RECLAMATION

Managing Water in the West

Design Standards No. 13

Embankment Dams

Chapter 3: Foundation Surface Treatment
Phase 4 (Final)

U.S. Department of the Interior
Bureau of Reclamation

July 2012

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 13

Embankment Dams

DS-13(3)-2: Phase 4 (Final)
July 2012

Chapter 3: Foundation Surface Treatment

Foreword

Purpose

The Bureau of Reclamation (Reclamation) design standards present technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Reclamation facilities in a way that protects the public's health, safety, and welfare; recognizes needs of all stakeholders; and achieves lasting value and functionality necessary for Reclamation facilities. Responsible designers accomplish this goal through compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholders' vision and values, that are then reflected in the constructed facilities.

Application of Design Standards

Reclamation design activities, whether performed by Reclamation or by a non-Reclamation entity, must be performed in accordance with established Reclamation design criteria and standards, and approved national design standards, if applicable. Exceptions to this requirement shall be in accordance with provisions of *Reclamation Manual Policy*, Performing Design and Construction Activities, FAC P03.

In addition to these design standards, designers shall integrate sound engineering judgment, applicable national codes and design standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs are produced that protect the public's investment and safety. Designers shall use the most current edition of national codes and design standards consistent with Reclamation design standards. Reclamation design standards may include exceptions to requirements of national codes and design standards.

Proposed Revisions

Reclamation designers should inform the Technical Service Center (TSC), via Reclamation's Design Standards Website notification procedure, of any recommended updates or changes to Reclamation design standards to meet current and/or improved design practices.

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 13

Embankment Dams

Chapter 3: Foundation Surface Treatment

DS-13(3)-2:[1] Phase 4 (Final)
July 2012

Chapter 3 – Foundation Surface Treatment is an existing chapter within Design Standards No. 13 and was revised to include:

- Reorganized chapter content
- Updated content to reflect modern construction practice
- Added detail describing shaping, slush grouting, dental concrete, foundation irregularities, water removal, inspection, and foundation approval
- Added figures and photographs
- Added definitions
- Added appendices
- Updated references

[1] DS-13(3)-2 refers to Design Standards No. 13, chapter 3, revision 2.

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Definitions

Dental concrete: Concrete used to fill or shape foundation irregularities such as holes, grooves, vertical surfaces, overhangs, solution features, shear zones, large joints, or buried channels.

Dewatering: Removal and control of ground water from pores or other open spaces in soil or rock formations to allow construction activities to proceed as intended; includes relief of ground water pressures.

Shotcrete: Concrete or mortar that is sprayed in place.

Slush grout: Neat cement grout (for cracks less than ½ inch) or sand-cement slurry (for cracks greater than ½ inch) that is placed into cracks in the foundation.

Unwatering: Control and removal of ponded, seeping, or flowing surface water or emerging surface water from excavated surfaces and from precipitation within and adjacent to excavations and construction zones using channel, ditches, gravel drains, gravel blankets, pipe, sumps, and discharge lines.

Chapter 3

Foundation Surface Treatment

3.1 Introduction

3.1.1 Purpose

This chapter discusses foundation preparation for and placement of the first several layers of earthfill for embankment dams and appurtenant structures. Preparation includes excavating overburden; initial cleaning and inspection; removal of unsuitable material; shaping the foundation surface by excavation and filling; excavation dewatering and unwatering; and final cleanup, inspection, and foundation approval. Final foundation cleanup is required before fill placement.

3.1.2 Scope

This chapter presents design criteria for surface treatment of an embankment dam foundation to make it suitable for placement of the overlying embankment. Criteria are discussed for both soil and rock foundations. Dimensions in this chapter are listed for guidance and have been used by Reclamation on structures.

Foundation treatment for concrete dams can be found in Design Standards No. 2 (Concrete Dams), Chapter 1 (Introduction). For foundation treatment for spillways and outlet works for both embankment and concrete dams, refer to Design Standards No. 14 (Appurtenant Structures for Dams), Chapters 3 (General Spillway Design Considerations) and 4 (General Outlet Works and Diversion Design Considerations). Subsurface treatments such as foundation grouting and cutoff walls can be found in Design Standards No. 13 (Embankment Dams), Chapters 15 (Foundation Grouting) and 16 (Cutoff Walls). Foundation surface treatments such as protective filters can be found in Design Standards No. 13 (Embankment Dams), Chapter 5 (Protective Filters).

3.1.3 Deviations from Standard

Foundation surface treatment for embankment dams and appurtenant structures should conform to this standard. Deviations from this standard should be documented and approved. The rationale for not using the standard should be described in the documentation. The technical documentation must be approved by appropriate line supervisors and managers.

3.1.4 Revisions of Standard

This chapter will be revised as its use indicates. Comments or suggested revisions should be forwarded to the Chief, Geotechnical Services Division (86-68300), Bureau of Reclamation, Denver, Colorado 80225; they will be comprehensively reviewed and incorporated as needed.

3.1.5 Applicability

The procedures and recommendations in this chapter are applicable to the construction of earth fill dams and appurtenant structures founded on either soil or rock.

3.1.6 Objectives at Structure/Foundation Contact

Geologic processes cause dam foundations to be much less than perfect for the construction of an embankment dam. Thus, foundation treatment is almost always required to improve a foundation to a suitable condition before a dam is constructed. Recognition of natural processes that damage foundations help formulate treatment objectives. Such processes and their effects include:

- Buried river channels
- Faulting
- Shearing
- Slope instability
- Solution cavities
- Potholes
- Benches
- Overhangs
- Steps
- Stress relief joints

Foundation treatments will be needed for these and other anomalies.

The basic objectives of foundation surface treatment are:

- **Embankment Foundation Contact**. Obtain appropriate contact between overlying embankment materials and the foundation. The foundation surface must be shaped by excavation or concrete placement (dental concrete) 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 the foundation without damaging the foundation during placement of the first and subsequent lifts.

- **Preventing Internal Erosion of Embankment Materials**. Defend against seepage-induced erosion of embankment materials into the foundation or by scour along the contact by filling surface cracks in the foundation, blanket grouting, protective filters, and the use of nonerodible embankment materials (natural or manufactured) at the foundation contact. Blanket grouting and filter design are covered in separate Design Standards chapters.

- **Remove Unsuitable Foundation Materials.** Remove or treat unsuitable, erodible, weak, unstable, liquefiable, or pervious materials to ensure a foundation of adequate strength and appropriate permeability. When in doubt, take it out. Beneath the impervious core, the foundation should be as impervious as possible. Defects in rock foundations including fault gouge, rock fragments, soft or pervious soil, fractures, joints, and bedding laminations must be evaluated. These defects in the foundation require removal to an adequate depth and treatment with slush grout, dental concrete, filter material, or specially compacted earthfill, as well as cleanup of the foundation immediately prior to the first placement of dam material.

- **Prevent Embankment Cracking.** Avoid cracking and resultant seepage problems in embankment dams that may be caused by irregularities in the foundation surface, such as stepped surfaces, abrupt changes in slope, overhangs, and excessively steep surfaces and deep narrow fill zones. Differential settlement may occur in embankment zones adjacent to these areas, resulting in the development of cracks. Arching can occur near steep surfaces with a zone of low stress adjacent to the steep surface. Such zones are also susceptible to hydraulic fracturing. The foundation surface should be shaped to obtain a smooth, continuous surface that minimizes differential settlement and cracking potential.

- **Prepare Foundation Outside of Core Contact.** Shape the foundation outside of the core contact to facilitate placement and compaction operations. Weak or compressible materials determined to be unsuitable must be removed. Shell and filter materials must be prevented from moving into open joints or pervious zones in the foundation, and erodible foundation materials must be prevented from moving into the embankment by using appropriately graded filters.

- **Prevent Foundation Damage.** Avoid construction excavation damage. Be careful! Damage can be caused by rippers, blasting, tracked equipment, and slaking of unprotected weak rock. Prevent damage to the foundation from placement equipment during the first few lifts of fill by routing equipment travel, allowing only rubber-tired equipment on the foundation surface, temporary coverings, or other means as needed. Rock surfaces that slake or disintegrate rapidly on exposure must be protected or covered immediately with embankment material, chemical sealants, or concrete.

- **Document and Verify the Foundation Conditions.** Map, photograph, and fully understand the significance of all geologic features before placing embankment fill or concrete. It is essential to verify that the project design remains suitable for the actual foundation conditions encountered. Formal foundation approval by the project engineer should be obtained prior to proceeding with dam construction.

3.2 Treatment for Earthfill Dams

3.2.1 Excavation

Zoned earthfill and rockfill dams are commonly constructed in broad sites where their foundations cover large areas. Embankment dams tend to be somewhat forgiving of some foundation and embankment settlement, which generally occurs primarily during construction, and they are often constructed on foundations that would be marginal or unacceptable for concrete dams.

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. When the foundation is soil, all organic or other unsuitable materials, such as stumps, brush, sod, and large roots should be stripped as shown in figure 3.2.1-1. Materials such as sod and topsoil can be reused to cover areas that are to be seeded, while other materials should be wasted. When the foundation is rock, the foundation should be treated as shown in figures 3.2.1-2 through 3.2.1-5. These figures detail slope modification and foundation excavation.

Stripping should be performed carefully to ensure the removal of all material that may be unstable because of saturation, slaking, 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 or rock significantly weaker or more compressible than the average foundation material. Exploratory test pits could be excavated if the stripping operations indicate the presence of unstable or otherwise unsuitable material.

Figure 3.2.1-1 All organic or other unsuitable materials should be removed from soil foundations.

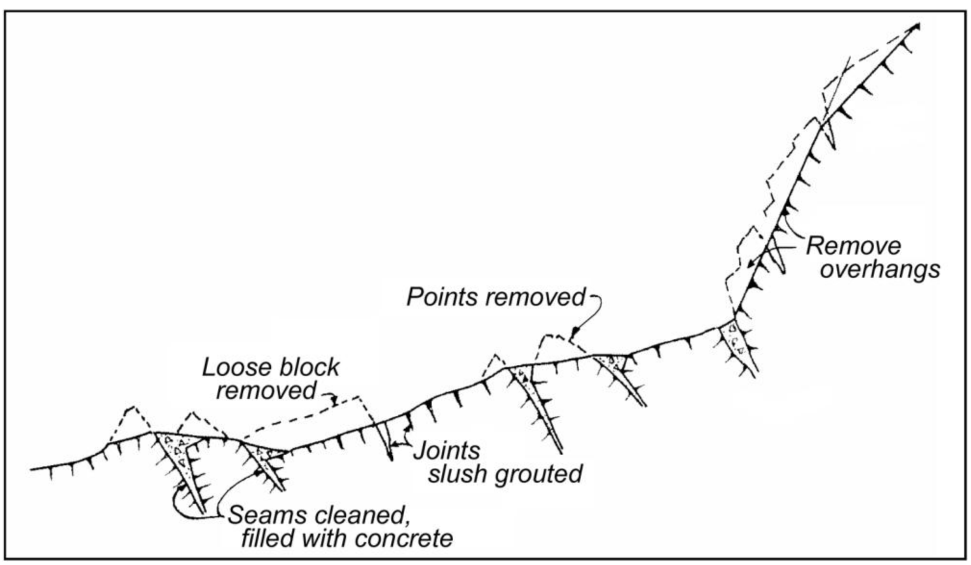

Figure 3.2.1-2 Treatment of rock foundation.

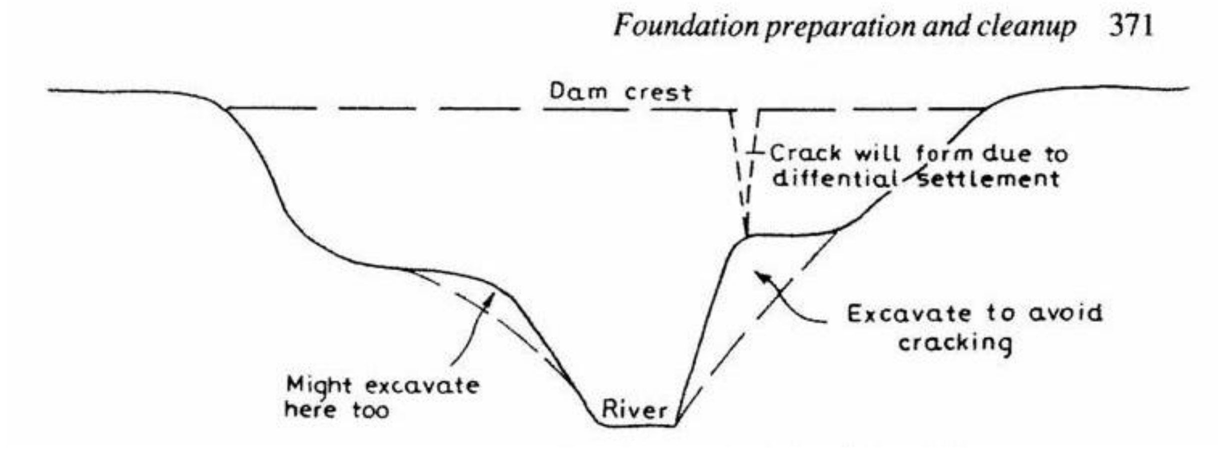

Figure 3.2.1-3 Slope modification to reduce differential settlement and cracking of the earthfill core (Fell et al., 1992).

