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Geotextiles earth reinforced retaining wall tests

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ABSTRACT: The Kinki Construction Bureau decided to utilize geotextile reinforced soil retaining wall to investigate the wall mechanic and monitor the wall behavior. This paper describes the geotextile reinforced retaining wall tests by static and dynamic loads and provides the design, construction and instrumentation details. The wall has a gunite facing after wall behavior had become stable condition in march 1987. The wall was designed by conventional method and was assigned a lower than usual factor of safety to provide a more critical condition for static and dynamic load test.
Since construction, the wall has settled and it's face displaced foreword by the lack of compaction during construction time, and by static and dynamic loads tests. The wall performance, however, has been satisfactory and has not exhibited distress. After the project, the Kinki Construction Bureau constructed other larger retaining wall at Nomura tunnel entrance access road on national road No.175 in order to investigate their cost comparison and monitor the movement.

1 INTRODUCTION

The wall's general scope is as follows: height 5.4m except foundation drainage layer 0.4m, cover layer 0.4m, and pavement layer 0.1m height, top length 31.5m, bottom length 6.0m.(shown in Fig.1(a), and 1(b)).
From No.1 layer(h=0m) to layer 8 (h=3.0m), combination fabric with polyester needle punched felt white nonwoven fabric and polypropylene monofilament black woven fabric were utilized. And from layer 9(h=3.4m) through layer 13 (h=5.0m), single polyester needle punched fabric was utilized only.
Instrumentation at the site was designed to provide both qualitative and quantitative information on settlement and displacement in vicinity of the wall and within backfill soil mass and to identify specific layers or zones of settlements.
Information on horizontal deflection in the foundation soils and vertical deflection of the wall face and the assumed and separated face from the wall face (d=0.5m, 1.75m, 3.5m) was obtained. Measurement survey of the deflection of the wall face and the surface above the wall top were conducted to indicate their settlement.
Movements within the backfill soil mass were also monitored.
These measurements were taken with 6 horizontal inclinometer casings (No.1 h=0m, No.2 h=1.4m, No.3,4,5 h=3.0m, No.6 h=4.6m) for settlement in the wall soil mass and foundation soil spaced vertically at the center section of the wall; 9 pressure gauge extensomater(h=1.4m, h=3.0m, h=4.6m, d=0.5m, 1.75m, 3.5m); 9 horizontal length gauge (h=1.4m, 3.5m, 4.6m, d=0.5m, 1.75m, 3.5m from wall face) for each their deflection of inclined face spaced horizontally 0.5m, 1.75m, and 3.5m in parallel with the wall faces; 18 direct measurement survey points for the wall face's displacement survey and 27 printed mark scale on the wall face fabric to investigate the occurrence of fabric creep on their layer lift fabric.
Most of these instruments can be identified in Fig.1(a),(b). After construction, 9 direct measurement survey points on the pavement surface above top of wall for the settlement above the embankment was installed.
To facilitate construction, geotextile layer spacing was 0.3m for lower layers (No.1 through No.3) and 0.4m for upper layers (No.4 through No.13) except 0.4m for cover layer and drainage layer. Therefore since the geotextile in upper layer

