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Monitoring of field data and its application to excavations – A survey on Japanese literature

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1. INTRODUCTION

The paper is prepared as a past of the study related to a survey on Japanese literature, which was carried out by the Japanese Society of Soil Mechanics and Foundation Engineering - Committee on "Underground Construction in Soft Ground" (JSSMFE TC-28). The outline of survey is contributed by S.Takagi et al. (1994), which is included in this proceedings.
This paper deals with studies on monitoring systems and instrumentation related to earth retaining systems for deep excavations to obtain necessary data during excavation, for the purposes of the observational procedures and operation control, as well as the contribution to the academic studies. Monitored data is processed for the back-analysis and feed-back to the design and construction of the retaining system and excavation. Details currently applied in Japan will be discussed in this paper, referring Japanese literatures published between 1965 and 1991.

2. PURPOSE OF MONITORING

Monitoring during excavation is necessary for the following reasons.

① Factors and conditions related to safety are so complex that it is difficult to predict them during the design stage.
② Since retaining systems are usually temporary, they are designed with relatively low allowable stress.

Therefore, in order to conduct effective monitoring, the monitored items should be selected to be able to provide an accurate evaluation of those areas which need careful observation during the design and construction phases. Monitoring is helpful for construction planning and operation control, especially for excavation projects in the urban area of Japan due to existing adjacent structures and buried structures etc. densely. Measuring data are also useful for comparing the designed values. With this objective, Endo et al. (1981) examined the case histories of braced excavation projects in Japan, and compared their designed and measured values.
The followings are examples of studies conducted on the monitoring of earth retaining systems in Japan.

3. DETERMINATION OF MONITORING SYSTEM AND ITEMS

Ground conditions and excavation methods are the essential factors to be considered when selecting items to be monitored. The most influential factors of these are the water pressure in sandy soil and the unconfined compressive strength (qu) in cohesive soil. Table 1 shows the monitoring items for water pressure of sandy soil and the stability number Nb (Nb= γ H/Su) of cohesive soil. This table was derived from earth retaining calculation for various water pressures in sandy soil and derived stability numbers in cohesive soils, as well as monitoring surveys conducted in Japan. Measuring instruments for each monitored item are shown in Table 2.
The selection of an effective monitoring system and establishment of its reference values for the operation control are important to systematically evaluate measured values and confirm safety of the excavation. Three types of monitoring systems have been developed, the use of which depends on the scale of the excavation, the number of measuring points and the measuring instruments. Fig.1 illustrates flow charts for these systems.

4. MEASURING AND MONITORING METHODS

Numerous studies have examined monitoring methods, including types and installation of measuring instruments, evaluation of measured values and establishment of control reference values. Kotoda et al. (1981A and 1981B) examined the accuracy of measured data with respect to the

Table 1. Combination of items to be monitored (after AIJ, 1988A)

Purpose	Object	Items	N_b*1) / H_w*2)	< 3 / < 5	3 ~ 5 / 5 ~ 10	> 5 / > 10	Ground Condition: Consolidation layer	Ground Condition: Large volume drain	Adjacent Structures: Important structures	Adjacent Structures: Cut off walls
(A) Monitoring retaining systems	Walls	①Earth pressure acting on walls				△ ○				△ (○)
		②Water pressure acting on walls			△	△ (○)		△ ○		△ (○)
		③Flexural stress in walls				△ (○)				
		④Deformation of walls			△ ○	△ ○				
	Struts and wales	⑤Axial force on strut			△ ○	△ ○				
		⑥Deflection and torsion of wale			△ ○	△ ○				
		⑦Loosen joints local failure			△ ○	△ ○				
		⑧Temperature of strut		△ ○	△ ○	△ ○				
(B) Monitoring adjacent ground and structures	Adjacent ground	⑨Deformation of retained ground		△ ○	△ ○	△ ○	△ ○		△ ○	
	Adjacent structures	⑩Settlement, inclination, and movement of structures		△ ○	△ ○	△ ○	△ ○		△ ○	
(C) Monitoring drainge and leakage	Ground water level	⑪Drain volume and ground water level		(△)	△	△ ○	△ ○	△ ○	△	△
	Leaking points	⑫Inspection of leaking points		△ ○	△ ○	△ ○				△ ○

