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M. Fukuoka
Science University of Tokyo, Noda City, Japan

Y. Imamura
Service University of Tokyo, Noda City, Japan

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Earth Pressure on Retaining Walls and Buried Pipes

M. Fukuoka
Professor of Civil Engineering, Science University of Tokyo, Noda City, Japan

Y. Imamura
Lecturer of Civil Engineering, Science University of Tokyo, Noda City, Japan

SYNOPSIS This paper describes the results of earth pressure measurements on the retaining walls and buried pipes. Conventional earth pressure gauges fixed on the walls were not used, instead, panel type earth pressure gauges which covers the whole wall surface were used. Vertical and tangential components of the resultant earth pressures were measured.

INTRODUCTION

For the purpose of measuring earth pressure on the back surface of the retaining wall, earth pressure gauges with a flexible metalic memrane on one side are commonly used. Defect of the earth pressure gauges of this kind is due to stress concentration, and they do not indicate exact values. Furthermore, they can not measure tangential stress nor wall friction. Fukuoka invented the panel type earth pressure gauge, and succeeded to measure both normal and tangential components of the earth pressure. First, earth pressure on a cantilever retaining wall was measured. Next, those on a gravity retaining wall was measured. The results of those measurements were reported in the Case History Volume of the IX International Conference on Soil Mechanics and Foundation Engineering, Tokyo. Afterward, concrete block retaining walls, including gravity retaining walls and inverted Y-type retaining walls were measured. This measuring method was also applied to buried pipes effectively. The results of measurements are reported herein.

GENERAL REMARKS FOR LARGE CONCRETE BLOCK RETAINING WALLS

Prior to reporting the test results on large concrete block retaining walls, it may be convenient to discuss some common problems related to them. There are three kinds of concrete blocks such as those shown in Fig. 1. Those concrete block have openings in them, which are to be filled with sand during construction. The concrete blocks are to be piled up on the base which is constructed at the site. After the wall is constructed, backfilling operation is to be conducted. Only the retaining wall of Test 1 was constructed by piling up the concrete blocks as backfilling proceeded, because the retaining wall body could not stand by itself. Geotextiles were fixed at the backside of retaining walls for the purpose of preventing leak of backfill and faciliating drainage. Panel type earth pressure gauges were installed at the backside of the blocks. The panel type earth pressure gauge is composed of a wide steel plate and 5 load cells; three of them measure the normal component of the total earth pressure, and two of them the tangential component. Figure 2 shows a side of the retaining wall. It has steps at its back, because blocks are different in size.

Block	Weight in kN		Size in m		
	Concrete without sand	Concrete with sand	W_B	B_B	H_B
1-ton	11.3	13.93	1	0.7	1
2-tons	18.4	23.15	1	1.15	1
3-tons	39.4	49.02	1	1.85	1

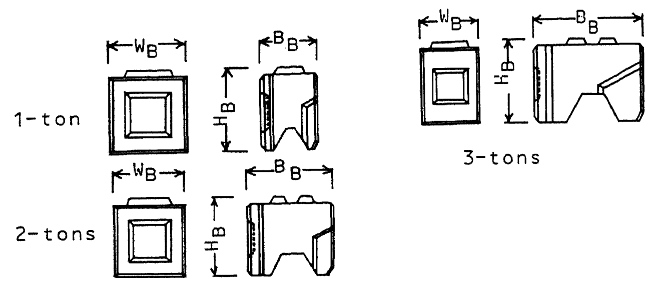

Fig. 1 Large Concrete Blocks used for Retaining Walls

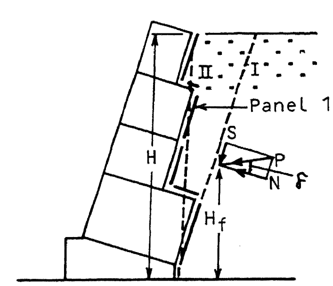

Fig. 2 Sketch of Retaining Wall

H: Height of a retaining wall in m

H_f: Height of the point of application of resultant backfill pressure

r_H: Relative height of the point of application, H_f:H

N: Normal component of the total earth pressure against the real or the assumed wall

S: Tangential component of the total earth pressure against real or

assumed wall
δ: Angle of wall friction, =arctan(S/N)
N_i, S_i :Normal and tangential compoments of earth pressure against panel i
k_N, k_S : Coefficient of earth pressure
$N=\frac{1}{2}k_N H^2$, $S=\frac{1}{2}k_S H^2$

LARGE CONCRETE BLOCK RETAINING WALL (I)

Figure 3 shows a cross section of a large concrete block retaining wall(I). Lower three blocks weigh about 20 kN and upper two about 10 kN. The base concrete block is placed on centrifugally cast concrete piles. Inclination of the retaining wall is very gentle as 1:0.5 to prevent the wall from collapsing by earthquakes. The back side of the retaining wall was equipped with four panel type earth pressure gauges, width of which was 1 m. Vertical and horizontal components of resultant earth pressure acting on each panel are denoted as N_1, S_1; N_2, S_2; N_3, S_3; and N_4, S_4. Backfill behind the Panels 3 and 4 was not compacted, but that behind the Panels 1 and 2 was compacted with a bulldozer. Soil properties are described in Fig. 3. The geotextiles were fixed on the back side of the retaining wall. It was revealed that they did not reduce the friction between concrete and backfil material.

