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Measurement of earth and water pressures acting on the great depth shield tunnel segments

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ABSTRACT : With rapidly increasing development of underground space in city centers, there is a tendency for shield tunneling to be at greater depth. It is usual in designing tunnel segment at Nippon Telegraph and Telephone(NTT) that the earth pressure acting on the segment in diluvial mutual layer is taken as the total overburden earthpressure. However there are still many uncertainties in the earth pressure theory is a basis of the shield tunneling concept. This paper reports measured earth pressures on segments of two deep shield tunnels in diluvial layer.

1. INTRODUCTION

In order to ensure the reliability of telecommunication networks, especially to keep it away from natural disaster such as earthquake and from human interference, important telecommunication cables in urban area are now usually laid in tunnel. The field measurement of shield tunneling reported in this paper is related to two such telecommunication cables tunnels. As shown in Fig. 1, one tunnel is along the route of the Yodo river and the other is along Shigino route, which forms part of the NTT Osaka Network.

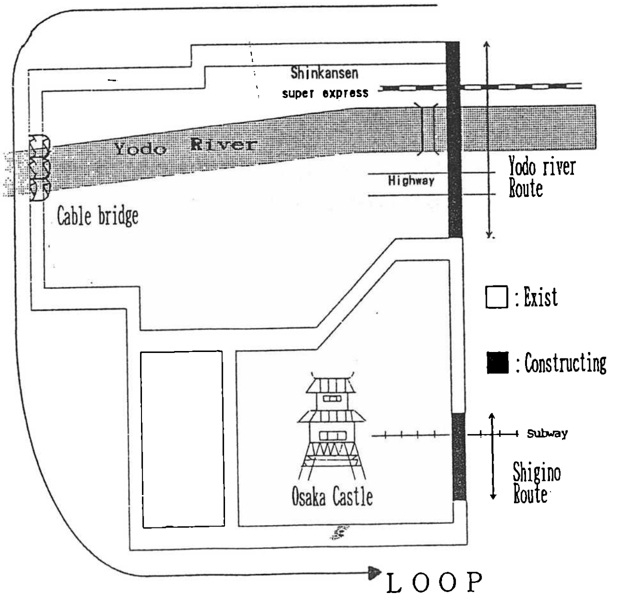

Fig.1 Telecommunication network in Osaka, Japan

2. FIELD MEASUREMENT

Measurement was made to analyze the earth pressures acting on segments of deep shield tunnel

2.1 Yodo river route

The soil strata at the point of measurement segment and the point of instruments are shown in Fig.2. The two soils are sandy soil (N-value is more than 50) and hard clay (N-value is 25). The layer above those among the segment is clay with sand (2m).
Items of measurement is shown in Table 1.
The segment is made of steel, being 3.7 m in outside diameter as shown in Table 2.

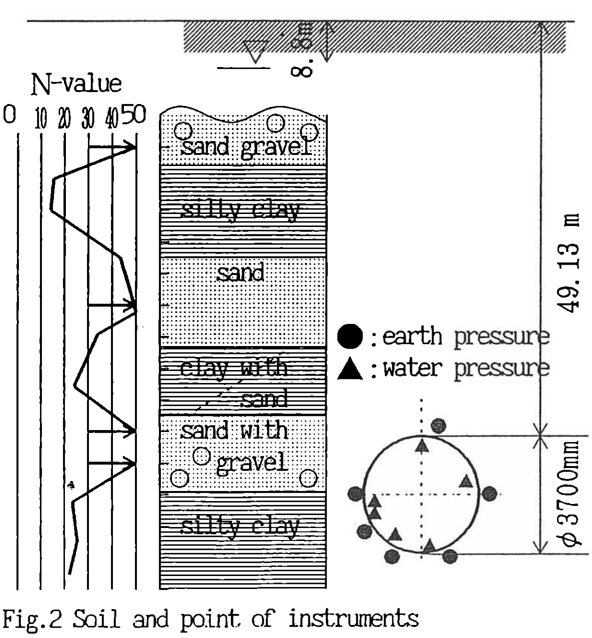

Fig.2 Soil and point of instruments

Table 1. Item of measurement

item	instrument	number
earth pressure	pad type	6
water pressure	manometer	6
stress	strain gauge	16

