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FABRIC RETAINING WALL WITH MULTIPLE ANCHORS
MUR DE SOUTIEN DE GROS-OEUVRE AVEC ANCRAGES MULTIPLES
STAHLGEWEBE-BÖSCHUNGSMAUER MIT MEHREREN ANKERN

About 5 years have passed since the fabric retaining wall with multiple steel anchors and reinforced concrete columns were installed. Earth pressures at ordinary and earthquake times, displacements, deformations and deterioration of fabrics have been measured during the past years. All the bolts fixing the steel anchor rods were screwed back and the earth pressure of the backfill against the wall was reduced to zero, although the displacement was only 0.6 mm (wall height: 5m). The ratio of displacement to the wall height was much smaller than the one reported by other authors. A part of the fabric wall was successfully replaced by the new fabric. As the result of the tests, the stability and durability of the fabric retaining wall was ascertained. Finally, more economical temporary retaining wall, semipermanent retaining wall with replaceable fabric facing, and permanent retaining wall covered with concrete facing are proposed.

Seit der Geotextil-Erde Wand mit mehreren Stahlankern und Säulen aus Stahlbeton sind etwa 5 Jahre vergangen. Die normalen Erddrücke und die bei Erdbeben, Verschiebungen und Verformungen und die Verschlechterung des Geotextiles wurden in den letzten Jahren gemessen. Alle Schrauben, die die Stahlankerstangen halten, wurden zurückgeschraubt, und der Erddruck der Rückfüllung gegen die Mauer wurde auf Null reduziert. Die Verschiebung betrug nur 0.6 mm. Das Verhältnis der Verschiebung zur Mauerhöhe war viel kleiner als das von anderen Autoren berichtete. Ein Teil der Geotextil-Erde Wand wurde erfolgreich durch neues Geotextiles ersetzt. Als Ergebnisse der Tests konnte die Stabilität und Dauerhaftigkeit der Geotextil-Erde Wand gesichert werden. Schliesslich werden noch wirtschaftlichere, zeitweise zu verwendende Stützmauern, semipermanente Stützmauern mit auswechselbarer Geotextil-Verkleidung und permanente Stützmauern mit Beton-Verkleidung vorgeschlagen.

INTRODUCTION

The paper titled, "Fabric Retainig Wall", was presented to the 2nd International Conference on Geotextiles in 1982. The height of the retaining wall was 5 m, and geotextiles were attached to the front face. This retaining wall is more economical and easy to construct than other types of retaining walls. However, durability was questionable. Therefore, behavior of this retaining wall has been exposed to observation for 5 years. The items observed were earth pressures at ordinary and earthquake times, displacements, deformations, deterioration of fabrics etc. Cohesive soil was used as backfill. The retaining wall was expected to be removed safely without causing collapse of the backfill, because the cohesion height was estimated to be higher than 5 m. Are the anchors useless after the construction? Is it possible to replace the old fabric with the new one? Have the resistance of anchors increased or decreased as the years elapsed? For the purpose of solving these problems, the investigation has been conducted for about 5 years.

DESIGN AND CONSTRUCTION OF THE RETAINING WALL

The structure of the plastic retaining wall was described in Ref. 1. Therefore, only major points are summarized here. The front wall is composed of the reinforced concrete columns (20x20x550 cm) and the fabric as shown in Fig. 1. Woven polyethylene cloths were used. Fabric No. 1 was a net type and Fabric No. 2 a sheet type. Unit weights were 310 and 460 g/m^2, respectively. Strength properties of the geotextiles tested according to the Japanese Industrial Standards are described in Table 1. The tests have been repeated every year in order to observe the degree of deterioration with time. Loss of strength was 45 to 66 percent.

First, design earth pressure of the backfill against the retaining wall was necessary to be assumed. There were no case record of measured earth pressure on fabric retaining walls. Fortunately, the authors had many case records of earth pressure measuremants on gravity walls, cantilever walls, concrete block walls and inverted Y-type walls of 5 m high measured for many years. These case records were used to estimate the earth pressure for the fabric retaining wall. A similer type of retaining wall with steel plates was constructed in 1979, though the earth pressure measurement was not successful. Therefore, the fabric retaining wall could be designed with confidence from the stability point of view. Only the fabric used at the lowest part was designed, and the same kind of fabric was used at other parts.

