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# Field performance of a geotextile reinforced soil wall with concrete facing blocks

T.Nakajima – *Sato Kogyo Co., Ltd, Tokyo, Japan*

N.Toriumi – *Seni Doboku Co., Ltd, Tokyo, Japan*

H.Shintani – *Mitsubishi Kagaku Sanshi Corporation, Tokyo, Japan*

H. Miyatake – *Public Works Research Institute, Ministry of Construction, Tsukuba, Japan*

K.Dobashi – *Public Works Research Center, Tokyo, Japan*

ABSTRACT : To investigate the wall-facing effects on geotextile reinforced soil wall, on-site performance tests were conducted using 8-meter high vertical reinforced soil wall with a large concrete block facing. From the test results the maximum reinforcement strain was approximately 1% and the facing's horizontal displacement 6.5 cm, both measured at the time of completion of construction. These results are acceptable for the stability of the reinforced soil wall. Both settlement and displacement measured at the time of approximately 160 days after the completion of construction suggest that the wall is in a stable state. In general the reinforced zone behaves as a rigid body, however that hypothesis is not justified for this performance test.

## 1. INTRODUCTION

It is learnt from past experiences that the high-stability effect together with the displacement-control effect can be obtained in case the reinforced soil wall is constructed with a comparatively stiffened wall facing such as concrete panel or concrete block. The authors have conducted on-site performance tests building in the Public Works Research Institute, Ministry of Construction, an eight-meter high geotextile vertical reinforced soil wall with the facing made up of dry masonry large concrete blocks, and the results obtained from various measuring instruments during and after construction are used for the analysis of structural stability during construction and stability on a long-term basis together with ease of construction.

## 2. SUMMARY OF TEST WALL

### 2.1 *Cross-section and reinforcement pattern*

Fig.1 shows one cross-section of reinforced soil wall built in this test. The reinforcements were laid out in 6 meters length and 11 layers, based on the test results of several design methodologies, each of which took facing effects into consideration. The predicted safety factor achieved by the cross-section used in the Manual's technique(Design and Construction Manual of Geotextile-Reinforced Embankments) is approximately 1.0, an ultimate state under ordinary as well as during earthquake. Total length of reinforcement designed by Manual is 30% longer than this test. To ensure stability during compaction work performed in the proximity of the wall, meter-long, stability additional short reinforcement were employed for the blocks without main reinforcements.

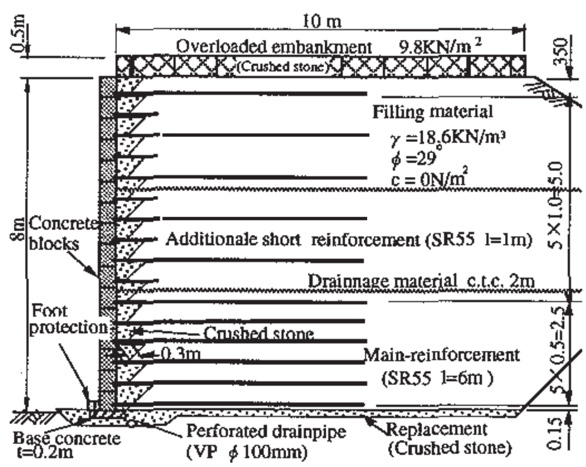

Fig. 1 Cross-section and reinforcement pattern

### 2.2 *Summary of construction*

The base of the facing was cast with base concrete(non-reinforced concrete). Because the facing must have embedment in the ground and because numerical analysis revealed that immobilizing the bottom of facing would be an effective way to prevent deformation, the concrete was cast for foot protection with reinforcement bars aligned in front of the bottom course of blocks.

Precast-concrete blocks were used as the facing in this test. Therefore, as Fig.2 shows, L-shaped round-bar was threaded through to form metal joints. Fig.3 shows the connection between the reinforcement and the metal joint. Slide joints were used to allow the settlements of the back fill both during the compaction process and long-term consolidation. Concrete blocks were lifted using a crane. The fine adjustment of the alignment and the leveling was done manually. As Fig.2 shows, concrete blocks are made so that the front and back of the wall are joined by a beam. This hollow is filled with crushed stones.

The finished thickness of a single layer filling was set at 25 centimeters. A 0.7 $m^3$ backhoe was used to spread the filling, which was followed by compaction using a 9.8KN hand-guide roller. After completion of a single layer filling, the embedded crushed stones were spread to prevent the backhoe from directly mounting the reinforcement, due to the space restrictions of the reinforced soil wall.

