SECTION 5
COST ESTIMATING GUIDELINES

General

Cost estimating is a specialized field and can best be performed by persons who routinely make cost estimates for the service required or the type of construction that is to be performed. However, in order to initiate a small hydroelectric project, administration must have a viable means of acquiring reasonable cost data for the integrity investigation of the existing facilities; and if the facilities are amenable to the addition of small hydroelectric plants, the cost of remedial work and maintenance must be determined as input for the economic feasiblity determination.

This section presents guides for methods of estimating costs, sources of cost estimating information, and some ranges of cost at 1978 prices for some of the major common items. Because of unique site conditions, climatic conditions, location, quantities, and other factors, unit costs may vary widely (sometimes by several hundred percent) from site to site.

Costs associated with the integrity investigations and rehabilitation of existing facilities consist of engineering costs, construction costs, and administration costs. These functional costs are composed of labor, material, and equipment with all of their associated variation. Costs can readily be determined if the quantities and unit prices of all of the cost factors are known for the time that the work is to be performed. However, determining the quantities and unit prices for all the items involved with a sufficient degree of accuracy for the intended purpose can be a major challenge. There are at least two different types of cost estimates. They are approximate estimates and detailed estimates. For a feasibility investigation, an approximate estimate is normally adequate. A detailed estimate would not normally be required and is not feasible until the design plans and specifications have been prepared.

The unit costs associated with rehabilitating an existing structure will vary more widely depending on quantities and location and will generally be more expensive than costs for similar items for new structures. Basic reasons for these widely varying costs are that working room and access are limited, demolition or preparation of the portion of the structure to be rehabilitated will be required, mating new equipment to old equipment is difficult or parts may not be available as a shelf item, quantities are normally small resulting in high mobilization and unit costs, and the work is normally labor intensive. As an example, concrete in place could cost less than $50 per cubic yard in a massive structure where a plant and raw materials are readily available, whereas the repair of a structure requiring a few cubic yards of concrete may cost several hundred dollars per cubic yard if it is located in a remote area where access is poor and if several man-days of labor are required to chip out old concrete, construct forms, mix and place the concrete, strip the forms, and cure the concrete.

Estimating Integrity Investigation Costs

Stage 1. The work associated with the Stage 1 integrity investigation of existing facilities is similar to work performed under the Corps of Engineers Phase 1 dam safety inspections program. The Phase 1 inspections are generally being performed by private consulting engineering firms and are reported to cost generally in the range of $7,000 to $9,000 per dam inspected during 1978. The $7,000 to $9,000 1978 costs properly escalated would give a reasonable cost estimate for Stage 1 investigation by consulting engineers for "average" facilities. Unusual or complex facilities could cost considerably more. Of course the most reliable method of acquiring a cost estimate would be to get a quotation from an engineering firm that is qualified to perform the work, or to estimate the time and materials costs if the investigation is to be performed by in-house staff.

Stage 2. The costs for Stage 2 investigations are highly variable and dependent on the extent of the investigations, laboratory testing, and analyses and evaluations that are required. The cost for this stage of the investigations should be estimated as part of the Stage 1 investigation work, or an estimate of the costs could be obtained from the engineer that would be performing the Stage 2 work. The following 1978 unit costs are pre-

Description	Cost
Engineering	$25 - $75/hour
Drilling, Soil	$ 7 - $12/L.F.
Rock	$20 - $40/L.F.
Classification Testing of Soils	
Atterberg Limits	$48 ea.
Specific Gravity	$33 ea.
Sieve Analysis	$40 ea.
Hydrometer	$38 ea.
Unconfined Compressive Strength	$22 ea.
Compaction Properties	$95 ea.
Direct Shear	$55/point
Triaxial Shear (with pore pressure measurement)	$90/point

sented as a guide for estimating major Stage 2 cost items after an estimate of time and quantities have been made. Approximately 10 to 20 percent should be added to the labor cost for miscellaneous items such as printing, telephone, transportation, etc.

Stage 3. The engineering costs for this stage will be highly variable, depending on the extent of the work to be performed as defined in Stages 1 and 2. The costs for performing the Stage 3 engineering work can best be estimated by persons that performed the Stage 1 and Stage 2 work or the persons that are to perform the Stage 3 work. Advanced estimates of Stage 3 costs can be made only if the man-hours required for engineering and supporting help can be reasonably estimated. The cost of this type of engineering is much higher than for new works for reasons similar to those that make rehabilitation construction cost more than new construction.

Construction Rehabilitation Costs

Information Required for a Feasibility Cost Estimate. The Stage 3 investigation must be completed before a reasonable feasibility cost estimate can be prepared. As part of Stage 3, the rehabilitation work that is to be performed must be well defined as to scope and extent. Drawings to scale showing the dimensions of materials that are to be removed, replaced, or added are necessary to determine the volumes of all significant materials and number of major items.

The major cost items associated with the rehabilitation of existing structures will generally fall within the classifications of earthwork, concrete, structural steel, timber, and electrical and mechanical items.

Unit prices for earthwork within a job can vary widely, depending on the type of earthwork involved which will affect the amount of labor, equipment, and materials and supplies required for a unit volume of earthwork. Earthwork is generally broken down into excavation and fill.

Excavation is normally broken down further according to material type, e.g., soil or rock (soil being defined as a fine-grained material which can be readily excavated with scrapers, and rock being defined as a material which requires heavy ripping or blasting prior to excavation). In addition to the two types of materials discussed above, there are coarse-grained materials (sands and gravels) which would cost about the same as soil per unit volume of excavation, fine-grained and coarse-grained materials containing cobbles and boulders which increase the cost of excavation, and soft rock which is easily rippable and has an intermediate unit cost of excavation. Excavation quantities must be computed for each material type which would have a different unit cost. In addition to material type, unit costs for excavation will increase greatly if the material is to be excavated from below the water table; quantities to be excavated below and above the water table should be separated. Of course, access to the excavation area and working room can have a significant effect on unit cost and must be considered when separating quantities to be used in preparing a cost estimate.

Unit costs for fill materials are primarily dependent on material type, availability, in-situ conditions, haul distance, access, working room, and placement and compaction requirements. Where a variety of material types are to be placed for remedial work, the above factors must be considered and separate volume computations made for material types that may have significantly different unit costs.

