Discussion Section

Editor's Note: Written discussion about material published in the Bulletin is invited, and will be published in this section, with the Author's response if this is available at the time of going to press. Contributions other than authors replies should reach the Editor not later than ten weeks before the publication of the issue in which they are to appear. Mr. Lord's closure to Mr. McKenzie's discussion will be published in a later issue.

JAMES LORD - "REAL-TIME SIMULATED EARTHQUAKE MOTION OF HIGH RISE STRUCTURES"

G. H. F. McKenzie *

Mr. McKenzie :

From the designer's point of view, the dynamic analysis system described in this article is one of the best and most comprehensive that has yet been reported for response in the elastic range. The information which the designer ultimately requires is not a mathematically exact response solution for one particular earthquake record which happens to be available, but rather an assessment of the envelope of responses for a variety of possible earthquakes. The author's procedure enables the designer to make this assessment, because it not only gives the direct integration response corresponding to the combination of all modes, but it also gives the separate magnitudes and time histories of the individual mode components. Thus, the method has, on the one hand, the advantage of the direct integration method in giving the exact combined response to one earthquake, and on the other hand allows the designer to see if the individual modes have any peculiarities in their magnitudes or time history or phase relationships that should be allowed for in interpreting the results.

The value of the latter facility can be demonstrated as follows, in interpreting the effect of second mode on the building described in the paper. Second mode response results in a very large maximum absolute acceleration at the 21st floor level, as shown in Fig. 7. by the dashed curve. However, the position can be even worse than shown, if the following considerations are taken into account. In the velocity spectra shown in Fig. 1, the second mode period corresponds to local troughs in the spectra for both El Centro earthquake and the artificial earthquake A_2. The finally constructed building is likely to have modal periods different from those theoretically calculated, and this may well shift the second mode period out of the troughs and towards the adjacent peaks. Again, another earthquake of similar spectral distribution is unlikely to have the same local trough. Hence, the second mode components should really be scaled up to the ordinates of smoothed response curves, when the designer comes to interpret the results. This would give peaks at the 21st floor level appreciately greater than those shown in Fig. 7.

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The comprehensive data given by the system described enables adjustments of this type to be made by the designer. Again, it allows the causes of local low values in the storey responses to be investigated, so that the designer can decide whether they correspond to the peculiarities of one particular earthquake record and consequently should be scaled up to give a more general result. For example, in Figure 7, the zero acceleration value on the dashed line at the 31st storey is obviously due to a chance combination of modal values and phase differences between modes which have a resultant of zero. A different earthquake would be most unlikely to produce a zero value at this level. Hence, if the designer had retained the structure represented by the dashed line, he would certainly not accept zero as a maximum value for the acceleration at this level to cover all earthquakes. He would take the individual modal components and would examine the effect of altering the phase differences between them to change the interaction to a mutual reinforcing effect. He might well finish by assessing the maximum local 31st floor acceleration as the "root sum square" of the modal values.

Similarly, for assessing design storey shears and overturning moments at various levels, it is desirable for the designer to know the components of shear and overturning from the various modes and their phase relationships, in order to determine whether unique peculiarities of the input earthquake are causing unusual effects, and to decide what adjustments to the direct integration results should be made. Here again, the excellent procedures outlined in the paper provide all the required data.

The use of artificial earthquakes provide a useful check of assessed results in the most usual case when only one appropriate natural strong earthquake record is available. However, because of the arbitrary basis of artificial earthquakes, the designer will tend to lean heavily on the results from the natural earthquake, provided that adjustments to it, on an informed basis, as outlined above, can be made.

I agree with the author that the root sum square method of combining modal responses has limitations. However, the example quoted by the author, from the article by R. Shephard[1], is rather harsh on this latter method, because it sets out an incorrect procedure for use of the root sum square method, and then blames it for totally erroneous results. From the theory on which this method of combination of modes is based, it is obvious that each mode of the base shear should be calculated separately, by summing algebraically the effects of all the member forces in that particular mode. The sense of each force must be taken into account, by adding or subtracting its effect as appropriate, in arriving the total base shear for the particular mode. After the base shears in each mode have been calculated, they should then have the root sum square operation applied to them, as the last step in the procedure. (This rule applies to any formula for combining modes.)

The incorrect procedures which gave erroneous results consisted of applying the root sum square operation to individual storey forces or individual member forces and then using the resulting values to calculate base shears. This will invariably give results that are too high.

Finally, I am concerned at the tendency for some designers to almost abdicate their responsibilities when dynamic analyses are involved, and to leave too great a share of the response considerations to the structural dynamics specialist. The designer should always accept that he takes the ultimate responsibility for the safety of the building and its occupants. He will naturally appreciate the value of the services which a good structural dynamics specialist can provide, but he should always satisfy himself that an appropriate set of input earthquakes have been used, that appropriate adjustments for any peculiarities of the earthquakes are made to the results, and that the procedures used produce all the information that he really needs for design. Above all, he is responsible for putting the correct interpretation on the results.

REFERENCE

1. Shephard, R., "Some Limitations of Modal Analysis in Seismic Design". Bulletin of the New Zealand Society for EArthquake Engineering, Vol. 2, No. 3, Sept. 1969, pp. 284-288.