To apply an overload pressure of 9.8KN/$m^2$, the anticipated pressure when the upper surface serves as a traffic, to the reinforced soil wall, a layer of crushed stone with a thickness of 50 centimeters was laid on top.of the reinforced soil wall.

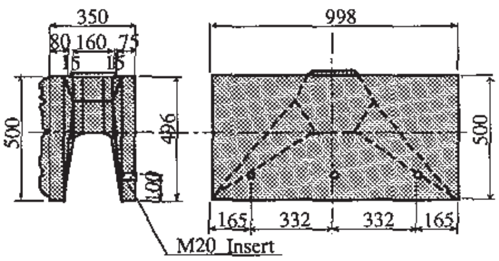


Fig. 2 Shape of concrete block

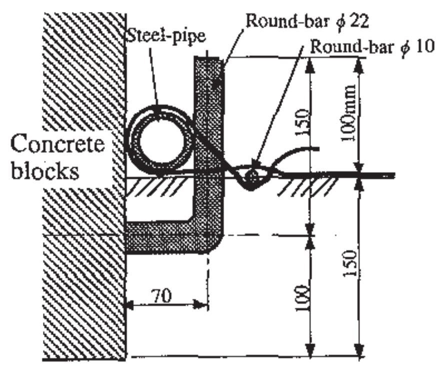


Fig. 3 Detail of the connection between the reinforcement and the metal joint.

## 2.3 *Measurement details and procedures*

Fig.4 shows one cross-section at the center of the reinforced soil wall was used for measurement.

(1) Horizontal displacement of wall

To assess the horizontal displacement of sections D2 to D9, the relative displacements were measured to D1 using a plumb added to the front of the concrete blocks. The horizontal displacement of D1 was calculated by measuring the distance from a pre-fixed point. To assess the vertical displacement level, the D1 level was measured as the index for vertical displacement of the entire facing.

(2) Settlement of embankment

With settlement plates placed underneath, within, and on top of the embankment (before the embankment overload), the height of the tip was measured using a level.

(3) Strain of reinforcement

The strain of reinforcement was measured using a strain gauge which was attached to the geotextile. We took the initial value at the stage before tension was applied.

(4) Earth pressure against the wall and subgrade reaction

Earth pressure gauges were embedded in the concrete blocks to measured the earth pressure against the facing blocks, and in the bottom of embankment and under the base concrete of the facing blocks to measured subgrade reaction.

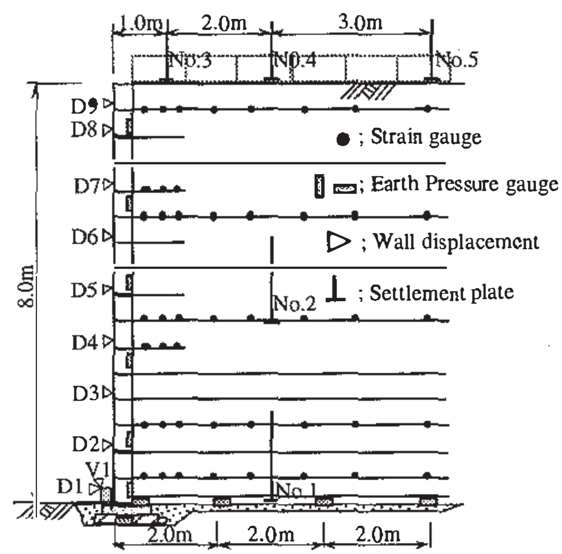


Fig. 4 Cross section used for measurement.

## 3. RESULTS OF MEASUREMENT

### 3.1 *Horizontal displacement of wall*

Fig. 5 and Fig. 6 show the horizontal displacement of the wall, measured during construction and after completion of the construction. Fig. 5 shows the displacement calculated by adding the value for the horizontal displacement experienced by foot protection(D1) to the increment in displacement experienced by each measuring point since the measurement started. Therefore, it does not reflect the final shape of the wall. The figure suggests that the maximum horizontal displacement at the construction finish is approximately 65 mm (approximately 85 mm if the horizontal displacement of the foundation is included). This produced a welling-out half-way up the wall. In general, conventional reinforced soil wall with geotextile