*1) N_b: Stability number ($N_b=\gamma H/S_u$)
γ : wet unit weight of soil
H : excavation depth
S_u: undrained shear strength of soil
*2) H_w: Water head at the bottom of excavation (m)

(Legend) ○ : when ground is cohesive soil ( ) : item required as selected
△ : when ground is sandy soil

Table 2. Items and instruments for monitoring (after AIJ, 1988B)

Purpose	Object	Items	Measuring Instrument	Notes
(A) Monitoring retaining systems	Walls	①Earth pressure acting on walls ②Water pressure acting on walls ③Flexural stress in walls ④Deformation of walls	•Differential type earth pressure cell •Differential type water pressure cell •Differential type strain guage, Reinforcing bar gauge •Differential type roller inclinometer, transit, measuring tape, piano wite	Monitoring of lateral pressure at retained side and excavated side Monitoring of water pressure at retained side and excavated side
	Struts and wales	⑤Axial force on strut ⑥Deflection and torsion of wale ⑦Loosen joints local failure ⑧Temperature of strut	•Hydraulic load cell, Differential type strain gauge, reinforcing bar gauge, piano wite, level, visual observation •Differential type thermometer	
(B) Monitoring adjacent ground and structures	Adjacent ground	⑨Deformation of retained ground	•Insertion type inclinometer, differential settlement gauge, transit, level	Monitoring of surface settlement, settlement in ground, water pressure in ground, deformation of soil
	Adjacent structures	⑩Settlement, inclination, and movement of structures	•Transit, level, plumb-bob, water level gauge, water tube inclinometer	
(C) Monitoring drainge and leakage	Ground water level	⑪Drain volume and ground water level	•Automatic water level recorder, electric water level sensor	Amount of rainfall, tidewater level, climate conditions
	Leaking points	⑫Inspection of leaking points	•Visual observation	

installation methods of earth pressure cells for braced walls.

Following are several examples of studies on the evaluation methods used for measuring lateral pressure acting on reinforced concrete diaphragm walls (RC diaphragm walls) and the associated stresses in the walls used in large scale excavations.

(1) Measuring method for lateral pressure acting on RC diaphragm walls

The measuring lateral pressure acting on braced walls is useful to confirm the accuracy of the lateral pressure assumed at the design stage. Measurements of lateral pressure are affected not only by the accuracy and performance of the earth pressure cell, but also by the installation technique and method. In most cases, the jack method is used in order to touch the pressure cell on the soil. Kanatani et al. (1980) examined the measured values of lateral pressure cells at the initial stage as shown in Fig.2 and pointed out that the reliability of measured earth pressure can be judged from the state of change in the values measured during the first several days after installation. For example, when the decreasing rate of lateral pressure from Ⓒ to Ⓓ in Fig.2 is similar, the lateral pressure distribution is considered reliable, whereas when the state of change during the first several days shows unusual, the measured lateral pressure is considered unreliable.

(2) Bending stress in RC diaphragm walls

There are numerous cases in which a reinforcing bar stress transducer is used to measure the bending stress of RC diaphragm walls. It is important to evaluate flexural rigidity in the relationship between reinforcing bar stress and the bending moment. Hayakawa and Honda (1985) examined the effect of various assumptions in flexural rigidity using the examples shown in Fig.3 Ⓐ, Ⓑ and Ⓒ. By using the comparisons between measured displacement derived from inclinometer values, and measured displacement derived from the secondary integration of the reinforcing bar stress of the bending strain, it is shown that the method with which the relationship between flexural rigidity and curvature in Ⓐ and Ⓒ will give reasonable values as a result. However, the authors pointed out that, since it is assumed that cracks develop at the calculated point, the measured reinforcing bar stress should be evaluated with average rigidity as shown in Fig.3 Ⓓ.

