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PREDICTION OF EMBANKMENT DAM PERFORMANCE DURING CONSTRUCTION

PREVISION DE LA TENUE D'UN BARRAGE A LEVEE DE TERRE AU COURS DE LA CONSTRUCTION

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SYNOPSIS : The generation of excess porewater pressure and settlement in the clay core during the construction of the Nanhua dam were studied by various methods. These methods included Hilf's method, stress path simulation in the laboratory and analytical method. A Comparson of the predicted results and the monitored values shows that porewater pressure development and settlement during construction stage can be predicted reasonably well. The study results demonstrate that porewater pressure and settlement during construction are intimately related to the placement moisture content. A placement moisture content of slightly less than the OMC value would result in more favorable dam performance in terms of construction porewater pressure and post-construction settlement of the core.

INTRODUCTION

During the construction of an embankment dam, the stability and hence the control of placement moisture content and construction speed are the major concerns. Excess porewater pressure and settlement are two indications often used in assessing the performance of the embankment during and after construction.

In the construction of the Nanhua dam, a 75 meter high earthfill zone dam in southern Taiwan, several approaches were used to predict the development of excess porewater pressure and settlement of the central impervious core. For porewater pressure development, (1) based on theory advanced by Hilf(1948), laboratory consolidation test results were used to calculate the excess porewater pressure; (2) excess porewater pressure were measured directly in the laboratory specimen subjected to the stress path expected during construction. For settlement, prediction was made by (1) using laboratory consolidation test results and porewater pressure estimated by the above-mentioned method, and (2) employing a numerical method which simulates the construction of embankment in layers under undrained condition.

Actual field measurements were compared directly or indirectly with the predicted values. Conclusions on the appropriateness of the current placement moisture content and settlement during and after construction derived from the results obtained were discussed . This paper presents the results of these studies.

EMBANKMENT DAM AND INSTRUMENTATION

Nanhua dam is a zoned earthfill dam with a maximum height of 75m. Typical cross-section is shown in Fig. 1. The embankment consists of an upstream shell of gravelly river deposit materials, central impervious clay core, and a downstream shell of spillway excavation materials. Various types of instruments, including foundation type piezometer, embankment type piezometer, inclinometer, settlement plate, horizontal movement extensometer, surface movement monument, earth pressure cell, seepage measurement weir, etc., were installed during construction. The instruments including embankment type piezometers and settlement plates installed up to the current embankment elevation of 150m are shown in Fig. 1.

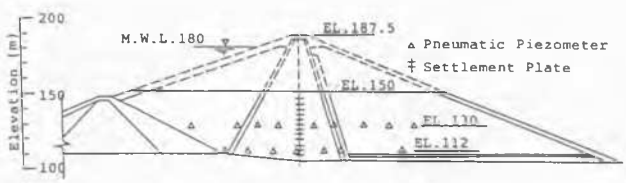

Fig.1 Typical zoning of Nanhua Dam

The core material consists mainly of low plasticity silty clay material. The plasticity index (PI) is in the range of 10 to 16 and liquid limit around 30%. Based on construction records, the optimum moisture content (OMC) is in the range of 15% to 17% and the maximum dry density is around 1.8 t/m^3. Statistics of the construction records on placement moisture content and dry density up to elevation 150m are given in Fig. 2. Placement moisture content about 1%+ higher than OMC may be seen from the construction records.

