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Fabric Retaining Walls

Mur de soutement de géotextile

The fabric retaining wall with multiple anchors was designed utilizing the merits of fabrics, light weight, ease of handling, and economy. Problems were earth pressure on the vertical wall, strength of fabrics, and method of construction. Results of a full scale model test revealed that the earth pressure estimated was satisfactory. The fabrics used were strong enough for this type of retaining wall. Problems related to construction were solved during construction. This type of retaining wall can be recommended for temporary construction work even soft ground without piling. Fabric gabions which were used for preventing the occurance of fault between bridge abutment and backfill, a retaining wall made of fabric sheets, and a large concrete block retaining wall with fabric at its back face are introduced here in brief.

La paroi de retenue structurée à ancres multiples a été réalisée en mettant en valeur des qualités remarquables, soit: une legerete de poids, une utilisation facile et un avantage économique. Le problème était la pression de terre contre la paroi verticale de face, c'est-à-dire la solisité de structure et la méthode de construction. Les résultats des examens sur des modèles de grandes dimensions ont révèlè que sa résistance à la pression de terre satisfaisante. La structure utilisée avait une solidité suffisante pour ce type de parois. Les problèmes relatifs à la construction ont été resolus au cours de celle-ci. Une paroi de retenue de ce type peut etre utilisée sans pilier, meme aux sols mous et est recommandable pour les travaux de constructions temporaires. La gabions de structure destinés à la prévention des différences de niveaux qui peuvent survenir entre les parois de retnue des butées et des remlais des butées des points, les parois de retenue fabriquées avec des feuilles structurées, etc. seront presentes brièvement.

INTRODUCTION

Professor Fukuoka has conducted research work on retaining walls collaborating with many engineers for about 20 years. Field tests, laboratory testings, and theoretical analysis have been carried out on cantilever walls, concrete block walls, inverted Y type walls, concrete frame walls, steel walls, and multiple anchored walls. He has been studying fabric retaining walls for about 10 years. Here are four examples.

(1) Cylindrical, fabric sand packs (gabions), were placed horizontally inside the backfill of a cantilever retaining wall (Fig. 1). Prior to this experiment with the prototype retaining wall, small scale model tests were performed in order to compare the effectiveness of sand pack and fabric sheets. According to the test results, a large fault between the concrete wall and the settled backfill did not appear due to the function of the sand packs. A car running at high speed on pavement laid on the backfill will run into the abutment at this large fault. The sand packs will serve as an anchor and drain in the backfill. Very strong fiberglass was used for the sand packs so that they would not break or tear.

(2) Fig. 2 shows a retaining wall made of fabric sheets and steel wire meshes with steel plates. This experiment was performed by Yamada and Sakaguchi of the Taisei Corporation as suggested by Prof. Fukuoka. The steel meshes and the fabric sheets were laid horizontally. The tail of the mesh is inserted into the backside slope as an anchor, and the front of the retaining wall felt with seeds is inserted between the steel mesh and vinyl net.

(3) The retaining wall in Fig. 17 is composed of heavy concrete blocks weighing 10, 20, and 40 kN. Fablic is placed behind the back of the retaining wall in order to let water drain out without bringing sand in the backfill. The fabric should be permeable, strong enough not to be torn even by the strong impact of rocks, and durable without aging. It is important for design to know earth pressure on the back side of the concrete blocks.

(4) Prof. Fukuoka inverted the multiple anchored retaining wall, and used fabric for the front wall. The following sections 1-7 are a report of the testing.

1 DESIGN OF FABRIC RETAINING WALL

The test retaing wall is 5m high. It has a row of columns, fabric stretched between them, and steel rod anchors. It is necessary to estimate earth pressure on the vertical wall and forces acting on the anchors. With reference to past case records, the following were assumed---unit weight 13.5 kN/m^3, coefficient of earth pressure on the assumed vertical wall at about 5m behind the vertical front wall 0.5, diameter of steel rod 19mm, frictional force on the steel rod 2 kN/m, frictional stress between the base ground and the backfill 3.5 kN/m^2. Fig. 3 shows earth pressures and forces acting on members of the retaining wall and backfill used for design. The cross section of the concrete column is square (20cm x 20cm) and 4 stages of steel bars (diameter 19mm) are inserted. Concrete anchor plates are square in shape, and their size is 40cm x 40cm x 10 cm. An anchor should be strong enough to resist pulling out force and small enough in order not to disturb the movement of a bulldozer. Two kinds of fabrics are used, namely net type and sheet type. The net type fabrics are easy to stretch, and therefore they were fixed flat

