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Bench-type wall with flat slabs and steel bars

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ABSTRACT: This paper describes test results of a bench-type reinforced soil wall with the combination of concrete slabs and steel bars. A steel bar with a piece of steel plate was inserted from outside through a hole in the slab. Backfill soil expanded horizontally, and the bars resisted expansion of the soil. The backside slope of the backfill was 45° in inclination. Panel-type earth pressure gages were placed there, to measure normal and tangential components of earth pressure. Both horizontal and vertical movements of several points in the backfill were measured. Therefore, relative displacement between bars and soil, and stress distribution in the backfill, could be clarified to some extent. Deformation was observed in early spring due to percolation of melting snow, but no sign of rupture was seen. The state of unequal settlement of soil layers in the backfill was recorded by the deformation of bars.

1 INTRODUCTION

An idea of reinforcing cohesive soils with steel bars used for reinforced concrete was applied to a fill, when a 40m-high fill was constructed on an artificially made soft foundation, in 1968. Inclination of the front face was 34°. Concrete bearing plates were fixed to steel bars, to resist horizontal expansion of soils and to transmit the earth pressure to the bars. The bars with plates were embedded horizontally in the embankment. The front slope was covered with grasses. The slope is covered with large trees now. A new type of wall with a steeper face was tested in 1980. Benches were made using concrete panels, steel bars, and anchor plates. In 1983, this type of wall was applied to restore a collapsed slope along a road. The wall was 20m in height and 45° in inclination. Steel plates, for the front face, and steel anchor plates were used. Benches were covered with crashed stones to prevent grasses and trees from growing. No sign of corrosion of steel plates has been observed yet. In 1995, a 10-meter-high wall with a steep slope was constructed. This wall was called ASP, which means "anchored slope protection". Inclination of the front slope was 32°. A great number of instruments were used, to monitor the behavior of the fill and reinforcement. Load cells were adopted to both ends of bars, to measure tensile force of the bars. The load cells fixed to the side of anchor plates gave smaller values of tension than one fixed to the side of front plates. A pull-out test was performed with bars. As a result of the tests, the smallest value of resistance was 15kN/m. The bars were 22mm in diameter. From this test, the idea of using steel bars without anchor plates for reinforced soil embankments and walls came to mind. What is described above is written in full detail in my book listed as "Earth Pressure").

2 DESIGN OF THE WALL

The test wall was 5m in height and 1:0.3 in inclination. The concrete panels protecting the bench walls were 1×2×0.1m in size, and steel bars were 22mm in diameter. Precast L-type reinforced concrete retaining walls were placed at both sides of the embankment. There was no concrete slab at the bottom of the embankment. The back- side of the embankment or backfill was a slope inclined 45°, which is a model of a mountain slope. Earth pressure against the concrete panels and bars was estimated using results of past tests, and a coefficient of earth pressure and unit weight of the soil were applied to this test wall. The largest earth pressure was computed as $17 \times 5 \times 0.1 = 8.5 kN/m^2$. Pull-out resistance of 6 kN/m was adopted referring to another test conducted under similar conditions. Then, the safety factor for pull-out resistance was $6 \times 5 \times 2 / 8.5 = 7$.A plate-bearing test was performed using concrete plate as a dead load. Settlement was 4mm against a load of 62.7 kN/m^2. From this result, settlement by the test wall was estimated to be no problem. Stability of this wall without reinforcement was examined using the test result of the triaxial compression test. As the result, this test wall was safe even without reinforcement. Horizontal displacement of the wall was calculated using past case records and simple assumption. A key point is at the front face 2.5m above the base. The horizontal displacement at this point is usually about half of the settlement of the crown of the fill. Assuming the settlement of the crown 3% of the fill height, the horizontal displacement is 1.5%. Then, the horizontal displacement is 75mm. The second way to estimate is based on the coefficient of linear deformation by the triaxial compression test, and the effect of the back slope of the backfill. This estimate was 95mm. In conclusion, the estimated horizontal displacement was 75-95 mm.

3 SOIL PROPERTIES

The soil properties of fill material are shown in Table 1. The fill material looked uniform in appearance, but it is not uniform in a strict sense.

Table 1. Soil properties.

