Dynamic response of dams and other structures to differential ground motions

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Until recently, almost all structural analyses of earthquake response have been based on the model of a rigid base and a point or uniform excitation. Nevertheless, the free field strong ground motion can vary considerably within the extent of a single engineering structure which may be very rigid, such as the base mat of a nuclear power plant, or very flexible such as a suspension bridge.

37. Any earthquake response analysis of bridges which does not take account of the different ground motions at the different piers is quite unrealistic. The Authors' development of a technique for taking this factor into account is very welcome.

38. The motion of a rigid base mat is completely described by a small number of variables, no matter what the variation of the free field motion from point to point may be. This has the effect of averaging out, and so reducing, the peaks of the free field ground motion at any one point. The effect is more significant for the higher frequency, shorter wavelength components of the motion. This has been studied by Ambraseys¹⁰ and Newmark, Hall and Morgan.¹¹ So far, no study has been made of the local stresses or displacements in the base mat and the ground caused by the effect.

39. An intermediate state of rigidity between these two cases occurs with many building structures set on pad footings, which must, according to most earthquake building regulations, be tied together by ground beams. At present, the choice of strength and deformation characteristics of these ground beams is quite arbitrary. The Authors' method of analysis provides scope for a more rational choice of properties of these ground beams.

40. Where there is only a single point record of ground motions, the spatial variation can be estimated only by the assumptions the Authors have made of a direction and velocity of propagation. In general, seismic energy at a site will be propagated along the line from the epicentre to the site, but in detail the pulses at a point arrive from many different directions at different times. One of the aims of the SMART 1 strong motion array¹² was to study this. Analysis of past earthquakes may lead to a rational procedure of providing for the effects of future earthquakes.

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We would like to thank *Mr Howells* for his generally appreciative comment of our Paper. The research was undertaken because, as a rule, seismic waves propagate

DISCUSSION

from the epicentre to the site and will arrive at a given point from many different directions at different times. Therefore, depending on the site conditions, structures will experience different seismic effect at different support points with varying time lag. Thus, the research subject generally is of two parts: in the first, the variation of the ground motion input along the base; in the second, variation of time lag from support point to support point. This time lag is a function of the velocity of the wave propagation.

42. The governing equation of motion is the same for both cases as explored in the Paper. The velocity of wave propagation, which eventually determines the time lag of input motions, was stressed. The results which were produced only attempted to indicate the importance of the wave velocity. However, the computer program developed is very general and can deal with variation of the ground motion and different arrival angles, as well as varying velocities. The program is also independent of the geometry of the structure.

43. Engineering structures with continuous support were analysed only on the assumption that they were connected to the base at nodal points chosen for the finite element model. It is true that ground motion also varies along the edge of the elements used. However, the length of these elements is assumed to be small to cause a major change to the arrival time. Sometimes, not only elements, but a region along the base has to be considered to change the arrival time.

44. *Mr Howells* mentions structures with long span, such as suspension bridges and this allows us to say that our recent work has been specially concerned with suspension bridges, using modern designs incorporating slender towers, box decks and inclined hangers. Both stochastic and deterministic analyses have been considered, and prototype measurements of natural frequency, modal shapes and damping are in hand.

45. It is also worth noting that the final draft of Eurocode 8, which deals with design for seismic loading, has, for the first time in any Code in our experience, a provision for differential ground movement caused by asynchronous motion. The simple formula proposed therein is certain to be subjected to close scrutiny in the near future, and our studies may therefore have an immediate practical value.

References

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