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Earth pressure acting on a deep circular shaft wall

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ABSTRACT : There are many facts to be clarified regarding the earth pressures acting on a deep circular shaft wall, and there are very few cases where the actual earth pressures acting on a shaft wall as large as the one in this report have been measured.

This report describes the measurement of earth pressures acting on a deep circular shaft wall which was constructed using the open caisson method. Generally, this method involves underwater excavation to sink the caisson; however, due to low groundwater level, this caisson was sunk in a completely dry state.

The circular shaft (outer diameter : 30.4 m, wall thickness : 1.4 ~ 1.7 m), shown in Figure 1, was of reinforced concrete structure, and the excavated depth was 36.2 m.

As shown in Figure 2, the caisson was constructed in 9 rings, which form the underground portion of a building having 2 stories above ground and a 6-level basement.

1. GEOLOGICAL CONDITIONS

The construction was located atop a sand hill, the geological conditions of which can be seen in Figure 1.

The upper portion of the ground is a fine alluvial sand layer with SPT N values of between 10~40, and the lower portion was alternating strata of diluvial sand and hard clay having SPT N values of around 30 and 10~15 respectively with a steep inclination in the northeast direction.

The groundwater level is extremely low, being some 40 m below the ground surface and thus several meters below the construction floor.

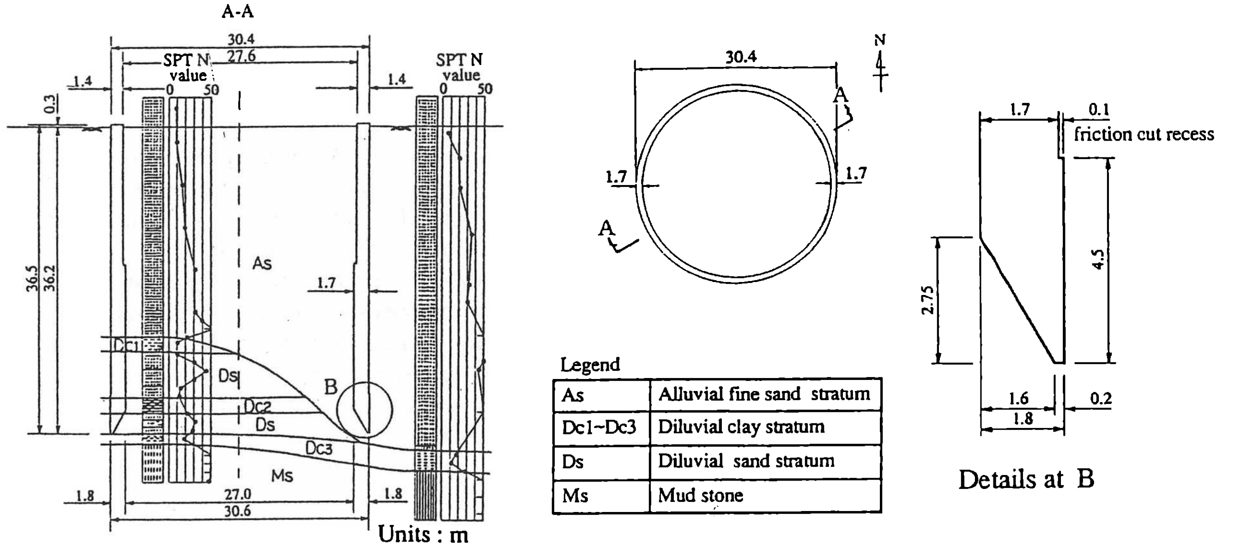

Figure 1 Shaft configuration and geological condition

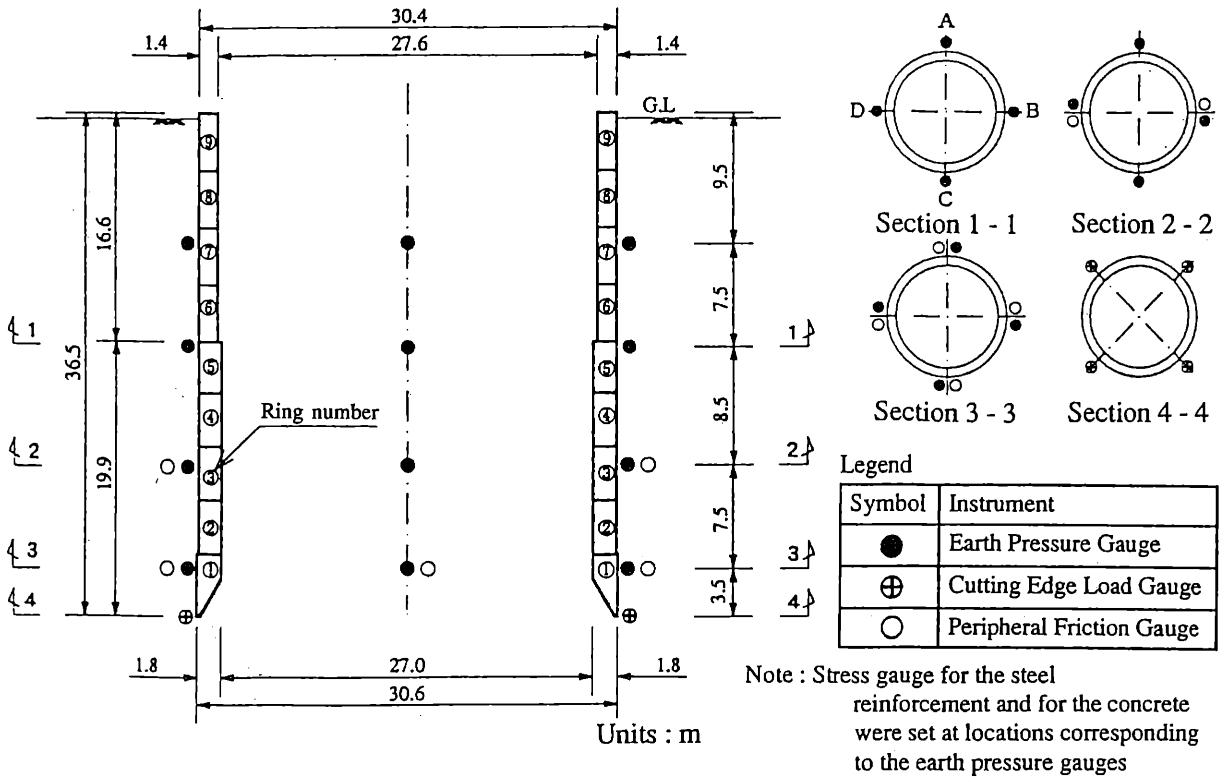

Figure 2 Arrangement of instrumentation

2. MEASURED ITEMS AND INSTRUMENTATION

The following items were measured:

- i) Earth pressure acting on the shaft wall
- ii) Reaction force at the cutting Edge
- iii) Friction force on the peripheral surface
- iv) Steel reinforcement stress
- v) Concrete stress

The arrangement of the instrumentation is shown in Figure 2.

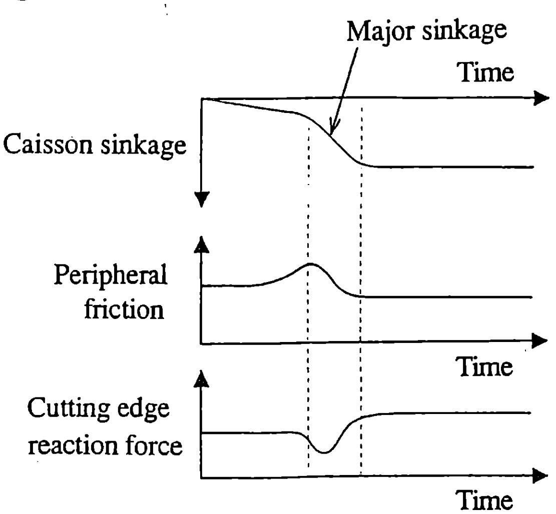

Figure 3 Mechanism of caisson sinking

3. SINKING OF THE CAISSON

As can be seen from Figure 3, there is an increase in frictional force when the caisson sinks several centimeters due to excavation at the cutting edge and then, after this frictional force peaks, there is a sudden and rapid sinking of the caisson.