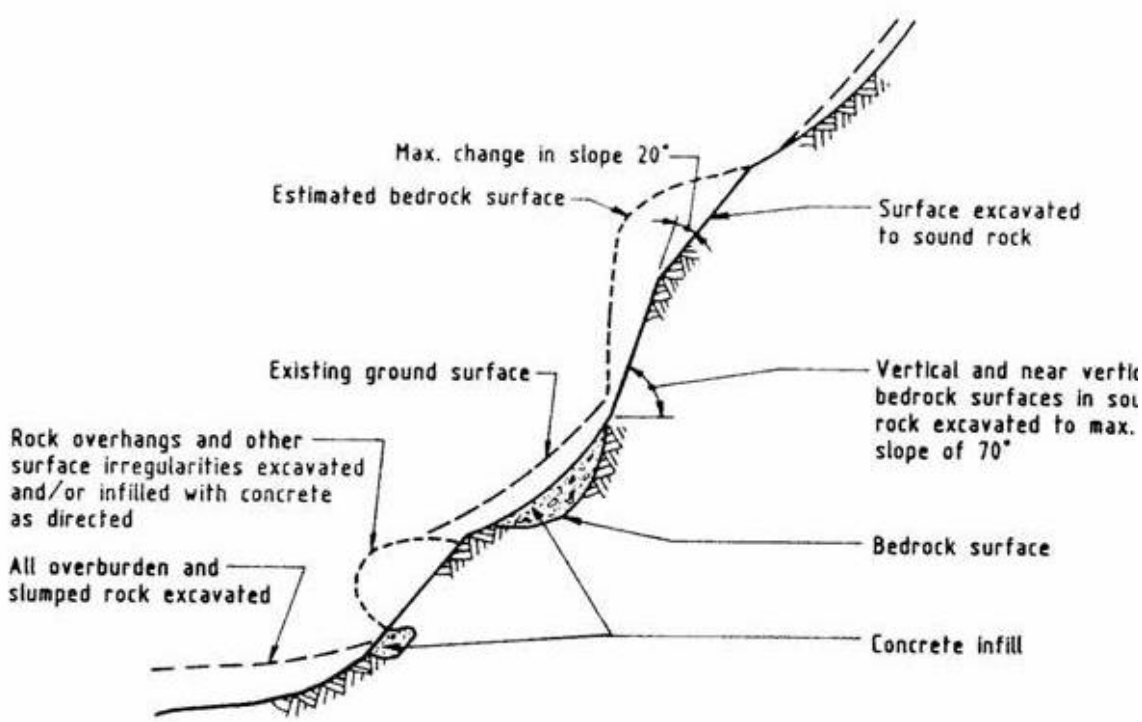

Figure 3.2.1-4 Mica Dam. Foundation excavation, typical excavation detail (Pratt et al., 1972; reproduced in Fell et al., 1992).

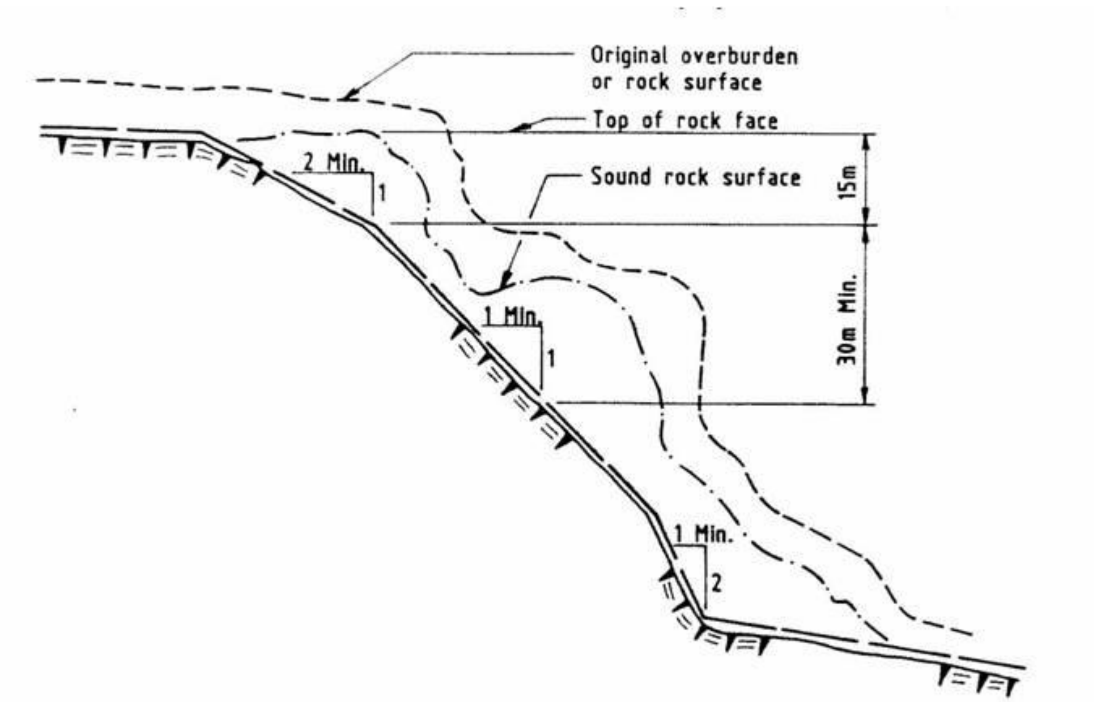

Figure 3.2.1-5 Bennet Dam, typical core abutment excavation requirements (Pratt et al., 1972;

3.2.2   Initial Cleaning and Inspection

Foundations are cleaned to provide acceptable conditions of contact between the body of the dam and its foundation, and to provide for observation and documentation of details of foundation conditions at that interface. Exposure of potentially adverse conditions during cleanup provides the opportunity to take remedial action. The foundation must be cleaned to make the necessary observations and to determine when additional treatment is required.

After initial stripping, or after sufficient excavation is accomplished so that excavation is nearing final lines and grades, the foundation should be cleaned to allow inspection by the designer, construction engineer, construction inspector, and geologist. Whenever possible, the Consultant Review Board or some of its members should be included in the initial foundation inspection. The initial foundation cleaning should be sufficient to allow observation, and possibly sampling, to determine if unsuitable materials or conditions (such as open fractures, shears, faults, overhangs, etc.) exist in the foundation. The initial inspection should be adequate to determine how to correct any deficiencies in the foundation.

3.2.3 Removal of Unsuitable Material

3.2.3.1 Soil Foundation

When the foundation is earth, 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 become unstable due to saturation 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. Highly pervious soils, such as open work gravels, may need to be removed or treated. Loose, low density soils should be removed to avoid excess settlement and the potential for seismic liquefaction. Exploratory test pits should be excavated if the stripping operations indicate the presence of unstable or otherwise unsuitable material.

3.2.3.2 Rock Foundation

When the foundation is rock, all erodible, weak, unstable, compressible (or loose), or pervious materials should be removed if they are unsuitable without treatment to ensure a foundation of adequate strength and appropriate permeability. In rock foundations, defects such as faults, fractures, open joints, erosion channels, or solution cavities or channels sometimes cannot be completely removed. Material in defects in the rock mass includes fault/shear gouge, rock fragments, soft or pervious soil, or solutioned rock. These materials require removal to an adequate depth, as well as replacement with slush grout, dental concrete, or specially compacted earthfill.

Other adverse foundation conditions may be caused by 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.

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

Slaking behavior varies with rock type and may require evaluation for each individual case. Faults, shears, joints, and solution channels may contain erodible material.

3.2.4 Shaping the Foundation Surface by Excavation and Filling

3.2.4.1 Soil Foundation

The foundation surface should be shaped by excavation and filling both under the core contact and outside of the core contact to facilitate placement and compaction operations.

Construction activities such as using tracked equipment on soft surfaces or using rippers near foundation grade may loosen or damage soil foundations. This type of damage can and should be avoided to limit excavation, backfilling, and cleanup. Unsuitable or damaged material must be removed, and the foundation surface must be shaped to provide a sufficiently regular surface on which earthfill can be placed without differential settlement. If the irregularities are small enough and discontinuous both horizontally and vertically, overexcavation can be appropriate, followed by backfilling with suitable material and compaction. Generally, the foundation surface can be shaped adequately by conventional excavation.

All irregularities, ruts, and washouts in a soil foundation should be removed to provide a satisfactory foundation that is smooth and firm. Cut slopes should be flat enough to prevent sloughing and not steeper than 1H:1V (horizontal to vertical). For cuts beneath the core, in a line oriented upstream-downstream, slopes of 4H:1V are preferable. Soil material that has been loosened to a depth of less than 6 inches is often treated by compaction. Loosened material deeper than 6 inches cannot be adequately compacted and should be removed.

3.2.4.2 Rock Foundation

The foundation surface should be shaped by excavation and filling, both under the core contact and outside of the core contact, to facilitate placement and compaction operations. How the exposed rock surface is shaped 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 can and should 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 (see figure 3.2.4.2-1). Unsuitable material must be removed from the irregularities, and the foundation surface must be shaped to provide a sufficiently regular surface on which earthfill can be placed without differential settlement (see figure 3.2.4.2-2). 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 would require excessively large quantities of excavation or blasting that could damage the foundation, shaping with dental concrete may be appropriate (see figure 3.2.4.2-3).

When overburden is stripped to bedrock, carefully clean the rock surface and all pockets or depressions of soil and rock fragments before the embankment is placed as shown in figures 3.2.4.2-1, 3.2.4.2-2, 3.2.4.2-4, 3.2.4.2-5, and 3.2.4.2-6. This may require compressed air or water cleaning and handwork as shown in figure 3.2.4.2-7. Rock surfaces that slake or disintegrate rapidly on exposure must be protected immediately with embankment material, concrete (dental, shotcrete), or by other means such as delaying final excavation until immediately before fill placement. Foundation rock should be shaped to remove overhangs and steep surfaces (figure 3.2.4.2-8). High rock surfaces must be stable during construction and should be cut back to maintain a smooth, continuous profile to minimize differential settlement and stress concentrations within the embankment. Final slopes should be 0.5H:1V or flatter. Beneath the impervious zone, all overhangs should be removed; stepped surfaces steeper than 0.5H:1V and higher than 0.5 foot should be excavated or treated with dental concrete to a slope of 0.5H:1V or flatter (figure 3.2.4.2-9). Outside the impervious zone, all overhangs should be removed, and stepped surfaces steeper than 0.5H:1V and higher than 5 feet should be excavated or treated with dental concrete to a slope of 0.5H:1V or flatter. These are guidelines. The final decision on shaping rock surfaces should be made during the foundation inspection and approval process.

Overhangs and steps should be removed or filled in with concrete. Removal is preferred. The finished surface should be formed by smooth blasting techniques or line drilling. High rock slopes 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 0.5H:1V or flatter, depending on the fill material.

On steep surfaces, ramping the fill aids compaction; no steeper than a 6H:1V slope should be used for ramping the fill.

Figure 3.2.4.2-1 Upper Stillwater Dam. Features such as this shear zone create foundation irregularities that require treatment. The surface should be cleaned of all loose and weathered rock, and the shear zone should be filled with dental concrete. Alternatively, the surface might be reformed by smooth blasting techniques.

Figure 3.2.4.2-2 Ridges Basin Dam. This dam foundation was shaped to ensure proper compaction of fill and to prevent stress irregularities in the overlying embankment.

Figure 3.2.4.2-3 Extensive use of dental concrete used to fill potholes, grooves, and channels in rock surface.

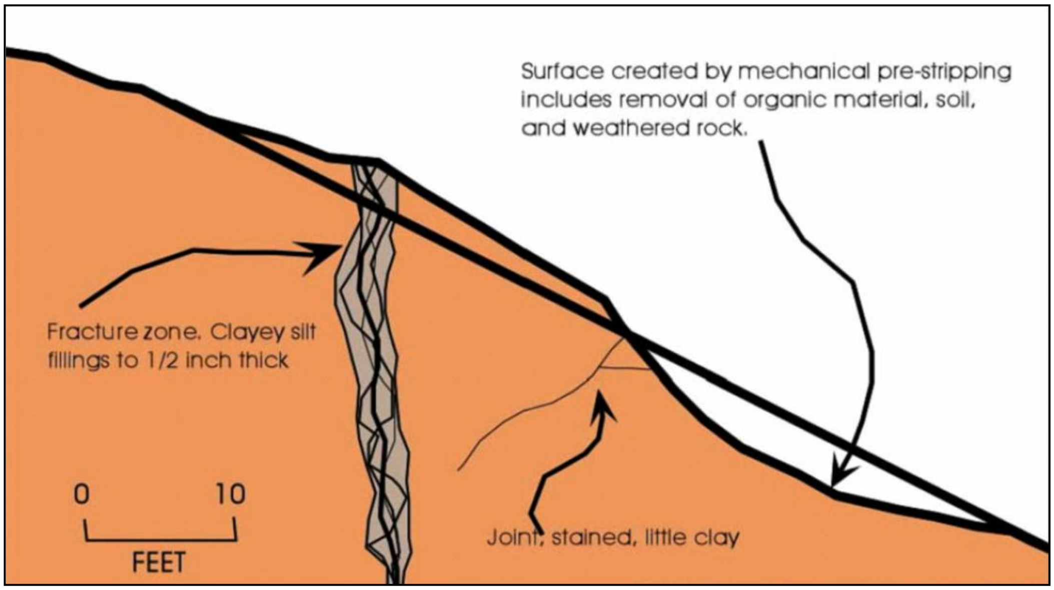

Figure 3.2.4.2-4 Stripping of foundation removes all vegetation, soil, weathered rock, and significant anomalies.

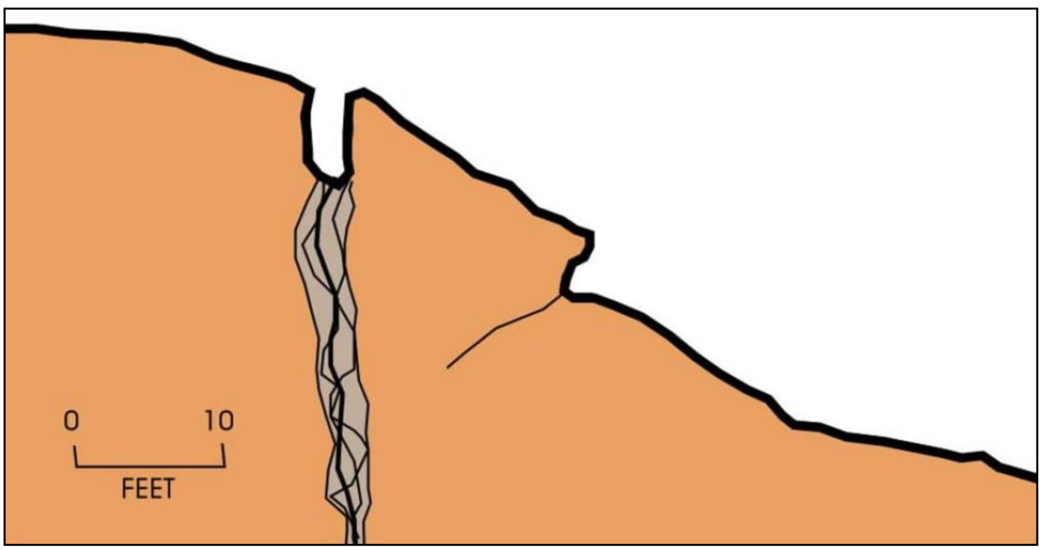

Figure 3.2.4.2-5 Foundation cleaning is complete. All unsound, loose, or detached blocks and soil-like sediment are removed.

