Consideration of scaling effects in the deformation analysis of high rockfill dams

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ABSTRACT: In this paper, a method to take the scaling effect into account in dam deformation analysis by numerical simulation is presented. The main concept is to modify the model parameters used in a chosen material model from the test state to the in-situ state. To achieve this, relations between key influencing factors and model parameters need to be established. A series of experimental data collected from the literature and a new dataset of Nam Ngum 2 (NN2) rockfill materials are used in this study. The influence of particle size, particle gradation and density on the $q - \varepsilon_1 - \varepsilon_v$ response of rockfill materials, as well as the strength, stiffness and volumetric strain, is discussed. The 3-D FE analysis of NN2 CFRD at the end of the construction stage is carried out using two sets of model parameters, i.e., (1) directly obtained from the calibration of laboratory tests and (2) using the established relations in this study to transform to in-situ conditions. Finally, the dam monitoring data are compared with the computed results to highlight the importance of scaling effects and to confirm the effectiveness of the developed method on the improvement of dam deformation analysis.

1 INTRODUCTION

The mechanical properties of rockfill materials are essentially determined from laboratory tests. In the laboratory, samples with maximum particle size in the range of 25-80 mm are typically prepared using one of the scaling techniques (i.e., parallel gradation technique, scalping method, equivalent substitution method and combination method). In reality, the composition of rockfill material in a construction site is typically comprised of silt, gravel, cobbles, and boulders, which probably have maximum sizes of over 1 m in diameter. This scaling effect results in differences of the engineering properties of rockfill materials between in situ and laboratory conditions.

For quarried rockfills (used in most dams), the experimental results indicate that an increase of the particle size reduces the elastic stiffness and peak deviator stress, and more contraction behavior is observed (Varadarajan, et al., 2003 and 2006; Honkanadavar and Sharma, 2014). However, the scaling effects correspond to not only the effect of particle size but also the effect of particle gradation. A number of scientific papers related to the influence of particle gradation on the mechanical behaviors of rockfill materials have been published during the past decades (e.g., Hamidi, et al., 2012; Tabibnejad, et al., 2014). The laboratory results indicated that the shear strength characteristics are enhanced with increasing gravel content. In recent years, a series of large scale triaxial compression on Tacheng rockfill materials with different initial densities has been conducted by Xiao, et al. (2014). For the specimen prepared with the highest density in the study, the material exhibits dilation behavior at the very beginning of shearing. The dilation behavior is gradually suppressed with diminished dry density. Although a number of research investigations have been conducted on the effects of different states between laboratory preparation and in situ conditions, each of them only focused on a certain factor (size or gradation or density).

In this paper, a method to take the scaling effect into account in dam deformation analysis by numerical simulation is presented. The main concept is to modify the model parameters used in a chosen material model from the test state to the in-situ state. To achieve this, relations between key influencing factors and model parameters need to be established. A series of experimental data collected from the literature and a new dataset of Nam Ngum 2 (NN2) rockfill materials are used in this study. The 3-D FE analysis of NN2 CFRD at the end of the construction stage is carried out using two sets of model parameters, i.e., (1) directly obtained from the calibration of laboratory tests and (2) using the established relations in this study to transform to in-situ conditions.

2 METHODOLOGY

2 .1 *General*

Figures 1(a)-(c) show the $q - \varepsilon_1 - \varepsilon_v$ relationship from the drained triaxial test of rockfill materials. The elastic stiffness decreases with the maximum particle size. In the same manner, the friction angle and dilation angle decrease with the maximum particle size. For particle gradation, the stiffness modulus decreases with an increase of fine content. For the effect of dry density, the peak deviator stress and stiffness modulus increase with increasing dry density. For the highest density specimen, the material exhibits dilation behavior at the very beginning of shearing. The dilation behavior is gradually suppressed with diminished dry density.

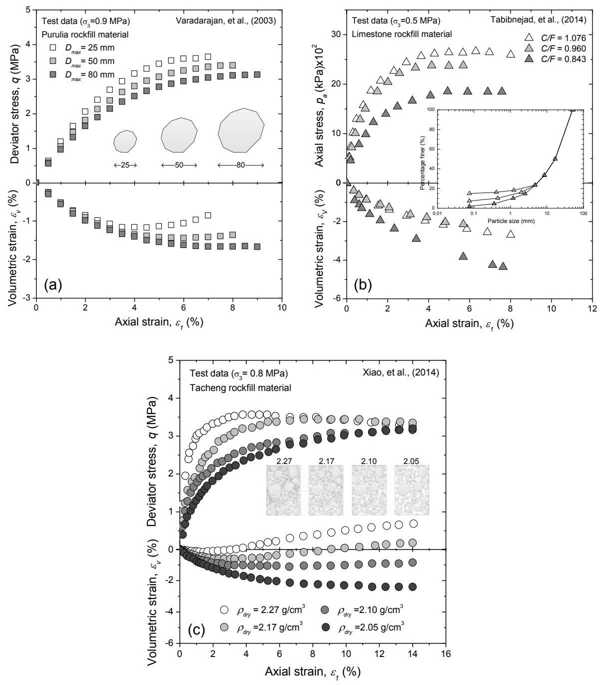

Figure 1. Stress-strain-volumetric strain behaviors of rockfill materials with various (a) particle size (b) particle gradation (c) density