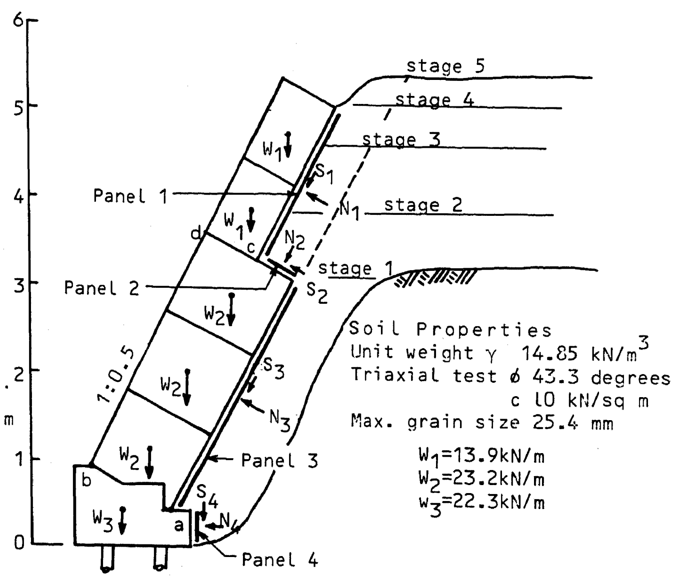

Fig. 3 Cross Section of Large Concrete Block Retaining Wall (I)

According to the Coulomb's formula, earth pressure coefficients with angle of internal friction ϕ equal 30 and 40 degrees, are 0.175 and 0.075, respectively. Distribution of earth pressure is trianglar, and the resultant of earth pressure acts at the one third point from the bottom. The result of measurement was as follows.
(1) At stage 1 in Fig. 3, the vertical and tangential coefficients of earth pressure, k_N and k_S were 0.04 and 0.02, respectively. Distribution of earth pressure was uniform. This might have been caused by no compaction and narrow backfill space.

TABLE I. Earth Pressure on Panels in kN

Stage	1	2	3	4
Filling height	3.0 m	3.8 m	4.6 m	5.3 m
N_1		1.25	4.30	7.23
S_1		0.67	1.33	1.67
N_2		2.86	7.19	11.26
S_2		1.60	1.80	1.80
N_3	2.43	5.99	8.56	11.68
S_3	0.90	4.05	4.48	7.50
N_4	0.49	1.95	2.36	3.29
S_4	0.09	1.19	2.14	4.78

(2) The coefficients of earth pressure for Panel 1 are k_N=0.19 and k_S=0.04. Compaction with a bulldozer might have contributed to ir crease the magnitude of these coefficients.
(3) The coefficients of earth pressure were k_N=0.105 and k_S=0.07. Relative height of the point of application of the resultant force from the bottom r_H was 0.67.
(4) Cohesion was neglected and only the angle of internal friction was adopted, when the Coulomb's formula was used to computed earth pressure on retaining walls. How to determir the angle of internal friction has always bee the problem. Is it possible to use results c soil testings? The angle of internal frictic determined by triaxial test was 43 degrees, a the cohesion was approximately zero. The coefficient of earth pressure computed with t value was very small. Angle of wall frictior is also very difficult to obtain. Collecting case records as many as possible seems to be the best way of clarifying these difficult phenomena.
(5) Figure 4 shows stability of the lower thi blocks covered by the Panel 3. The abscissa indicates the inclination of the wall and the ordinate the resultant forces acting at the middle of the panel. If the inclination, β , the wall is too large, the wall will fall backward only by its own weight. On the contrary, if the earth pressure is too large, it will fall forward. The straight lines 1 a 4 show the border lines. If the resultant force of the weight of the wall and earth pressure falls in the middle third on the bas the retaining wall is stable. This region is indicated with hatch between straight lines 2 and 3. The normal component of the resultant earth pressure on the Panel 3 was 2.43 kN/m a the stage 1. This value is plotted with a dc in Fig. 4. It is impossible to be plotted under the straight line 1. Therefore this is due to some error of measurement. The dot moved upward in accordance with the progress of backfilling. But it did not come into the hatched area. It means that this retaining wall has tendency of falling backward.

Concrete block retaining walls with no or little connection between blocks are somewhat different from monolithic retaining walls. Distribution of earth pressure is used to che stability of every block which composes the retaining wall. Of course for the purpose of designing the wall body, the distribution of earth pressure is needed even for the monolithic retaining walls.

(6) There is a step at the backside of the retaining wall. Earth pressure against the step cannot be calculated with Coulomb and Rankine Formulae. As the result of measurement earth pressure against the Panel 2 are N_2=11.26 and S_2=1.80 kN/m. Accordingly, normal and tangential components of the average earth pressure are 28.15 and 4.50 kN/$_m$2 , respectively. Depth of the panel from the top surface is about 2 m, unit weight of backfill 14.85 kN/$_m$3, and their product is 29.70 kN/m^2. This is nearly equal to the normal component. Ratio of tangential component to the vertical component is 16 %. Ratio S/N with every stage of construction is indicated in Table II. The ratio decreased in accordance with fill height at the Panel 1. But the ratio increased remarkably at the Panel 4. Wall friction seems to be obtainable only by multiplying normal stress with relative displacement. But, the value shown in the Table may be sufficient to surmise difficalty of explaining the phenomena.

