A Case Study of Settlement Behavior of Dynamic Compacted High Rock Embankment with Construction Path

Kyung-Tae Bae[1], Tae-Hoon Kim[2] and Young-Jin Kim[3]
[1] *Associate Researcher, Ph.D., Institute of Construction Technology, DAEWOO Engineering & Construction Co. Ltd.*
[2] *Researcher, Ph.D., Institute of Construction Technology, DAEWOO Engineering & Construction Co. Ltd.*
[3] *Research Fellow, Ph.D., P.E., Institute of Construction Technology, DAEWOO Engineering & Construction Co. Ltd.*
E-mail: baekt@dwconst.co.kr

ABSTRACT: A high rock embankment by means of dynamic compaction has hardly carried out in Korea. For the successful accomplishment of such a high rock embankment, construction quality and measurement control are conducted. Plate loading tests are carried out to verify the bearing capacity and safety against the long term settlement. In addition, settlement of each layer is measured in order to verify the effect of dynamic compaction and to predict long term settlement. A high rock embankment is generally constructed by dividing into several sub-embankments. Unlike any soil embankment, a rock embankment is constructed by means of dynamic compaction. Such a sub-embankment and dynamic compaction may induce an increase of pressure at the lower part of embankment and cause a different behavior of ground from initial status. In this study, settlement of a high rock embankment is estimated using a hyperbolic model taking into construction history. The results from prediction are compared with those obtained from field measurements and plate loading tests

1. INTRODUCTION

The foundation of transformer substation (Fig. 1) in Korea was supposed to be constructed on a high embankment of 63m with rocks and reinforced by a bored piling method. However, such a foundation system has serious limitations in the effectiveness of construction and cost, since the embankment was going to be accomplished by means of roller compaction. On account of a long term displacement, such as creep, the first design of the foundation system has been changed by dynamic compaction with 9EA sub-embankments (7m thickness) and piled raft (Figs. 2 and 3).

Figure 1. Air view of transformer substation

Figure 2. Scene of dynamic compaction

In this study, a series of in-situ experiments and measurements were conducted in order to verify the stiffness of the embankment and to evaluate the quality of the dynamic compaction and long term displacement. Plate load tests were carried out for verification of stiffness that affects the bearing capacity and creep of the embankment. Settlement measurement was also performed during entire period of construction to estimate the long term displacement. In the mean time, a numerical analysis taking into account construction history was carried out in order to take into account the change of the ground deformation characteristics during construction. as well. The results predicted from the numerical analysis were then compared with those obtained from measurements.

Figure 3. Construction sequence of sub-embankment

2. MEASUREMENT

A potentiometer type of settlement logs were used in this study as shown in Fig. 4. Once one step of embankment is completed, a reference point, as seen in the Fig. 5, is mounted on bed layer by boring up to the original ground and a settlement log is installed on the top of the layer. This procedure is repeated at every step of embankment. Table 1 shows the matrix of measurement.

Figure 4. Settlement logs

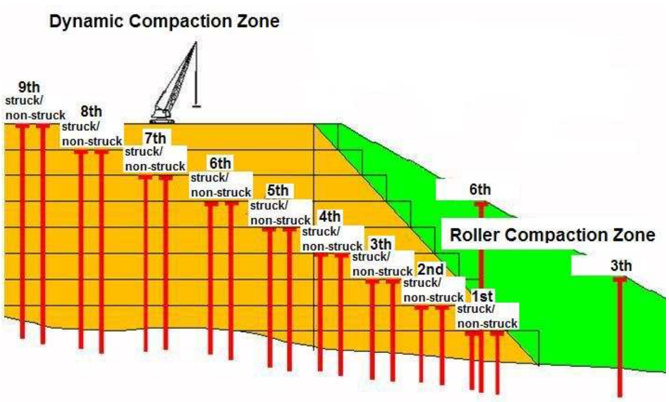

Figure 5. Cross section of the settlement logs installation

Table 1. Matrix of measurement by settlement logs

Construction Zone	Install position of settlement logs	Install quantity of settlement logs
Dynamic compaction	1st □ 9th upper layer	2EA per each layer (struck zone and non struck zone)
Roller compaction	3rd, 6th upper layer	1EA per each layer

3. SETTLEMENT PREDICTION

It is precisely estimated that the initial ground deformation characteristics are going to be changed as the embankment proceeds because of an increase of effective confining pressure (Fig. 6). In order to figure out the behaviors of the original ground and body of sub-embankment in each step, a numerical analysis taking into account construction history is performed. In this study, a commercial software, so called FLAC-2D, was used. In the analysis, the ground was modeled as a unit element of 10m width and 7m height. Figure 7 shows the initial configuration and mesh generated for embankment.

