Chapter 2

LITERATURE REVIEW

The vibrations of single-anchor inflatable dams are similar to the cases of vibrations of double-anchor inflatable dams, cylinders, etc. Earlier works involving vibrations of flexible structures in water are also discussed.

The inflatable dams are usually modeled as a shell or a membrane structure with the resistance in the form of tension and bending (in the case of shells). The loads applied on the inflatable dam include the internal pressure (air, water, or their combination) and the external water. The external water pressure can be hydrostatic pressure or hydrodynamic pressure (in the case of flowing water).

Anwar (1967) performed calculations for water-inflated dams under hydrostatic conditions, and air - inflated dams under both hydrostatic and steady overflow conditions. The results were compared with experiments. Under the assumption that the weight of the dam was negligible and the inflated pressure was proportional to the storage head, the hydrostatic shape of an inflatable dam (inflated by air or water) was derived partly in terms of elliptic integrals and partly in terms of an equation of a circle from the equilibrium of forces. No restrictions were set for the perimeter and the base length of the dam. For the hydrodynamic case, the pressure on the downstream face was atmospheric and the downstream dam shape was part of a circle. By a set of power series approximations for the vertical coordinate, the pressure, and the horizontal force distribution, an ordinary differential equation was established and numerically solved for the upstream dam shape. A parabola was found to be a good approximation in the power series formulation. A model test was set up with the height of the dam equal to 12 in. in the static case and 9 in. in the overflow case. A trip rod or wire placed near the crest of the dam prevented the flow from clinging to the downstream face and reduced the skin vibration considerably, provided the nappe was fully aerated. There was no sign of flow separation when the dam was operating without a trip wire, in which water followed the profile of the dam over the major part of the downstream face. It was observed that an inflatable dam was not suitable for a high overflow condition.

Harrison (1970) studied air-inflated dams and water-inflated dams subjected to hydrostatic pressure from both the upstream and downstream heads. The two-dimensional membrane section was considered as composed of a finite number of small elements with concentrated loads acting on the ends of the elements only. The base width and curved perimeter were specified. Newton's method was employed to improve the shape of the dam and to match the specified positions of the anchored points. For a rising upstream head, an air-inflated dam was found to reduce the membrane tension more than a water-inflated dam. Air-inflated dams might entail more risk of an explosive failure if the membrane was damaged, but may be more economical. Binnie (1973) dealt with water-inflated dams impounding water at the crest level. Besides the problem of the unrestricted curved perimeter and base width, it was mentioned that the anchorage of the upstream and downstream faces should not be at different levels as in Anwar (1967). Assuming that the membrane was weightless and inextensible, a solution for the shape of the dam was obtained, with the upstream face being part of a circle and the downstream face expressed by an equation in terms of elliptic integrals, and this shape corresponded to the anchored points at the same level. The drawback is that the inverse formulation was not performed so that the curved perimeter and the base width would be part of the solution instead of input quantities, while the tension in the membrane and the slope at the downstream anchored point were given.

Parbery (1976) derived the differential equations of equilibrium using membrane theory and solved those equations with a fourth order Runge-Kutta method and the Newton-Raphson method for the inflatable dams under hydrostatic conditions. The self-weight and the modulus of elasticity of the membrane were considered, as well as the restrictions on the base width and the curved perimeter. In his second paper (Parbery, 1978), the weight and the elasticity of the membrane were found to have minor influences on the shape of the dams for the hydrostatic conditions. For a given base width, the major influences resulted from the internal pressure, the inflation method, the impounded head, and the curved perimeter. Watson (1985) dealt with the theoretical calculation of the shapes of the water-inflated or air-inflated dams impounding water at the crest level (without overflow) in a way similar to Anwar (1967) and Binnie (1973). The weight and the modulus of elasticity were ignored. Design charts for various loading parameters and fabric length/anchorage spacing ratios were presented. Parachute dams in which the upper end of the membrane was fixed to a floating buoy and restrained by guy wires were also discussed.