2.2 *Constitutive model and FEM*

In this study, a modified model (Sukkaral et al., 2017) based on the framework of the HS model is chosen. The stiffness modulus, shear strength characteristic and dilatancy are represented by E_{50} (together with E_{oed} and E_{ur}), and, respectively, in the HS model. The finite element software ABAQUS was employed to simulate the deformation response of NN2 CFRD.

2.3 *Prediction of model parameters*

Figure 2 shows the model parameters- relations of Purulia rockfill materials (with sizes in actual laboratory tests) in semi-logarithmic space. The calculation of model parameters at is also conducted by interpolating from as shown in this figure.

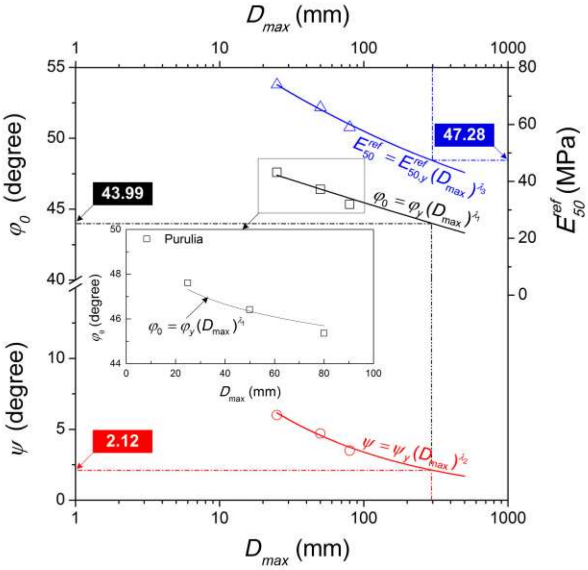

Figure 2. Model parameters-in D_{max} for Purulia rockfill material

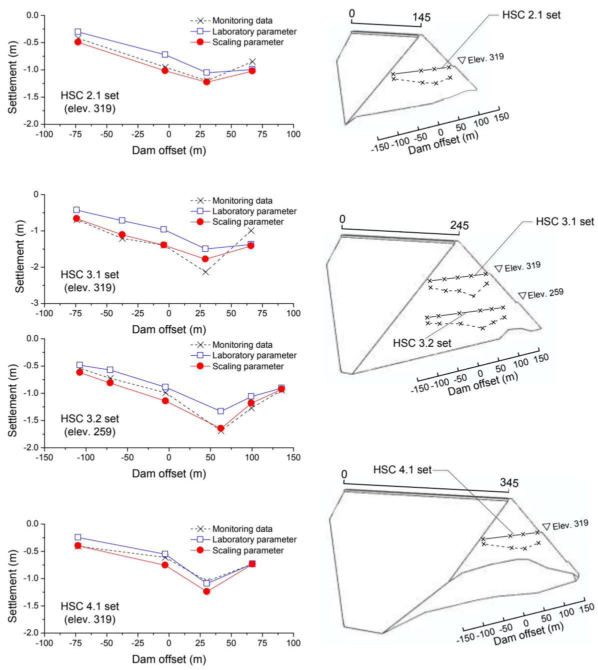

Figure 3. The predicted settlements and measured settlements using HSC

3 RESULT

Figure 3 shows the comparison between the computed settlement and the monitoring data observed by the HSC sets. It can be immediately seen that the computed settlements with scaling parameters achieve a satisfactory match with the monitoring data in terms of the magnitude values and settlement trend.

4 CONCLUSION

Comparisons between the computed dam deformations (by both laboratory parameters and scaling parameters) and monitored data showed that by taking account of the scaling effect into model parameter modification using the developed method, the dam deformation prediction by numerical analysis can be fairly improved. Consequently, this proposed method was able to transform the parameters obtained from laboratory for dam analysis.

5 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of the Thailand Research fund (TRF) and King Mongkut's University of Technology Thonburi through the Royal Golden Jubilee Ph.D. program, under contract grant PHD/0006/2556. The authors also extend their appreciation to the Office of the Higher Education Commission for granting financial support through the Higher Education Research Promotion and National Research University (NRU) Project of Thailand. They are also indebted to the CK Power Public Company Limited and Nam Ngum 2 Power Company Limited for providing the valuable data.

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