FUNDAMENTAL EXPERIMENTS ON EARTHWORK IN WINTER

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Abstract

Hokkaido, which is the northernmost of the Japanese islands, receives heavy snow and cold temperatures in winter. Average February temperatures in the major cities of Hokkaido range from –3℃ to –8℃, which means moderately cold weather. Earthwork in winter is avoided due to such weather in Hokkaido. As motorways in Hokkaido extend to every part of the island, earthwork in winter has been attempted to complete construction within a given period of time. Quality of such embankments, however, is usually not satisfactory, and seems to be caused by poor compaction due to frozen soil mixing and increased water content due to snow mixing.

In order to improve the quality of embankments constructed in winter, test construction was conducted in a test field near Sapporo. Three kinds of soil were used in this test; volcanic ash, clayey sand and sandy clay. Three types of embankments were constructed for each soil; one was constructed in autumn and the other two were constructed in winter. The size of the embankment was 4×4 m in crown area and 3 m in height. One type of construction in winter allowed frozen soil to mix into embankment, while the other type avoided it.

Compaction degree of winter embankment was smaller than that of autumn. This appeared to be caused by insufficient compaction due to the occurrence of frozen soil. Among the cases of earthwork in winter, however, compaction without frozen soil performed better than that with frozen soil. This suggests that good compaction can be expected from earthwork in winter, in which frozen soil is excluded as much as possible.

The embankments with frozen soil constructed in winter increased in density the following summer and were deformed. Embankment of coarse-content soil, however, did not indicate this so much.

The results of this test construction were summarized as follows:

1) Exclusion of frozen soil from embankment material prevented the decrease of compaction, and deformation of embankment was rather limited.

2) Coarse-content soil is relatively suitable for earthwork in winter.

3) Soil in embankments constructed with frozen soil remains frozen inside for an extended period. Embankment deformation continues as this frozen soil gradually thaws.

1. Introduction

Hokkaido, the northernmost island of the Japanese Archipelago, has heavy snowfall and low temperatures in winter. With average February temperatures in major cities in Hokkaido ranging from –3 to – 8℃, however, it has moderately cold weather. In cold areas like this, wintertime earthworks have been avoided thus far because embankments constructed in winter had qualitative problems, such as the occurrence of settlement in spring.

In cold areas in Japan, however, large-scale construction works requiring long construction periods have recently tended to increase in number following the construction of expressways. Accordingly, attempts at wintertime earthworks have come to be made. Furthermore, as it is economically advantageous to execute sluiceway and sluice pipe works for river embankments in the low-water season, i.e., in winter, it is desirable to construct accompanying embankments also in winter. Nevertheless, there are many cases in which embankments do not have satisfactory quality under such meteorological conditions as those of Hokkaido in winter. This is supposedly caused by increased moisture content due to snow mixture, which occurs because of insufficient compaction caused by frozen soil mixture into filling materials.

Aiming to ensure wintertime earthworks of satisfactory quality, a committee was once established in Japan for research purposes[1]. It is difficult to assert that the research results have been fully utilized thus far. One of the reasons is lack of established execution control and quality control methods for wintertime earthworks.

The author and his research group are investigating methods that excel in workability and economical efficiency in order to improve the quality of embankment for wintertime earthworks. In this context, research on basic characteristics of frozen soil was conducted in the past.[2] [3] The research has helped obtain the following results among others:

1) For embankments in cold conditions, the lower the moisture content of soil is, the higher the compaction density becomes.
2) Even if frozen soil is mixed, compaction strength after thawing is not different from that of the soil compacted at normal temperatures as long as the same density as that of normal temperature compaction is obtained.

Taking the aforementioned results into account, full-scale embankment tests were performed in the suburbs of Sapporo. This report sheds light on observation results of the first season.

2. Experiment details

2.1 Summary of field yard

The test site, which is located in Tomakomai, south of Sapporo, has a total area of approximately 2.5 hectares. According to meteorological conditions of this area in winter from 2000 to 2001, the maximum snow depth was relatively small in Hokkaido at 30 cm or less, but it registered the lowest temperature of -20℃ or below. These meteorological conditions are suitable for experimental earthworks in winter.

