Stability Analysis of Buried Waste Water Pipeline in Soft Ground

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ABSTRACT: Recently, ground collapse are increasing due to the old pipelines buried under the ground like waste water pipeline. The purpose of this research was to analyze the causes of pipe deformation during the test construction of the channel pipeline improvement project with the nature river work. The particle distribution, physical and mechanical characteristics were investigated through laboratory, and field test using the additional boring exploration. Stability analysis was performed by applying soil cement wall with high strength deep cement mixing method(SCW+HDCM) and Sheet Pile with HDCM method to two points, No. 84+4.0 and No.100+0.0, which are the most vulnerable to subsidence of pipeline. The soft ground layer was reinforced by HDCM method for 2m to improve the strength of the clay soil and to prevent settlement, satisfying the allowable residual settlement of 100mm.
Keywords: Waste water pipeline, stability, temporary earth wall, ground improvement, differential settlement.

1. INTRODUCTION

Recently, ground subsidence cases are increasing due to the structures buried under the road. Much of this is caused by the deterioration of the waste water pipe and the leakage of pipelines. The number of leakage incidents is increasing as the city is aged. The increase in the underground space utilization due to the overcrowding of the city is accompanied by the excavation and backfilling of the ground, which weakens the ground and increases the risk of collapse of the ground.
In general, the deep cement mixing(DCM) column improving the soft clay ground by mixing chemical stabilizer which consisted of cement and lime at the original site is used for the infrastructure construction. Deep cement mixing is used to reduce the generation of waste during soft soil improvement and achieve low noise in a short period of time. The fundamental improvement principle of the deep mixing process is in the formation of a rigid hardened body produced by the hydration reaction between the stabilizer and water. The chemical reaction (pozzolanic reaction) between the product by the hydration reaction and the marine clay material improves the soft ground (Shin et al., 2009).

Deep mixing method started to be developed from a research work by the Research Institute of Harbor Technology belonged to the Ministry of Transport of Japan since 1976. At the same time, lime column was developed and used by now in Sweden which is method of mixing soil in underground as injecting the powder of quick lime into the ground through the air pipe with high pressure. In domestic study about deep mixing, since the SEC (special earth concreting) method with which cement is used as hardening agent was introduced from Japan in 1985. It has been applied mainly to a retaining wall, foundation for building, foundation of seawall or quay as a harbor construction. In the related research, Bergado et al. (2002) studied rrecent developments of ground improvement in soft Bangkok clay. Kim et al. (2005) conducted a reliability analysis of the external stability of the quay wall installed in the deep mixed soil. Park et al. (2006) studied reliability analyze with respect to external stability of quay founded on deep mixing ground. Lee et al. (2007) studied with respect to formation shape of cement mixing bulb with construction condition of deep mixing method. Han et al. (2007) studied about strength of cement mixing bulb by construction condition of deep mixing method. Chon (2010) studied about compressive strength characteristics for deep mixing method. Kim et al. (2011) analyzed the effect of the deep ground mixing and sand treatment method on the application of the lower ground and retaining line. Recently DCM lift injection method has been applied in Incheon coastal area (Park, 2017).

The purpose of this study was to analyze the cause of deformation and differential settlement during the installation of waste water pipeline around a natural river and to propose a countermeasure through stability analysis.

2. EARTH PRESSURE DURING EXCAVATION ON SOFT GROUND

The active thrust on the bracing system of open cuts can be estimated theoretically by using trial wedges and Terzaghi’s general wedge theory (1941). Triangular distribution earth pressure theory used in the design of retaining wall is significantly different in case of retaining wall in soft ground. The larger the deformation behaves the smaller the earth pressure.
When determining the construction depth of the retaining wall and the cross-section of the self-supporting sheet pile, the earth pressure mainly used for Rankine-Resal earth pressure calculation is mainly used. In the case of assuming that the back ground of the retaining wall is horizontal, ignoring the wall friction angle with the wall, the main earth pressure and the passive earth pressure at the bottom of the excavation are expressed by the following Eq. (1) and (2), respectively.

$$P_a = \gamma_t z_w + \gamma'(z - z_w) + qK_A - 2c\sqrt{K_A} \quad (1)$$

$$P_p = \gamma_t z_w + \gamma'(z - z_w) + qK_P - 2c\sqrt{K_P} \quad (2)$$

where, P_a is the main earth pressure at the depth of z, P_p is the passive earth pressure at the depth of z, γ_t is the wet unit weight of the soil, γ' is the unit weight of the soil in water, z is the depth to any point on the surface, z_w is the depth from the surface to the groundwater surface, q is the surface load on the surface, and Φ is the internal friction angle of the soil.

