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The Effects of Sand Compaction by Watering through Field Compaction Test and Numerical Analysis

현장 및 수치해석을 통한 모래 물다짐지반의 다짐효과 연구

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ABSTRACT : This study examines a cause for damage of synthetic resins straight pipe occurred after pipe construction of underground electric power duct pipelines of ○ section work, ○ line, ○○ city railroad. For this, we analyzed a parameter used for plan and structural analysis through a literature review. And the site condition was analyzed in detail, and test construction of the pipe line that simulated the site pipe line and test on compaction by watering were performed. In addition, an examination on subsurface settlement influence of foundation ground through a structural safety and a numerical analysis of power transmission pipe line was performed. As a result of the performance, relative density gained by compaction by watering was more than average and relative degree of compaction according to technical specification standard showed the result of about 90% in the case of good compaction by watering.

Keywords : Field compaction test, Numerical analysis, Electric power duct, Water compaction

요 지 : 본 연구에서는 ○○도시철도 ○호선 ○공구의 지중 전력구관로 매설공사 후 발생한 합성수지 직관의 파손에 대한 원인을 고찰하기 위하여 문헌연구를 통하여 설계 및 구조해석에 사용된 매개변수를 분석하였다. 그리고 현장조건을 면밀히 분석하고 현장 관로를 모사한 관로의 시험시공 및 물다짐 시험을 수행하였다. 또한, 송전관로의 구조적 안정성과 수치해석을 통한 송전관로 기초지반 침하영향 검토를 수행하였다. 수행결과 물다짐에 의하여 얻을 수 있는 상대밀도는 보통 이상이었으며 시방기준에 의거한 상대다짐도는 양호한 물다짐을 수행할 경우 90%정도의 결과를 얻을 수 있었다.

주요어 : 현장다짐시험, 수치해석, 전력구관로, 물다짐

1. Introduction

In urban area, subway lines, electric power transmission lines and sewer lines etc. are sometimes simultaneously constructed to reduce the excavation works and construction time. Careful examination and prediction of possible problems that may occur at a parallel construction of the lines should be performed to reduce some accident risk during construction (Korean Society of Civil Engineers, 2006).

In this study, to examine causes for damage of electric power pipe lines made of synthetic resins, test pilot pipe lines to simulate the field conditions were constructed and the compaction by watering were performed. In situ soil density tests using sand cone and water were performed at the site and soil samples were taken to conduct sieve analysis, laboratory compaction test, and specific gravity test and so on. Numerical analyses which simulate the condition of the field power transmission liners were also performed to examine the amount of settlements of pipe lines as well as the foundation settlements.

2. Summary on a layer for research

The section for research performed in this study is a construction section of 1,103 m in length and to estimate ground ratings that is needed for a structural analysis. The ground investigation was performed in ranged through the total 10 places (BX: 8 places, NX: 2 places) and Table 1 shows the result of drilling survey.

A series of field tests and laboratory tests were performed as shown in Table 2 and the result is shown in Table 3.

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Table 1. Depth of layer by the borehole measurements (unit : m)

Name of layer / Bore hole	Groundfill soil		Paddies soil	Sand	Sand & gravel	Sand, gravel, & Boulder	Weathered soil	Weathered rock	Soft rock	Total
	Sediment	Sand & gravel								
BH - 1	3.0	-	3.0	1.0	-	-	11.0	5.0	-	23.0
BH - 2	-	1.0	3.0	-	-	-	14.0	0.5	-	18.5
BH - 3	-	3.0	-	-	2.5	-	8.5	8.0	-	22.0
BH - 4	-	-	-	1.0	2.0	1.0	8.0	11.0	-	23.0
BH - 5	-	2.5	-	-	-	5.0	9.5	5.0	-	22.0
BH - 6	2.0	-	-	-	-	4.0	9.0	8.0	-	23.0
BH - 7	-	-	-	-	5.0	-	9.0	10.0	-	24.0
BH - 8	-	-	-	-	-	-	16.0	28.0	-	45.0
BH - 9	-	-	-	-	3.5	1.0	-	2.0	-	6.5
BH - 10	-	-	-	-	4.0	2.5	-	2.0	-	8.5

