EXPERIMENTAL TECHNIQUES AND RESULTS FOR DYNAMIC TESTS ON STRUCTURES AND SOILS

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SYNOPSIS

This paper discusses the experimental techniques that are currently available to determine the dynamic characteristics of structures from full-scale tests, and the influence upon these characteristics of the supporting soils impedance. Methods and results are presented from tests that have used static, impulsive, steady state and random forces. The structures that have been tested include multi-storey buildings, bridges and the elevated turbine foundation in a nuclear power station.

INTRODUCTION

Earthquakes have provided full-scale tests on structures in many cities and towns throughout the world for a number of years. Engineers have been able to accumulate hard-earned knowledge from these catastrophic events so as to identify the features that predominantly control a structure's response to earthquakes. The two main features are the spectrum of the ground motion and the dynamic characteristics of the structures, which include factors like structural stiffness, damping and the soil-structure interaction problem. Modern instrumentation methods and data analysis techniques mean that information on structural dynamic characteristics can now be obtained from a wide range of test methods which are both rapid, relatively cheap and not destructive[1 to 3]. Some of these approaches, together with a few results, are dealt with in the remainder of this paper.

RANDOM VIBRATION TESTS

There are two main requirements for any full-scale test of a large structure; a means for applying forces and a method for measuring the resulting response. It is convenient that the dynamic component of the wind acting on a bluff body can be considered to approximate a 'white noisė' input to multi-storey buildings. This means the lateral wind-induced vibrations of these structures can be interpreted in such a way that their natural periods, mode shapes and equivalent damping values can be measured[4, 5]. The results that have been obtained by this method for the periods of seven multi-storey buildings are produced in Fig.1. All of the structures included in this particular set were founded on a rock or till, and therefore there were no complications associated with the soil-structure interaction problem.

Although straight lines have been drawn through the data in Fig.1, it should not be assumed that the objectives of full-scale structural testing are only to obtain empirical relations. What must be done is to use the information as a means for improving theoretical predictions, so that the dynamic characteristics of tall buildings can be accurately forecast in advance of their construction. It is only in this way that a rational method can be developed for the design of structures to with-

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stand earthquakes. With current analytical techniques, experience has shown that it is possible to achieve a good correlation between theory and experiment for the lower modes of vibration for tall buildings.

Once confidence has been established in the ability to predict the dynamic characteristics of structures founded on rock, one can extend this approach to investigate the soil-structure interaction phenomena. For example, attempts have been made to determine, from wind-induced vibrations, the soil impedance of a multi-storey building founded on a deep layer of clay [6]. Work along these lines is of a comparatively recent origin, but it does seem to present a line of attack that is worth pursuing. Some preliminary results for the damping values observed in the lower modes of tall buildings are given in Fig.2. It can be seen that both modern steel and reinforced concrete structures founded on bedrock have very small values of equivalent viscous damping. From the one set of results for the structure located on a deep layer of clay, there is, as might be expected, a significant increase in damping over the level found for rock. There is no alternative method to the experimental approach for evaluating the damping parameter in structures.

The measurement of wind-induced vibrations is now a well-established testing method. At present day costs, it is possible to buy the necessary transducers and recorder for around £7,000. Results for a large structure can normally be obtained in something like five days. The interpretation of these results has been considerably simplified by real-time analysis equipment, but it is this aspect of the work that requires skill and experience.

STATIC TESTS

The wind-induced vibrations in tall buildings are small, and it can be argued that the results from this type of study are not relevant to earthquake resistant design. The action of the wind together with such things as locomotives produce large quasi-static loads that develop structural movements nearer to those expected during an earthquake. Unfortunately the measurement of large slowly varying displacements presents difficulties that conventional instrumentation cannot cope with. There are a number of promising methods for tackling these problems [7]. One of the better approaches incorporates a laser with a servo-tracking system, and Fig.3 illustrates measurements made with prototype equipment that is now undergoing further development. It is likely that this sort of instrumentation could be used to great advantage in the study of long-term settlements in soils. A breakthrough on instrumentation developments in this area could open up this method of testing, and it is estimated the costs of automatically measuring the movement at a point in a two-dimensional plane could be reduced to about £1,000.