(a) Laboratory test
Grain size: 37-20 mm; 6%, 20-2mm; 2%, 2-0.01 mm; 48%, 0.01mm- 25%, Sandy loam
Liquid limit w_L=80%
Plastic limit w_P=56%
Maximum dry unit weight: γ_{max}=12.14 kN/m^3
Cohesion: c=23.7kN/m^2
Optimum moisture content: wopt=38.7%
Angle of internal friction: φ=9 (tanφ=0.158)
Modulus of linear deformation: E=2-5MPa
(b) Field test
Wet unit weight: 14.94-17.63, mean 16.47 kN/m^3
Dry unit weight: 11.04-12.66, mean 11.59 kN/m^3
Moisture content: 36.9-46.4, mean 42.1%

4 INSTRUMENTATION

Many instruments were used to monitor the behavior of the test wall. Figure 1 shows the types of instruments used for measuring and their location. A two-meter section of the center of the wall was used as a test section, and both sides served as dummy. Table 2 gives a list of instruments.

Table 2. List of instruments.

Item		Instruments	Position	Numbers
Earth pressure		Panel-type earth pressure gage	Backslope	5
		Earth pressure gage in soil	Base of fill	3
		Earth pressure gage for base	Base of wall	1
Bar tension		Load cell	Head of bar	10
Wall Displacement	Horizontal	Dial gage	Face of panel	5
	Vertical	Levelling	Top of panel	2×5
Displacement in backfill	Horizontal	Plate and rod	Steps 2,3,4	5
	Vertical	Plate and rod	Steps 1,2,3,4	4

5 CONSTRUCTION

Construction work was conducted as follows. A simple foundation was constructed under the concrete panel of the first step. The panel was erected

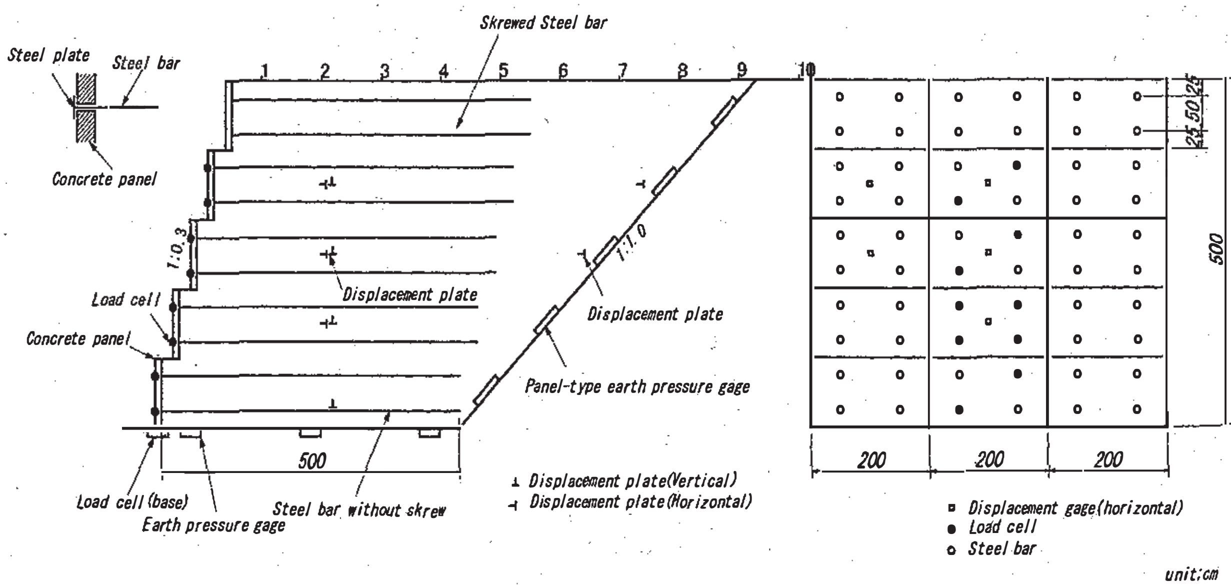

Figure 1. A sketch of the wall.