Table 2. Specification of segment

outside diameter of lining segment	3700mm
width of lining segment	900mm
height of rib	225mm
thickness of rib	22mm
number of ribs	4
thickness of skinplate	4mm

2.2 Shigino route

The soil stratra at the point of measurement segment and the point of instruments are shown in Fig.3. The soil at the upper part of segment is hard the sandy gravel (N-value is more than 50), and the soil at lower part is clay (N-value is 15). The soil at upper part of sand gravel is silt with sand(3m).

Items of measurement are shown in Table 3.

The segment is made of steel with 3.55 m outside diameter. The specification of the segment is shown in Table 4.

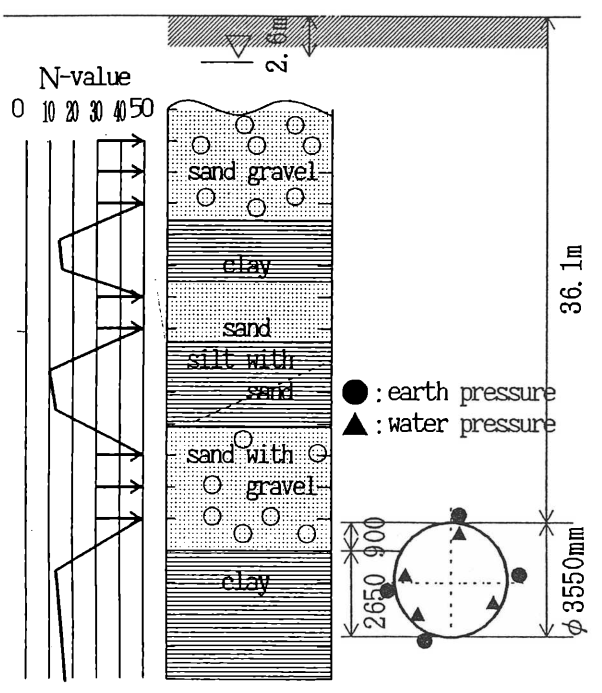

Fig.3 Soil profile and location of instruments

Table 3. Item of measurement

item	instrument	number
earth pressure	pad type	4
water pressure	manometer	4
stress	strain gauge	16

Table 4. Specification of segment

outside diameter of lining segment	3550mm
width of lining segment	1000mm
height of rib	150mm
thickness of rib	22mm
number of ribs	4
thickness of skinplate	3.2mm

3. DEVELOPMENT OF THE PAD TYPE EARTH PRESSURE CELL

3.1 Pad type earth pressure cell

We developed a " pad type " earth pressure cell with a thin, face which can be used to receive the earth pressure acting on the segment correctly as outlined in Fig.4.

The pad type earth pressure cell of about 5 mm thickness can be attached on a segment face within tail clearance (20～30 mm) of the shield machine. Earth pressure can then be measured by the variation of oil pressure of the cell. The earth pressure cell possesses the following features.

1) Average earth pressure can be measured on the large face area.
2) The cell can be attached to segment by bonding.
3) There is no section loss as normal earth pressure cell in box shape of the segment.
4) The distribution of earth pressure will not be disturbed because of the smooth face on the pad of the earth pressure cell.
5) The cell can be attached independently regardless of the type and the planning process of the segment unit.

The applicability of the pad type earth pressure cell and the influence of the tail seal in shield machine on the measured data is discussed here.