Table 2. Test contents

Classification	Contents
Field test	Layer survey, standard penetration test, underground water level measurement, pressuremeter test, permeability test
Laboratory test	Soil : water content, specific gravity, liquid & plastic limit, grain size analysis Rock material : uniaxial·triaxial compressive strength, Poisson's ratio, tensile strength, shear strength, modulus of elasticity, elastic wave velocity, specific gravity, water absorption

Table 3. Result of a field and laboratory test

Layer	Coefficient of permeability (m/sec)	Unitweight (tf/m^3)	Uniaxial strength (tf/m^2)	Poisson's ratio	Tensile strength ($\times 10^4 tf/m^2$)	Angle of internal friction (°)	Cohesion (tf/m^2)
Sand	10^{-3}~10^{-6}	2.0	-	0.3	0.1	25	0.5
Weathered zone	10^{-3}~10^{-5}	2.50	1800	0.3	2	28	10
Sedimentary rock	10^{-3}~10^{-6}	2.60	3700	0.25	15	30	20
Normal rock	10^{-4}~10^{-7}	2.65	6600	0.25	20	35	25
Soft rock		2.69	14700	0.20	100	40	105

3. Field compaction test and laboratory test

In the field compaction tests, among electric power sections of pre-constructed layer on research, pipe line of underground transmission pipe line section was broken down and its cable was damaged. So, according to it, to make the cause clear, in the same condition as the field, by simulating a condition of damaged field pipe line of ○○○ dong, Yongin-si, Gyeonggi-do. After performing compaction by watering of refilling material according to the specification and disassembling the pipe line, relative density of refilling material was tested.

The purpose of this test is to estimate a relative density of the field layer where the watering was performed by simulating the same condition.

Compaction work by watering in May 8, 2006 and disassembling work in May 9 had been performed for two days. Compaction by watering of layer for research was revived itself and examination on effectiveness in compaction of watering of the field was performed through field density test using water and sand. And for sample gathered from the field, sieve analysis tests, compaction tests, and unit weight tests were performed.

3.1 Plan for field test and initial disassembling work

Being simulated as the same field condition with the layer for research (Fig. 1), a field compaction work by watering was performed on May 8, 2006 (Korea Highway Corporation, 2002), and disassembling work was performed on May 9. A work disassembling pipelines constructed at the field was performed step by step after the top surface soil was removed (Korea Electric Power Corporation, 1996), and for the condition of a sand compaction by watering on the immediate lower part of pipelines, it was proved in a good construction through pre-installed transparent acrylic plate (Fig. 2) and confirmation of it by sight (Fig. 3).

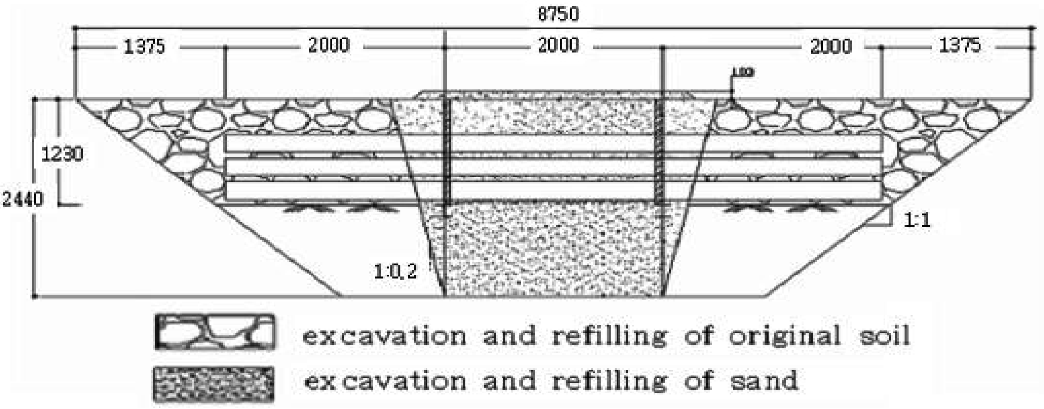


Fig. 1. Drawing of site test plan

Fig. 2. Acrylic plate placed to confirm compaction by watering

Fig. 3. Status of sand compaction condition by watering at lower part of bottom pipe line