Fagan (1987) investigated the effect of the weight of the membrane on the vibrations of the air-inflated dams. For the equilibrium shape of the dams, a Runge-Kutta-Verner fifth and sixth order method and a bisection iteration algorithm were employed to solve the simultaneous ordinary differential equations derived from membrane theory in Parbery (1976). The analysis of vibrations was performed by applying an eigenvalue solution approach to the finite difference form of the equations of motion for the membrane under small vibrations. The weight of the membrane was found to have an insignificant impact on the static shape of the dams as long as extensibility of the membrane was neglected. The self-weight of the dams tended to lower the tension and vibration frequencies for the membrane, but the effect was much less than other factors, such as the base width. The vibration modes were not affected by the weight of the dam significantly, as well (Plaut and Fagan, 1988).

Leeuwrik (1987) analyzed the vibrations of air-inflated dams by the Galerkin approximation with one term or two terms of sine functions, and a Runge-Kutta-Verner method. The dams were assumed to be weightless, inextensible, and sufficiently long so that a two-dimensional analysis was acceptable. In some cases, the inflatable dams were found not to oscillate about the equilibrium state, but about a position with some displacement from the equilibrium shape. The frequencies of vibrations were reduced by such a displacement, but not much (which was a result of the non-linear terms in the equation of motion). Moreover, solutions were not guaranteed by the method, thus either more terms of approximation functions or an alternate solution routine was needed. A comparison between the numerical solution and the result of the asymptotic analysis (the method of multiple scales) was given in Plaut and Leeuwrik (1988). It was confirmed that the vibration frequencies tended to decrease as the amplitude of motion increased.

Hsieh (1988) considered the free vibrations of both air-inflated dams and water-inflated dams, and the forced vibrations of water-inflated dams impounding upstream water, with the weight of the dams neglected. A finite difference method was used for the membrane equation of motion and the water domain was analyzed by a boundary element method. For the water-inflated dam without water outside, the vibration frequencies increased as the internal water head increased, the perimeter/base width ratio decreased, or the water/dam density ratio decreased (see also Hsieh et al., 1989). With impounding water outside, the water/dam density ratio displayed similar effects in the vibration frequencies. In Hsieh and Plaut (1990), it was further clarified that the frequencies increased when the internal and external water heads increased simultaneously. If the external head increased with the internal head fixed, the frequencies decreased at the beginning, then some of them started to increase.

Dakshina Moorthy *et al*. (1995) investigated three-dimensional vibrations of a double-anchored inflatable dam impounding water. The dam was modeled as a shell with internal air pressure, and the finite element method was applied to both the structure and the external water. Several water depths were considered. The equilibrium shape of the dam was computed first, and then small vibrations about this shape were analyzed. The effect of the water depth on the vibration frequencies and modes was studied.

Steady-state overflow of a double-anchored inflatable dam was treated by Wu and Plaut (1996). The dam was assumed to be an inextensible air-inflated membrane. The fluid flow was assumed to incompressible, inviscid, and irrotational, with specified total upstream head. First the steady-state shapes of the dam and the free surface of the water were computed. Then linear vibrations of the structure about its steady-state configuration were analyzed. Similar to Hsieh and Plaut (1990), the dam was discretized using the finite difference method, whereas the boundary element method was applied to the fluid. Frequencies and modes were obtained, and the effects of the dam density and structural damping were investigated.

As discussed above, most of the early research on inflatable dams concentrated on finding the equilibrium shapes of inflatable dams. The more recent research has been on the vibration behavior of such dams in the presence of external water. The dams were considered to be double-anchored and were modeled as membranes. The present work concentrates on the vibration behavior of single-anchor dams, which are more in use currently, in the presence of hydrostatic and parallel flowing water. The dam is modeled as a shell here and the effect of internal pressure, external water head, and the parallel flow velocity on the dam vibrations are investigated.