3.1 Analysis

A hyperbolic model proposed by Duncan and Chang (1970) is adopted for the analysis. The concept of the model is represented in Figs. 8(a) and (b). In this model, an elastic modulus varies depending on the confining pressure as shown in Fig. 8(c). Adopted were the parameters used for analysis that KOWACO (2008) had obtained and used for the analysis of behavior of a dam (Fig. 9) from large triaxial compression tests. The parameters used in this analysis are presented in Table 2.

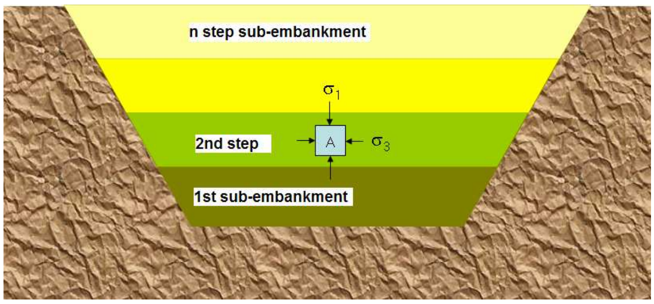

Figure 6. Step construction concept

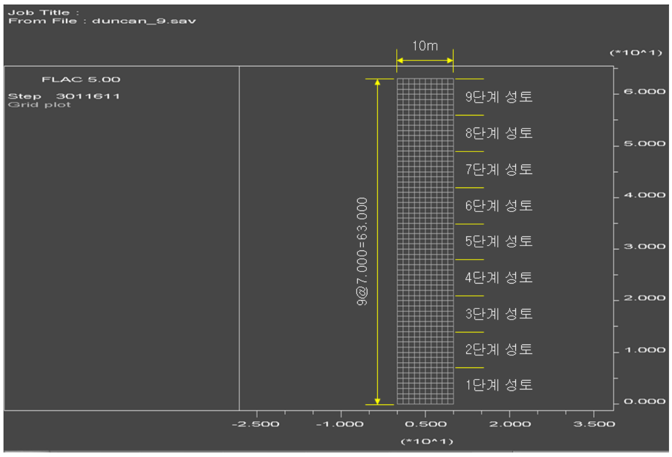

Figure 7. Initial configuration and mesh generated for embankment

Table 2. Duncan and Chang (1970) hyperbolic model parameters used in this analysis

Section	***K***	***n***	R_f	K_b	***m***
Zone-2	1,037.6	0.37	0.75	3,065.0	-0.37

Table 3 Predicted elastic modulus from numerical analysis with construction history (Zone-2, unit : t/m2)

Layer	Construction sequence of sub-embankment									mean elastic modulus	ratio
	after 1st	after 2nd	after 3rd	after 4th	after 5th	after 6th	after 7th	after 8th	after 9th		
upper ↑	4,820	4,810	4,810	4,820	4,810	4,820	4,820	4,820	4,810	4,820	1.0
		11,130	11,130	11,120	11,130	11,120	11,120	11,130	11,130	11,130	2.3
			13,210	13,210	13,210	13,210	13,210	13,210	13,210	13,210	2.7
				14,390	14,380	14,380	14,380	14,380	14,380	14,380	3.0
					15,150	15,140	15,140	15,140	15,140	15,140	3.1
						15,670	15,670	15,660	15,670	15,670	3.3
							16,050	16,050	16,050	16,050	3.3
								16,320	16,320	16,320	3.4
↓ bottom									16,530	16,530	3.4

