Dynamic structural studies on models

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Dynamic Structural Studies on Models

Essais sur modèles dynamiques

Untersuchungen an dynamisch beanspruchten Modellen

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1. Introduction

Important improvements in dynamic structural studies have only recently been possible due to better understanding of the fundamental character of most of the dynamic loads. It is particularly so for wind and earthquake actions.

Machine vibrations may, in general, be well represented by sinusoidal varying forces. The same is not true for wind and earthquakes loads. Convenient information on the random character of these actions has been obtained only very recently [1] and [2].

Two types of randomness must be distinguished. The first refers to the probability of occurrence of an action with a given intensity. The second to the random character of the vibration itself, in the sense that, although with different power levels, random vibrations simultaneously include a large range of frequencies. In the following this last type of randomness is the only one considered.

Civil engineering studies on wind actions usually assimilate these actions to static forces, the wind velocity being supposed constant. Even in the problems of aeroelasticity, particularly those concerning the aerodynamic stability of suspension bridges and stacks, the real turbulent character of wind is, generally, not considered.

Most of the modern earthquake engineering studies suppose the random character of seismic vibrations, defining this through mean velocity spectra. This representation, very convenient for the study of the behaviour of one-degree of freedom linear oscillators, can only be generalized to systems of several degrees of freedom through simplifying hypotheses and is not applicable for non-linear behaviour.

Recent studies showed that earthquakes can be well represented by a random vibration of constant spectral density of acceleration in the range 0 to 5 Hz, and zero density beyond this range. For reference, the spectral density may be taken equal to 675 $cm^2 s^{-4} Hz^{-1}$ which corresponds to the recorded N-S component El-Centro, 1940, earthquake. Duration is generally taken equal to 30 s.

A more accurate representation of an earthquake could be obtained by assuming that the spectral density of acceleration changes in function of the frequency according to a law analogous to that of a simple oscillator transfer function. The data so far available, based on recorded earthquakes, is not yet sufficient to justify this refinement.

2. Studies in the Linear Range

The matric formulation of dynamical problems allows the analytical study even of involved structures. Numerical solutions can be easily obtained with modern electronic computers.

For determining the vibration modes, the knowledge of the stiffness and mass matrices is sufficient. The analytical determination of the stiffness matrix is sometimes involved and can be substituted by an experimental determination based on model tests. Model tests may also be very useful for a check of the simplifying assumptions to be considered in the analytical methods.

If complete information on the dynamic behaviour is needed, damping can not be disregarded. In this case dynamical tests on models may give convenient information but it is necessary to use models built of the same materials as the prototype. Even so, as the influence of scale in the damping factors is not yet well known, it is necessary to judge the results taking in consideration the values of the damping factors determined in dynamic tests of real structures of the same type. The problem is particularly involved because damping may increase with the vibration amplitudes and, in general, it is only possible to study the behaviour of real structures for vibrations of very small amplitude.

Theoretically, if the structure behaves linearly, it is possible to derive the behaviour under the action of random vibrations by studying the behaviour for sinusoidal vibrations. The simplest way would be to experimentally determine the transfer functions of the magnitudes to be determined. By multiplying the spectral densities of acceleration by the corresponding values of the square of the transfer function, the spectral density of the response of the structure is computed. Integrating this response for the range of frequencies considered, the mean square value of the interesting quantities (displacements, strains, stresses) is then obtained. Finally, if maximum values (mean maximum values or extreme values with a given probability) are to be obtained, the root mean square values must be multiplied by suitable coefficients.

The method just described is, in practice, difficult to apply and, in general, the results obtained are not sufficiently accurate. This is why a different testing technique has been adopted at the Laboratório Nacional de Engenharia Civil in Lisbon [3].

Models are directly submitted to random vibrations and the magnitudes of interest, such as displacements and strains are directly recorded. In the case of earthquake studies, the duration of the earthquake is also reduced to scale, several tests being performed for a level of acceleration. So, it is easy to determine for each test the maximum values of the magnitudes of interest, and to compute from several tests the mean of these maximum values. It has been shown that these mean maximum values are in general the magnitudes of interest for design purposes [4].

