Design and Construction of Earth Dams

An Online Continuing Education Course for Engineers

Course Number: G-6005

Credit: 6 Hours / 6 PDH / 6 CPD

Design and Construction of Earth Dams

Chapter 1
Introduction

This course presents fundamental principles underlying the design and construction of earth and rock-fill dams. The general principles presented herein are also applicable to the design and construction of earth levees. The construction of earth dams by hydraulic means was curtailed in the 1940's due to economic considerations and liquefaction concerns during earthquake loading and are not discussed in this course.

The objective of this course is to present guidance on the design, construction, and performance monitoring of and modifications to embankment dams. The course presents general guidance and is not intended to supplant the creative thinking and judgment of the designer for a particular project. The increased development and expansion of the population in the Nation's watersheds have created a definite need to develop additional water supply. In many areas the existing national infrastructure cannot meet these needs. The increase in urban development has also had a negative impact on water quality. The public is asking that preservation of the environment be an equal goal with the economic benefits of water resources projects.

Since the current infrastructure is not meeting public needs, this situation is placing lives, livelihood, and property at risk. Several options are available to provide the additional quantity of water. The simplest and most cost-effective method to obtain the quantities needed is to add additional storage at existing dams. Many of the Nation's existing water resources projects must be modified to add the additional purpose of water supply.

Chapter 2
General Considerations

2-1. General

a. Introduction. The successful design, construction, and operation of a reservoir project over the full range of loading require a comprehensive site characterization, a detailed design of each feature, construction supervision, measurement and monitoring of the performance, and the continuous evaluation of the project features during operation. The design and construction of earth and rock-fill dams are complex because of the nature of the varying foundation conditions and range of properties of the materials available for use in the embankment. The first step is to conduct detailed geological and subsurface explorations, which characterize the foundation, abutments, and potential borrow areas. The next step is to conduct a study of the type and physical properties of materials to be placed in the embankment. This study should include a determination of quantities and the sequence in which they will become available. The design should include all of the studies, testing, analyses, and evaluations to ensure that the embankment meets all technical criteria and the requirements of a dam as outlined in b below.

Construction supervision, management, and monitoring of the embankment and appurtenant structures are a critical part of the overall project management plan. Once the project is placed into operation, observations, surveillance, inspections, and continuing evaluation are required to assure the satisfactory performance of the dam.

b. Basic requirements of an embankment dam. Dams are a critical and essential part of the Nation's infrastructure for the storage and management of water in watersheds. To meet the dam safety requirements, the design, construction, operation, and modification of an embankment dam must comply with the following technical and administrative requirements:

(1) Technical requirements.

- The dam, foundation, and abutments must be stable under all static and dynamic loading conditions.

- Seepage through the foundation, abutments, and embankment must be controlled and collected to ensure safe operation. The intent is to prevent excessive uplift pressures, piping of materials, sloughing removal of material by solution, or erosion of this material into cracks, joints, and cavities. In addition, the project purpose may impose a limitation on allowable quantity of seepage. The design should include seepage control measures such as foundation cutoffs, adequate and nonbrittle impervious zones, transition zones, drainage material and blankets, upstream impervious blankets, adequate core contact area, and relief wells.

- The freeboard must be sufficient to prevent overtopping by waves and include an allowance for settlement of the foundation and embankment.

- The spillway and outlet capacity must be sufficient to prevent over-topping of the embankment by the reservoir.

(2) Administrative requirements.

- Environmental responsibility.

- Operation and maintenance manual.

- Monitoring and surveillance plan.

- Adequate instrumentation to monitor performance.

- Documentation of all the design, construction, and operational records.

- Emergency Action Plan: Identification, notification, and response subplan.

- Schedule for periodic inspections, comprehensive review, evaluation, and modifications as appropriate.

c. Embankment. Many different trial sections for the zoning of an embankment should be prepared to study utilization of fill materials; the influence of variations in types, quantities, or sequences of availability of various fill materials; and the relative merits of various sections and the influence of foundation condition. Although procedures for stability analyses a convenient means for comparing various trial sections and the influence of foundation conditions, final selection of the type of embankment and final design of the embankment are based, to a large extent, upon experience and judgment.

d. Features of design. Major features of design are required foundation treatment, abutment stability, seepage conditions, stability of slopes adjacent to control structure approach channels and stilling basins, stability of reservoir slopes, and ability of the reservoir to retain the water stored. These features should be studied with reference to field conditions and to various alternatives before initiating detailed stability or seepage analyses.

e. Other considerations. Other design considerations include the influence of climate, which governs the length of the construction season and affects decisions on the type of fill material to be used, the relationship of the width of the valley and its influence on river diversion and type of dam, the planned utilization of the project (for example, whether the embankment will have a permanent pool or be used for short-term storage), the influence of valley configuration and topographic features on wave action and required slope protection, the seismic activity of the area, and the effect of construction on the environment.

