Chapter 21

FOUNDATION PREPARATION, TREATMENT, AND CLEANUP

This chapter discusses foundation preparation for and the placement of the first several layers of earthfill and concrete. Preparation includes excavating overburden; shaping the foundation surface with dental concrete; filling surface irregularities with slush grout (usually a cement/water mixture poured in cracks) or dental concrete (conventional concrete used to shape surfaces, fill irregularities, and protect poor rock); treating faults, shears, or weak zones; and cleanup.

Earthfill Dams

Shaping

Shape the foundation to ensure proper compaction of fill and to prevent stress anomalies in the overlying embankment. Fractures and resultant seepage problems in embankment dams may be caused by irregularities in the foundation such as stepped surfaces, abrupt changes in slope, and excessively steep surfaces. Embankment zones may differentially settle adjacent to these areas, resulting in cracks. Arching occurs near stepped surfaces resulting in a zone of low horizontal stress adjacent to the steep surface. Preventing arching is more important in the upper 1/6 to 1/4 of a dam or in low dams where stresses are low and tension zones develop along steep or diverging abutments. Tension zones or areas of low stresses are susceptible to hydraulic fracturing. The foundation surface should be shaped by excavating or by using concrete to obtain a smooth, continuous surface that minimizes crack potential. When an inclined core is used in a rockfill dam, the core derives support from the underlying filter and transition material. The zone beneath the filter and transition should be shaped using core contact criteria.

Foundation outside the core contact must be shaped to facilitate fill placement and compaction, and unsuitable weak or compressible materials must be removed. Impervious materials beneath drainage features which would prevent drainage features from properly functioning must also be removed. Materials may move into the foundation, and erodible foundation materials may move into the embankment. Appropriately graded filters between the drainage materials and foundation may be necessary.

The minimum treatment of any foundation consists of stripping or removing organic material such as roots and stumps, sod, topsoil, wood, trash, and other unsuitable materials. Cobbles and boulders may also require removal depending on the type of embankment material to be placed.

The weak points in earthfill dams are generally within the foundation and especially at the contact of the foundation with the embankment. Foundation seepage control and stability features must be carefully supervised by the inspection force during construction to ensure conformance with the design, specifications, and good practice. Water control methods used in connection with excavating cutoff trenches or stabilizing the foundations should ensure that fine material is not washed out of the foundation because of improper screening of wells and that the water level is far enough below the foundation surface to permit construction “in the dry.” Whenever possible, locate well points and sumps outside the area to be excavated to avoid loosening soil or creating a "quick" bottom caused by the upward flow of water or equipment vibration. Avoid locating sumps and associated drainage trenches within the impervious zone because of the difficulty in properly grouting them after fill placement and the danger of damaging the impervious zone/foundation contact.

Found cutoff walls or concrete grout caps in the best rock available. Prohibit or strictly control blasting for the excavation of these structures to avoid damaging the foundation. If the material cannot be excavated with a hydraulic excavator fitted with a rock bucket, a grout cap or cutoff wall is probably not needed and grout nipples can be set directly in the foundation. A highly weathered zone can be grouted effectively by:

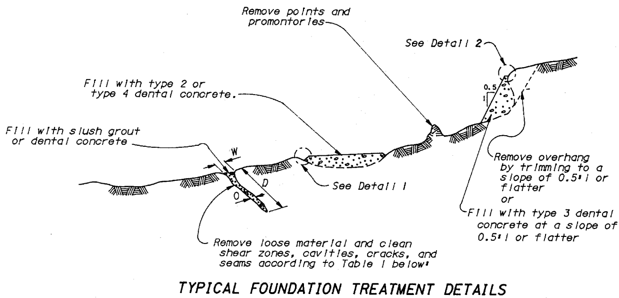
- Leaving the foundation high.

- Setting grout nipples through the unsuitable material. Long grout nipples may be necessary in poor rock.

- Excavating to final foundation grade after grouting.

In hard, sound rock, neither a grout cap nor a high foundation is necessary.

When overburden is stripped to rock, carefully clean the rock surface and all pockets or depressions of soil and rock fragments before the embankment is placed. This may require compressed air or water cleaning and handwork. Rock surfaces that slake or disintegrate rapidly on exposure must be protected or covered immediately with embankment material or concrete. Foundation rock should be shaped to remove overhangs and steep surfaces (figure 21-1). High rock surfaces must be stable during construction and should be cut back to maintain a