Experimental earth pressure distributions are presented based on actual field measurements, and Peck (1969) 's empirical earth pressure distribution is the most used. These diagrams for cuts in sand, soft to medium clay, and stiff clay are given in Figure 1.

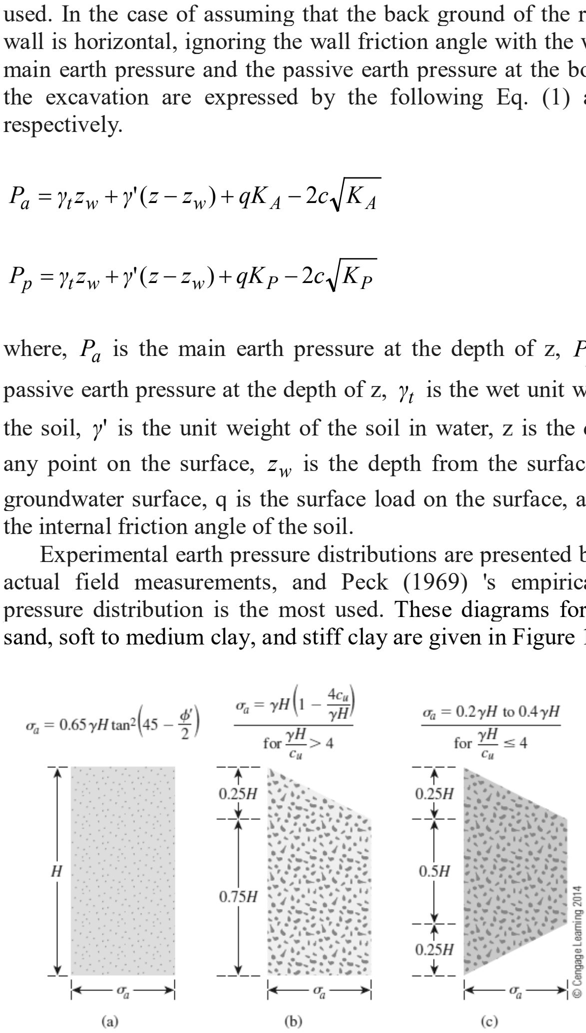


Figure 1 Pressure diagram for cuts in sand(a), soft to medium clay(b), and stiff clay(c) (Das & Sobhan, 2014)

The transverse earth pressure starts from the stationary earth pressure. When the wall is pushed to the excavation side, the earth pressure decreases to the main earth pressure. If it is pushed to the back side, the earth pressure continues to increase but the manual earth pressure can't be increased. In other words, the minimum and maximum earth pressure limits are set. The ground modeling is simulated by a spring, and the basic equation of carbon spring is given by the following Eq. (3).

$$E_w I_w \frac{d^4 y}{dz^4} + \frac{A_p E_p}{L_p} y = p_i \pm k_h y \quad (3)$$

where, E_w, L_w are elastic modulus and moment of inertia of the earth retaining wall and A_p, E_p, L_p are cross sectional area, elastic modulus and length of the supporting structure, respectively. p_i is initial at rest earth pressure (σ_0), k_h represents the horizontal reaction force coefficient.

Using Eq. (3) in SUNEX ver. w6.16(Jang, 2015) and EXCAV ver. 2.51(Oh, 2004), which are currently used as commercial software, stability of the wall is analyzed. The lateral displacement of the wall at each step, the shear force and moment acting on the wall, and the axial force acting on the support are obtained. Figure 2 shows the analyzing model using the equation.

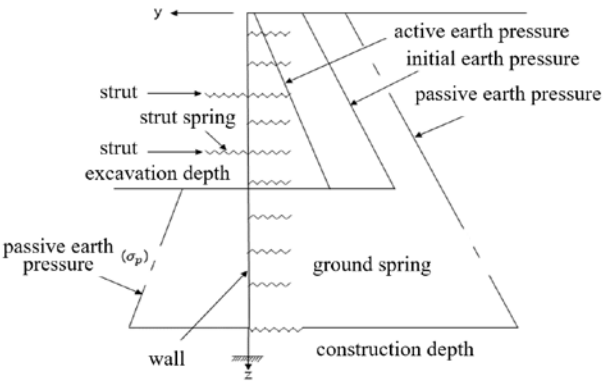


Figure 2 Schematics of elastic beam model

3. SUBSURFACE EXPLORATION ON SOFT GROUND AND SOIL CHARACTERISTICS

The total length of this construction is 7.9km and 3.55km is overlapped with natural river construction. A total of three investigations were conducted on the design subsurface exploration of the waste water pipeline. In this study, the existing ground surveys were combined and re-confirmed the soft ground layer through additional drilling of 5 holes. Figure 3 shows sewer pipeline construction map and situation of subsurface exploration.

