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Earth retaining system for excavation in Japan

S. Kazama
Science & Engineering Research Laboratory, Waseda University, Tokyo, Japan

Y. Miyazaki
Technical Research Institute, Obayashi Corporation, Tokyo, Japan

T. Sugimoto
Institute of Civil Engineering, Tokyo Metropolitan Government, Japan

SYNOPSIS: The degree of difficulty of earth retaining works in Japan is considerably high because of the fact that much of the ground that is the object of excavation is of the Pleistocene series and that most of the excavation is near structures such as buildings or subways. This report gives an outline of the types of soil in Japan and the scope and method of construction, and also introduces the designing method and present state of research.

1. INTRODUCTION

In Japan, approximately 65% of the total land area is mountainland of strong relief, with the remaining 35% being plain areas consisting of hill areas, tablelands, and lowlands. The majority of the population of 120 million lives in the tablelands and lowlands corresponding to two thirds of the plain area. Large cities exceeding 1 million in population are mainly especially concentrated in lowlands deposited from the end of the Pleistocene Epoch to the Holocene Epoch. Pleistocene series are composed of alternations of sandy soil and cohesive soil, with volcanic ash fall deposits also distributed at the upper level. Cohesive soils of the Pleistocene series are in an overconsolidated state, higher than 200 to 300 kPa in terms of unconfined compressive strength. Holocene series naturally deposited at the lowlands may be considered to be in normally consolidated states, with most having high sensitivity ratios, while unconfined compressive strengths are low at around 10 to 50 kPa. Further, there are many areas thickly deposited with cohesive soils which have natural water contents exceeding liquid limits and which are unstable from an engineering standpoint. As for groundwater levels, they are generally high and are at depths of 1 to 2 m from the ground surface. Because of the fact that large cities are concentrated in plain areas where Holocene series strata are thickly deposited, ground conditions encountered in excavation work are necessarily poor, and it may be said that excavation and earth retaining works involve a high degree of difficulty.

Meanwhile, the social restrictions on ground deformations, noise, and vibrations accompanying execution of work are severe. Improvements, betterment, and development of design and construction technologies are being strongly called for as measures to cope with this situation.

As stated above, the situation in Japan is that excavation and earth retaining works must be carried out under adverse ground conditions and subject to various restrictions which are becoming more stringent and numerous year by year. Research and technology development in this regard are being pushed forward with extreme aggressiveness, and many guidelines have been prepared on design techniques taking into account these results.

This report, together with its presentation on the current state of design methods for earth retaining works in Japan, gives an outline of research concerning earth pressure/water pressure, and ground deformation in earth retaining which are the main themes of Technical Committee 28 (TC28).

2. PRESENT STATE OF EARTH RETAINING WORKS

Most of the earth retaining works in Japan (approximately 70%) are being carried out to depths of not more than 10 to 15 m, but it is not uncommon for excavation depths to reach down to around 25 to 30 m. There have also been large-scale earth retaining works of 80 m diameter and 60 m excavation depth carried out for anchorages of long bridges.

Of earth retaining work methods, bracing is used in the majority of cases, but when there are height differences within the compounds or when the excavated planes are extremely irregular, ground anchors are also adopted. In projects in which excavation depths are great and which are in proximity to important structures, the inverted construction method is frequently adopted.

Because of high groundwater levels, earth retaining walls are mostly of the kind providing good portection against water penetration, such as steel sheet piles and slurry walls (reinforced concrete walls or soil cement walls). In work in urban areas, slurry walls are used most often because of severe restrictions on vibration and noise.

Design of earth retaining is done following nearly perfect guidelines prepared by the various agencies and institutions.

There are more than 10 kinds of guidelines for earth retaining design in Japan, counting only those which are representative. These guidelines describe everything from equations to be used in designing, methods of determining earth pressure and water pressure corresponding to external forces to details such as methods of proportioning cross sections of members like struts and wales. As a rule, design is done according to these guidelines. Many guidelines

have been written to take into consideration the respective features of various structures, such as office buildings and subways, for which excavation plans and configurations or depths of excavation differ. However, although the details may have special features, fundamental matters do not differ greatly.

Specially, first in terms of frequently used design methods, there is the one in which the earth retaining structure is modelled as a simple beam (simple beam system) and the one in which ground deformation is considered as a spring (beam-spring method). Generally, the simple beam method is used in designing of comparatively small-scale and shallow excavation works, while the beam-spring method is utilized for projects from small-scale to large-scale works. For large-scale projects, there are cases of designing done by the finite element method, but this practice is not very widespread.