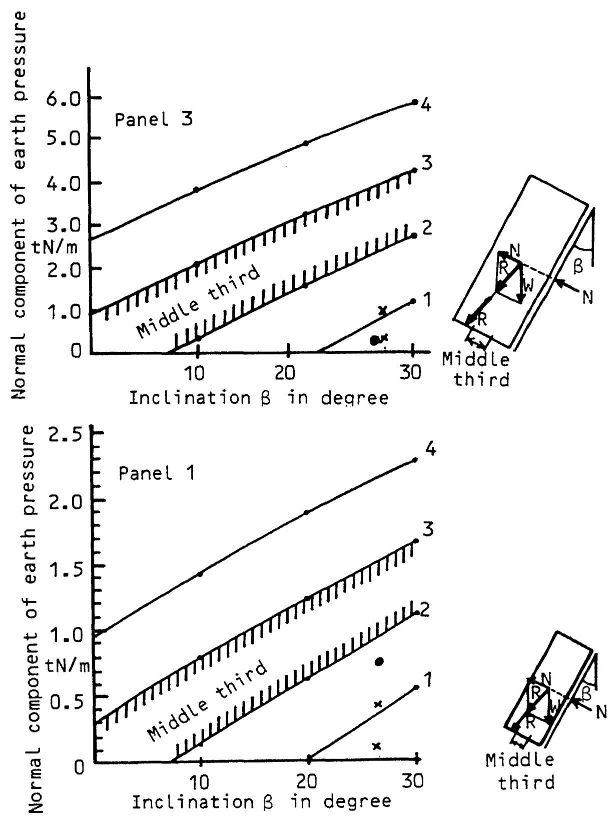

Fig. 4 Inclination of Retainig Walls versus Normal Component of Earth Pressure against the Walls

TABLE II. Ratio of Wall Friction to Normal Component of Earth Pressure in %

Panel	Stage				
	1	2	3	4	Mean
1		54	31	23	
2		56	25	16	52
3	37	68	52	64	
4	18	61	91	145	

LARGE CONCRETE BLOCK RETAINING WALL (II)

Figure 5 shows a cross section of the large concrete block retaining wall (II). The backfill was not compacted. The earth pressure measurement at the end of construction was shown in Table III. The normal and tangential components of the total backfill pressure against the assumed surface shown with the dotted line in Fig. 5 were N=61 and S=32 kN/m, respectively. Coefficient of earth pressure are k_N=0.41 and k_S =0.22. Angle of wall friction was δ=28 degrees. The coefficients of earth pressure were much larger than the case of the large concrete block retaining wall (I), mainly because of the difference in inclinations. The k_N value of the upper block was 0.45. The ratio S/N varied from 26 to 94 %, and their average was 56 %. The earth pressure against the step was approximately equal to the product of the depth from the surface multiplied by the unit weight. The earth pressure on Panel 4 is supposed to become smaller under this influence. The point of application of the resultant backfill pressure was approximately at the lower third point of the wall height. The height of the resultant backfill pressure H_f seems to have some relations with the normal earth pressure coefficient k_N. If k_N is large, H_f becomes low.

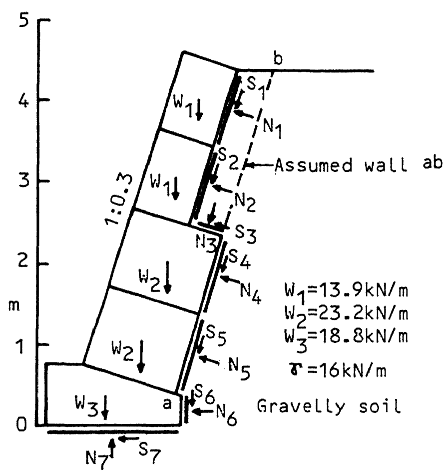

Fig. 5 Large Concrete Block Retaining Wall(II)

TABLE III. Eaeth pressure in kN/m

No.	1	2	3	4	5	6	7	Mean
N	3.3	8.5	12.8	2.8	14.8	21.9	87.3	
S	3.1	2.9	-	2.0	8.1	12.2	22.8	
N/S %	94	34	-	71	55	56	26	56

LARGE CONCRETE BLOCK RETAINING WALL (III)

Figure 6 shows the cross section of the large concrete block retaining wall (III). Length along the front was 5.6 m. Large amount of gravels were contained in the backfill, and the backfill was placed without compaction. The results of earth pressure measurements at the end of construction are given in Table IV. The normal earth pressure against the assumed wall represented with the dotted line in Fig. 6 was N=58 kN/m, and the height of the point of application of the resultant backfill pressure was 2.55 m (r_H=0.425). The wall friction on the