INPULSIVE TESTS

In the case of bridge structures, it can be convenient to use the impact loading of motor vehicles or trains as a cheap form of dynamic excitation. For tall buildings, it is possible to use local blasting or piling operations. The potential of this approach has been established during a study of a steel box girder bridge, and Fig.4 shows one result for the vibrations generated by a 10 ton truck driving over a 3·8 cm high projection in the road surface. The instrumentation and data analysis methods are similar to those used in random vibration tests, as are the derived data about the structure's characteristics.

STEADY STATE VIBRATION TESTS

There are two standard methods for producing a controlled sinusoidal force in a structure; the one approach uses an electro-hydraulic vibrator and the second contra-rotating weights. The measuring and analysis procedures are simplified when such vibrators are available, but large forces can be obtained only at a price of around £10,000. In some circumstances, however, it is possible to use cheaper forms of steady state sinusoidal tests. Such an opportunity is provided during the speed trials of any large rotating machinery.

The feasibility of this latter technique has been proven during the speed trails of a 250 MW turbine set at a nuclear power station. This turbine was isolated from the ground by a reinforced concrete frame structure , 13·4 m high, 12·2 m wide and 34·4 m long. Data were recorded during the first two days of speed trials and the complete set of results has still to be written up. Fig.5 shows just one sample of the data, and represents the spectrum of the vertical motion at one of the main turbine bearings as the speed increased from 900 r.p.m. to 1800 r.p.m.

INSTRUMENTATION AND ANALYSIS TECHNIQUES

Perhaps the greatest stumbling block to a more widespread application of the ideas outlined in this paper, is the generally poor education of civil engineers in modern instrumentation and data analysis techniques. Fortunately there are not really profound problems that cannot be overcome by someone with a rudimentary knowledge of electronics and a desire to make an original contribution. Special purpose seismometers, with natural frequencies of vibration adjustable down to about 0·2 Hz, together with servo-drive accelerometers present the best solution for measuring vibration levels in the frequency range of 1 - 100 Hz. There are problems, however, due to the fact that both types of transducer respond to rotations as well as translational movements. New methods such as those based on photogrammetry or the use of a laser present engineers with an opportunity to overcome this difficulty, and also offer ways for measuring large slowly varying displacements.

It is probably most convenient to record the data on a F.M. tape-recorder; this follows because the system can record low frequency signals, there is also the possibility of compressing or expanding the data on playback, and of course the information can be stored for a long time. In a normal operation there will be a central recording location connected to transducers that can be hundreds of metres away. The easiest way of transmitting an electrical signal is to use a cable, but this can lead to problems on a busy construction site. For this reason it is worth thinking about a telemetry link, if it is feasible, particularly since the adoption of such a solution is not now so very expensive.

The final phase of all the experimental work involves the identification of a structure's natural frequencies of vibration, its mode shapes and damping. Special purpose computers are now available which provide a rapid Fourier analysis of analogue signals, and all of the required information can be established very quickly. Indeed, the appearance of this so-called real-time analysis capability has removed what was originally the most time consuming part of all the full-scale test methods.

CONCLUSIONS

One of the main needs for the development of a rational approach to the earthquake resistant design of buildings is the ability to accurately predict their dynamic characteristics. The first and most fundamental step in achieving this objective is to correlate measured and calculated results. There are now numerous experimental techniques that can be used to assist in this process.