2-2. Types of Embankment Dams

a. Introduction. The two principal types of embankment dams are earth and rock-fill dams, depending on the predominant fill material used. Some generalized sections of earth dams showing typical zoning for different types and quantities of fill materials and various methods for controlling seepage are presented in Figure 2-1. When practically only one impervious material is available and the height of the dam is relatively low, a homogeneous dam with internal drain may be used as shown in Figure 2-1a. The inclined drain serves to prevent the downstream slope from becoming saturated and susceptible to piping and/or slope failure and to intercept and prevent piping through any horizontal cracks traversing the width of the embankment.

Earth dams with impervious cores, as shown in Figures 2-1b and 2-1c, are constructed when local borrow materials do not provide adequate quantities of impervious material. A vertical core located near the center of the dam is preferred over an inclined upstream core because the former provides higher contact pressure between the core and foundation to prevent leakage, greater stability under earthquake loading, and better access for remedial seepage control. An inclined upstream core allows the downstream portion of the embankment to be placed first and the core later and reduces the possibility of hydraulic fracturing. However, for high dams in steep-walled canyons the overriding consideration is the abutment topography. The objective is to fit the core to the topography in such a way to avoid divergence, abrupt topographic discontinuities, and serious geologic defects. For dams on pervious foundations, as shown in Figure 2-1d to 2-1f, seepage control is necessary to prevent excessive uplift pressures and piping through the foundation.

The methods for control of underseepage in dam foundations are horizontal drains, cutoffs (compacted backfill trenches, slurry walls, and concrete walls), upstream impervious blankets, downstream seepage berms, toe drains, and relief wells. Rock-fill dams may be economical due to large quantities of rock available from required excavation and/or nearby borrow sources, wet climate and/or short construction season prevail, ability to place rock fill in freezing climates, and ability to conduct foundation grouting with simultaneous placement of rock fill for sloping core and decked dams (Walker 1984). Two generalized sections of rock-fill dams are shown in Figure 2-2. A rock-fill dam with steep slopes requires better foundation conditions than an earth dam, and a concrete dam (or roller-compacted concrete dam) requires better foundation conditions than a rock-fill dam.

b. Earth dams. An earth dam is composed of suitable soils obtained from borrow areas or required excavation and compacted in layers by mechanical means. Following preparation of a foundation, earth from borrow areas and from required excavations is transported to the site, dumped, and spread in layers of required depth. The soil layers are then compacted by tamping rollers, sheepsfoot rollers, heavy pneumatictired rollers, vibratory rollers, tractors, or earth-hauling equipment. One advantage of an earth dam is that it can be adapted to a weak foundation, provided proper consideration is given to thorough foundation exploration, testing, and design.

c. Rock-fill dams. A rock-fill dam is one composed largely of fragmented rock with an impervious core. The core is separated from the rock shells by a series of transition zones built of properly graded material. A membrane of concrete, asphalt, or steel plate on the upstream face should be considered in lieu of an impervious earth core only when sufficient impervious material is not available. However, such membranes are susceptible to breaching as a result of settlement. The rock-fill zones are compacted in layers 12 to 24 in. thick by heavy rubber-tired or steel-wheel vibratory rollers. It is often desirable to determine the best methods of construction and compaction on the basis of test quarry and test fill results. Dumping rock fill and sluicing with water, or dumping in water, is generally acceptable only in constructing cofferdams that are not to be incorporated in the dam embankment. Free-draining, well-compacted rock fill can be placed with steep slopes if the dam is on a rock foundation. If it is necessary to place rock-fill on an earth or weathered rock foundation, the slopes must, of course, be much flatter, and transition zones are required between the foundation and the rock fill. Materials for rock-fill dams range from sound free-draining rock to the more friable materials such as sandstones and silt-shales that break down under handling and compacting to form an impervious to semipervious mass. The latter materials, because they are not completely free-draining and lack the shear strength of sound rock fill, are often termed "random rock" and can be used successfully for dam construction, but, because of stability and seepage considerations, the embankment design using such materials is similar to that for earth dams.