Figures 1 and 2 indicate the layout plan and detailed drawing of this experimental embankment, respectively, whereas Photo 1 describes post-embankment conditions. The embankment's crown width measured 4 m to allow working with heavy machinery by assuming an actual site, and the embankment height was set at 3 m, taking into account the freezing depth that penetrates from the surface. Due to quantitative constraints of materials, however, one type of soil was filled up to a height of 2 m. Each embankment had thermocouples arranged like grids to indicate soil temperature distribution two-dimensionally. These data are controlled by computers in the observation room and can be retrieved from the research laboratory in Sapporo via telephone lines. Likewise, meteorological data, such as outside air temperature, rainfall and snowfall, are also automatically retrieved real-time.

2.2 Experiment objectives

Pursuing the potential of earthworks in winter, this research focused on the following two matters:

- Method of ensuring embankment quality even when frozen soil is used as a filling material
- Optimal method of preventing soil to be used as a filling material from freezing

This experiment confirmed the following matters by conducting ordinary summertime embankment and wintertime embankment in order to obtain basic data for experiments scheduled in the future:

1) Difference in embankment quality due to different construction periods

Using the same filling materials, this experiment aimed to verify the impact of a difference in construction period on embankment quality. Embankment was conducted in November, when filling materials are not frozen, and in February in mid-winter. In addition, two cases were studied in February: mixture of frozen soil was allowed in one case and such mixture was avoided as much as possible in the other case. Confirmed through this experiment were differences in degree of embankment density and shape between wintertime and summertime earthworks. As the study of differences caused by the presence or absence of frozen soil mixture enables consideration of the extent to which wintertime earthworks can improve the embankment quality as compared with that of summertime earthworks, wintertime earthworks play an important role in exploring their own potential.

2) Difference in embankment quality due to different soil types

The intent of this experiment was to verify the impact of different filling materials on embankment quality in wintertime earthworks. Soil types with which satisfactory quality can be easily achieved in wintertime earthworks were confirmed by conducting embankment using three types of filling materials under the same conditions. This experiment is instrumental when two or more types of filling materials are optional in actual embankment sites.

2.3 Embankment method

Although embankment works were carried out according to actual field works, the following method was adopted for the mixture ratio of frozen soil:

1) The mixture ratio of unfrozen soil to frozen soil was 1 to 3, and was measured using a backhoe bucket. With regard to the mixing method, frozen soil that existed in the surface layer in the temporary material storage was broken and then mixed when loaded into dump trucks.
2) In order to find the actual frozen soil mixture ratio, approximately 1 m^3 of filling was collected both before and after placing, and sieve analyses were performed on frozen soil of 19 mm or more in grain size to ascertain grain size distribution.

After completion, the embankments were regularly measured until late September, when they were broken down. Also at the time of demolition, density measurement was performed to compare differences during construction and after demolition.

2.4 Experiment and measurement contents

Table 1 and Fig. 3 indicate the physical test results of soil used for embankment and grain size accumulation curves. Although natural moisture content of Sample No. 1 is significantly higher than that of other materials, it is a favorable filling material due to its low ratio of fine grain content. Sample Nos. 2 and 3 have higher ratios of fine grain content, but they are within the range normally used for river embankment, which attaches importance to impermeability. As for the grain size accumulation curves, the three samples show different grain size distributions, meaning that they are suitable for studying wintertime embankment trends by soil type.

Field measurements are divided into three categories: measurements during construction, regular post-construction measurements and measurements at the time of embankment demolition. Details of these measurements are described in Table 2. For density measurement, the sand replacement method and the easily measurable RI measurement were employed concurrently[4].

3. Experiment results and consideration

3.1 Comparison by compaction degrees

Generally, embankment quality is controlled by compaction degrees of soil. For example, roads require minimum compaction degrees of 85% and 90% for filled up ground and subgrade embankment, respectively. Table 3 indicates mean values obtained from measurements of compaction degrees by the sand replacement method. With regard to the density measurement by ＲＩ, as significant errors occurred during mid-winter measurement, it was removed from the study of compaction degrees.