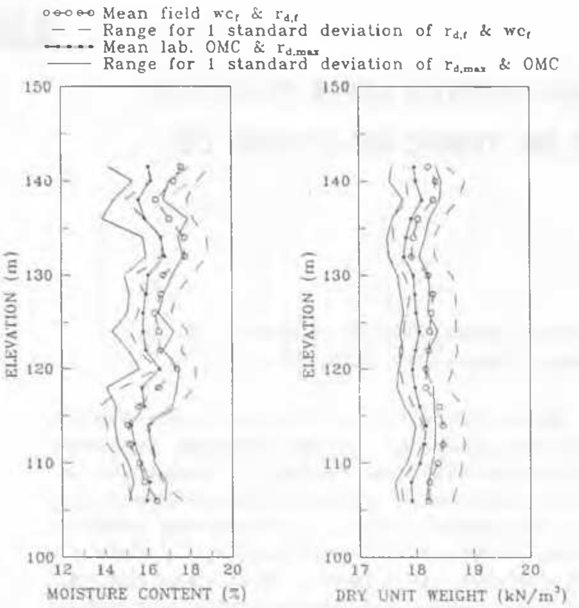

Fig.2 Statistics of field moisture content and dry density

PREDICTION OF PORE WATER PRESSURE DEVELOPMENT

Porewater pressure development during construction was estimated by two approaches. The first one was by using the porewater pressure formula derived by Hilf(1948) based on Boyle's Law and Henry's Law for partially saturated soil under undrained condition.

$$U = \frac{P_a\ v}{V_a + h\ V_w - v}$$

where U = porewater pressure, P_a = air pressure in the void after initial compaction, h = Henry's constant of solubility of air in water by volume (0.02 at 20°C), V_a and V_w = volumes of air and water in the voids after initial compaction in percentage of initial volume of soil mass, V = consolidation volume change in percentage of initial volume of soil mass. Consolidation characteristics of core material, as shown in Fig. 3, was used to establish the relationship between excess porewater pressure and total overburden stress. The results derived from laboratory compacted samples are shown in Fig. 4. It may be seen that when the placement moisture content is higher than OMC, nearly full response in porewater pressure is expected. Dramatic reduction in porewater pressure response may be seen when the placement water content is less than OMC.

Undisturbed samples obtained at the embankment were also studied for comparison with the laboratory compacted samples. Their consolidation characteristics and pore pressure development are shown in Figs. 3 and 4 respectively. The undisturbed samples, whose placement moisture content was about 1% higher than OMC, show rather consistent results as compared with those of the laboratory compacted samples with similar moisture content and dry density.

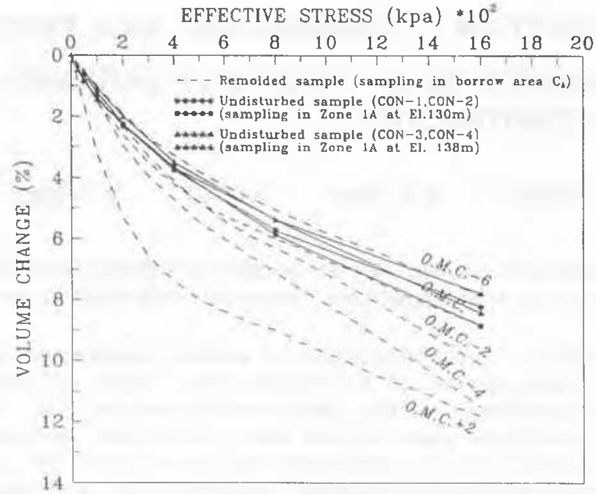

Fig.3 Consolidation characteristics of core material

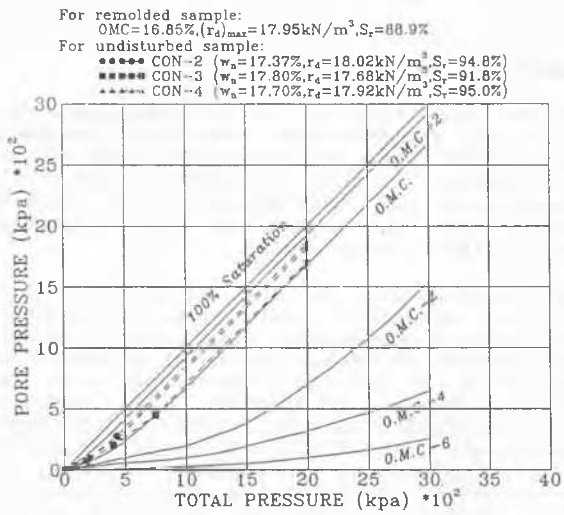

Fig.4 Predicted porewater pressure development with overburden stress - Hilf's approach

The second approach employed to predict the porewater pressure generation is stress path simulation in the laboratory. In this approach, a specimen, either laboratory compacted or undisturbed, was tested in the laboratory following a stress path expected in a specific location within the dambody during construction. The stress path used was obtained by numerical analysis which simulates the construction of the dam in 8 layers. The results for locations at El. 112m and 130m, where piezometers were installed, together with those obtained by Hilf's approach are shown in Figs. 5a and 5b.