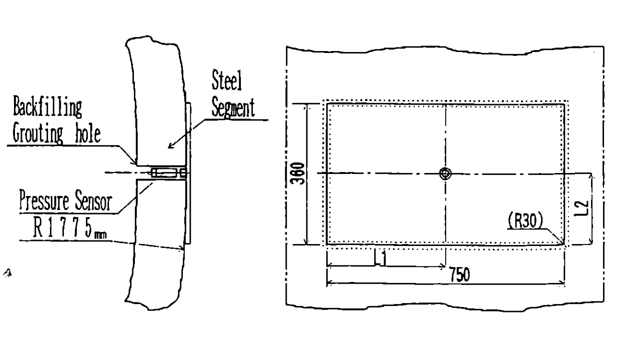

Fig.4 Pad type earth pressure cell

3.2 Attachment

The shape of the earth pressure cell is a rectangle of 750mm×360mm. Its radius of curvature is about 178 cm. As to the attachment of the cell to a segment (φ3550mm), after the cell was bonded on the segment, the end of the cell was held down with a metal clamp. The pad length is 3.2 % of the circumference of the segment ring.

3.3 Measured results

The passing sequence of the tail-seal and the segments (relative to the wire brush of tail seal and segment) is shown in Fig.5.

The tail-seal used in this project has three brushes made of steel.

The tail seal of the shield machine passes across the earth pressure cell from a state backfilled around the segment to the rear of the measured segment.

When the brush of tail-seal is loaded on the cell, the measured data record the face pressure.

For the moving condition of the tail-seal, at first only brush I loads the cell, both brush I and brush II load it then brush II and brush III, brush III only is loaded.

Then the passing over the cell is complete.

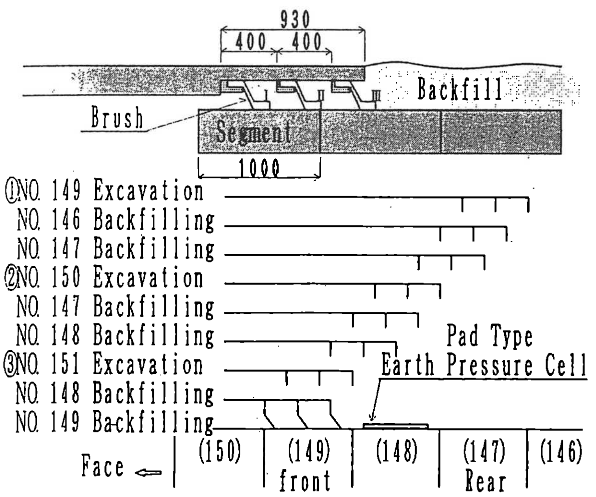

Fig. 5 Conditions of tail-seal on the segment

Effective percentage (k %) of output from the earth pressure cell whom a partial pressure of the brush was estimated by FEM analysis assuming that the first and the second brush act on the pad as a distributed load as shown in Fig.6.

Measured results of earth pressure before and after backfilling are shown in Fig.7.

The measured value at stage ① began to increase with brush I pressure, and then brush II is loaded during backfilling-1 to the rear segment, brush III is loaded on the end of the rear segment.

The measured value at stage ② is the state when

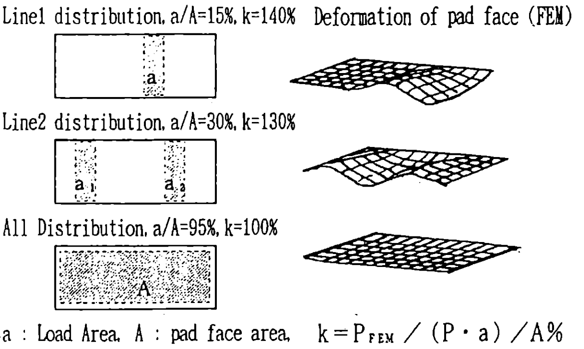

Fig.6 Influence of tail-seal on pad

brush I is unloaded from the cell, brush III is loaded with backfilling-2 to the rear segment and continuous backfilling-1 to measured segment with until at last brush III is unloaded from the cell.

The measured value at both stages ①and ② is thought to be the pressure of tail-seal through the brush and are not the backfilling pressure to the segment nor earth pressure.

It is considered that -30% of the revised value of measured can be used as the controlled value of backfilling pressure.

It is found that the measured value from the pad type earth pressure cell is influenced by the measurement of the brush on the segment.

Measured values of the latter half of stages② and ③ and after④ are backfilling and earth pressures themselves which shore that the brush clears the cell.

