ENVIRONMENTAL SAFEGUARDS DURING ROCK ANCHORING: A CASE HISTORY

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Summary

Rock anchoring is a popular technique for stabilizing concrete dams against the dangers of sliding, overturning or seismic events. It involves a variety of special drilling, grouting and post-tensioning activities, each of which can have major impacts on the structure, the environment and on personal safety. This paper uses the case history of Stewart Mountain Dam, Arizona to illustrate how such works can be executed with minimum structural or environmental impact and with maximum safety.

Resumé

La technique d'ancrage des roches pour la stabilization des barrages en beton vis-à-vis des risques de glissements, renversement, ou activités sismiques est devenue une pratique couramment utilisée. Cette technique fait intervenir une large varieté des activites de forage, injection, et post-tension, pouvant avoir des impacts majeurs sur la structure, l'environment, ou la securité. Cet article presente l'étude et observations sur une site du barrage dû Stewart Mountain à Arizona, illustrant le success de la methodology de construction entreprise afin de minimizer les impacts sur la structure et son environment et guarantir une securité maximale.

1. Introduction

The technique of rock anchoring has been used since 1934 [1, 2] to stabilize concrete dams. In this context, the major applications have been:

- to resist sliding

- to resist overturning
- to strengthen against seismic events
- to stabilize abutments, portals, plunge pool, and spillway excavations, and similar apurtenant structures

Rock anchoring includes the drilling of holes up to 300 mm in diameter and perhaps to depths of over 100 m; the flushing, water testing and grouting of these holes; the handling and installation of tendons, often multistrand units weighing several tonnes; the stressing and testing of these tendons to loads of several hundreds of tonnes; and the final "patching up" of the anchor head area. These operations require large scale equipment to be utilized either directly (e.g., drill rig, grout plant, hydraulic jacks) or as ancillaries (access platforms, cranes). They involve water, compressed air, fuels, lubricants, cements and corrosion protections. They generate debris, dust, noise and vibrations. They all constitute a certain threat to personal safety. In short, such operations may be regarded as having the potential to cause detrimental effects to (i) the structure being repaired, (ii) the environment around it, and (iii) the personnel engaged in the works.

There is clearly a growing awareness of the need to protect our environment from the effects of our labors, and this has had a major impact on the entire dam engineering community. In parallel, however, it is equally clear that within this community, maintenance, surveillance and rehabilitation (where necessary) have taken precedence over new construction. Therefore, it is timely to consider the preventative steps which must be taken when executing a major dam repair.

This paper describes the remediation recently completed at Stewart Mountain Dam, Arizona, [3, 4] a thin, double-curvature, arch dam considered under Maximum Credible Earthquake calculations to need significant upgrading by prestressed rock anchors. It is the intention of the authors to illustrate what was specified and executed at this project: it is not their intention to stipulate what should be enforced on other sites, although clearly the standards observed at Stewart Mountain Dam set a very desirable standard.

Incidentally, this contract was let using relatively innovative procurement procedures. Far in advance of bidding, the USBR interviewed, unofficially, a wide range of specialists in all facets of the industry. As a consequence, the specifications, though by necessity very rigorous, were both eminently practical and right up to date. The decision to invite separate technical and price proposals - independently assessed - ensured that not only was the best qualified contractor chosen, but also that he was motivated to contribute "heart and soul" to every stage of the project's execution. As a consequence, the work was carried out virtually as an engineering joint venture, at site and head office levels, between equally committed parties. The project was completed within program and under budget without a hint of contractual dispute or litigation.