Figure 3.2.4.2-6 Ridges Basin Dam. Foundation after stripping and before cleanup.

Figure 3.2.4.2-7 Ridges Basin Dam. Foundation cleanup using compressed air blow pipe.

Figure 3.2.4.2-8 Drilling blast holes to facilitate removal of a rock overhang at Teton Dam.

Slush grout or joint mortar should be used to fill narrow cracks in the foundation as shown in figures 3.2.4.2-10 and 3.2.4.2-11. 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 generally for openings less than ½ inch or, in some cases, Portland cement, sand, and water generally for openings greater than ½ inch. The slush grout is preferably used just before fill placement to eliminate potential for hardened grout to crack under load as the fill is placed. 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 as shown in figure 3.2.4.2-3. Formed dental concrete can be used to fillet steep slopes and fill overhangs.

Figure 3.2.4.2-9 Teton Dam. The stepped surface in this right abutment key trench could result in cracking and seepage problems in overlying embankment. Embankment may differentially settle adjacent to these surfaces, resulting in cracks.

Stepped surfaces that are steeper than 0.5H:1V and higher than 0.5 foot should be excavated or treated with dental concrete to a resultant slope of 0.5H:1V or flatter, depending on the fill material.

Remove overhangs as shown in figure 3.2.4.2-8. Overhangs should be trimmed, or the undercut below the overhang should be filled with dental concrete. If concrete fill is used, grouting would be required to ensure a watertight joint between concrete and rock.

Figure 3.2.4.2-10 Ridges Basin Dam. Open stress relief joint in foundation requires filling with slush grout.

Figure 3.2.4.2-11 Slush grout being applied to an open joint in a dam foundation.

If shaping requires blasting, proper blasting procedures are essential to ensure that the permeability and strength of the rock are 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 techniques, can result in unacceptable excavated surfaces. Prohibit or strictly control blasting for the excavation to avoid damaging the foundation. Review, approval, and enforcement of the contractor's blasting plan, control of blasting details, requirements for acceptability of the excavated surface, and control of vibration levels can help obtain the desired excavation surface. Refer to Reclamation’s Position Paper on Construction Blasting Vibration Limits in appendix A.

If the material cannot be excavated with a hydraulic excavator fitted with a rock bucket, grout nipples can be set directly in the competent foundation. An intensely weathered zone can be grouted effectively by leaving the foundation high and setting grout nipples through the unsuitable material. Long grout nipples may be necessary in poor quality rock. Excavation to final foundation grade is completed after grouting.

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 (see figures 3.2.4.2-4 and 3.2.4.2-5 and figure 3.2.4.2-12):

- Openings narrower than 2 inches should be cleaned to a depth of three times the width of the opening and treated by filling.
- Openings wider than 2 inches and narrower than 5 feet should be cleaned to a depth of three times the width of the opening or to a depth where the opening is 0.5 inch wide or less, but usually not to a depth exceeding 5 feet and treated by filling.
- Openings wider than 5 feet constitute a special situation requiring the depth of cleaning and treatment to be determined in the field.

Shape the foundation to ensure proper compaction of fill and to prevent stress irregularities in the overlying embankment (see figures 3.2.4.2-2 and 3.2.4.2-8). The foundation surface should be shaped by excavating or by filling with concrete to obtain a smooth, continuous surface.

Figure 3.2.4.2-12. Upper Stillwater Dam. Shear zone in foundation being cleaned out for concrete backfill.

Stress cracking, 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 can occur near steep surfaces, resulting in a zone of low stress adjacent to the steep surface. Tension zones or areas of low confining stresses in the embankment are susceptible to hydraulic fracturing and seepage forces.

3.2.5 Excavation Dewatering/Unwatering

Methods for removal and control of water (dewatering and unwatering) for excavating cutoff trenches or stabilizing foundations should ensure that fine material is not washed out of the foundation because of improper filtering of wells or sumps. The water level should be drawn down sufficiently to permit construction “in the dry” and to maintain stability of cut slopes and the excavation invert.

Whenever possible, locate well points and sumps outside the area to be excavated to avoid work interference. 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 and pipes within the impervious zone because of the difficulty in properly grouting them after fill placement and due to the danger of damaging the impervious zone/foundation contact. Trenches and pipes, if used, should not be aligned in the upstream to downstream direction.

3.2.6 Final Cleanup

Proper cleaning and water control on a foundation before placing fill or concrete allow 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.

Special cleanup procedures are required for foundation materials that deteriorate (slake) when exposed to air or water. 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. Cleaning the surface and placing a lean concrete “mud slab” approximately 4 inches thick may be effective. Usually, removing the last few inches (or feet) 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 footprint is typically less critical. Loose material should be removed so that the embankment is in direct contact with suitable rock. If defects are small and outside the core, they may not require cleaning and refill. If defects are continuous upstream to downstream, they require cleaning similar to the foundation beneath the core.

3.2.6.1 Cleaning

Foundation cleanup is labor intensive (as shown in figure 3.2.6.1-1) and costly yet necessary. When cleaning is neglected, it results in substandard foundations that do not meet design requirements. As appropriate, 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

Figure 3.2.6.1-1. Foundation cleanup is labor intensive and costly but should not be neglected.

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 often be cleaned by scraping/dragging a steel plate (butter bar) welded across the teeth of a backhoe or hydraulic excavator and scraping, “shaving,” or “peeling” objectionable material off the surface, leaving a clean foundation requiring very little hand cleaning.

The choice of using air, air and water, or a water jet spray for cleaning is site specific. Rock materials such as slaking shales and chalks should be cleaned with air jets because they may be damaged by water. Where plastic soils cover rock, surfaces cleaned with combined air and water jet sprays or water sprays are more practical. In such cases, air is usually ineffective. Water-only sprays apply the greatest cleaning force to the surface and are preferred in cleaning strong and highly irregular rock surfaces. Weaker rocks such as thinly bedded sandstone may be damaged by powerful water sprays and are often better cleaned using an air/water mixture, which has less impact than a water-only jet. This blowdown can be supplemented with high volume vacuum (vacuum truck) to clean the surface of large areas, or small volume vacuum (shop vacuum) in small areas. In areas where the rock is prone to slaking, the foundation cleanup should be completed before slaking occurs, and foundation cleanup should not commence until fill materials or concrete are available to be placed on the foundation.

3.2.6.2 Water Removal

Remove all water from low-lying areas. Refrain from using compressed air to displace standing water (this normally creates a muddy coating on the surrounding rock surface that subsequently requires removal because it will not provide adequate bond with fill or concrete). Remove muddy coatings from the rock.

Water in small quantities can be removed by vacuuming (with a high volume vacuum 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. Avoid aligning trenches or pipelines in an upstream-downstream orientation. Sumps and associated drainage trenches should not be within the impervious zone because of difficulty in properly grouting them after fill placement and due to the danger of damaging the impervious zone/foundation contact.

3.2.6.3 Dental Concrete

Dental concrete is used to fill or shape holes, grooves, extensive areas of vertical surfaces, and sawteeth or stair steps created by bedding planes, joints, and other irregularities such as previously cleaned out solution features, shear zones, large joints, or buried channels (see figures 3.2.6.3-1 through 3.2.6.3-3). Formed dental concrete can be used to fillet steep slopes and fill overhangs. Placing a concrete mat over a zone of closely spaced irregularities may be appropriate in local areas. Dental concrete shaping can be used instead of removal by blasting when excessive amounts of excavation would otherwise be required.

Unless this backfill concrete has undergone most of its volumetric shrinkage at the time overlying embankment is placed, cracks can occur in the overlying embankment near the boundaries of the backfill concrete. Loss of support occurs because of continuing shrinkage of the backfill concrete. Where dental work is extensive, the backfill concrete should be placed and cured before embankment is placed over the area.

Figure 3.2.6.3-1 Dental concrete and acceptable vertical steps can be tolerated in the foundation.

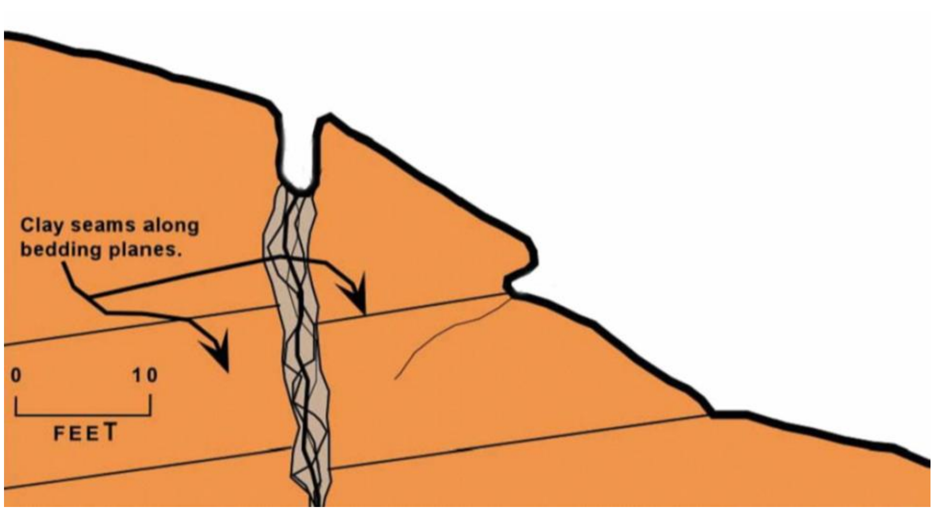

Figure 3.2.6.3-2 Bedding planes may modify cleanup plans. Here, a decision is made to remove the rock mass. This affects the decisions on the subsequent treatment.

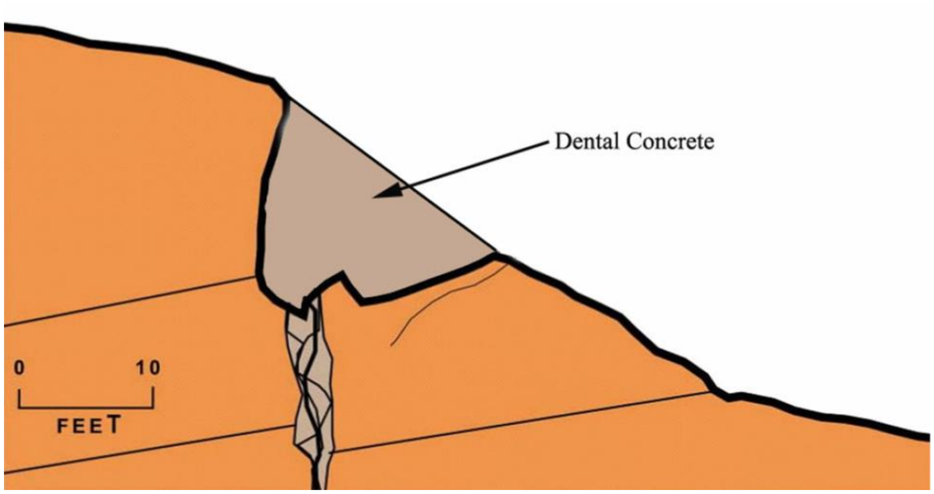

Figure 3.2.6.3-3 Block is removed between fractured zone, bedding plane, and joints. Treatment to further shape the surface required dental concrete.

Slabs of dental concrete should have a minimum thickness of 2 to 6 inches depending on the quality of the foundation. 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 the placement of continuous slabs of concrete over areas containing numerous irregularities on weak foundations. Feathering (thin edges) should not be permitted at the end of concrete slabs on weak foundations, and the edges of slabs should be sloped no flatter than 45 degrees as shown in figure 3.2.6.3-4.

Concrete mix proportions should provide a 28-day strength of 3,000 pounds per square inch. The maximum aggregate size should be less than one-third the thickness 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 ground water. Low-alkali cement is required for alkali-reactive aggregates. Aggregate and water quality should be equal to that required in structural concrete.

The rock surface should be thoroughly cleaned 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 and to prevent air pockets between the concrete and the upper surface of the overhang. The concrete must be formed and placed so that the top of the concrete is higher than the upper surface of the overhang so that the pressure creates a tight fit. Grout pipes should be installed in the dental concrete for later filling of the air voids. If grouting through dental concrete takes place, pressures should be closely controlled to prevent jacking the concrete or fracturing the fill.

Figure 3.2.6.3-4 Feathering at the ends of concrete placements should not be permitted. The edges of concrete should be sloped no flatter than 45 degrees.

Finished 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 (or until 70 percent of design strength is achieved) to allow concrete time to develop sufficient strength to withstand stress caused by placing and compacting earthfill. Inadequate curing may cause the concrete to crack.

3.2.6.4 Slush Grout

Slush grout is a neat cement grout (for cracks less than ½ inch) or a sand-cement slurry (for cracks greater than ½ inch) that is placed into cracks in the foundation. Cracks or joints are filled with grout rather than spreading grout on the surface (as shown in figure 3.2.6.4-1). Slush grout should be used to fill narrow surface cracks and not to cover areas of the foundation. 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. The consistency of the slush grout mix may vary from a very thin mix to mortar as required to penetrate the crack. The water to cement ratio should be kept as low as possible to prevent shrinkage. The grout preferably should be mixed with a mechanical or centrifugal mixer, and the grout should be used within 30 minutes after mixing.