3.2 Field density test

Field density tests by using sand was performed at a surface part and a lower part of a straight line. From the test results, unit weight on ground part was 1.75 t/m^3 (water content 11.3%), and a straight line, it showed as 1.655 t/m^3 (water content 11.2%) on an immediate lower part of pipes. When they are calculated by unit weight of dry, they correspond to 1.57 t/m^3 and 1.48 t/m^3, respectively. And when a test for field density using water was performed for an immediate lower part of pipes, the wet unit weight indicates 1.59 t/m^3 (water content 9.23%), and when calculating it by dry unit weight, it corresponds to 1.46 t/m^3 (refer to Table 4).

3.3 Laboratory soil test

Through sieve analysis tests for the sand used as refilling materials in the field, grain size analysis has been performed, and by measuring maximum and minimum void ratio, relative density and relative degree of compaction were calculated on the condition of field refilling.

3.3.1 Sieve analysis

From the results of sieve analysis tests on sample soil gathered from the field, the grain-size accumulation curve is shown in Fig. 4. Coefficient of uniformity (C_u) was 3.33 and coefficient of curvature (C_c) was 1.13. Soil classification by unified soil classification system showed its soil classification as SW (sand and gravel sand having good grain size distribution).

3.3.2 Water content and specific gravity test

To measure natural water content of a sample soil gathered from the field, water content test was performed, and to measure specific gravity value of the sample that was a data needed for calculating e_{max} and e_{min}, specific gravity test was performed. The result showed that average water content was 12.4% and specific gravity was 2.625 (Table 5).

3.3.3 Compaction test

To calculate γ_{dmax} and e_{min} of a dried sample, D compaction was performed by using compaction mold that are a diameter of 15 cm and a height of 17 cm. From the result, γ_{dmax} is 1.83 t/m^3 in Fig. 5.

Table 4. Field density test result by using sand and water

Test result \ Method of test	Field density test using sand cone		Field density test using water at immediate lower part of pipes
	Surface	Immediate lower part of pipes	
Total unit weight (water content)	1.75 tf/m^3 (11.3%)	1.655 tf/m^3 (11.2%)	1.59 tf/m^3 (9.23%)
Calculating it as dry unit weight	1.57 tf/m^3	1.48 tf/m^3	1.46 tf/m^3

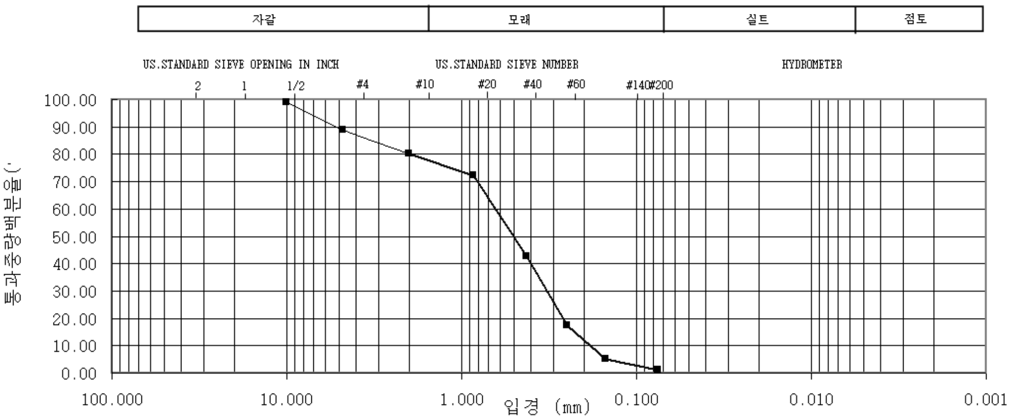


Fig. 4. Soil particle size distribution

Table 5. Result on water content and specific gravity

Classification	Water content (%)	Specific gravity (Temperature adjusted)
Sample 1	12.4	2.624
Sample 2	12.5	2.579
Sample 3	12.2	2.673
Average	12.4	2.628