2. Outline of the rock anchoring conducted

2.1. Background

The dam is a double-curvature, thin arch structure built over 60 years ago on the Salt River 30 miles east of Phoenix, Arizona. At its highest point, it stands 60 m above the riverbed, while the 180 m long crest is flanked by gravity buttresses and two spillways. As the importance of good cleanup on the horizontal construction joints was not recognized at the time of construction the joints were left untreated. This resulted in a layer of laitance on the horizontal joints, which later compromised bond across them. A three-dimensional finite element model of the dam was used to evaluate the dam's performance during various loading conditions, including seismic loads generated by the Maximum Credible Earthquake of Richter magnitude 6.75, occurring 15 km from the dam [5] and so generating an estimated site acceleration of 0.34 g. The analysis indicated that the dam would lose arch action during such an event, leaving vertical cantilever sections to support themselves. Because of the lack of bond at the horizontal lift lines, the blocks in the upper portion of the dam would be free to displace under these conditions. Sixty-two tendons were thus designed to stabilize the arch, each at about 2.7 m centers, with free lengths ranging up to 66 m, and bond lengths ranging from 9 to 14 m. Their inclination varied from vertical to 8° 40'. All but 7 of the tendons (all located immediately above the river outlet works openings through the dam) were anchored into the dam foundation bedrock (Figure 1). The arch tendons each comprised twenty-two 15.2 mm diameter epoxy coated strands. Design working loads averaged 285 tonnes (range 250-340) per tendon, equivalent to about 50% GUTS.

In addition to the arch tendons, 22 tendons were designed for the Left Thrust Block of the dam to stabilize this portion of the structure against a potential failure plane at or just below the structure/foundation contact (Figure 2). The thrust block tendons varied in length from 12 to 38 m (free length) plus 12 m bond length, and each comprised 28 strands. Design load for each tendon was 450 tonnes (60% GUTS).