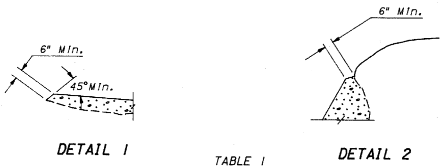


TABLE I

CASE	WIDTH OF FEATURE (W)	DEPTH OF FEATURE (D)	TREATMENT
1.	2 Inches or less	3 Times the width	Slush grout
2.	2 Inches to 5 feet	3 Times the width or to a depth where opening (O) is 0.5 inch or less	Type 4 dental concrete
3.	Greater than 5 feet	3 Times the width or as directed by Contracting Officer	Type 1 dental concrete

Figure 21-1.—Example foundation treatment details from specifications.

smooth, continuous profile to minimize differential settlement and stress concentrations within the embankment. Final slopes should be 0.5:1 (horizontal to vertical [H:V]) or flatter. Beneath the impervious zone, all overhangs should be removed; stepped surfaces steeper than 0.5:1 and higher than 0.5 foot (15 cm) should be excavated or treated with dental concrete to a slope of 0.5:1 or flatter. Outside the impervious zone, all overhangs should be removed, and stepped surfaces steeper than 0.5:1 and higher than 5 ft (1.5 m) (should be excavated or treated with dental concrete to a slope of 0.5:1 or flatter.

Slush grout or joint mortar should be used to fill narrow cracks in the foundation (figure 21-1). However, they should not be used to cover exposed areas of the foundation. Slush grout and joint mortar are composed of Portland cement and water or, in some cases, Portland cement, sand, and water. The slush grout is preferably used just before fill placement to eliminate any tendency for hardened grout to crack under load. Dental concrete should be used to fill potholes and grooves created by bedding planes and other irregularities such as previously cleaned shear zones and large joints or channels in rock surfaces. Formed dental concrete can be used to fillet steep slopes and fill overhangs.

Care should be used during all blasting to excavate or to shape rock surfaces. Controlled blasting techniques, such as line drilling and smooth blasting, should be used.

Soil Foundations

When the foundation is soil, all organic or other unsuitable materials, such as stumps, brush, sod, and large roots, should be stripped and wasted. Stripping should be performed carefully to ensure the removal of all material that may be unstable because of saturation, shaking, or decomposition; all material that may interfere with the creation of a proper bond between the foundation and the embankment; and all pockets of soil significantly more compressible than the average foundation material. Stripping of pervious materials under the pervious or semipervious zones of an embankment should be limited to the removal of surface debris and roots unless material removal is required for seismic stability. Test pits should be excavated if the stripping operations indicate the presence of unstable or otherwise unsuitable material.

Before placing the first embankment layer (lift) on an earth foundation, moistening and compacting the surface by rolling with a tamping roller is necessary to obtain proper bond. An earth foundation surface sometimes requires scarification by disks or harrows to ensure proper bonding. No additional scarification is usually necessary if the material is penetrated by tamping rollers.

All irregularities, ruts, and washouts should be removed to provide a satisfactory foundation. Cut slopes should be flat enough to prevent sloughing, and not steeper than 1:1. Material that has been loosened to a depth of less than 6 in (15 cm) may be treated by compaction. Loosened material deeper than 6 in (15 cm) cannot be adequately compacted and should be removed.

Foundation materials at the core/foundation contact must be compacted to a density compatible with the overlying fill material. A fine-grained foundation should be compacted and disked to obtain good mixing and bond between the foundation and the first lift of core material.

Fine-grained foundations should be compacted with a roller. If the foundation is too firm for the tamping feet to penetrate, the foundation surface should be disked to a depth of 6 in and moistened before compaction. Smooth surfaces created by construction traffic on a previously compacted foundation surface should be disked to a depth of 2 in (5 cm).

Coarse-grained foundations should be compacted by rubber-tired or vibratory rollers. Vibratory compactors create a more uniform surface for placement of the first earthfill and are the preferred method of compaction.

Cemented and highly overconsolidated soils that break into hard chunks should not be reworked or disked to mix foundation and core material. The first lift of embankment material should be placed in a manner similar to that required for rock foundations as described above.

Soil foundation compaction requirements beneath filter and shell zones should be the same as those outlined above, except bonding the foundation to the overlying fill is not required.

The moisture content of the upper 6 in (15 cm) of a fine-grained soil foundation should be within 2 percent dry and 1 percent wet of the Proctor optimum moisture content for adequate compaction. Coarse-grained foundation materials should be just wet enough to permit compaction to the specified relative density, but saturation is not permitted. Dry materials must be disked and moistened to provide a homogeneous moisture content within the specified limits in the upper 6 in (15 cm) of the foundation. Wet materials must be dried by disking to bring the upper 6 in of foundation materia1 within the specified moisture content limits. Wet foundations should be unwatered or dewatered sufficiently to prevent saturation of the upper 6 in (15 cm) of foundation material due to capillary rise or pumping caused by construction equipment travel.