vertically on the foundation. The earth pressure gages and the settlement plate were laid on the ground. The fill was placed layer by layer, and the thickness of the layer was 25mm. As the time of construction was early winter, the soil moisture content was high. Heavy compaction machines could not be used. The used compaction machines were,weight=1-5kN. The lower part of the layer was loose compared with the upper part, and bars were embedded in the loose layer. Cone resistance of a cone-penetrometer (top angle 30°, diameter 12.5mm) was $0.3kN/m^2$ in the upper part and $1.0kN/m^2$ in the lower part. For the pull-out test, a smooth skin steel bar (M-bar) and a screw skin steel bar (N-bar) of 22mm in diameter were embedded at the dummy parts of the wall. After finishing the second step of the wall, the pull out test was performed. The pull-out resistance was 3 kN with the M-bar, and 10 kN with the N-bar, which were far below the expected value (30kN). The M-bars were used for the lower 2 steps, and the N-bars were used for the upper 3 steps. The pull-out resistance test was conducted at the end of the measurement. The pull-out resistance of the M-bar was 7kN,and that of the N-bar was 58 kN.

6 RESULTS OF MEASUREMENT

6.1 *Displacement of the front panel*

The front panel moved both horizontally and vertically. Figure 2 shows the displacement of panels during and after the construction. Large displacement occurred after the construction. The three months from December to February are winter, and the temperature drops to below zero (coldest: -18° C), and snow falls. This is the cause of large displacement. Displacements of steps 2 and 3 were larger than those of other steps. The base of the front wall moved both horizontally and vertically. Therefore, inclination of the front face did not change very much. The original inclination was 16.7°, and the final inclination was 16.7+1.7=18.4° .The predicted value of displacement was 75mm, which is 1.4° in

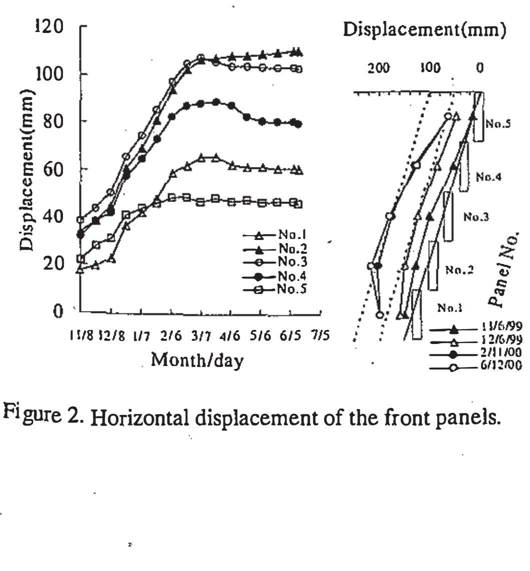

Figure 2. Horizontal displacement of the front panels.

inclination. This value is very close to the measured value of 1.7°.

6.2 *Horizontal displacement in the backfill*

Five plates were buried in the backfill. Two plates were placed near the back slope, to measure displacement of the backfill there. It was found that the back slope did not move. Three plates were buried at points about 2.5m from the face panel. These plates moved only 2-3mm. This shows that the backfill between the plates and the back slope elongated very little. The backfill between the front wall and the 3 horizontal displacement plates elongated largely, and the front panels moved forward as shown in Figure 2. Figure 3 shows a change of length between the front panels and the horizontal displacement plates with the passage of time. An increase in length was found only during winter. As for friction between soil and bars, bars near the wall face work to prevent forward movement of soil and the rest part of the bars work as an anchor.

6.3 *Settlement of front panels and settlement plates*

Results of settlement measurement are given in Figure 4. The settlement of the front panels were much larger than those of the settlement plates, which were installed in the backfill. The front panels settled largely at the time of snow water percolation, in December and April. The amount of ground settlement was about 46mm,which was much larger than the reduction of fillheight 13mm.

6.4 *Displacement of the fill top*

Figure 5 shows the displacement of the fill top. Large horizontal displacement was recorded between 1 and 2m, and percentage of elongation between 1 and 2m is 1.5%. There is no elongation between 4 and 7m. The amount of settlement decreased linearly, influenced by settlement of the base.

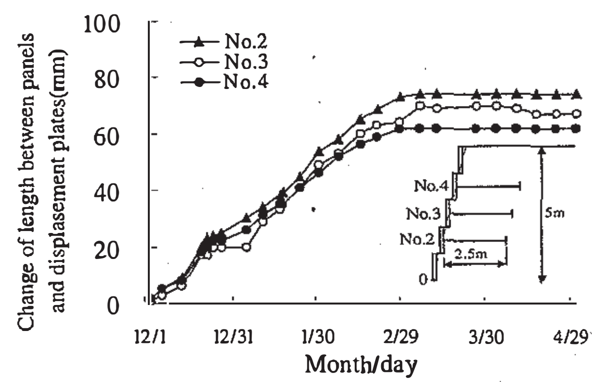

Figure 3. A change of length between front panels and the horizontal displacement plates with the passage of time.