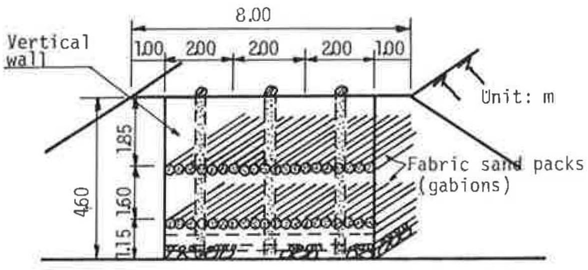


Fig.1 Front view of gabions placed in backfill behind vertical wall of cantilever retaining wall.

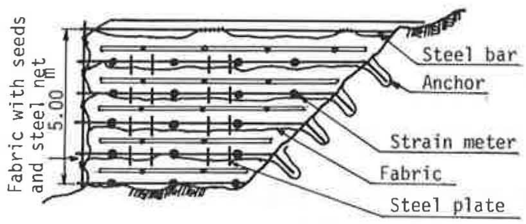


Fig. 2 Cross section of fabric retaining wall.

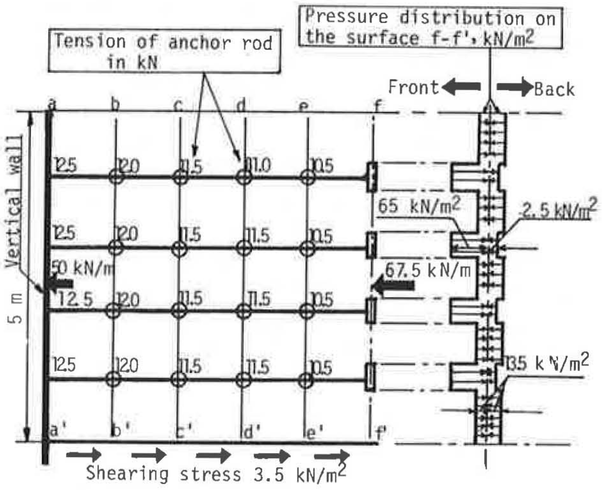


Fig.3 Assumed forces and stresses used for design.

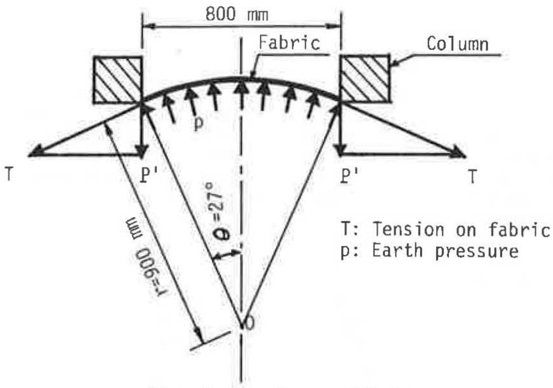


Fig. 4 Tension on fabric.

Table 1. Test results of fabrics.

Name	Testing	Direction	Before construction (A)	After one year(B)	B/A in %
Sheet type fabrics	Tensile strength in kN/m	Longitudinal	72.0	66.0	92
		Transversal	74.0	53.0	72
	Elongation in %	Longitudinal	20.0	15.8	79
		Transversal	18.0	9.0	50
Neet type fabrics	Tensile strength in kN/m	Longitudinal	61.0	57.0	93
		Transversal	62.0	55.0	89
	Elongation in %	Longitudinal	27.5	25.3	92
		Transversal	26.8	24.7	92