The magnitude of earth pressure on a retaining wall is usually expressed by the following formula.

$$p = k\gamma z \text{ --------- } (1)$$

where,
- p : earth pressure of the backfill against the vertical wall,
- γ : unit weight of the backfill,
- z : depth from the top of the backfill.

The active earth pressure by Coulomb and Rankine is the earth pressure at a limiting condition,

and, $k=\tan^2(\frac{\pi}{2} - \frac{\phi}{2})$ for cohesionless soils. A retaining wall lower than the cohesion height of the backfill is subjected to the negative pressure or tention by the Coulomb's formula. There was a proposal that the tension should be neglected for cohesive soils. But the fabric retaining wall cannot be designed by the use of such modified Coulomb's formula, because the earth pressure of the cohesive backfill actually acts against the fabric wall. The case records of earth pressure messurements

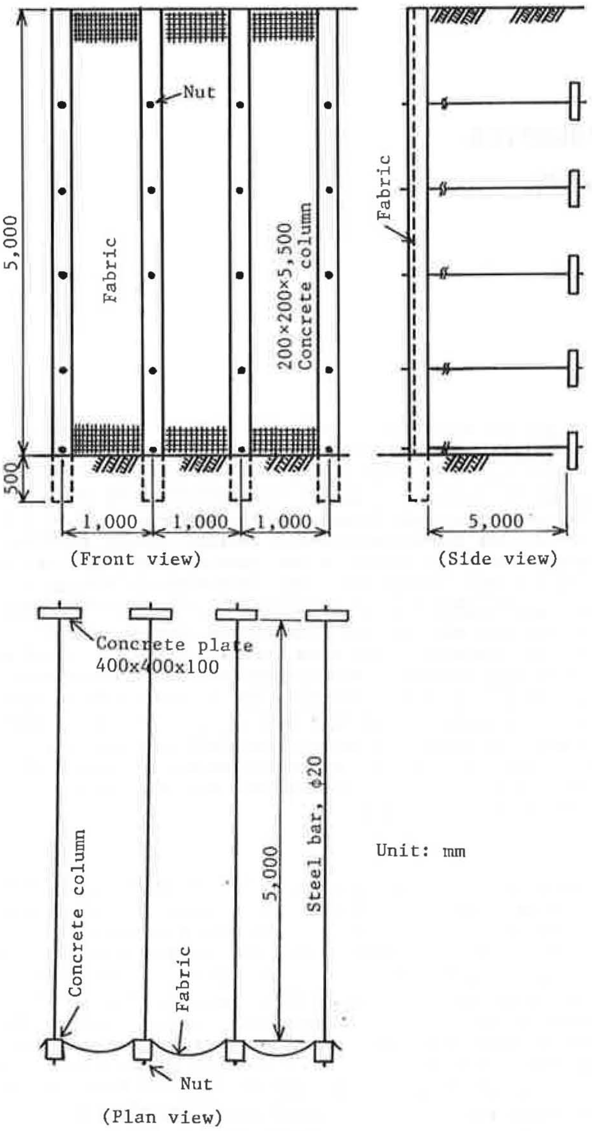


Fig. 1 Fabric retaining wall with multiple anchors

give no significant difference between cohesive and cohesionless soils when they are used as backfills of retaining walls. Generally, even deformation or displacement of the wall during construction do not significantly affect the earth pressure. It was decided to take larger factor of safety to provide ample security.