The repetition of this cycle forms the caisson sinking process.

As shown in Figure 4, No.1~No.3 Rings sank about 0.2 ~ 0.5 m per cycle, and for No.4~No.9 Rings the sinkage per cycle was considerable, being about 1.0 m.

It was assumed that this large value was due to the large difference in the peripheral friction forces measured directly before and immediately after the sinking of the caisson (Figure 4).

To promote smooth sinking, as shown in Figure 1, friction cut recess (10 cm) was made at top of No.1 Ring, and from No.2 Ring and above, a combination of NF (Non-Friction) sheet and air jet was used but with little effect. For the sinking of No.8~No.9 Rings , fine particle (particle size < 2 mm) lubricant injection using a bentonite and elastomeric compound was carried out to reduce the frictional force.

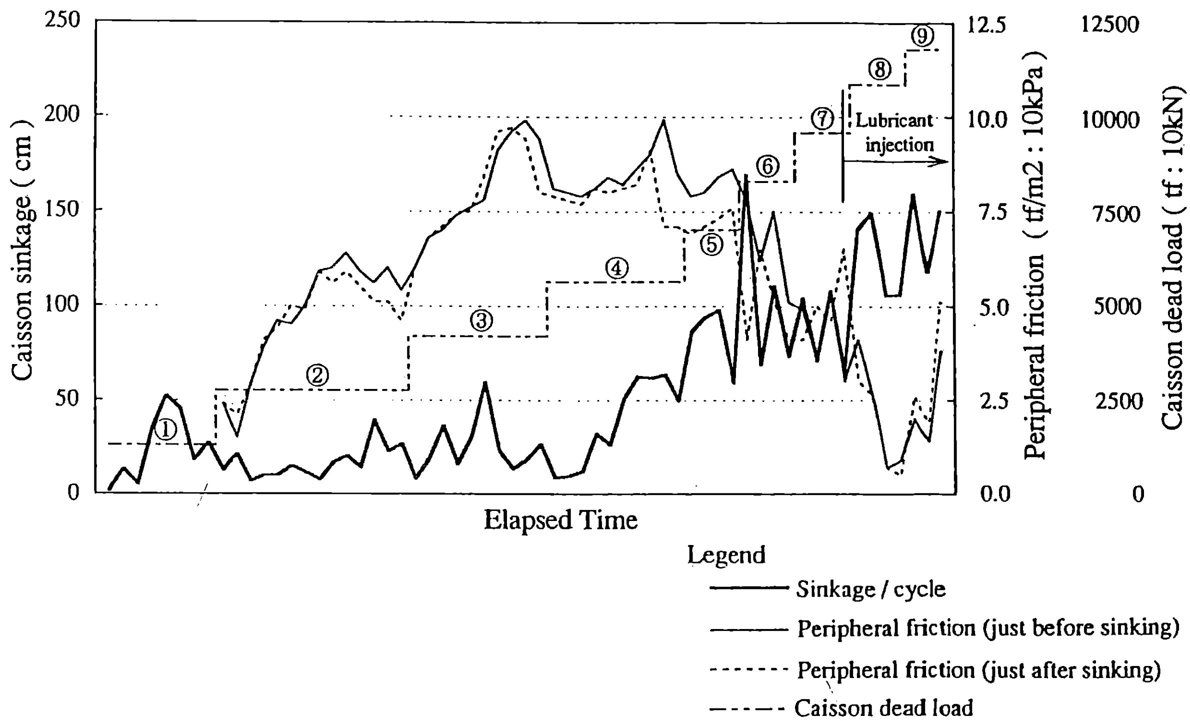

Figure 4 Variations of shaft dead load, sinkage and peripheral friction with time (for No.1 Ring)

4. RESULTS OF MEASUREMENTS

4.1 *Earth Pressure*

As well as measuring the earth pressure at 1.0 minute intervals during the entire construction process, measurements were made at 0.1 second intervals during caisson sinking, to provide detailed data regarding the earth pressures acting on the caisson during this process.

