Assessment of Dynamic Properties of Wushantou Dam

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SYNOPSIS: Accurate assessment of material properties is essential for a meaningful evaluation of the dynamic behavior of a dam. Comprehensive studies using in-situ measurement and labaoratory testing techniques coupled with back calculations of dam responses in recorded motion gives the following conclusions: (1) Response in good agreement with actual motion can be obtained by using appropriate analytical models and material properties; (2) a labaoratory test may give reasonable result, but allowance should be made for the effects of strain level, sample disturbance and re-consolidation, especially in loose, non-cohesive soil; (3) in-situ shear wave velocity measurement is considered to be the most representative technique and gives the best estimation in G_{max}.

INTRODUCTION

Wushantou dam is located in Kuantien, Tainan county in southern Taiwan. The maximum height of the dam is 56m and the length is 1175m. It was constructed by semi-hydraulic fill method in the 1920s. The dam was constructed by hauling borrowed material to form two dikes upstream and downstream of the dam. Water jet was then used to wash the fine material down to form the central clayey impervious core, sandy shell and gravelly outer shell. The construction procedures are illustrated schematically in Fig. 1 and Photo 1.

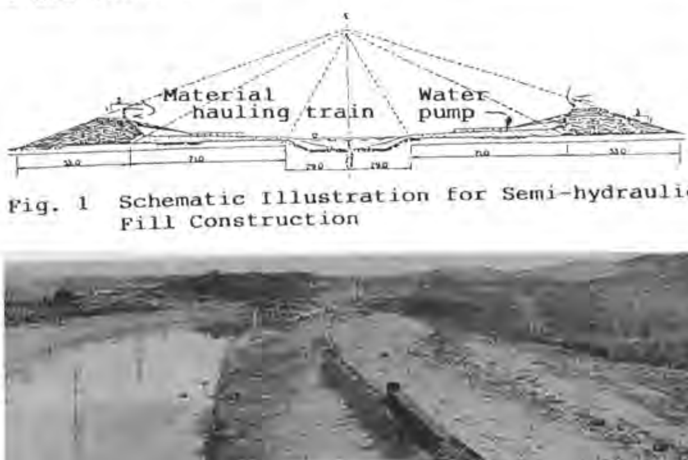

Fig. 1 Schematic Illustration for Semi-hydraulic Fill Construction

Photo 1 Embankment Construction: Material dumping and Water Jet Washing

The dam is located in a seismically active region in southern Taiwan, and the method of construction has resulted in a dam which is considered weak against earthquake shaking. Therefore, seismic safety was incorporated in the safety evaluation program. In this program, dynamic analyses were carried out to assess the safety of the dam regarding the potential of failure due to liquefaction, sliding of the embankment slope and excessive deformation and settlement of the dambody.

In this approach, the level of confidence in material properties, which affects the results of assessment tremendously, is of most serious concern. Therefore, a comprehensive investigation and testing program, including examination of construction records, exploration, sampling and testing, were carried out. In addition, two sets of strong motion records obtained at the dam foundation and dam crest were used to calibrate the dynamic properties obtained in-situ and in the laboratory. This enabled us to assess the parameters used in the analysis. This paper describes the results of these studies.

INVESTIGATION AND TESTING

The major field investigation included drilling of 18 holes with total depth of 893m, standard penetration testing, undisturbed specimen sampling, downhole V_s logging in the clayey core and sandy shell, and 2 test shafts for in-place density and physical property measurement of the outer shell material. This was incorporated with laboratory tests for physical properties, static triaxial testing for stress-strain and strength parameters, and cyclic triaxial testing for dynamic properties and strength for various materials.

In these investigations and tests, the following results related to dynamic analysis are worthy of mention:

(1) In-situ V_S logging : In-situ shear wave velocity measurements were made by the downhole technique to estimate the maximum shear moduli for dambody materials and foundation rock. The correlation of maximum shear moduli vs. mean normal stress for the clayey core and sandy shell are shown in Fig. 2.