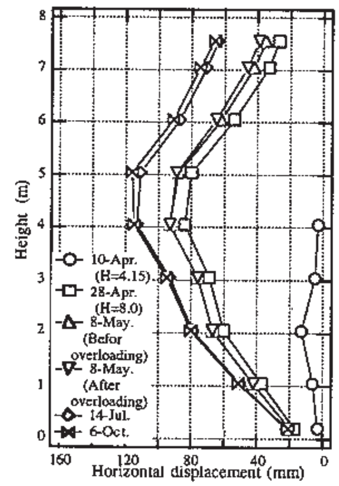

Fig. 5 Horizontal displacement of the wall

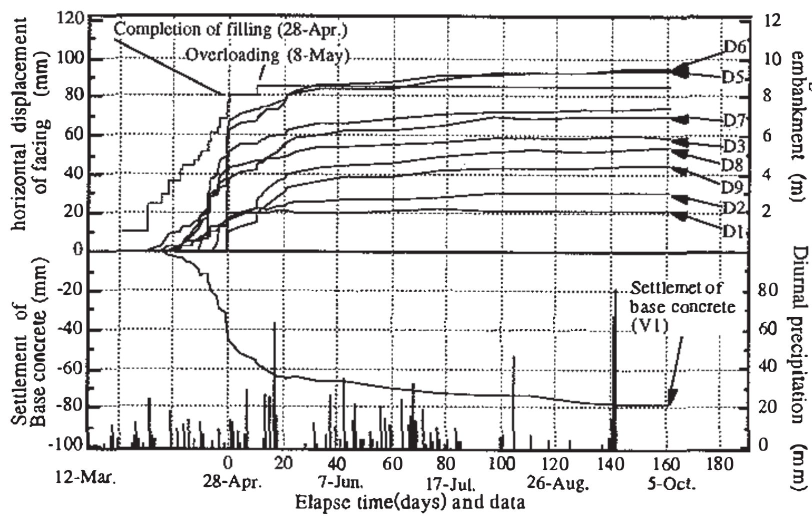

Fig. 6 Horizontal displacement of the wall with elapsed time

which incorporated wrapped-around reinforcement, showed that one third up from the bottom of the wall experienced maximum displacement. However, indoor tests conducted prior to this test and the results of numerical analysis have confirmed that when concrete blocks are used as the facing, maximum horizontal displacement occurs half-way up the wall. Our test result matches these theoretical predictions, and shows characteristics of high-rigidity facing. The level of displacement at the completion of construction is considered to be small in terms of stability of the reinforced soil wall. Moreover, the facts that filling was leveled using a backhoe at a certain distance from the facing and compacted using small compacting equipment are believed to have contributed to achieving this small displacement level. This suggests that some care should be taken against possible displacement encountered during the construction process when this methodology is employed. Furthermore, the existence of an overhang as a soil retaining structure presents problems in terms of appearance and stability; thus, it is desirable that the reinforced soil wall shape should slope back a little.

While the displacement recorded on October 6, 161 days after completion of construction, was approximately 95 mm, the change in displacement from approximately 100 days after completion onwards remained small, and the deformation of embankment virtually stopped. The effect of rainfall was most evident in the initial stage after the completion of construction. Although some change in displacement was encountered as a result of heavy rainfall from the typhoons that hit the area in September, the displacement remained very small compared to that induced by the heavy rainfall in mid-May, suggesting no major problems with long-term stability. Furthermore, the change in settlement of the facing foundation and horizontal displacement of wall were correlated. This suggests that building a firm foundation is vital for reducing displacement of the entire wall.

3.2 *Settlement of embankment*

Fig.7 shows the daily fluctuations in embankment settlement and settlement of the facing foundation. The settlement experienced under construction rapidly increased when the embankment reached a height of three meters. This represents the effect of preloading by the existing embankment. The values measured at settlement plate 1, located at the bottom at the far end of the embankment, as well as the values showing the settlement of the facing foundation, shifted in the same manner during construction, with the settlement of the foundation slightly greater than that of settlement plate 1 after construction was completed. When approximately 160 days passed after completion of construction, settlement at each measuring spot ceased, suggesting a stable state.

3.3 *Strain of reinforcement*

Fig.8 shows the distribution of the reinforcement strain recorded on October 13, 168 days after the completion of construction, as well as the reinforcement strain registered on the completion of construction. The distribution of strain in each layer suggests that it was maximized in the section close to the reinforcement joints. The maximum strain value of the reinforcement registered at the completion of construction (approximately 1%, or about 9KN/m when converted into a tensile force) is noticeably smaller than the design strength of 29.4KN/m, in construction stage was completed without any safety problems. The distribution of strain for additional short reinforcement similar to main reinforcement, which shows the contribution to the stability of the reinforced soil wall.

