Discussion

R. Shepherd* and the Author

Editor's Note: Written contributions relating to material published in the Bulletin will generally appear in the Discussion Section of the Bulletin. Occasionally individuals may be invited to offer discussion for printing with the original paper, article or note. In this instance, Mr. Shepherd, whose paper was referred to by Mr. McKenzie, was invited. His comment and Mr. McKenzie's response appear below. Others may contribute for publication in later issues.

MR. SHEPHERD:

The approach outlined by Mr. McKenzie to overcome the limitations in the use of modal analysis results in the seismic design of particular structures appears reasonable and may well be warranted in exceptional circumstances.

The only point on which I take issue with Mr. McKenzie is contained in his first sentence. Direct numerical integration of the equations of motion of a structure, using a digitised earthquake record as the exciting function, enables the time varying response to be computed without specific determination of the normal mode properties. Consequently the problem of mode superposition will at no stage be encountered if the direct integration analysis procedure is used.

MR. McKENZIE:

I find myself at issue with Mr. Shepherd over the last sentence of his comments. The statement is correct in one sense, in that a result can be obtained from direct integration without consideration of mode superposition. However, full design information cannot be obtained from such results without consideration of individual modes.

As an illustration, consider three successive earthquakes of equal intensity, which can be called A, B, C respectively. Assume that they all excite the first three modes of a structure strongly, and that the maximum response in each mode has a value which is the same in each of the three earthquakes. However, due to slight differences in the vibration patterns, the following phase relationships exist at the instant when the fundamental mode reaches its maximum amplitude of response. In earthquake A, as an extreme example, the higher modes are in phase opposition to the fundamental, while in earthquake B they are one-eighth of a cycle out of phase with the fundamental and in earthquake C they are exactly in phase with the fundamental. Direct integration would show a larger response from earthquake B than from earthquake A, and a still larger response from earthquake C, without revealing the cause. If earthquake A occurred before the building was designed, and earthquakes B and C occurred after the building was constructed, design would be based on earthquake A. If a direct integration procedure was used on earthquake A, the design would cater for the response from earthquake A and would not be adequate for the subsequent earthquakes B and C If modal analysis was used, the response for earthquakes B and C could be calculated from earthquake A, together with any other desirable phase combinations. In most cases, designers would probably design for earthquake B and check that earthquake C could be accommodated as an extreme case, with a reduced load factor.

Another advantage of modal analysis is that the designer can ensure that his modal values lie on smoothed response spectra. An unsmoothed spectrum shows large dips and peaks at local points, and if the fundamental period of the structure happens to lie on a local low dip in the curve direct integration would give a correspondingly low value for the total response, without revealing the existence of a local dip. This is dangerous, because the elastic properties of structure are never exactly known, and the true period could be on an adjacent peak. With modal analysis, on the other hand, the fundamental response can be scaled up from the low dip in the original curve to the corresponding value in the smoothed response spectrum. The same procedure would apply to any higher modes that happen to lie on local dips in the spectrum.

Again, where some ground conditions require longer period response modes to be scaled up, this can readily be done with modal procedures.

The writer is aware that there are circumstances where direct integration procedures have advantages. However, for providing information to designers, who have to obtain adequate values from a very limited number of earthquake records, modal analysis procedures have advantages. in many cases, over direct integration methods.

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