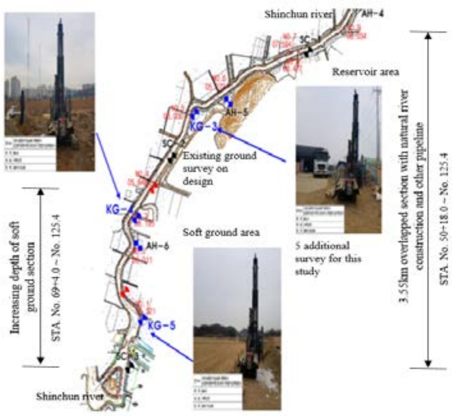


Figure 3 Overview of waste water pipeline in soft ground area

The sample was mostly fine grained soil which is over 50% passing of sieve number 200. It was carried out water washing method and hydrometer distribution test. The particle size distribution of the soil is as shown in Figure 4. As a result of particle size analysis by unified classification method, the soil type of KG-1 to KG-3 was CL, and KG-4 was identified as ML and KG-5 as GC.

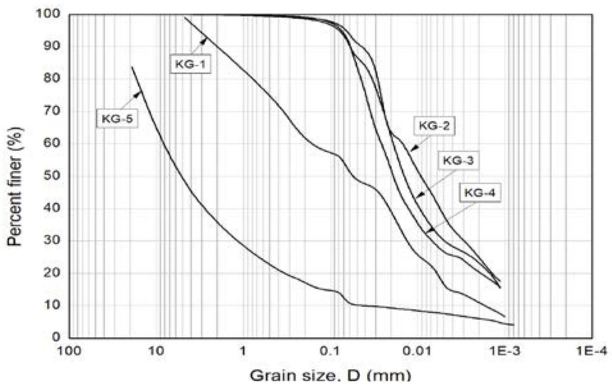


Figure 4 Particle distribution of sample

The preliminary consolidation load was 79.36 *kPa* to 101.40 *kPa*, the compression index was 0.302 to 0.4337, Moisture unit weight of soil was 17.18 kN/m^3 to 18.09 kN/m^3, and the initial void ratio was 1.162 to 1.420. Over consolidated ratio was about 1.0 as a normally consolidated soil. Table 1 shows the results of the consolidation test on the undisturbed samples taken from the boring.

Table 1 Test results of consolidation by laboratory test

No.	Consolidation Test(ASTM D2435)					
	Preconsol-idatin load, P_c(*kPa*)	Comp-ression index, c_c	Swelling index, c_s	Unit weight r_t (kN/m^3)	OCR	e_o
KG-1	82.92	0.41	0.11	18.09	1.04	1.42
KG-2	80.32	0.43	0.07	17.18	1.09	1.30
KG-3	79.36	0.39	0.06	17.66	1.08	1.19
KG-4	101.40	0.30	0.05	18.05	0.95	1.16

In-situ test was performed. Cohesion of soil was measured with a field vane tester in order to confirm the undrained shear strength of undisturbed state and disturbed state. The test results showed that the boring depth was about 3.5~5.0, cohesion of undisturbed sample with depth was 21.4 ~ 23.3 *kPa*, cohesion of disturbed sample was 2.6 ~ 3.5, and the sensitivity ratio of each boring was 7.15 ~ 8.23. On the design, cohesion was similar with additional survey as 22.0 ~ 35.3, but sensitivity was not considered. Soil samples of KG-1, KG-2, KG-3, KG-4, and KG-5 were very sensitive. Therefore, it is expected that the ground has large deformation or the settlement possibility is high due to the ground disturbance during excavation. The results are shown in Table 2.

Table 2 Result of vane shear test in the construction site

Boring No.	Depth (m)	c_u (undisturbed, *kPa*)	c_{ur} (disturbed, *kPa*)	c_u (Design, *kPa*)	Sensitivity
KG-1	3.5	22.9	2.8	22.3	8.08
KG-2	4.0	23.3	2.8	23.9	8.23
KG-3	5.0	21.4	2.6	22.0	8.17
KG-4	5.0	28.4	3.5	35.3	8.13

4. ESTIMATION OF SOFT GROUND SOIL PROPERTY

Cohesion and internal friction angle were compared and examined by Dunham, Terzaghi-Peck, Meyerhof, Osaki, Schmertmann, and Hisatake using empirical formulas based on N values. The design constants were calculated as shown in Table 3 based on the laboratory test results of the drilled specimens.