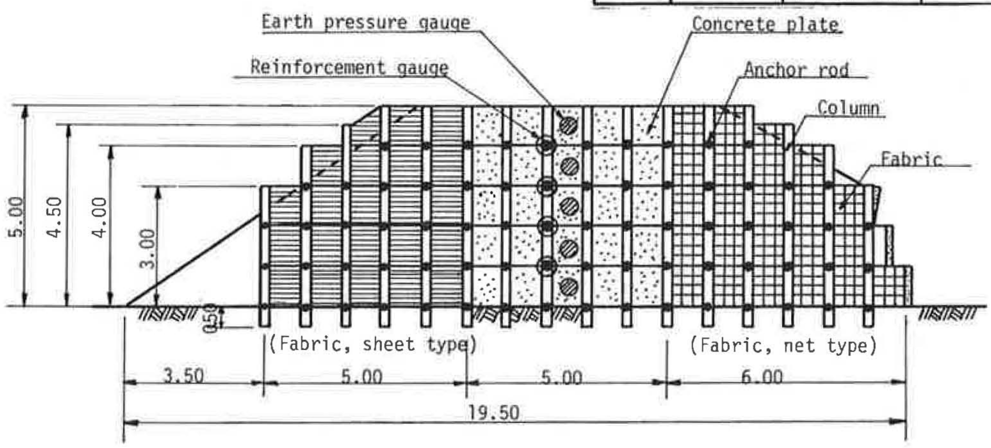


Fig.5 Front view of retaining wall (unit:m).

to the concrete columns without any slack. The sheet type fabrics were fixed to the concrete columns with slack. Both of them are expected to become a semi circle as shown in Fig. 4. The earth pressure on the front wall was assumed to be 12.5 kN/m^2, but the design earth pressure for the fabric wall was taken as 20kN/m^2, considering the scattering of earth pressure. The fabric used was 1.25m wide and its tensile strength was 60-72 kN/m (Table 1). The tensile force acting on the fabric was computed as 18 kN/m, which was much less than its tensile strength. Fig. 5 shows the front view of the test retaining wall. Concrete slabs were used at the middle part of it for measuring earth pressure with earth pressure gauges.

2 PLAN OF MEASUREMENT

Earth pressure gauges were attached to the front and rear faces of the concrete anchor plates. Wire strain gauges were pasted to the 4 steel rods. Earth pressure gauges were attached to the back faces of the concrete plates placed just behind the concrete columns. Fig. 6 shows a picture of the instrumentation arrangement. Displacement of columns and settlement of the backfill were measured.

3 TEST RESULTS OF FABRIC AND SOIL

Water content, unit weight, and static cone resistance were measured during construction. Table 2 shows the results of soil tests. Table 3 shows the properties of the fabrics.

4 CONSTRUCTION OF RETAINING WALL

First, the holes were excavated, and the concrete columns were erected. The cross section of a hole was 0.4 m x 0.4 m and the depth was 0.5 m. The size of the column was 0.2 m x 0.2 m x 5.5 m. It was about 5.5 kN in weight. The column had 5 holes with a diameter of 0.3 m at the heights of 1.0, 2.0, 3.0, 4.0 m from the ground surface. The steel anchor rod had two long bolts (diameter 19 mm, length 400 mm) at each end. The concrete anchor plate had a hole for the anchor rod. The threaded long bolts were used instead of turnbuckles. The concrete plates attached behind the columns were 1 m x 1 m x 0.15 m in size and had no reinforcement. The concrete columns erected vertically at 1 m intervals (Fig. 5). The lowest stage of anchors were set on the ground. The concrete plates and fabrics were attached behind the columns. The net type fabric was stretched on the right as one faced the wall, and the plate type fabric was attached on the left with slack. Both ends of the fabrics were wound around wooden square beams, and fixed to the concrete columns with steel wires. The fabrics were fastened lightly to the columns with wires. A small bulldozer weighing 4 tons was used for the filling operation. Dry density of the backfill was rather low as indicated in Table 1, and it was 79-85 % of the maximum dry density by laboratory compaction test. The second stage anchors were laid on the fill surface 1 m high. The second stage fabrics and concrete plates were fixed to the concrete columns. The backfill was raised up to 2 m. Similar operations were repeated until the fill height reached the level of 5 m. A light steel frame work was installed to support the concrete columns from the beginning of construction work till the completion of the second layer of 2 m, in order to prevent the columns from inclining. If the frame work had been used from the beginning to the end of construction, the deformation of the retaining wall would have been much smaller. Steel pipes of 80 mm in diameter could have been used instead of the heavy concrete columns which required a crane for erection.