Slopes of excavations and fills for rehabilitation of existing dams are typically irregular and the volume cannot usually be computed by volume formulas for standard shapes. The common method of determining excavation and fill quantities is by the average end area method by the formula $V = \ell/2\ (A_1 + A_2)$ where V is the volume (cubic feet) of the prismoid of length ℓ (feet) between cross-sections having areas (square feet) A_1 and A_2. End areas can be determined by drawing vertical cross-sections to scale and planimetering the areas; or quite often it is quicker to planimeter the areas of horizontal planes from the plan view on a contour map. A great deal of ingenuity is required to obtain some quantities quickly and accurately. As an example, thin layers of slope protection can be computed by planimetering the plan area and converting the planimetered area to the true surface area by multiplying the area times the square root of the sum of the squares of the horizontal and vertical distances along the slope divided by the horizontal distance, and then multiplying this area times the thickness to develop its volume.

Primary work items for concrete work are preparation of the area where concrete is to be placed, forming, placing reinforcing steel, placing and finishing the concrete, curing, and removal of forms and clean-up. To make an accurate estimate of concrete cost, the quantities for labor, materials and equipment must be determined. Sometimes, however, if the volume of concrete is determined, a unit price can be assigned by using unit prices determined from a previous job where similar concrete work was performed.

Structural steel is normally priced on the basis of weight. The American Institute of Steel Construction *Steel Construction Manual* (AISC, 1973) provides weights per linear foot for all standard shapes and sizes of structural steel members.

The cost of timber items can best be determined by computing the boardfeet of the various types of timber members required to replace rotted or damaged material or for a required addition.

Each major mechanical/electrical item, along with the necessary controls and leads to be replaced or added, must be identified and sufficiently specified so that proper replacements can be secured. The manufacturer's name and model or identification numbers are most helpful for replacement items, while specifications for new items such as valves, the type, size, head, type of controls, etc., must be identified.

Sources of Cost Information. After the volumes of materials or number of items have been identified for rehabilitation, unit or item costs must be applied. There are many sources of information for costs, several of which are discussed below.

The most reliable method of obtaining a good cost estimate is to have a professional estimator or local contractor that regularly performs the type of work being considered prepare the estimate. When small and difficult jobs are bid competitively by contractors, it is not unusual for the high bidder to be double the total price of the low bidder, with wide variations from the engineer's estimate. Therefore, even having a professional estimator or contractor estimate the cost does not assure that his estimate is what the cost will be if and when the project goes to construction. Reserves and contingencies must be used to protect the project in the event that the cost estimates prove to be inadequate due to circumstances beyond the control of the estimator.

Another method of obtaining reasonably reliable costs is to utilize adjusted unit costs from a similar project. Costs should be adjusted for inflation, difference in locale, site conditions, quantities, etc. Considerable judgment is required to determine if the work is similar and what adjustments should be made in unit prices for any differences.

Engineering News Record, published weekly by McGraw-Hill, gives quarterly statements of construction trends, cost indexes for common items for a number of years, equipment rental rates, and material rates. Periodically *Engineering News Record* prints unit prices bid for government projects. These prices can be indicative of costs. However, the projects are generally large and conditions at the sites are not defined; thus the unit prices are of questionable value for application to rehabilitation of existing small dams.

Unit costs for many construction items, equipment rental costs, equipment production rates, and labor rates are available in some annual publications. Two of these, *Dodge Guide to Public Works and Heavy Construction Costs,* (McGraw-Hill, annual) and Heavy Construction cost File (Engelsman, 1977), provide good unit cost data for use in estimating the civil works costs. The total unit cost, as well as the labor, material, and equipment unit costs, is presented. *Estimating Construction Costs* (Peurifoy, 1975) is an excellent general reference for methods of preparing detailed cost estimates.

Equipment rental firms will supply costs as well as information on equipment specifications and production. Local material suppliers will readily furnish costs for items which they have for sale, and costs of materials for concrete, steel, timber and such items are readily available. The cost for mechnical/electrical items such as gates, valves, hoists, etc. can best be determined by the supplier of the specific items. The local office of the U.S. Department of Labor will supply labor rates.

Cost Summary

The cost estimates for investigating and rehabilitating existing facilities for the addition of small hydroelectric facilities are intended for use in planning and in economic and financial feasibility analyses. (Volume II of this manual, *Economic and Financial Analysis,* discusses in detail the use of the cost data developed.) The costs developed, as discussed above in this section, must be summarized and documented in a form that is usable by the economic and financial evaluators. (See Figure 5-1 under "Examples," below).

The project and type of cost estimate should be identified in the title. The major work items should be identified by number, described briefly, and the units of measurement, quantity, unit prices and the total amount of the cost for each major work item should be given in tabular form. The cost of major work items should be totaled and an appropriate contingency factor applied to account for minor items not included in the cost estimate and for additional work which may be required by conditions revealed during final design investigations and analyses or during construction. The contingency factor that should be applied depends on the level of the study at the time the cost was prepared (i.e., conceptual, feasibility, final design, construction), whether site conditions are well defined or not, the extent to which minor items are included in the estimate, and the reliability of quantities and unit prices. The contingency factor should never be less than 10 to 15 percent for this type of work and could be as high as 30 to 40 percent or more if site conditions are not well defined and the work is in a preliminary stage.

The cost should be based on the prevailing costs at the time that the estimate is made and the date of the estimate should be identifed. Volume II discusses in detail methods of applying escalation factors. It should be left to the people performing the economic and financial feasibility analyses to escalate costs for all phases of the project.

Cost Examples

Unit Costs for construction Items. Typical 1978 unit costs for the more common rehabilitation construction items are presented in Table 5-1. These unit costs must be adjusted for escalation and specific site conditions. Manufactured items are not included in Table 1 because they can be readily checked by a telephone call to a supplier.

TABLE 5-1
TYPICAL UNIT COSTS

Item	Units	Unit Cost
Common excavation (dry)	C.Y.	$ 1.50
Common excavation (wet)	C.Y.	3.00
Rock excavation	C.Y.	3.50
Earth fill	C.Y.	2.00[a]
Rock fill	C.Y.	4.50[a]
Filter-drain material	C.Y.	15.00
Concrete (reinforced)	C.Y.	200.00

[a] Includes excavation, haul, placement, and compaction.