Earth pressures and water pressures used in design are determined by distribution patterns obtained from reactions of struts, and by distribution patterns proposed based on results of directly measuring earth pressures and water pressures acting on earth retaining walls. In determining earth pressures and water pressures also, the former distribution pattern is used for designing of comparatively small-scale works or for proportioning cross sections of members such as struts and wales, while the position of the latter is that it is to be applied from small-scales to large-scale works. As for the method of evaluating earth pressures and water pressures below the base of excavation, there have been few concrete proposals made, and in general, they are determined by the Rankine-Résal equation. Further, in executing work, observational construction control systems are widely used in order to ascertain the safety of design, and in addition, because of the facts that ground conditions are adverse and work is carried out in proximity to existing structures. Measurement methods range diversely from using transits, levels and the like to employing gauges such as earth pressure cells, water pressure cells, displacement meters, and strain gauges. Particularly, monitoring is done at large-scale projects and automatic monitoring systems and automatic analyses are systematized. Still further, numerous techniques are used for predicting deformations and stresses of earth retaining walls at individual excavation stages for proceeding with work while ascertaining safety quantitatively.

With regard to investigations of deformations occurring at surrounding ground and structures, measurements are made on settlement, inclination, and horizontal displacement.

3. BRIEF DESCRIPTION OF EARTH RETAINING IN JAPAN

The number of papers concerning earth retaining presented at annual conferences of the Architectural Institute of Japan (AIJ), the Japan Society of Civil Engineers (JSCE), and the Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE), major engineering societies of Japan, during the past 25 years (1965 - 1991) compiled by year are as shown in Fig. 1. By theme, these may be arranged as shown in Fig. 2. Research reports on earth pressure/water pressure, and ground deformation, which are the main themes of TC28, are approximately 25% and approximately 9% of the whole, respectively. Research techniques may be broadly

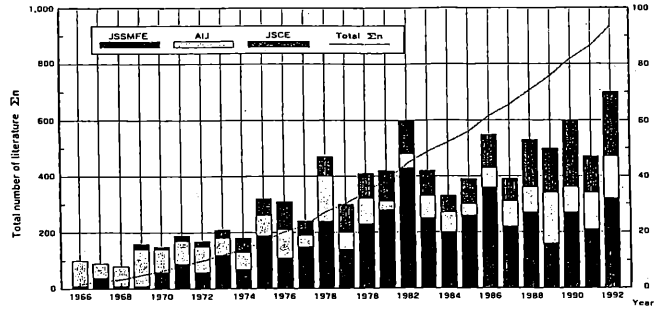


Fig. 1 Number of published literature

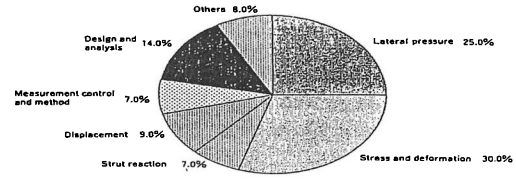


Fig. 2 Configuration ratio by item

divided into the two kinds of research based on measurements in actual projects and theoretical research or research by model experiments. But more than 60% of the research is based on measurement results in actual work. Research aiming to verify earth pressures/water pressures or design methods is mostly based on measurements proposed by various persons and prediction methods for ground deformation.

In earth retaining works in Japan, observational construction control systems based on measurements are in widespread use as a common technique for assuring safety of work as previously mentioned.

Earth pressure/water pressure acting on earth retaining walls, stresses and deformations occurring in such walls, and strut reactions are main items of measurement. Data on this accumulated by researchers or various agencies comprise an enormous volume. It is a great feature of the research being carried out on earth retaining in Japan that it is conducted based on actual measured data.

Whereas there is a trend that research presentations concerning earth pressure/water pressure have decreased annually since 1983 year by year there has been an increasing a trend for research concerning ground deformation and research concerning design methods. Notably, more than 10 papers concerning design methods have been reported annually since 1981, this gives an idea of the direction in which research on earth retaining will proceed in Japan hereafter.

4. EARTH PRESSURE/WATER PRESSURE

As previously stated (see Figs. 2, 4), studies on earth pressure/water pressure acting on earth retaining structures are being actively carried out in Japan and the majority are based on measurement results.

Based on research methrodology, research works may be broadly divided into those based on results of measurements made directly of earth pressure and water pressure acting on retaining walls installing earth pressure cells and water pressure cells on earth retaining walls, and those

based on reactions of struts.