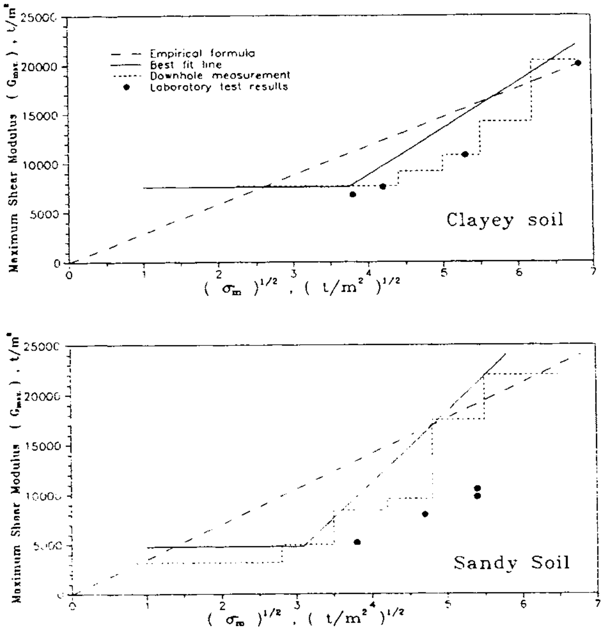

Fig. 2 Maximum Shear Modulus vs Mean Normal Stress

(2) Laboratory Testing : Cyclic triaxial tests were used to obtain the modulus ratio(G/G_{max}), damping ratio and maximum shear modulus. The triaxial test apparatus was modified to measure very small load and deformation. Proximeter and load cell were installed directly on top of the specimen cap to delete the inaccuracy arising from loading ram friction and loose link in connections in the conventional triaxial test apparatus. This enabled the measurement of sample deformation up to strain level of 10^{-6}. In this way, it further avoids the difficulty of matching the modulus ratio and damping ratio curves obtained by using different testing apparatus and specimens for different levels of strain amplitude. The results of maximum shear moduli thus obtained are shown in Fig. 2, and the relationships of modulus ratio and damping ratio vs. strain level are shown in Fig. 3.

Comparing the results of maximum shear modulus obtained in-situ and in the laboratory, generally good agreement in trend may be seen. Slightly higher values were obtained by the in-situ shear wave velocity measurement technique than those obtained in the laboratory. Generally, this is in agreement with experience. Better agreement may be seen for clayey soil than for sandy soil. This may be due to less disturbance in clayey soil and generally softer sandy soil was chosen for sampling, which is prone to disturbance and resulted

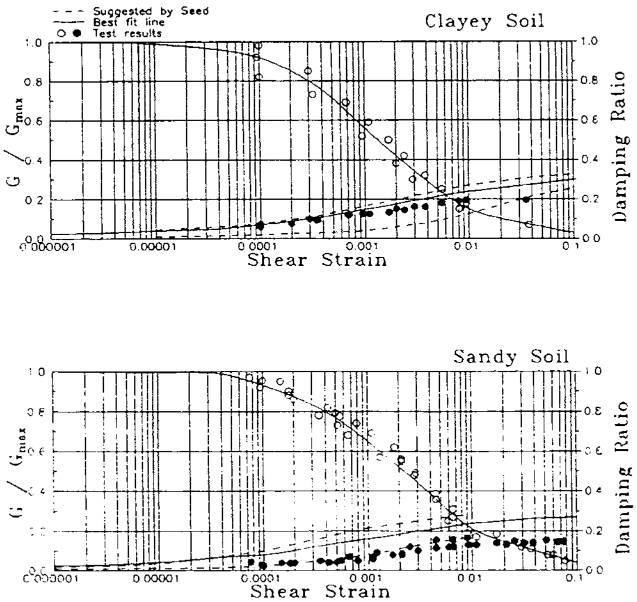

Fig. 3 Modulus Ratio and Damping Ratio vs Strain Level

in a denser specimen. The results also show that empirical formula, which relates the maximum shear modulus to the void ratio and mean normal stress, may cause significant under-estimation or over-estimation in the modulus value.

(3) Zoning of the Dambody : One of the major difficulties of modelling the dam behavior is the heterogeneity of the material as a result of the hydraulic fill technique, which makes the appropriate zoning of the dambody difficult. In the Wushantou dam, this was resolved by the use of construction records and exploration results. A total of 8 sections of construction record showing the grain size distribution contours were used to examine the material properties obtained in the exploration. Fig. 4 shows the contour of $D_{10} \leq 0.005$mm and the classification of the soils obtained. The central portion of the dam section corresponds to cohesive soils ranging from clay, silty clay to clayey silt as obtained in this investigation program. Outside of this zone, mainly sandy soils were encountered. Remarkably good agreement may be seen. This enabled us to use these records to obtain a representative zoning of the dambody. The zoning of the dambody with the finite element mesh used for analysis is shown in Fig. 5. The material properties for each zone are as follows.