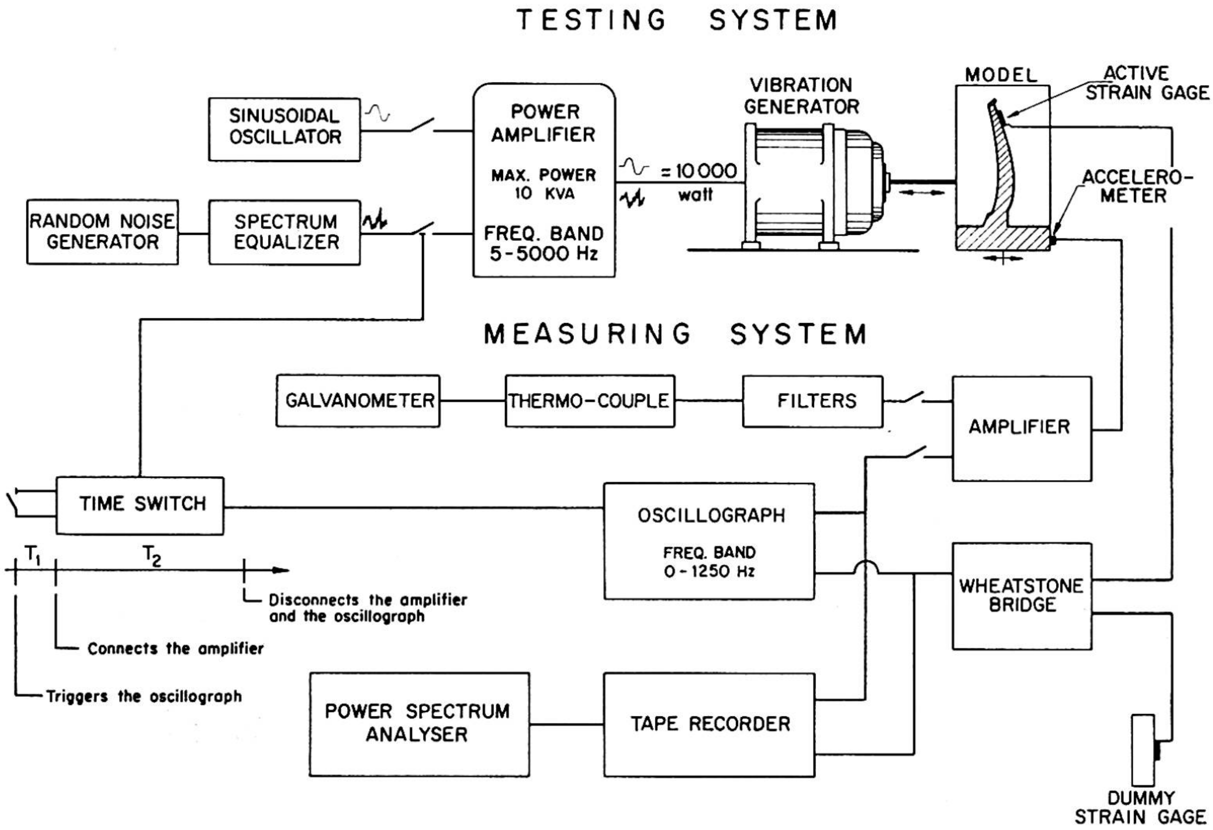

Fig. 1.

A diagram of the testing set-up used for this type of tests is presented in fig. 1. Both sinusoidal and random vibrations may be induced in the model by an electromagnetic vibrator and for the latter it is possible, by acting on a spectrum equalizer, to adjust the convenient values of the acceleration spectral density at the different frequency ranges. The quantities of interest such as acceleration, displacements and strains, can be directly recorded on paper (fig. 2) or in magnetic tape. Tape records are used in an electronic spectrum analyser to determine spectral density diagrams.

