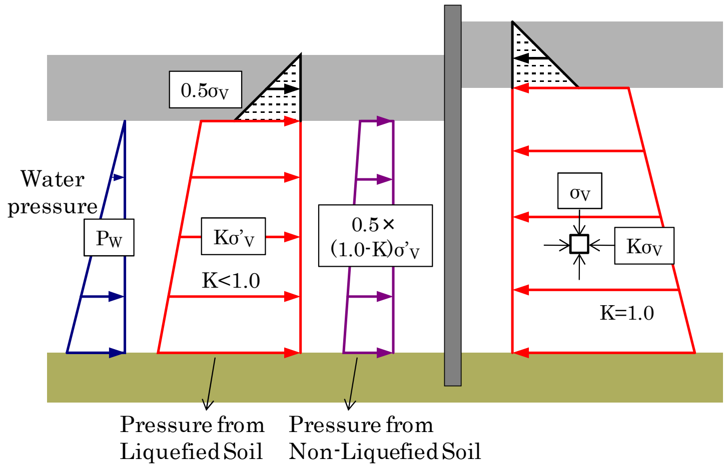
(a)Schematic Drawing of the movement of existing seawall and ground



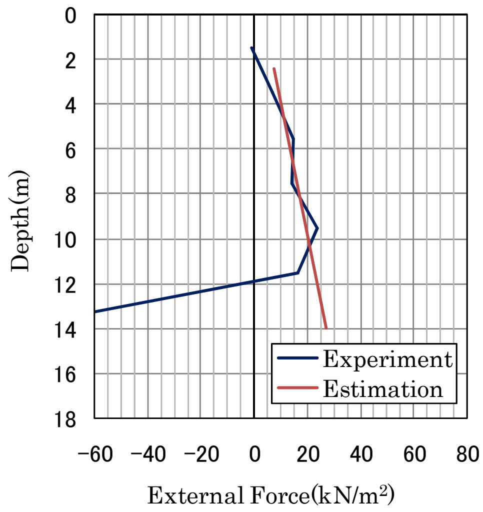
(b)Excessive pore-water pressure ratio

Figure5 Movement of the existing seawall and ground, and excessive pore-water pressure ratio

Figure 6 (a) shows the external force on the countermeasure wall based on the above-mentioned discussions, and Figure 6 (b) shows the comparison between the experimental external force and the estimated one. A good agreement was obtained between experiment and the estimation.



(a)External force on countermeasure wall



(b)Estimated external force and experiment

Figure6 Estimation of external forces on the countermeasure walls

4. CONCLUSIONS

The followings were obtained from the model experiment on the countermeasure walls to prevent and to reduce the flow of the liquefied soil, and on discussions on the experimental results.

ｉ) The steel sheet piles are effective to prevent and to largely reduce the ground displacement behind the walls. The location of the sheet piles (the distance from the seawall) largely affects their effectiveness. When the sheet pile was driven far from the existing seawall, the effectiveness was highly expected.

ⅱ) The external forces on the countermeasure walls can be estimated by the differences of the ground surface elevation and of the excessive pore-water pressure between the upstream and downstream sides of the countermeasure walls.

REFFERENCES

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