Materail Zone	N-value	IP	Unified Classification
Impervious Clay core	5-20	0-17	CL,CL-ML,ML
Sandy Shell	7-30	-	SM,ML(S),ML
Outer Shell	-	-	GP,GM

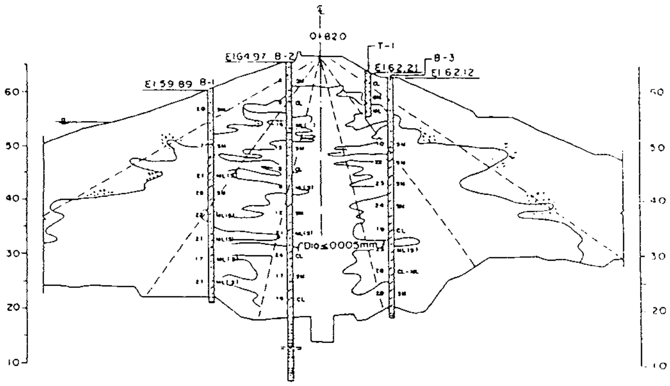

Fig. 4 Comparison of Exploration Results and Construction Records

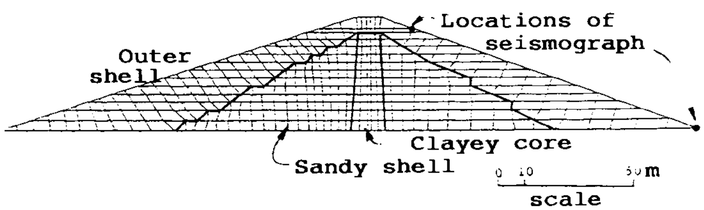

Fig. 5 Material Zoning of Dam

NUMERICAL MODELLING

In dynamic response analysis of earth structures, non-linear behavior of soil is often being approximated by a viscously damped linear elastic model in which the damping and stiffness are represented by strain dependent moduli and damping ratios. Computer code FLUSH has been used extensively for such an analysis. In this analysis, a computer code FLUSH-VB modified by Katayama(1987) which further considers the foundation as an elastic medium, which dissipates and reflects energy through the lower boundary during the process of shaking, instead of using a rigid boundary as is conventionally done. This is considered more appropriate in view of the soft mudstone foundation encountered, for which the stiffness is only two to three times higher than those of the dambody materials.

The strong motion records obtained during Hualien earthquake with a magnitude of 6.7 on the Richter scale occurred about 150km from the dam site on November 15,1986 gave us a unique opportunity to assess the dynamic properties used in the analysis. The recorded motions in the direction normal to the longitudinal axis of the dam are given in Fig. 6. Parametric studies were made on maximum shear moduli, modulus ratios and damping ratios to get the best fit in dam responses. Two aspects of response were examined, i.e., acceleuation amplitudes and frequency contents. After considering the effects of these parameters on the results, maximum shear moduli and damping ratios were adjusted. The responses which gave the best fit are shown in Fig. 7, and the parameters used are given in Figs. 2 and 3.