All embankment materials should be protected from eroding into coarser soil zones in the foundation by transitions satisfying filter criteria or by select zones of highly plastic, nonerodible material. Transition zones or filters on the downstream face of the cutoff trench and beneath the downstream zones should prevent movement of fine material in the foundation into the embankment. Dispersive embankment materials must be protected from piping into coarse material in the foundation by placing select zones of nondispersive material between the embankment and foundation. Lime-treated or naturally nondispersive earthfill is appropriate for the first several lifts of fill material or filters. Except for areas where an impervious seal between the embankment and foundation is required, filter zone(s) are the preferred method.

Rock Foundations

Rock foundation surfaces should be moistened, but no standing water should be permitted when the first lift is placed. The use of very wet soil for the first lift against the foundation should generally be avoided, but having the soil slightly wet of optimum moisture content is better. Any material more plastic than what is typically available for embankment construction is commonly used on the first few lifts. The foundation should be properly moistened to prevent drying of the soil. On steep, irregular rock abutments, material slightly wetter than optimum may be necessary to obtain good workability and a suitable bond. Be careful when special compaction is used to ensure that suitable bonds are created between successive layers of material. This usually requires light scarification between lifts of compacted material. Where a rock foundation would be damaged by penetration of the tamping roller feet, the first compacted lift can be thicker than that specified. The first lift thickness should never exceed 15 in (40 cm) loose for 9-in-long (23-cm) tamper feet, and additional roller passes are probably required to ensure proper compaction. Special compaction methods, such as hand tamping, should be used in pockets that cannot be compacted by roller instead of permitting an unusually thick initial lift to obtain a uniform surface for compaction. Irregular rock surfaces may prevent proper compaction by rollers, and hand compaction may be necessary. However, where foundation surfaces permit, a pneumatic-tire roller or pneumatic-tire equipment should be used near foundation contact surfaces. An alternative to using thick lifts is using a pneumatic-tire roller or loader with a full bucket and disking or scarifying the lift surfaces to obtain a bond between lifts. The tamping roller can be used when the fill is sufficiently thick and regular to protect the foundation from the tamping feet. Unit weight and moisture should be carefully monitored in the foundation contact zone, and placing and compacting operations should be carefully inspected.

On steep surfaces, ramping the fill aids compaction; about a 6:1 slope should be used for ramping the fill. The surfaces of structures should be sloped (battered) at about 1:10 to facilitate compaction.

The basic objectives of foundation surface treatment within the impervious core are:

- Obtain a good bond between the impervious core materials and the foundation. The foundation surface must be shaped by excavation or concrete placement to provide a surface suitable for earthfill compaction. Compaction techniques used for initial earthfill placement should result in adequately compacted embankment material in intimate contact with and tightly bonded to the foundation without damaging the foundation during placement of the first lifts. A plastic material is preferred next to the foundation, and special requirements on the plasticity, gradation, and moisture content are commonly specified.

- Defend against erosion of embankment materials into the foundation by filling or covering surface cracks in the foundation, using blanket grouting, protective filters, and nonerodible embankment materials (natural or manufactured) at the foundation contact.

- Remove erodible, weak, unstable, compressible, loose, or pervious materials to ensure a foundation of adequate strength and appropriate permeability. When in doubt, take it out. In rock foundations, defects such as faults, fractures, erosion channels, or solution cavities or channels sometimes cannot be completely removed. Material defects in the rock mass include fault gouge, rock fragments, soft or pervious soil, or solutioned rock. These materials require removal to an adequate depth and replacement with slush grout, dental concrete, or specially compacted earthfill.

How the exposed rock surface is treated after removal of unsuitable overlying materials depends on the type of rock and the irregularities present. Construction activities such as using tracked equipment on soft rock surfaces, using rippers near foundation grade, or nearby blasting may loosen rock or open joints in originally satisfactory rock. This type of damage should and can be avoided to limit excavation and cleanup. The configuration of exposed rock surfaces is controlled largely by bedding, joints, other discontinuities, and excavation methods. Depending on discontinuity orientations, these features can result in vertical surfaces, benches, overhangs, or sawteeth. Features such as potholes, buried river channels, solution cavities, and shear zones can create additional irregularities requiring treatment. Unsuitable material must be removed from the irregularities, and the foundation surface must be shaped to provide a sufficiently regular surface that earthfill can be placed without differential settlement. If the irregularities are small enough and discontinuous both horizontally and vertically, overexcavation can be appropriate. Generally, the foundation surface can be shaped adequately by conventional excavation or smooth blasting. When smoothing of irregularities requires excessively large quantities of excavation or requires blasting that may damage the foundation, shaping with dental concrete may be appropriate.

