CHAPTER 2

GENERAL DESIGN CONSIDERATIONS

2-1. Dam Site. Unlike a concrete gravity dam which carries the entire load by its self weight, an arch dam obtains its stability by both the self weight and, to a great extent, by transmitting the imposed loads by arch action into the valley walls. The geometry of the dam site is, therefore, the most basic consideration in the selection of an arch dam. As a general rule, an arch dam requires a site with abutments of sufficient strength to support the arch thrust. On special occasions artificial abutments - thrust blocks - may be used in the absence of suitable abutment(s); see Chapter 3 for additional discussion on thrust blocks.

2-2. Length-Height Ratio. Traditionally, most of the arch dams in the United States have been constructed in canyon sites with length-height ratios of less than 4 to 1. Although the greatest economic advantage may be realized for a length-height ratio of less than 4 to 1, sites with greater ratios should also be given serious consideration. With the present state of the art in arch dam design automation, it is now possible to obtain "optimum design" for sites which would have been considered difficult in the past. An arch dam must be given first consideration for a site with length-height ratio of 3 or less. For sites having length-height ratios between 3 and 6, an arch dam may still provide the most feasible structure depending on the extent of foundation excavation required to reach suitable material. The effect of factors other than length-height ratio becomes much more predominant in the selection process for dam sites with length-height ratios greater than 6. For these sites a careful study must be performed with consideration given to the diversion requirements, availability of construction material, and spillway and outlet works requirements. The results of these studies may prove the arch dam as a viable choice for wider sites.

2-3. Smooth Abutments. The arch dam profile should be made as smooth as practicable. The overall appearance on each abutment should resemble a smooth geometric curve composed of one or two parabolas or hyperbolas. One point of contraflexure in the profile of each abutment will provide for a smooth force distribution along the rock contact. Each original ground surface may have a very irregular profile before excavation, but the prominent points should be removed together with removing weathering to sound rock. Each abutment surface irregularity of peaks and valleys represents points of force concentration at the peaks and correspondingly less force in the valleys. As can be readily surmised, design difficulties lead to structural inefficiencies, more concrete, and increased costs. Thus, it is generally prudent engineering from the beginning to overexcavate the rock and provide for a smooth profile. At the microscale, the abutment should be made smooth, that is, rock knobs remaining after the macroexcavation should, after consensus with the geologist, be removed. Generally, the excavation lines shown in the specifications have tolerances such as ± 1 foot in 20 feet.

2-4. Angle Between Arch and Abutment. Given a geometrically suitable site, another important consideration of an arch dam is the rock contour lines, or the angle which the arches make with the abutment rock contour lines. The angle α in Figure 2-1 should, as a general rule, be greater than 30 degrees to avoid high concentration of shear stresses near the rock surface. Inasmuch as this angle is determined only after the results of the stress analysis are available, the angle β may be used as a guideline during the preparation of the layout. The arches should be arranged so that β is larger than 40 degrees in the upper half. Care must be taken in using these guidelines since the arch thrust, H, is only the tangential component of the total force, and the other two components, vertical and radial, and their respective orientations, must also be examined in the more advanced stages of design. Additionally, the elevation of the arch being investigated should be considered, e.g., an arch located at or near the top of the dam may not be carrying appreciable tangential thrust if the continuity of the arch is broken by an overflow spillway. Observing this criterion - the minimum angle - ensures that there is sufficient rock mass downstream to withstand the applied loads. In addition to this requirement, the directions of joint systems in the rock should be given careful consideration in making the layout to ensure stable abutments under all loading conditions.

2-5. Arch Abutments. Full-radial arch abutments (normal to the axis) are advantageous for good bearing against the rock. However, where excessive excavation at the extrados would result from the use of full-radial abutments and the rock has the required strength and stability, the abutments may be reduced to half-radial as shown in Figure 2-2a. Where excessive excavation at the intrados would result from the use of full-radial abutments, greater-than-radial abutments may be used as shown in Figure 2-2b. In such cases, shearing resistance should be carefully investigated. Where full-radial arch abutments cannot be used because excessive excavation would result from the use of