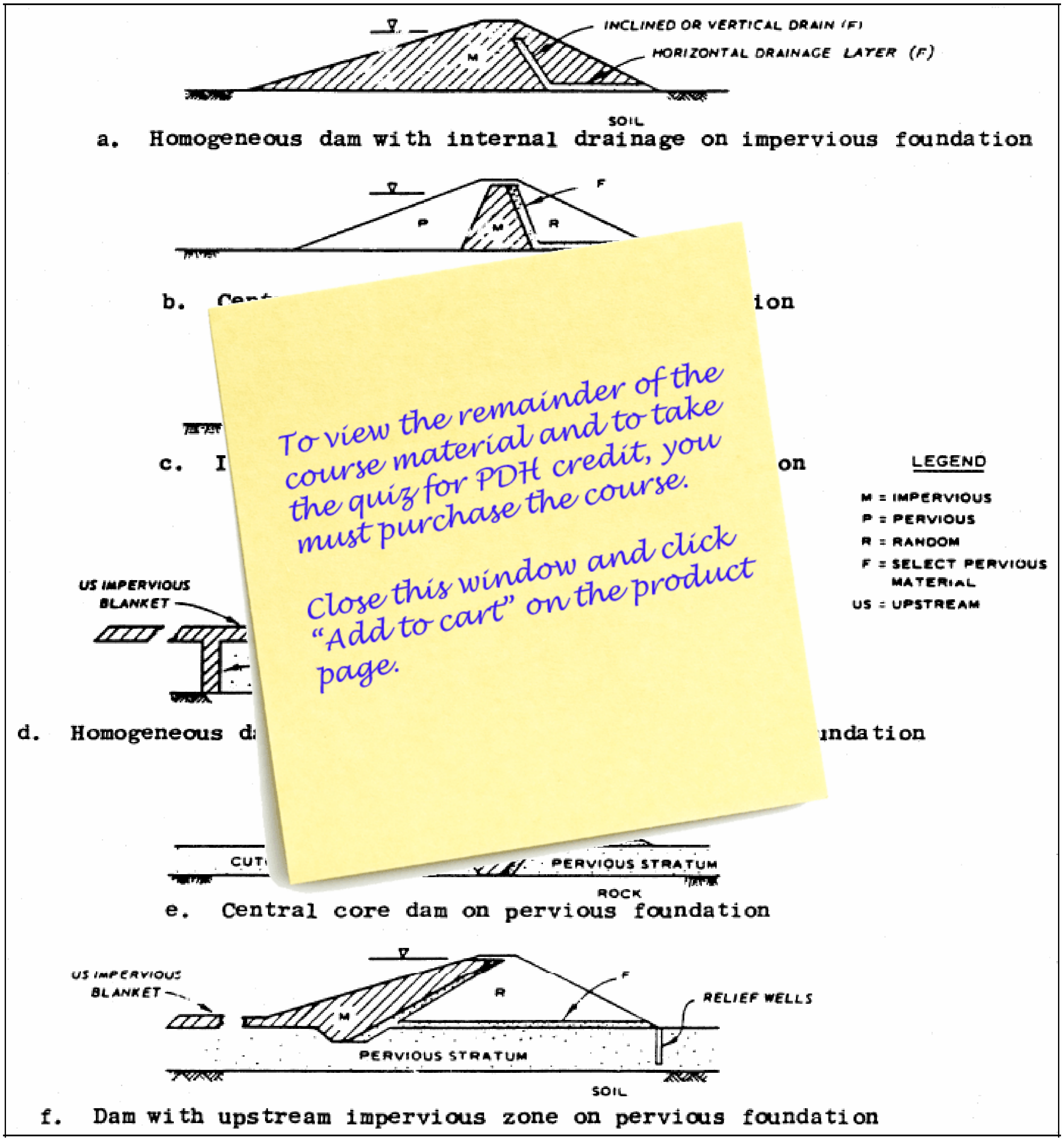

Figure 2-1. Types of earth dam sections