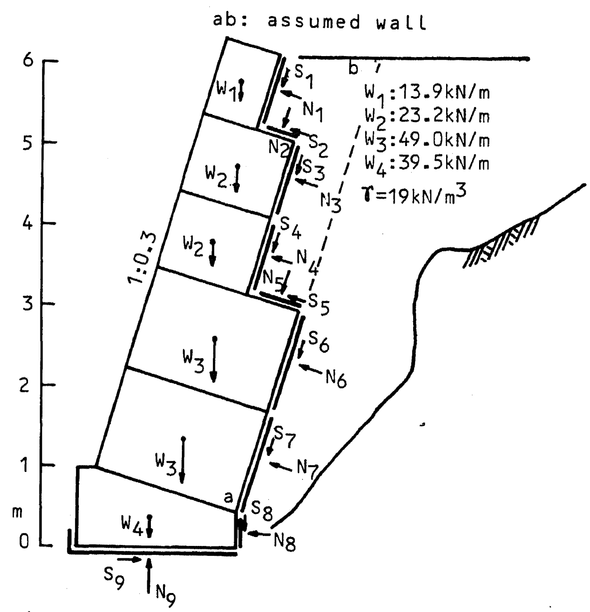

Fig. 6 Large Concrete Block Retaining Wall (III)

TABLE IV. Earth pressure in kN/m

No.	1	2	3	4	5	6	7	8	9
N	1.8	9.1	4.4	4.1	13.3	12.2	9.6	16.0	250.4
S	0.3	-	4.8	4.8	-	1.9	3.0	7.1	95.6
S/N %	17	-	109	117	-	16	31	44	38
S/N mean: 53 %									

assumed wall was S=39 kN/m, and the ratio S/N =0.67 (δ=33.8 degrees). The earth pressure acting on the upper step was approximately equal to the product of the depth multiplied by the unit weight, but that acting on the lower step was only 33 % of the product. The earth pressure just below the step did not decrease in this case.

LARGE CONCRETE BLOCK RETAINING WALL (IV)

Many difficulties exist in conducting field measurements, and large errors of measurement cannot be avoided. Therefore, prototype model tests were contemplated in the laboratory of Giken-Kogyo in Hachioji City. Tests were repeated for many years, but only 3 cases are reported here. The foundation of the test site is firm, and no deformation was observed during construction. A cross section is shown in Fig. 7. Three panels were fixed on the slope behind the backfill to secure precision of measurement. As the backfill is surrounded by the panel type earth pressure gauges, forces acting on the boundary were obtained. The gravity force was calculated by using the unit weight of soils. The total sum of forces and moments should be zero due to the Newton's Law. If the forces and moments are unbalanced, they are considered to contain some errors. Inclination of the back slope was 60 degrees by taking into account the conditions of the common construction site. Sands were used as backfill without compaction. The unit weight was 15 kN/m^3 . Result of measurements are given in Table V. The ratios N/S are in the lowest line. They varied from 48 to 105 %, and the mean value was 68 %. The earth pressure on an assumed wall ab was computed. The normal component N =48.5 kN/m, and the relative height of the point of application of the total earth pressure r_H=0.62. The coefficients of earth pressures were k_H=0.3 and k_S=0.13. Change of earth pressures from 78.4.23 to 79.1.7 are represented in Table V. According to the records, the earth pressures changed with time, and tendency of increase as time elapsed was observed. The normal force increased by 14 %, and the tangential force 44 %. The large weight of the retaining wall body and the firm ground might have made a great contribution. Increase in the wall friction seemed to have made a great contribution to the stability of the retaining wall, in spite of the increase of the normal pressure. The lines of thrust on 78.4.23 and 78.12.30 are drawn in Fig. 8. The point of intersection with the base plane moved from the outer middle third point to the center. The earth pressure surrounding the backfill were completely measured. The principal stress lines were drawn in Fig. 8. Principal stresses are not indicated in this diagram, but the total pressure against the assumed surface can be obtained by using this diagram. The coefficient of earth pressure on the assumed wall inclining 1:0.3 was computed as k_H=0.17 and k_S=0.08, r_H =0.33, and so the results observed are quite different. The back slope of backfill can be regarded as a kind of retaining wall. The normal and tangential components of the total earth pressure are 73.4 and 40.3 kN/m, respectively, and the ratio S/N is 0.55. The height of the point of application was 2.67 m from the bottom, and its relative height r_H=0.4

LARGE CONCRETE RETAINING WALL (V)

Figure 9 shows the cross section of the large concrete block retaining wall (V). The width of the backfill was widened by 1 m for the purpose of raising measurement precision. The precisions of vertical and horizontal forces, and moments are 4, 2, and 1.8 %, respectively at the end of construction. Those precisions are the highest obtained in the series of the tests The earth pressure changed during 20 days after the end of construction. The mean values of earth pressure are given in Table VI. The ratio N/S are given at the bottom of the table. The mean value was 76 % and comparatively large. As the measurement precision was high, stresses in the backfill could be obtained by interpolation. Figure 11 shows the principal stress lines, and Table VII gives the principal stresses at crossing points. Almost no disturbance was observed from the backfill surface to the depth of one meter. Vertical stresses began to be affected by the walls from a depth of one meter. under the depth of 3 m, vertical stresses were approximately constant. Minor principal stresses were increasing in simple proportion to the depth. Total earth pressure on any assumed wall may be obtained with high precision. The coefficient of earth pressure with respect to the assumed wall I were k_N=0.18 and k_S=0.13, and the height of the point of application of the total earth pressure H_f=2.1 The relative height r_H=42 %, which was higher than the one third point. The arrows in Fig.9