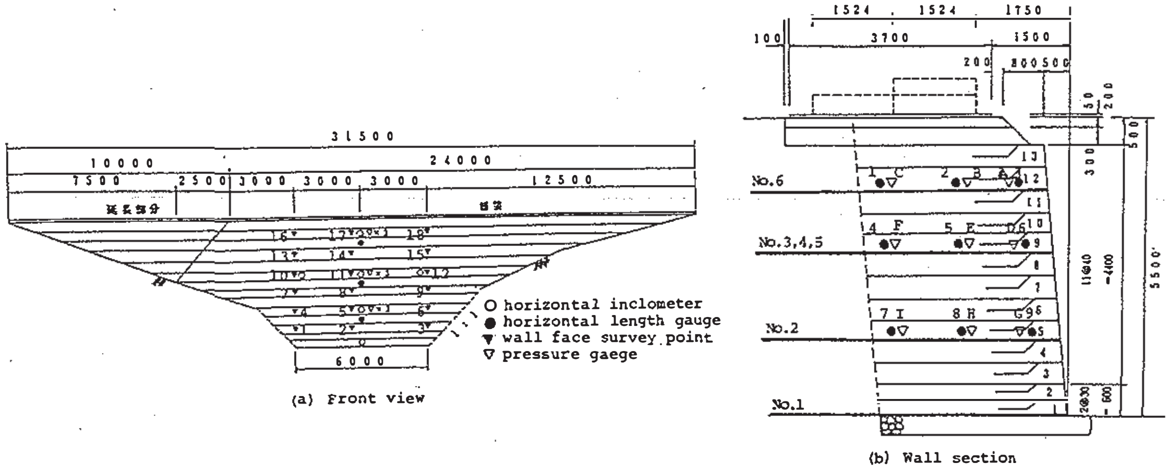


Fig.1 Profile of the retaining wall

and lower layer have different strength, the factor of safety are different for upper layer and lower layer. Safety considerations dictated that the wall not fail rapidly by static and dynamic load tests except excessive static loads test's pattern Ⅳ. Therefore some conservation was retained in this design method. However in static load pattern Ⅳ test, it is evident that the wall was falling forward rapidly and would exhibit significant strains in some fabric layers.
The wall was faced with a gunite after the wall's settlement was confirmed to be stable in March 1987. The project was performed by hanging the wire mesh on the end of folded rebars (ϕ =9mm, l=1.2m) buried in the wall soil and guniting about 11.5m^3 of gunite were required for the approximately 100m^2 of wall face.

2 STATIC AND DYNAMIC LOADS TESTS

After the completion of the wall in Feb. 1981, the static loads and dynamic load tests were conducted from Aug. 4th through 7th and after that, the continuous applied static load condition was applied until Aug. 23. This paper describes the wall behavior from this period and to present.

2.1 Test methods

In this static load test, the steel plate (l=6m, b=1.5m, t=25mm,w=1.8tf), 30 sheets were placed in various pattern shown in Fig.2, in one line or 2 lines. The static load's application is listed in Table 1. At first in Aug. 5th, static applied loads

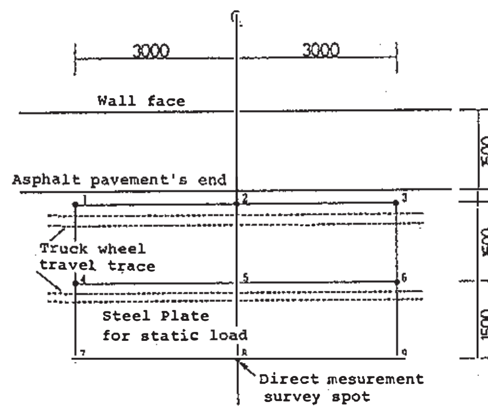


Fig.2 Loading positions

Table 1 The applications of static loads

	Front load		Back load	
	Number of plate	q (tf/m^2)	Number of plate	q (tf/m^2)
Pattern Ⅰ	10	1.96	——	——
Pattern Ⅱ	10	1.96	10	1.96
Pattern Ⅲ	20	3.92	10	1.96
Pattern Ⅳ	30	5.88	——	——
Pattern Ⅴ	——	——	30	5.88
Pattern Ⅵ	15	2.94	15	2.94

pattern Ⅰ, Ⅱ, Ⅲ, Ⅳ test by static loads was conducted. Next, dynamic loads test was performed. After dynamic load tests, static loads test Ⅴ, Ⅵ were done. The static load pattern Ⅵ load test was continuously applied for 16 days.
The dynamic load test was carried out by applying the truck loads (total weight 19.6tf). Every 50, 100, 200, 400, 600, and

