Chapter 4
Design Earthquakes

4-1. Definition

The term "design earthquake" refers to the specification of the free field ground motion that would be felt at the dam site due to a particular seismic event that is used as the basis for earthquake resistant design of new RCC dams, or to evaluate the response of existing RCC dams.

4-2. Operating Basis Earthquake (OBE)

The OBE is defined as the earthquake producing the greatest level of ground motion that is likely to occur at the site during the service life of the dam. The service life shall be taken as 100 years for both new dams and existing dams. The seismic risk or adverse consequences of failure of an existing dam is not reduced as long as the dam is in operation; therefore, the "remaining service life" of an existing dam shall not be substituted for the 100-year service life specified above. The OBE is determined using probabilistic methods and, as such, is defined as the earthquake with a 50 percent chance of exceedance in the service life of the dam.

a. General performance requirements. All structural, mechanical, and control equipment used to regulate the reservoir shall be capable of remaining fully operational during and after an OBE. New RCC dams located in low seismic regions shall be designed to prevent the initiation of cracking in the concrete structure. Tensile cracking in new RCC dams located in high seismic regions and in existing dams in all seismic regions is allowed; however, it shall be limited to only "minor cracking" that requires little or no repair.

b. Structural criteria. The following general structural criteria shall be the basis for satisfying the concrete cracking performance requirements stated above.

(1) Initiation of cracking is prevented when the tensile stresses are less than 0.60 f'_t as shown in Figure 3-7.

(2) The level of cracking is considered to be "minor cracking" when the tensile stresses are less than 1.25 f'_t as shown in Figure 3-7.

c. Allowable tensile stress. The allowable tensile stresses $f_{t\,(allowable)}$ for the OBE are established below. The formulae apply to the calculation of both allowable tensile stress of the parent material and allowable tensile stress of the lift joints. DTS = Dynamic Tensile Strength, and f'_t = direct tensile strength.

(1) Existing dams:

$$f_{t\,(allowable)} = 1.25 \times DTS = 1.875 \times f'_t$$

(2) New dams in seismic zones 0, 1, 2A, and 2B:

$$f_{t\,(allowable)} = 0.60 \times DTS = 0.90 \times f'_t$$

(3) New dams in seismic zones 3 and 4:

$$f_{t\,(allowable)} = 0.90 \times DTS = 1.35 \times f'_t$$

d. Damping. Studies on dams under severe ground motion which cause stresses in the upper reaches of the elastic range indicate a dampened response which corresponds to a damping factor of about 5 percent of critical. On this basis the OBE shall be analyzed using a damping ratio equal to 5.0 percent of critical damping for the concrete dam structure only. This factor must be modified as outlined in paragraph 7-3 to account for foundation damping.

4-3. Maximum Credible Earthquake (MCE)

The MCE is defined as the largest possible earthquake that could reasonably occur along the recognized faults or within a particular seismic source. Often several fault sources must be investigated to determine which will produce the critical site ground motion. By definition the MCE has a very low probability of occurence. Ground motion associated with the MCE is established using the deterministic approach.

a. General performance requirements. Both new RCC dams and existing dams shall be capable of surviving the MCE without a failure of a type that would result in the loss of life or significant damage to downstream property caused by an uncontrolled release of the reservoir pool. Nonlinear behavior with associated damage is permissible, but the post earthquake damaged condition of the dam shall allow for controlled lowering of the pool to facilitate repair.

b. Structural criteria. The upper limit of linear elastic analysis is considered to be that point on the straight stress/strain line corresponding to a linear stress level of 1.33 f'_t (see Figure 4-7). When tensile strains exceed the strain associated with this linear stress limit, macrocracking occurs and the RCC will be subject to some degree of structural damage. As the strain level increases well into the tensile softening zone, response becomes markedly nonlinear and it is clear that a linear-elastic analysis no longer approximates the response. Although crack damage increases in this zone, performance requirements may still be satisfied. Thus, the structural criteria for the MCE, when using linear-elastic analysis, are set by limitations of the method of analysis rather than on criteria that relate to an acceptable level of structural concrete damage.

c. Allowable tensile stresses. The allowable tensile stress $f_{t\ (allowable)}$ for the MCE is established below. DTS = Dynamic Tensile Strength, and f'_t = the direct tensile strength.

$$f_{t\ (allowable)} = 1.33 \times DTS = 2.000 \times f'_t$$

d. Damping. The linear-elastic analysis for the MCE shall utilize a damping ratio equal to 7.0 percent of critical damping for the concrete dam structure only. The increase in the damping ratio from 5 percent for the OBE to 7 percent for the MCE helps account for some additional nonlinear behavior while using a linear-elastic approach.