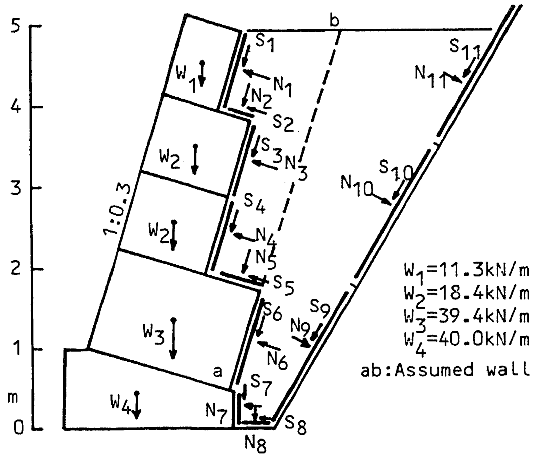

Fig. 7 Large Concrete Block Retaining Wall (IV)

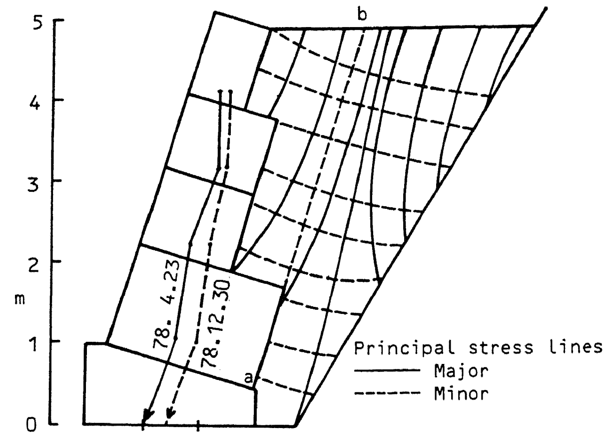

Fig. 8 Displacement of Line of Thrust and Principal Stress Lines on December 30, 1978

TABLE V. Earth Pressure in kN/m^2

		1	2	3	4	5	6	7	8	9	10	11	Sum
78.4.23	N	4.7	16.7	8.9	9.7	27.1	3.3	5.9	8.1	12.0	18.7	6.0	121.1
	S	1.1	2.0	8.7	6.3	2.1	3.4	5.8	0.2	5.0	11.4	3.7	49.7
78.5. 2	N	1.6	16.2	6.4	9.8	26.5	3.5	2.1	4.4	12.3	20.0	6.3	
	S	1.4	0.4	7.8	8.7	0.9	2.8	7.5	0.0	4.0	16.3	3.8	
78.5.13	N	2.1	15.3	6.0	9.5	24.6	3.4	3.2	7.1	11.4	21.6	6.3	
	S	0.5	0.6	7.7	7.5	1.6	2.8	7.0	0.2	5.8	15.3	3.6	
78.11.1	N	1.3	17.1	1.5	14.2	31.8	2.6	1.7	12.6	12.0	22.0	5.8	
	S	0.7	2.8	1.8	9.3	4.6	2.9	10.2	0.0	6.6	15.8	4.0	
78.12.30	N	2.1	15.8	1.0	9.0	29.4	5.4	4.7	13.7	14.3	20.0	8.8	
	S	1.5	1.6	3.0	9.7	4.1	2.9	15.1	0.2	7.2	10.4	3.8	
79.1.9.	N	3.0	17.5	1.6	10.9	32.0	5.4	6.7	13.3	13.5	21.0	8.8	
	S	1.6	1.8	1.7	10.3	8.7	7.9	16.5	1.9	7.3	12.5	4.6	
79.1.17	N	3.1	18.0	1.9	10.9	33.4	6.0	8.0	13.7	13.2	20.6	9.1	137.9
	S	1.5	2.1	2.0	10.3	7.0	3.2	16.8	3.1	7.6	13.2	4.6	71.4
79.1.17 S/N in %		48	(12)	105	94	(21)	53	(210)	(23)	58	64	51	