Table 2 Pavement surface settlement

Load pattern	Survey point								
	1	2	3	4	5	6	7	8	9
Pattern III	0.003	0.004	0.002	0.002	0.003	0.0	0.0	0.0	0.0
Pattern IV	0.011	0.019	0.011	0.006	0.010	0.002	0.001	0.001	-0.001
50 passes	-0.008	0.0	0.001	0.003	0.001	0.0	0.001	0.001	-0.001
100 passes	-0.006	0.0	0.002	0.003	0.002	-0.001	0.0	0.0	-0.001
200 passes	0.006	0.002	0.005	0.003	0.001	0.0	0.0	0.0	-0.002
400 passes	0.015	0.003	0.007	0.003	0.001	0.002	0.0	0.001	-0.002
600 passes	0.010	0.008	0.010	0.006	0.0	0.002	0.0	0.001	-0.002
1000 passes	0.014	0.012	0.014	0.008	-0.001	0.002	0.003	0.002	0.002
Pattern V	0.014	0.013	0.014	0.008	-0.004	0.002	—	—	0.001
Pattern VI	0.011	0.012	0.017	0.011	-0.005	0.005	0.006	0.010	0.005

Table 3 Horizontal displacement in wall mass

Height(m)	Distance from wall face(m)		Date						
			2/16	7/17	7/30	8/4	8/7	8/20	3/27
h=0.0	Wall face	D=0.0	0	-0.3	-0.9	-1.2	-1.2	-1.1	-0.8
h=1.4		D=0.0	0	-0.1	0.3	0.3	0.3	0.7	1.2
h=3.0		D=0.0	0	1.4	1.5	1.8	3.7	3.9	4.6
h=4.6		D=0.0	0	1.9	3.3	4.9	7.1	7.2	7.5
h=1.4	No.3	D=0.50	0	0.2	-0.3	-0.3	-0.2	-0.2	0.6
h=3.0	No.5	D=0.50	0	1.1	1.0	1.5	3.1	3.3	4.2
h=4.6	No.9	D=0.50	0	1.8	2.7	4.4	6.5	6.5	7.6
h=1.4	No.2	D=1.75	0	-0.95	-0.85	0.75	-0.8	-0.5	-0.1
h=3.0	No.6	D=1.75	0	0.45	0.05	0.05	0.85	0.95	1.75
h=4.6	No.8	D=1.75	0	0.85	1.55	3.05	6.5	3.35	4.25
h=1.4	No.1	D=3.50	0	0.2	-0.9	-1.0	-1.2	-1.5	-0.5
h=3.0	No.4	D=3.50	0	1.1	-1.0	-1.0	-1.3	-1.4	-0.6
h=4.6	No.7	D=3.50	0	1.8	0.25	1.05	3.1	0.25	1.05