Variations in the earth pressure with depths are shown in Figure 5. From this figure it can be seen that the earth pressures at depths down to 10 m in the upper sand stratum during construction were a little larger than considered (taking the earth pressure coefficient = 0.5), while at levels lower than 10 m the earth pressures were quite small showing no tendency to increase with depth.

As the partial appearance of clay strata occurred in the region of GL - 25 m, the earth pressures of No.1 Ring for the lower part are indicated separately for clay and sand strata. From that point, the earth pressures is large for the clay portion and were approximately equivalent to anticipated values.

It can also be seen that around GL - 15 m, before injection of the lubricant, the earth pressures acting on No.3, 5 and 7 Rings were lower than for No.1 Ring.

This is thought to be because No.1 Ring is below the friction cut recess (10 cm) and so there is no loosening of the ground and earth pressures at rest are acting, whereas No. 3, 5, and 7 Rings are above friction cut recess where loosening of the ground has occurred and earth pressure at rest is tending toward the active earth pressure state resulting in lower pressures.

In Figure 6 is shown the earth pressure distribution with depth approximately one month after the sinking of the caisson to the final position. From this figure it can be seen that the earth pressures for No.3 and No.5 Rings have dropped.

This is assumed to be the result of dispersion of the lubricant liquid pressure and arch action of the ground in the vertical direction causing redistribution of the earth pressure.

In Figure 7 is shown the earth pressure distribution of Figure 6 in plan view.

In this figure it can also be seen that the asymmetry of pressure in relative terms is by about a factor of two.

The results of the earth pressure measurements taken at 0.1 second intervals are shown in Figure 8.

From this figure it can be seen that there are pronounced variations in the earth pressure with large caisson sinkage.

4.2 *Peripheral Friction Force*

The results of peripheral friction force and earth pressure measurements are shown in figures 9 and 10. From these figures it can be seen that the effect of NF sheet was small but that the effect of lubricant injection was considerable.