Measured values vary by backfilling pressure in the front segment and the near to front segment as shown in the later half of stage ③ and the later part of stage ④ for several hours after the passing of tail seal. This means that the backfilling material is in filling the tail clearance.

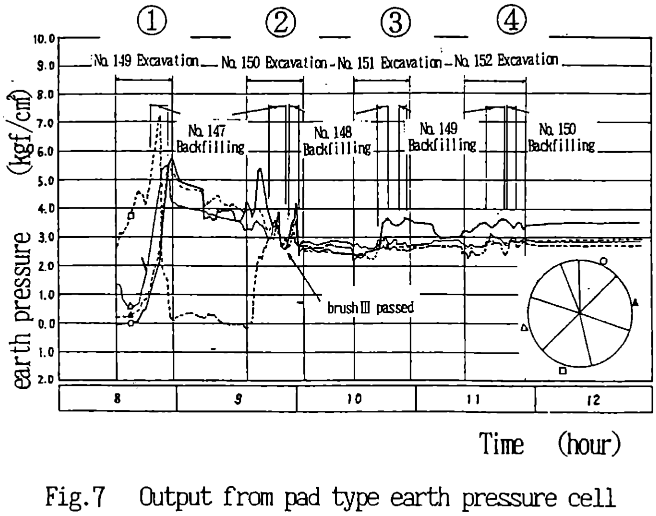

Fig.7 Output from pad type earth pressure cell

The pad type earth pressure cell can be used to output reliable measured data of earth pressures among the period of passing tail-seal and backfilling. The measured results proved that the cell can be used for field measurement.

4. RESULTS OF MEASUREMENTS

4.1 Earth and water pressures at Yodo river route

The earth pressure acting on the segment increased to about 3.9~4.9 kgf/cm² by backfilling as shown in Fig.8. Later behavior of earth pressure can be separated into two patterns. One is when the earth pressure decreased gradually after backfilling, and reached stable conditions after a month. The other is when the earth pressure increased rapidly, and then increased and decreased cyclicly.
Water pressure was almost stable at all the measurement work is after backfilling as shown in Fig.9. This can be regarded as the reason that variation of earth pressure was controlled by effective earth pressure due to the fact that variation of water pressure was compared with the variation of earth pressure. Effective earth pressure reached a stable condition after nine months. Distribution of earth and water pressure after ten months is shown in Fig 10.
Earth pressures on the left part were a little bit, of large but about the right and left the pressures increased from water pressures were symmetric about the right and left.

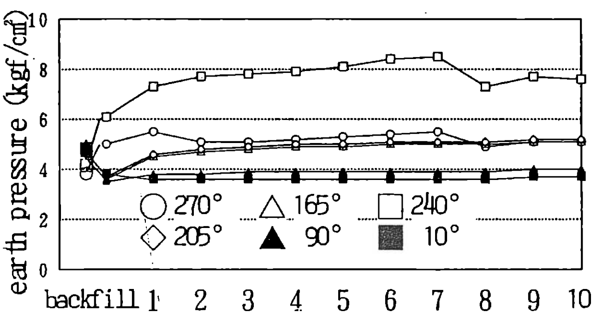

Fig.8 Variation of earth pressure (month)

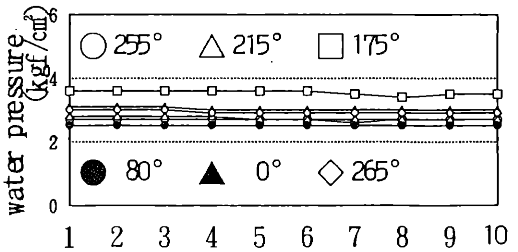

Fig.9 Variation of water pressure (month)