Table 4 Horizontal displacement in wall by load

Height (m)	Distance from wall face(m)		static load test				dynamic load test						static load test		
			8/4	III	IV	deloading	50	100	200	400	600	1000	V	VI	8/26
h=0.0	Wall face	D=0.0	0	0.1	0.2	0.2	0.0	0.0	-0.1	-0.1	-0.2	-0.2	-0.1	-0.1	-0.1
h=1.4	Wall face	D=0.0	0	0.4	0.6	0.6	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.4
h=3.0	Wall face	D=0.0	0	0.7	1.4	1.6	1.5	1.5	1.5	1.5	1.6	1.7	1.6	1.8	1.8
h=4.6	Wall face	D=0.0	0	0.6	1.5	1.8	1.8	2.0	2.4	2.7	3.0	3.2	3.2	3.4	2.2
h=1.4	No.3	D=0.50	0	0.2	0.5	0.4	0.0	0.2	0.2	0.1	0.1	0.0	0.1	0.0	0.1
h=3.0	No.5	D=0.50	0	0.2	1.2	1.4	1.3	1.4	1.4	1.3	1.4	1.5	1.3	1.3	1.6
h=4.6	No.9	D=0.50	0	0.6	1.6	1.9	1.8	1.9	2.3	2.6	3.0	3.3	3.2	3.3	2.0
h=1.4	No.2	D=1.75	0	0.3	0.4	0.5	-0.2	-0.7	-0.1	-0.1	-0.1	-0.3	-0.2	-0.2	-0.2
h=3.0	No.6	D=1.75	0	0.2	0.5	0.7	0.8	0.7	0.7	0.6	0.7	0.7	0.6	0.3	0.6
h=4.6	No.8	D=1.75	0	0.4	0.7	0.8	0.9	0.9	0.9	1.1	1.2	1.4	1.4	1.4	0.2
h=1.4	No.1	D=3.50	0	0.1	0.3	0.0	-0.1	-0.1	-0.1	-0.2	-0.2	-0.3	-0.2	-0.2	-0.5
h=3.0	No.4	D=3.50	0	0.0	1.3	0.8	-0.3	-0.2	-0.3	-0.4	-0.4	-0.4	-0.5	-0.8	-0.8
h=4.6	No.7	D=3.50	0	0.0	1.3	0.2	0.1	0.0	1.4	0.2	0.3	0.3	0.4	0.4	-0.9

1000 passes the rut depth and settlement at the direct measurement survey point on the pavement surface were surveyed and their result are listed in Table 2.

The largest direct settlement on the pavement above the top wall was about 2cm at pt.2 and about 1cm at pt.1,3 and 5 in the case of loads pattern . At that time, cracking grew through pt.4 and 6 as a circle which pt.2 is the center. As for dynamic load test, about 4p rut depth was produced after 1000 passes because of new pavement roads (Table 2).

2.2 Measurement of the wall face behavior

The wall face movement by the static and dynamic load test was shown in Fig.3,4 and Table 3,4. The displacement and movement became rapidly larger near the wall top.