BLUE RIVER HYDROELECTRIC PROJECT
FEASIBILITY COST ESTIMATE
FOR
INVESTIGATION AND REHABILITATION OF
EXISTING FACILITIES

Item No.	Description	Units	Quantity	Unit Price	Amount
1	Foundation Excavation, Soil	C.Y.	5,000	$ 2.50	$ 12,500
2	Foundation Excavation, Rock	C.Y.	2,000	10.00	20,000
3	Zone 1 Fill	C.Y.	4,000	3.50	14,000
4	Zone 2 Fill	C.Y.	50,000	2.75	137,500
5	Slope Protection	Sq.Ft.	5,000	8.00	40,000
6	Remove and Replace Concrete Spillway Walls	Sq.Ft.	500	250.00	125,000
7	Furnish and Install 18" Butterfly Valve	Ea.	1	3,000.00	3,000
			Subtotal		$352,000
	Contingency fl 25%				88,000
			Subtotal		$440,000
	Investigations				30,000
	Engineering				50,000
	Administration				10,000
			TOTAL		$530,000

Note: This estimate is based on current (1978) unit prices. Unit prices must be escalated for work performed after 1978.

Figure 5-1. Sample feasibility cost estimate summary

Feasibility Cost Estimate. A sample cost estimate summary is presented in Figure 5-1 as a guide for summarizing and documenting the cost estimate data.

Actual Costs for Repair of a Non-standard Dam. An example of a timber crib dam was shown in Figure 2-9. Figure 5-2 is a close-up of a segment of the same dam, showing downstream wood planking in disrepair. The dam is approximately 400 feet long and 24 feet high. Interior timber cribs were rehabilitated and refilled with rock where necessary, and the downstream face was replaced with gunite over wire mesh. The cost of the repair work in 1978 was approximately $300,000, or about $15 per square foot of facing. This example demonstrates the high cost for types of repair work that contractors are not used to performing. Figure 5-3 shows a segment of the dam after rehabilitation.

Utilization of Cost Information in Decision-Making Processes

As discussed above, the cost information will be utilized to evaluate the economic justification and financial feasibility of the project. In addition to the cost of investigating and rehabilitating the existing facilities, many other factors such as cost of installing hydroelectric equipment, power production capacity, marketing, financing, etc. have major effects on the feasibility of adding hydroelectric facilities to existing structures. However, the existing facilities are different from the other aspects to be evaluated in that they are there and something must be done with them.

If they are suitable for their existing use and are not a financial liability to the owner, leaving them in their current state would not adversely affect the owner. However, if the investigations should reveal that the existing facilities are unsafe under existing operating conditions, the facilities would have to be rehabilitated and operated in a different manner which would be safe, or breached and abandoned. Any of the above courses of action would have a financial impact on the owner, and this should be considered in the decision making process.

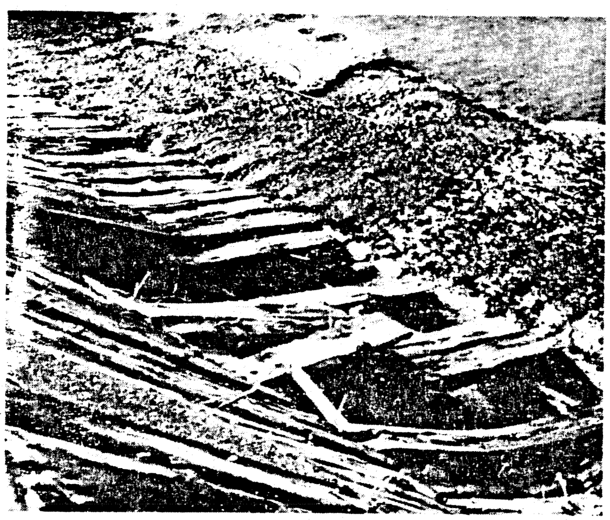

Figure 5-2. Close-up of broken, rotting timbers and rock washed out at toe of dam

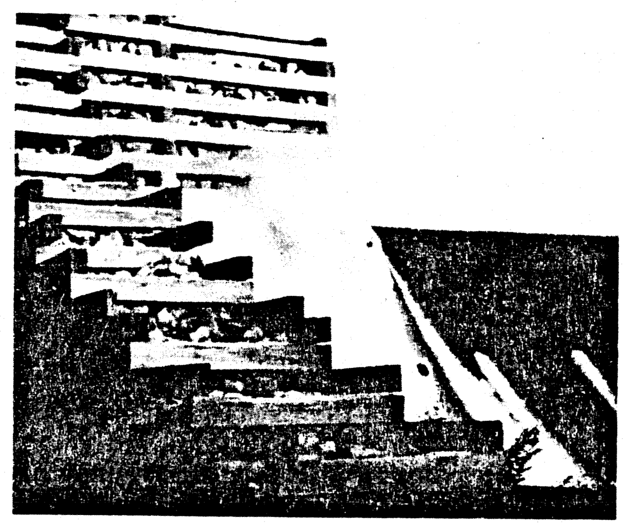

Figure 5-3. One segment of dam after repairs to timbering, replacement of rock fill, and placement of gunite facing

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EXHIBIT I

UNIVERSAL CHECKLIST FOR INSPECTIONS

(Adapted from USBR, 1978, Appendix D)

1. GENERAL

The integrity of dams and appurtenant works is controlled by (1) their designs, (2) the characteristics of their constituent materials, (3) the nature of their foundations, and (4) their regional settings.

The objective of the inspection is to visually examine the structural conditions and hydraulic performance characteristics in relationship to these "performance controllers."

2. CHANGES IN THE CHARACTERISTICS OF MATERIALS

2.1 *General* - Observe for defective, inferior, unsuited, or deteriorated materials. A variety of different materials makes up the different types of dams and appurtenances. The quality and durability of these materials must be determined for each specific structure.

2.2 *Concrete* - (1) alkali-aggregate reaction, pattern crazing and cracking, (2) leaching, (3) frost action, (4) abrasion, (5) spalling, (6) general deterioration, (7) strength loss.

2.3 *Rock* - (1) disintegration, (2) softening, (3) dissolution.

2.4 *Soils* - (1) degradation, (2) dissolution, (3) loss of plasticity, (4) strength loss, (5) mineralogical change.

2.5 *Soil-cement* - (1) loss of cementation, (2) crumbling.

2.6 *Metals* - (1) electrolysis, (2) corrosion, (3) stress-corrosion, (4) fatigue, (5) tearing and rupture, (6) galling.