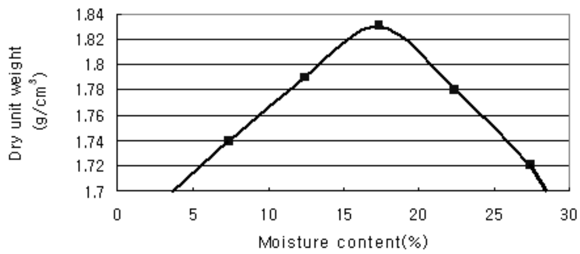


Fig. 5. The result of compaction test

3.3.4 Measuring result of $\gamma_{d\min}$ and $e_{\max}$

$\gamma_{d\min}$ and $e_{\max}$ were estimated by having dried sample fallen free on molds from a height of 2 cm. From the result, $\gamma_{d\min}$ is 1.31 and $e_{\max}$ is 1.004.

3.3.5 Estimation of field relative density (D_r) and relative compaction degree (R_c)

From test results for field density that has been performed at the field and laboratory test result, a relative compaction degree was calculated by formula (1), (2), and (3) (Kim, 2002). The calculation result is shown in Table 6.

$$D_r = \frac{\gamma_{d\max}}{\gamma_d} \times \frac{\gamma_d - \gamma_{d\min}}{\gamma_{d\max} - \gamma_{d\min}} \tag{1}$$

$$R_c = \frac{\gamma_d}{\gamma_{d\max}} \tag{2}$$

$$R_c = 80 + 0.2 D_r \tag{3}$$

4. Analysis on settlement of electric power pipes

Causes on breakdown of pipelines buried under construction on the field of ○ section work, ○ line, ○○ city railroad has been analyzed from the aspect of ground settlement. The finite-element analysis programs PENTAGON 3D was used on ground settlement interpretation.

4.1 Construction condition and land condition application

Before finite-element analysis, in modeling step, construction condition reflected field condition like Fig. 6 and it was performed for a case that C-type angles of one pair was installed with a distance of 2 m (Gwak, 2004) and ground condition was classified by relative density of dense, medium, and loosen according to compaction degree to consider compaction condition of sand.

Also, refilling material on 1.0 m section on lower straight pipe was performed by field soil and waste instead of sand on construction. Therefore, refilling condition by using wastes

Table 6. Summary of the relative density and the relative degree of compaction

Field Density Method		Relative density (%)	Relative degree of compaction (%)	
			From compaction curve relation formula (2)	From empirical formula (3)
Sand cone	Surface soil	90.1	96.2	98.0
	Lower straight pipe	72.3	90.1	94.4
Water	Lower straight pipe	52.3	89.6	90.5

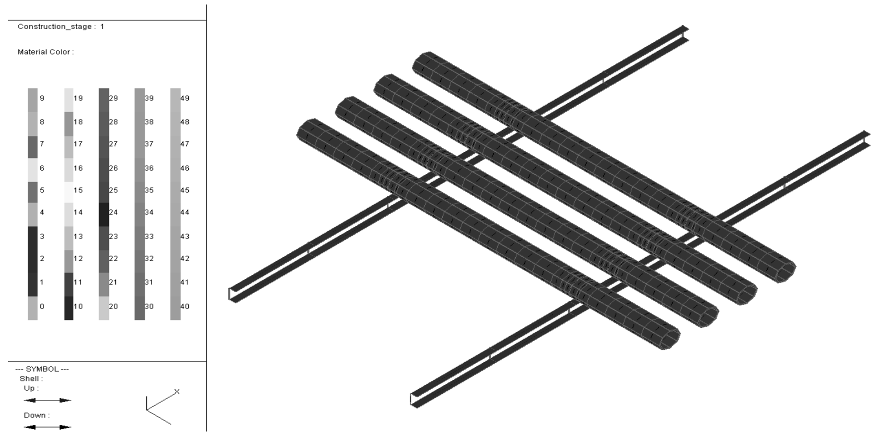


Fig. 6. Layout of pipes with the pair angles installed at a distance of 2m

was included to ground condition for this analysis.