Comparison of differences caused by different construction periods indicates that compaction degrees in wintertime earthworks are lower than in summertime earthworks. This is because frozen clods easily occur in wintertime earthworks, making sufficient compaction difficult. Nevertheless, even in the same wintertime earthworks, comparison of the presence or absence of frozen soil mixture indicated higher compaction degrees with embankment where no frozen soil was mixed. This suggests that density can be expected to increase by minimizing frozen soil in wintertime earthworks. Sample No. 1 indicates low compaction degrees despite being summertime earthworks. This may be due to the reduced accuracy of measured values, caused by the characteristic unique to volcanic ash that peaks of compaction curves are not apparent as described in Fig. 4. In Embankment No. 4, the compaction degree during demolition was the smallest among all embankments, but compaction degrees are expected to increase as frozen soil in the embankment thaws.

Compaction degrees of all embankments had increased at the time of demolition compared with at the time of construction. Changes in compaction degree during construction and demolition were described in percentage (Fig. 5). This figure indicates that these values in the embankment mixed with frozen soil are larger because voids created by frozen clods during construction gradually collapsed as thawing occurred.

In terms of differences by soil types, Fig. 5 indicates increasing tendencies in the order of Sample Nos. 1, 2 and 3. This order also corresponds with the mixing ratio of fine grain content. Generally, soil types with high fine-grain content are prone to retain large quantities of pore water that freezes soil. Accordingly, as frozen clods grew in size, the number of voids inside embankment increased. In this way, it is thought that the higher fine grain content the soil has, the wider the difference in density becomes after thawing. Based on the aforementioned facts, it was confirmed that soil types with low fine-grain content are advantageous for wintertime earthworks.

3.2 Comparison by soil temperature distribution

Figure 6 is a soil temperature distribution map of each embankment as of the end of August. Although there are no summertime earthworks (Embankment Nos. 1-3) with temperatures of 2℃ or below, the presence of frozen soil was confirmed in Embankment Nos. 4, 5 and 7 among those constructed in winter (Embankment Nos. 4-9). Embankment No. 4 has particularly large amounts of frozen soil remaining in soil. Photo 2 shows the situation when Embankment No. 4 was demolished on September 25. This photo also confirms the presence of frozen soil, indicating the conformity with the range of Fig. 5., i.e., 2℃ or below. As this freezing range decreases by approximately 20 cm in thickness per month, some frozen soil is considered to remain unthawed until the following winter if this embankment is left undisturbed. Table 4 indicates thermal conductivity measured by soil types after the winter season was over. Thermal conductivity of Sample No. 1, in which large quantities of frozen soil remained, was small whereas that of Sample No. 3, in which frozen soil disappeared early, was high. The low thermal conductivity of Sample No. 1 was considered to be caused by increased air-space ratio, a factor affecting insulation effectiveness, which in turn was caused by low compaction density of soil itself. The aforementioned facts suggest that soil types with low thermal conductivity, such as volcanic ash soil, require a long time for underground frozen soil to thaw.

3.3 Comparison by measurement of installed embankment profiles

Figure 7 describes changes over time in the results of installed embankment profile measurements. Summertime earthworks (Embankment Nos. 1-3) indicate few changes irrespective of differences in soil types. Among wintertime earthworks, however, embankments mixed with frozen soil (Embankment Nos. 4-6) experienced increased deformation volume of embankment with the passage of time. In contrast, deformation volume was significantly restrained in embankments mixed with no frozen soil (Embankment Nos. 7-9). Effects of removing frozen soil can also be acknowledged from this figure.

With regard to deformation volume by soil types, that of Sample No. 3 is the largest. The embankment mixed with frozen soil (Embankment No. 6), in particular, underwent deformation beyond recognition of its initial shape. As in the consideration mentioned above, it is presumed to be caused by settlement that occurred due to voids created by frozen clods that thawed gradually. Although Embankment No. 4 did not experience any major deformation as of September, an increase in deformation volume is expected because large amounts of underground frozen soil remain as mentioned in the consideration above. This indicates that deformation continues in embankments mixed with frozen soil even if adjustments are made to embankments unless underground frozen soil thaws completely.