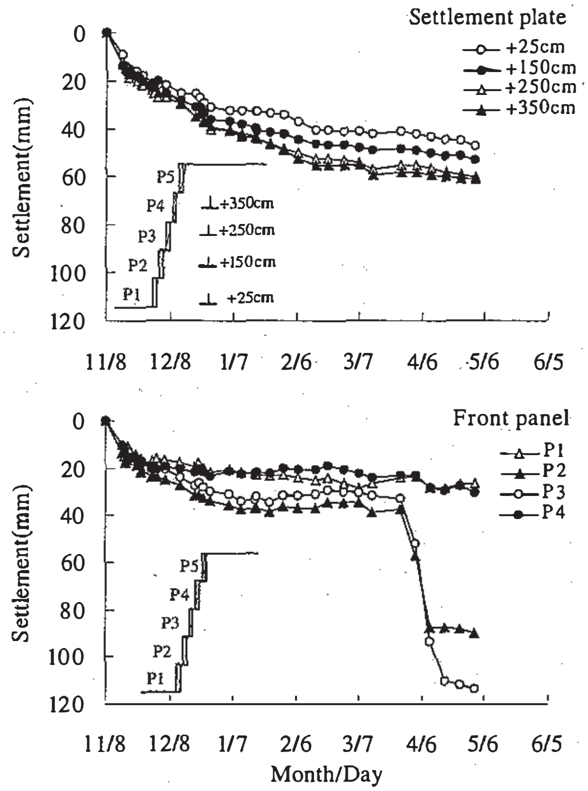

Figure 4. Vertical settlement.

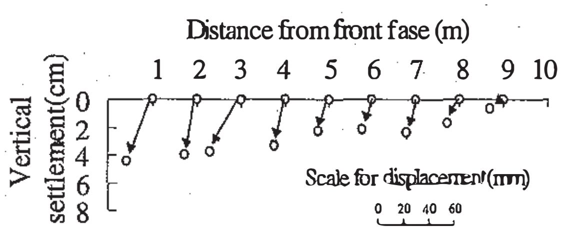

Figure 5. Displacement of the fill top. (Nov. 8, 1999-May 1, 2000)

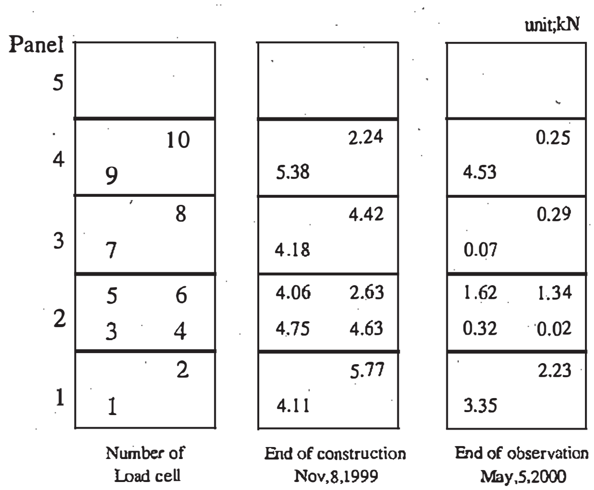

Figure 6. Tension of bars at the end of construction and observation.

6.5 *Tension of bars*

Load cells fixed to the tops of the bars to measure tension of the bars. Figure 6 shows the records of measurement at the end of construction (Nov. 8,1999) and at the time of observation (May 1, 2000). Tensile forces went down suddenly and recovered soon in December, but they went down remarkably and never recovered again after March 20. Figure 7 shows the results of tensile forces of bars for Panel No. 2 after the end of construction. The term of measurement is divided into 5 sections. Section I is early winter. Snowfall is not deep, and frost heaving begins. This increases the tension of bars. Section II is deep winter, and the wall is covered with about 30cm of snow. Section III is early spring. The temperature rises, frost melts, and soil becomes loose. Then, snow water percolates into soil. This causes sudden drop of tensile forces of bars. Bar tension in terms of the coefficient of horizontal earth pressure at the end of construction was K=0.13, and the apparent angle of internal friction was ϕ=50°. K and ϕ values at the end of construction was 0.05 and 60°, respectively. Figure 8 shows the relationship between horizontal displacement and earth pressure on Panel 2. The earth pressure is deduced from bar tension.