Figure 3.2.6.4-1 Ridges Basin Dam. Slush grout application in an open, cleaned joint.

The type of cement required will depend on the concentration of sulfates in the foundation materials and ground water. Low-alkali cement is required for alkali sensitive aggregates. Sand and water quality should be equal to that required for structural concrete. Reclamation uses type K cement that contains anhydrous calcium aluminate, an expanding agent that counteracts shrinkage.

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. Brooming slush grout is best done just before material placement so that cracking will not occur during compaction.

3.2.6.5   Shotcrete

Shotcrete is concrete or mortar that is sprayed in place. Some shotcrete is mixed with synthetic fibers to obtain a stronger product and so it can adhere to steeper slopes. 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. Shotcrete should be placed in thin lifts (2 inches or less) to ensure intimate contact with the foundation rock. Areas that have not yet been prepared 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 can be an acceptable alternative to dental concrete outside the core contact area (figure 3.2.6.5-1).

Figure 3.2.6.5-1 Shotcrete application.

3.2.6.6 Additional Examples of Dam Foundation Excavation, Treatment, and Cleaning

Figures 3.2.6.6-1 through 3.2.6.6-10 provide additional examples of foundation excavation, treatment, and cleaning.

Figure 3.2.6.6-1 Upper Stillwater Dam. Foundation excavated to material capable of withstanding loads imposed by the dam. Left side of photograph shows acceptable steps; right side shows steps requiring concrete fillets.

Figure 3.2.6.6-2 Treating foundation with dental concrete.

Figure 3.2.6.6-3 Foundation for outlet works structure was shaped and treated with dental concrete.

Figure 3.2.6.6-4 Ridges Basin Dam. Foundation dental concrete. Sometimes a dental concrete slab is a mass placement.

Figure 3.2.6.6-5 Entire footprint of a concrete gravity dam is excavated to material capable of withstanding loads imposed by the dam.

Figure 3.2.6.6-6 Upper Stillwater Dam. After stripping and before cleanup.

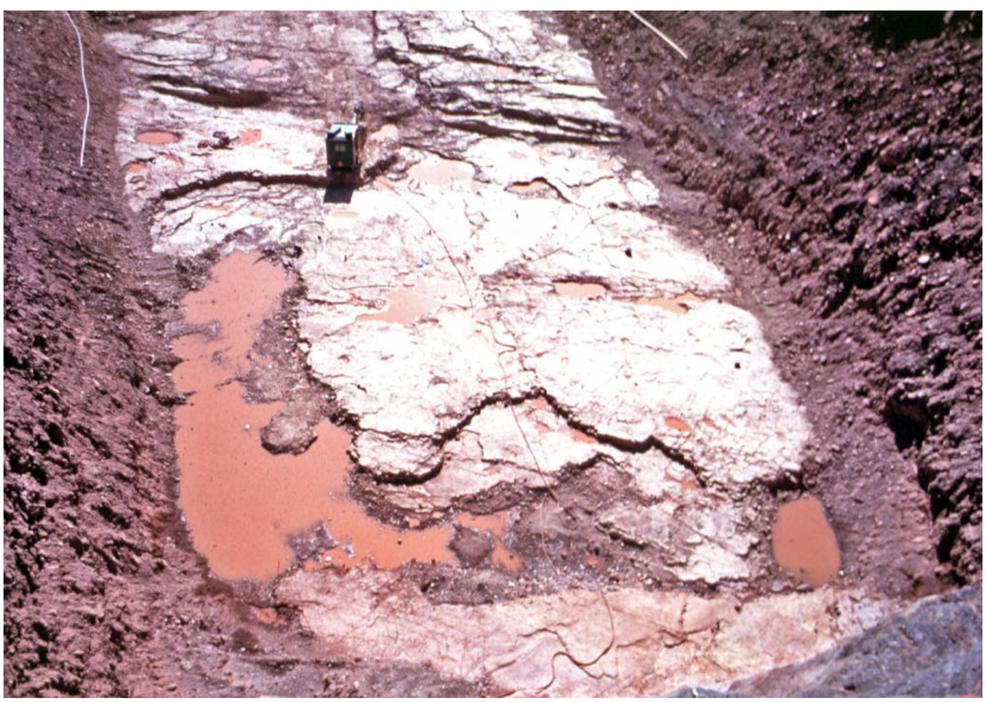

Figure 3.2.6.6-7 New Waddell Dam. After initial cleanup. Before any treatment.

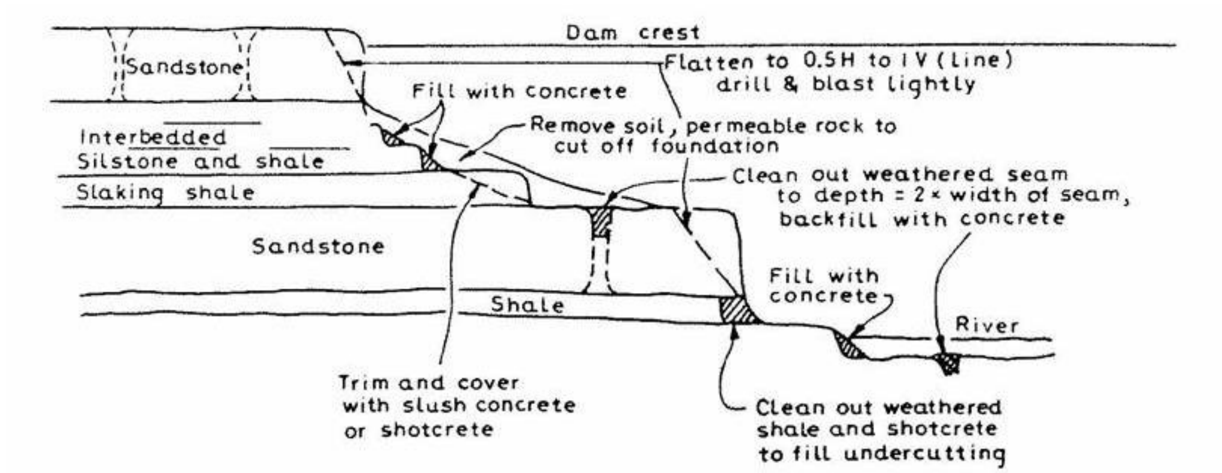

Figure 3.2.6.6-8 Mica Dam foundation excavation, typical excavation detail (Fell et al., 1992).

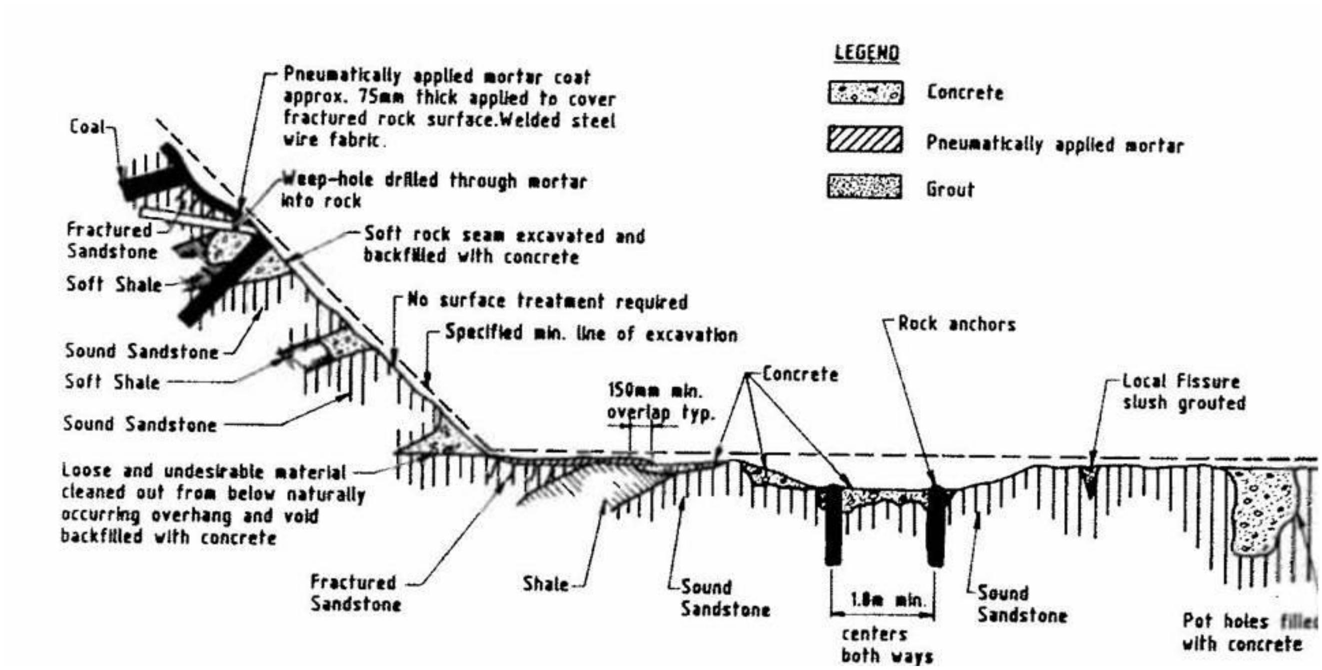

Figure 3.2.6.6-9 Typical core contact surface treatment details, Mica Dam (Pratt et al., 1972; as reproduced in Fell et al., 1992)

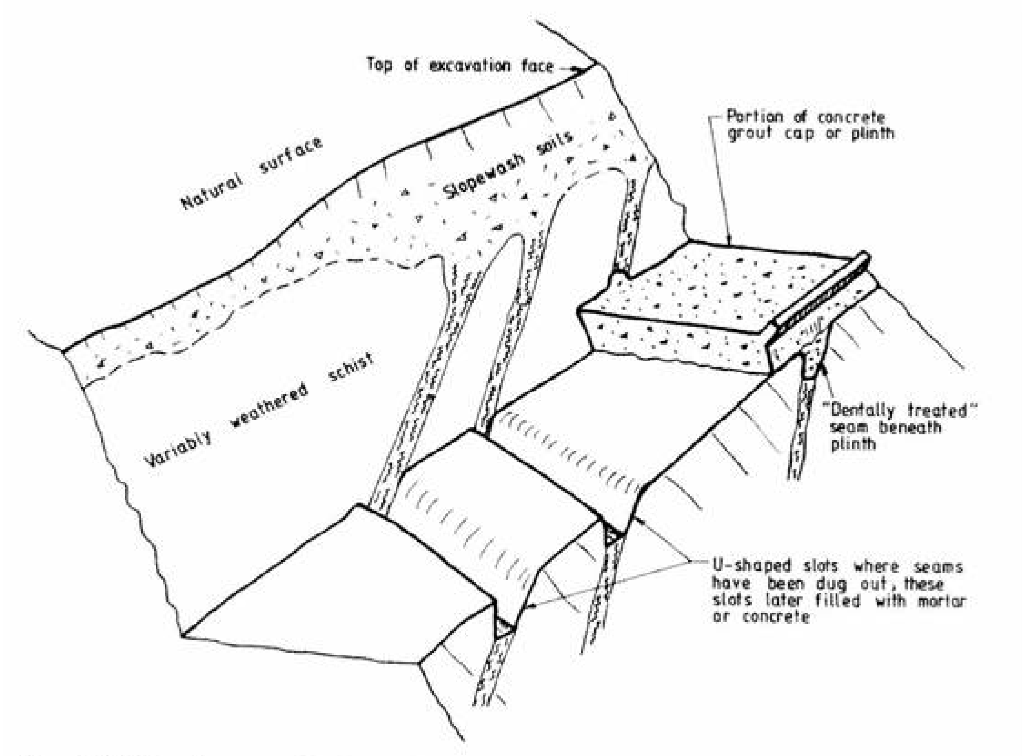

Figure 3.2.6.6-10 Dental treatment of weak seams in the plinth foundation of Kangaroo Creek Dam (Fell et al., 1992).

3.3 Inspection and Foundation Approval

The lead embankment designer and geologist should inspect the final excavated foundation surface to verify that the final foundation conditions are as anticipated and design intent is achieved. This is considered critical. Timely inspections and effective resolution of any foundation-related issue should occur. Foundations should not be approved for concrete or embankment fill placement until the following is verified:

- The quality and sufficient details of foundation geologic records.
- An experienced engineering geologist has reviewed and signed technical approval of the geologic records.
- Topographic survey of final excavated surfaces at a scale sufficient to confirm that adverse surfaces such as overhangs, unacceptable slope changes, etc., do not exist.

- Geologic maps and photographs of final excavated surface, and a full understanding of the significance of all geologic features should be ensured before placing embankment fill.
- The lead embankment designer has evaluated the foundation and has determined that the foundation conforms to the design intent; that shaping, treatment, and cleaning are adequate; and that the foundation is acceptable for commencement of embankment placement.

The foundation should be segmented into manageable areas if the area is too large.

Figures 3.3.1 and 3.3.2 illustrate geologic mapping and photographic methods to document foundation conditions.

Foundation inspection and approval must be formally documented in a memorandum, including photographs and geological mapping. A clear statement of conclusions resulting from the inspection should be provided. The memorandum should be included with the Technical Report of Construction. Refer to appendix B for a sample Foundation Inspection and Acceptance Report. The memorandum should include, but is not limited to, description of:

- Site conditions
- Foundation geology
- Foundation conditions not meeting design intent
- Geotechnical considerations
- Foundation treatment that is required, and what was accomplished
- Locations approved and special requirements for approval
- Photographs and geologic maps

Many times, the geologic features outside of the dam footprint are critical to dam stability. For example, some very important features may not actually be exposed in the foundation but could pass underneath it, such as low angle joints, shears, or faults.

Documentation should reflect a complete understanding of the foundation and having the best information to be able to predict foundation behavior relative to potential failure modes.

