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Ten-year field measurement of forces acting on lining of shield driven tunnels

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SYNOPSIS: The Second Ueno Tunnel on JR's Tohoku Shinkansen is large cross-section shield tunnel built in layers of diluvial material. Earth pressure and water pressure acting on the lining of this tunnel and stress occurring in the lining were measured over a period of 10 years since construction of the tunnel. This paper reports the results of the measurement.

1. Outline of the Tunnel

1.1 Structure

The Second Ueno Tunnel on JR's Tohoku Shinkansen line is a 1,245m long, double-track tunnel specificaliy design for Shinkansen that has a mean earth cover thickness of 19 m and an outer diameter of the segment ring of 12.66m. The tunnel was constructed with pneumatic manual shields. The segment used was a pin-joint type, flat reinforced concrete component. The thickness of the segment was 55 cm. After the segments were erected, a 30cm thick inner lining was cast. (Fig.1, cross section of the Tunnel. Phot.1, Pin joint)

1.2 Geology

The mean thickness of the earth cover of the tunnel is 19 m, and most of it is in diluvial layers. The tunnel was constructed in layers of dilluvial sand and silt.

Until 1979, groundwater in the lowest sand layer had been droughty. During the construction of the tunnel, the groundwater level showed a tendency to rise. (Fig.2, Longitudinal Profile)

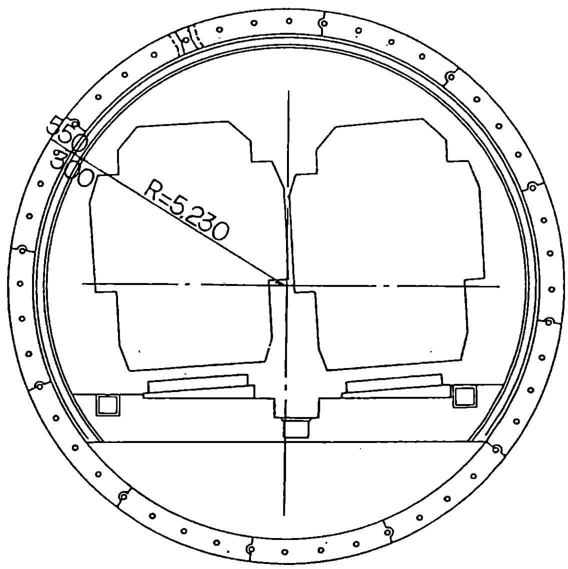


Fig. 1 Cross section of the Tunnel

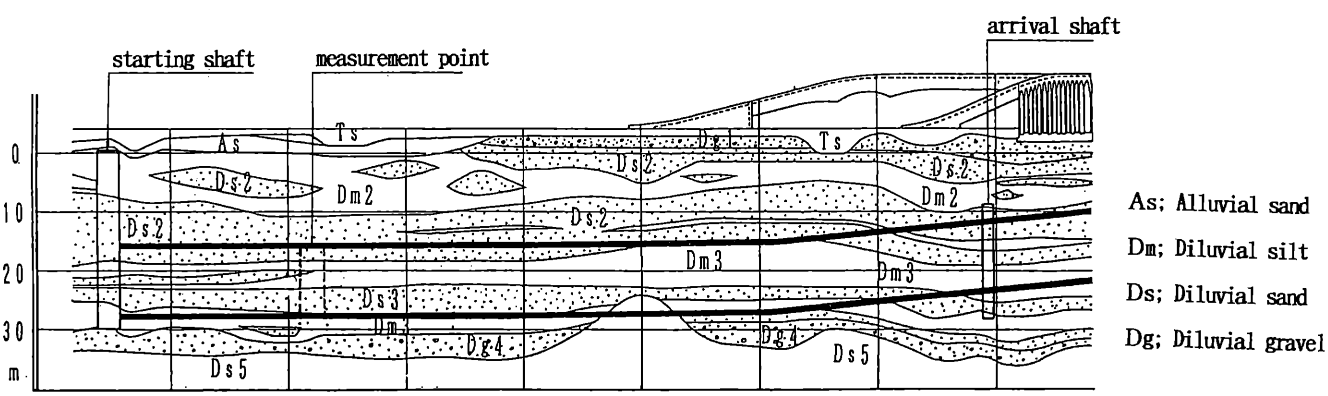


Fig. 2 Longitudinal Profile

2.Results of Measurement

In-process measurement was conducted for about four years after the segment ring was assembled(December 1981 to March 1986). About 10 years after the segment ring was assembled(January 1992)postconstruction measurement was conducted as a follow-up survey.