High rock surfaces must be stable during construction and must be laid back to maintain a smooth, continuous profile to minimize differential settlement and stress concentrations. Slopes should be 0.5:1 (H:V) or flatter, depending on the fill material.

Remove overhangs. Stepped surfaces that are steeper than 0.5:1 and higher than 1 foot (30 cm) should be excavated or treated with dental concrete to a resultant slope of 0.5:1 or flatter, depending on the fill material (figure 21-1). In the lower portions of a high dam, this requirement may be relaxed. For example, a vertical surface less than 20 ft (6.1 m) long and 5 ft (1.5 m) high might be tolerated if the surface is well within the impervious zone.

Remove all overhangs under the outer zones of earthfill dams and under transitions and filters of rockfill dams. Stepped surfaces that are steeper than 0.5:1 and higher than 5 ft (1.5 m) should be flattened or treated with dental concrete to a slope of 0.5:1 or flatter. Beneath the outer rockfill zones of rockfill dams, nearly vertical abutment contact slopes have been permitted in high, steep-walled canyons. Overhangs should be trimmed or the undercut below the overhang filled with concrete.

If shaping requires blasting, proper blasting procedures are essential to ensure that the permeability and strength of the rock is not adversely affected and that the rock can stand on the slopes and handle the imposed loads. Existing fractures and joints in a rock mass, as well as poor blasting, often result in unacceptable excavated surfaces. Prior competent review, approval, and enforcement of the Contractor's blasting plan, control of blasting details, requirements for acceptabi1ity of the excavated surface, and control of vibration levels can help obtain the desired excavation surface.

All loose or objectionable material should be removed by handwork, barring, picking, brooming, water jetting, or air jetting. Remove accumulated water from cleaning operations. When the rock surface softens or slakes by water washing, compressed-air jetting or jetting with a small amount of water added to the air should be used. Loose or unsuitable material in cavities, shear zones, cracks, or seams should be treated as follows (figure 21-1):

- Openings narrower than 2 in (5 cm) should be cleaned to a depth of three times the width of the opening and treated.

- Openings wider than 2 in (5 cm) and narrower than 5 ft (1.5 m) should be cleaned to a depth of three times the width of the opening or to a depth where the opening is 0.5 in (12mm) wide or less, but not to a depth exceeding 5 ft (5 cm) and treated.

- Openings wider than 5 ft (1.5 m) are a special case where the required depth of cleaning and treatment is determined in the field.

Special cleanup procedures are required for foundation materials that deteriorate when exposed to air or water (slake). The foundation must be kept moist if deterioration is caused by exposure to air and kept dry if deterioration is caused by exposure to water. Spray coating with material (similar to concrete curing compound) designed to reduce slaking may (but probably will not) be effective. Cleanup and placing a lean concrete "mud slab" approximately 4 in (15 cm) thick may be effective. Usually, removing the last few inches of material and doing final cleanup just before first placement of fill is the best approach. A maximum time interval may also be specified between the time of exposure of the final grade and the time that the foundation is protected with earthfill or a suitable protective coating.

Cleanup outside the core is normally less critical. Loose material should be removed so that the embankment is in direct contact with suitable rock. If defects are contained within the foundation area, they may not require cleaning and refill. If a defect crosses the entire foundation area, it may require cleaning similar to the foundation beneath the core.

Dental concrete is used to fill or shape holes, grooves, extensive areas of vertical surfaces, and sawteeth created by bedding planes, joints, and other irregularities such as previously cleaned out solution features, shear zones, large joints, or buried channels. Formed dental concrete can be used to fillet steep slopes and fill overhangs. Placing a concrete mat over a zone of closely spaced irregularities is appropriate in local areas that are not large in relation to the core dimensions. Dental concrete shaping can be used instead of excavation by blasting or when excessive amounts of excavation would otherwise be required.

Slabs of dental concrete should have a minimum thickness of 6 in (15 cm) if the foundation is weak enough to allow cracking of the concrete under load (figure 21-1).

Thin areas of dental concrete over rock projections on a jagged rock surface are likely places for concrete cracking and should be avoided by using a sufficient thickness of dental concrete or by avoiding continuous slabs of concrete over areas containing numerous irregularities on weak foundations. Feathering at the end of concrete slabs on weak foundations should not be permitted, and the edges of slabs should be sloped no flatter than 45 degrees. Formed dental concrete should not be placed on slopes greater than 0.5:1 (H:V). When dental concrete fillets are placed against vertical or nearly vertical surfaces in weak rock, feathering should not be permitted, and a beveled surface with a minimum thickness of 6 in (15 cm) is required at the top of the fillet.