Assuming unit weight, γ= 15 kN/m^3 and coefficient of earth pressure, k= 0.33, the magnitude of earth pressure at the bottom of the retaining wall was calculated to be 0.33 x 15 x 5 = 24.75 kN/m^2, and the total earth pressure $\frac{1}{2}$ x 5 x 24.75 = 62 kN/m. The earth pressure distribution in the case records was rather trapezoidal than triangular. Therefore, the design earth pressure was taken to be 20 kN/m^2. The fabrics were easy to elongate, hence they were supposed to be bent in the shape of arc. There was no reasonable method to estimate the curvature of the arc. It seemed to be better to keep the fabric inside of the outer face of the column. The calculation was made

Table 1 Strength properties of geotextiles

No.	Items	Dir.	Init. A	1year B	B/A (%)	2years C	C/A (%)	4years D	D/A (%)	5years E	E/A (%)
1	Str. kN/m	L	61	57	95	52	86	33	55	16	22
		T	62	55	90	54	87	30	48	-	-
	El. %	L	28	25	92	34	124	22	81	4	20
		T	21	25	119	19	91	10	50	-	-
2	Str. kN/m	L	72	66	92	34	47	27	38	25	41
		T	74	53	72	35	47	25	34	-	-
	El. %	L	20	16	79	10	48	8	40	17	62
		T	18	9	50	6	32	3	18	-	-

Note: Dir., Direction; L, Longitudinal; T, Transverse; Init., Initial; Str., Strength; El., Elongation

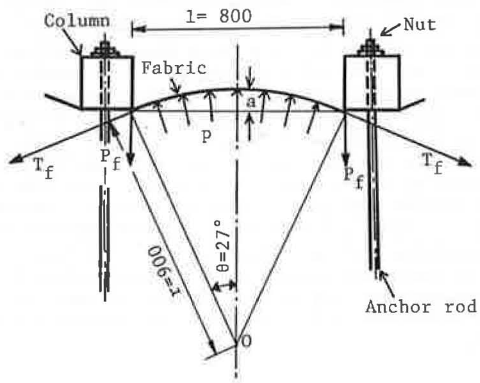


Fig. 2 Earth pressure and tension on fabric

by assuming the value of "a" to be 10 cm as shown in Fig. 2. The tensile force acting on the fabric was calculated as follows.

$$T_f = \frac{1}{2} p l \operatorname{cosec}\theta = 17.6 \text{ kN/m} \quad \text{------- (2)}$$

The tensile strengths of the fabrics used were 61 and 72 kN/m. Therefore, the fabrics were proved to be strong enough for the wall. It was not certain whether the value of a= 10 cm could be kept right on the occasion of the actual construction. Figure 3 shows the relationship between T_f and "a". As T_f decreases remarkably with "a", it seemed that the shortage of tensile strength could be covered by increasing the value of "a". The fabric No. 1 was a net type and its coefficient of elongation is larger than that of the fabric No. 2 of the sheet type. Fabric No. 1 would be given the aimed curvature by stretching it behind the columns without giving some special sag. It would be bent by the earth pressure of the backfill. Fabric No. 2 seemed to be difficult because its coefficient of elongation was small and amount of elongation during construction would not contribute to the increase in curvature. The amount of sag given to the fabric No. 2 should be large enough to give the design curvature. The construction work was carried out by filling soils behind the fabric step by step. In order to prevent the backfill soil from spilling out through the joints of the fabrics, the adjacent fabrics were fully overlapped. Therefore, it may be said that the fabrics were doubly stretched. Tensile forces in steel rods were measured by reinforcement gauges at the front ends and strain gauges. Earth pressures of the backfill against the fabrics were measured by the earth pressure gauges embeded in the concrete plates attached to the columns, instead of the fabrics. The earth pressures acting against the front and rear faces of the anchor plates were measured by the earth pressure gauges embeded in each face. The earth pressures measured by earth pressure gauges and reinforcement gauges are illustrated in Fig. 4 and 5. The maximum earth pressures measured were a little larger than the predicted ones. The distribution of earth pressure on the back of the wall was different from that of forces on anchor rods. However, the resultant forces by the above two were almost the same.