Mean value of S/N except (), 68 %

shows the total earth pressures on the wall I and the back slope. The measured values were entirely different from the calculated ones by the Coulomb's theory. After the completion of the backfilling, testings of surcharge load and artificial rainfall were performed. Soil properties of the backfill are given in Table VII and Fig. 10. It is not easy to estimate the earth pressure against back of the retaining wall with steps. Therefore, it would be wise to obtain many case records, when earth pressure for design is needed. These records may be of great help. The design should be made assuming the dangerous states, and taking reasonable factor of safety. Friction between the backfill and the back of the retaining wall and the slope behind the backfill have large influence on the earth pressure. Average value of the coefficient of wall friction between concrete block and sand was 0.5 by a simple laboratory test. The coefficient of wall friction, k_S, obtained by the test V was much larger than 0.5. The reason has not yet been clarified. This point should be investigated in future. Vertical earth pressure increases as the construction work proceeds, and the soil layer is pressed down. Thus the wall friction begins to act to the downward direction. Compressibility of the backfill has close relations with the amount of relative movement. Assuming the elastic modulus of the soil to be 2-10 MN/m^2 , wall friction is supposed to be fully mobilized. The steps make stress conditions complicate, because the stress concentration may occur there. If the above examples are compared each other, this fact could be found easily. The part of the wall immediately under the step, which is subjected to high pressure, is acted by weaker earth pressure. Back slopes of the real retaining walls are not so simple in structure as that used here. The back slopes are sometimes slippery with water or collapsible. Retaining walls with steps have been presented above. But retaining walls without steps are commonly used, and they are much easier to handle. Therefore, examples of those retaining wall will reported as follows.

LARGE CONCRETE BLOCK RETAINING WALL (VI)

Figure 12 shows the cross section of the large concrete block retaining wall (VI). The soil properties are given in Table IX. The unit weight increased from 15.0 to 16.4 kN/m^3 during the test. The precision of measurements were 8 % in vertical direction, 4 % in horizontal direction, and 3 % in moments. The earth pressures during 26 days after the end of construction are given in Table X. Horizontal movements of blocks during construction were as follows.

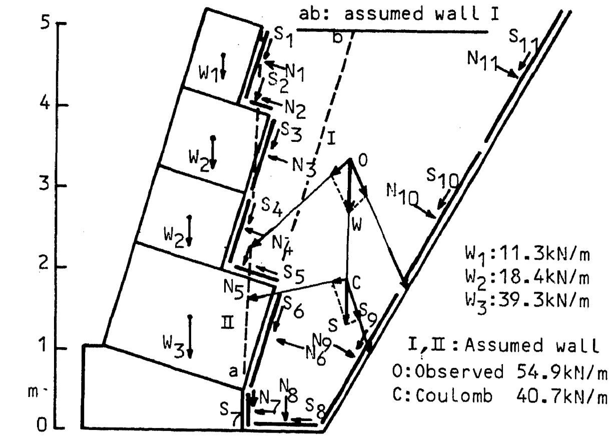

Fig. 9 Large Concrete Block Retaining Wall (V)

TABLE VII. Soil Properties

Specific gravity; G_s=2.758
Unit weight; γ=15.0 kN/m^3
Water content; w=9 %
Void ratio; e=0.77
Angle of internal friction; ø=44 degrees

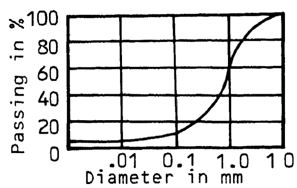

Fig. 10 Grain size

TABLE VI. Earth pressure in kN/m^2

No.	1	2	3	4	5	6	7	8	9	10	11
N	2.7	17.0	4.0	9.5	42.6	9.5	7.3	28.5	17.4	18.4	6.3
S	1.5	2.9	3.2	5.9	0.5	6.0	8.6	0.0	11.9	16.3	4.3
S/N %	56	(17)	80	62	(1)	63	118	(0)	68	89	68

Mean value of S/N except (), 76 %

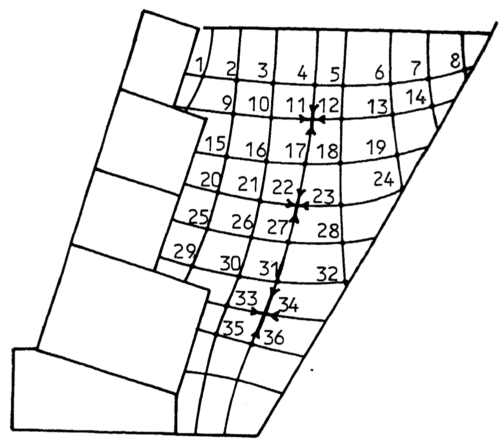

Fig. 11 Principal Stress Lines

TABLE VIII. Principal Stresses in kN/m^2

No.	1	2	3	4	5	6	7			
σ1	10	10	10	10	10	10	10			
σ2	2	2.1	2.2	2.2	2.2	2.3	2.5			
No.	9	10	11	12	13	14	15			
σ1	16.5	16.5	16.5	17	17	17.5	20			
σ2	3.0	3.5	4.0	4	4	4	4.4			
No.	17	18	19	20	21	22	23	24	25	
σ1	21	22	22	22.5	23	24	25	25.5	25	
σ2	4.7	4.8	4.8	5.4	5.5	5.5	5.5	5.5	6	
NO.	26	27	28	29	30	31	32	33	34	35
σ1	26.5	27	28	27.5	28	28	28	28	28.5	29
σ2	6.4	6.5	6.3	7.0	7	7	7	7.5	8	7.5