2.7 *Timber* - (1) rotting, (2) shrinkage, (3), combustion, (4) attack by organisms.

2.8. *Lining fabrics* - (1) punctures, (2) seam partings, (3) light deterioration, (4) disintegration of boundary seals, (5) loss of plasticity and flexibility.

2.9 *Rubber* - (1) hardening, (2) loss of elasticity, (3) light deterioration, (4) chemical degradation.

2.10 *Joint sealers* - (1) loss of plasticity, (2) shrinkage, (3) melting.

3. GENERIC OCCURRENCES

3.1 *General* - Observe generic occurrences for their characteristics, locations, and recency. These occurrences are of a universal nature, regardless of structure type or foundation class. The details of what to look for in observing these generic occurrences, actual or evidential, must be observed at all structures and locations.

3.2 *Seepage and leakage* - (1) Discharge-stage relationship, (2) increasing or decreasing, (3) turbidity and piping, (4) color, (5) dissolved solids (6) location and pattern, (7) temperature, (8) taste, (9) evidence of pressure, (10) boils, (11) recency and duration.

3.3 *Drainage* - (1) obstructions, (2) chemical precipitates and deposits, (3) unimpeded outfall, (4) sump pump facilities, (5) bacterial growth.

3.4 *Cavitation* - (1) suface pitting, (2) sonic evidence, (3) implosions, (4) vapor pockets.

3.5 *Ice action* - (1) evidence of ice forces decreasing stability of structures, lifting gate hoists, obstructing gate leaves and operational and mechanical installations.

3.6 *Stress and strain* - evidence and clues - (1) in concrete cracks, crushing, displacements, offsets, shears, creep; (2) in steel - cracks, extensions, contractions, bending, buckling; (3) in timber - compression, buckling, bending, shears, extensions, compressions; (4) in rock and soils - cracks, displacements, settlement, consolidation, subsidence, compression, zones of extension and compression.

3.7 *Stability* - evidence and clues - (1) in concrete and steel structures - tilting, tipping, sliding, overturning; (2) in embankment structures, cutslopes, natural slopes - bulging, sloughing, slumping, sliding, cracks, escarpments; (3) in rock cutslopes, foundation, and unlined tunnels - slumps, slides, rockfalls, bulges, cracks.

4. OPERATION AND MAINTENANCE

4.1 *Service reliability of outlet, spillway, sump pump mechanical/ electrical features* - (1) broken or disconnected lift chains and cables, (2) test operation including auxiliary power sources, (3) reliability and service connections of primary power sources, (4) ease and assurance of access to control stations, (5) functioning of lubrication system.

4.2 *Gate chambers, galleries, tunnels, and conduits* - (1) ventilation and heat control of damp, corrosive environment of mechanical/electrical equipment.

4.3 *Accessibility and visibility* - (1) obscuring vegetal overgrowth; (2) galleries, access ladders, lighting; (3) access roads and bridges; (4) communication and remote control lines, cables, and telemetering systems.

4.4 *Control of vegetation and burrowing animals* - (1) harmful vegetation on embankments - oversize, dead root channels; (2) harmful vegetation in structural concrete joints; (3) obstructing vegetal growth in hydraulic flow channels; (4) ground squirrels, muskrats, and beavers.

5. BEHAVIOR

5.1 *General* - Resident operational personnel can often supply valuable information and may have been the only observers (during earthquakes, for example).

5.2 *Warning, safety, and performance instrumentation* - (1) piezometers, flow recorders, accelerometers, seismoscopes, joint meters and gage points, strain meters, stress meters, inclinometers, direct and inverted plumblines, surface reference monuments, stage recorders, extensiometers; (2) serviceability; (3) access to readout stations; (4) type and location suitable for condition being observed; (5) need for recalibration; (6) faulty readings, sources, and reasons; (7) alarm systems operable and at appropriate set points; (8) random check readings during inspections.

5.3 *During and after large floods* - (1) driftmarked high waterlines; (2) evidence of taxed spillway capacity; (3) undesirable or dangerous spillway flow patterns directly observed or deduced from flow stains, erosion trails, swept vegetation, deposition of solids.

5.4 *During and after large outlet releases* - (1) undesirable or dangerous discharge flow patterns, dynamic pressures, vibrations, cavitation sonics.

5.5 *After earthquakes* - (1) cracks, displacements, offsets in structural features; (2) cracks, slumps, slides, displacements, escarpments, settlements in embankments, cutslopes, and fill slopes; (3) broken stalactites in galleries, tunnels, chambers; (4) toppled mechanical equipment; (5) sand boils, (6) changes in seepage patterns and rates.

6. CONCRETE AND MASONRY DAMS

(Any of these observations are applicable also to reservoir-impounding power intake structures, spillway control structures, lock walls.)

6.1 *Stress and strain* - evidence and clues - (1) cracks, crushing, displacements, offsets in concrete monoliths, buttresses, face slabs, arch barrels visible on exterior surfaces and in galleries, valve and operating chambers, and conduit interior surfaces; (2) typical stress and temperature crack patterns in buttresses, pilasters, diaphragms, and arch barrels; (3) retention of design forces in post tensioned anchorages and tendons.

6.2 *Stability* - evidence and clues - (1) excessive or maldistributed uplift pressures revealed by piezometers, pressure spurts from foundation drain holes, construction joints, and cracks; (2) differential displacements of adjacent monoliths, buttresses, and supported arch barrels or face slabs; (3) disparities in regions near the interface between arches and thrust blocks; (4) movement along construction joints; (5) uplift on horizontal surfaces revealed by seepage on downstream face and in galleries at construction lift elevations.

6.3 *Hillsides and river channels adjacent to the abutments and river section foundation along the downstream toe of the dam* - (1) leakage, (2) seepage, (3) stability, (4) boils.

6.4 *Special attention to stability and seepage control at discontinuities and junctures* - (1) embankment wraparound sections, (2) waterstops in monoliths and face slabs, (3) reservoir impounding backfill at spillway control sections and retaining walls.

6.5 *Foundation* - (1) piping of weathering products from old solution channels and rock joint structure; (2) efficiency of foundation seepage control systems - drains, drainage holes, grout curtains, cutoffs, drainage tunnels; (3) history of shear zones, faults, cavernous openings; (4) zones of varying permeability; (5) orientation of stratification and bedding planes effect on permeability, uplift, foundation stability; (6) subsurface erosion and piping; (7) thin weaker interbeds - effect on stability.