5 RESULTS OF MEASUREMENT

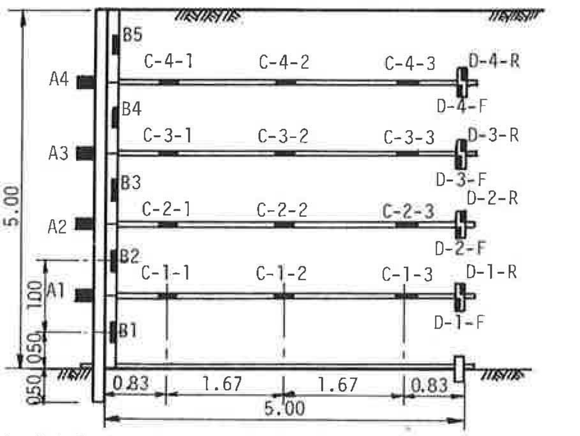
Fig. 7 shows the earth pressures on the back side of the vertical wall and the back and front faces of the anchor plates, and the tensions of the anchor rods. The measurements have been continued for more than one year after the completion of construction, and earthquake forces were recorded. Fig. 8 shows displacement of the concrete column. Unit weight, water content, and cone resistance, were measured as 14.5 kN/m^3 (12.3-15.4), 71.0 % (55.0-94.9), and 40 kN/m^2 (20-100), respectively. Fig. 9 shows the cone resistance with depths. The settlement plates were placed on the ground surface (EL 0), and at the levels of EL 0.782 m, EL 2.424 m, EL 3.795 m respectively. The amounts of settlement were measured as 0.082, 0.087, 0.142, and 0.075 m respectively. A reinforcement gauge and three sets of wire strain gauges were attached to the steel anchor rod. Fig. 10 shows the results of these measurements. The tensile forces measured with the reinforcement gauges were lower than those of the wire strain gauges. Friction between the rod and the column may be the reason for this difference. The tensile force of the anchor rod is caused by the relative displacement of the anchor plate. The relationship between the relative displacement and tensile force of rod can be obtained as shown in Fig. 11. The anchors at the levels of 1 and 2 m (C-1,C-2) have a resistance of about 10 kN corresponding to displacement 25 mm, but the resistance of the anchors at the level of 3 and 4 m (C-3, C-4) is 5 kN for the same 25 mm displacement. The reason for this displacement may be soil properties which are represented as the cone resistance of the backfill as shown in Fig. 9. Frictional force acting around the rods C-2,3, and 4 is small, and that of C-1 is 2-3 kN. Earth pressure on the backside of the vertical wall was measured with earth pressure gauges. If the fabric had been fixed without any slack, and stretched out only by by the earth pressure, acting earth pressure on the fabric could have been back calculated. However the acting earth pressure could not be back calculated because the fabric was fixed to the columns with slack. The shapes of the fabric between the columns, bent by the earth pressure, were measured. Fig. 12 shows one example of the lower part of the wall, where the earth pressure is the highest. Tensile strength of the double fabrics was 142 kN/m at the end of construction, and so the fabrics will be safe for many years even if they lose their strength by aging. Fig. 13 shows earth pressure obtained by the earth pressure gauges installed in the anchor plates.

6 COMPARISON OF MEASURED VALUES WITH PREDICTED ONES

The design of the retaining wall was made based on assumed earth pressure on the vertical wall and anchor plates, and assumed tensile forces acting on the anchor rods. Fig. 3 shows the assumption used for design. Comparing the measured values with the assumed ones, the following conclusions may be reached.

(1) The earth pressure on the vertical wall is shown on Fig. 14. The distribution of earth pressure was assumed to be similar to that on sheeting of open cut. In this case the earth pressure diagram has a triangular shape, but a trapezoidal shape was assumed for design. Total horizontal earth pressure was 65 kN/m, and this is much larger than the design earth pressure of 50 kN/m. The coefficient of earth pressure 0.36 is plotted on Fig. 15 showing inclination of walls versus coefficients of earth pressure. Earth pressure on the assumed vertical wall ff' is 82.5 kN/m, which is much larger than the predicted one of 67.6 kN/m, and the coefficient of earth pressure is 0.45 contrary to the expected one of 0.4.

(2) The tensile force on each rod was assumed to be



A : Reinfocement gauge. B : Earth pressure gauge on front wall.
C : Wire strain gauge.
D : Earth pressure gauge on anchor plate.

Fig.6 Arrangement of gauges (unit in m).