Concrete mix proportions should provide a 28-day strength of 3,000 pounds per square inch (21 MPa). The maximum aggregate size should be less than one-third the depth of slabs or one-fifth the narrowest dimension between the side of a form and the rock surface. Cement type will depend on the concentration of sulfates in the foundation materials and groundwater. Low-alkali cement is required for alkali-reactive aggregates. Cement type should be the same as used in structural concrete on the job. Aggregate and water quality should be equal to that required in structural concrete.

The rock surface should be thoroughly cleaned, as described below, and moistened before concrete placement to obtain a good bond between the concrete and the rock surface. When overhangs are filled with dental concrete, the concrete must be well bonded to the upper surface of the overhang. The overhang should be shaped to allow air to escape during concrete placement to prevent air pockets between the concrete and the upper surface of the overhang. The concrete must be formed and placed so that the head of the concrete is higher than the upper surface of the overhang. If this is impractical, grout pipes should be installed in the dental concrete for later filling of the air voids. If grouting through dental concrete is done, pressures should be closely controlled to prevent jacking the concrete or fracturing the fill.

Finished horizontal dental concrete slabs should have a roughened, broomed finish for satisfactory bonding of fill to concrete. Dental concrete should be cured by water or an approved curing compound for 7 days or covered by earthfill. Earthfill placement may not be permitted over dental concrete for a minimum of 72 hours or more after concrete placement to allow concrete time to develop sufficient strength to withstand stress caused by placing earthfill. Inadequate curing may result in the concrete cracking.

Slush grout is a neat cement grout or a sand-cement slurry that is applied to cracks in the foundation. Cracks or joints are filled with grout rather than spreading grout on the surface (figure 21-1). Slush grout should be used to fill narrow surface cracks and not used to cover areas of the foundation. Slush grout may consist of cement and water, or sand, cement, and water. To ensure adequate penetration of the crack, the maximum particle size in the slush grout mixture should be no greater than one-third the crack width. Generally, neat cement grout is used. The consistency of the slush grout mix may vary from a very thin mix to mortar as required to penetrate the crack. The grout preferably should be mixed with a mechanical or centrifugal mixer, and the grout should be used within 30 minutes after mixing.

The type of cement required will depend on the concentration of sulfates in the foundation materials and groundwater. Low-alkali cement is required for alkali sensitive aggregates. Cement type should be that specified for structural concrete. Sand and water quality should be equal to that required for structural concrete.

Clean out cracks as described above. All cracks should be wetted before placing slush grout. Slush grout may be applied by brooming over surfaces containing closely spaced cracks or by troweling, pouring, rodding, or funneling into individual cracks. Slush grout is best applied just before material placement so cracking will not occur during compaction.

Shotcrete is concrete or mortar that is sprayed in place. The quality of the shotcrete depends on the skill and experience of the crew, particularly regarding the amount of rebound, thickness, feather edges, and ensuring adequate thickness over protrusions on irregular surfaces. Untreated areas can be inadvertently covered because of the ease and rapidity of placement. Shotcrete should be used beneath impervious zones only when site conditions preclude using dental concrete. If shotcrete is used, close inspection and caution are necessary. Shotcrete is an acceptable alternative to dental concrete outside the core contact area.

The fill compaction method used depends on the steepness of the surface, the nature of the irregularities in the foundation surface, and the soil material.

A hand tamper may be used to compact earthfill in or against irregular surfaces on abutments, in potholes and depressions, and against structures not accessible to heavy compaction equipment. Hand-tamped, specially compacted earthfill is typically placed in 4-in (10-cm) maximum compacted lifts with scarification between lifts.

Site-specific conditions determine whether hand-compacted earthfill or filling with dental concrete is the best solution.

The feet of the roller must not penetrate the first layer of earthfill and damage the foundation. Penetration can be prevented by using a rubber-tired roller or loader to compact the first few lifts above the foundation surface with scarification between lifts. Earthfill specially compacted by pneumatic-tired equipment is typically placed in 6-in (15-cm) maximum compacted lifts. Placement of horizontal lifts against mildly sloping rock surfaces can result in feathering of the earthfill lift near the rock contact. Placement of the initial lift parallel to the foundation surface (as opposed to a horizontal lift) for foundation surfaces flatter than 10:1 (H:V) is acceptable if the compactor climbing up the slope does not loosen or disturb the previously compacted earthfill.

Core material compacted against steep surfaces is typically placed in 6-in (15-cm) compacted lifts with scarification between lifts. Earthfill 8 to 10 ft (2.4 to 3 m) from a steep surface should be ramped toward the steep surface at a slope of 6:1 to 10:1 so that a component of the compactive force acts toward the steep surface.