7. EARTH AND ROCKFILL, STONEWALL-EARTH, AND ROCKFILLED TIMER CRIB DAMS

7.1 *Stress and strain - evidence and clues* - (1) settlement; (2) consolidation; (3) subsidence; (4) compressibility; (5)cracks, displacements, offsets, joint opening changes in concrete facings on rockfills; (6) loss of freeboard from settlement; (7) zones of extension and compression visible along dam crest or elsewhere; (8) crushing of rock points of contact; (9) differential settlement of embankment cross sectional zones visible along dam crest, indicating stress transfer along region of zone interface (increases possibility of hydraulic fracturing).

7.2 *Stability* - evidence and clues - (1) cracks, displacements, openings, offsets, sloughs, slides, bulges, escarpments on embankment crest and slopes and on hillsides adjacent to abutments; (2) sags and misalignments in parapet walls, guardrails, longitudinal conduits or other lineaments parallel to embankment axis; (3) irregularities in alignment and variances from smooth, uniform face planes; (4) bulges in ground surfaces beyond toes of slopes.

7.3 *Inadequate seepage control* - evidence and clues - (1) wet spots; (2) new vegetal growth; (3) seepage and leakage; (4) boils; (5) saturation patterns on slopes, hillsides, and in streambed; (6) depressions and sinkholes; (7) evidence of high escape gradients.

7.4 *Erosion control* - (1) loss, displacement, and deterioration of upstream face riprap, underlayment, and downstream face slope protection; (2) beaching.

7.5 *Foundation* - (1) see 6.5 also, (2) consolidation, (3) liquefaction potential.

7.6 *Other endangerments* - (1) utility pressure conduits on, over, or through embankments; (2) diversion ditches along abutment hillsides.

8. SPILLWAYS

8.1 *Approach channel* - (1) obstructions; (2) slides, slumps, and cracks in cutslopes.

8.2 *Log booms* - (1) submergence, (2) uncleared accumulated drift, (3) parting, (4) loss of anchorage, (5) inadequate slack for low reservoir stages.

8.3 *Hydraulic control structure* - (1) stability, (2) retention of capacity rating, (3) erosion at toe, (4) installations on crest, raising storage level and decreasing spilling capacity, (5) gate piers, (6) trash control systems, (7) nappe and crotch aeration, (8) siphon prime settings.

8.4 *Headwater control (gates, flashboards, fuse plugs,* *fabric dams)* - (1) position, (2) wedging, (3) gate trunnion displacements, (4) loss of gate anchorage post tensioning, (5) undesirable eccentric loads from variable positions of adjacent gates, (6) gate-seal binding, (7) erosive seal leakage, (8) failure of lubrication system, (9) availability of bulkhead facilities for unwatering, and of cranes and lifting beams.

8.5 *Operating deck and hoists* - (1) broken or disconnected lift chains and cables; (2) unprotected exposure of electrical/mechanical equipment to weather, sabotage, vandalism; (3) structural members and connections.

8.6 *Shafts, conduits, and tunnels* - (1) vulnerability to obstruction; (2) evidence of excessive external overloading - pressure jets, contorted cross sections, cracks, displacements, circumferential joints; (3) serviceability of linings (concrete and steel), materials deterioration, cavitation, erosion; (4) rockfalls; (5) severe leakage about tunnel plugs; (6) support system for pressure conduits in walk-in tunnels.

8.7 *Bridges* - (1) possibility of collapse with consequent flow obstruction, (2) serviceability for operational and emergency equipment transport.

8.8 *Discharge carrier (open channel or conduit)* - (1) vulnerability to obstruction; (2) evidence of excessive external sidewall loading - large wall deflections, cracks, differential deflections at vertical joints; (3) invert anchorage and foundation support - drummy soundings, buckled lining, excessive uplift; (4) observation or evidence of dangerous hydraulic flow patterns - cross waves, inadequate freeboard, wall climb, unwetted surfaces, uneven distribution, ride-up on horizontal curves, negative pressures at vertical curves, pressure flow, deposition; (5) drain system serviceable; (6) air ingestion and expulsion; (7) tendency for jump formation in conduits; (8) buckling, slipping of slope lining; (9) erosion of unlined channels.

8.9 *Terminal structures* - (1) inadequate dissipation of energy, (2) jump sweep out, (3) undercutting, (4) retrogressive erosion, (5) loss of foundation support for flip bucket substructure, (6) unsafe jet trajectory and impingement, (7) erosive endangerment of adjacent dam or other critical structures.

8.10 *Return channels* - (1) impaired outfall; (2) obstructions; (3) slides, slumps, cracks in cutslopes; (4) erosion of deposition creating dangerous tailwater elevations or velocities; (5) evidence of destructive eddy currents.

9. OUTLETS

9.1 *General* - Many of the observations made of outlet components are similar in nature and purpose to those made for spillway components, stilling basins for example.

9.2 *Approach channels (may seldom be directly visible and may require underwater inspection)* - (1) siltation, (2) underwater slides and slumps.

9.3 *Intake structures (including appended, inclined, and freestanding towers, both wet and dry* - (1) lack of dead storage; (2) siltation; (3) potential for burial by slides and slumps; (4) damage or destruction of emergency and service bulkhead installation facilities; (5) availability of bulkhead, cranes, lifting beams; (6) serviceability of access bridges.

9.4 *Trashracks and raking equipment* - (1) clogging of bar spacing, (2) lodged debris on horizontal surfaces, (3) collapse.

9.5 *Gate chambers, gates, valves, hoists, controls, electrical equipment, air demand ducts* - (1) accessibility to control station under all conditions; (2) ventilation; (3) gate or valve positions; (4) binding of gate seals; (5) seizing; (6) erosive seal leakage; (7) failure of lubrication system; (8) drainage and sump pump serviceability; (9) vulnerability to flooding under reservoir pressure through conduits, bypasses, and gate bonnets surfacing in chamber.

9.6 *Conduits and tunnels* - (1) see 8.6 also, (2) seepage or leakage along external periphery of conduit, (3) extension strains in conduits extending through embankments, (4) capacity and serviceability of air relief and vacuum valves on conduits.

9.7 *Terminal structures* - See 8.9.