The results indicate that both approaches gave

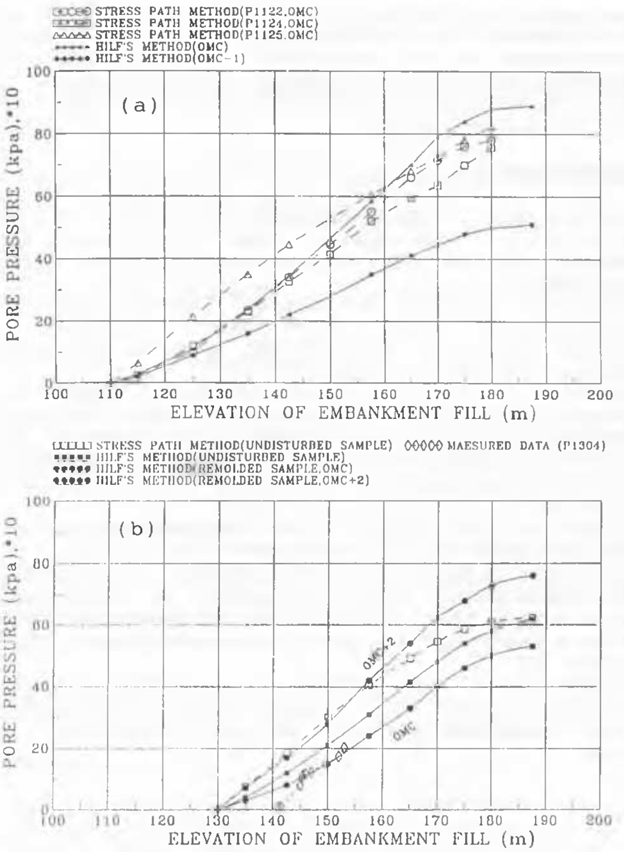

Fig.5 Predicted porewater pressure development with construction progress - stress path simulation in the laboratory

rather similar values. For the piezometer installed at El. 112m, very little porewater pressure was monitored. This may attribute to the fact that rather dry material was used for backfilling the piezometer pit. Therefore, the monitored values are not considered to be representative. The monitored porewater pressures at El. 130m are also shown in Fig. 5b. For the results obtained up to the present, the monitored values are much less than the predicted values at the early stage of embankment filling. The monitored pore pressure approaches the predicted results as the filling becomes higher. This may attribute to the compaction effect when the soil overlying the instrument is shallow. As the fill height becomes larger, the porewater pressure appears to approach the predicted value.

From the studies performed, it seems that under the current placement moisture content, which is about 1% higher than OMC, the central core would develop rather high porewater pressure near the end of construction. This was also supported by the UU tests which show the characteristics of material with a high degree of saturation and core settlement discussed below. Although stability analyses of the embankment showed plenty of safety margin during construction, large settlement is expected to occur after the completion of construction.

PREDICTION OF SETTLEMENT

Two approaches were used to predict the settlement of the core during construction. In the first approach, laboratory test results and the porewater pressure development curve (Fig.4) discussed above were used to estimate the settlement during construction. For embankment height up to El.150m, the predicted settlements based on laboratory compacted and undisturbed samples are shown in Fig. 6. Monitored values are also presented in the figure.