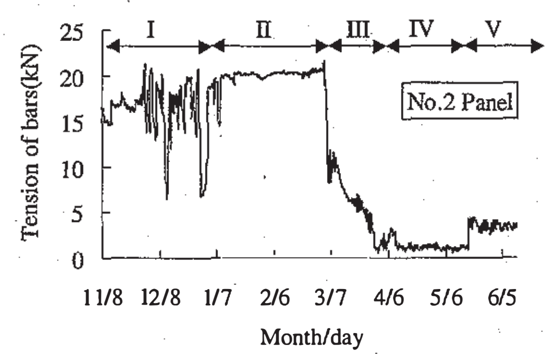

Figure 7. Tension of bars after the end of construction of Panel 2. (Nov. 8,1999)

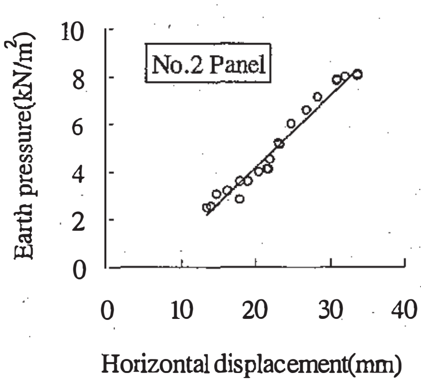

Figure 8. Horizontal displacement versus earth pressure for Panel 2 during construction

The coefficient of linear deformation E=3.3 MPa was obtained by taking the following data.

Horizontal earth pressure σ_h=8.5kN/m^2,
Vertical earth pressure σ_v=18.47×3.5=57.6kN/m^2,
Horizontal displacement Δ l=0.034m,
Horizontal length of the soil layer l=6m,
Poisson's ratio 1/m=1/3.

Figure 9 shows a soil layer, which is confined by the upper and lower horizontal planes, and a vertical wall at the end of the bars. Figure (a) is the situation at the end of construction. The earth pressure acting on the vertical wall is equal to the friction along the lower surface minus that along the upper surface. The earth pressure acting on the back of the front panel is balanced by the friction on the perimeter of bars. The maximum tensile force is at the back of the panel. The tensile force decreases gradually in the backward direction, and it becomes zero at the end of the bars. Figure (b) show the situation at a certain time after the end of construction. The panel moves a little bit forward, and the earth pressure against the back of the panel become smaller. As the front part of the soil is extended a little, the frictional force of the soil to the bars acts in the forward direction. The rest of the bars act as anchor. Figure (c) shows the situation of the elapsed time during or after winter. The upper bar projects out of the panel, because no rigid connection exists between the panel and the bar. Tensile force of the bar tip is zero. Friction of the front part of the bar becomes larger and acts in the forward direction, and that of the rest of the bar acts in the backward direction.

The panel has 4 bars, but those bars are not in the same situation. As to this wall, frictional force depends on the compactness of soil around the bar. The bars near the front wall were bent down due to settlement of the panels, and this part of the bars moved out from the soft layer to the compacted soil layer. Therefore, the pull-out force of the bars near the front wall became larger than the rest of the bars, which were embedded in the soft layer. This is why some bars projected out of the panels.

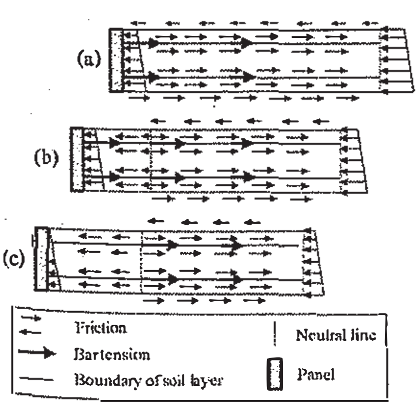

Figure 9. A model showing relationship between earth pressure and friction.