2.1 Earth Pressure Gauge

2.1.1 Earth Pressure during Construction

During costruction, earth pressure increased with the progress of back-fill grouting and stabilized in about a week. The resultant earth pressure at the top of the assembled ring was approx,1.6 kgf/cm²(156.9kPa),which was lower than the design earth pressure (3.4kgf/cm² 333.4kPa). (Fig.3,Changes in Earth Pressure during Construction)

The changes in earth pressure after the segments were assembled until the completion of grouting and excavation show substantial unsymmetrical pressures due to grouting and excavation. It seemed that these unsymmetrical pressures still exist.

2.1.2 Earth Pressure After 10 Years

In January 1992, about 10 years after the measurement began, a follow-up survey was conducted in which earth pressure, water pressure, and steel stress were measured.(Fig.4,Changes in Earth Pressure in 10 Years)

Earth pressure, which showed a tendency to increase after completion of the secondary lining, was still on the increase. The increase in earth pressure, which was calculated as the difference between the result of final measurement during costruction and the result of this postconstruction measurement, averaged 0.38 kgf/cm² (37.3kPa). Of this increase in earth pressure,0.21 kgf/cm²(20.6kPa) was actually an increase in pore water pressure.

The distribution of measured earth pressures shows that the mean difference in earth pressure measured at two points on the ring after 730 days was 0.45kgf/cm²(44.1kPa). The postconstruction measurement showed that after 3,680 days the difference was 0.30kgf/cm²(29.4kPa). This indicates that the earth pressure distribution tends to become uniform.(Fig.5,Changes in Earth Pressure Distribution)