9.8 *Return channels* - See 8.10.

10. ENVIRONS

10.1 *Reservoir* - (1) stage at time of inspection; (2) indications of recent noteworthy stages; (3) depressions, sinkholes in exposed reservoir basin surfaces; (4) massive water-displacing slide potentials - leaning trees, escarpments, hillside distortions; (5) flood pool encroachments; (6) siltation adversely affecting loading on dam, and forming approach channel and waterway obstructions.

10.2 *Reservoir linings - compacted, PCC (Portland Cement Concrete) and AC (Asphaltic Concrete), fabric* - (1) depressions, sinkholes; (2) erosion; (3) animal disruption.

10.3 *Downstream proximity* - (1) tailwater stage at time of inspection, (2) reservoir-connected springs; (3) endangering seepage or leakage regardless of source, (4) river obstructions creating unanticipated tail- water elevations or interference with outfall channel capacities of the spillway and outlets.

10.4 *Watershed* - (1) surface changes that might materially affect runoff characteristics.

10.5 *Regional vicinity* - (1) subsidence indications - sinkholes, trenches, subsidence surveys, settlements of buildings, highways, other structures in the region; (2) assessment of land forms and regional geologic structure; (3) records of mineral, hydrocarbon, and groundwater extractions, locations, producing horizons, accumulated production, and current rate of production.

10.6 *Downstream flood plain* - (1) limits of natural, improved, or leveed channel; (2) areas of potential inundation - for spillway design flood, for hypothetical failure; (3) proximity of developed areas, (4) habitation, population, communication and transportation corridors.

11. EXAMPLE - SPECIFIC CHECKLIST

An example of a specific checklist for a zoned earth dam follows. Lists for other types of dams, for reservoirs, and for appurtenant works can be similarly prepared with the aid of the universal list.

Check List For Inspection of Zoned Earth Dam

Upstream face - (1)slides; (2) settlement, cracks, and displacements; (3) vegetative growth; (4) slope protection for erosion, beaching, grading, durability, loss of bedding.

Downstream face - (1) slides; (2) settlement, cracks, and displacements; (3) seepage, saturation, wetness; (4) vegetation; (5) slope protection for furrowing, durability; (6) rodents.

Regions adjacent to abutments and foundations - (1) seepage; (2) cracks, slides; (3) vegetation; (4) groins for erosion; (5) formation joints, fractures, bedding planes; (6) boils; (7) depressions; (8) sinkholes, (9) rodents.

Crest - (1) cracks; (2) settlement; (3) lateral movements; (4) camber; (5) parapet walls for sags and misalignment.

Performance Instrumentation - piezometer gauge house and equipment; (2) surface positions of observation wells, piezometers, deflectometers, cross-arm settlement devices; (3) surface settlement and deflection monuments; (4) reference monuments.

Adjacent endangerments - (1) utility pressure conduits; (2) diversion ditches along abutment hillsides.

EXHIBIT II

CONSIDERATIONS AND PROCEDURES FOR IMPOUNDMENT INTEGRITY EVALUATIONS

(Adapted from USBR, 1978, Appendix C)

Note: The term "review" as used in this Exhibit means a study of project records or project-related publications; or an appraisal or analysis of a condition, apparent or suspected, based on available information or supplemental data acquired during Stage 2.

1. GEOLOGY

1.1 Review geologic mapping, plans, and cross sections showing exploration features and summarizing drill logs and geologic interpretations for the dam, appurtenant structures, materials sources, and the reservoir geology. Particular attention should be paid to geologic features such as: shear zones; faults; open fractures; seams, joints, fissures, or caverns; landslides; variability of formations; compressible or liquefiable materials; weak bedding planes, etc.

1.2 Review exploration logs for lithologic and physical conditions, water test data, standard penetration or other resistance testing results.

1.3 Review geophysical data.

1.4 Review groundwater level records in the vicinity of the reservoir.

1.5 Review petrographic or chemical studies of foundation materials and natural construction materials.

1.6 Review geologic portions of all reports relevant to the site.

1.7 Review aerial photographs of site and reservoir.

1.8 Review published or unpublished regional geologic studies that are relevant to the dam and reservoir setting.

1.9 Inspect the pertinent features of the areal geology at the dam and appurtenant sites, borrow and quarry sites, and, to the extent practicable, in the reservoir basin. Inspect representative core recovered from exploration, particularly from zones indicated on the logs as being badly broken, weathered, or highly pervious.

1.10 On the basis of general geologic setting, is this an acceptable site for the type of dam? Are attitudes of bedding and joints particularly favorable or unfavorable to seepage, slope stability, foundation stability, acceptance of dam and reservoir loads and pressures, and sliding?

1.11 Review any effect of raised groundwater levels on the stability of abutment and reservoir slopes.

1.12 Review potential chemical activity - reactivity of aggregate, quality of surface and groundwater, type of cement.

1.13 Was foundation improved by treatments such as pressure grouting slurrying grouting, blanket grouting, drainage, dental concrete, and deeper or more extensive excavation?

1.14 Was the actual treatment of the geologic conditions adequate?

2. SEISMICITY

2.1 Review seismic and tectonic history of region.

2.2 Review seismic history of site.

2.3 Determine location and relative influence of active and potentially active faults which could affect the project site.

2.4 Consider all potential earthquake effects which could influence the project site such as:

- Surface rupture
- Ground tilting
- Elevation changes
- Shaking
- Landsliding
- Slumping
- Liquefaction
- Settlement
- Seiches

2.5 Review design earthquake - location, magnitude, and recurrence interval.

2.6 Were expected baserock motions for design earthquake developed? What are they and how were they developed? Are design accelerograms available?

2.7 Were pseudostatic "g" factor(s) recommended for design? How were they determined?

2.8 Review aerial photographs and space imagery of site and region.

3. HYDROLOGY AND SPILLWAY DESIGN FLOODS

3.1 Review summary hydrologic data contained in project reports.

3.2 Review design reports, operations and maintenance manuals, and contract plans and specifications regarding spillway design and operation.

3.3 Review design flood criteria:

- Hazard potential of impoundment.
- Downstream risk evaluation.
- Appropriate flood magnitude.

3.4 Review design storm precipitation, duration, and runoff values:

- Storm distribution with time.
- Assumed snowpack conditions.
- Watershed characteristics - antecedent moisture, vegetation type, topography, land use, etc.