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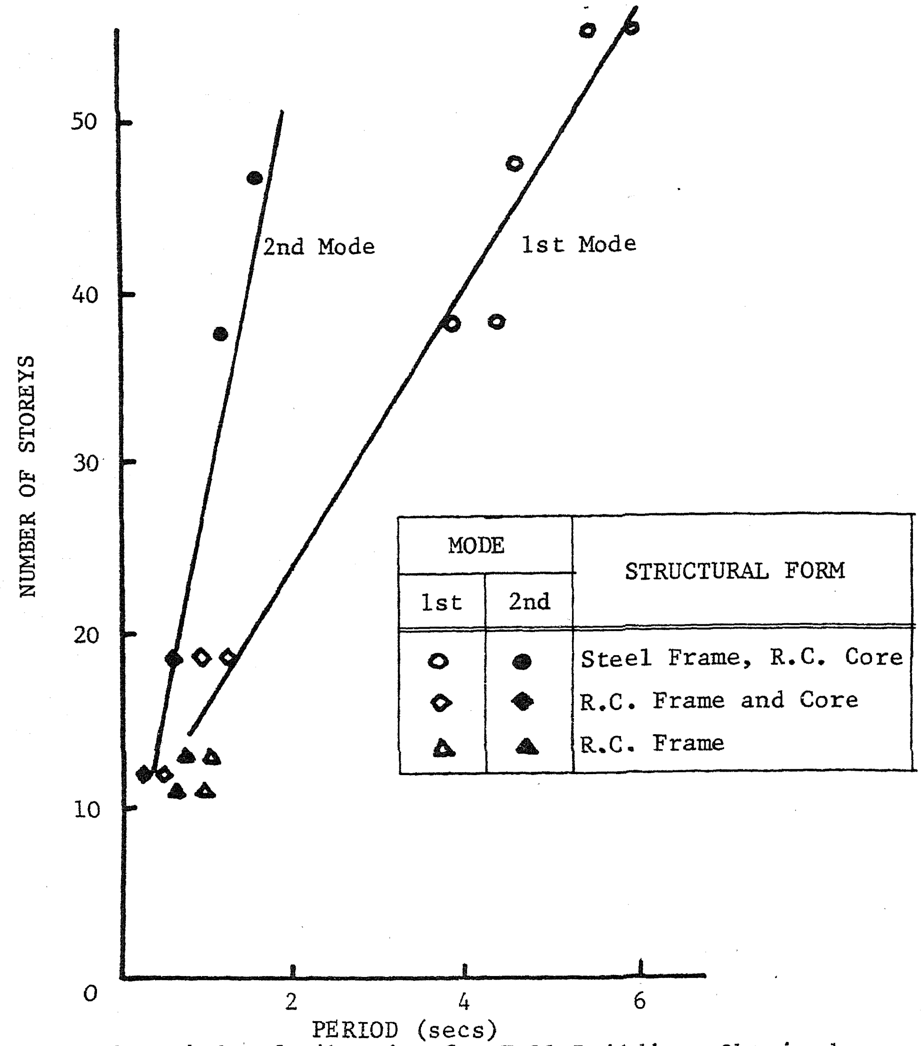

Fig.1 Lateral Periods of Vibration for Tall Buildings Obtained from Wind-Induced Measurements

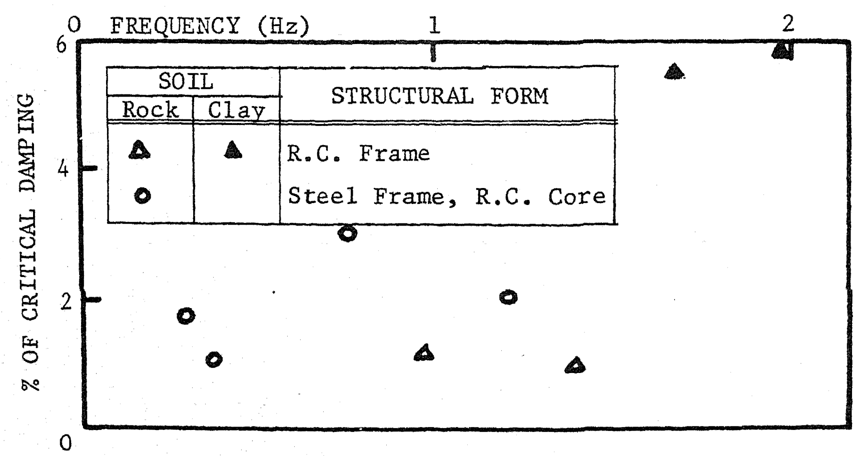

Fig. 2 Critical Damping Values for Tall Buildings Obtained from Wind-Induced Vibration Measurements