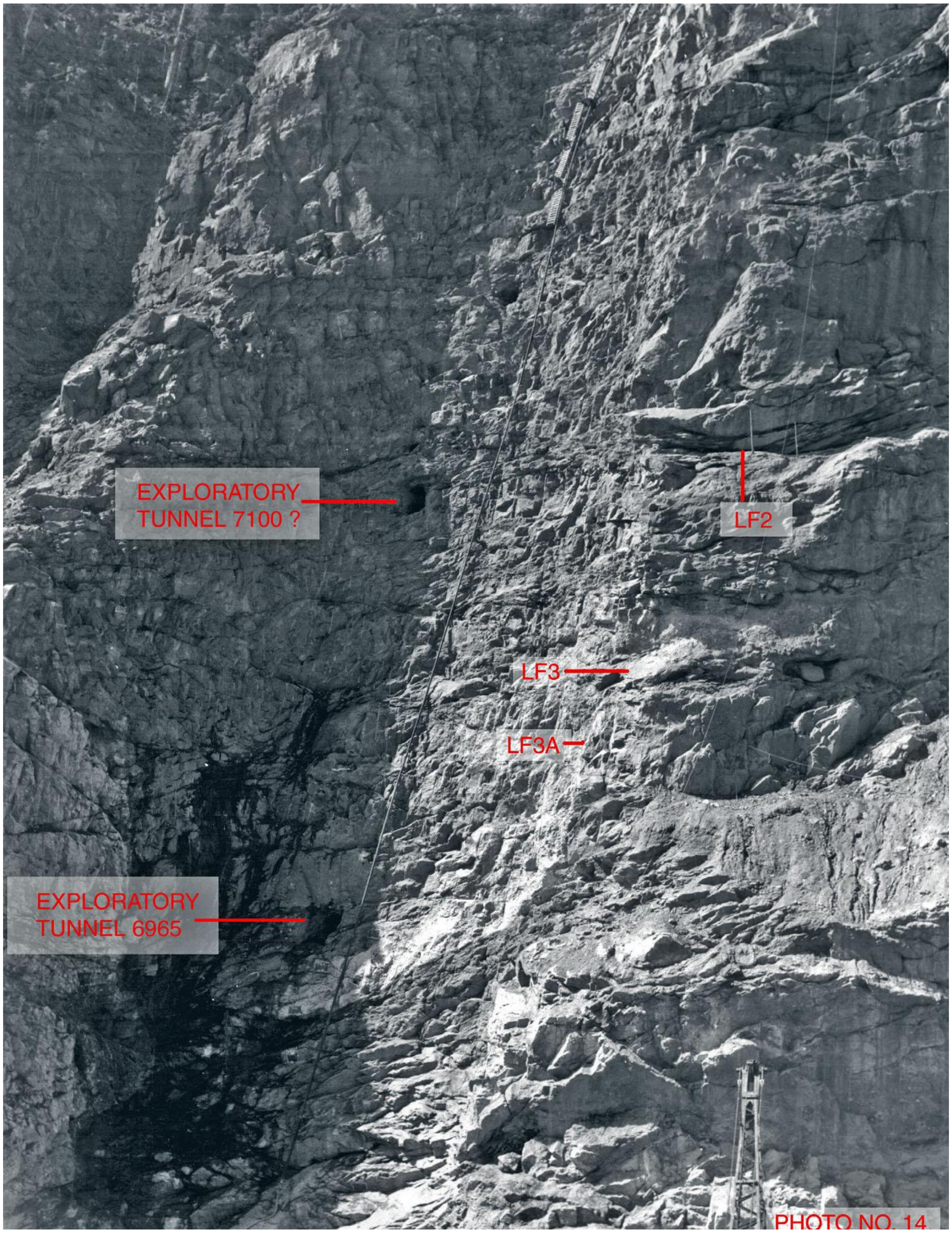

Figure 3.3-1 Photographic records are critical! Photos should be labeled and related to the foundation geologic map.

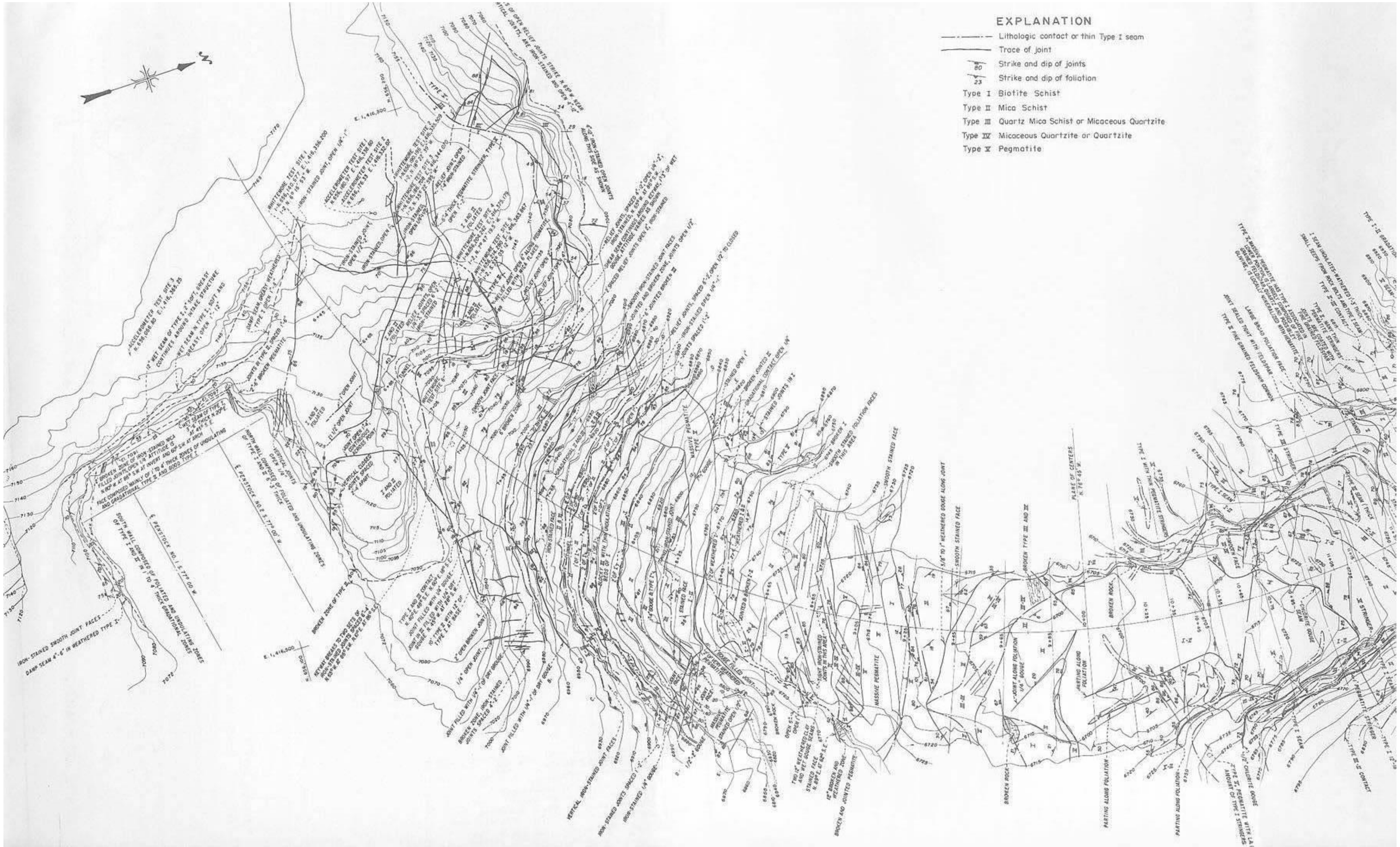

Figure 3.3-2 Typical detail of geologic foundation map.

3.4 Placement of Embankment Materials

3.4.1 Soil Foundations

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 a 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.

Foundation materials at the core/foundation contact must be compacted to a density compatible with the overlying fill material. A fine-grained foundation may need to be compacted, the first layer of embankment material placed, and then 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 tamping roller. If the foundation is too firm for the tamping feet to penetrate, the foundation surface should be disked to a depth of 6 inches and moistened before compaction. Smooth surfaces created by construction traffic on a previously compacted foundation surface should be disked to a depth of 2 inches or more.

Coarse-grained foundations should be compacted by 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 may require special procedures. In some cases, they can be left in place and 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.

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

The moisture content of the upper 6 inches of a fine-grained soil foundation should generally 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 inches of the foundation. Wet materials must be dried by disking to bring the upper 6 inches of foundation material to within the specified moisture content limits. If drying is ineffective or disking creates muddy conditions, removal and replacement with soil material having proper moisture content may be required. Wet foundations should be unwatered or dewatered sufficiently to prevent saturation of the upper 6 inches 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 filter material as needed. (The reverse may also be necessary if coarse fill is to be placed over finer foundation soils.) 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.

The use of dispersive embankment material should be avoided if possible. If used, dispersive embankment materials must be protected from eroding and moving into coarse material in the foundation by placing select zones of engineered filter material between the embankment and foundation. Lime-treated or naturally nondispersive earthfill is preferred for the first several lifts of fill material. Except for areas where an impervious seal between the embankment and foundation is required, filters are the preferred method.

Precautions should be taken against placing embankment or filter material on muddy or frozen surfaces.

3.4.2 Rock Foundations

Rock foundation surfaces should be moistened, but no standing water should be permitted when the first lift is placed. The foundation should be properly moistened to prevent drying of the soil as shown in figure 3.4.2-1. The moisture content of impervious embankment material should be between 0 and 2 percent wet of optimum moisture content, and the maximum particle size is 1 to 2 inches. When the availability of plastic material is limited, it is common practice to select and use the more plastic material at the foundation contact. Because of the high plasticity of these lifts, they are vulnerable to dessication if allowed to dry too much. Lifts that have been allowed to dessicate shall be removed entirely. On steep, irregular rock abutments, material slightly wetter than optimum may be necessary to obtain good workability and a suitable bond. When using special compaction, be careful to ensure that suitable bonds are created between successive layers of material. This usually requires light scarification between lifts of compacted material. Special compaction methods, such as hand tamping, should be used in pockets that cannot be compacted by roller, such as irregular rock surfaces. However, where foundation surfaces permit, a pneumatic-tire roller or other pneumatic-tire equipment should be used near foundation contact surfaces. An alternative to using thin lifts is using a pneumatic-tire roller or loader with a full bucket (see figures 3.4.2-2 and 3.4.2-3) 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. For an illustration of the process of placing embankment fill on a rock foundation, see figures 3.4.2-4 through 3.4.2-6.

Figure 3.4.2-1 After final cleanup, the foundation is moistened prior to placing and compacting embankment fill.

For irregular surfaces and hard to reach areas, site-specific conditions determine whether hand-compacting earthfill or filling with dental concrete is the best solution. The fill compaction method used depends on the steepness of the surface, the nature of the irregularities in the foundation surface, and the fill 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-inch-maximum compacted lifts with scarification between lifts.

Figure 3.4.2-2 Pneumatic-tire equipment should be used to compact fill near the foundation contact surfaces. A sheep's foot or tamping roller may be used when the fill is thick enough to prevent contact of the tamping feet with the foundation.

Figure 3.4.2-3 Pneumatic-tire equipment forces the plastic and deformable earthfill into all remaining uneven surfaces in the foundation surface and may create a feather edge at the ends of the placement.

Figure 3.4.2-4 Ridges Basin Dam. Final foundation cleanup and placing the first lift of embankment fill.

Figure 3.4.2-5 Ridges Basin Dam. Final foundation cleanup, wetting, and placing first lift.

Figure 3.4.2-6 Ridges Basin Dam. Final foundation cleanup and spreading first lift. Note the dozer is working on the fill, not on the foundation surface, to prevent foundation damage. Foundation rock in foreground has been moistened.

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-inch-maximum compacted lifts. Placement of horizontal lifts against mildly sloping rock surfaces can result in feathering of the earthfill lift near the edge of the lift. Placement of the initial lift parallel to the foundation surface (as opposed to a horizontal lift) for foundation surfaces flatter than 10H:1V 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-inch compacted lifts with scarification between lifts. Earthfill 8 to 10 feet from a steep surface should be ramped toward the steep surface at a slope of 6H:1V to 10H:1V so that a component of the compactive force acts toward the steep surface.

Earthfill placed against remaining, small, uneven surfaces should be plastic and deformable so that the material is forced (squeezed) into all irregularities on the foundation surface by compaction or subsequent loading as shown in figure 3.4.2-3. The soil moisture content at the first layer 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. Feathered edges of compacted fill should be removed prior to subsequent placements as shown in figure 3.4.2-7.

Figure 3.4.2-7 Feather edge of first lift of compacted fill removed, cleaned, and ready for fill placement.

Core materials that are erodible include low-plasticity or nonplastic, fine-grained soils, silty sand, and dispersive clays. Prevent erosion of embankment materials into the foundation by 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 erosion resistant material (high plastic index soils) 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 or other imported clay to produce core material to be placed against the foundation. Laboratory testing should establish the amount of clay required to give the soil the characteristics of a clay. Mixing must produce a uniform, impervious material. Generally, mixing must be accomplished by using pug mills or tillers. Disking in the borrow area or on the fill cannot be expected to produce uniform material.

Nondispersive material should be used instead of dispersive material 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 dispersivity 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; therefore, 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.

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Appendix A

Position Paper

Construction Blasting Vibration Limits

RECLAMATION
Managing Water in the West

Position Paper
Construction Blasting Vibration Limits

Technical Service Center

Prepared: /s/
Gregg A. Scott, P.E.

Peer Review: /s/ .
Ernest Hall, P.E.

Date: 9/15/2008 .
Revised

Background and History

The Bureau of Reclamation has a long history of protecting structures from the adverse impacts of construction blast vibrations. However, as experienced technical and construction staff leave through retirement, the agency is in danger of losing expertise in this area and having to re-learn the lessons of the past. This is evidenced by several recent construction specification reviews where the vibration limits in the standard specifications were reduced, with the only justification being a desire to be "more conservative" without a clear idea of how this would affect the cost of the project or what level of conservatism was really achieved. In some cases this may have resulted from a belief that the values should lie closer to the conservative values in the Reclamation Safety and Health Standards (RSHS). In addition, changes have been made to the RSHS manual without consulting the technical staff, resulting in unrealistic blast vibration limits and unclear airblast limits. Currently the agency is not allowing anything in the RSHS document to be overridden by the construction specifications without a lengthy and time-consuming waiver process, no matter how costly or unreasonable it might be on a specific job. In the past, the construction specifications could override the RSHS blast vibration limits, as discussed below.