4. Conclusion

Full-scale embankment tests were carried out at the Construction Test Field in Tomakomai in order to compare the quality of wintertime embankment by different construction periods and soil types. As a result, the following points were clarified:

1) Removal of frozen soil prevents the reduction of compaction degrees and significantly suppresses the deformation of embankment.
2) Soil types with high coarse-grain content are relatively advantageous for wintertime earthworks
3) In embankments mixed with frozen soil, the underground frozen soil remains for a long period of time, and embankment deformation is facilitated by slow thawing.

References

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2) Sakuraba and Nishikawa: Influence of freezing to soil compaction, Research Report No.39, Hokkaido Branch of Japanese Geotechnical Society, pp.93-98, 1999.(in Japanese)
3) Sakuraba and Nishikawa: Compaction characteristics of frozen soil mixing soil, Proceedings of 34th annual meeting, Japanese Geotechnical Society, pp1835-1836,1999.(in Japanese)
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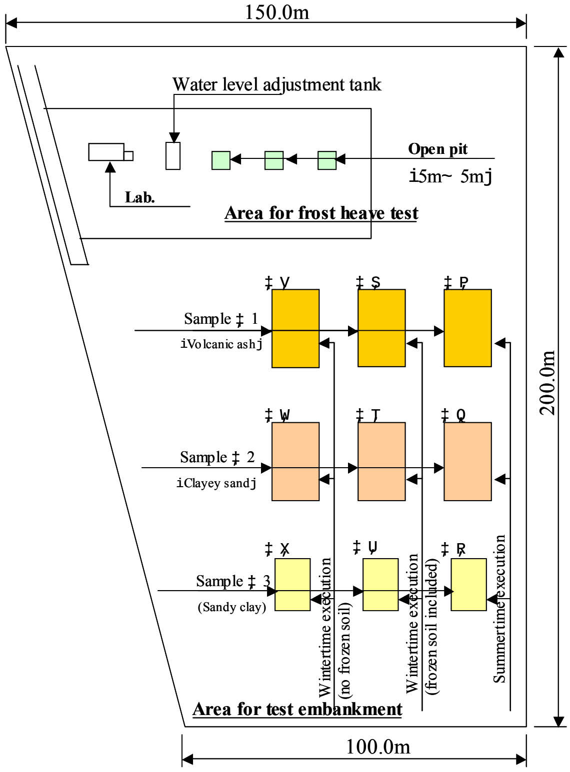