Earthfill placed against irregular surfaces should be plastic and deformable so that the material is forced (squished) into all irregularities on the foundation surface by compaction or subsequent loading. The first layer soil moisture contents should range from 0 to 2 percent wet of optimum. Select material with a required plasticity range is commonly specified. A soil plasticity index ranging from 16 to 30 is preferred although not absolutely necessary.

Core materials that are erodible include low plasticity or nonplastic, silty materials and dispersive clays. Preventing erosion of embankment materials into the foundation includes sealing cracks in the foundation with slush grout and dental concrete and using filter zone(s) between the fine-grained material and the foundation. Sealing cracks is not totally reliable because concrete and mortar can crack due to shrinkage or loading. Using natural or manufactured nonerodible material for the first several lifts of embankment at the core-foundation contact is good practice.

If erosion-resistant plastic materials are available, these materials should be used for the first several lifts along the foundation contact to avoid placing erodible nonplastic materials directly against the rock surface. If plastic materials are not available, the natural soil can be mixed with sodium bentonite to produce core material to be placed against the foundation. Laboratory testing should establish the amount of sodium bentonite required to give the soil the characteristics of a lean clay.

If nondispersive material is available, it should be used instead of dispersive material, at least in critical locations such as along the core-foundation contact. In deposits containing dispersive material, the dispersion potential generally varies greatly over short distances. Selectively excavating nondispersive material from a deposit containing dispersive materials is frequently difficult and unreliable. Lime can be added to dispersive materials to reduce or convert the soil to a nondispersive material. The amount of lime required to treat the dispersive soil should be established by performing dispersivity tests on samples of soils treated with varying percentages of lime. Adding lime to a soil results in reduced plasticity and a more brittle soil. The lime content should be the minimum required to treat the soil. Do not treat material that has naturally low plasticity with lime if it is not necessary.

Concrete Arch Dams

The entire area to be occupied by the base of a concrete arch dam should be excavated to material capable of withstanding the loads imposed by the dam, reservoir, and appurtenant structures. Blasting operations must not damage the rock foundation. All excavations should conform to the lines and dimensions shown on the construction drawings, where practical, but it may be necessary to vary dimensions or excavation slopes because of local conditions.

Foundations containing seams of shale, siltstone, chalk, or mudstone may require protection against air and water slaking or, in some environments, against freezing. Excavations can be protected by leaving a temporary cover of unexcavated material, by immediately covering the exposed surfaces with a minimum of 12 in (30 cm) of concrete, or by any other method that will prevent damage to the foundation.

Shaping

Although not considered essential, a symmetrical or nearly symmetrical profile is desirable for an arch dam for stress distribution. However, asymmetrical canyons frequently have to be chosen as arch dam sites. The asymmetry may introduce stress problems, but these can be overcome by proper design. Abutment pads between the dam and foundation may be used to overcome some of the detrimental effects of asymmetry or foundation irregularities. Thrust blocks are sometimes used at asymmetrical sites. The primary use of a thrust block is not to provide symmetry but to establish an artificial abutment where a natural one does not exist. Overexcavation of a site to achieve symmetry is not recommended. In all cases, the foundation should be excavated in such a way as to eliminate sharp breaks in the excavated profile because these may cause stress concentrations in both the foundation rock and the dam. The foundation should also be excavated to about radial or part radial lines.

Dental Treatment

Exploratory drilling or final excavation often uncovers faults, seams, or shattered or inferior rock extending to depths that are impracticable to remove. Geologic discontinuities can affect both the stability and the deformation modulus of the foundation. In reality, the foundation modulus need not be known accurately if the ratio of the foundation modulus E_f to the concrete modulus E_c of the dam is known to be greater than 1:4. Canyons with extensive zones of highly deformable materials and, consequently, E_f /E_c ratios less than 1:4 should still be considered potential arch dam sites. The deformation modulus of weak zones can be improved by removing sheared material, gouge, and inferior rock and replacing the material with backfill concrete.

Analytical methods can provide a way to combine the physical properties of different rock types and geologic discontinuities such as faults, shears, and joint sets into a value representative of the stress and deformation in a given segment of the foundation. This also permits substitution of backfill concrete in faults, shears, and zones of weak rock and evaluates the benefit contributed by dental treatment.

Data required for analysis are the dimensions and composition of the lithologic bodies and geologic discontinuities, deformation moduli for each of the elements incorporated into the study, and the loading pattern imposed by the dam and reservoir.

Dental treatment concrete may also be required to improve the stability of a rock mass. By using data related to the shear strength of faults, shears, joints, intact rock, pore water pressures induced by the reservoir and/or groundwater, the weight of the rock mass, and the driving force induced by the dam and reservoir, a safety factor for a particular rock mass can be calculated.

