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Criteria for the validation of Oasys DYNA3D for the analysis of dynamic soil-structure interaction

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ABSTRACT : The aim of this paper is to examine the validation criteria that were used in a project to validate the computer code Oasys DYNA3D for the analysis of dynamic soil-structure interaction. The validation was achieved by comparison of computer code calculations with the measured response of prototype, centrifuge test and shaking table test soil-structure systems subjected to earthquake loading. The site response analysis program SIREN was used to identify the relative merits of using acceleration time histories, Fourier spectra and response spectra as criteria in the validation process.

1 OBJECT

In March 1990 Ove Arup and Partners and the Earthquake Engineering Research Centre at the University of Bristol began a two year research project under the auspices of the Teaching Company Scheme. The aim of the project was to validate the computer code Oasys DYNA3D for the analysis of dynamic soil-structure interaction. The validation was achieved by comparison of computer analysis with the measured response of prototype, centrifuge test and shaking table test soil-structure systems subjected to earthquake loading.
This paper will examine the validation criteria which were used in this research project. A criterion is defined as the standard by which judgements are made and as such their suitability determine the quality of the validation. The paper will explore the use of fourier amplitude spectra, response spectra and time histories for suitability as validation criteria.

2 DATA FOR THE VALIDATION PROGRAMME

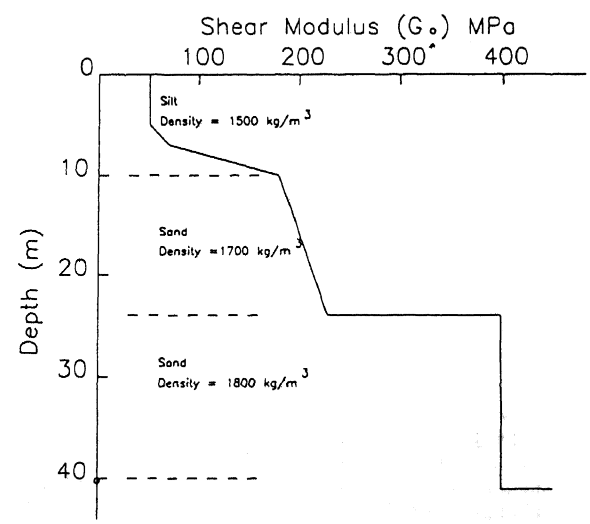
For the validation the response of soil and structures measured from both field recordings and small physical experiments were used. The field recordings consist of a borehole array in Japan and the physical models include centrifuge tests carried out at Princeton University. The quality of validation is determined by how good an agreement is achieved between calculated and measured values. Prototype systems are harder to model due to the uncertainty of the in situ soil parameters and an often complicated soil profile but represent the real life situation. Centrifuge experiments use very simple systems which are easy to model but reflections within the centrifuge bucket are an unknown quantity.

2.1 Chibaken-toho-oki experiment station, Japan

Observations were recorded at the Chiba borehole array of the Institute of Industrial Science, University of Tokyo, Japan (Katayama and Sato, 1988) due to a magnitude 6.7 earthquake at an epicentral distance of 46km.

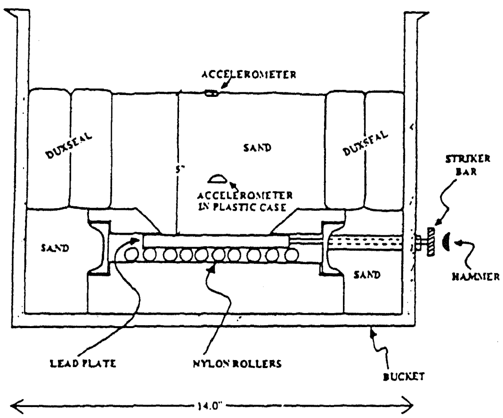
The site consists of 5m of loam overlying 35m of sandy clay and fine sand. Accelerometers were sited at 1m, 5m, 10m, 20m and 40m depths, each accelerometer having two components, E-W and N-S.

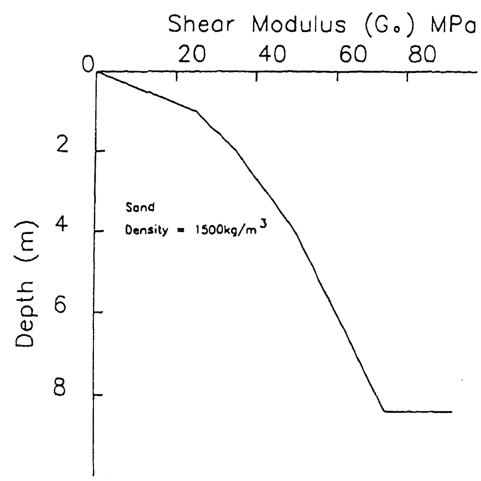
This data gives an ideal data set for evaluating the effects of site response and effects of soil on the free field motion.