From results of measurements made directly on earth pressures and water pressures acting on earth retaining walls, the equation below has been proposed as the equation for calculating such pressures:

$$P = K\gamma t^2 \text{ (kPa)} \quad .....(1)$$

where,

P: sum of earth pressure and water pressure at depth Z, with this defined as lateral pressure (kPa)

K: coefficient of lateral pressure

γt: wet unit weight of soil (KN/m^3)

Z: depth from ground surface (m)

In effect, the feature is that earth pressure and water pressure acting on an earth retaining wall are considered to be of a triangular distribution. Further, this is given as lateral pressure, the sum of the two. That water pressure which is more than 60% of lateral pressure is given in the form of the sum with earth pressure instead of separating the two is because water pressure is greatly influenced by regional characteristics such as type of ground, groundwater level, supply of ground water, etc., and construction conditions such as period and season of construction, water-tightness of earth retaining wall, dewatering method for groundwater, etc., so that under present circumstances it is difficult to quantitatively express the properties. The proposition to handle earth pressure and water pressure acting on an earth retaining wall as lateral pressure was made by the Architectural Institute of Japan in 1974. This is being used in design of excavation works where areas and depths of excavation are large-such as for office and hotel buildings. Although there have been many proposals made in accordance with ground conditions regarding the coefficient of lateral pressure, the values given in "Recommendation for Design and Construction Practices in Earth Retaining for Excavation" of the Architectural Institute of Japan are explained below (see Table 1).

The method of evaluating coefficient of lateral pressure is a matter of great concern in the concept of triangular distribution handling earth pressure and water pressure acting on an earth retaining wall together as lateral pressure. There have also been estimating formulae using the plasticity index (I_p), unconfined compressive strength (q_u), or N-value of soil, with many of the proposals made in the form of tables subdividing Table 1 into more detail basically processing measured data statistically. These are covered in the recommended practice for design. In research in this field, the phenomenon of earth pressure and water pressure decreasing with excavation has also been pointed out. A method of quantitatively evaluating variations in coefficient of lateral pressure in accordance with depth of excavation has also been proposed. Other than research concerning evaluation methods for coefficient of lateral pressure and variations in lateral pressure accompanying excavation, there is also the theme of how lateral pressure below the base of excavation is to be evaluated. Research reports on this are still few in number, and further study on this matter is awaited.

Meanwhile, regarding studies for proposing the distribution patterns of earth pressure and water pressure from strut reaction, few papers have been published compared with studies on earth pressure and water pressure acting directly on earth retaining walls. However, the situation in Japan is that measurements of strut reactions are being made at practically all projects for the sake of safety control, and there is an enormous reservoir of data accumulated by individuals and various institutions.

As one example, the distribution pattern of earth pressure adopted in guidelines of the Metropolitan Expressway Corporation on compilation of study results is shown in Fig. 3.

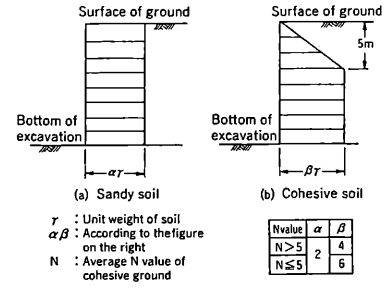


Fig. 3 Distribution of latelal pressure by Metoroporitan Expressway Cop.

With this distribution pattern, the hydrostatic pressure from the groundwater surface is to be added in case of adopting an earth retaining wall of good watertightness. Distribution patterns, with their respective features considering research results, have been proposed in other guidelines also, but fundamentally, most are the distribution form reproposed by Peck in 1967 partially modified, as shown in Fig. 4.

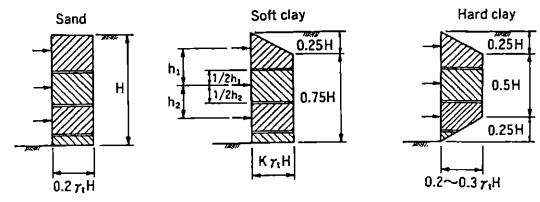


Fig. 4 Distribution of latelal pressure by Peck

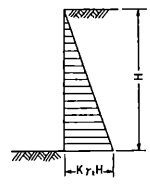
In addition to proposals of distribution patterns of earth pressure and water pressure or research concerning verifications of the proposals, there are studies on the relationship between strut reaction and temperature, and a practical proposal has been made concerning an evaluation method for thermal stress.