Frequently, relatively homogeneous rock foundations with only nominal faulting or shearing do not require the sophisticated analytical procedures described above. The following approximate formulas for determining the depth of dental treatment can be used:

$$d = 0.002\ bH + 5 \text{ for } H \geq 150 \text{ ft}$$

$$d = 0.3b+5 \text{ for } H<150 \text{ ft}$$

where:

H = height of dam above general foundation level in ft

b = width of weak zone in ft

d = depth of excavation of the weak zone below the surface of adjoining sound rock in ft. In clay gouge seams, d should not be less than 0.1 H.

These rules provide an estimate of how much should be excavated, but final decisions must be made in the field during actual excavation.

Protection Against Piping

The methods described in the preceding paragraphs will satisfy the stress, deformation, and stability requirements for a foundation, but the methods may not provide suitable protection against piping. Faults, shears, and seams may contain pipable material. To protect against piping, upstream and downstream cutoff shafts may be necessary in each seam, shear, or fault, and the shafts backfilled with concrete. The dimension of the shaft perpendicular to the seam should be equal to the width of the weak zone plus a minimum of 1 foot on each end to key the concrete backfill into sound rock. The shaft dimension parallel to the seam should be at least one-half the other dimension. In any instance a minimum shaft dimension of 5 ft (1.6 m) each way should be used to provide working space. The depth of cutoff shafts may be computed by constructing flow nets and computing the cutoff depths required to eliminate piping.

Other adverse foundation conditions may be caused by horizontally bedded clay and shale seams, caverns, or springs. Procedures for treating these conditions will vary and will depend on the characteristics of the particular condition to be remedied.

Foundation Irregularities

Although analyses and designs assume relatively uniform foundation and abutment excavations, the final excavation may vary widely from that which was assumed. Faults or crush zones are often uncovered during excavation, and the excavation of the unsound rock leaves depressions or holes which must be filled with concrete. Unless this backfill concrete has undergone most of its volumetric shrinkage at the time overlying concrete is placed, cracks can occur in the overlying concrete near the boundaries of the backfill concrete as loss of support occurs because of continuing shrinkage of the backfill concrete. Where dental work is extensive, the backfill concrete should be placed and cooled before additional concrete is placed over the area.

Similar conditions exist where the foundation has abrupt changes in slope. At the break of slope, cracks often develop because of the differential movement that takes place between concrete held in place by rock and concrete held in place by previously placed concrete that has not undergone its full volumetric shrinkage. A forced cooling of the concrete adjacent to and below the break in slope and a delay in placement of concrete over the break in slope can minimize cracking at these locations. If economical, the elimination of these points of high stress concentration is worthwhile. Cracks in lifts near the abutments very often develop leakage and lead to spalling and deterioration of the concrete.

Concrete Gravity Dams

The entire base area of a concrete gravity dam should be excavated to material capable of withstanding the loads imposed by the dam, reservoir, and appurtenant structures. Blasting should not shatter, loosen, or otherwise adversely affect the suitability of the foundation rock. All excavations should conform to the lines and dimensions shown on the construction drawings, where practicable. Dimensions or excavation slopes may vary because of local conditions.

Foundations such as shale, chalk, mudstone, and siltstone may require protection against air and water slaking or, in some environments, against freezing. These excavations can be protected by leaving a temporary cover of unexcavated material, by immediately applying a minimum of 12 in (30 cm) of mortar to the exposed surfaces, or by any other method that will prevent damage to the foundation.

Shaping

If the canyon profile for a damsite is relatively narrow and the walls are steeply sloping, each vertical section of the dam from the center towards the abutments is shorter in height than the preceding one. Consequently, sections closer to the abutments will be deflected less by the reservoir load, and sections toward the center of the canyon will be deflected more. Since most gravity dams are keyed at the contraction joints, a torsional effect on the dam is transmitted to the foundation rock.

A sharp break in the excavated profile of the canyon will result in an abrupt change in the height of the dam. The effect of the irregularity of the foundation rock causes a marked change in stresses in the dam and foundation and in stability factors. For this reason, the foundation should be shaped so that a uniform profile without sharp offsets and breaks is obtained.

Generally, a foundation surface will appear as horizontal in the transverse (upstream-downstream) direction. However, where an increased resistance to sliding is desired, particularly for structures founded on sedimentary rock foundations, the surface can be sloped upward from heel to toe of the dam.

Dental Treatment

Faults, seams, or shattered or inferior rock extending to depths that are impractical to remove require special treatment by removing the weak material and backfilling the resulting excavations with dental concrete. General rules for how deep transverse seams should be excavated have been formulated based on actual foundation conditions and stresses in dams. Approximate formulas for determining the depth of dental treatment are:

$$d = 0.002\ bH + 5 \text{ for } H \geq 150 \text{ ft}$$

$$d = 0.3\ b + 5 \text{ for } H < 150 \text{ ft}$$

where:

H = height of dam above general foundation level in feet

b = width of weak zone in feet

d = depth of excavation of weak zone below surface of adjoining sound rock in feet. In clay gouge seams, d should not be less than 0.1 H.