Early Blast Vibration Limits

The Bureau of Reclamation first included blast vibration control limits in the construction specifications for East Canyon Dam and Grand Coulee Forebay Dam issued in the mid-1960's. These limits were based on ground acceleration and frequency. About the same time, the Bureau of Mines was conducting research into the effects of quarry blasting on residential structures, using peak particle velocity (which is a function of acceleration and frequency) as the controlling parameter. The Bureau of Mines published their work in 1971 [1], and the industry quickly adopted their guidance. They proposed a peak particle velocity limit of 2 in/s to prevent damage to residential structures. However, it should be noted that the type of damage observed was largely cosmetic, such as cracking of plaster, drywall, or mortar joints between masonry blocks. In addition, these blasts were typically large quarry blasts with the houses located at some distance from the blasting with various foundation conditions.

Blasting Review Team

In the late 1970's, Jim Legas, who was the Head of the Concrete Dams Section, recognized a need to update Reclamation's blasting specifications paragraphs. As a result, Al Lindholm, acting Chief of the Dams Branch formed a Blasting Review Team in 1978, consisting of Louis Roehm (chairman), Gregg Scott, Clarence Duster, Ralph Atkinson, Jim Kleppe, and Dave Daniels. The team's charge extended beyond just blast vibrations to include all aspects of blasting specifications. However, blast vibrations were an important part of that study [2].

About the time the Blasting Review Team was formed, the Bureau of Mines was expanding its research into the effects of quarry blasting on residential structures. Word leaked out that they were going to come out with more restrictive criteria. The Office of Surface Mining reacted to this by publishing a peak particle velocity limit of 1 in/s in a 1979 edition of the Federal Register [3]. Presumably, this was intended to be an interim guideline until the Bureau of Mines study was published. At that time the RSHS document was being updated, and the blast vibration limit of 1 in/s from the Federal Register was included in the revision. The Blasting Review Team recommended that this be taken out of the RSHS, but the decision was made to leave it in, the rationale being that it would serve as a fall back position in cases where there were no specifications paragraphs to cover blast vibrations. Thus, the wording "unless otherwise specified by the Bureau" was included in the RSHS document. As noted by the Blasting Review Team report, "The Construction Safety Standards guideline provides conservative control of blast vibrations in the absence of a specifications paragraph." This provision was later removed for some unknown reason.

When the Blasting Review Team Report was published in 1979, it was noted that "Due to numerous reasons (usually short distance from blast site to a structure), it is often difficult to maintain low peak particle velocities . . . *(and)* most structures can tolerate a higher particle velocity without damage for small charges close to the structure because the motion occurs at a higher frequency." As a result, the team recommended allowing peak particle velocities as high as 4 in/s for substantial structures.

When the updated Bureau of Mines criteria were published in 1980 [4], the value of 2 in/s was retained to protect residential structures when the blast vibration frequencies are greater than 40 Hz, which is typically where construction blasts fall. At lower, more damaging frequencies, lower vibration limits were recommended, depending on the condition of the structure.

Upper Stillwater Dam

In the mid- 1980's, a situation arose during the construction of Upper Stillwater Dam that tested the "fall back" position of the RSHS. The specifications were silent on blast vibration, but required the blasting to be kept at a distance of 100 feet from any structures. A concrete diversion structure was also required that eventually would become embedded in the main roller-compacted concrete (RCC) dam. A diversion channel through natural rock (less than 100 feet from the diversion channel) was to be maintained until the diversion structure was constructed and river flows diverted through it, and then the rock forming the channel was to be removed to foundation grade. The contractor, Tyger Construction Co, claimed the 100-foot distance could not be maintained, and the excavation could not be reasonably completed under a blast vibration limit of 1 in/s. The contractor hired Lew Oriard, a blasting expert, and was preparing to submit a large claim.

The design team quickly reviewed as much information as could be found on the effects of blasting on concrete structures. To no one's surprise, Lew Oriard had done significant research into this topic in the early 1980's, and had a major hand in developing blast vibration specifications for the Tennessee Valley Authority (TVA). These specifications allowed up to 20 in/s peak particle velocity at close distances for massive concrete structures where the concrete was more than 10 days old. Other cases were found in the literature where no damage was reported for concrete structures exposed to blast vibrations up to 8 in/s. Very few cases of concrete structures damaged by blast vibrations could be found, and those that could be found were for very green concrete (less than 2 days old) at vibrations from 6 to 20 in/s, or were old concrete in questionable condition damaged by high vibrations exceeding 30 in/s. Based on this review, criteria were proposed at Upper Stillwater that allowed a peak particle velocity of 8 in/s for blasting adjacent to the diversion structure. This was accepted by the contractor, and construction proceeded as planned. In fact, the diversion structure was exposed to blast vibrations as high as 9 in/s with no apparent damage [5].

Subsequent Blasting Jobs

Following Upper Stillwater, the Reclamation guide specifications paragraphs were updated to include allowance for up to 10 in/s peak particle velocity blast vibrations for close in blasting adjacent to massive concrete structures where the concrete was more than 14 days old. However, these specifications were intended for large foundation excavation blasting jobs with associated dental concrete foundation treatment placements and construction of concrete structures while the blasting proceeded. Reclamation had very few of these types of jobs remaining, and most blasting jobs were smaller. Therefore, the guide specifications eventually reverted back to blast vibration limits similar to those recommended by the Blasting Review Team, allowing peak particle velocities up to 4 in/s. These limits were used successfully on a number of jobs. Notable among these were Buffalo Bill Dam, and the outlet works air supply tunnel at Folsom Dam, both of which involved blasting within the concrete of the dam structure itself. However, when using these specifications, it is important to specify where the vibrations will be monitored.

At Buffalo Bill Dam, the work included excavating a new gate chamber within the lower body of the dam, demolishing some old penstock sections, and excavating a short section of new penstock tunnel in the left abutment adjacent to the dam. Blast vibration monitoring stations were established at some distance from the blasting. Blast vibrations up to 4 in/s were allowed at these locations. Although this value was never exceeded, it was recognized that blast vibrations in the concrete just beyond the gate chamber excavation were considerably higher. For example, vibrations one foot beyond the excavation line were estimated to be as high as 100 to 150 in/s based on the recordings that were made [6], but these vibrations would be at extremely high frequencies and not damaging. Indeed, a smooth surface was obtained with very little damage beyond the controlled perimeter of the excavation.

At Folsom Dam, severe cavitation occurred in the outlet works during large releases. The remedy to this situation included excavating an additional air supply tunnel through the concrete dam. The spillway gate trunnion anchors needed to be protected, as they were embedded within the mass concrete of the dam structure, and the tunnel passed within close proximity of the anchors. In all, six blasts produced a peak particle velocity at the trunnion anchors in excess of 5 in/s, with a maximum recorded value of 7.2 in/s, with no damage noted [7]. These vibrations occurred at high frequencies. It should be noted that strain gages were placed on four of the trunnion anchors to monitor strains within the steel during the blasting, and all strains were below damaging levels.

Recommendations

Reclamation has developed considerable experience and expertise in blast vibration monitoring and limits over the past 30 years. This expertise is in danger of being lost due to retirement of experienced personnel. Given the decline in Reclamation blasting expertise, and especially that related to blast vibration limits and monitoring, it is recommended the following steps be taken to help ensure the agency remains credible and that reasonable limits are placed on contractors to obtain competitive bid prices:

1. **Allow the specifications paragraphs to once again over-ride the RSHS for air blast and blast vibrations.** Airblast limits are primarily related to preventing cracked windows and tripping of sensitive switches. The limits to be placed on airblast levels are dependent on the frequency response of the monitoring instruments, as shown in the following table. The RSHS document is silent on the instrumentation to be used. Hence, the airblast limits in the RSHS are not very meaningful.

Flat Response Frequency Range of Instrumentation, Hz	Maximum Level, dB
0.1 to 200	134 peak
2 to 200	133 peak
6 to 200	129 peak
C-Weighted, slow response	105 C

The blast vibration limits currently in the RSHS were taken from a 1979 interim guideline from the Office of Surface Mining, and are not found in any other guidelines currently in use. These limits are overly restrictive in most cases.

Once again, the RSHS document is silent on the instrumentation characteristics to be used in measuring peak particle velocity. As originally specified, there was a clause that allowed these limits to be overridden by the specifications paragraphs. That clause was removed for some unknown reason.

2. **The guide specifications paragraphs related to blast vibration limits should be updated as shown in the following table.** These limits will provide conservative protection, while in most cases allowing the contractor to incorporate reasonable blasting practices to perform the excavations in an economical manner. They will also help to maintain credibility of the agency with the profession by not being overly restrictive. The notes at the end of the table represent important considerations when changing the values in the table.

Table 02305A- Maximum Peak Particle Velocity Permitted at Structures

Structure Type	Vibration frequencies (cycles/second)	Peak particle velocity (inches/second)
Relatively new residential with drywall walls	Below 40 Above 40	0.75 2.0
Older residential with lath and plaster walls, or other structures in precarious condition, sensitive switches	Below 40 Above 40	0.5 2.0
Industrial (more substantial than residential)	--	2.0
Government-owned concrete or steel structures, or grouted or treated foundations	--	4.0
Embankment dams		4.0

Notes:

1. Specify where the blast monitoring will be performed. Indicate which structures will be monitored, and where the seismographs will be positioned relative to each.
2. Do not lower the recommended values without performing an economic evaluation of the likely impacts to the blasting operations. Lowering the vibration limits will result in the need to add more delays and possibly more blasts.
3. For close-in blasting (e.g. less than 50 to 100 feet), it may be necessary to raise these limits in order to accomplish the blasting. Vibrations from such blasting will be at a high frequency, and will be less damaging. Therefore, higher values can be tolerated. Consult with a blasting specialist when in doubt.

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[5] Scott, G.A., "Concrete and Grout Damage Control for Blasting at Upper Stillwater Dam," ASCE National Convention, Boston, MA, 1986.

[6] Scott, G.A., and D.L. Hinchliff, "Blasting in and Adjacent to Concrete at Buffalo Bill Dam," ASCE Geotechnical Earthquake Engineering and Soil Dynamics Conference, Seattle, WA, 1998.

[7] Scott, G.A., "Blasting the Outlet Works Air Intake Tunnel through Folsom Dam," Technical Memorandum No. FOL-8110-CS-98-1, Bureau of Reclamation, Denver, CO, June 1998.

Appendix B

Decision Memorandum No. DEC-RB-8311-29

Foundation Inspection Documentation and Approval No. 5 of Zone 1 Foundation

7-1596B (9-89)
Bureau of Reclamation

DATE	PEER REVIEWER(S)	CODE
6-19-06	PShaffner Signature P Shaffner Printed Name	86-6 8320
	Signature Printed Name	
Author initials	PEER REVIEW NOT REQUIRED	

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Classification		
Project		
Control No.		
Folder I.D.		

86-68320
PRJ-8.00

19 JUN 2006

MEMORANDUM

To: Construction Engineer, Construction Management Group
Attention: ALP-100 (Ehat)

From: Curtis P. Cain, Geologist

Subject: Transmittal of Decision Memorandum NO. DEC-RB-8311-29, Foundation Inspection Documentation and Approval #5 of Zone 1 Foundation – Contract No. 04-NA-40-8064 – Weminuche Construction, Contractor –Ridges Basing Dam Completion, Ridges Basin Dam – Animas-La Plata Project, Colorado

Foundation Inspection Documentation and Approval #5 of Zone 1 Foundation for Ridges Basin Dam is attached for your information and use.

Attachment

cc: FCO-100 (Deming)
ALP-300 (Gates)
ALP-710 (Gates)
ALP-810 (Tarket)
86-68311 (Cyganiewicz)
86-68320 (Cain)

WBR:CCain:kw:06-12-06:303-445-3155
C:kwasik:transmittalletterZone1#5

Animas-La Plata Project

U. S. BUREAU OF RECLAMATION
DECISION MEMORANDUM NO. DEC-RB-8311-29
DATE: June 7, 2006

RIDGES BASIN DAM
ANIMAS-LA PLATA PROJECT
COLORADO AND NEW MEXICO
RIDGES BASIN DAM COMPLETION, PUBLIC LAW 93-638
CONTRACT NO. 03-NA-40-8064

Foundation Inspection Documentation and Approval #5 of Zone 1 Foundation

Features: Dam embankment foundation

Area: Zone 1 footprint on the lower left and right abutments up to approximate elevation 6700.

The left abutment is approved between approximate elevations 6662 and 6700, above a line identified by Stations 22+10, 3'DS to 22+23, 225'US and below a line identified by Stations 22+93, 204' US to 22+90, 100' US to 14+36, 3' DS.

The right abutment is approved between approximate elevations 6662 and 6700, above a line identified by Stations 15+65, 3'DS to 14+13, 225'US and below a line identified by Stations 13+69, 204'US to 14+28, 100' US to 14+25, 10' US to 14+36, 3' DS (see attached foundation approval drawing and geologic maps).

Mapped by: Tom Strain, and Ryan Christianson, FCO/ALP geologists

Participants in the inspection:

Allen Gates, Field Engineer, ALP-300
Jim Gates, Supervisory Geologist, ALP-710
John Cyganiewicz, Geotechnical Engineer, D-86-68311
Dave Paul, Construction Liaison, D-86-68160
Curtis Cain, Principal Geologist, D-86-68320

This memorandum describes the conditions for dam foundation acceptance for final cleaning of the exposed dam foundation beneath the Zone 1 embankment. No specific site inspection was performed for the entire portion of the foundation described in this document. Portions of this area were inspected by design team members prior to final excavation and cleanup on April 25th and 26th, 2006 and during occasional site visits during May and June. Subsequent foundation cleanup, preparation, and Zone 1 placement without the Designer present was accomplished using the attached checklist. Initial foundation approval was granted on April 26th for both abutments between elevations 6662 and 6700 with the following stipulations:

1) Removal of fractured, slaked or otherwise deleterious rock.
2) Adherence to foundation approval checklists.
3) Additional TSC review of scraping and cleaning of the Pictured Cliffs Sandstone when it is reached at approximate elevation 6680 along the downstream portion of the Zone 1 footprint on the right abutment.
4) TSC review of any areas requiring formed dental concrete which stretches through an area greater than 20 feet laterally.