RESPONSE OF THE FABRICS TO THE BACKFILL

Relationship between the tensile force of the fabric stretched between the lowest two anchors and the earth pressure is illustrated in Fig. 6, though it is not very accurate. There are four axes showing the time, fill height, lateral pressure, and tensile force of the fabric, respectively. Curves 0-1 corresponding to the period of construction, 1-2 period of observation, 2-3 period of screwing back the nuts and reducing the earth pressure to zero.

(Period of construction)
This stage is divided into two.
(1) The backfill soil is loose and has practically no tensile strength. It is deformable and it moves to the wall with gravity force or light compaction. It behaves like a pulverulent material with low internal friction.
(2) The backfill soil is compacted into a state of solid, which behaves like a solid mass. The solid mass tends to expand laterally with gravity forces of the upper layers of soils. The expansion is controlled by the fabric.
The behavior of soil in the stage (1) is expressed by the following formula.

$$\sigma_x = \sigma_z \tan^2\left(\frac{\pi}{4} - \frac{\phi}{2}\right) \text{ ----- } (2)$$

$$\sigma_x = k_s \delta_x \text{ ---------------- } (3)$$

where,
- σ_x: contact pressure between the backfill soil and the fabric,
- σ_z: the surcharge pressure,
- ϕ : frictional angle of the loose soil,
- k_s: coefficient of horizontal deformation,
- δ_x: horizontal deformation of the contact surface.

The surcharge pressure is the pressure of a bulldozer. The 3.5 tons bulldozer, the contact pressure of which is 21kN/m^2, was used for the test. The horizontal earth pressure against the fabric was not directly measured, but it was measured with the pressure gauges installed in the concrete plates. The results of measurements are given in Table 2.

Table 2 Earth pressure against the vertical wall, p, kN/m^2

No.	1	2	3	4	5	mean
p	2.51	4.74-13.30	5.01	7.59	1.96-3.74	5.5

The value of ϕ is obtained, by using Eq. (2), to be 13°. Figure 7 gives relationship between tensile force and elongation of the fabrics. Figure 8 gives relationship between a and p of the fabric No. 1. From Table 2, Figs. 7 and 8, p=5.5 kN/m^2, a=7.0 cm, and the tensile force of the fabric Tf = 6.6 kN/m are obtained. The lateral deformation and earth pressure of the backfill is to be calculated as the soil mass has become a solid state. The test results of the soil 5 years after the completion of the retaining wall are given in Table 3.

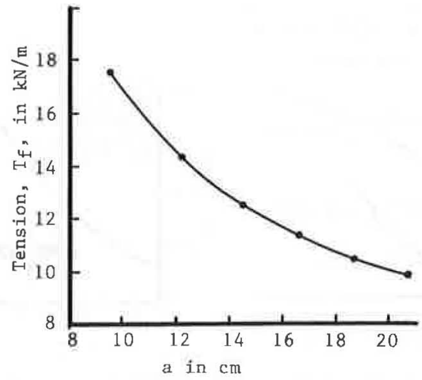
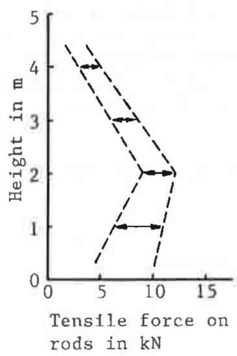


Fig. 3 a versus T_f.



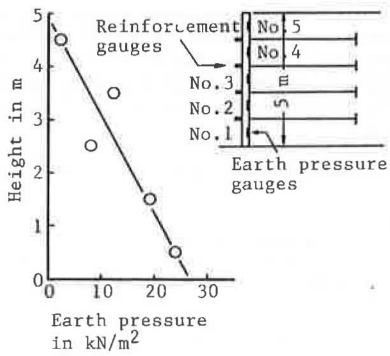


Fig. 4 Tensile force on anchor rods.

Fig. 5 Earth pressure against vertical wall.