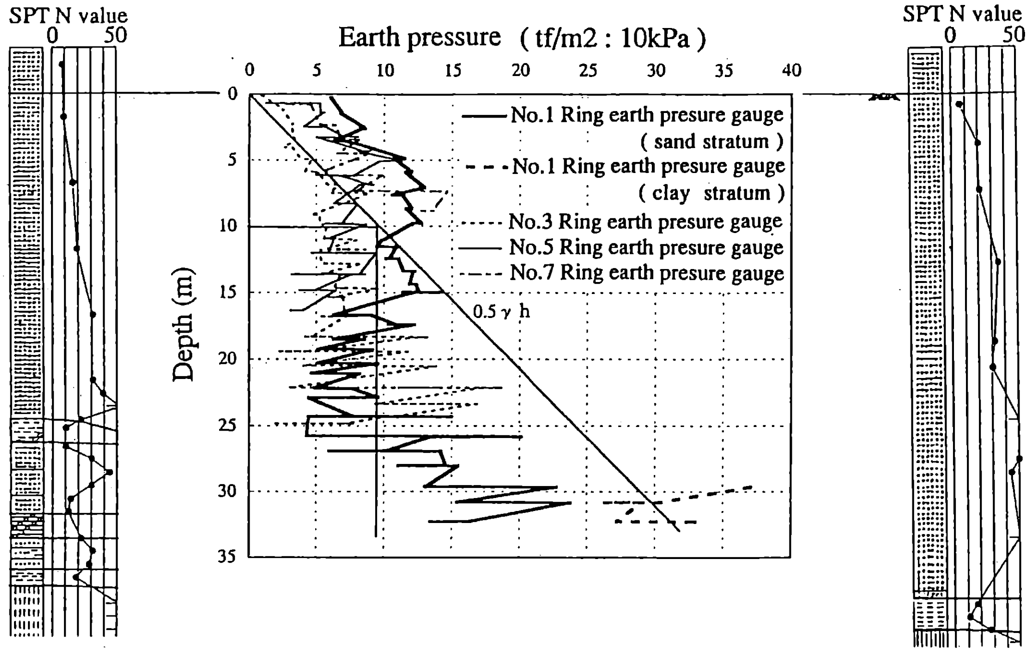

Figure 5 Variation of earth pressure with depth for each pressure gauge

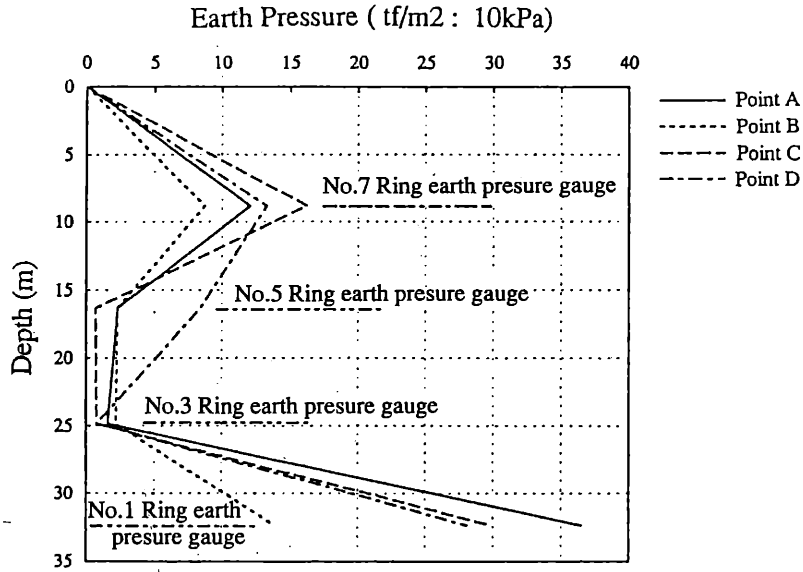

Figure 6 Earth pressure distribution with depth

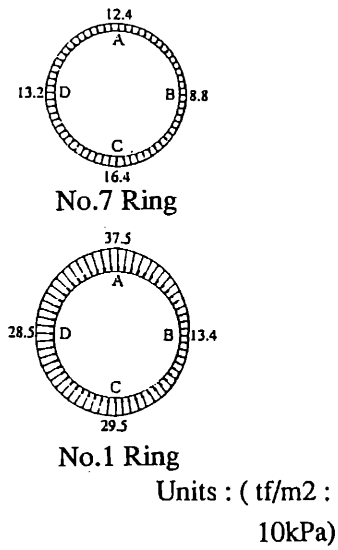

Figure 7 Plan view of earth pressure distribution

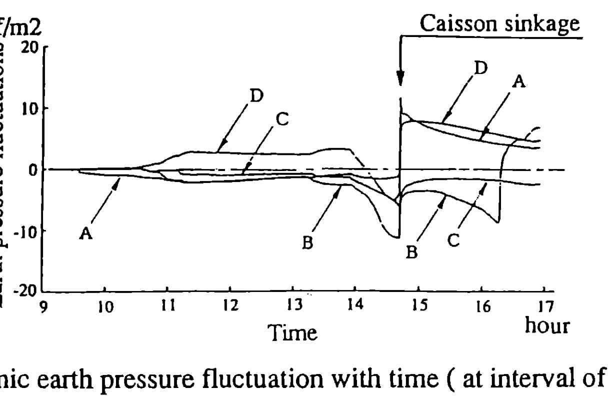

Figure 8 Dynamic earth pressure fluctuation with time (at interval of 0.1 second)

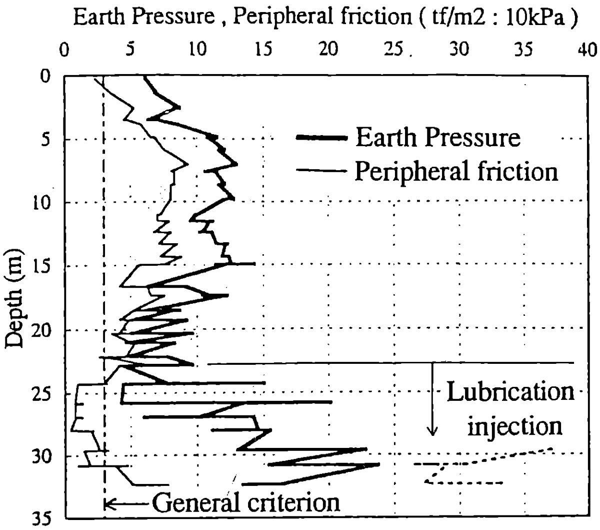

Figure 9 Variation of earth pressure and peripheral friction with depth (No.1 Ring)