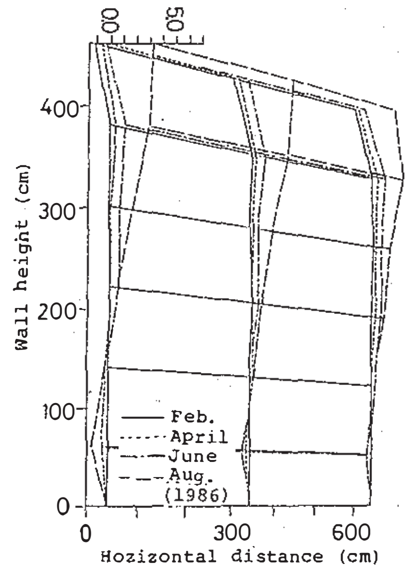


Fig.3 Wall face movement

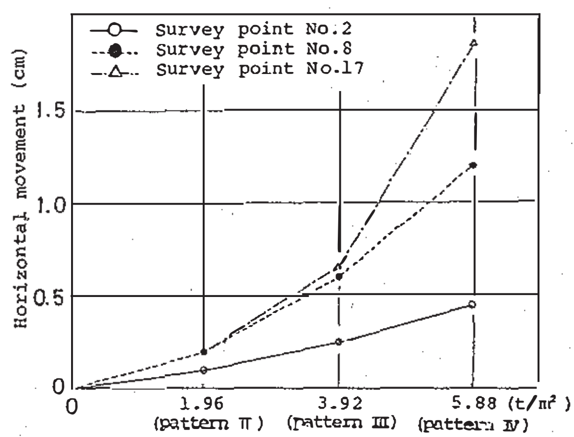


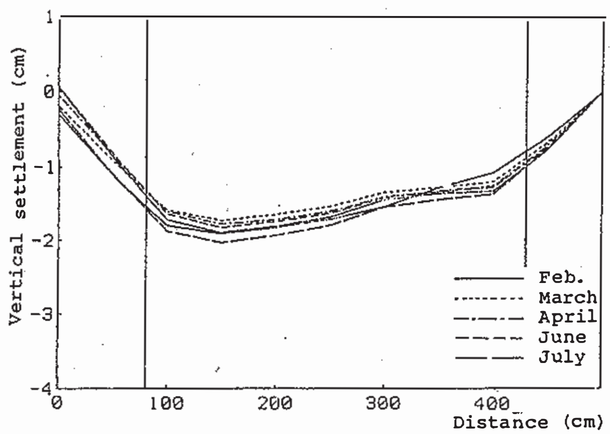
Fig.4 Horizontal movement on No.2,No.8, No.17 under the pattern Ⅳ load

In static load patternⅣ, the top of the wall moved about 2cm forward but at foundation ground, less displacement was produced at any loads pattern. For load application patternⅣ, the displacement was the largest and in very short time, the wall top started to incline forward rapidly. So this test was stopped. We could recognize this displacement to be the critical condition.

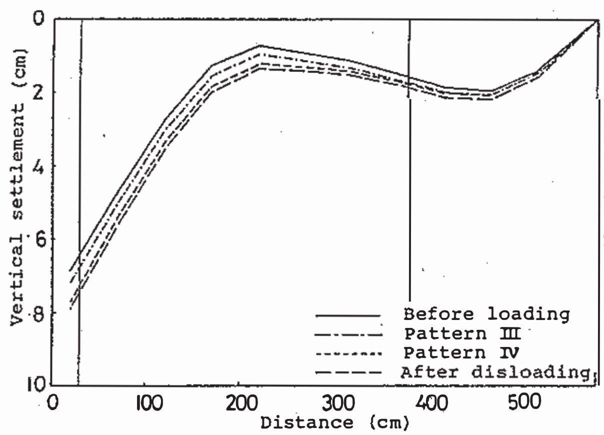
In the dynamic load test, as a number of passes increase, the displacement grew larger at h=4.6m survey point, however, their values were less than 1cm. Under h=3.0m, layers 8, the movement disappeared gradually.

2.3 Horizontal distance variations measurement in the wall mass

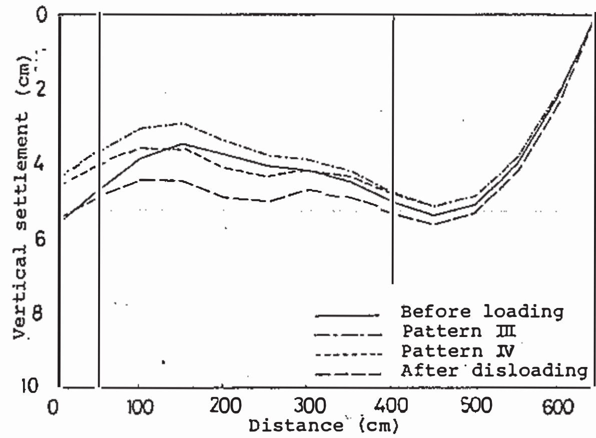
On layer 4(h=1.4m), layer 8(h=3.0m) and layer 12(h=4.6m) at the center section, the displacement at pt.A-I which are at 0.5m, 1.75m and 3.5m from the wall face on layer 4,layer 8 and 12 of the wall center section were surveyed and calculated by observation of horizontal length gauge's relative and differential displacement. Their movement at each point looked similarly to the wall face movement but their values reduced as the distance from wall increased and the distance from the wall crest increased. The result was accurate and useful. Moreover their movement has a tended to displace toward back side under layer 4(h=1.4m) and beyond D=1.75m from the wall face. The wall top's movement was about 2cm forward in the case of