2.2. Geology

Most of the arch dam foundation consisted of hard, pre-

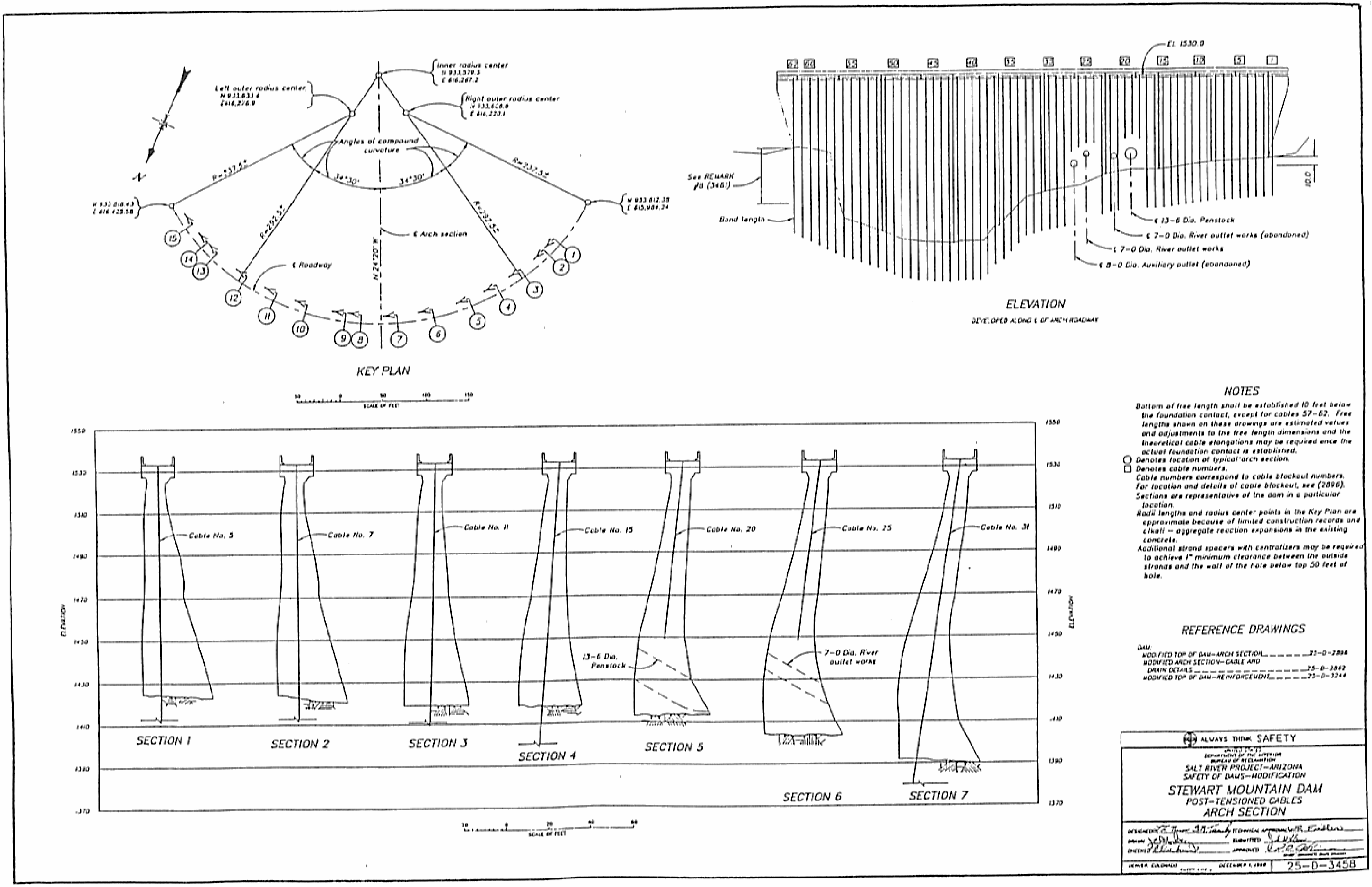
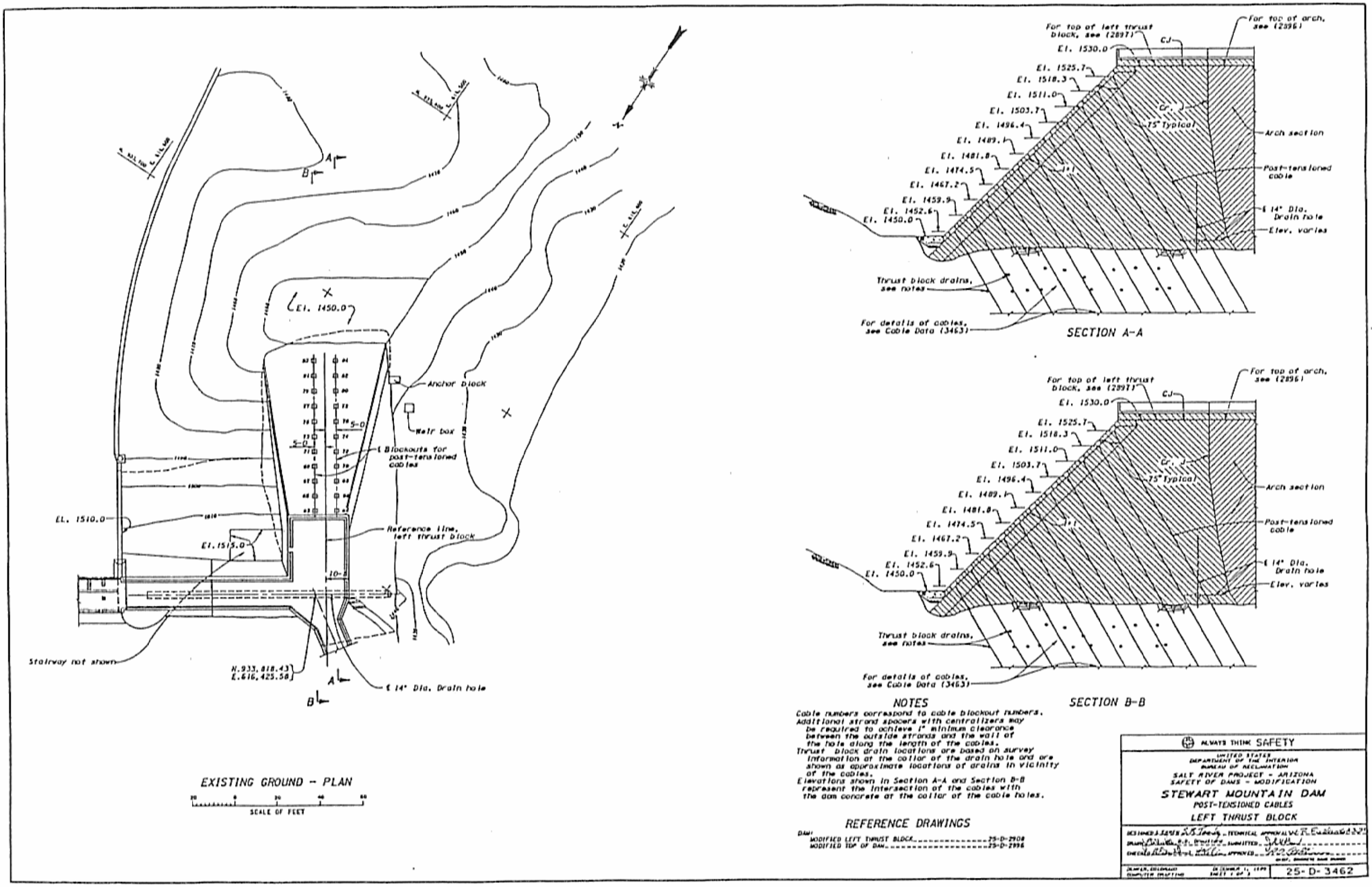