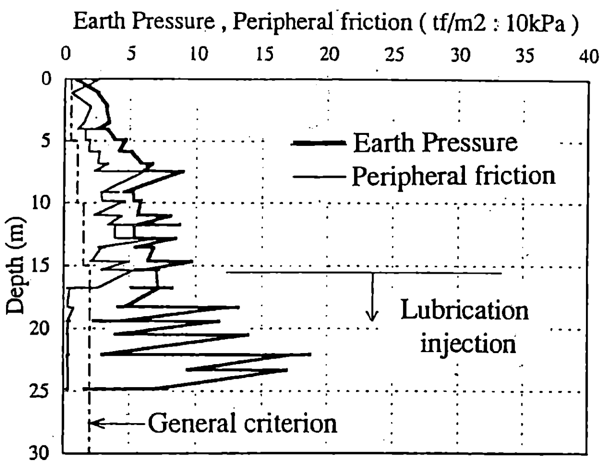

Figure 10 Variation of earth pressure and peripheral friction with depth (No.3 Ring)

It can also be seen that the frictional forces were about 3 times larger than generally assumed levels.

The friction coefficient for No.1 Ring of the caisson was about 0.7, and for No.3 Ring, for which NF sheet was used, the friction coefficient was about 0.6 .

This was assumed to be due to the fact that there was no groundwater present in the ground surrounding the caisson.

4. 3 *Caisson Stresses*

In Figure 11 is shown a comparison of the cross sectional forces obtained by back calculation using the measured steel reinforcement stress with the cross sectional forces obtained by 3 dimensional FEM analysis (Figure 12) based on the measured earth pressures (Figure 6).

From Figure 11 it can be seen that in the case of No.1 Ring of the caisson, on which the earth forces were considerable, there is a good analytical agreement for the bending moments and axial forces acting on the wall section. On No.5 Ring, however, where the earth forces were small, noticeable differences occurred in the results.

The cross sectional forces obtained by back calculation from the measured reinforcement stress were corrected to take into account the effect of the thermal stresses and construction conditions. Errors due to influence of such correction were assumed to be large at the portions where the actual cross sectional forces were small .

4.4 *Displacement of the Surrounding Ground*

Displacements of the surrounding ground resulting from the caisson construction work measured at the surface are shown in Figure 13.

5. CONCLUSIONS

5.1 *Earth Pressures*

The earth pressures acting on a caisson during construction vary according to the geology of the ground.

The earth pressures occurring in the case of sand strata increase with depth down to a particular depth (in this case down to about GL -10 m), but tend to decrease with increasing depth after that point.

The earth pressures acting in the case of clay ground are proportional to the depth.

5.2 *Peripheral Friction Forces*

In sandy ground where there is no groundwater present, the peripheral frictional forces acting are considerably greater than in traditional design.

6. FUTURE STUDIES

In this report, the earth pressure and others acting on the caisson wall were described qualitatively; however, it is planned to follow this with an analytical study.

Furthermore, measurement of the earth pressures are being continued to determine the variations with time and to study a method for evaluating the earth pressures acting after completion of construction. It is also planned to measure the earth pressures acting at the time of an earthquake to study a method for determining the earth pressures acting during seismic activity.