The testing of a buttress dam model is shown in fig. 3 and the testing of

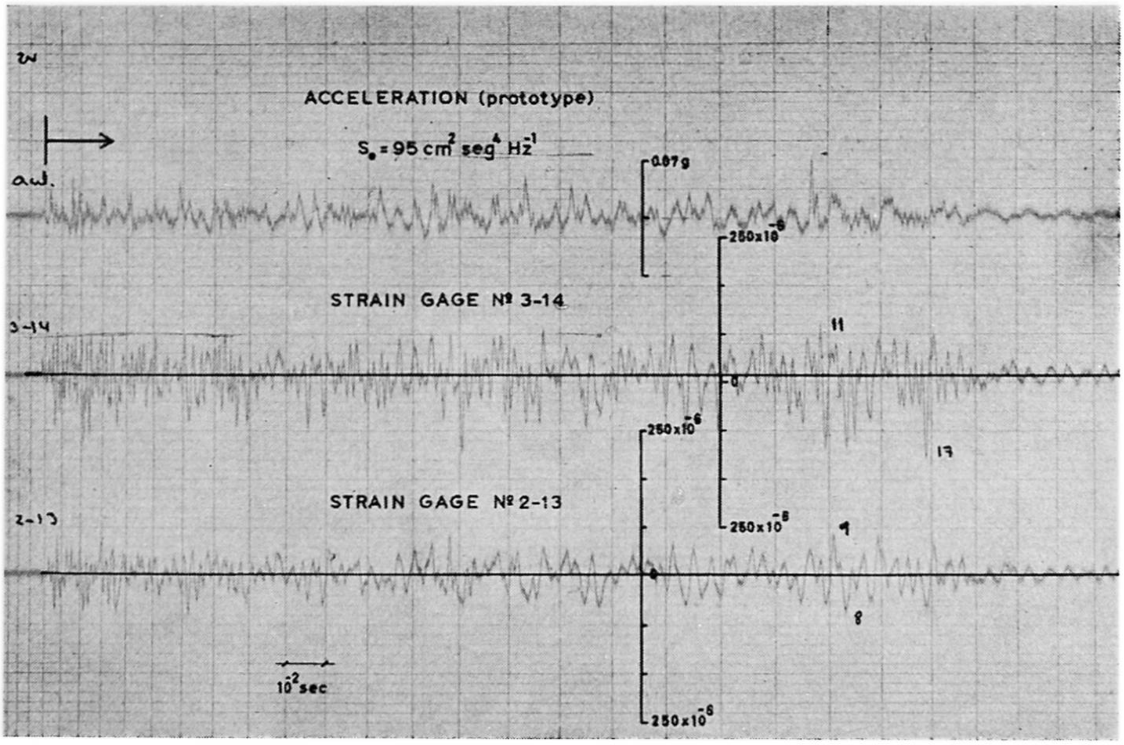

Fig. 2.

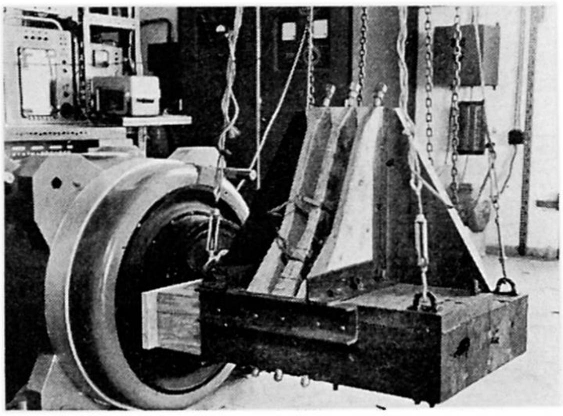

Fig. 3.

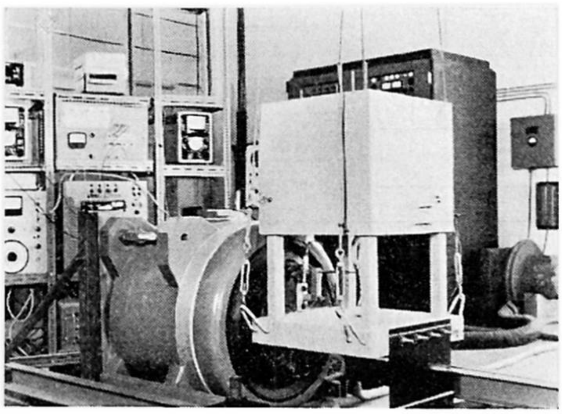

Fig. 4.

a reinforced concrete model that reproduces an usual type of building is presented in fig. 4.