Figure 1. General arrangement of tendons, Arch Section.



<u>Figure 2.</u> General arrangement of tendons, Left Thrust Block.

Cambrian quartz diorite. The diorite was cut by irregular dikes of hard, medium grained granite, which varied in orientation and thickness. A fault divided the arch dam foundation into three zones - the zone to the right of the fault, the zone to the left of the fault, and the fault zone itself. Each zone had distinct mechanical properties, joint systems, and permeabilities. The rock underlying the right portion of the dam was hard, slightly weathered to fresh, and generally of excellent qualities. The rock to the left of the fault (which included the Left Thrust Block foundation) was slightly inferior, being more fractured, sheared and weathered. The fault and the surrounding fractured zone were very intensely fractured and moderately to slightly weathered. During the design phase, it was assumed that 32 of the arch tendons would be anchored in the right foundation zone (with 7 of the tendons in this area anchored in the dam concrete); 15 of the arch tendons would be founded in the left foundation zone; and 8 of the arch tendons would be founded in the fault zone. All 22 of the Thrust Block tendons were founded in the left foundation zone.

2.3. Test anchor program

Prior to the installation of the production anchors, an intense test anchor program [6] was run and analyzed. This confirmed the practicality of the construction methods, and the suitability of the major anchor design assumptions in each of the three major geological zones.

Overall, the test verified that the originally designed bond lengths had satisfactorily high safety factors in the Site 1 and 2 rock, but merited a slight lengthening when installed in the poorest quality Site 3 material. The production anchors proceeded accordingly.

2.4. Production anchors

Recesses, 1.45 m square and 0.6 m deep, had been formed in the dam crest under a previous contract. At the precise location, bearing and inclination, a 300 mm diameter hole was cored about 1.52 m deep at each anchor entry position. A 260 mm diameter steel guide tube was then surveyed and cemented into this hole to thereafter ensure the anchor hole drilling rig would have the exact prescribed starting orientation: angles were measured by independent state-of-the-art methods to within minutes of accuracy.