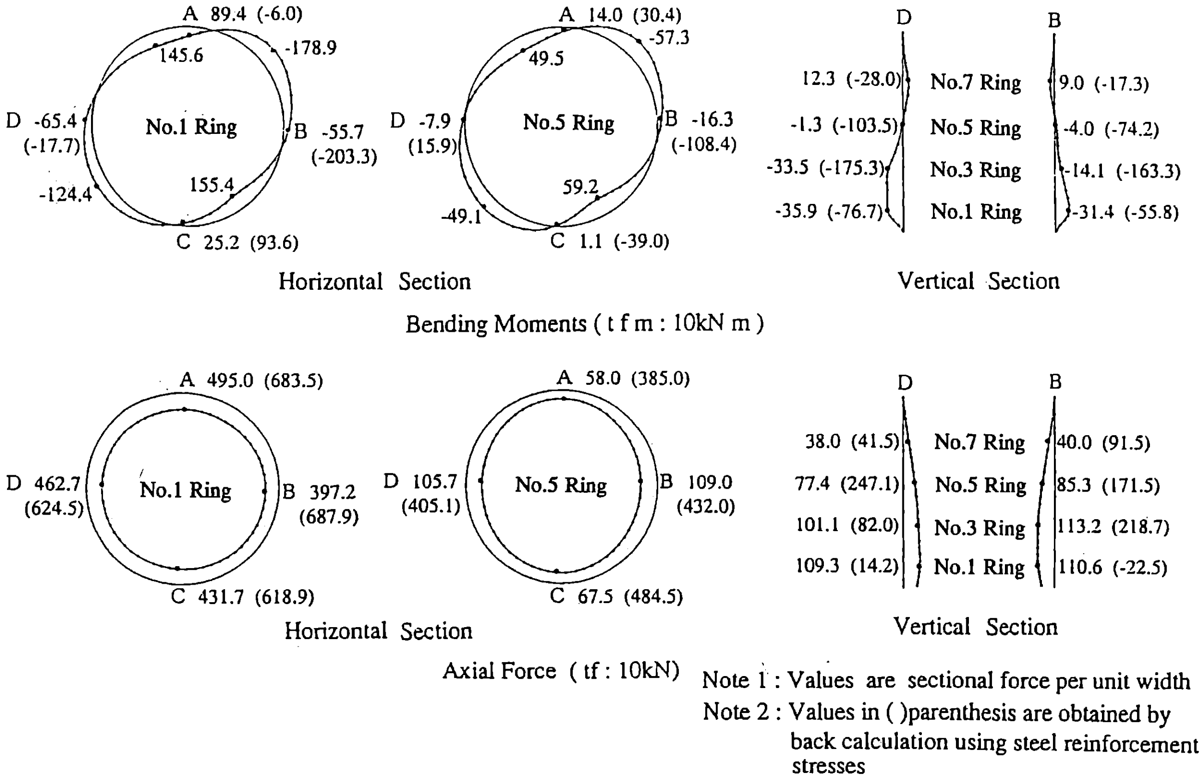

Figure 11 Comparison of section forces obtained by back calculation using steel reinforcement stresses and FEM analysis based on measured earth pressure

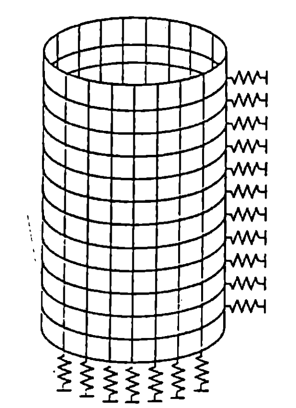

Figure 12 FEM analysis model

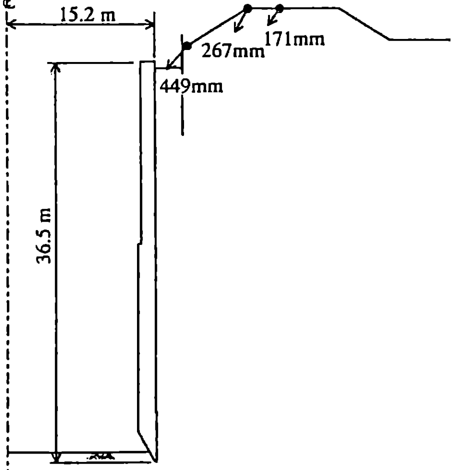

Figure 13 Displacements of the surrounding ground