2.2 Centrifuge modelling of dynamic soil-structure interaction, K.Weissman and J.H.Prevost(1989)

This research performed at Princeton University presented a centrifuge model that was capable of realistically representing soil-structure systems subjected to earthquake like excitation. The centrifuge model shown was composed of a sand bed surrounded by Duxseal, a clayey substance which has been shown to partially absorb radiated energy (Coe, 1985). The earthquake motion was generated by the hammer-excitor plate method, which was shown to be similar in amplitude and frequency to a very near field small magnitude earthquake of short duration and peak acceleration of 0.3g.





3 COMPUTER METHODS

Oasys DYNA3D is a finite element program written by Dr J.Hallquist, which was specifically developed for the non-linear analysis of structures and mechanisms. Originally developed for the solution of impact problems, the code is capable of handling a wide range of static and dynamic phenomena. It is an explicit code which is most effective for solving problems with a high degree of non-linearity. due to its solution technique when analyzing complicated models under earthquake loading the run time can be long due to a very small time step needed for a stable solution.

The Oasys program SIREN (Heidebrecht et al, 1990), which has been specifically written for site response analysis, was used to analyse these systems. SIREN analyses the response of a one-dimensional soil column of an earthquake motion at its base. the soil column is characterised by a stress-strain relationship and a bulk density. The program operates in the time domain enabling it to model non-linear soil properties with hysteretic damping. It uses the same analysis techniques as Oasys DYNA3D.

4 CRITERIA FOR VALIDATION

In an elastic system it is usually adequate to validate by comparing frequency domain transfer functions. However, in non-linear soil systems this is not sufficient as the size of the earthquake loading affects the resulting response. For most design purposes the comparisons achieved will be adequate if good agreement is observed for frequency and energy content, response spectra and duration of motion. Various media for defining the characteristics of an earthquake will determine different aspects.

4.1 Time histories

A time history is the simplest form of representing a specific earthquake motion. The acceleration time history is a record from a strong motion accelerometer and numerical integration can be used to achieve velocity and displacement time histories. Care must be taken in the numerical integration due to low frequency drift. Important parameters associated with time-based records are the peak values and the duration and shape of the strong motion.

4.2 Response spectra

A response spectrum is the locus of the absolute maximum responses of a series of single degree of freedom oscillators of different natural frequencies. Response may be in the terms of acceleration, velocity, displacement, force, stress etc. Continuous response spectra can be defined for a range of damping levels so a response spectrum is represented by a family of curves. A response spectrum is related to the frequency content and peak acceleration, velocity and displacement.

4.3 Fourier spectra

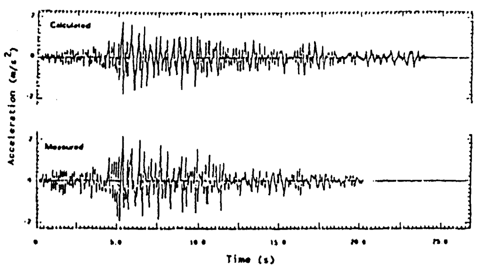
The Fourier spectrum gives the frequency content of a time history obtained by Fourier analysis. It has two components at each frequency, amplitude and phase.

5 RESULTS OF COMPARISON

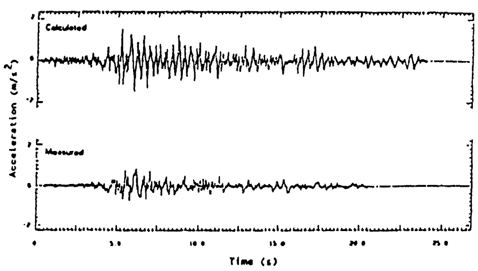
5.1 Chibaken-toho-oki borehole array

A site response analysis using SIREN was carried out for the borehole array by inputting the measured acceleration time history at 40m depth. The figures below show the comparison between measured and calculated responses using time histories, response spectra and Fourier spectra at 1m and 20m depths.