Table 3 Soil property of shear strength for each layer in soft ground

Soil type	Unit weight, $r_t(kN/m^3)$	Cohesion, $c(kPa)$	Internal friction angle(°)
Reclaimed layer	19.0	10.0	20
Accumulation (clay, N≤4)	17.0	17.0	5
Accumulation (clay, 4<N≤10)	17.6	40.0	5
Accumulation (sand)	18.0	5.0	25
Weathered soil	19.0	20.0	30
Weathered rock	20.0	30.0	33
Soft rock	23.0	100.0	33

Table 4 shows that the pre-consolidation load was 70.6*kPa* to 85.1*kPa*, compression index was 0.325 to 0.522, swelling index was 0.06 to 0.124, consolidation coefficient was 1.96e-3cm^2/sec to 8.09e-3cm^2/sec, and initial void ratio values was 1.032 to 1.311. It was applied in the design of sewer pipeline construction.

Table 4 Soil property on design around waste water pipeline

Boring No.	Preconsoli-dation load, $P_c(kPa)$	Compress-ion index, c_c	Swelling index, c_s	Consolidation coefficient $c_v(cm^2/sec)$	Initial void ratio, e_o
BH-1	70.6	0.522	0.124	1.96E-03	1.311
BH-2	77.1	0.347	0.060	4.44E-03	1.032
BH-3	85.1	0.325	0.063	8.09E-03	1.195

In this study, consolidation data was revised using additional boring and existing boring data for the soft ground settlement sections. The average value showed little bit lager than that of design value. The revised soil property was shown in Table 5.

Table 5 Revised soil property around sewer line on this research

Division	Boring No.	Preconsoli-dation load, $P_c(kPa)$	Compre-ssion index, c_c	Swelling index, c_s	Consolida-tion coefficient, $c_v(cm^2/sec)$	Initial void ratio, e_o
No.8+0 ~ No. 50+18.0	KG-1	82.9	0.410	0.118	3.148E-03	1.42
No.50+18 ~ No. 125+4.0	BH-3	85.1	0.325	0.063	8.090E-03	1.19

After STA. No. 50+18.0, there is a pressure pipeline along the waste water pipeline in the adjacent area, and the overburden load is expected to increase due to the embankment construction in the future. Also it was found that the depth of soft ground layer was deeper than that of original design from STA. No. 69+ 4.0 to STA. No. 125 + 4.0.

5. COMPARISON WITH NUMERICAL ANALYSIS

5.1 Elasto-plastic modelling for temporary earth wall

Structural analysis was carried out a beam on elasto-plastic foundation model. It is similar to the beam on winkler foundation used to design piles with a foundation or horizontal load. The wall stability at the final stage was evaluated from the stepwise excavation analysis. It is assumed that the stress is redistributed due to the empirical earth pressure over time after the excavation is completed. The stability of the earth retaining walls and support materials to the earth pressure is evaluated.

Soft soil property was revised using the additional ground survey of 5 boring data, the subsurface exploration data of basic and detailed design of the sewer pipeline and the subsurface exploration data of the basic and detailed design of the natural river improvement project. As a result, the soft ground layer was deeper than the original design ground survey with a maximum of 12*m*, and the ground layer also changed. Based on the revised plan, three weakest section sites were selected. EXCAV and SUNEX were used to evaluate the stability of the pipeline by prefabricated wall.

5.2 Stability analysis for deep wall after ground improvement

Stability of construction depth of temporary wall was analyzed. When the construction depth of temporary wall is 4.0*m* at the maximum excavation depth of 5.5*m*, the safety factor of the construction depth is calculated to be 2.46 which satisfy 1.2 as a standard of safety factor. The results are shown in Table 6.

Table 6 Safety factor of section no.18+11.00

Section	Excavation depth(m)	Construction depth(m)	Safety factor	
			Result	Minimum Standard
No.18+11.00	5.5	4.0	2.46	1.2

Safety for ground settlement was calculated. The section no. 24+0.0 was 7.2*m* in the thickness of the soft ground, and no other channel was buried in the vicinity. The section no.84+4.0 is 8.6*m* in thickness of soft ground. An existing line appeared at a distance of 2.98*m* from the position where the sewer pipeline is constructed. The section no.100+0.0 point was 12*m* in thickness of the soft ground, and the soft ground thickness of the three sites was the largest. Figure 5 shows the result of settlement with elapsed time.

