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Discussion

Determination of parameters for a hyperbolic model of soils

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I am dismayed that *Geotechnical Engineering* should have published this paper, which encourages the use of non-linear elastic modelling for soils. The hyperbolic model of Duncan and Chang,[1] which forms the basis of the paper, has been superseded many years ago for modelling boundary value problems in soil. For a number of very good reasons, all serious modelling of soil non-linearity now employs plasticity theory or one of its many derivatives.

Why is non-linear elasticity of such little value? First, it is incapable of distinguishing between loading and unloading conditions, so that if at any point the soil unloads, the model simply 'backtracks' down the initial non-linear loading curve, giving a totally unrealistic response. However, even for problems that involve pure loading, there is a more subtle, but equally important, problem: the model is totally incapable of realistic modelling of volume changes during shearing.

In their paper the authors successfully curve fit a hyperbola to the shear-stress–shear-strain response of soil under triaxial compression, and from this derive a tangent Young's modulus. As a separate exercise they curve-fit the response of the soil in hydrostatic compression, and obtain a tangent bulk modulus. However, they ignore the measurements of volume change in the triaxial test, shown in the lower part of their Fig. 5, where it is seen that the soil dilates considerably during shearing. The non-linear elastic model is incapable of capturing this vital feature of soil behaviour. In the analysis of any problem principally controlled by stresses their model would give totally incorrect strains in the lateral direction during shearing. Conversely, if the strains were controlled it would give incorrect stresses.

The above are the principal objections to the non-linear elastic model, but they are not an exhaustive list: for example, there are also thermodynamic objections to this type of elasticity. The uncomfortable reality is that soil is a rather complex material, and to model its non-linear behaviour, with even passing resemblance to the real behaviour, it is necessary to adopt at least an elementary version of plasticity theory. Non-linear elasticity cannot be used for any purpose beyond the curve-fitting of some simple tests (and even then it does not fit the dilation behaviour). The fact that it can easily be used to provide quite a good fit to selected curves (as well demonstrated in the paper) is no indication that it will be useful in providing realistic solutions to any boundary value problems.

REFERENCE

1. DUNCAN J. M. and CHANG C. Y. Non-linear analysis of stress and strain in soils. *Proceedings of the ASCE, Journal of the Soil Mechanics and Foundations Division*, 1970, **96**, No. SM5, 1629–1653.

Authors' reply

All comments raised in the discussion, regarding non-linear analysis, are well taken and agreed upon. However, the objective of the paper, as stated clearly, was to present the parameters for a hyperbolic model determined for soils from the Eastern Province of Saudi Arabia. These parameters are needed for the hyperbolic model used for the analysis of soil–pipeline–interaction problems as required by some widely used software, such as CANDE (Culvert ANalysis and DEsign). Perhaps what causes the confusion is the elimination of the last phrase from the title of the paper. The title appearing in the proofs was 'etermination of', and what was finally printed was 'determination of parameters for a hyperbolic model of soils'.

The hyperbolic model is capable of representing the state of stresses in the vicinity of buried pipes, to model such boundary value problems. Furthermore, the hyperbolic model was selected after obtaining satisfactory agreement between its results and those obtained from full-scale tests in the field and small-scale tests using centrifuge modelling.

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