0-1: The period of construction
1-2: The period of observation
2-3: The period of screwing back the nuts

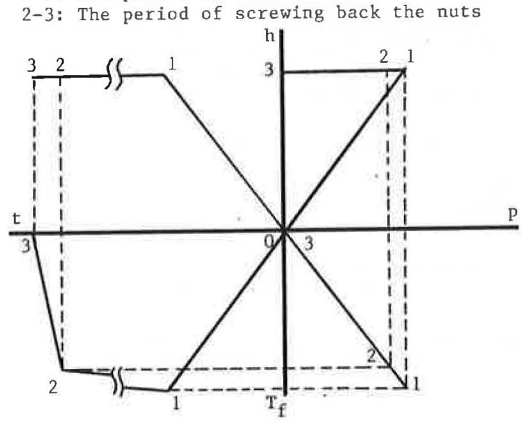


Fig. 6 Relation between fill hight, h - earth pressure, p - tension, T_f - time, t

Table 3 The test results of the soil 5 years after the completion of the retaining wall

Unit weight, 13.2 kN/m^3
Water content, 73 %
Triaxial test,
  Cohesion, 25 kN/m^2
  Angle of internal friction, 18°
Poisson's ratio (1/m), 0.327
Modulus of deformation, 1.80 MN/m^2

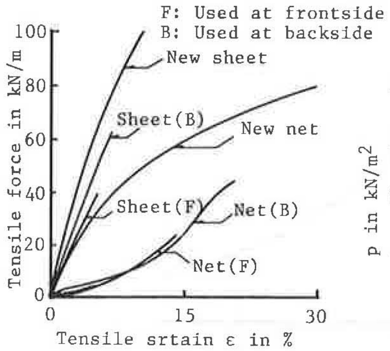


Fig. 7 Tension test results of fabrics.

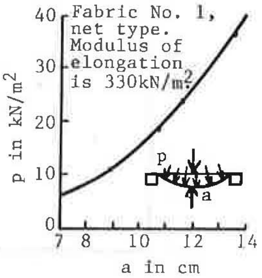


Fig. 8 "a" versus p for fabric No. 1.

Modulus of deformation of the soil E= 1.8 MN/m^2 at the confining pressure 100 kN/m^2, Poisson's ratio 1/m = 0.327 are given in the Table 3. The surcharge pressure on the surface of the lowest 1 m layer z= 4 x 14.63= 58.52 kN/m^2. The horizontal strain ε_x is obtained by the equation below.

$$\varepsilon_x = \frac{1}{E} [k - \frac{1}{m} \{ 1 + \frac{1}{m} (k + 1)\}] \sigma_z \text{ ------ } (4)$$

where,
E: modulus of deformation, kN/m^2,
k: coefficient of lateral earth pressure.
The strain ε_y is given in Table 4.

Table 4 Strain of fabric No. 1

k	0.2	0.3	0.4	0.5
ε_y(%)	0.00083	0.0054	0.0025	0

The value of k is estimated to be 0.5 at the faces of the columns and 0.2 or less at the parts of the fabrics. Assuming k=0.2, the earth pressure is obtained as 58.52 x 0.2 = 11.7 kN/m^2. The total earth pressure is 11.7 + 5.5 = 17.2 kN/m^2. The results of measuring the "a" values are described in Table 5.

Table 5 Deflection of fabric No. 1

Height from the ground, m		0.5	1.5	2.5	3.5	4.5
Deflection "a", cm	No. of Column 1.	8.5	11.0	11.4	10.2	9.5
	No. of Column 2.	12.5	10.0	12.5	9.8	10.0

The earth pressure calculated by using Fig. 8 are given in Table 6. The fabric No. 1 had slight sag. Therefore, the fabric was assumed to be a single fold, though it was actually double fold.

Table 6 Earth pressures of backfill against Fabric No. 1

Hight from the ground, m		0.5	1.5	2.5	3.5	4.5
Earth pressures, kN/m^2	No. of Column 1.	10.0	21.0	23.2	16.9	13.8
	No. of Column 2.	30.0	16.0	30.0	15.1	16.0

EFFECTS OF RAINS AND EARTHQUAKES

The amount of annual rainfall in Tokyo area is about 1,300 mm. The rainy season is in summer. There are two types of rains which damage reataining walls. The first type is called Baiu which brings 400 - 500 mm of rain in a month or so and it comes in late June to early July. The second type is typhoon which brings about 200 - 300mm of rain and comes upon in September. The largest amount of rainfall by Typhoon was more than 1,000 mm. Table 8 describes the record of rainfalls supposed to be the worst conditions against the fabric retaining wall.

