Coupled hydrodynamic response of a gravity dam

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The major advance made by the Author and outlined in his Paper is the development of an analytical method to predict reservoir–dam interaction during sinusoidal motion of the system allowing for compressibility of water in the reservoir.

46. The effect of compressibility of water is that pressure waves in the reservoir generated by acceleration of the dam or the valley can, in theory, tend to very large values if the excitation frequency approaches the resonant frequency of these waves. This phenomenon is similar to the behaviour of air in an organ pipe.[13] Resonance of pressure waves in the water in a vertical direction corresponds to that in an organ pipe open at one end and sealed at the other. Longitudinal and, in a three-dimensional system, lateral pressure wave resonances correspond to those in a pipe sealed at both ends. The fundamental frequencies of the three reservoir resonances are:—

$$f\,(\text{vertical}) = \frac{c}{4H}\ \text{cycles/s}$$

$$f\,(\text{longitudinal}) = \frac{c}{2L}\ \text{cycles/s}$$

$$f\,(\text{lateral}) = \frac{c}{2B}\ \text{cycles/s}$$

where c is the velocity of sound in water
H is the reservoir depth
L is the reservoir length, and
B is the reservoir width

47. However, a small amount of damping inherent in the reservoir would limit the pressure response and also cause the pressure response to be a function of the number of cycles of excitation.[14] A second question concerning dynamic pressure magnification is whether longitudinal acceleration of the dam is a suitable form of excitation for establishing pressure resonance in the reservoir. Consider for analogy the result of exciting a beam by a shaker positioned near a node point of the normal mode in question. A third practical detail affecting vertical pressure wave resonance is the inclination to the horizontal of the reservoir bottom. If this angle is significant the pressure waves will be refracted from their vertical path, thereby destroying the resonance situation.

48. In § 34 the Author states that his theory predicts the fundamental natural frequency more accurately than does the added mass method. However, provided the hydrodynamic pressures can be accurately estimated, an added mass solution derived from these pressures (and hence dependent on mode shape) will describe the effect of the reservoir to the same level of accuracy, assuming the damping effect of the reservoir to be negligible. Hence the problem resolves into the estimation of hydrodynamic pressures. Implied in this is the knowledge of a dynamic magnification factor for water pressure.

49. An investigation into this dynamic magnification is in progress at Bristol University. Model dams are excited sinusoidally by electromagnetic shakers, and dam response and hydrodynamic pressures are measured over a range of frequencies

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including values at theoretical reservoir resonance. Pressures are then compared with those calculated from the solution of Laplace's equation. Preliminary results suggest very limited dynamic magnification, despite an idealized rectangular section model valley with horizontal floor, so it is suggested that, in calculations of response of prototype dams to earthquakes, when excitation is transient and the valley floor and sides are irregular, the effects of compressibility will be of negligible importance.

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The points raised by **Mr Selby** are interesting and need careful consideration.

51. The question of damping in the reservoir–dam system and its effect on response is an important aspect of the problem. It is generally agreed that extremely high resonant response is not likely, due to a number of sources contributing to the overall damping of the system. Mr Selby is right in pointing out the additional contribution to it arising out of the refraction of pressure waves at the reservoir bed, which is usually inclined to the horizontal. Another point raised is about the resonance of dynamic pressures, presumably the uncoupled dynamic pressures. It can be easily verified that the matrices governing such pressures in a finite fluid domain are independent of the direction along which accelerations are active; consequently, their roots and eigenvectors, defining the dynamic characteristics of the fluid body are also independent of the direction of acceleration. Further, the dynamic pressure magnification functions for horizontal and vertical[1] motions of a finite fluid body are almost identical.

52. Although the determination of dynamic pressure magnification functions may be of some importance, it is felt nevertheless that the most important aspect of the problem from the design point of view is the determination of coupled response of the system to arbitrary motions. This can be evaluated, for example, by using the standard response spectra techniques, in which case the system frequencies and corresponding mode shapes must be determined accurately; these dynamic characteristics can be determined accurately by using sophisticated[5,12] numerical methods. However, if only the fundamental and/or first harmonic frequencies of the system are required, then the method described in the present Paper should be adequate. The alternative method suggested by Mr Selby in which the dynamic pressure magnification function is known in advance sounds interesting and the results of this investigation are eagerly awaited. It may be pointed out however that a parallel method in which dynamic pressure magnification functions are assumed, has been used[15] with considerable success to determine the forced harmonic response of reservoir–dam systems.

53. Finally, it is also generally agreed that the effect of compressibility of water at a given excitation frequency is determined primarily by the stiffness of the dam, relative to that of the fluid body. The effect of damping, particularly radiation damping and transient excitation on this phenomenon, is as of now largely unknown; it is hoped that Mr Selby's work will provide satisfactory answers to some of these aspects of this problem.

References

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