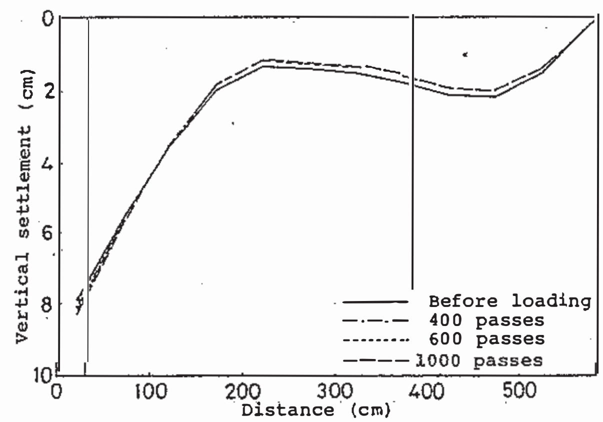
(a) Vertical settlement of No.1 inclinometer as the time elapsed



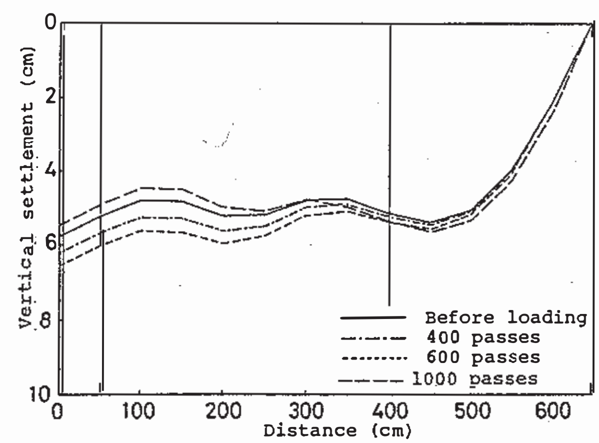
(b) Vertical settlement of No.4 inclinometer under the static load



(c) Vertical settlement of No.6 inclinoneter under the static load



(d) Vertical settlement of No.4 inclinometer under the dynamic load



(e) Vertical settlement of No.6 inclinometer under the dynamic load

Fig.5 Vertical settlement curves by inclinometer pattern and about 1.4cm at 1000 pass cycle run time.

2.4 Settlement measurement by horizontal inclinometer

The settlement curves measured by the horizontal inclinometer installed in foundation ground (h=0.0m), layer 4, layer 8 and layer 12 was shown Fig. 5(a),(b),(c),(d),(e).

The settlement curves on foundation ground at construction completion was about 1.5cm the maximum settlement in vicinity of 1.0m from the wall face looked like downward bow. Their ground had been almost in stationary up to date, except critical situation by excessive loads because their curves were unchangeable up to date. The distance length between the left fine line, the wall face and the right fine line, the end of fabric are fabric installation length and the right ends of curves is the fixed point of the inclinometer casing. The vertical axis indicate the settlement and horizontal axis indicate the horizontal length. From Feb. to 4th Aug. the settlement on layer 8 and 12 inclined to increase rapidly in parts of beyond 3.4m length from the wall face, no fabric areas and front parts of less 2.0m from the wall face, the fabric folding back sections because lack of the compaction. Their shape were laterally adverse S character shape toward the fixed point from Feb. to 4th Aug.. In static and dynamic loads test the settlement curves on layer 12 (No.7) and 8 (No.3,4,5 h=3.0m) increases in proportion with the load's increasing and as shown in Fig.5(c),(e) the settlement curves in back fill soil just under the application loads is producing a very interesting second curves by loads.

The maximum settlements on layer 12 and 8 were about 1.0cm and less 0.5cm respectively in the case of loads pattern Ⅳ. At 1000 passes of dynamic load test, about 1.0cm settlement was observed on layer 12 while it disappeared on layer 8.

In the parts beyond the application load point, the settlements were not visible apparently and conversed toward a fixed point. It is found that the movement in the wall soil look like one on the pavement surface and the wall face.