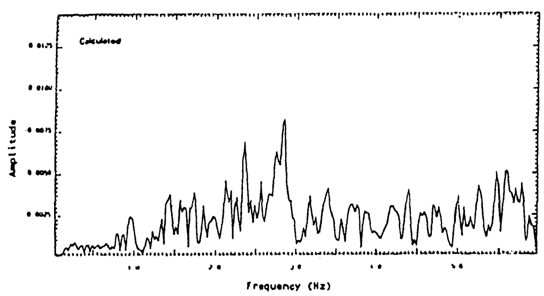
Time histories : 1m depth

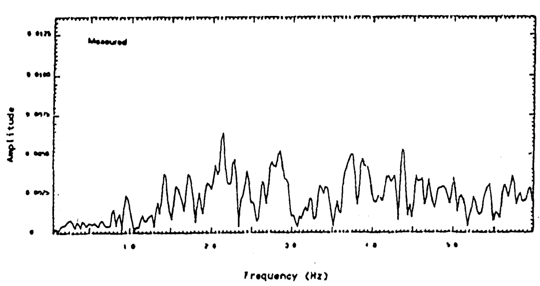


20m depth

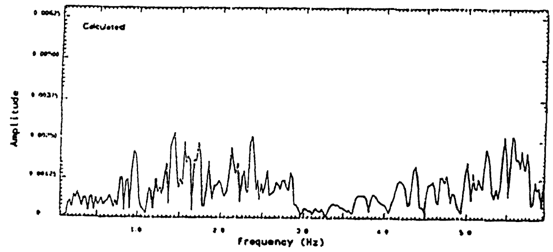


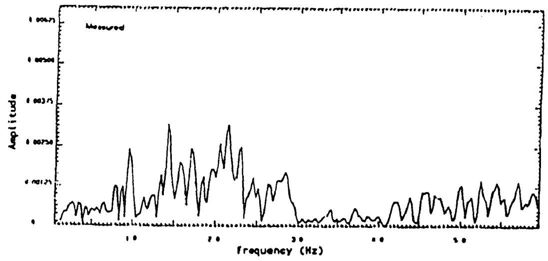
Fourier amplitude spectra : 1m depth



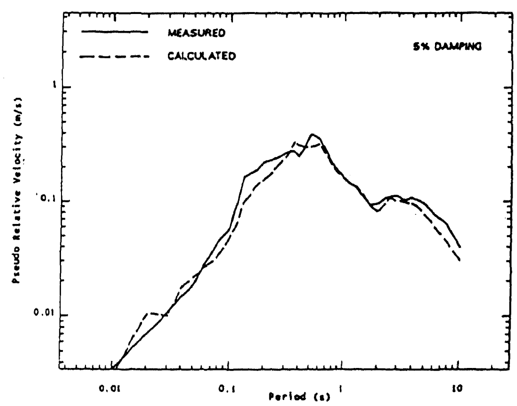


20m depth

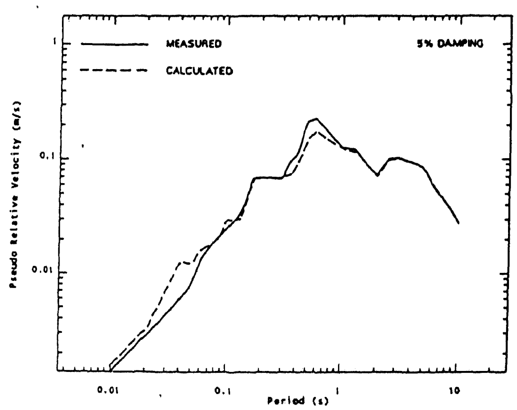




Response spectra : 1m depth



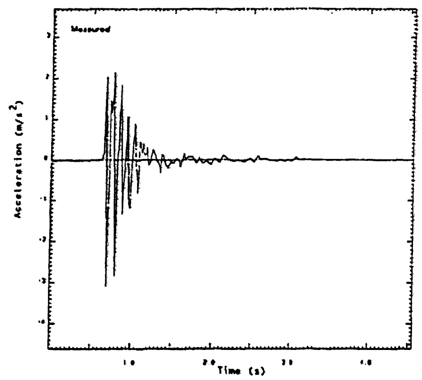
20m depth

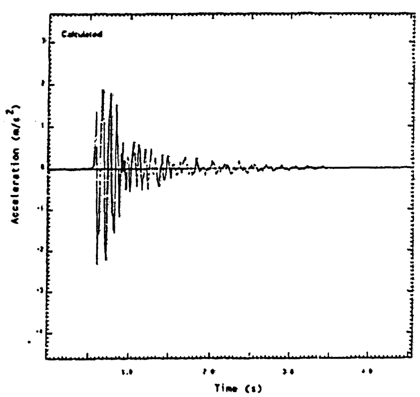


5.2 Centrifuge modelling

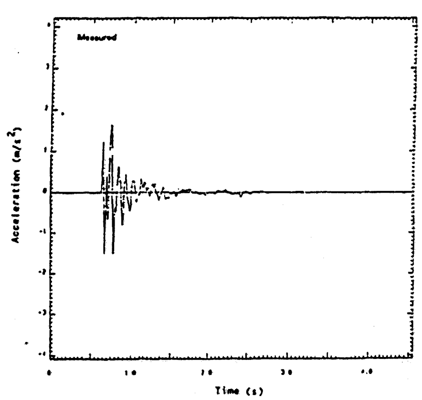
A site response analysis using SIREN was carried out for a centrifuge model tested at 100g using the acceleration time history measured on the lead plate. The figures below show the comparison between measured and calculated responses using time histories, response spectra and Fourier spectra at the surface and mid depth of the soil deposit.

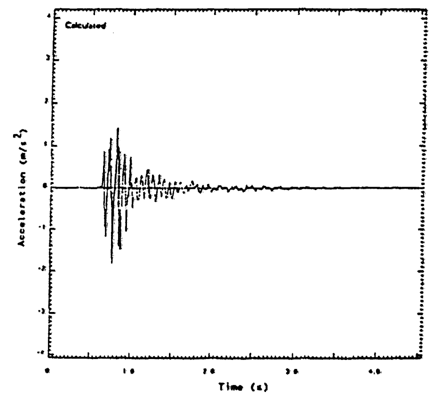
Time histories : Soil surface



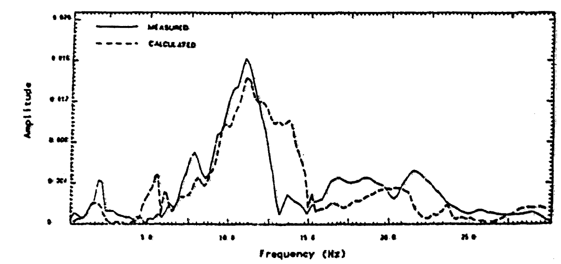


Mid-depth

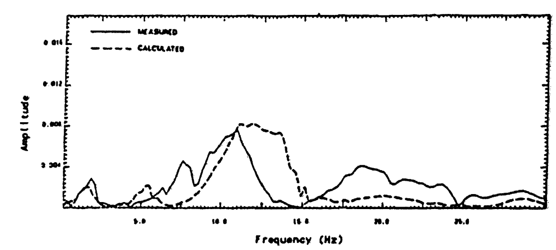




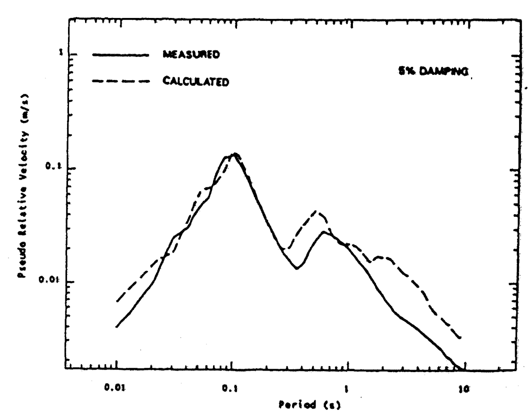
Fourier spectra : Soil Surface



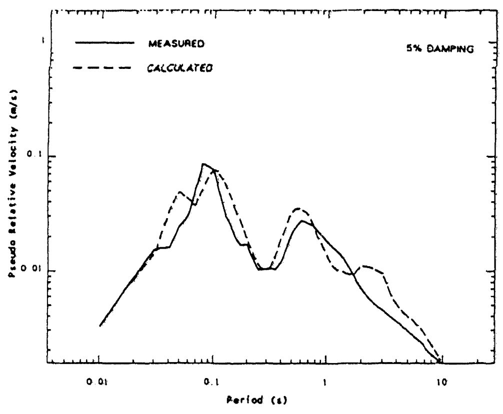
Mid-depth



Response spectra : Soil surface



Mid-depth



6 DISCUSSION

The quality of validation can be determined by the degree of agreement between calculated and measured values. By comparing the results of the analyses it was shown that the response spectra gave a very good match for both data sets. However, there are an infinite number of time histories that are compatible with each response spectrum. Hence response spectra are unable to characterise an earthquake motion alone. The acceleration time histories were not generally that useful. The shape and peak acceleration values showed a good match, but there were definite difference between calculated and measured motions. The Fourier amplitude spectra showed a fair agreement of frequency content especially around the resonant frequency. However Fourier amplitude spectra like response spectra can not define the whole motion.

7 CONCLUSIONS

In conclusion it has been shown that no single criterion should be used in the validation process. Preferably response spectra, Fourier spectra and time histories should all be employed in the validation process.

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