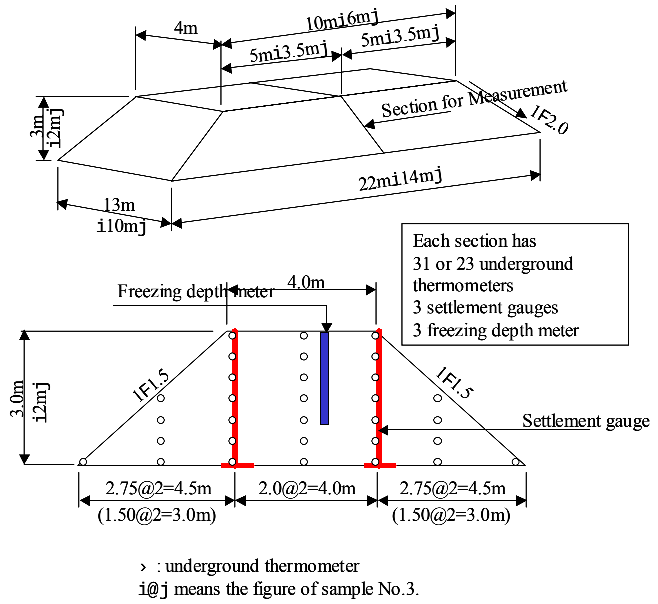

Fig.2 Details of test embankment

Fig.1 Distribution of test embankment

Photo 1 Experiment of test embankment

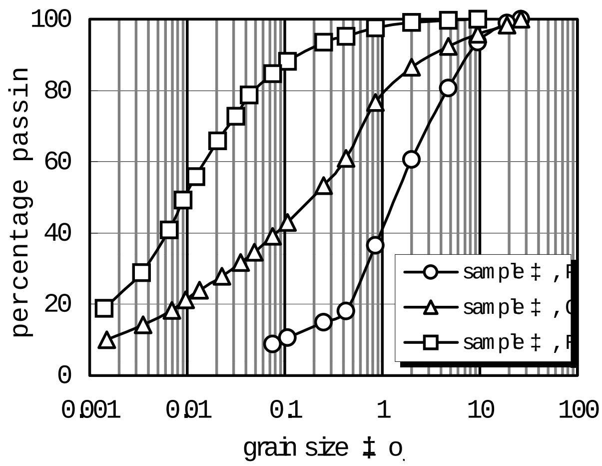

Fig.3 Grain size distribution

Table 1 Physical characteristics of the embankment material

sample No.	Japanese unified soil classification system	symbol	natural moisture content (%)	density of soil particle (g/cm^3)	grain size distribution (%)			
					gravel	sand	silt	clay
‡1	volcanic gravelly sand	,r f | u	74.59	2.395	39.3	51.9	8.8	-
‡2	clayey gravelly sand	,r f r | f	41.04	2.659	13.4	47.5	22.9	16.2
‡3	sandy clay	,bk | r	36.63	2.691	0.9	14.4	48.5	36.2

sample No.	consistency i “j			maximum dry density ƒ Ï dmax (g/cm^3 j	optimum moisuture ratio , y, ,”i “j	frost heave test
	LL	PL	Plasticity index			forst heave ratio i “j av.of three
‡1	,mo	,mo	-	0.792	77.9	17.6
‡2	39.6	26.0	13.6	1.510	21.0	34.9
‡3	45.7	21.4	24.3	1.575	22.0	17.6

Table 2 Measurement conducted in this study

measurement time	measurement	method	measurement frequency	Remarks
at execution	density	sand displacement	three times/embankment	twice for No3,6,9
	density	RI	seven times/embankment	five times for No3,6,9
	grain distribution of frozen soil	sieve test	once/embankment	
after execution	underground temperature	thermocouples	once/hour	
	freezing penetration	methylene blue	once/month	
	settlement of embankment	settlement gauge	once/month	
	shape of embankment	tape measurement	once/month	
at demolition	density	sand displacement	twice/embankment	once for No3,6,9
	density	RI	five times/embankment	three times for No3,6,9

Table 3 Measurement of compaction degree

	material‡ ,P		material‡ ,Q		material‡ ,R	
	at execution	at demolition	at execution	at demolition	at execution	at demolition
summertime earthwork	78.4	85.9	89.1	93.0	80.0	91.5
wintertime earthwork (with frozen soil)	55.2	68.1	56.2	85.9	56.3	91.0
wintertime earthwork (without frozen soil)	67.7	75.4	79.3	92.0	73.9	91.2