2.5 Checking of safety factors

As for safety factors of pullout resistance and rupture resistance, the checking

Table 5 Calculation of safety factor under the pattern Ⅳ load

Layer	Depth to bottom of layer(m)	Depth to middle of layer(m)	F_{hd} (t/m)	F_{hl} (t/m)	F_h (t/m)	L_e (m)	P (t/m)	F.S. (Pullout)	F.S. (Rupture)
13	0.95	0.75	0.211	0.517	0.728	1.392	1.882	2.586	1.551
12	1.35	1.15	0.324	0.546	0.869	1.600	3.015	3.531	1.265
11	1.75	1.55	0.436	0.084	0.520	1.808	4.504	8.662	2.135
10	2.15	1.95	0.549	0.121	0.670	2.016	6.171	9.123	1.627
9	2.55	2.35	0.661	0.083	0.744	2.225	8.015	10.849	1.479
8	2.95	2.75	0.774	0.091	0.865	2.433	10.216	11.805	5.431
7	3.35	3.15	0.887	0.095	0.982	2.641	12.594	12.828	4.181
6	3.75	3.55	0.999	0.096	1.095	2.849	15.210	13.894	4.293
5	4.15	3.95	1.112	0.094	1.205	3.055	18.062	14.986	3.900
4	4.55	4.35	1.224	0.090	1.314	3.266	21.152	16.094	3.576
3	4.95	4.75	1.337	0.086	1.422	3.474	24.478	17.209	3.304
2	5.25	5.10	1.077	0.061	1.138	3.630	27.129	23.849	4.132
1	5.50	5.40	1.140	0.058	1.198	3.786	29.913	24.968	3.923

Table 6 Calculation of safety factor under the dynamic load

Layer	Depth to bottom of layer(m)	Depth to middle of layer(m)	F_{hd} (t/m)	S_{ld} (t/m)	F_h (t/m)	L_e (m)	P (t/m)	F.S. (Pullout)	F.S. (Rupture)
13	0.95	0.75	0.211	0.144	0.355	1.392	1.882	5.295	3.095
12	1.35	1.15	0.324	0.109	0.432	1.600	3.015	7.118	2.541
11	1.75	1.55	0.436	0.071	0.508	1.808	4.504	8.874	2.167
10	2.15	1.95	0.549	0.046	0.595	2.016	6.171	10.375	1.849
9	2.55	2.35	0.661	0.030	0.692	2.225	8.075	11.677	1.591
8	2.95	2.75	0.774	0.020	0.794	2.433	10.216	12.962	5.917
7	3.35	3.15	0.887	0.014	0.901	2.641	12.594	13.983	5.218
6	3.75	3.55	0.999	0.010	1.009	2.849	15.210	15.070	4.657
5	4.15	3.95	1.112	0.007	1.119	3.058	18.062	16.139	4.200
4	4.55	4.35	1.224	0.006	1.230	3.266	21.152	17.198	3.821
3	4.95	4.75	1.337	0.004	1.341	3.474	24.478	18.251	3.504
2	5.25	5.10	1.077	0.003	1.079	3.630	27.129	25.139	4.355
1	5.50	5.40	1.140	0.002	1.113	3.786	29.913	26.138	4.115

was conducted, ignoring the fabric's elongation because the time from construction to test is very short, only 5 months.

Table 5,6 showed the safety factor calculation by static and dynamic loads. The calculation was conducted by New mark for uniform steel plates loads and Boussinesq's formula by the truck loads. The rupture resistance was a little short at some layers. For example, safety factor on layer 8 is 1.47 for rapture in the case of pattern Ⅳ and 1.59 for pullout in dynamic test. So it is safer for pullout resistance but is insufficient for rupture resistance. Thinking of long term creep criteria, the rupture resistance becomes a little dangerous. The present design method which takes long term creep criteria and safety factor 1.5 for both pullout and rupture resistance is believed to be conservative.