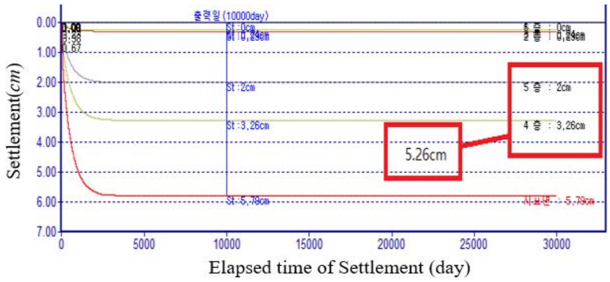


Figure 5 Ground settlement with elapsed time

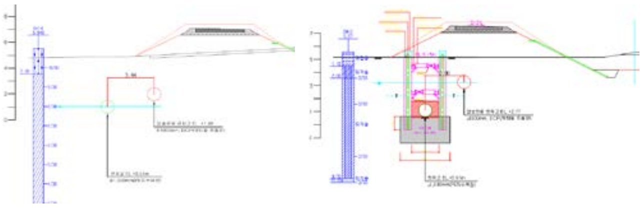
Before ground improvement, settlement of some area using K-Embank ver. 3 did not satisfy the criteria on the road settlement standard. Table 7 shows the basement settlement of pipeline and allowable settlement after ground improvement.

Table 7 Reviewed allowable settlement on weakest soft ground

Section	Diameter of pipe *(mm)*	Settlement of base *(mm)*	After ground improvement	
			Result*(mm)*	Criterion*(mm)*
No.84+4.0	1,000	146.1	65.3	100
No.100+0.0	1,000	109.7	48.5	100

6. DISCUSSION

As a result of the analysis of the soft ground, it is confirmed that it is highly sensitive soft clay. Therefore, it is suggested to improve the ground using the high strength DCM method(HDCM). Figure 6 shows cross section of No.100+0.0 as original design section and reinforced section for ground improvement.



(a) Original design section (b) Reinforced section

Figure 6 Cross section No. 100+0.0 with ground improvement

For the construction of sewer pipeline on the deep soft ground, combination method like SCW, SGP, and sheet pile with ground improvement were proposed. The lower part of the pipeline was stabilized by using HDCM. The SCW method is effective in passive earth pressure resistance, forming foundation that resists heaving, and in the reclamation area. The SGP method is capable of forming a foundation that is resistant to heaving, and is inexpensive when buried. The sheet pile has the advantage of being able to increase the effect of passive earth pressure resistance and to form the foundation to resist the heaving. We propose a method to prevent disturbance by using the semi-shield method in the section after No.100+0.0 where the soft ground depth is highly deep in the lower part of the basement. Table 8 shows the result of safety review of the construction depth safety of the representative section.

Table 8 Comparison of safety factor on temporary wall type after soil improvement

Division		Excav-ation depth (m)	Const-ruction depth (m)	Maximum settlement (mm)	Safety factor	
					Result	Decision
Original design		7.1	5.9	76.47	1.786	O.K
Reduce construction depth (SCW+ HDCM)	EXCAV	7.1	1.0	17.19	1.875	O.K
	SUNEX	7.1	1.0	31.34	2.13	O.K
Reduce construction depth (SGP+ HDCM)	EXCAV	7.1	1.0	18.88	2.188	O.K
	SUNEX	7.1	1.0	28.89	2.43	O.K
Reduce construction depth (Sheet Pile+ HDCM)	EXCAV	7.1	1.0	10.22	2.237	O.K
	SUNEX	7.1	1.0	21.45	2.43	O.K

7. CONCLUSION

This study carried out to find the causes of pipe deformation during the test construction in the overlapping section of the sewer pipeline and natural river construction. It was proposed the countermeasures for the application. In order to clarify the causes of pipe deformation and differential settlement, the present state of soft ground was reviewed by collecting the drill log data. In addition, the distribution and physical soil characteristics of the boring data were examined through laboratory and field experiment test based on the 5 boring data. The results of the causes and countermeasures of pipe damage are presented as follows,

1. In case of high sensitivity, it may cause the settlement due to ground disturbance at the extraction, which may damage the stability of the pipeline. Therefore, it is suggested that the improvement of the soft ground should be done as a way to minimize disturbance to the lower part of the basement.

2.Stability analysis was performed by applying SCW + HDCM and Sheet Pile+HDCM method to the No. 84+4.00 and No.100+0.0 sites as the representative sections most vulnerable to subsidence of pipeline.

3.As a result of 2*m* strengthening with HDCM method, the soft clay ground was improved and the strength increased and settlement amount decreased. The settling amount satisfies the allowable residual settlement amount, 100*mm*.

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