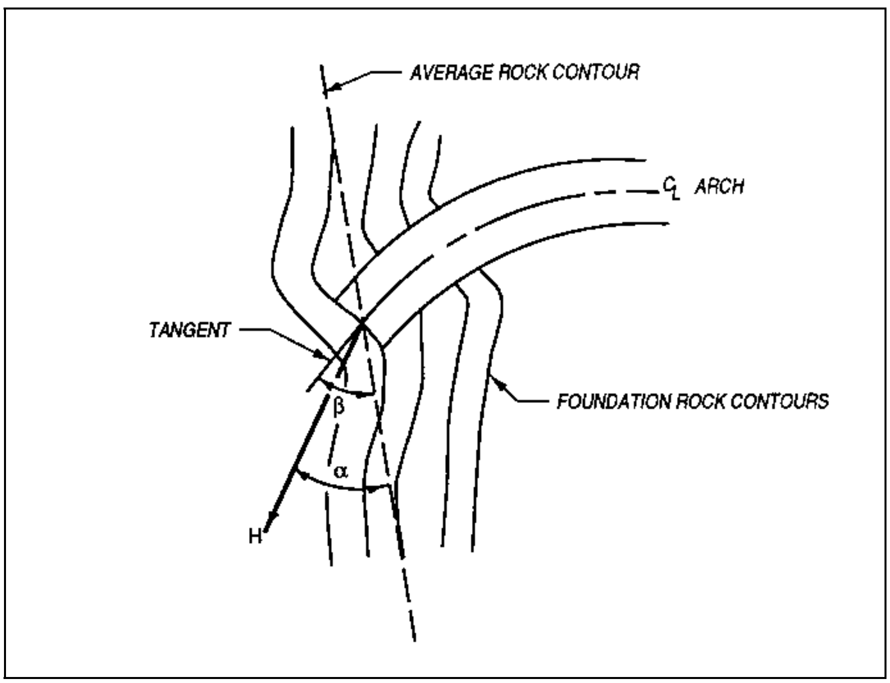

Figure 2-1. Angle between arch thrust and rock contours

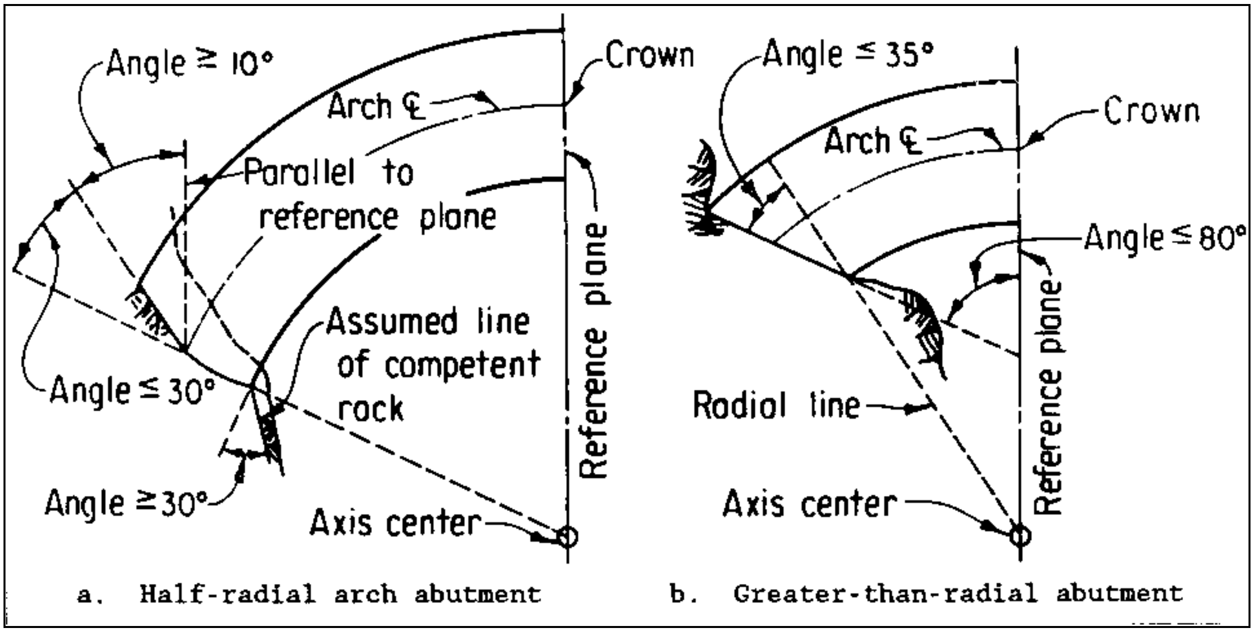

Figure 2-2. Arch abutment types

either of the two shapes mentioned, special studies may be made for determining the possible use of other shapes having a minimum excavation. These special studies would determine to what extent the arch abutment could vary from the full-radial and still fulfill all requirements for stability and stress distribution.

2-6. Foundation. An arch dam requires a competent rock foundation of sufficient strength to withstand the imposed loads from the dam and the reservoir. Inasmuch as the loads are transmitted to the foundation along the entire dam-foundation contact area, the abutment must meet the same minimum foundation requirements as that for the deepest part of the dam, commensurate with the magnitude of resultant forces at a given arch elevation. Because of its small dam-foundation contact area, as compared to other types of dams, an arch dam exerts a larger bearing pressure on the foundation. For the purpose of site selection, a foundation with a compressive strength sufficient to carry the load from a gravity dam would also be satisfactory for an arch dam, recognizing that very seldom are foundations made up of a single type of rock of uniform strength and that this is only an average "effective" value for the entire foundation. Arch dams are capable of spanning weak zones of foundation, and the presence of faults and shears does not appreciably affect the stresses in the dam provided that the thickness of a weak zone is no more than about one times the base thickness of the dam. A description of the treatment of these faults and shear zones is discussed in paragraph 3-5.

2-7. Foundation Deformation Modulus. Deformation behavior of the foundation has a direct effect on the stresses within the dam. Lower values of foundation deformation modulus, i.e., a more yielding foundation, reduce the tension at the base of the dam along the foundation and, conversely, a foundation with high- deformation modulus values results in higher tensile stresses along the base. It is, therefore, important to determine the deformation modulus of the foundation at the earliest stage of design. This information becomes more critical when there are indications that the deformation modulus for one abutment may be drastically different than for the other abutment. Having this knowledge at early stages of design, the structural designer can shape the dam properly so that excessive stresses are avoided. A foundation should not be considered inadequate solely because of low values of deformation moduli. Foundation grouting may improve the deformation behavior of the rock mass and should be considered in determining the deformation moduli used in the design of the dam. When deformation values smaller than 500,000 pounds per square inch (psi) are present, the question of how much a grouting program can improve the foundation becomes critical, and a thorough stress analysis should be performed using a reasonable range of deformation moduli. The design is acceptable if the dam stresses are within allowable stresses under all assumed conditions.

2-8. Effect of Overflow Spillway. If an overflow type of spillway is used and is located near the center of the dam, no arch action is considered above the crest elevation of the spillway. If a spillway is located near one side of the dam, there may be some arch action above the crest elevation of the spillway. In either case, the upper portion of the dam above the spillway crest must be designed to withstand the effects of the loading imposed above the crest by water pressure, concrete mass, temperature, and earthquake.