average of three for No1 & No2, average of two for No3

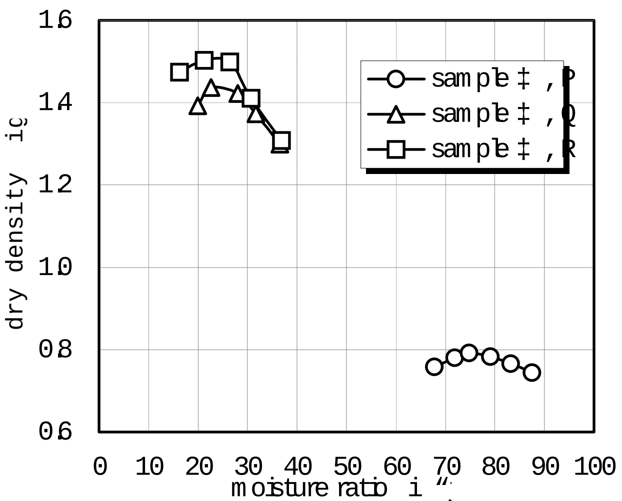

Fig.4 Compaction curve of embankment material

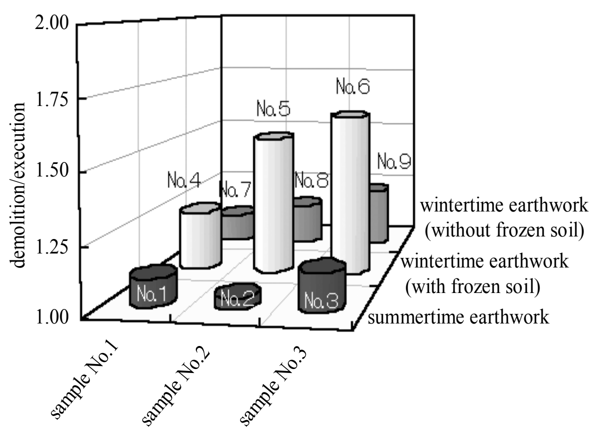

Fig.5 Change in compaction degree at execution and at demolition

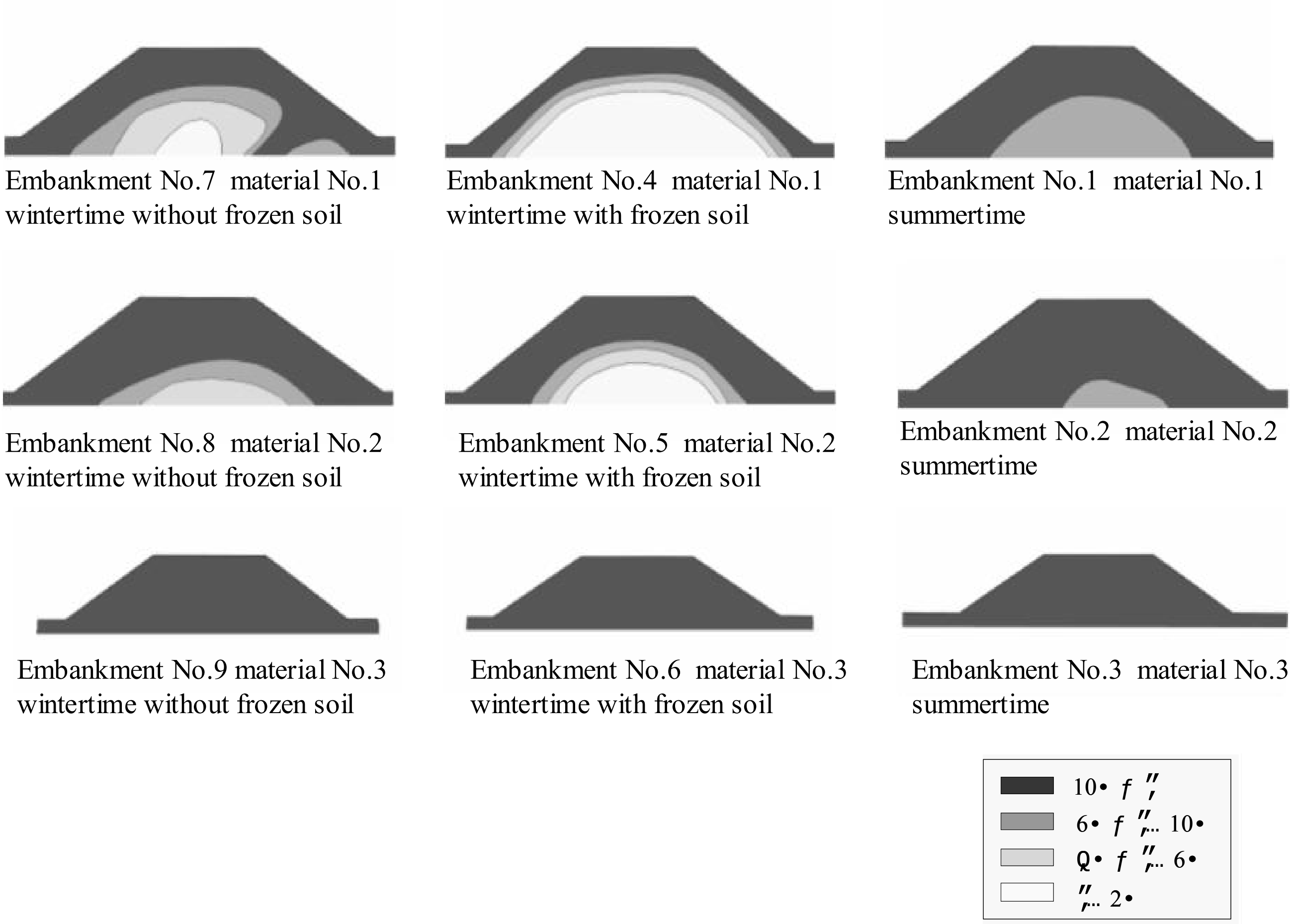

Fig.6 Distribution of underground temperature (on 31 Aug.2001)