Final foundation approval was granted on June 7, 2006 based on occasional site visits, email, photographic documentation, and conference call discussions. Zone 1 embankment was placed on foundation in these areas during April, May, and June 2006.

DESIGN INTENT:

The intent of the foundation is to provide a sound, competent and properly shaped surface upon which to place dam core material. In addition, all material in the foundation which is susceptible to piping should be removed. Potential seepage paths that could affect the core material should be treated to eliminate/isolate them from the core.

DESCRIPTION OF AS_EXCAVATED CONDITIONS:

The foundation has been excavated to bedrock within the area of acceptance. The foundation material was generally found to be in excellent condition. Bedrock of the Lewis Shale (unit L1) exposed in the excavation will meet the design intent at the currently excavated depths provided that final foundation preparation is performed as described below. The Lewis Shale is composed primarily of siltstone with some interbedded shale and ranges from moderately hard to moderately soft.

Initial foundation excavation included the removal of the overlying alluvium and weathered or loose bedrock. This excavation was performed primarily using Caterpillar 365 and 385 trackhoes. Excavation of the left abutment was completed in January, 2005 and was followed by cleanup for geologic mapping during February and March, 2005. Excavation of the right abutment was completed in April and May, 2005 with the removal of the temporary diversion channel. Excavation was followed by removal of the remaining rubble and slaked material by backhoe bucket mounted with a butterbar. Blowdown using high pressure air was performed to complete cleanup for geologic mapping. Foundation grouting took place in this area from August to November 2005 and final foundation excavation and cleanup for placement of embankment was performed in April, May, and June, 2006. The final cleanup consisted of scraping with a Caterpillar 325 trackhoe with butterbar to perform final foundation excavation, followed by cleanup with compressed air.

LEFT ABUTMENT

Final cleanup on the left abutment was performed in strips (roughly 5 feet in elevation) extending upstream to downstream along the lower portions of the abutments. The foundation in this area consists of the Lewis Shale. Several "A" joints trending approximately N20-30W are exposed in this area of the foundation. The joints are predominantly tight to slightly open to 1/16-inch but occasionally contain weathered siltstone to a width of 1- to 2-inches. Where this material is weathered and soft, it is removed by either compressed air or rock pick to a depth of three times the width and the opening is slush grouted immediately prior to placement of Zone 1. The removal of this material often creates an opening with a depth of 1- to 4-inches and the material generally becomes firm and the joint tightens with depth. The slush grout is a cement/sand/water mixture which is mixed thin enough to penetrate the joint being treated.

Photograph 1. Weathered rock materials have been excavated from an "A" joint on the left abutment at approximate Station 22+58, 132' US in preparation for slush grouting. The weathered materials have become firm throughout most of the exposed joint at the excavated depth.
May 23, 2006 (Photo by J. Gates) Reference Image Only

Photograph 2. Crew finishes preparing the foundation for Zone 1 placement on the lower left abutment at approximate Station 22+30, 150' US. View looking downstream.
May 5, 2006 (photo by R. Christianson) Reference Image Only

Final cleanup for Zone 1 placement commenced on April 25th, 2006 within the acceptance area. A Caterpillar 325 trackhoe with a butterbar initially scraped slaked and weathered material from the previously exposed foundation surface (3- to 6-inches average). This material was hauled to placement in Zone 5. Near vertical ledges were scraped down to less than 1-foot in height with the trackhoe. Grout nipples were either removed or cutoff at the surface. A blow-down crew followed the rock scraping as final foundation cleanup progressed in approximate 5-foot high strips. The edges of the previously placed Zone 1 is trimmed with either a backhoe or shovels to expose fresh moist clay. The Zone 1 is then scarified prior to wheel rolling the new lift onto the foundation. The material utilized at the foundation/embankment interface is Zone 1 from the center of Borrow Area A, having a PI of generally greater than 18 and a moisture content which has averaged about 3 percent wet of optimum. This material is wheel-rolled onto the foundation using either a Caterpillar 980 or a Volvo 220D loader.

Dental concrete within this approval area of the left abutment was limited to one small area requiring less than 2 cubic yards. This occurred near Station 22+25, 15’ US where a near vertical ledge could not practically be excavated to a height less than 1-foot. Sandbags and a 8” piece of plywood were used at the base of the pour to hold the concrete in place. The location of the dental concrete is shown on the attached geologic maps.

RIGHT ABUTMENT

A Caterpillar 365 excavator has been used to excavate weathered and fractured rock along the right abutment between approximate Stations 14+60, 125' US and 14+10, 215' US. The fractured rock was originally identified during geologic mapping in June 2005 as requiring removal prior to placement of dam embankment. The fractured rock is adjacent to a clay filled joint trending upstream/downstream along the right abutment. The joint was identified during geologic mapping as JR234 (N84W, 68NE) and is representative of the "C" Joint set. Joint JR 244, also mapped in this area, was similar in nature and indicated that additional excavation was necessary. The decision was made at that time to leave the material in place during the foundation grouting operation and remove it as the embankment was brought up. There was no additional excavation until late April 2006, when initial scraping for final cleanup was performed with a Caterpillar 325 excavator equipped with a butterbar, revealing a significant, clay-filled (up to 2-inches) joint. Attempts at removing the intensely fractured rock overlying the joint using the 325 excavator were unsuccessful. The 365 track-hoe was mobilized to excavate the rock mass on May 1st, 2006 and again May 9th and 10th, 2006.

Photograph 3. Upstream view of fractured rock prior to additional excavation taking place above approximate elevation 6665 on the upstream right abutment. Geologist and inspectors are standing at approximate Station 14+55, 135' upstream of centerline.
April 27, 2006 (Photo R. Christianson) Reference Image Only

Photograph 4. Caterpillar 365 excavator beginning the additional excavation on the right abutment to remove fractured Lewis Shale.
May 1, 2006 (Photo by J. Gates) Reference Image Only

The additional excavation has resulted in the exposure of a joint face along the abutment. The joint strikes from N88W to N65E, and dips toward the valley at 51 to 68 degrees. Dental concrete was used along the upstream portion of the joint face where it intersects bedding.

Photograph 5. Additional excavation is being accomplished using a Caterpillar 365 trackhoe and is exposing a prominent joint face on the upstream right abutment. The excavator can be seen working on the upstream transition.
May 10, 2006 (Photo by J. Gates) Reference Image Only

Foundation grouting was performed in the area upstream of the joint face in the fall of 2005 with some of the blanket holes in the area having moderate takes in the 0 to 15- foot stages. Many of the joints near the blanket holes were exposed during final foundation cleanup and were filled with grout. However, it appears the grout travel in the upstream direction was limited by the clay joint fillings.

Stress relief "exfoliation" joints are common within a section of the Lewis Shale which is approximately 20 to 40 feet below the contact of the overlying Pictured Cliffs Sandstone and is most prevalent along the lower portion of the grouting stairway. The jointed rock has locally required additional excavation of up to about 4- to 6-feet. The joints roughly parallel the excavated slope trending N60E to N80E, dipping about 50 to 60 degrees toward the north with spacings ranging from 0.2 to 1.5 feet. The joints are predominantly tight to slightly open to about 1/16th inch with an occasional clay filling. Minor groundwater seepage of less than ½ gpm appears along the exposed joint traces near Station 15+50, 50' upstream of dam centerline. Grout from the foundation grouting program is often seen penetrating the joints in thicknesses ranging from about 1/16th to 3/4 inch. Exposed joint traces are generally less than 3 feet long and are slush grouted where open.

Photograph 6. Joint on right abutment near Station 14+55, 130' US that is filled with grout from foundation pressure grouting operations. The grout reaches a maximum thickness of about ¾ inch. Grout can also be seen along a joint at the upper right of photo. View looking downstream. April 27, 2006 (Photo by R. Christianson) Reference Image Only

Final cleanup in this acceptance area is predominantly within the Lewis Shale with the exception of the extreme downstream Zone 1 footprint near the right abutment ravine area where the Pictured Cliffs is exposed. The upper portions of the Lewis Shale remains classified as a siltstone although it becomes increasingly sandy approaching the contact with the overlying unit P1 of the Pictured Cliffs Sandstone. This gradational contact between the sandy siltstone and the interbedded sandstone, siltstone, and shale, of unit P1 can be seen near the green and orange line in the following photograph.

Photograph 7. Slush grout being placed in preparation for Zone 1 embankment. This area represents the gradational contact between the Lewis Shale and the overlying Pictured Cliffs Unit P1. View looking downstream from approximate Station 15+00 40' U/S.
May 24, 2006 (Photo by R. Christianson) Reference Image Only

Individual placements on foundation were generally restricted to 5 feet in elevation. The final cleanup was performed using the same methods described for the left abutment above. In addition to blowing with compressed air, washing the foundation with water has been required in occasional areas due to the accumulation of mud on the rock. This method has been effective in removing the mud without causing additional slaking of the shale and siltstone. Cleanup methods used in the Pictured Cliffs Sandstone remain to be essentially the same as used for the Lewis Shale.

Slush grout has been required in occasional open joints along the base of the right abutment. Most of the joints are classified within the “C” joint set and trend roughly

N65E, dipping 50-70 degrees northwest toward the valley center. Dental concrete was required in two locations to flatten the slope to less than 0.5:1.

Photograph 6. Unformed dental concrete at the base of the exposed joint face on the right abutment between approximate Stations 14+15, 168' US and 14+98, 190' US.
May 22, 2006 (Photo by J. Gates) **Reference Image Only**

GENERAL FOUNDATION CLEANUP METHODS

During the foundation inspection and other site visits, methods observed which resulted in an acceptably clean foundation for placement of Zone 1 embankment have included the following steps:

1) Scraping with butterbar;
2) blowdown using high pressure air;
3) cleaning of discontinuities;
4) removal of any mud coatings on the rock;
5) removal of standing water;
6) removal of any remaining rock chips or fragments that remained after the initial blowdown using either a light blowdown or vacuum.

These steps (methods and criteria) are described in detail in the attached foundation cleanup checklist and are used as the basis for this and future foundation acceptance.

GEOTECHNICAL CONSIDERATIONS:

The three key functions of the bedrock foundation material beneath the Zone 1 foundation is that it must 1) not provide a weak seam of material that will form a shear plane beneath the core of the embankment 2) provide cutoff for seepage and 3) not contain seepage that can adversely affect the core.

The conditions exposed will provide the needed functionality after final foundation preparation is performed (see below).

ADDITIONAL FOUNDATION PREPARATION REQUIRED:

Decision:

The foundation within the limits prepared for this inspection is acceptable and meets design intent, pending foundation preparation as established above and within the attached foundation cleanup checklist.

U. S. BUREAU OF RECLAMATION
DECISION MEMORANDUM NO. DEC-RB-8311-29
DATE: June 7, 2006

RIDGES BASIN DAM
ANIMAS-LA PLATA PROJECT
COLORADO AND NEW MEXICO
RIDGES BASIN DAM COMPLETION, PUBLIC LAW 93-638
CONTRACT NO. 03-NA-40-8064

Foundation Inspection Documentation and Approval #5 of Zone 1 foundation

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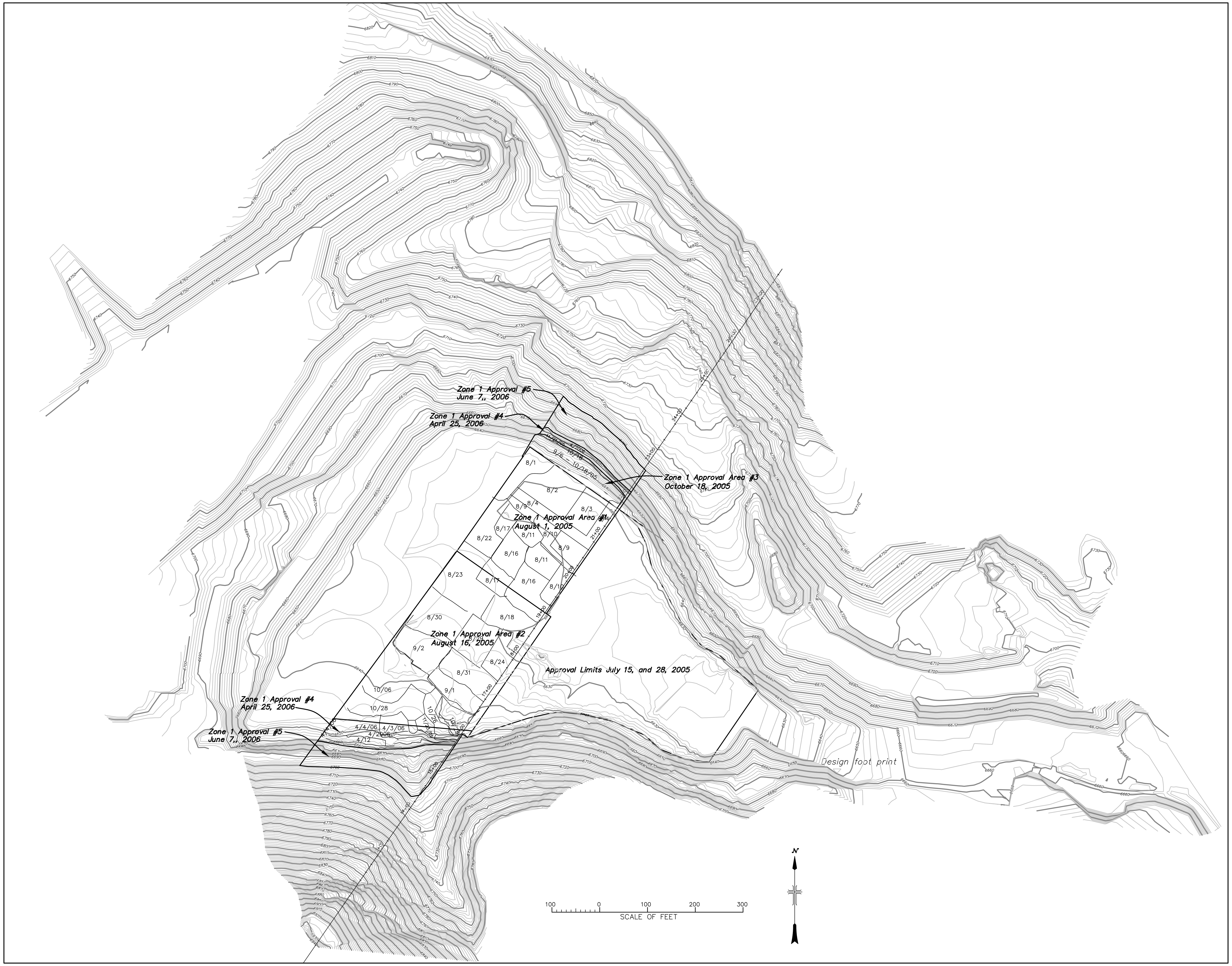
Concurrence with the above decision is provided by the following signatures, subject to the additional work outlined in this memorandum.