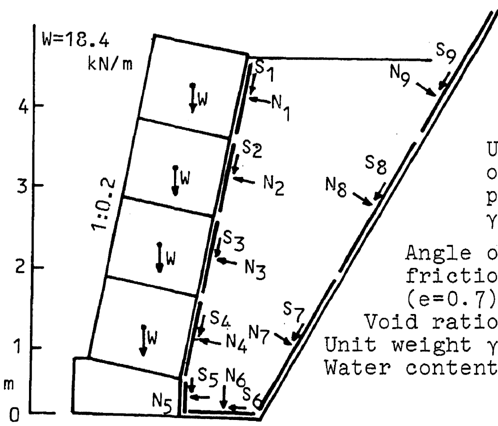

TABLE IX. Soil Properties

Unit weight of solid particles γ_s:27.58 kN/m^3
Angle of internal friction ø=44 deg. (e=0.7)
Void ratio e: 0.97
Unit weight γ: 15.0 kN/m^3
Water content w: 9.7 %

Fig. 12 LARGE CONCRETE BLOCK RETAINING WALL (VI)

TABLE X. Earth Pressure in kN/m^2

No.	1	2	3	4	5	6	7	8	9
N	1.8	6.8	12.0	14.3	26.0	25.5	19.6	15.4	4.7
S	2.3	3.4	5.2	3.0	13.1	1.3	8.3	16.9	0.7
S/N %	128	50	43	21	50	(5)	42	110	15

Mean value of S/N except (), 57 %

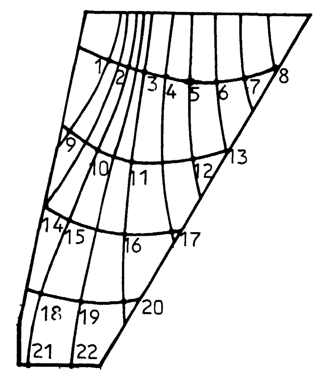

Fig. 13 Principal Stress Lines

TABLE XII. Principal Stresses in kN/m^2

No.	1	2	3	4	5	6	7	8	9	10	11
σ_1	8	9	10	10	11	10	9	7	15	18	2[illegible]
σ_2	2.7	3	3	3	3	2.8	2.5	2	5	6	[illegible]
No.	12	13	14	15	16	17	18	19	20	21	22
σ_1	20	19	24	24	25	26	26	26	26	26	26
σ_2	5	4	9	8	8	9	9	9	9	9	9

Concrete blocks	Base	1st	2nd	3rd	top
Displacement in mm	5	9	4	5	6

No movement was observed after the completion. The height of the point of application of the total pressure H_f=1.39 m, and the relative height r_H=32 %. The normal and tangential components of the total earth pressure against the back side of the wall were 46.5 and 20.1 kN/m^2, respectively. The ratio S/N was 43 % (δ=23 degrees). The distribution of earth pressure on walls are illustrated in Table X. The distribution of the normal components is in triangular shape, and that of the tangential components is in parabolic shape. The earth pressure coefficients and the angles of wall friction are given in Table XI. The distribution of stresses in the backfill was obtained by interpolation. The principal stress lines and the principal stresses are given in Fig. 13 and Table XII, respectively.

TABLE XI. Earth Pressure Coefficients and Wall Friction Angles

	Back of the retaining wall, inclination -11.3 degrees	Back of the backfill, inclination +30 degrees
Normal component, k_N	0.333	0.533
Tangential component, k_S	0.144	0.364
Total, k	0.363	0.645
Angle of wall friction, δ degrees	26.6	34.4

Total vertical earth pressure increased in simple proportion to the depth of 1.5 m below the backfill surface. It still increased down to the depth of 2 m, but the resisting force of the walls were balanced with the weight of the backfill below this level. The similar phenomena could be seen in silos.
Figure 14 shows changes of earth pressure at the back of the retaining wall and the back slope of the backfill versus depth from the top surface of the backfill. The width of the backfill is approximately the same as the depth of 2 m. Earth pressure increased lineally from the top to this depth, but it became constant or decreased below this depth. The earth pressure on the back slope of the backfill showed sililar tendency.

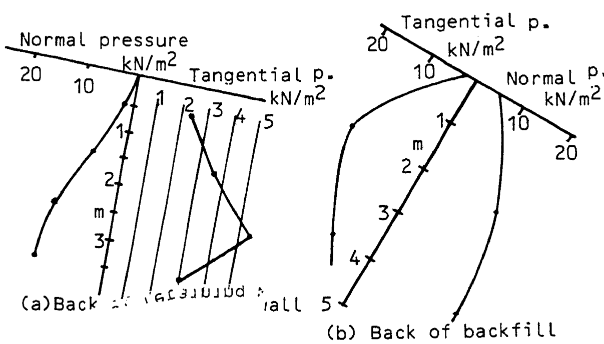

Fig. 14 Distribution of Earth Pressure on Walls

COEFFICIENTS OF EARTH PRESSURE ON RETAINIG WALLS

Table XIII is to compare the results of measurements with retaining walls about 5 m in height. It contains data on other retaining walls which do not appear in this paper because of limited pages. Figure 15 was drawn by use of Table XIII. It shows total resultant earth pressures in the form of coefficient of earth pressure and relative heights of the point of application.