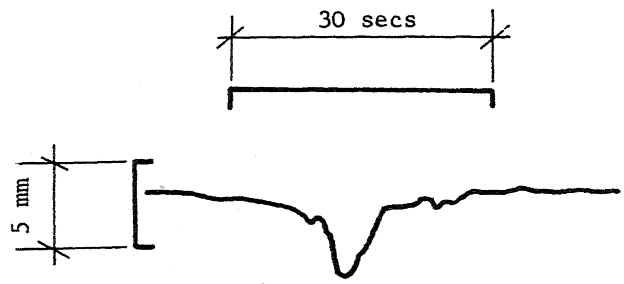

Fig.3 Quasi-Static Displacements Caused by a Locomotive Moving Slowly over a 46 m Span Truss Bridge

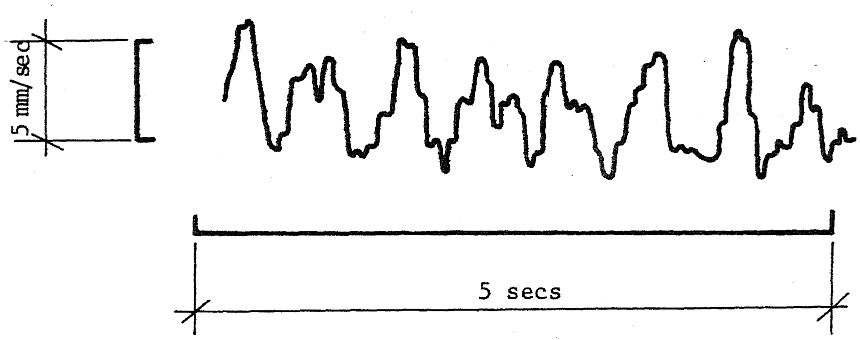

Fig.4 Velocity Response to an Impulsive Load at the Centre Span of a 620 m Steel Box Girder Bridge

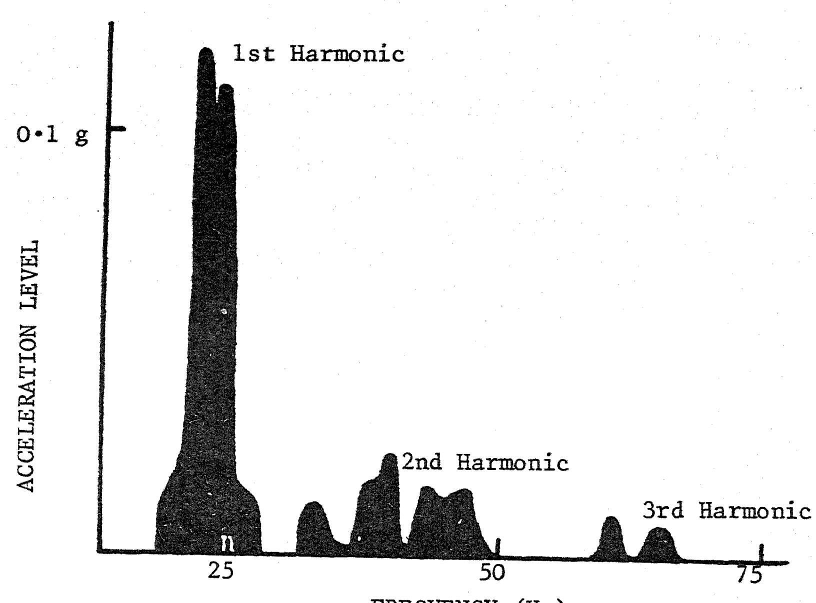

Fig.5 Vibration Spectrum of the Large Pedestal Foundation of a 250 MW Generator During its Speed Trials