Table 8 The worst rainfalls against the fabric retaining wall

Typhoon,	October 22 - 23, 1981.
	Total amount of rainfall: 215.0 mm
	Intensity of rainfall: 46.5 mm/hour
Baiu,	June 17 - august 4, 1982.
	Total amount of rainfall: 378.0 mm

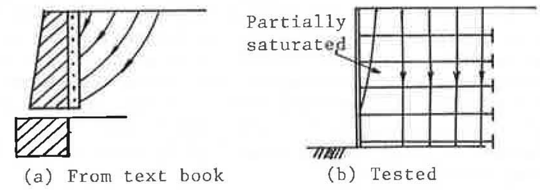


Fig. 9 Drainage of backfill behind retaining wall.

A figure like Fig. 9 is sometimes found in text books. The retaining wall has a layer of drain behind the back of the wall. There is no need to install such a drain, because the fabric is permeable. Actually a part of the rain water flows away on the surface of the backfill, and another part of it percolates into the backfill. The percorated water flows downwards, and do not flow along the flow lines as shown in the figure. It is also true for the other retaining walls. The authors have tested in many cases. A retaining wall fails due to softening of foundation soil or uplift water pressure at the lower surface of the base of the retaining wall. The fabric retaining wall is supported by a soft foundation having the N-value of 1 to 2, and it has no piles underneath. Its lowest part was submerged by surface water of 30 to 50 cm deep. The soil layer at the bottom kept stable against sliding even at the submerged state, since it had steel anchors of 5 m long. Surface of soils is eroded by heavy rains. The fabric surfacing worked very effectively to prevent the erosion. The fabric seems to protect the surface even after loosing its tensile strength. Grasses grow through the meshes of the fabric No. 1 in summer. The roots of the grasses act as a reinforcement of the soil.

(Behavoir during earthquakes)
Earth structures should be designed in due consideration of earthquakes, because strong earthquakes often attack them in Japan. The number of felt earthquakes is 10 - 20 per year in Tokyo area. The largest earthquake during the test occured in September, 1985.

The maximum acceleration was about 100 gals. That was the largest earthquake ever experienced for the past 40 years. The fabric retaining wall did not show any sign of deformation or displacement. Judging from it, the fabric retaining wall may be said to be stable against any earthquake. No record of earth pressure was taken, because the record system had been removed. The second and third largest earthquakes of February 27 and May 25 in 1983 were recorded well. Maximum accelerations at the ground and the top surface of the backfill are given in Table 9.

Increase of tensile forces in anchor rods are illustrated in Fig. 10. The maximum amount of increase was only 7 % of the ordinary tensile force. The factor of safety for tensile strength in anchors is about 4. Therefore, the retaining wall is guaranteed to be safe. Mononobe - Okabe formula has been used for earthquake resistant design very widely in the world. The result of computation betweem the calculated and observed values is illustrated in Fig. 11. The ordinary earth pressure is obtained by the Coulomb's formula assuming $\phi = 30°$. The additional earthquake force is computed by the Mononobe - Okabe formula. The result of test gave much smaller values than the computed values. Moreover, the earthquake forces are quite different in the distribution and magnitude. It was clarified that the increase was resulted from the inertia force on the columns and the backfill soil mass did not deform to exert dynamic force on the wall. It may be said that a fabric retaining wall with cohesive backfill soil is safe under earthquakes, if it is designed by using earth pressure at ordinary time.

Table 9 Maximum accelerations, gals.