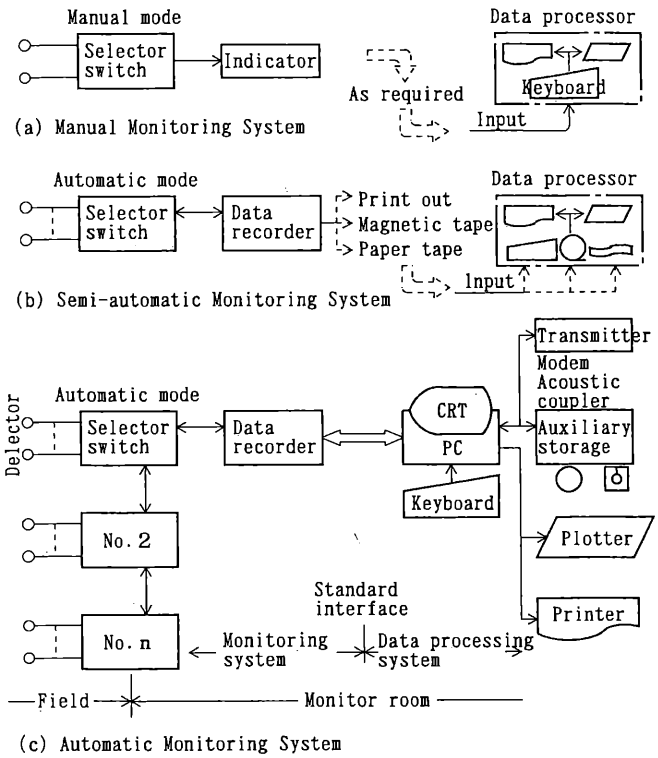

Figure 1. Diagrams for field monitoring system

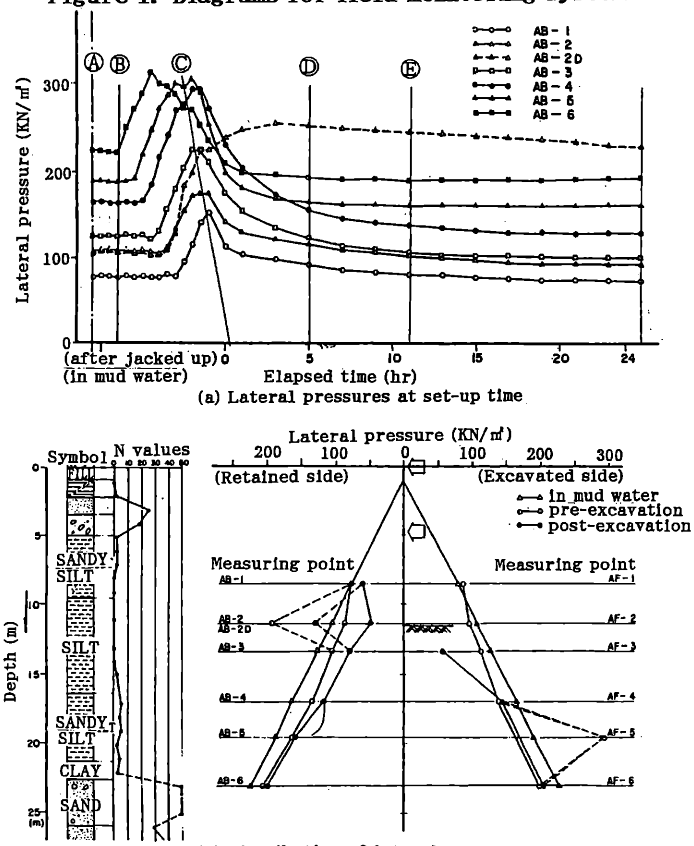

Figure 2. Lateral pressure at set-up time and lateral pressure distribution after excavation (Kanatani et al., 1980)

5. STUDIES ON APPLICATION OF MEASURED DATA

The importance of monitoring is being recognized. As the number of measuring items and points increases, study is being conducted to make greater use of measured data in future construction stage. The application of measured data can be illustrated by the flow chart in Fig.4. The difference of Fig.4 from the existing methods of monitoring control and manegement is found in utilizing re-evaluated input data to the analysis of re-prediction, after judging monitored data. Three major aspects related to the input data for back analysis, which being regarded as the theme of numerous researchers concerned, are as follows ;

① Input data related to design parameters which have to be back analyzed.