4.2 Analysis conditions

4.2.1 Material parameters used

Table 7 and 8 show the material parameters assumed in the analysis.

4.2.2 Load conditions

Table 9 shows the applied loads (Pipe load, Cable load in the pipe, Backfill sand load and Vehicular laod).

4.2.3 Analysis result

After installing C-type angles of one pair with a distance of 2 m, calculation result on an amount of ground settlement of lower straight pipe according to weight operation is shown in Table 10 and Fig. 7.

As the result of settlement analysis, in the case of refilling lower straight pipe by using sand, according compaction condition, amount of settlement showed a little difference, but it was analyzed that it had margin more than about 30% until a basis amount of settlement to occur damage to

Table 7. Soil parameters used

Kind of soil	Modulus of elasticity (tf/m^2)	Poisson’s ratio	Unit weight (tf/m^3)	Angle of internal friction (°)	Cohesion (tf/m^2)
Dense sand	4,500	0.375	1.85	37.5	0.0
Medium sand	2,250	0.325	1.75	32.5	0.0

Table 8. Pipe and supported beam parameters used

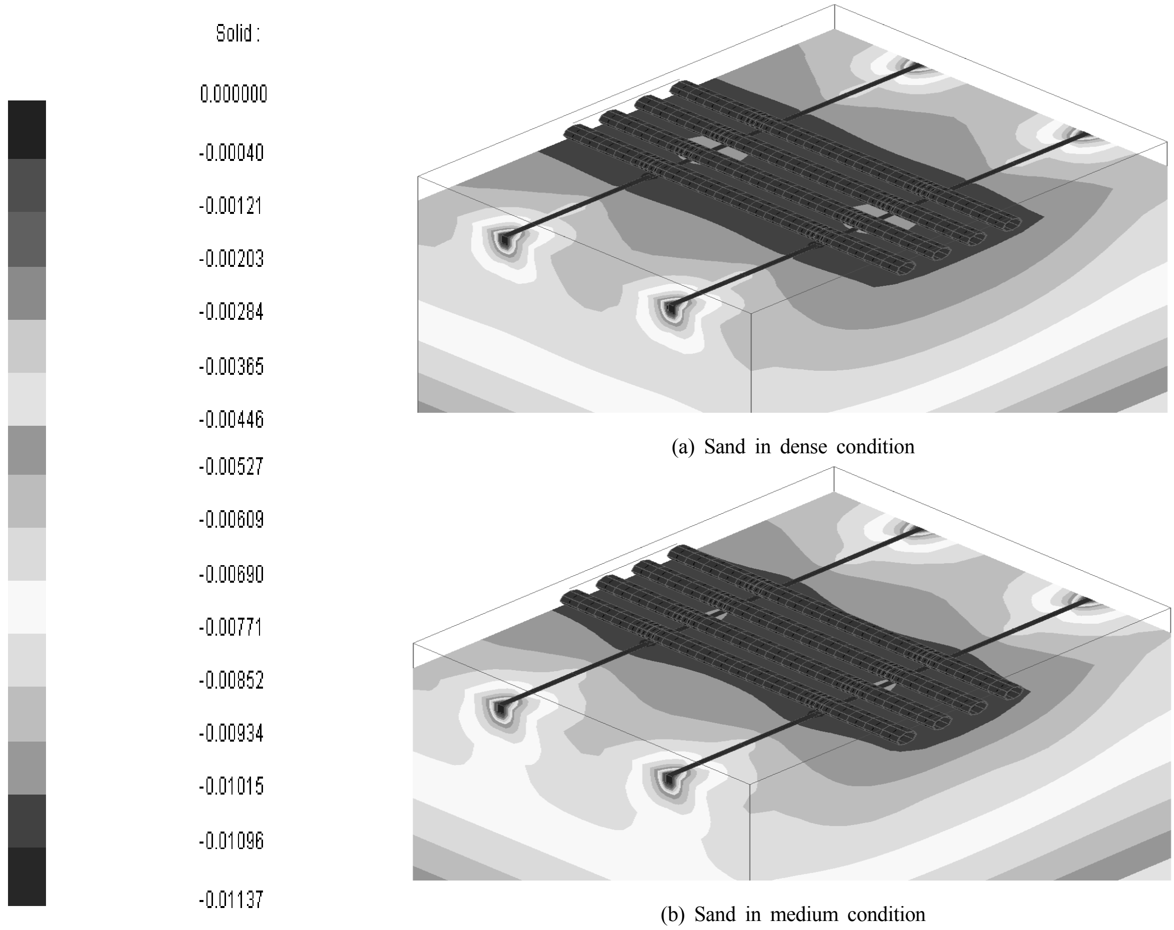
Kind of material	Modulus of elasticity (tf/m^2)	Poisson’s ratio	Unit weight (tf/m^3)	Note
Pipe	3.45 × 105	0.417	1.53	-
H-Beam	2.0 × 107	0.3	7.85	H-250 × 255 × 14 × 14
C-Beam	2.0 × 107	0.3	7.85	C-150 × 75 × 6.5 × 10