	1983. 2.27	1983. 5.25
Top surface	80	30
Ground	52	13

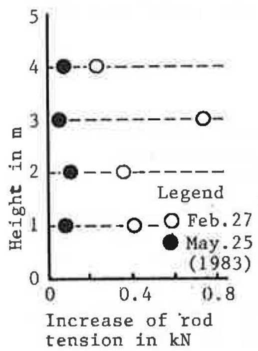


Fig. 10 Increase of rod tension.

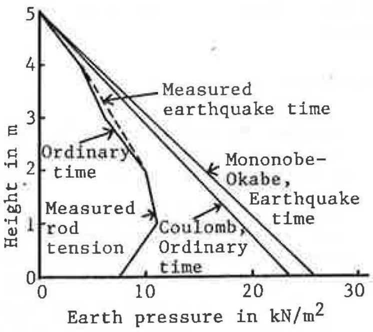


Fig. 11 Earth pressure calculated and measured.(February 27)

MEASUREMENT OF EARTH PRESSURE AT ORDINARY TIME

The total pressure cell was used to measure horizontal earth pressure in the backfill in 1984, after 4 years since the completion of the retaining wall. The total pressure cell is composed of a hollow thin square plate, which is pressed by the earth pressure to be measured, and a measuring device. The plate is 5 mm thick, 120 mm wide and 220 mm long. It is pushed into the bottom of a borehole. The earth pressure acting on the surface is measured after the disturbance by pushing is minimized as time goes by. The result of measurement is shown in Fig. 12. The earth pressure increases if the distance from the wall increases. This tendency agrees with the assumption adopted for the original design very well. The pressure difference between two assumed vertical surfaces is balanced by the friction at the contact surface of the backfill and the ground. It should be necessary to check the frictional resistance at this contact surface when it is designed.

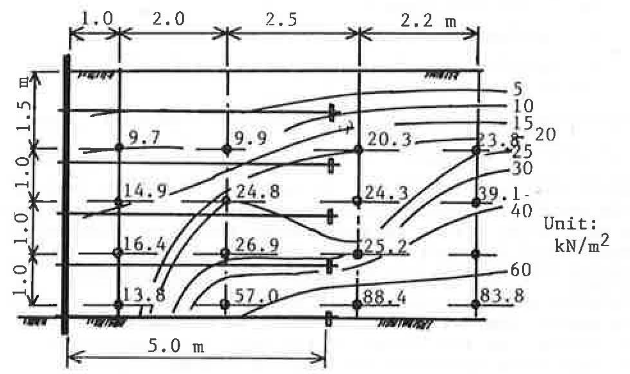


Fig. 12 Horizontal earth pressure in the backfill.

PULL-OUT TEST OF ANCHORS

The pull-out test of anchors was performed with four anchors in 1983. The result is given in Fig. 13. The tensile force was estimated to be about 10 kN, and the measured tensile force was approximately the same. As the tensile strength of the anchors was about 40 kN, the factor of safety pertaining to the anchor rod is calculated to be about 4. Relationship between tensile force and displacement of anchor rods during construction is illustrated in Fig. 13 for reference. The ratio of the tensile force to the displacement during construction is much smaller than that of 4 years later.

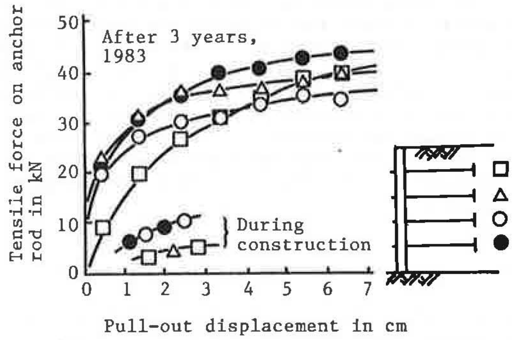


Fig. 13 Pull-out test of anchors, and tensile force versus displacement during construction.