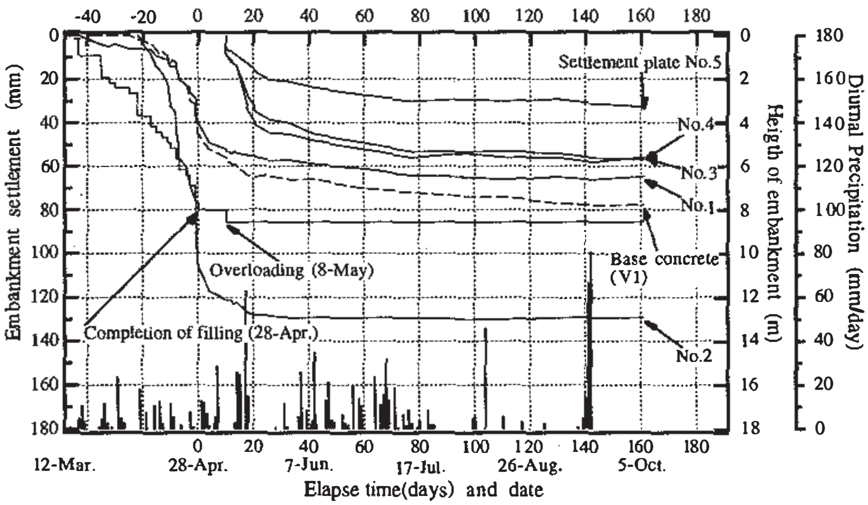


Fig. 7 Settlement of embankment with elapsed time

Fig.9 shows the strain distributions recorded during the construction process for certain reinforcements. The figure suggests that when the earth covering on the reinforcement is not thick, the maximum strain for recorded far from facing. As the earth covering became thick, the peak of strain approached the facing. This is believed to be caused by a phenomenon the compacting and settlement of the filling pulled down the reinforcement. The reinforced soil wall with rigid facing usually incorporates slide joints designed to mitigate excessive tension of reinforcement. However, crushed stone was used as the embedded draining material in this test, the slide joints were not able to display their full function.

Fig.10 shows in a graphic format the status of the near the facing, as observed in mid-October. This revealed a void between the reinforcement and embedded crushed stone in sections around joints. While near the facing the reinforced soil wall large lateral outflows of fine particles occurred, the absence of measures to prevent washout in the back of the facing resulted in the same situation taking place in the center of the embankment. What ever crushed stones was used as backfill near the facing, the settlement of backfill is much larger than sliding capacity. This can also be deduced from the fact that while the strain found in close proximity to the facing of the additional short reinforcement at a height of 3.15 meters rapidly increased beginning around July (exceeding the limit of the strain gauge), virtually no change was seen in the facing displacement.

These results suggest that it is essential that the facing have a mechanism to quickly discharge water which permeates the embankment as a result of rainfall, and that preventive measures must be taken to preclude any particle outflow from the filling, using high-quality consolidation material and applying sufficient compaction.

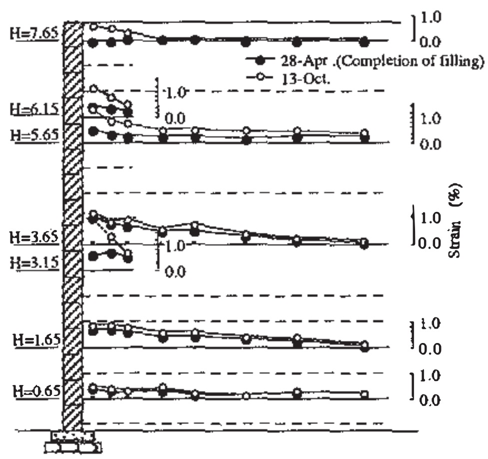


Fig. 8 Strain distribution of reinforcement

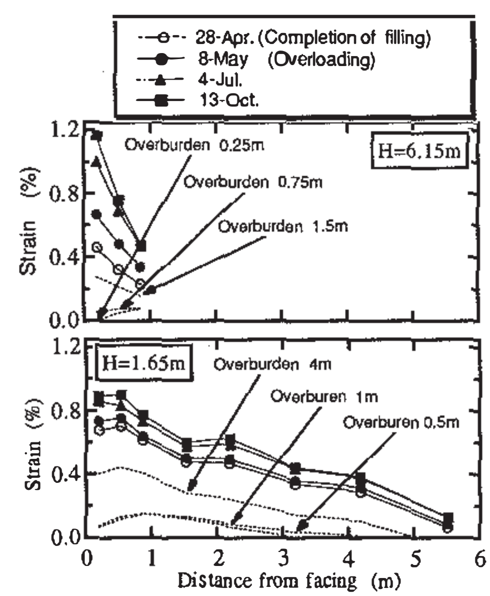


Fig. 9 Strain distribution of reinforcement on the process of construction and after the construction