The 254 mm diameter anchor holes were then drilled using a down-the-hole hammer, mounted on a new Nicholson Casagrande C12 long stroke, diesel hydraulic track rig. Special hammer and rod attachments were used to promote hole straightness. In accordance with the specifications, the position of the hole was measured at 3 m intervals in the upper 15 m of each hole, and thereafter at 6 m intervals to final depth: a maximum of 82 m. This high frequency of measurement - and the precision required - to within 75 mm in 30 m - demanded very special attention. Nicholson worked with Eastman Christensen from Bakersfield, California, to adapt their Seeker 1 rate gyro inclinometer from its usual oil field duties. The Seeker's suitability was proved during the test anchor program, and in parallel specific tests. This instrument not only allowed the bit's position to be accurately measured through the drill rods, but modifications of the computer software ensured that the acceptability of each hole's progress could be demonstrated within minutes - at the rig, to minimize "down time" in the construction cycle.

As a further check, USBR personnel ran independent precision optical surveys using a Pentaprism instrument, on randomly selected holes: these confirmed the immaculate straightness of the holes, and their correct bearing and inclination. Every hole proved acceptable.

For the Thrust Block holes, a massive frame was erected up the face of that structure. This carried platforms to which was affixed the drill mast. Again, special precautions were taken to ensure hole correctness and direction. Every hole was water pressure tested, and pregrouted and redrilled if necessary - prior to a final directional acceptance survey. Most test stages - which ranged in rock and concrete from 15 m to 40 m - proved tight, but other stages needed as many as four pre-treatments to allow the specification to be met - 0.2 litres per minute per lineal metre of hole at 0.03 Mpa excess pressure.

The special epoxy coated strand tendons, assembled off-site by DSI Inc., Illinois, were placed in reels on special uncoilers and transported to the holes. Using extreme care to prevent abrasion of the epoxy coating, each tendon was slowly placed to full depth. A specially researched high strength, plasticized grout was then tremied into each hole to provide the exact bond length. Fluid and set grout properties were rigorously recorded as routine quality control throughout construction.

2.5. Quantities

Overall, the following quantities were recorded:

	Dam Crest	Thrust Block
Rock Drilling	1137 m	462 m
Concrete Drilling	2482 m	407 m
Water Tests	252 ea	90 ea
Redrilling	1102 m	494 m

Stressing commenced 14 days after grouting. Twelve tendons were subjected to cyclic Performance Tests, as per PTI Recommendations [7] to verify in detail the correct operation of these tendons. The other anchors were tested more simply, as per the PTI Proof Test provisions. Given the high loads, and long free lengths, extensions as long as 440 mm were recorded at Test Load on the longest tendons (permanent extension of 9 mm). Creep and lift-off checks rounded out the initial verification of the anchors: in all aspects, every anchor proved to have outstanding qualities, with details closely mirroring the conclusions of the test program.

Each anchor was proved to 133% of design working load and destressed to alignment load, prior to interim lock-off at 117%. Monitoring of the dam during stressing confirmed no structural deflections as a result of the imposition of this extra load. This was probably helped by the USBR's idea of trying to minimize any loading impact by building up the load gradually in each block of the dam: Anchor 60 was followed by Anchor 58, by Anchor 6, 4, 13, 11, and so on. The structure and the anchors were then monitored for a further 100 days after stressing before final lock-off (at a minimum of 108.5% of design working load) and secondary grouting. Again the anchors were proved to have performed well, while no discernible movements were induced in the arch of the dam.

3. Protection of the structure during construction

The two basic principles which had to be observed were a) the structural integrity of the dam could not be compromised, and b) the internal and external features and fixtures of the dam had to be preserved without in any way threatening the operation of the in-place safety measures.