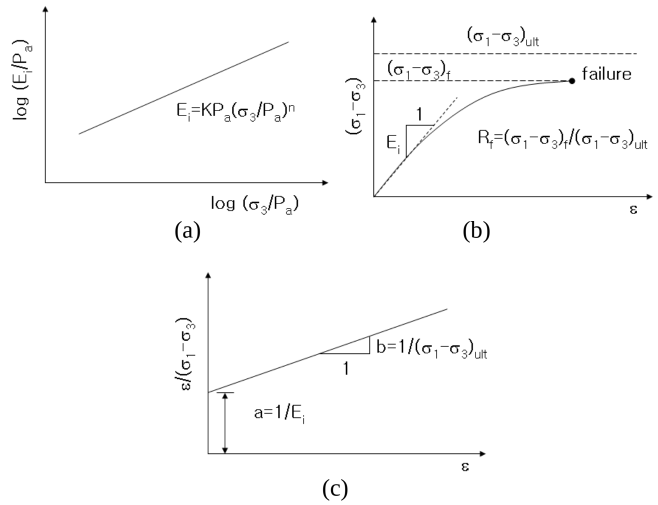

Figure 8. Duncan and Chang (1970) hyperbolic model concept

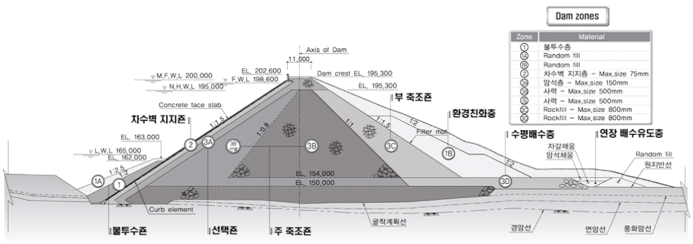

Figure 9. Cross section of the dam used in this analysis

3.2. Results

As a results of the numerical analysis, it appears that the initial elastic modulus increases by from 2.3 times up to 3.4 times when the construction proceeds more than 2 stages (Table 3), and therefore the maximum settlement after the completion of entire embankment is 86.1mm at the center (Table 4). In order to compare the settlements obtained from measurement at every each step, the settlements predicted by the numerical analysis were summarized in Table 5. Looking at the table, the maximum settlement appears to measure by 72.2mm at the log installed on the top of the 5th layer after 9th embankment completed.

Table 4. Predicted settlement from numerical analysis with construction history (Zone-2, unit : mm)

Layer	Construction sequence of sub-embankment								
	after 1st	**after 2nd**	**after 3rd**	**after 4th**	**after 5th**	**after 6th**	**after 7th**	**after 8th**	**after 9th**
upper ↑	1.4	3.4	6.6	10.9	13.9	17.8	21.8	25.9	30.1
		3.1	8.3	15.0	22.3	29.9	37.9	46.0	54.2
			5.9	14.6	25.0	36.2	47.9	59.9	72.2
				8.9	21.4	35.7	50.9	66.7	82.9
					12.2	28.5	46.9	66.2	86.1
						15.5	35.9	58.3	81.8
							19.0	43.4	70.1
								22.5	51.1
↓ bottom									26.1

Table 5. Predicted settlement from numerical analysis with construction history (unit : mm)

Adopt Position of Numerical Analysis	Construction sequence of sub-embankment							
	after 2nd	**after 3rd**	**after 4th**	**after 5th**	**after 6th**	**after 7th**	**after 8th**	**after 9th**
1st upper layer	1.7	4.5	7.5	10.8	14.1	17.6	21.1	24.7
2nd upper layer	-	4.9	11.2	18.0	25.1	32.5	40.0	47.7
3rd upper layer	-	-	8.4	18.4	29.1	40.3	51.7	63.5
4th upper layer	-	-	-	11.4	25.3	40.0	55.3	70.9
5th upper layer	-	-	-	-	16.0	34.0	52.8	72.2
6th upper layer	-	-	-	-	-	20.1	42.1	65.1
7th upper layer	-	-	-	-	-	-	24.2	50.4
8th upper layer	-	-	-	-	-	-	-	28.3

4. COMPARISON OF SETTLEMENTS ACCORDING TO STEP CONSTRUCTION

4.1. Introduction

The measured settlements from the logs and plate load tests installed on the top of each layer were compared with the predicted settlements from the numerical analysis. In this comparison, the settlements by the logs and the plate load tests were shown in Table. 6 and Table. 7.