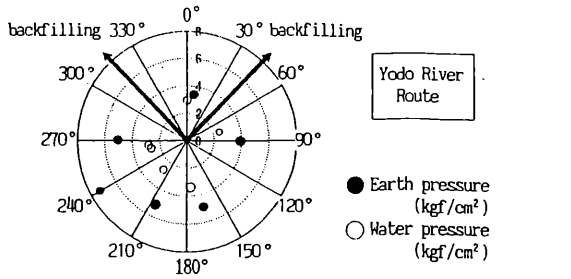

Fig.10 Distribution of earth and water pressure

4.2 Earth and water pressure at Shigino route

Variation of earth and water pressures acting on the segment are shown in Fig.11 and Fig.12.
Earth pressure acting on the segment increased up to about 5.7~7.3 kgf/cm² by backfilling, and then decreased rapidly. It reached stable conditions after one day. Earth pressures decreased a little after three months, later to increase again.
This could be regarded as the reason the variation of earth pressure was controlled by the water pressure due to the fact that the water and earth

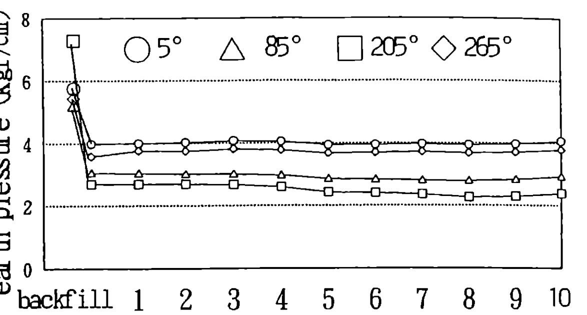

Fig.11 Variation of earth pressure (month)

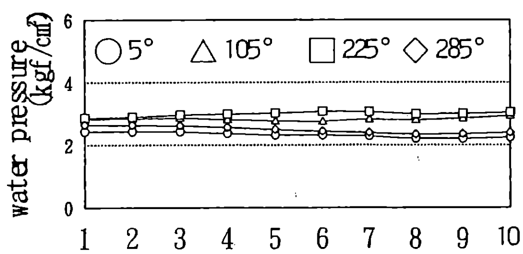

Fig.12 Variation of water pressure (month)

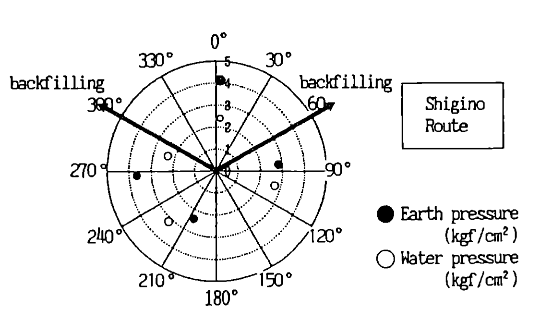

Fig.13 Distribution of earth and water pressure

pressures change in the same way and the effective earth pressure is almost unchanged.
Earth pressure, in the upper part was greatest as shown in Fig. 13. Distribution of water pressure was symmetric about the right and left.

5. COMPARISON BETWEEN MEASURED AND DESIGNED VALUES

5.1 Designed value

Outline of the segment design of the shield tunnel in NTT Kansai is described in following way,

○ Earth and water pressures

① Water pressure and earth pressure are treated separately.

② Hydrostatic pressure is the standard water water pressure condition.

③ Vertical earth pressure is the total earth pressure from the ground surface because of layered ground.

④ Horizontal reactive earth pressure is distributed in triangular form.

○ Sectional force

It is assumed that bending rigidity of the segment ring is uniform without reduction of bending rigidity at segment joints.

Design conditions of the shield tunnel and analytical model are shown in table 5 and Fig.14, respectively.

Table 5. Segment design conditions

item	Yodo river	Shigino
soil	clay	clay
overburden	49.13m	36.10m
ground water level	8.80m	2.60m
coefficient of earth pressure	0.50	0.55
coefficient of sectional ground reaction	2400 tf/m³	1600 tf/m³
average of N-value	25	15