3.5 Review flood routing studies:

- Reservoir area - capacity curve.
- Spillway rating curve (gated or uncontrolled).
- Flood routing analysis.
- Assumed reservoir water surface prior to design flood inflow
- Maximum flood surcharge level.
- Residual freeboard between crest of dam and maximum flood surcharge level.

3.6 Review flood control and other storage operation plans.

- Seasonal storage requirements.
- Seasonal flood potentials.
- Potential operational conflicts.
- Normal outlet releases.

3.7 If spillway is gated:

- Review seasonal gate operation procedures and schedules.
- Do the flood routing studies consider gate malfunctions and any redundant provisions for passing floods?

3.8 Review downstream flood plain conditions:

- Limits of improved channel and/or flood levees.
- Areas of potential inundation for spillway design flood discharges.
- Proximity of developed areas.

3.9 Is a spillway capacity reevalutation needed in light of the present state of-the-art and post-construction hydrological records?

4. GENERAL CONSIDERATIONS FOR DAMS OF ALL TYPES AND APPURTENANT STRUCTURES

4.1 Review contract plans and specifications and design reports.

4.2 Review basic design including dam layout, cross-sections and zoning, specified foundation treatment, and grouting. Note any unusual aspects or omissions.

4.3 Review exploration, geology, and seismicity data for dam and reservoir, and evaluate. Note potential adverse effects of known geologic features.

4.4 Review laboratory test procedures and results.

4.5 Assess unforeseen conditions and their treatment for relationship to safety and performance of dam and appurtenances.

4.6 Review construction photographs.

4.7 Review construction control test results. Compare these with the design-phase exploration and test results and with the design assumptions.

4.8 Compare materials and foundation properties determined during construction with general criteria used for design. Assess adequacy of criteria and specifications provisions from safety standpoint with regard to specific items such as seepage control, capacity, and clogging potential of foundation and interior drains, piping potential, etc.

4.9 Evaluate design criteria and methods of analyses and their relationships to present state-of-the-art.

4.10 Are there any activities in the region such as mining or oil or water extraction which could adversely affect the dam or appurtenance?

4.11 Evaluate whether construction specifications, procedures, and materials were compatible with general design assumptions and known site conditions.

4.12 Review instrumentation installations and assess adequacy of instrumentation for monitoring probable operational performance in general or for specifically identified behavioral patterns.

4.13 Review instrumentation records and evaluate significance of results.

4.14 Conduct detailed inspection of site and environs. Note any unusual or suspect conditions. Observe selected drill cores, if available.

4.15 Was design and construction in accord with the state-of-the-art at the time?

4.16 How would design and construction compare with present state-of-the-art?

5. EARTH AND ROCKFILL, STONEWALL-EARTH, AND ROCKFILLED TIMBER CRIB DAMS

5.1 *General*

5.1.1 See Section 4 of this exhibit.

5.1.2 Review adopted foundation and embankment materials design properties and compare with exploration and field and laboratory test results for appropriateness. Evaluate compatibility of the dam and foundation.

5.1.3 Review stability analyses, including the loading and operational conditions analyzed. Note any apparent deficiencies and/or unusual appearing results. Were currently acceptable methods of analyses employed?

5.1.4 Review as-built drawings and data including foundation configuration, grouting summaries, drainage provisions, construction changes, type and depth of cutoff, foundation discontinuities, special foundation treament, etc., and assess their potential effects on performance.

5.2 *Materials Properties - Placement, Testing, and Control*

5.2.1 Classification, gradation, Atterberg limits.

5.2.2 Laboratory maximum densities for fine-grained materials, relative density for coarse-grained materials. Optimum moisture.

5.2.3 Freeze-thaw (riprap durability).

5.2.4 Consolidation and settlement.

5.2.5 Dispersive clay tests, solubility tests.

5.2.6 Filter and drain materials, gradation, permeability, etc.

5.2.7 Petrographic and minerological descriptions.

5.2.8 Lift thickness, compactive effort, method of compaction.

5.2.9 Number and distribution of control tests. Variation of density and moisture.

5.2.10 Select material and placement methods at abutments and around structures.

5.2.11 Variability of material in borrow areas.

5.2.12 Relative settlement of adjacent zones.

5.2.13 Dynamic and static strength properties (friction angle and cohesion).

5.3 *Foundation*

5.3.1 Methods used in determining the strength and behavioral characteristics of the foundation mass.

5.3.2 Extent of foundation investigation - area covered - number and type of exploratory holes.

5.3.3 Summary of grouting - depth, take, pressures, additives, and mixes.

5.3.4 Drain holes, seepage, and uplift control systems.

5.3.5 Strike and dip of joint system.

5.3.6 Specified foundation treatment.

5.3.7 Size and location of seams and shears.

5.3.8 Characteristics of any joint fillings.

5.4 *Analytical Data*

5.4.1 Method of analysis - finite element, slip circle, wedge, etc. What materials, engineering properties (strength, etc.) were used? Were they valid? What were assumptions for foundation strengths and interaction with the dam?

5.4.2 What loading conditions were adopted?

5.4.3 Results of analysis - stresses, strain, displacements, stability factors, foundation pressures.

5.4.4 Was any analysis made of pore pressure distribution within the dam and foundation?

5.4.5 Was analysis made of seepage distribution within the dam and foundation?

5.4.6 Were the abutments analyzed?

5.4.7 Compare computed and measured deformations in dam and foundation.

5.4.8 Was uplift and fracturing caused by grouting considered and monitored?

6. CONCRETE AND MASONRY DAMS

6.1 *General*

6.1.1 See Section 4 of this exhibit.

6.1.2 Review adopted foundation and concrete materials design properties and compare with exploration and field and laboratory test results for appropriateness. Evaluate compatibility of the dam and foundation.

6.1.3 Review results of stress analyses or stability analyses, including loading and operational conditions analyzed especially for any apparent deficiencies and/or unusual appearing results. Were currently accepted methods of analyses used?

6.1.4 Evaluate possible effects of freezing and thawing on structural response and operational performance of the impoundment.

6.2 *Material Properties - Placement, Testing, and Control*

6.2.1 Strength and durability of concrete employed - 90-day strength, etc.; size of cylinders (design vs. construction values), coefficient of variation - high and low values - number of cylinders.