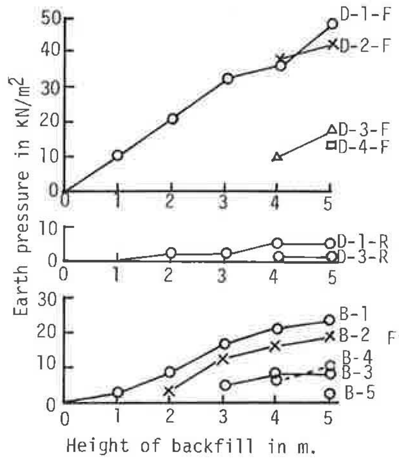


Fig.7 Earth pressure on vertical wall versus height of backfill.

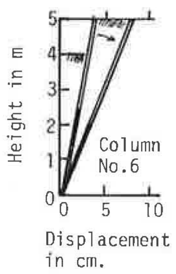


Fig.8 Displacement of concrete column.

Table 2. Results of soil test.

	Backfill	Foundation	Remarks
Natural water content w %	73.0	85.0	
Unit weight γ kN/m^3	14.6	15.1	
Specific gravity Gs	2.61	2.71	
Liquid limit w_L %	85.2	156.5	
Plastic limit w_P %	66.9	52.7	
Cohesion Cu kPa	1.1 2.6	1.1	Triaxial test
Angle of inter friction ϕ_u	15	5	
Optimum moisture content w_{opt} %	62.0	JIS 1-1-b	
Maximum dry unit weight γ_{dmax} kN/m^3	9.42		
Optimum moisture content w_{opt} %	71.0	JIS 1-1-a	
Maximum dry unit weight γ_{dmax} kN/m^3	8.70		

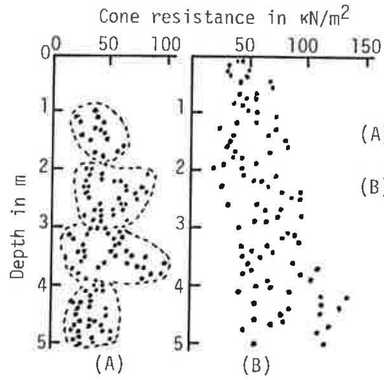


Fig.9 Cone resistance.

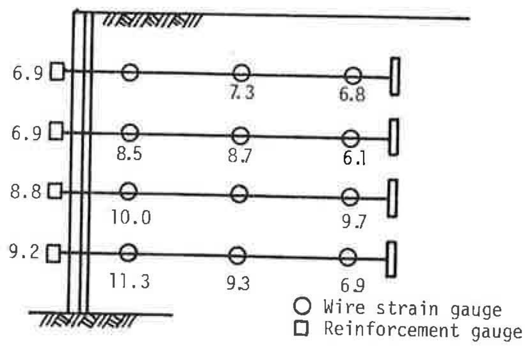


Fig.10 Tension on anchor rod in kN.

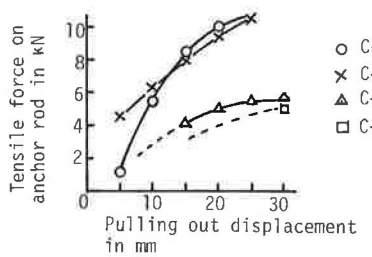


Fig.11 Pulling out displacement versus tensile force of anchor.

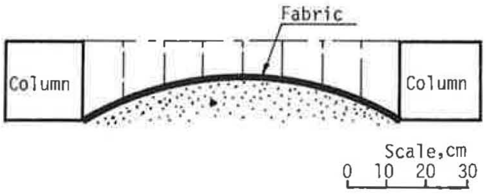


Fig.12 Lower part of fabric wall.

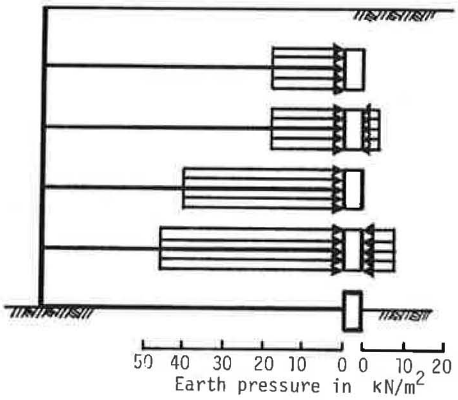


Fig.13 Earth pressure on anchor plate.