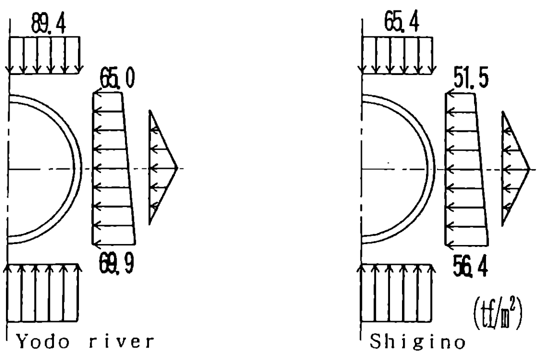

Fig.14 Analysis model of design

5.2 Comparison between measured and designed earth and water pressures

Comparison of earth and water pressures at the top of the segment ring is shown in table.6. The relation between depth from ground wee vs. earth and water pressures measured at the Yodo river shield tunnel is shown in Fig.15.
Measured water pressure is about 75 % of design value at the top of the segment ring. The distribution is almost the same as a hydrostatic distribution calculated as artesian pressure in the sand layer of the upper half of the segment. It is considered that water pressure at the side is smaller than that of the top because the upper part of the segment is in sand and the lower part is in clay. At the top part, measured earth pressure is about 40% of design pressure. Measured effective earth pressure is about 14 % of the design one and is about twice the effective measured pressure of Terzaghi. It is considered that the effective earth pressure in the lower half is large because the upper half is in a douse sand layer and the lower half is in a diluvial deposit clay so that the coefficient of earth pressure of the lower part is larger than that of upper part. The relation between the depth from ground vs. earth and water pressures measured at Shigino shield tunnel is shown in Fig.16. Measured water pressure is about 65% of design pressure at the top of the segment ring. The distribution of water pressure is almost the same as artesian pressure in the upper sand layer. As to the distribution of measured earth pressure, it decreases with depth, in contrast to the water pressure. At the top part, measured earth pressure is about 62% of design pressure and the measured effective earth pressure is about 59% of the design value.

5.3 Presumption of earth pressure

Earth pressure presumed from measurement results is shown in Fig.17.

Table 6. Comparison of earth and water pressure at the top of the segment ring (tf/m²)

kinds of pressure	Yodo	Shigino
measured earth	37.0	40.6
measured water	30.0	22.5
measured effective earth	7.0	18.1
designed earth	89.4	65.4
designed water	40.3	33.5
designed effective earth	49.1	30.8
loosened (of Terzaghi)	43.8	38.0
effective loosened earth	3.5	3.4
during backfilling	48.4	58.1