These rules provide guidance for how much should be excavated, but actual quantities should be determined in the field during excavation.

Although the preceding rules are suitable for foundations with a relatively homogeneous rock foundation and nominal faulting, some damsites may have several distinct rock types interspersed with numerous faults and shears. The effect on the overall strength and stability of the foundation of rock differences complicated by large zones of faulting may require extensive analysis. Data required for analysis include the dimensions and composition of the rock mass and geologic discontinuities, deformation moduli for each of the elements incorporated into the study, and the loading pattern imposed on the foundation by the dam and reservoir.

Dental treatment may also be required to improve the stability of the rock mass. A safety factor for a particular rock mass can be calculated using data related to the strength of faults, shear zones, joints, intact rock, pore water pressures induced by the reservoir and/or groundwater, the weight of the rock mass, and the driving forces induced by the dam and reservoir.

Protection Against Piping

The methods discussed above can satisfy the stress, deformation, and stability requirements for a foundation, but they may not provide suitable protection against piping. Faults and seams may contain pipeable material, and concrete backfilled cutoff shafts may be required in each fault or seam. The dimension of the shaft perpendicular to the seam should be equal to the width of the weak zone plus a minimum of 1 foot (0.3 m) on each end to key the concrete backfill into sound rock. The shaft dimension parallel to the seam should be at least one-half the other dimension. A minimum shaft dimension of 5 ft (1.6 m) each way should be provided for working space. The depth of cutoff shafts may be computed by constructing flow nets and calculating the cutoff depths required to eliminate piping.

Other adverse foundation conditions may be caused by horizontally bedded clay and shale seams, caverns, or springs. Procedures for treating these conditions will vary and will depend on field studies of the characteristics of the particular condition to be remedied.

Foundation Irregularities

Although analyses and designs assume relatively uniform foundation and abutment excavations, the final excavation may vary widely from that which was assumed.

Faults or crush zones are often uncovered during excavation, and the excavation of the unsound rock leaves depressions or holes that must be filled with concrete. Unless this backfill concrete has undergone most of its volumetric shrinkage at the time overlying concrete is placed, cracks can occur in the overlying concrete near the boundaries of the backfill concrete. Shrinkage of the backfill concrete results in loss of support. Where dental work is extensive, the backfill concrete should be placed and cooled before additional concrete is placed over the area.

Similar conditions exist where the foundation has abrupt changes in slope. At the break of slope, cracks often develop because of the differential movement that takes place between concrete held in place by rock and concrete held in place by previously placed concrete that has not undergone its full volumetric shrinkage. A forced cooling of the concrete adjacent to and below the break in slope and a delay in placement of concrete over the break in slope can be employed to minimize cracking at these locations. If economical, the elimination of these points of high stress concentration is worthwhile. Cracks in lifts near the abutments very often leak and lead to spalling and deterioration of the concrete.

Cleanup

Proper cleaning and water control on a foundation before placing fill or concrete allows the structure and soil or rock contact to perform as designed. Good cleanup allows the contact area to have the compressive and shear strength and the permeability anticipated in the design. Poor cleanup reduces the compressive and shear strength resulting in a weak zone under the structure and providing a highly permeable path for seepage.

Cleaning

Foundation cleanup is labor intensive and costly, so it is routinely neglected. The result is substandard foundations that do not meet design requirements. Rock foundations should be cleaned by:

- Barring and prying loose all drummy rock
- Using an air/water jet to remove as much loose material and fluff as possible
- Removing by hand loose material that an air/water jet misses

Soil foundations should be cleaned by removing material missed by machine stripping that will not be suitable foundation after compaction.

Foundations of weak rock or firm soil can be cleaned by placing a steel plate (butter bar) across the teeth of a backhoe or hydraulic excavator and “shaving” or “peeling” objectionable material off the surface, leaving a clean foundation requiring very little hand cleaning.

Water Removal

Water in small quantities can be removed by vacuuming (with a shop vac or air-powered venturi pipe) or blotting with soil and wasting the wet material just before fill placement. Larger water quantities from seeps can be isolated in gravel sumps and pumped. Grout pipes should be installed; the sumps covered with fabric or plastic; fill placed over the fabric; and after the fill is a few feet above the sump, the sump should be cement grouted by gravity pressure. Seeps in concrete foundations can be isolated and gravel sumps constructed and subsequently grouted as described above or if the seeps are not too large, the concrete can be used to displace the water out of the foundation during placement.

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