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Article / Book Information

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Title(English)	Stability of large diameter cantilever type steel tubular pile wall embedded in soft rock subjected to various loadings
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The application of Cantilever type Steel Tubular Pile (CSTP) walls as permanent or temporary retaining structures has increased in recent decades. Technological advancements like the rotary cutting press-in technique make constructing this wall in populated urban areas possible. Also, it becomes possible to construct this type of wall on comparatively stiff ground like soft or hard rock. Although technology has advanced, the current design guidelines are not well rationalized to consider the specific features of the wall, like a very large stiffness wall embedded in stiff ground. Several concerns were raised by the engineers and researchers, for example, the selection of minimum embedment depth, 3D behaviour of steel tubular pile wall, heterogeneity of embedment conditions in the stiff ground, and the applicability of the bi-linear p-y curve for dynamic conditions. Also, the stability of the CSTP wall against extreme loadings like earthquakes, buildup of water pressure on the retain side or the combination of both should be checked from the serviceability limit to the ultimate conditions. Not enough research has been done to investigate the concerns mentioned above by physical means, such as physical modelling. This research addresses these concerns by physical modelling using the Tokyo Tech Mark III centrifuge. At first, the complex CSTP walls model is simplified into simple pile loading and wall loading tests, with clear loading conditions, to avoid the complex soil wall interaction observed in actual CSTP walls with retained soil. Then, five centrifuge model tests were conducted using the actual CSTP wall with retained soil embedded into soft rock subjected to sequential loadings.

Using the Tokyo Tech centrifuge facility, a single pile loading test with different rock socketing depths (d_r) was conducted in 1g. Three stainless steel piles with outer diameter (Φ) of 40mm and thickness (t) of 0.5mm were used. The piles were socketed into artificially prepared soft rock with normalized rock socketing depths (d_r/Φ) of 1.0,1.5,2.0. By controlling the displacement, a one-way horizontal cyclic load was applied on each pile at a loading height (h_L) of 130mm from the rock surface. The 1g pile loading test results were compared with the previously conducted 50g pile loading test. The lateral resistance of the piles was increased with the rock socketing depth in both the 1g and 50g pile loading tests. The 1g model could predict the lateral resistance of the centrifuge model test up to a small imposed displacement. However, at larger imposed displacement, the 1g model underestimated the lateral resistance compared to the 50g model due to early crack formation, proving the advantage of using the centrifuge model test.

The simplified CSTP wall loading test under 50g centrifugal acceleration with clear loading conditions was used to study the load resistance (p-y) curve concept, specifically to investigate the JARA (2017)-recommended bilinear p-y curve. The analytical tool "Lpile" by Ensoft was utilized to study the p-y curve. Furthermore, using the centrifuge test condition, a stability analysis using the limit equilibrium method was carried out to discuss the effect of base shear on the lateral resistance of the wall. It was found that mobilization of the base shear resistance could provide additional stability to the wall. However, the contribution of base shear resistance depends on the d_r/Φ ratio, i.e., a smaller ratio would mobilize larger base shear resistance. Based on the p-y analysis, the design recommended bi-linear p-y curve by JARA (2017) underestimated the lateral resistance at small to large imposed displacement compared to the centrifuge model. It suggests that using the JARA (2017) recommended bilinear p-y curve, a significant safety margin could be ensured at small to large imposed displacement.

A large diameter (Φ=2m) cantilever steel tubular piles (CSTP) walls embedded in a soft rock were modelled in a centrifuge with the wall height H=12m and different embedment conditions and dry dense sand as the retained soil under 50g centrifugal acceleration. Five centrifuge tests were conducted. Three tests included a single rock layer with embedment depth (d_r) of 2.5 ($\beta.d_r$=1.0) and 3.0m ($\beta.d_r$=1.2). Two tests included rock with overlaying sand layer (d_s) to discuss the effect of heterogeneity of the embedment condition. Among them, the first model had an embedment depth equal to 3m (d_r=2.5m;d_s=0.5m), and the latter had an embedment depth of 3.5m (d_r=2.5m;d_s=1.0m). Sequential loadings were applied to the wall to investigate the wall performance under extreme loading conditions. Dynamic loadings were first applied by sinusoidal input acceleration with a predominant frequency of 1Hz, followed by the water rise to the water height h_w>2H/3 in the retained sand as a static loading. Another series of dynamic loadings was applied in the wet condition. The water level was increased further, and dynamic loading was finally imposed on the wall. In one single rock layer model, static loading by water rise was applied first, followed by large dynamic loading. Stability against the catastrophic failure was confirmed for the single rock layer model with d_r=2.5m ($\beta.d_r$=1.0) even at a wall displacement of more than 4%H. Further increasing the d_r by 0.5m could significantly improve the wall stability. The weathering of the shallow rock layer could reduce the

factor of safety and increase the wall top displacement. For high-stiffness walls embedded into the stiff ground with good confinement conditions, the residual effective earth pressure increases with the wall displacement by dynamic loadings, defined as the "elastic resilience effect" in this study. The effective earth pressure ratio (σ'_h/σ'_v) observed after final loading was larger than the design active (K_a) or even at-rest (K_0) pressure coefficient due to the resilience effect. It suggests that commonly assumed K_a or K_0 earth pressure in the design might lead to underestimating the wall bending moment. The long-term creep displacement could reduce the resilience effect for the less redundant CSTP wall used in this research. The long-term creep displacement of the wall will be less of a concern for the dynamic loading than the static loading due to the reduction of earth pressure developed by the resilience effect. For the large diameter thin wall tubular pile, a stress concentration or a propping action might cause the local deformation of the pile near the rock surface, which affects the bending moment measurement using strain gauges. If the actual total earth pressure acting on the wall can be measured in the real site, using the two-spring model , where the lateral spring is defined by the JARA (2017) and a base shear spring with stiffness 1/3 of the lateral spring recommended for caisson type foundation by JARA (2017) and actual total earth pressure as imposed load, could reasonably predict the residual wall displacement up to $\delta t<0.5\%H$. However, assuming the commonly used active or at-rest earth pressure as imposed external load might underestimate the residual wall displacement due to the resilience effect, which is unique for the high stiffness wall embedded into stiff ground. There are several limitations of using the bi-linear p-y curve to predict the residual wall displacement. Firstly, in actual conditions, as the residual wall displacement increases, the plastic deformation of the rock could reduce the k_H, which cannot be predicted by the bi-linear p-y curve with constant k_H. Therefore, a bi-linear p-y curve with variable k_H based on the plastic deformation could provide a more accurate residual wall top displacement prediction. Secondly, the bi-linear p-y curve cannot predict the resilience effect, which occurs during the dynamic loadings.