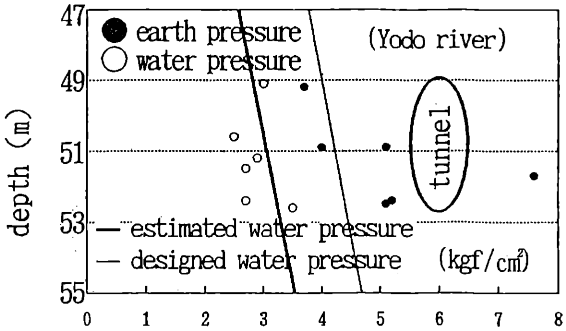

Fig.15 Depth and earth and water pressure

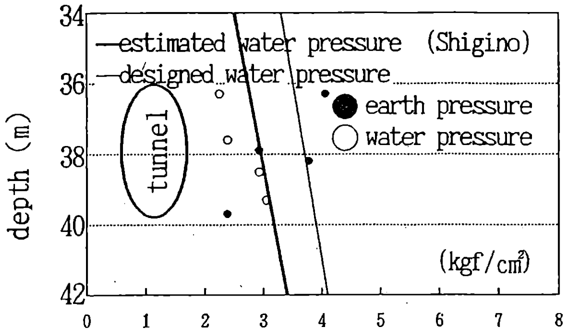

Fig.16 Depth and earth and water pressure

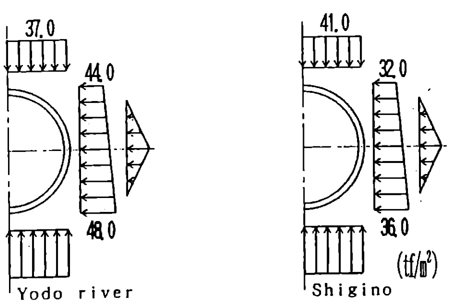

Fig.17 Presumed earth pressure

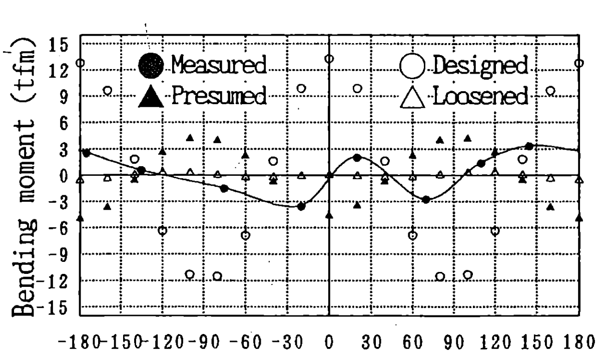

Fig.18 Bending moment of Yodo river (angle)

5.4 Comparison between measured stress and designed one

Measured bending moment, design bending moment and bending moment calculated from presumed earth

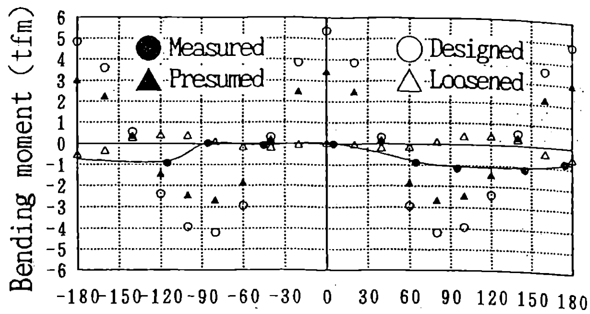

Fig.19 Bending moment of Shigino (angle)

pressure were shown in Fig.18 and Fig.19. It is found that the measured moment distribution of the Yodo river is similar to the design value, but the measured moment is about 30% of the design one. The measured moment distribution of Shigino is not similar to others, and measured moment is between the loosened one and presumed one. Maximum moment and stress of each kind is shown in Table 7. The measured stress is about 20 % of the design one is similar to loosened stress. Presumed stress is about two times the measured one, this might be the reason that the balance of vertical earth pressure and horizontal earth pressure distribution is different.

Table 7. Maximum values of moment and stress

item		moment	stress
Yodo river	measured	3.7	360
	designed	13.3	1,840
	loosened	0.5	370
	presumed	5.0	820
Shigino	measured	1.2	400
	designed	5.4	1,820
	loosened	0.5	600
	presumed	3.4	1150
		(tfm)	(kgf/cm²)

5.5 Examination of design earth pressures

Based on the data from two field observations the earth pressures acting on segment in layers of sand and clay at overburden depth of 36 ~50m is proved in following way.

The earth pressure acting on a segment is about 40~60% of overburden pressure and is similar to the earth pressure contributed from loosened ground. The stress in the segment is similar to the earth pressure contributed from loosened ground.

Maximum measured earth pressure occurred in the backfilling on the Shigino route.

Measurement results show loosened earth pressure can be used as the design value. In such case, the backfilling pressure must be considered in the loading acting on the segment.

6. CONCLUSIONS

1) The measured earth pressure is about 40-60% of the total overburden earth pressure and is almost the same as the earth pressure contributed from loosened ground.
2) The measured water pressure is smaller than static water pressure but almost the same as artesian pressure.
3) The measured effective earth pressure is 14~59 % of total overburden effective earth pressure.
4) Measured stress is about 20% of design stress and is almost the same as the stress applied by loosened ground.
5) It is found that the maximum measured earth pressure occurred when simultaneous backfilling was being done. Therefore it is necessary to take into account the backfilling pressure when considering the load acting on a segment.
6) Pad type earth pressure cell is applicable in field measurement.
7) It is found that -30% of the reviced value of meassured can be used as the controlled value of backfilling pressure.
8) Based on these measured and further accumulated data, we are trying to find out a suitable method of the earth pressure prediction for future design of tunnel segments.