3. Studies on the Non-Linear Range

The need to study structural behaviour in the non-linear range is well recognized. In fact if safety against rupture is to be judged, plastic deformations must be considered. This is particularly true for earthquake actions.

In fact, earthquake actions usually give rise to displacements exceeding those of elastic behaviour. By increasing the stiffness of the structure the situation is not modified because, if the stiffness increases, seismic forces also increase.

The analytical study of non-linear behaviour, both elastic or hysteretical, is much more involved than in the linear case. At present only very simple problems can be dealt with.

Numerical methods based on finite differences are easy to program for the digital computer and may give valuable information. Results of similar type may be obtained in analogical computers, even in a more economical way. But it must be considered that these methods may only be used by introducing many simplifying hypotheses whose validity it is very difficult to judge.

Structural models are particularly useful for studies on the non-linear range. If the testing technique described above is used, it is sufficient to conveniently increase the spectral level of acceleration to follow the behaviour in the non-linear range, till rupture is attained.

Also in this case the most convenient materials to build the models are those of the prototype, this being the easiest way to maintain their rheological properties, but, it can not be forgotten that dynamic similitude imposes a change of frequency range from the prototype to the model, and this change may affect the interesting mechanical properties. This is a problem that deserves further study.

Also it may occur that, after a certain level of vibration, the behaviour of the structure be modified by incipient ruptures or cracks, the structure being, even so, able to sustain important horizontal forces.

In this case it is necessary to further analyse the behaviour taking in consideration that the initial deterioration may affect the similitude conditions. Gravity forces may then be of paramount importance as compared with elastic forces. Concrete dams are a good example of cases where problems of this type occur. Also for this purpose model tests may give very valuable information, difficult to obtain by other means.

4. Conclusions

The main conclusions that can be derived concerning dynamic structural studies are the following:

a) Improvement in dynamic structural studies must be based in the convenient representation of dynamic actions. Particularly, the random character of wind and earthquake actions must not be forgotten.

b) The statical determination of the stiffness matrix by model tests may be of much help for the further analytical solution of vibration problems.

c) Dynamical model tests in the elastic range may give complete information on structural behaviour, the determination of transfer functions being particularly recommended.

d) For judging the safety against rupture it is necessary to explore the dynamic behaviour in the non-linear range. In the case of brittle structures it may be necessary to study the behaviour after cracks have developed.

e) The testing technique described seems to be particularly convenient, since it directly allows the measurement of the magnitudes of interest.

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Summary

The usefulness of model tests for dealing with dynamic structural problems is discussed. Attention is called to the possibility they afford to study the dynamic behaviour both for sinusoidal and random vibrations, in the linear and non-linear ranges.

Special reference is made to the testing techniques adopted at the Lisbon research institute, LNEC.

Résumé

L'auteur discute de l'utilité des essais sur modèles dans la résolution des problèmes dynamiques. Il rappelle que ces essais permettent d'étudier le comportement dynamique pour des vibrations aussi bien sinusoïdales qu'aléatoires, dans les domaines linéaire et non-linéaire.

On mentionne tout particulièrement les techniques d'essai employées au laboratoire de recherches de Lisbonne, LNEC.

Zusammenfassung

Es wird über die Nützlichkeit von Modellversuchen bei der Behandlung dynamisch beanspruchter Tragwerke gesprochen. Besonders hervorgehoben wird die sich dabei bietende Möglichkeit, das dynamische Verhalten sowohl unter sinusförmigen als auch unter beliebigen Schwingungen im linearen und nicht linearen Bereich zu untersuchen.

Die verschiedenen vom Laboratório Nacional de Engenharia Civil (LNEC) in Lissabon angewendeten Prüfmethoden werden besonders hervorgehoben.