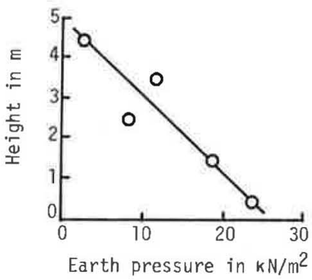


Fig.14 Earth pressure on vertical wall.

Table 3. Fabric used for large concrete block retaining wall.

	Longitudinal	Transversal
Maximum tensile strength (kN/m)	6.08	9.87
Elongation at failure (%)	180	89
Tearing strength (N)	255	665
Weight:300 g/m^2, Thickness:4 mm Coefficient of permeability:3 x 10^{-2}cm/s		

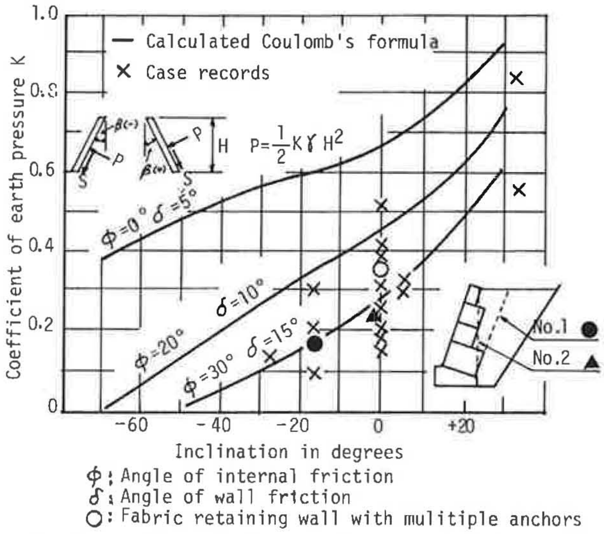


Fig.15 Coefficient of eath pressure and inclination of retaining wall.

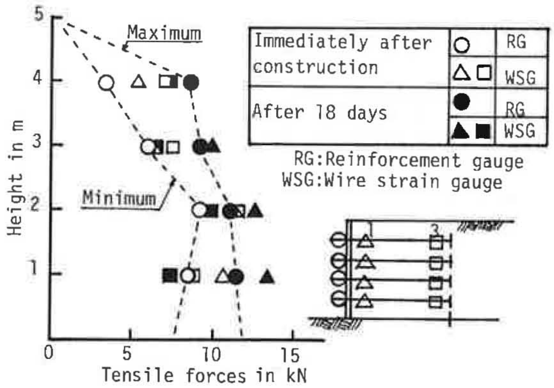


Fig.16 Maximum and minimum tensile forces measured.

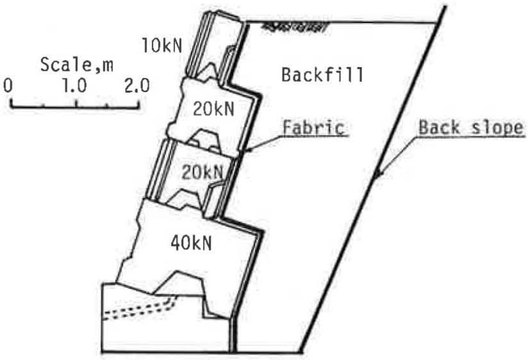


Fig.17 Large concrete block retaining wall with fabric sheet backside.

12.5 kN near the vertical wall and 10 kN near the anchor plate. The assumed values are rather smaller than the predicted ones, with a maximum 11.3 kN and minimum 6.8 kN. The friction on rods was assumed to be uniform and 0.2 kN/m, but actually ranged from -0.1 to +1.6 kN/m, and their magnitudes and directions were not the same. Only the anchor 1 m high showed high frictional force.
(3) Earth pressures on the front and rear sides of the anchor plates were assumed to be 65 kN/m^2 and 2.5 kN/m^2, respectively. The earth pressures on the other plates measured were smaller than the assumed ones. The reason for this difference seems to be the difference of earth pressure distribution, and non uniform tensile forces on anchor rods.
(3) The assumption, as shown in Fig. 4, used for designing fabrics seems to have been quite satisfactory.