The state of engineering of the abovementioned lateral pressure distribution patterns proposed based on the results of direct measurements on earth pressure and water pressure

Table. 1 Coefficient of latelal pressure

Ground			Coefficfent of lateral pressure
Sandy soil	ground-water level	shallow	0.3~0.7
		deep	0.2~0.4
Cohesive soil	Soft clay		0.5~0.8
	Hard clay		0.2~0.5

K : Coefficient of lateral pressure
γ_t : Wet unit weight (t/m^3)
H : Excavation depth



acting on a retaining wall and the distribution pattern estimated from strut reactions are as previously discussed. With the proposition that earth pressure and the state of water pressure evaluation employed in design has applicability depending on the design calculation method adopted and the scale of the project, the Architectural Institute of Japan has proposed yardsticks for scopes of application as given in Tables 2 and 3.

The circles in the tables indicate desirable methods and the crosses indicate methods which cannot be recommended.

Table. 2 Relation between evaluation method and calculating method of lateral pressure

Calculating method / Caloulating method of lateral pressure	Elastic support (Engel) method	Simple beam method	Virtual support method	Continuous support method (Elastic, elasto-plastic method)
Proposed shape from strut reaction	×	○	△	×
Proposed shape from actual measurement of the earth retaining wall	○	×	○	○
Rankine-Resal equation	○	×	○	○

Table. 3 Scope of work and lateral pressure evaluation method

Lateral pressure calculating method / Scope of work	Calculating method of lateral pressure		
	Proposed shape from strut reaction	Proposed shape from measurement of earth retaining wall	Rankine Resal equation
Independent	△	○	△
Small scale with excavation depth to about 15m	○	○	○
Medium scale with excavation depth of about 15m	×	○	○
Large scale	×	○	○

5. GROUND DEFORMATION

With respect to studies on ground deformation, papers published have increased since 1973. This is thought to be because, in addition to the fact that large-scale projects in urban areas have increased, the critical eye of society focusing on public annoyances such as settlement has become extremely strict. Regarding the affect of excavation on neighboring structure, it may be said that research on this aspect will be even more intensified to take into account the present situation in which it is demanded for not only qualitative but also quantitative examinations of the degree of influence from occurrence of ground deformation from construction.

Studies concerning ground deformation classified according to contents are as follows:

(1) Those concerning surface settlement of ground behind the earth retaining wall resulting from excavation

(2) Those concerning underground displacement behind the earth retaining wall resulting from excavation

(3) Those concerning heaving of the excavation base resulting from excavation

(4) Those concerning surface settlement of the ground behind due to removal of the earth retaining wall and of struts

The category with the largest number of papers is the one concerning ground surface settlement. Studies on this theme all concern settlement possible to occur and the technique for predicting the form. Study techniques may be broadly divided into (1) those based on measurement data of the past, (2) the technique of assuming a slip surface of the soil, and (3) a technique according to the finite element method.

In research on underground displacements behind earth retaining walls, there are many proposals for prediction methods employing the finite element method. With regard to contents, those based on effective stress analyses along with considering the range of enlargement of the plastic zone of the ground behind accompanying excavation are on the increase.

Studies on heaving of the base of excavation are also plentiful from the fact that excavation in ground of soft, cohesive soil, excavation at areas of high groundwater levels, or large-scale excavation projects have increased. On this theme, many of the elements concern estimation methods for the amounts of heaving based on the theory of elasticity. Recently, there has been research done in which the failure types of ground under bases of excavation have been examined analyzing the effects of seepage water on heaving of the bases accompanying boiling and heaving phenomena through the coupled analysis method of soil and water using the finite element method.

A possibility exists for deformation of the surrounding ground accompanying earth retaining and excavation work to occur at stages of work execution other than mentioned above and in a great variety of forms. For example, there are diverse research themes such as the stability of trench walls and deformation of the surrounding ground during construction of diaphragm walls, deformation occurring due to soil improvement, deformation on removal of bracing and when backfilling. Investigations and research on these matters have been reported in recent years.

In Japan, because there is much excavation work going on in urban areas with dense build-up of structures, there is much concern about ground deformation accompanying excavation work. Beginning with the Ministry of Construction, the various agencies and institutions have prepared special guidelines regarding ground deformations in which methods of judging whether or not ground deformations occurring due to excavation work will affect neighboring structures. When a possibility exists that there will be an impact, the ground deformation to occur is predicted, and moreover, the degrees of functional and structural effects on neighboring structures are examined. In these guidelines, criteria on allowable displacements according to the structures administered by the various agencies are clearly indicated, and methods of predicting displacements are stipulated. Therefore, ground deformations are predicted by individuals making selections from the various proposals based on their own judgments.

6. CONCLUSION

An outline of research and design guidelines concerning earth pressures/water pressures and ground deformations in Japan have been discussed in the foregoing. The contents of this report are a part of the results of investigations and studies made by the Japanese National Committee of TC28 carried out over a period of one year.