2.6 The wall's behavior with time and rainfall

The measurement was conducted twice or once month from 28th Feb. 1986, the day which is the construction completed to 4th Aug. and after that was continuously performed once a month. The wall's face horizontal movement on layer 8 exposed face from 27th Feb. to 4th Aug. on layer 12 was 4.4cm(5 month), caused by soil consolidation and compaction. The displacement by static and dynamic load test was 2.2cm while the movement from 20th Aug. to 27th Mar. 1987 was only 0.3cm during 7 months. The back fill soil was consolidated by excessive (static and dynamic) loads. So it is very important to compact the soil for geotextile reinforced wall engineering. There were total amount rainfalls 1046mm from Mar. to Aug. and over 200mm in May, June and July (shown in Fig.6). Especially in 20th July, there were 137mm rainfall and 31mm one hour rainfall (Yamashiro heavy rain disaster) about 0.9o horizontal displacement was observed on layer 12 face from 17th July to 30th July. However in 1986 there were less displacement.

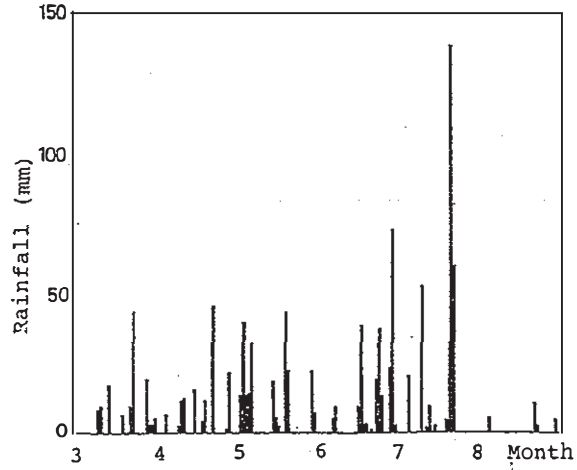


Fig.6 Rainfall data

2.7 Facing and cost consideration

The wall was faced with a gunite in March 1986 after the wall stabilization was confirmed.
At Nomura tunnel entrance approach road, the geotextile reinforced retaining wall was constructed. This wall's scope is following. Height 3.9m, wall top length 159.4m, surface area 217u. At this project, the comparative checking was made for cost and construction time on the geotextile wall, reinforced concrete wall (inverse T type) and Terre-arme type (metal crib or concrete crib). It is found that the geotextile reinforced wall is the most economical and construction time is the shortest. The geotextile reinforced wall was adopted because of this reason and limited right of way.
The behavior survey was performed but was not accurate because of the project work's vandalism.

3 CONCLUSION

As stated above, the static loads test to maximum loads intensity $5.88tf/m^2$ was performed. The maximum settlement was 2.0cm at pt.2, and less than 1.0cm at other point on the pavement and as for horizontal displacement the movement on the wall top was about 3.0cm forward ,but there were less than 1.0cm displacement backward displacement on the foundation ground as the consolidation progress. In dynamic loads test, the truck 20ton travel forth and back 1000 times and the settlement was less than 1.5cm at their maximum settlement point on the pavement surface and the settlement in proportion with numbers of pass increasing had not been observed.
As for safety factor, there are no problems as long as granular materials is utilized as backfill. Values of 35° and 1.6 t/m^3 are assumed for ϕ and unit weight of backfill. This value of ϕ may be low. The analysis is assumed the at rest earth pressure (K_0) rather than the active pressure (Ka). The use of the at rest pressure was reasonable when the heavy traffic loads were expected but may be excessively conservative for the dead loads only. This could result in over estimation of the total load to be resisted by the geotextiles. The theory is tie back analysis but wall is composite reinforced materials but how conservative is not known. At the present conventional design, safety factor values 1.5 for rupture resistance was appropriate. This wall was made of the granular material. The study for cohesion material will be done in the future.

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