7 RESULT OF LONG TERM OBSERVATION

The retaining wall has been left for about one year, and earth pressure, deformation, and its behavior during heavy rains and earthquakes have been observed. The test was performed after about one year with the fabrics to study the effects of aging.
(1) The earth pressure has changed with time. Fig. 16 shows the maximum and minimum limits of earth pressures. The effects of earthquakes and heavy rains were relatively small compared with the changes at ordinary times.
(2) It has been said that a retaining wall with cohesive soils as backfill moves forward with time, but this retaining wall has shown no appreciable movement since its completion.
(3) Increment of earth pressure during heavy rains were on the order of 0.1 kN with the C-1 anchor. There were several earthquakes recorded. The tensile force on C-1 anchor was 0.3 kN during the earthquake, accelaration of of which was 16 gals at the ground, and 51 at the top. The tensile force was generated by inertia force on the column.
(4) Pieces of the fabrics were cut out and tested. The results are written in Table 1. Judging from the test results, the fabrics may be used for 5 to 10 years.

8 TEST ON LARGE CONCRETE BLOCK RETAINING WALL WITH FABRIC SHEET BACKSIDE

Large concrete blocks weighing 10-60 kN are piled up

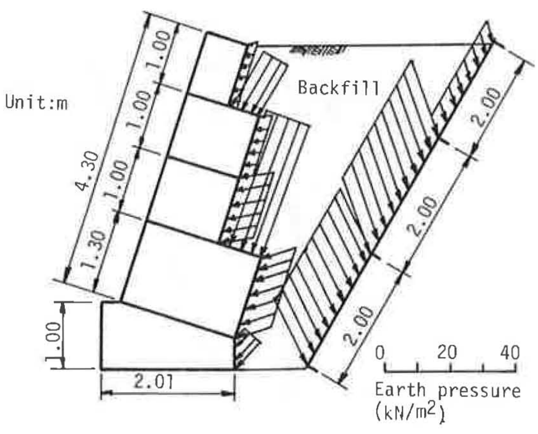


Fig.18 Earth pressure measured.

and an inclined retaining wall is constructed with mixture of coarse gravels and sands with silts as backfill (Fig. 17). The concrete blocks have cavities, through which water in the backfill can be drained. Fabrics are placed on the backside of the retaining wall in order to prevent spilling of fine materials in the backfill. The fabric should be permeable. As large rocks are thrown into the backfill space, the the fabric should be strong enough to withstand the shock of rocks. The life of the fabric should be sufficiently long. Table 3 shows the characteristics of the fabrics used. A spilling test with fine sands 0.105 - 0.25 mm in diameter was performed. No sign of spilling of sands was noticed. Good results were obtained in a shock test with gravel and a laboratory aging test. The prototype model test was performed to study earth pressure on the retaining wall at ordinary times. The increment of earth pressure was very small when artificial heavy rain was applied. Fig. 17 shows a cross section of the retaining wall. The panel type pressure gauges were installed behind the blocks. This particular retaining wall has fabrics on the back face, and has steps too. It makes it quite difficult to estimate earth pressure on the retaining wall. Fig. 18 shows measured earth pressure by arrows. Coefficients of earth pressures on the assumed surfaces No. 1 and No.2 on Fig. 15 are K=0.18 and 0.25 respectively. Those coefficients are plotted on the figure. Angles of wall friction δ are as large as 47 and 36 degrees for the assumed surface No. 1 and 2 respectively. Those values are much larger than what would be commonly thought.

CONCLUSIONS

(1) Fabric retaining walls with multiple anchors were tested. It was revealed that a retaining wall of this type can be constructed easily even by unskilled workers, that speed of construction is very high, that relatively soft foundations can be used without piling, and more over that it is very economical. Therefore, it can be used for temporary construction of 5-10 years.
(2) The large concrete block retaining wall has been used at mountainsides. The back side of the retaining wall has steps and fabric. The panel type earth pressure measuring system was used to get accurate earth pressure on this retaining wall. It was found that a large angle of wall friction appeared on the back face. The use of fabrics was justified.

ACKNOWLEDGEMENTS

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REFERENCES

Fukuoka, M. and others, "Earth pressure measurements on retaining walls," Proceedings of Tenth International Conference on Soil Mechanics and Foundation Engineering, Case History Volume,(Tokyo, 1981), 237-296.

Fukuoka, M., "Static and dynamic earthpressure on retaining walls," Proceedings of Third Australia-New Zealand Conference on Geomechanics, Volume 3, (Wellington, 1980), 3-77 - 3-46.