6.2.2 Modulus of rupture and elasticity of concrete.

6.2.3 Have any cores been taken from dam and tested? How do the results compare with design criteria?

6.2.4 Type of cement, cement factor, admixtures, and water-cement ratio. What tests were conducted on the cement used? Proportions of concrete mix? Was the creep property of concrete determined?

6.2.5 Lift height and method of placement.

6.2.6 Treatment of vertical or contraction joints and lift surfaces.

6.2.7 Concrete placement and joint grouting schedule - as performed.

6.2.8 Heat generation characteristics of the concrete mixes.

6.2.9 Physical, chemical, and mineralogical characteristics and sources of aggregates used.

6.3 *Foundation*

6.3.1 Methods used in determining the strength and behavioral characteristics of the rock mass.

6.3.2 Extent of foundation investigation - area covered - number and type of exploratory holes.

6.3.3 Summary of grouting - depth, take, pressures, additives, and mixes.

6.3.4 Drain holes, seepage, and uplift control systems.

6.3.5 Strike and dip of joint system.

6.3.6 Specified foundation treatment.

6.3.7 Size and location of seams and shears.

6.3.8 Characteristics of any joint fillings.

6.4 *Analytical Data*

6.4.1 Method of analysis - trial load - finite element - number of cantilevers - arches, etc.

6.4.2 How was the foundation deformation considered?

6.4.3 What loading conditions were adopted?

6.4.4 What temperature variation was assumed?

6.4.5 When were construction joints grouted relative to construction sequence?

6.4.6 How much cooling occurred prior to grouting?

6.4.7 Results of analysis - stresses, thrust, movements, stability factors, shear-friction safety factors, foundation pressures.

6.4.8 Was any analysis made of pressure distribution within the foundation?

6.4.9 Abutments radial or nonradial?

6.4.10 Shear keys in vertical or contraction joints?

6.4.11 Was the effect of cracked sections included?

6.4.12 Were the abutments analyzed?

6.4.13 Impact forces of water in plunge pool (arch dams only)

6.4.14 Compare computed and measured stresses and deformations in dam and foundation.

7. APPURTENANT STRUCTURES

7.1 *General*

7.1.1 See Section 4 of this exhibit.

7.1.2 Review basic design, including plans, section, details, assumptions, and criteria. Note any unusual aspects and omissions.

7.1.3 Review laboratory and hydraulic model test procedures and results.

7.1.4 Review adopted foundation, concrete and steel reinforcement design properties, and compare with exploration, field and laboratory test results, and generally accepted practice, for appropriateness. Evaluate compatibility of the structure with its foundation and environment.

7.1.5 Review results of stress and stability analysis, including loading and operational conditions analyzed. Note any apparent deficiencies and/or unusual appearing results.

7.1.6 Evaluate possible effects of freezing and thawing on structural and operational service of structures.

7.2 *Spillway*

7.2.1 Hydraulic evaluations - Evaluate spillway capability to pass all design floods without endangering the dam. If the spillway has control gates, evaluate redundant provisions for safely passing floods should the gates fail to fully operate for any reason. Review provisions (log booms, etc.) for keeping spillway entrance free of obstructions.

7.2.2 Structural evaluations - Review and evaluate the following relevant to the security of the dam:

- Geologic data regarding the spillway foundation and compatibility with structural design.
- Design criteria in comparison with generally accepted standards. The evaluation would include review of the various combinations of loading for which components of the spillway facility might be subjected, such as:

  Earth loads
  Hydrostatic loads
  Uplift forces
  Dynamic water forces
  Earthquake forces

- Design of seepage cutoffs and drainage provisions behind spillway walls and beneath floor slabs.
- Energy dissipation features.

7.3 *Outlet Works Structures and Controls*

Review and evaluate the following items relevant to the security of the dam:

7.3.1 Design criteria with regard to hydraulic and structural requirements.

7.3.2 Operational criteria including capability of outlets to reduce or completely withdraw reservoir storage in event of emergency.

7.3.3 Geologic conditions and any potentially adverse effects on structural or operational requirements.

7.3.4 Backup systems available in event of operation malfunctions.

7.3.5 Energy dissipation features.

7.4 *Materials Properties for Spillways and Outlets - Placement, Testing, and Control*

7.4.1 Strength and durability of concrete employed - 90-day strength etc., size of cylinders (design vs. construction values), coefficient of variation - high and low values - number of cylinders.

7.4.2 Modulus of rupture and elasticity of concrete.

7.4.3 Type of cement, cement factor, admixtures, and water-cement ratio. What tests were conducted on cement? Proportions of the concrete mix?

7.4.4 Methods of concrete placement.

7.4.5 Treatment of construction and contraction joints.

7.4.6 Physical, chemical, and mineralogical characteristics and sources of aggregates.

7.4.7 Properties of steel reinforcement.

7.4.8 Do the properties of the materials actually used conform with design assumptions?

7.5 *Foundations of Spillways and Outlets*

7.5.1 Methods used in determining the strength and behavior characteristics of the supporting rock.

7.5.2 Extent of foundation investigation - area covered - number and type of exploratory holes.

7.5.3 Summary of grouting - depth, take, pressures, mixes, additives.

7.5.4 Drain holes, seepage, and uplift control systems.

7.5.5 Strike and dip of joint systems.

7.5.6 Specified foundation treatment.

7.5.7 Size and location of seams and shears.

7.5.8 Characteristics of any joint fillings.

7.6 *Analytical Data for Spillways and Outlets*

7.6.1 Were methods of analysis adequate and appropriate?

7.6.2 How were foundation characteristics handled?

7.6.3 Were adopted loading conditions adequate and appropriate?

7.6.4 Results of analyses - stresses, stability factors.

7.6.5 Evaluate anticipated hydraulic performance of energy dissipation features, channel or conduit flow patterns, and scour resistance.

8. OPERATION AND MAINTENANCE

8.1 Review reservoir topography and geology and assess reservoir landslide potential.

8.2 Review any established designers' operating criteria and standard operating procedures or similar documents, for the project. Note particularly the operational capability of outlets to reduce reservoir storage in an emergency, the redundant systems available to operate gated spillways and outlets works during power and operational malfunctions. Identify project operation and maintenance factors relating to the safety of the dam.

8.3 How often are operators required at the dam?

8.4 Identify any adverse or difficult operational aspects related to dam impoundment integrity.