Table 9. Applied load used

Applied	Magnitude (kgf/cm^2)
Pipe load	146.7
Cable load in the pipe	445.3
Backfill sand load	3,587.9
Vehicular laod	1,532.0

Table 10. Settlement calculated in various materials and conditions

Fill material and condition		At the part of angle support (mm)	Central part of pipe lines (mm)	Expected ratio of settlement versus limited amount of settlement (15.7 mm) (%)
Sand	Dense	9.56	9.56	67
	Medium	10.18	11.24	72
	Loose	10.40	11.26	72



(a) Sand in dense condition

(b) Sand in medium condition

Fig. 7. Settlement contours around the electric power lines with angle support

straight pipe. From geotechnical engineering characteristics of refilling material, we can guess that it is because sand has small compressibility.

5. Conclusion

To examine a cause for damages of synthetic resins straight pipe occurred after a burring construction of designated pipe line that was performed in parallel with ○ section work, ○ line, ○○ subway, parameter used from plan and structure analysis through a literature review analysis of field condition in field construction, pipe line test construction to simulate field pipelines, and compaction by watering tests were performed and analyzed. From the analysis following conclusions can be drawn.

(1) As the result of ground survey, the ground for research consists of soil, sand, weathered soil, and weathered rock. Angle of internal friction (∅) and cohesion (c) showed 25° and 5 tf/m^2 for soil and 28° and 10 kgf/cm^2 for zone, respectively.

(2) To find out a clear cause of cable demage, in the same condition as the field, by simulating damaged field at Pungdeokcheon-dong, Yongin, Gyounggi-do, after performing compaction by watering about refilling material in a condition suitable for a specification, relative density of filling material was tested. As the result, relative density of sand layer of compaction using water showed 90.1% for ground and 72.3% for an immediate lower part of pipelines respectively. Relative degree of compaction

showed 96.2% for ground and 89.6%-90.1% for an immediate lower part of pipelines.

(3) As the result of settlement analysis, in the case of refilling lower straight pipe by using sand, according compaction condition, amount of settlement showed a little difference, but it was analyzed that it had margin more than about 30% until a basis amount of settlement to occur damage to straight pipe. From geotechnical engineering characteristics of refilling material.

(4) From the result to examine influence of ground settlement, in the case of refilling by using sand and through relative density more than average, it seems to have insignificant influence on the damage of the pipe line. On the basis of it, when cause of straight pipe damage of ground for this study is examined in an aspect of geographical engineering, in refilling lower straight pipe, performance of compaction does not to agree with a specification.

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