6.6 *Earth pressure gages*

Four load cells were installed under the front panel No. 1, to measure load from this panel. Three earth pressure gages were installed on the ground, to measure the pressure from the backfill. Table 3 gives the results of measurement. Despite that the influence of the back slope of the backfill on earth pressure of a retaining wall is great, the condition of the back slope has not been studied well yet. To obtain a case record,5 panel-type earth pressure gages were installed on the back slope, which is 45° in inclination. A part of the records is given in Table 4. Maximum frictional resistance of the back slope is computed by using the result of the triaxial compression test, which is cohesion c=23.7 kN/m^2,and angle of international friction ϕ=9° .Then, maximum frictional resistance is about 180kN/m, and the sliding safety factor is more than 3.

6.7 *Excavating the test wall*

The wall was excavated in August 2000. The settlement of bars was measured during the excavation. Figure 10 shows the levels of the bars. The bars were bent down near the front wall. The backfill did not settle uniformly. A cone penetration test was conducted, to check the compactness of soil. Alternation of soft and hard layers, and loose soil about 2m from the front panels, were found by the test.

7 EFFECT OF THE DISTURBED ZONE ON THE SAFETY OF THE WALL ITSELF

As a result of the test, it was found that a part of the fill about 2m back from the wall face was disturbed. The effect of disturbance on the safety of the wall itself was examined. Figure 10 shows the wall with the disturbed zone. Weight of (oabd), W_1=350 kN/m, (acd), W_2=206 kN/m. From Table 3, the earth pressure on (oa) at the end of construction is 384 kN/m. Friction on (ad) is 384-350=34 kN/m. Earth pressure on (ad) is obtained, using the force triangle, 37 kN/m (K=0.18). Frictional resistance on (oa) is 180 kN/m. The safety factor along (oa) is

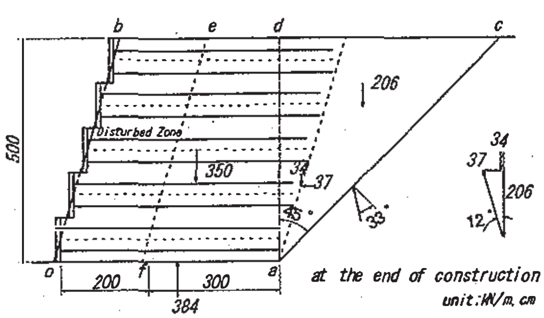

Figure 10. The test wall with the disturbed zone.

Table 3. Loads and earth pressure.

Date	load (kN)	Earth pressure (kN/m^2)
Nov. 8, 1999	48.82	75
Jan. 8, 2000	26.06	88
June 12,2000	20.62	78

Table 4. Earth pressure on the back slope.

Date	Normal component, N, kN/m	Frictional compoment, S, kN/m	S/N	$\tan^{-1}(S/N)$ (°)
Nov. 8	70.4	46.8	0.66	33
Feb. 28	79.5	57.5	0.72	36
Jun. 8	78.6	51.2	0.75	33

180÷37=4.9. On the other hand, at the end of observation, earth pressure on (oa) is 400 kN/m. On (ad), friction is 400-350=50 kN/m. and earth pressure on (ad) is 33 kN/m (K=0.16). Frictional resistance on (oa) is larger than the cohesive shearing resistance of the undisturbed portion of the fill 23.7×3=71.1 kN/m. The safety factor is 71.1÷33=2.1.

Assuming the earth pressure on the front wall is equal to the tension of bars, the amount of tension is calculated from Figure 6 as 14.76 kN/m. Earth pressure on (ef) is about (33+14.76)÷2=24 kN/m. As a result of the pull-out test of bars, pull-out resistance is more than 1.6 kN/m. The length of bars that remained in the undisturbed zone is 3m.Total pull-out resistance is 1.6×3×10=48 kN/m. The safety factor is 48÷24=2.0. In conclusion, the wall with the disturbed zone is still safe.

8 CONCLUSION

(1) A bench-type wall with flat slabs and steel bars was constructed with concrete panels; steel bars, which are used for reinforced concrete and cohesive soil with a high moisture content. It could stand safe in severe conditions of heavy snow and low temperature.

(2) The backfill about 2m behind the front face was disturbed by low temperature, and the front face moved forward about 46mm, which is 1% of the wall height of 5m.

(3) The maximum bar tension was about 10 kN, which was observed in winter. Screwed face steel bars had high pull-out resistance.

(4) Mechanism of reinforcing the bench-type wall with steel bars was partly clarified by this test.

(5) It will be necessary to replace a cohesive soil with frost-free materials near the front face, if horizontal movement is to be avoided.

(6) The method of estimating deformation should be improved in the future.

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