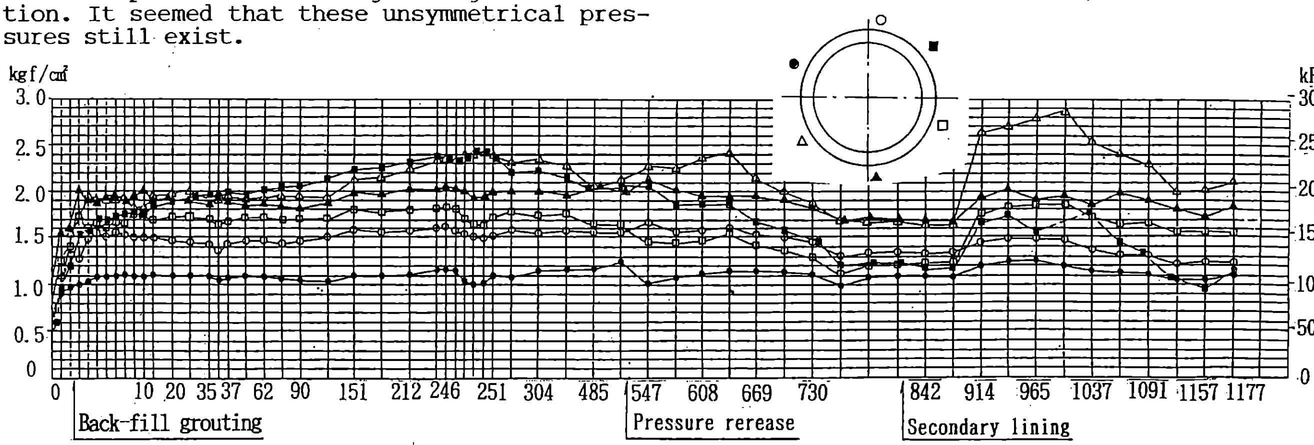


Fig. 3 Changes in Earth Pressure during Construction

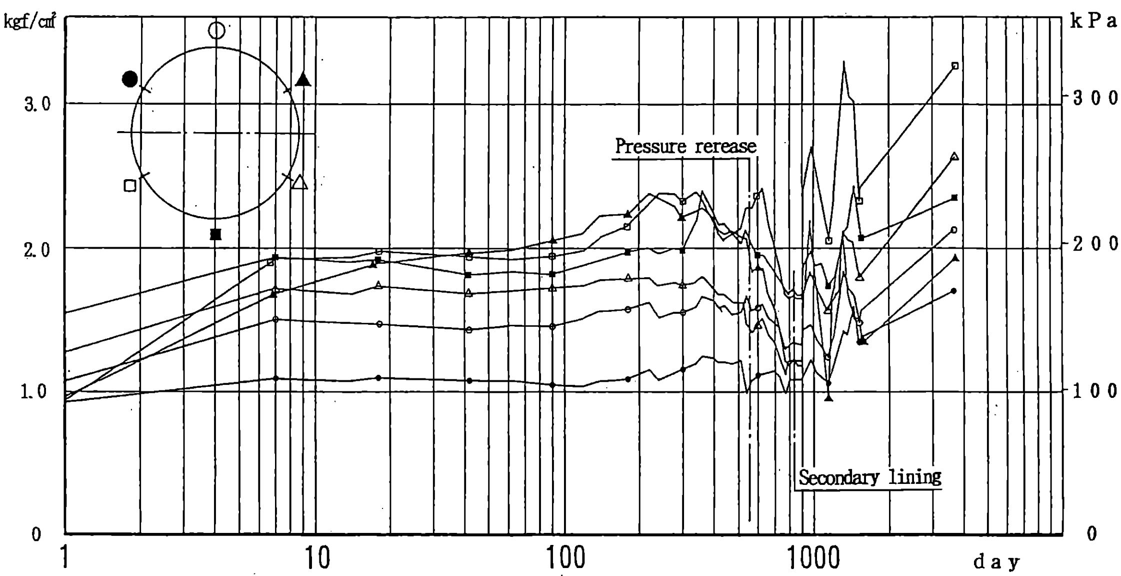


Fig. 4 Changes in Earth Pressure in 10 Years

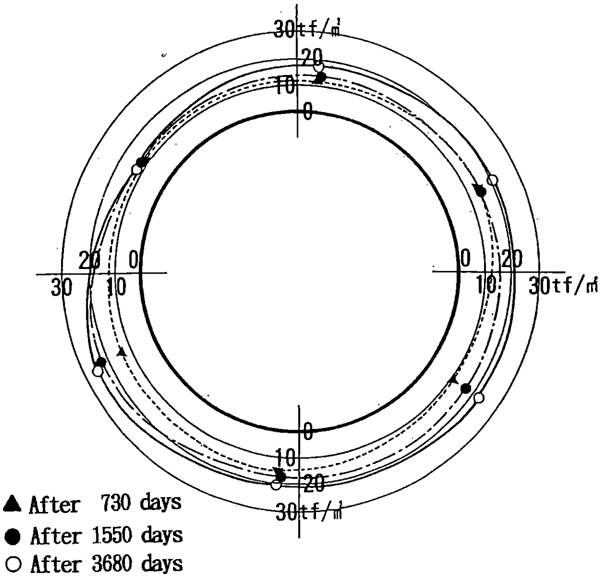


Fig. 5 Changes in Earth Pressure Distribution

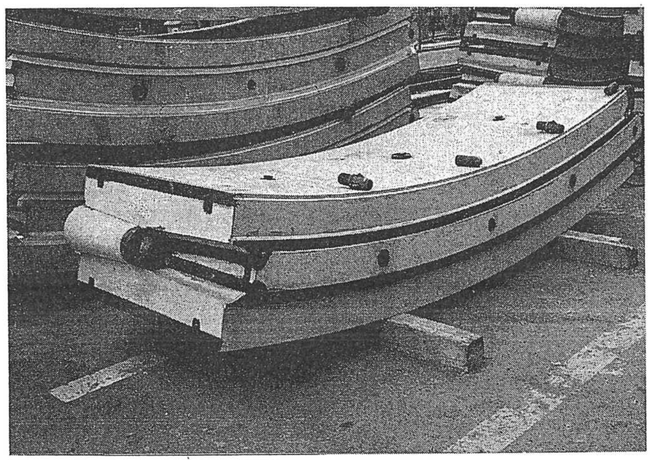
2.2 Water Pressure Gauge

Pore water pressure changed little during excavation, but it began to rise immediately after pressure release and continued to increase slowly even after completion of secondary lining. It seems that even today, 10 years after completion of the tunnel, the water pressure continues to rise.

The difference between the result of the final measurement during construction and the water pressure measured during the postconstruction measurement averaged 0.21kg f/cm² (20.6kPa). (Fig.6,Changes in Water Pressure in 10 Years)

2.3 Steel Stress Meter

The distribution of bending moments calculated from steel stresses was anaiyzed (Fig.7,Distribution of Bending Moments Calculated from Steel Stresses). Comparison of the distribution patterns of bending moment after 1,550 days (result of final measurement during construction) and 3,680 days (values obtained from the postconstruction measurement) indicates that the distribution pattern became somewhat symmetrical. Supposedly, this has something to do with the results of earth pressure measurement mentioned above. The fact that bending moments at most points showed positive bending suggests that there is not any significant difference between the vertical load and the horizontal load.