② Evaluation methods foe assessing, processing and combining measured data.

③ Method of back analysis and the algorithm for determining input data.

The prediction is conducted by the calculation with input values which were back analyzed. Fig.5 illustrated an example of using this method to improve the accuracy of predicted values by comparing them with measured values.

When input values were back analyzed based on measured values (Xmi: e.g., wall displacement at various depths, axial forces in struts at various levels, etc.), the function as shown equation (1) (measured value Xmi, calculated value Xci) is established, and the minimum value of the function gives the condition of the most probable relations between measured and calculated values. Furthermore, a relative weight Wj (j: measuring items such as wall displacement and axial force of strut) in numerous measuring items of varying degrees of accuracy was examined. Maruoka et al. (1984) considered α for the coefficient for various measuring items which corresponded to average values for the squares of the differences between measured and calculated values. A coefficient was considered for each α j measuring item, and the weighted mean was set as shown in equation (2).

$$f(x)=\min\left\{\sum_{j=1}^{n}\left(W_j\sum_{i=1}^{n}(X_{mi}-X_{ci})^2\right)\right\} \quad \text{------------ (1)}$$

$$W_j=\frac{1}{\alpha_j^{\,2}\sum_{i=1}^{n}(X_{mi})^2} \quad \text{------------------------- (2)}$$

Several methods were examined for minimizing the function f(x), including a trial and error method in which various constants were input to derive minimum values (Uchiyama et al. (1982)), the least squares method (Yanagita et al. (1982)), a

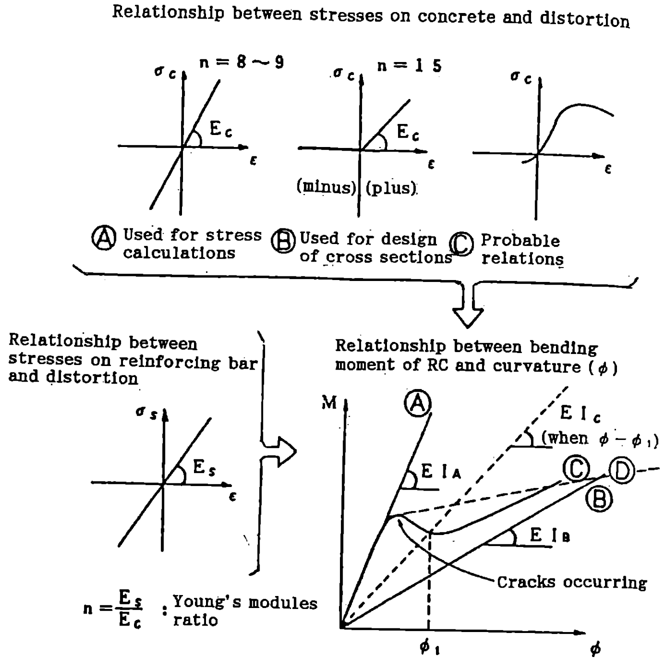

Figure 3. Assumed flexural rigidity of RC diaphragm wall (Hayakawa and Honda, 1984)