RELEASE TENSION OF ANCHORS

The test was performed to measure horizontal displacement of the front wall by screwing back the nuts holding the anchor rods. (Fig. 1) The sequence of release was from the highest anchor down to the lowest one. The horizontal strain of the backfill caused by reducing the side pressure to zero may be expressed as,

$$\varepsilon_x' = \frac{\sigma_x}{E}\left(1 - \frac{1}{m^2}\right) \text{-------} (5)$$

where,

ε_x: horizontal strain,

σ_x: acting horizontal earth pressure,

E : modulus of deformation of the backfill,

1/m: Poisson's ratio.

Substituting $\sigma_x = 20\ kN/m^2$, $E=1.8MN/m^2$, $1/m= 0.327$, then $\varepsilon_x = 0.09$ is obtained. From the above calculation, the horizontal earth pressure is supposed to become zero by the horizontal displacement of about 1 cm. According to a text book, active earth pressure may be achieved by a horizontal movement 1 to 2 % of the wall height. The height of the backfill is smaller than the cohesion height, and the active earth pressure should be negative or zero. The horizontal movement is estimated to be 5 to 10 cm. As the result of the test, the top of the column moved horizontally by about 0.6 mm, and the bottom of it about 0 mm. Angle of rotation of the column was 12×10^{-5} radian with no tension in the rods. The amount of measured displacement may coincide with the calculated one, if the coefficient of deformation is ten times of $E=1.8MN/m^2$.

REPAIR OF THE FABRIC RETAINING WALL

If the old fabric can be replaced by a new one, the life of the retainig wall may be extended as long as one wishes. The test of replacing a new fabric with the old one was performed to ascertain a possibility of repair of the wall. A small gap was made between the concrete columns and the backfill by screwing back the nuts. There was a possibility of inserting the new fabric through the gap. But it was impossible to do it, because the gap was too narrow. Removal of the backfill soil behind the columns with a straight edge was necessary to excavate enough space for inserting the new fabric. The newly replaced fabric was not subjected to tensile force, because the backfill was self standing. The old fabric was cut open with a knife, but no sign of tensile force was felt. The reason may be explained by phenomenon of relaxation. If a material is subjected to a certain amount of tension or compression, and then the strain is fixed, the tensile or compressive force continues to decrease with the time lapse. This is called relaxation. The test of relaxation was performed on the fabric.

PROPOSAL OF NEW TYPES OF FABRIC RETAINING WALLS

1. Aging of fabric is a serious problem for the fabric retaining wall. One of the solutions is to replace the old fabric with a new one. Facing with concrete, brick, and earthware with earth fill between the facing and fabric may be another solution.

2. The fabric retaining wall as shown in Fig. 14 may be used for a temporary structure. This is more economical than the existing fabric retaining walls. It can be used as a semi-permanent structure by covering with a concrete slab.

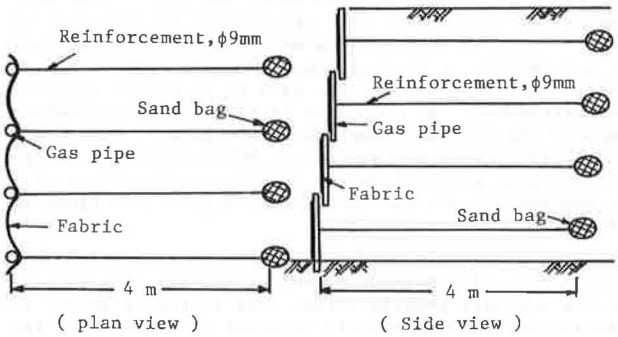


Fig. 14 Proposed new type of fabric retaining wall.

CONCLUSIONS

1. The fabric retaining wall composed of the concrete columns and fabrics with multiple anchors has been proved very stable against heavy rains and severe earthquakes, and moreover economical. It may be constructed on soft ground without pile foundations.

2. The old fabric can easily be replaced with a new one. Then the life is extended by repairment.

3. The test result can be used for preparing a standard method of design or a manual.

4. The fabric retaining wall with cohesive soil as backfill stands by itself without tensile force acting on anchors. Therefore, the roll of the anchors is only to resist earth pressure during construction. However, the anchors are needed to prevent falling down of the front wall by external forces or by its own weight.

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