Table 6 Measured settlements from settlement logs with construction history (unit : mm)

Install Positions of Settlement Logs	Construction sequence of sub-embankment							
	after 2nd	**after 3rd**	**after 4th**	**after 5th**	**after 6th**	**after 7th**	**after 8th**	**after 9th**
1st upper layer	0.37	0.06	0.20	0.13	0.13	0.02	under construction	
2nd upper layer	-	1.68	2.18	3.56	4.46	10.1		
3rd upper layer	-	-	0.28	0.61	1.30	1.89		
4th upper layer	-	-	-	3.48	4.18	7.38		
5th upper layer	-	-	-	-	0.59	4.54		
6th upper layer	-	-	-	-	-	1.99		
7th upper layer	-	-	-	-	-	-		
8th upper layer	-	-	-	-	-	-		

Table 7 Settlements derived from the plate load test with construction history (unit : mm)

Test Positions of Plate Load Test	Construction sequence of sub-embankment							
	after 2nd	**after 3rd**	**after 4th**	**after 5th**	**after 6th**	**after 7th**	**after 8th**	**after 9th**
1st upper layer	1.03	2.06	3.09	4.12	5.15	6.18	under construction	
2nd upper layer	-	1.36	2.73	4.09	5.45	6.81		
3rd upper layer	-	-	0.87	1.75	2.62	3.50		
4th upper layer	-	-	-	0.78	1.55	2.33		
5th upper layer	-	-	-	-	0.69	1.38		
6th upper layer	-	-	-	-	-	0.91		
7th upper layer	-	-	-	-	-	-		
8th upper layer	-	-	-	-	-	-		

4.2. Discussion

So far, the 7th step out of 9 steps total has been complete. Also, a settlement log has been installed and a couple of plate load tests has been carried out. After that, the measured settlements according to step embankment at the time of the completion of the 7th step of embankment and the load-displacement relationship of the plate load test were compared with those predicted from the numerical analysis. Overall, the settlements from prediction seem to be overestimated comparing to others. Both the measured settlements by logs and the settlements derived from the load-displacement relationship of the plate load test appear to be similar. On the basis of this comparison, it may be said that the construction has been well controlled. The difference between prediction and measurement might be because of the parameters that used in this study. That is, the parameters that used in the hyperbolic model proposed by Duncan and Chang (1970) are not the very values representing the material in the field but the values of similar material, which used for the analysis of a dam behavior and obtained from large triaxial compression tests. In addition, nonuniform compaction energy between struck zone and non struck zone might induce a different settlement as well.

5. CONCLUSION

(1) On the basis of the results of the settlement analysis measured by logs, in which the settlements at the struck zone are relatively smaller than those at the non struck zone, the dynamic compaction is effective enough for improvement. In addition, the rate of settlement increment, according to the result of monthly variation of settlement, appears to decrease. In other words, the effects of compaction and increase of surcharge on the settlement appear to mitigate as the embankment goes up. In contrast, an intensive rainfall seems to affect much on the ground compression.

(2) It appears that the predicted initial elastic modulus increases by from 2.3 times up to 3.4 times when the construction proceeds more than 2 stages, and therefore the maximum settlement after the completion of entire embankment is 86.1mm at the center. In order to compare the settlements obtained from measurement at every each step, the settlements predicted by the numerical analysis were analyzed. As a result, the maximum settlement appears to measure by 72.2mm at the log installed on the top of the 5th layer after 9th embankment completed.

(3) Both the measured settlements by logs and the settlement derived from the load-displacement relationship of the plate load test appear to be similar. However, the settlements seem to be a little underestimated comparing to that from prediction. On the basis of this comparison, it may be said that the construction has been well controlled.

(4) The difference between prediction and measurement might be because of the parameters that used in this study. That is, the parameters that used in the hyperbolic model proposed by Duncan and Change(1970) are not the very values representing the material in the field but the values of similar material, which used for the analysis of a dam behavior and obtained from large triaxial compression tests. In addition, nonuniform compaction energy between struck zone and non struck zone might induce a different settlement as well.

6. REFERENCES

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