Photo 2 Progress of demolition for Embankment No.4

Table 4 Thermal conductivity of each embankment material

Embankment ‡ ,	Thermal conductivity W/m¥K j	moisutre ratio (")
‡ ,P	0.35+0.05	39.0
‡ ,Q	0.54+0.12	25.2
‡ ,R	0.74+0.21	22.1

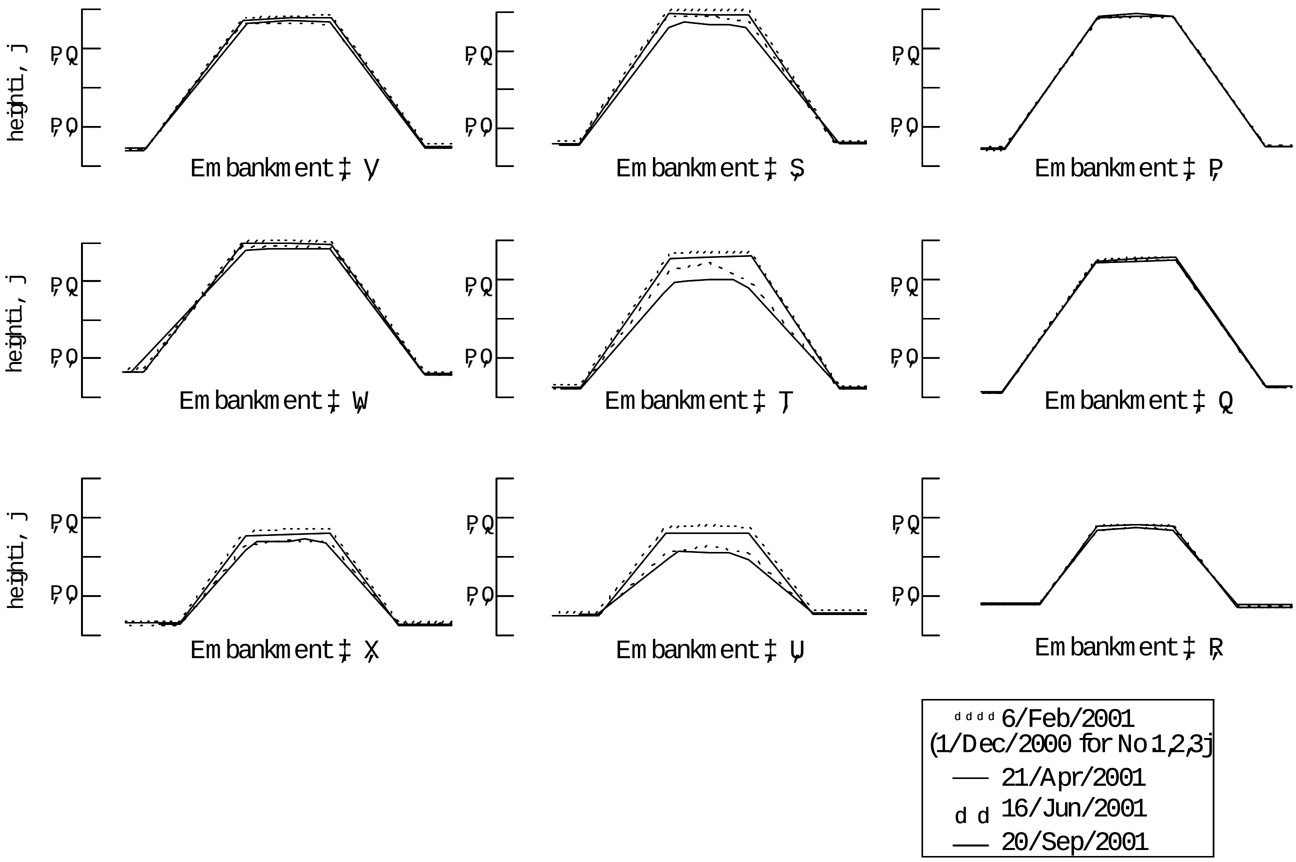

Fig.7 Change in shape of embankment