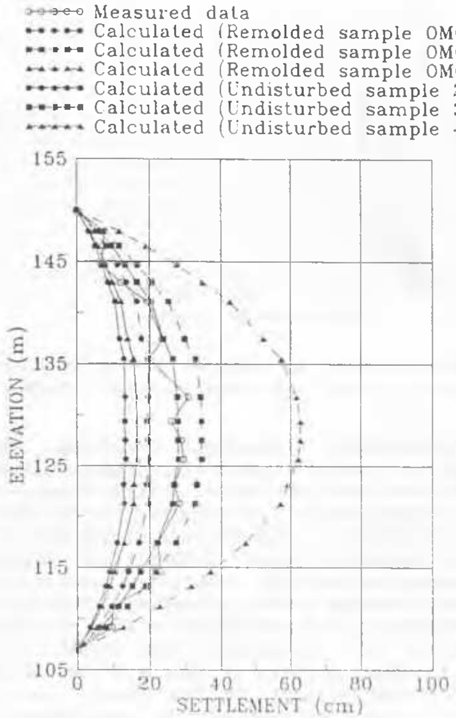

Fig.6 Measured core settlement and predicted values under various placement conditions

The results clearly demonstrate the influence of placement moisture content on the settlement of the core. With a change of placement moisture content from OMC+2% to OMC-2%, the maximum settlement can be trippled. Slightly lower values are predicted when undisturbed samples were used. This may be due to slightly higher field density than the laboratory sample. However, very good agreement in predicted values and monitored results may be seen. Also, test results from laboratory compacted sample with similar moisture content and density to the field conditions should give a rather good estimate of the settlement of the dam.

In the second approach, numerical analysis by using finite element program ISBILD was employed. In the analysis, hyperbolic stress-strain relationship of the material obtained by triaxial test under unconsolidated, undrained condition was used. The dam construction was simulated by 8 placement layers to the final height. The results of analysis together with the monitored values at fill elevations of 135m, 142.5m and 150m are shown in Fig. 7. Extremely good agreement in results may be seen.

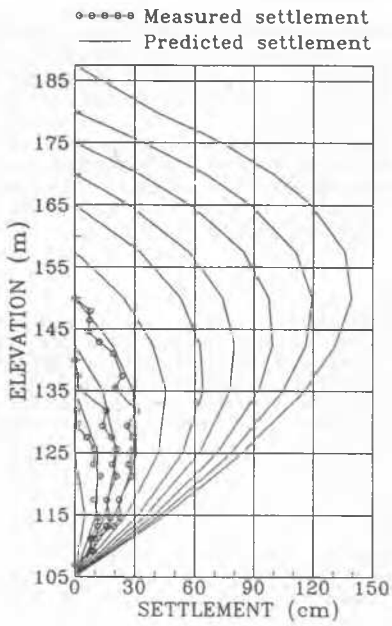

Fig.7 Measured core settlement and predicted values at various construction stages

From the preliminary results obtained, both approaches give fairly accurate predictions of settlement of the central core. This enables us to assess the performance of the dam with better confidence. From the results obtained in these studies, it appears that under the current placement moisture content, the core would build up rather high excess pore pressure. Therefore, the post-construction settlement would be high, and there exists a potential for crack in the core due to arching action of the stiffer shells outside. From the study on the lower limit of the placement moisture content of the material, construction of the clay core on the dry side of OMC would be more desirable from the point of view of pore pressure development and settlement.

CONCLUSIONS

From the preliminary results of porewater pressure development and settlement during construction obtained in these studies for the Nanhua dam, the following conclusions may be drawn:

(1) The development of excess pore pressure during construction can be predicted fairly accurately by both the Hilf's method and stress path simulation in the laboratory.

(2) The settlement during construction may also be predicted by the consolidation test result and the porewater pressure development described in this paper. Numerical analysis can also be used with proper selection of soil parameters.

(3) By comparing the results of prediction and the monitored values, it can be seen that the predictions appear to be reasonable for engineering purposes.

Based on the preliminary results obtained, the dam behavior during and after construction may be assessed with confidence. This process is considered to be essential since the remedial measures would be expensive and difficult if non-satisfactory performance is found near the end of construction.

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