Allen Gates, ALP-300 — Date: 6/7/2006

John Cyganiewicz, D-8311 — Date: 6/7/2006

Jim Gates, ALP-710 — Date: 6/7/06

Curtis Cain, D-8320 — Date: 6/7/06



PRELIMINARY

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

ANIMAS – LA PLATA PROJECT
COLORADO – NEW MEXICO

RIDGES BASIN DAM

APPROVAL LIMITS

DESIGNED ____________ CHECKED________________

DRAWN ______________ TECH. APPR. ______________

APPROVED__________________
MANAGER – TECHNICAL SERVICES DIVISION

CADD SYSTEM AutoDesk Civil 3D 2005	CADD FILENAME 69-403-63.dwg	DATE AND TIME PLOTTED
DURANGO, COLORADO	JULY 2005	69-403-63

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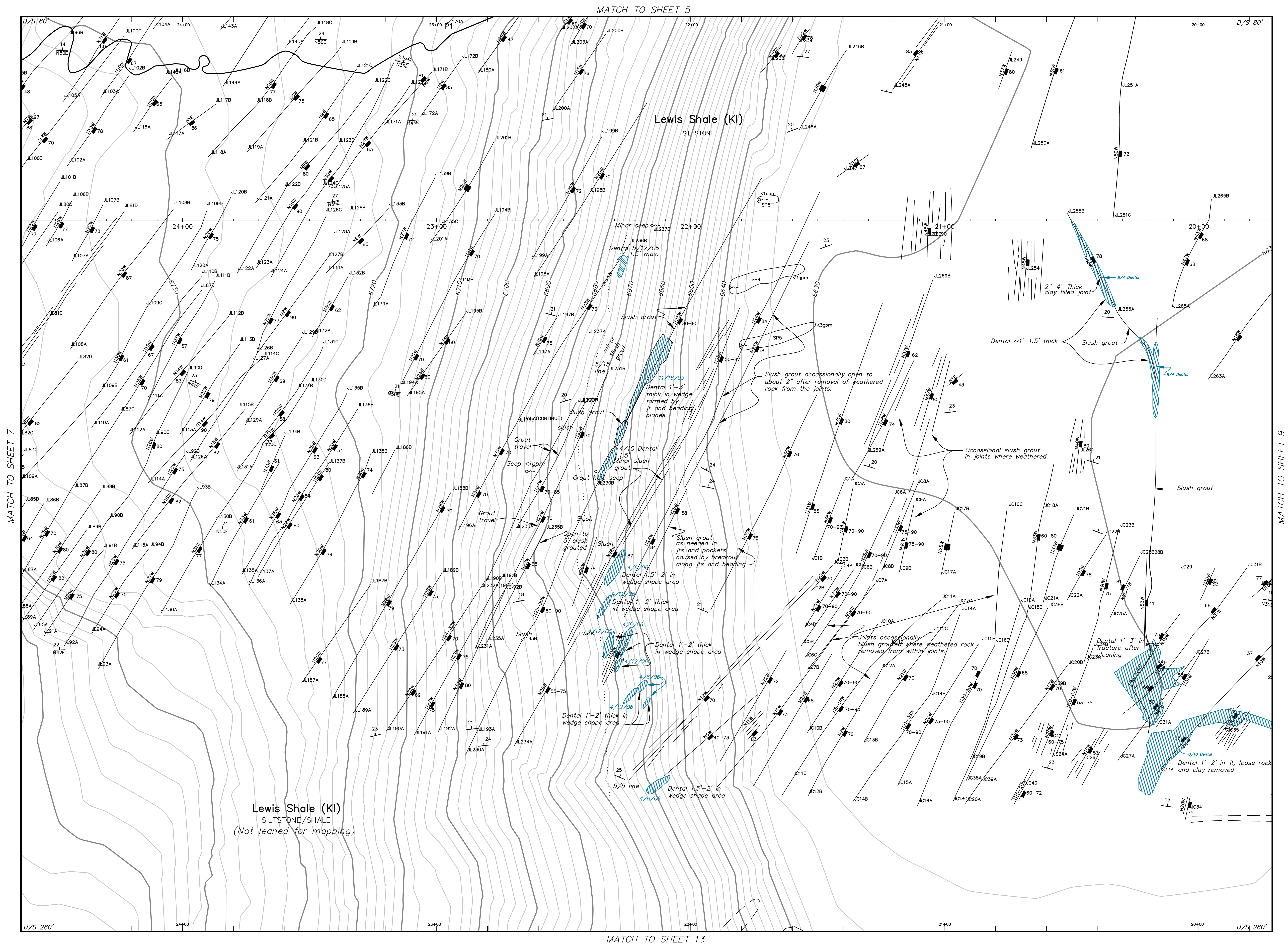

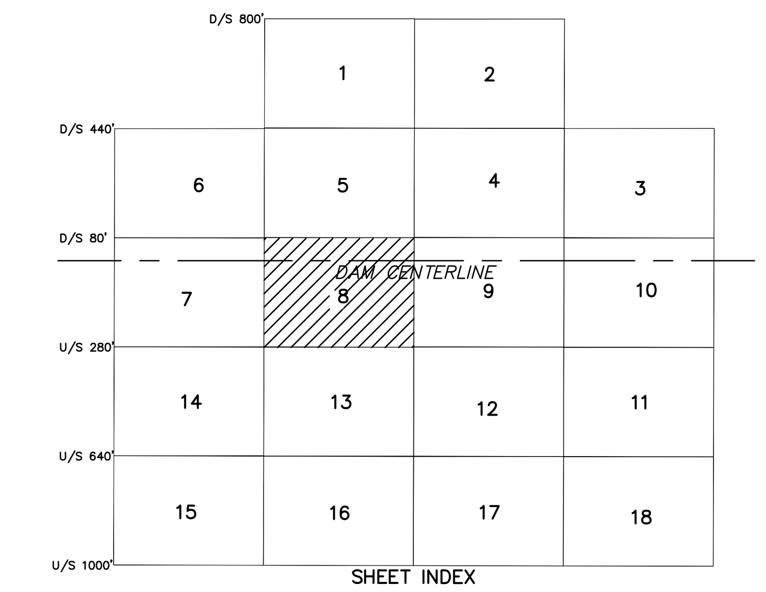

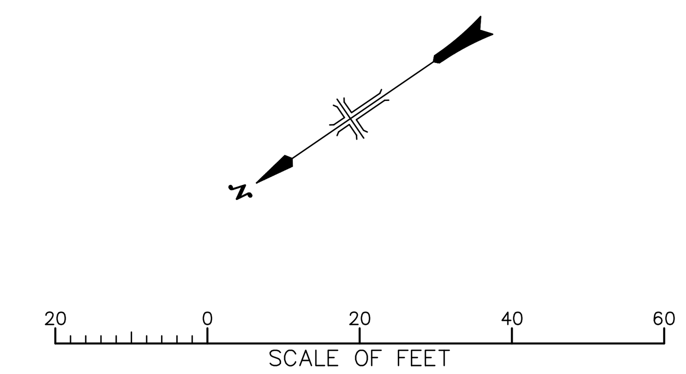

PRELIMINARY

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

ANIMAS – LA PLATA PROJECT
COLORADO – NEW MEXICO

RIDGES BASIN DAM
DAM FOUNDATION
SURFACE GEOLOGY

GEOLOGY__________CHECKED__________

DRAWN__________TECH. APPROVAL__________

APPROVED__________
PROJECT MANAGER

CADD SYSTEM	CADD FILENAME	DATE AND TIME PLOTTED
AutoCAD	Unknown	Not Plotted
DURANGO, COLORADO	SEPTEMBER 2004	69-403-13

SHEET 8 OF 18

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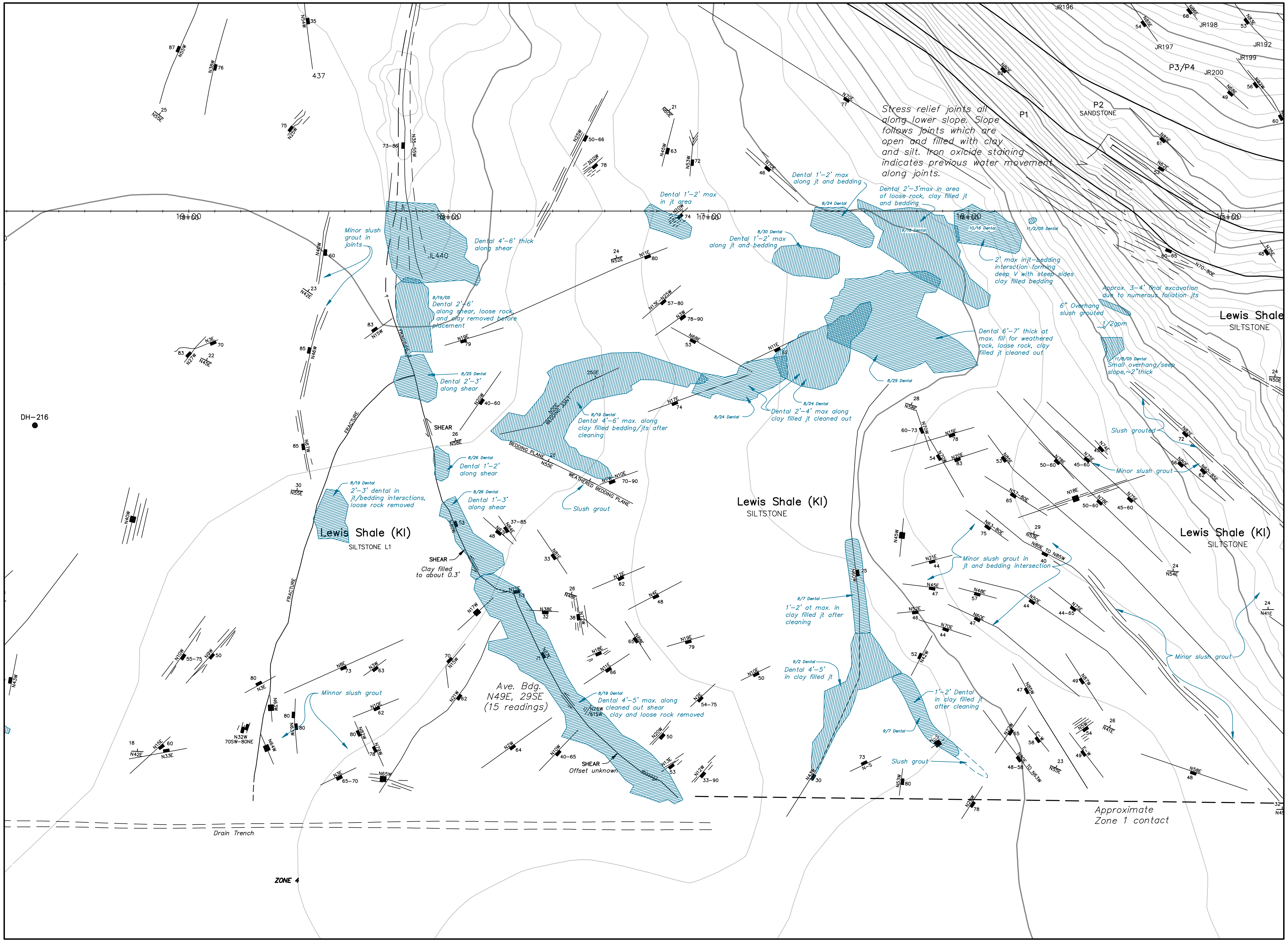

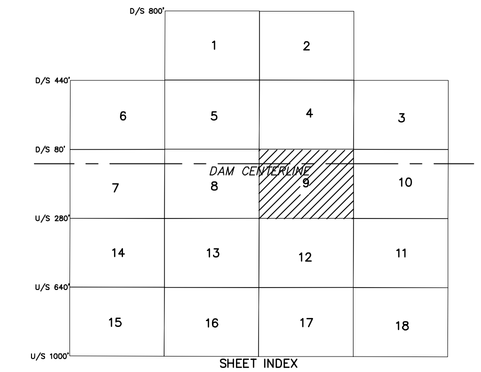

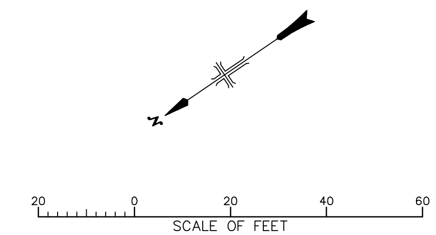

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GEOLOGY__________ CHECKED__________

DRAWN__________ TECH. APPROVAL__________

APPROVED__________
PROJECT MANAGER

CADD SYSTEM AutoCAD	CADD FILENAME Unknown	DATE AND TIME PLOTTED Not Plotted
DURANGO, COLORADO	SEPTEMBER 2004 SHEET 9 OF 18	69-403-14