Phot. 1 Phot of Pin-joint type Segment

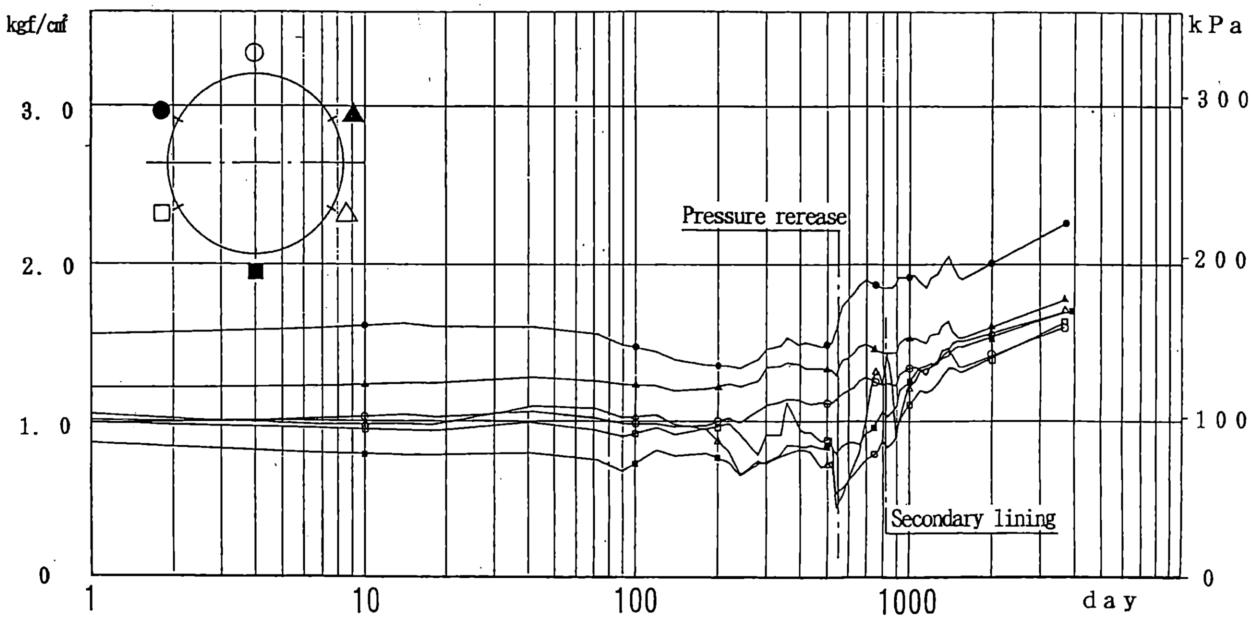


Fig. 6 Changes in Water Pressure in 10 Years

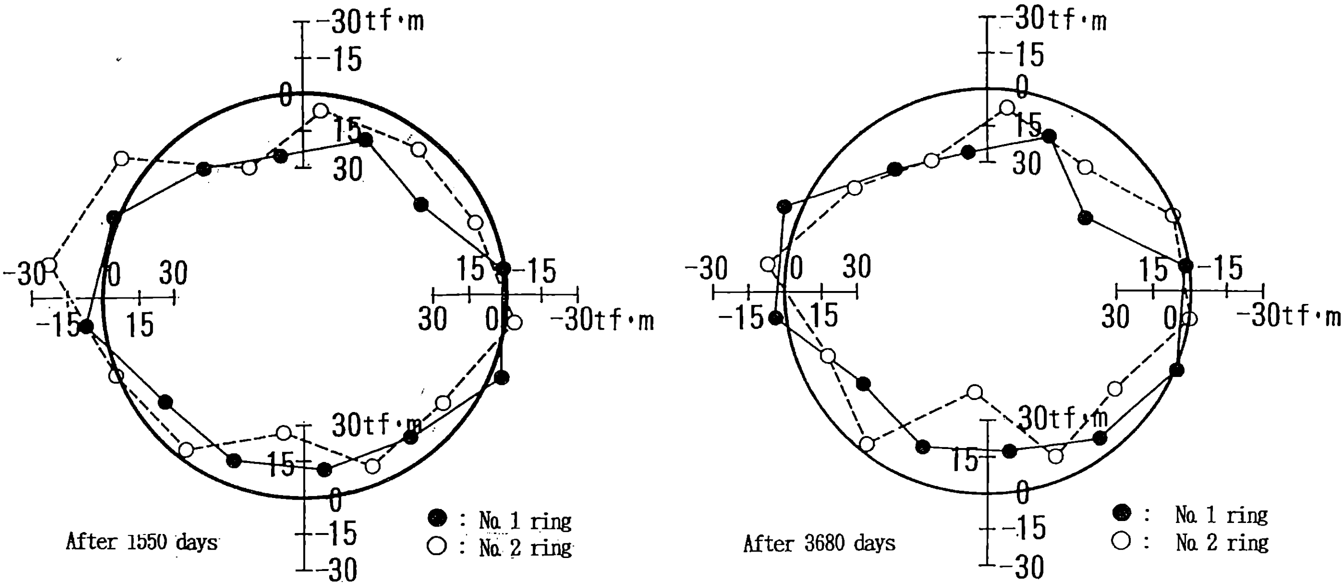


Fig. 7 Distribution of Bending Moments

3. Conclusion

(1) Earth pressure, which had been increasing since completion of the secondary lining, was still rising slowly when it was measured 10 years later. The increase in vertical earth pressure averaged 0.38kgf/cm² (37.3kPa). Of this increase, 0.21kgf/cm² (20.6kPa) was actually an increase in water pressure. The cause of this increase in water pressure is thought to be the restriction on pumping laid down by Tokyo Metropolitan Govemment in 1971. The cause of the effective earth pressure increase is that the effectiveness of chemical grouting carried out during construction decreased under the influence of, for example, leaching. The values of earth pressure measured 10 years later were approx.45 % of the design earth pressure, which had been calculated as total overburden pressure. On of the possible causes of the measured earth pressures being smaller than expected is influence of a dilluvial silt layer 5 m above the crown of the tunnel.

(2) The distribution pattern of earth pressure became somewhat uniform. This tendency agreed with the distribution pattern of bending moments calculated from measured stresses obtained from steel stress meters. The difference between the vertical load and horizontal load tended to decrease.