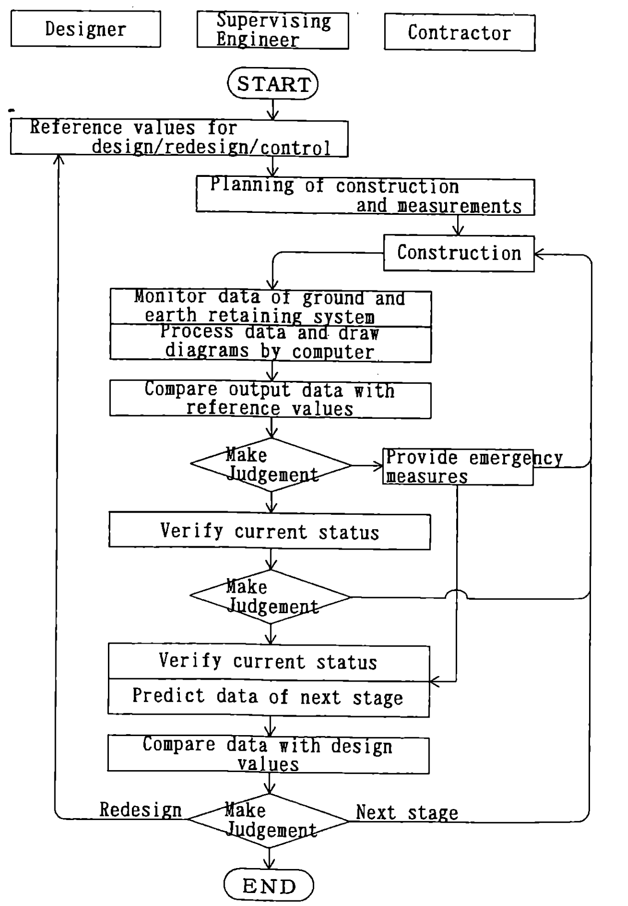

Figure 4. Flow chart of construction control by monitoring (observational procedures)

non-linear optimization method (Maruoka et al. (1984)), and a method based on probability theory (Saito et al. (1985)). Fig.6 illustrates an example of analyzed values for retained side lateral pressure and predictive calculations based on the analyzed values using the above methods.

6. CONCLUDING REMARKS

Instrumentations with monitoring systems for the earth retaining systems have been employed in Japan, intending to safe deep excavations.

A part of current state on this subject in Japan could be described mainly on the date monitoring and its feeding back to operation control and procedures.

Use of monitoring is depending upon the size, depth and grade of difficulty of the excavations and the results are utilized not only to the job site but also on the studies concerned. The current state of study in Japan could be introduced shortly.

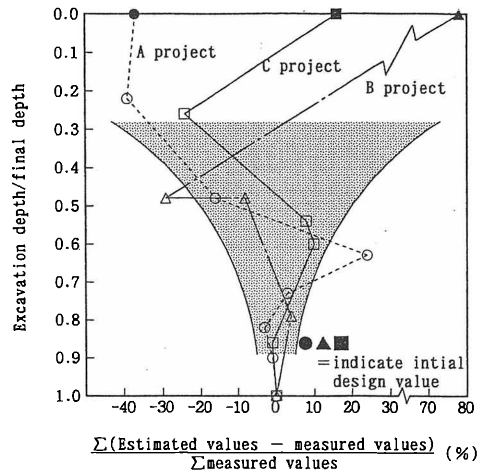

Figure 5. Comparison between estimated and measured values (Tominaga et al, 1977)

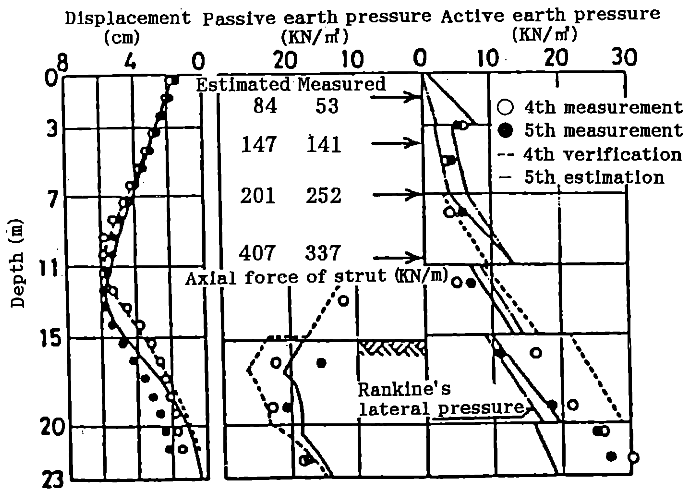

Figure 6. Prediction based on lateral pressures obtained by back analysis (Maruoka et al, 1984)

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