TABLE XIII. Coefficients of Earth Pressure and Relative Heights of the Point of Application of Total Earth Pressure

Inclination	Test No.	r_H	k_N	k_S
Vertical	(1)	0.46	0.26	0.15
	(2)	0.34	0.39	0.17
	(3)	0.39	0.26	0.11
	(4)	0.36	0.51	0.14
1:0.2	VI	0.32	0.33	0.14
1:0.3	II	0.31	0.41	0.22
	III	0.40	0.16	0.11
	IV	0.62	0.30	0.13
	V	0.42	0.18	0.13
	VII	0.47	0.20	0.20
	IX	0.41	0.30	0.05
1:0.4	I	0.67	0.105	0.07

Test Nos.(1), (2), (3), and (4) are not in this paper.

$k^2=k_N^2 + k_S^2$

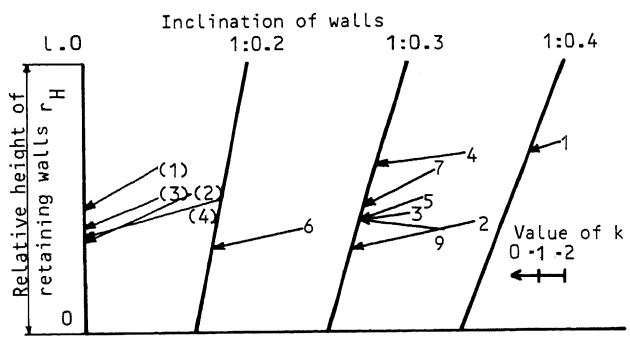

Fig. 15 Coefficient of Earth Pressure and Relative Heights of the Points of Application of Total Earth pressure

BURIED PIPE

A steel tube with the diameter of 2 m and the thickness of 20 mm were buried in the ditch and filled with sands as shown in Fig. 16. The tube was encircled by 8 panel type earth pressure gauges. The properties of the backfill soil are given in Table XIV. The size of the panel was 58 x 68 cm. The earth pressures at the end of backfilling are presented in Fig. 17. A minus sign of the tangential components S represents clockwise direction. Apparent earth pressure diagram, which is widely used, was obtained as shown in Fig. 18. The earth pressure measured with the panel attached to the bottom of the pipe was extremely high. The foundation of the pipe might not be even and uniform. This should be the main reason of the stress concentration. The apparent earth pressure diagram of Marston-Spangler is compared with that of test as shown in Fig. 19.

TABLE XIV. Soil Properties

Density γ kN/m^3	16.0
Dry density γ_d kN/m^3	13.8
Angle of internal friction ϕ degrees	40
Cohesion c	0

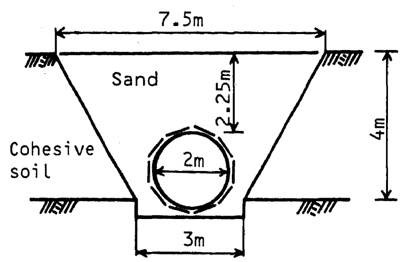

Fig. 16 Buried Pipe

N: Normal pressure
S: Tangential stress
-: Clockwise direction

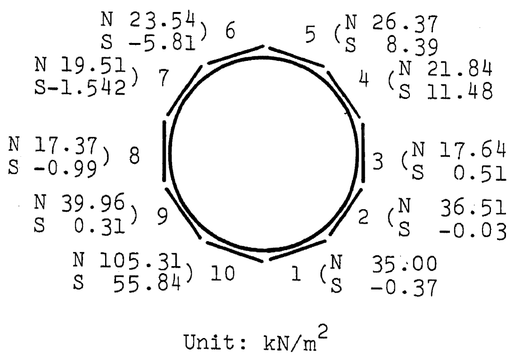

Fig. 17 Earth Pressure on Pipe

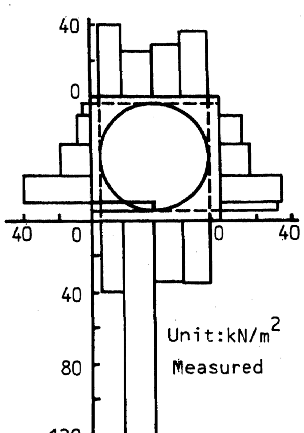

Fig. 18 Apparent Earth Pressure on the Pipe

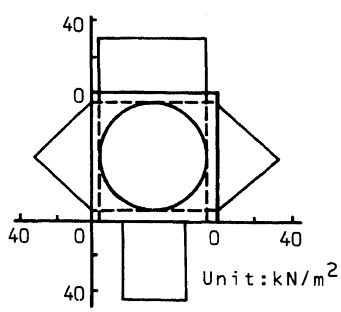

Fig. 19 Earth Pressure Diagram by Marston-Spangler

CONCLUSIONS

(1) The panel type earth pressure gauges were used for measuring the earth pressure against retaining walls and buried pipes. The normal and tangential components of earth pressure w simultaneously and acctually measured.
(2) Stress distribution in the backfill was obtained by interpolation. Relationship between the total earth pressure acting on an assumed wall and the real wall surface was clarified.
(3) Influence of shape and size of the space between the wall and the back slope upon the earth pressure against the retaining wall was made partly clear.
(4) The wall friction acting on the buried pi was successfully measured, and the earth pressure acting on the pipe was partly clarified.

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