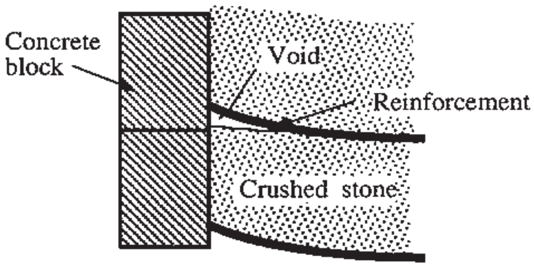


Fig. 10 Graphic format the status of the void between the reinforcement and the crushed stone

### 3.4 *Earth pressure against the facing and subgrade reaction*

(1) Earth pressure against the wall

The full-scale indoor test model and numerical analysis showed an earth pressure recorded toward the facing bottom is similar to Coulomb's earth pressure and an earth pressure at the base of the facing is smaller than Coulomb's earth pressure. On the other hand, as Fig.11 shows, the distribution of earth pressure recorded at the completion of construction (H = 8 m) is concave, showing a considerably smaller value overall than Coulomb's earth pressure level. As previously mentioned, void is formed under the reinforcement near the back of the facing. Therefore, caution must be used when assessing measured values, and we hope to study this point further after observing future changes.

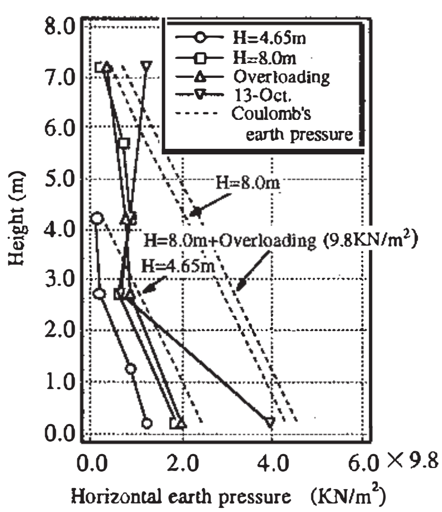


Fig. 11 Distribution Earth pressure against the facing

(2) Subgrade reaction

Fig.12 shows the results of measurements taken on October 13, 168 days after the construction was completed, as well as those taken during the construction process and at the completion of construction. The results of measurements using the earth pressure gauge located in the lower section of the facing foundation are converted values, taking into account the width of the foot protection. As the Figure suggests, the shape of the subgrade reaction distribution shows that: in the distant area from the facing, the subgrade reaction is equal to or smaller than the pressure due to the weight of the filling; and that in the section of the facing, the value far exceeds the pressure due to the self weight of the concrete blocks. This type of distribution of the subgrade reaction was also seen in indoor tests and in the numerical analysis. In the Manual, the external stability calculation assumes that the reinforced zone behaves as a rigid body, creating a trapezoid shape where the subgrade reaction undergoes a linear change. However, that hypothesis is not valid for this result. The factor for large subgrade reaction at the bottom of the facing is based on both the effect of the vertical component of the earth pressure against the facing, transmission of reinforcement force.

Given that this kind of subgrade reaction distribution shape is characteristic of the reinforced soil wall with highly-rigid facing, further study and a quantitative assessment is needed on the ground and the base structure of the facing.