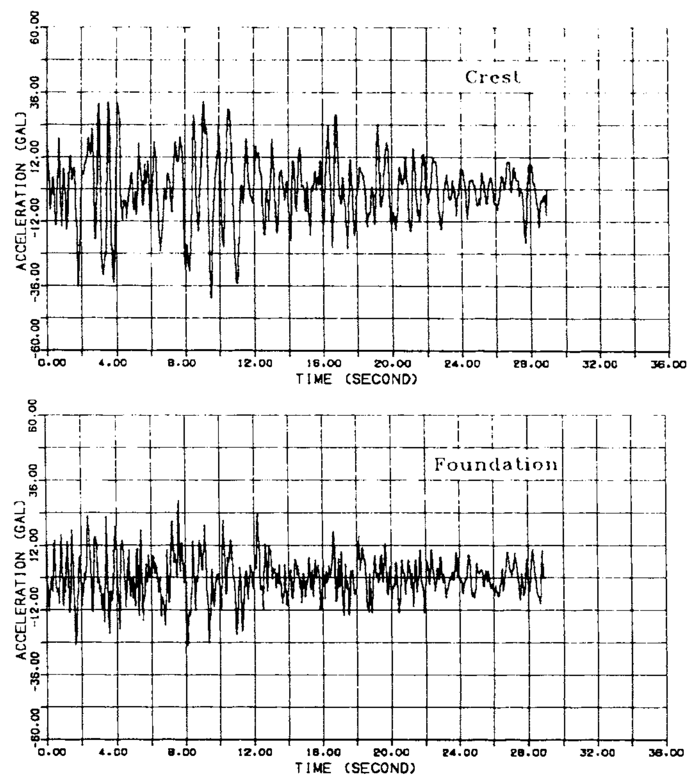

Fig. 6 Recorded Motions at Foundation and Dam Crest

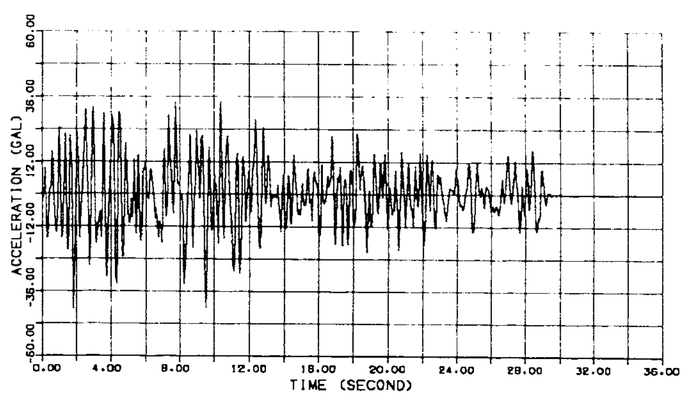

Fig. 7 Calculated Response at Dam Crest

Comparing the results of the calculated responses with the recorded motion, it may be seen that the shape of the response and significant peaks agree remarkably well, but the frequency contents do not agree so well.
It contains more high frequency vibrations than the recorded motion. This is illustrated by the plots of response spectra in Fig. 8.

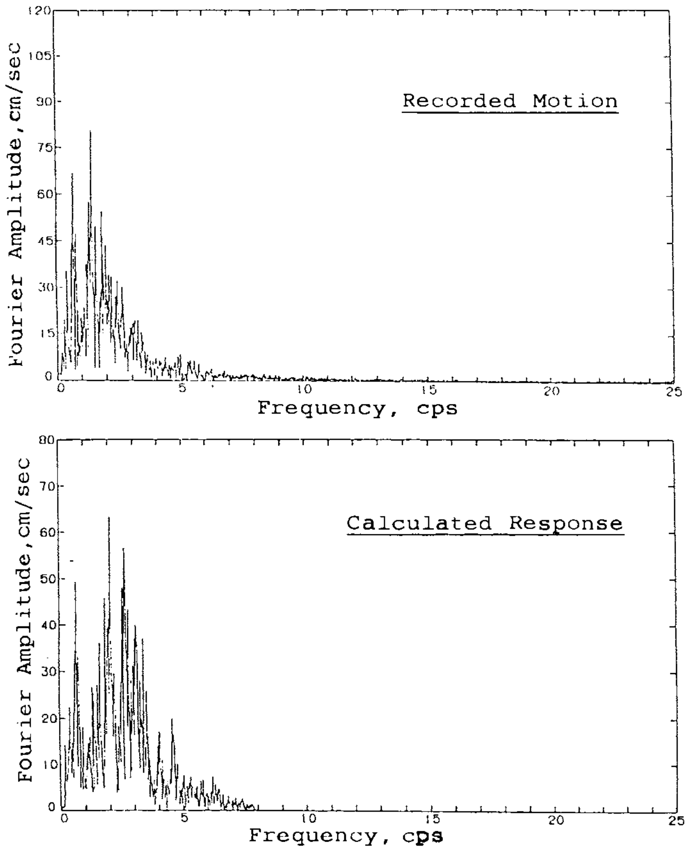

Fig. 8 Fourier Spectra of Recorded Motion and Calculated Response

CONCLUSIONS

From the results of these studies, the following points may be drawn:

(1) Use of an elastic foundation model is considered essential, especially if the relative stiffness of the foundation and dambody material is not too different. Difference in maximum acceleration amplitude up to 40% can be obtained in this case.

(2) The most important parameters affecting the dynamic responses are maximum shear modulus and damping ratio. The modulus ratio appears to be less significant.

(3) The maximum shear modulus obtained in-situ by the shear wave velocity measurement appears to give a more representative value than the laboratory result. The difference may attribute to strain level, sample disturbance and the specimen selected for testing.

(4) The damping ratio obtained in the laboratory seems on the low side. The effects of sample disturbance and re-consolidation on the result are difficult to assess.

(5) Considering the heterogeneity of the materials, the results of numerical simulation appear to be satisfactory for the purpose. The discrepancy in frequenc content may be the result of assumption about the outer cobble/gravel shell. Due t the method of construction, the outer shel material may be quite different i cobble/gravel contents at differen locations. This makes the assessment o material properties difficult.

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