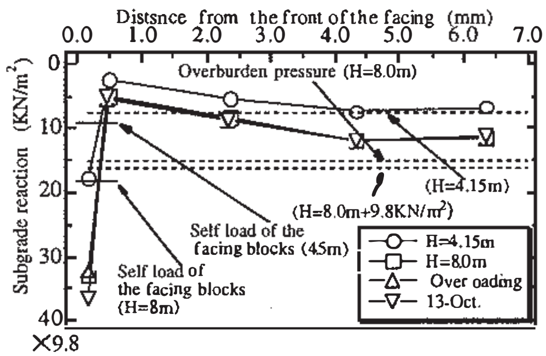


Fig. 12 Distribution of subgrade reaction

Fig.13 shows the result of survey taken near the test embankment on 1983.. The N-value of clay and Kanto-loam which lies from the ground surface to 5m deep are about 2 to 6. The allowable bearing power which is estimated from N-value by the method of "Highway earthwork series - manual for retaining wall, culvert and temporary structures -" is about 49KN/m². It is not enough to bear the test embankment stably. The authors tried to analyze the external stability on the rotational failure by the same method as stability analysis of embankment. Strength parameters of foundation were estimated from N-value by the method of Terzaghi and Osaki. And the trial calculation considering the increase of strength parameter by the effect of preloading of existing embankment was carried out. Fig. 14 shows the result of the trial calculation. Fig.14 shows only the results of a trial calculation, but it shows the probabilities that stability analysis of the Manual estimates stability of relatively flexible structure such as reinforced soil wall lower in the external stability analysis on rotational failure. It is needed to carry out more detailed survey and continue to examine validity of the results of trial calculation.

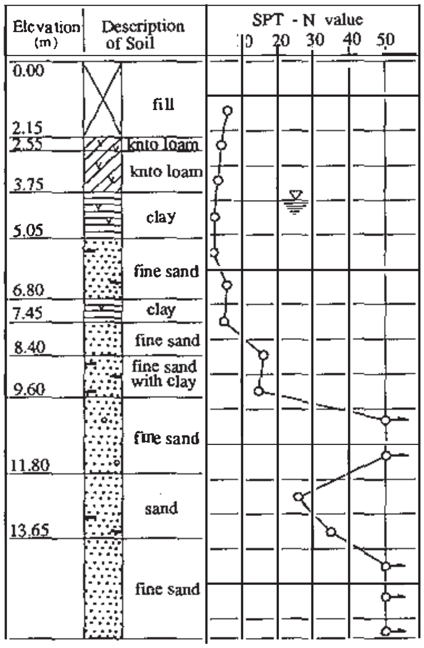


Fig. 13 Soil profile of ground

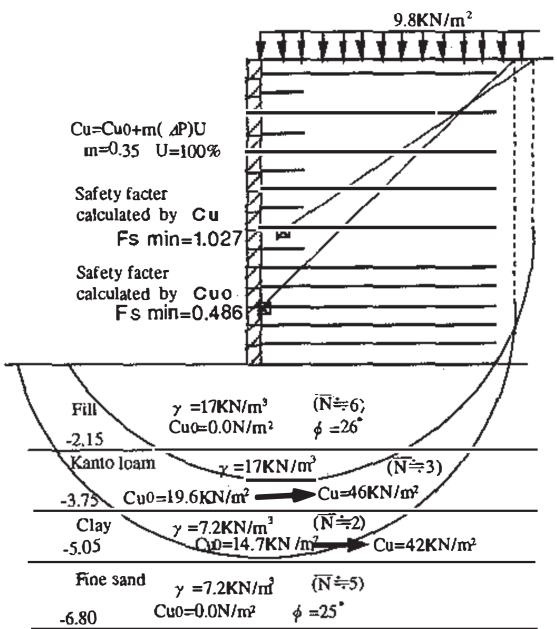


Fig. 14 Study of the external stability on the rotational failure

## 4. CONCLUSIONS

The authors constructed and tested a reinforced vertical soil wall of 8 meters in height which used a concrete block as the facing. The findings of the test are shown below.

(1) However reinforcements were laid out fewer than designed the Manual, test embankment was constructed without any stability problems.

(2) The distribution of strain for additional short reinforcement similar to main reinforcement, which shows the contribution to the stability of the reinforced soil wall.

(3) The change in the horizontal displacement of the wall and the settlement of the facing foundation are correlated. The section located beneath the facing foundation experiences the subgrade reaction, which is greater than that of the self weight of concrete blocks. It is therefore vital that sufficient care be taken when designing the foundation and the soil ground for a reinforced soil wall with high-rigidity facing.

(4) The horizontal displacement of wall and the settlement of the embankment on the 160th day after the completion of construction declined, suggesting test embankment has enough long-term stability.

(5) It is better to use slide joints for reinforcement and facing blocks. It is necessary to compact the back of the wall with good fills and take steps to prevent washout.

(6) The method suggested here is relatively good in terms of ease of construction. Applications for the method are feasible. However, to ensure greater stability, the reinforced soil wall shape should back a little.

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