Regarding the first concern, various steps were taken at each stage of anchor construction:

- drilling: as described in Section 2.4., very precise drilling tolerances were specified, measured and provided in order to ensure the correct trajectory of each hole (and so the subsequent correct point of application of the prestress loads). In addition, during drilling of the first crest hole, a dense array of instrumentation on the downstream face (as close as 1.5 m to the hole edge) confirmed that a) the amplitude of the vibrations were insignificant at the peak particle velocities recorded, and b) that the amount of lift joint opening was merely of the scale normally induced by daily temperature fluctuations. Special care was taken with the details of the hammer and rod stabilizer systems to avoid sudden blockages leading to air flush pressure surges acting on the lift joints. Overall, these readings proved that, even using a large drilling rig, and high pressure, high volume compressed air, holes can be drilled close to free faces of even delicate, jointed concrete structures without a hint of structural damage.

- water testing: excess pressures for water tests within the dam were kept very low (0.03 Mpa).
- stressing: was accomplished in a well defined sequence across the crest to prevent the potential of local overloading, or block distortion. Crest movements were monitored during stressing, and for an observation period of 100 days thereafter. They were never larger than 1 mm.
- Grouting of the free length: this was accomplished in two steps to minimize the fluid grout head acting on any given lift joint.

Regarding the second concern, the crest of the dam (placed during an earlier phase of modifications) was protected against the impact of the drilling rig tracks with timber mats and rubber overlays. The parapet walls were protected by heavy duty visquene screens, while the grout plant was placed in a steel "bath" to prevent grout or waste from splashing the concrete. During all drilling and grouting operations the dam's underdrains were continually flushed with water, and closely monitored to prevent blockage. Major service lines for air, water and electricity were mounted in steel ducts suspended off the parapet walls. Any movable components, e.g., lifting frames, were temporarily dismantled and stored off-site prior to reassembly upon completion of the anchoring.

4. Protection of the environment during construction

The environmental protection goal for this project was simply to minimize the potential for detrimental impact associated with the construction work. Basically, environmental protection concerns can be divided into four basic categories: land, water, air and wildlife.

<u>LAND</u>

The land related environmental concerns include the protection of wildlife, plants and minerals. The potential for damage from hazardous materials used in construction is a primary concern. The government mandates regulations and procedures for the handling, storage and use of hazardous materials. Development and implementation of an overall plan is required prior to construction commencing. The particular items that were required to be addressed for this project were as follows:

<u>1. Land for Construction Use</u>

In order to avoid detrimental impact from grading operations which might disturb sensitive vegetation areas or animal habitats, the basic concept was simply to minimize areas disturbed by construction. Erosion was controlled by the utilization of a grading plan which emphasized the use of erosion barriers, and by applying water to reduce dust and wind related erosion. Areas which were disturbed by grading and other operations were regraded, and some areas were also replanted.

2. Fences

To protect the public, as well as wildlife, it was necessary to limit access to work areas during construction. Temporary fences with lockable gates were erected, and the proper advisory signs attached.

3. U.S. Forest Service Lands

The adjacent property was part of the Tonto National Forest. This fragile eco-structure was very sensitive to disturbance. In addition to the other concerns, because of the arid climate, there was a major potential for fire, and so all potential sources of combustion required control under a Fire Prevention and Control plan. All equipment and areas with a fire hazard were supplied with fire extinguishers. This included any area with combustion engine powered equipment, as well as any areas where welding or cutting torches were used. Also, all storage and use areas for combustible materials, and all buildings with electrical power required fire extinguishers. In order to ensure adherence to the plan, routine inspections were conducted daily by a representative trained in risk prevention. Routine training of all crew members was also conducted to ensure the safety of the working environment.

In addition, to reduce the potential for fire hazard, all site wiring and power distribution tasks were completed in accordance with uniform codes. Licensed electricians were used to design, install and ensure proper installation of permanent and temporary services. Ground fault protection was used to avoid electrical shocks. Also, employees were trained in site safety meetings for proper procedures when working with or around high voltage and power tools. Visitors were initiated by brief orientation and were escorted for protection.

4. The Landscape and Vegetation

Any land disturbed during construction was required to be returned to its original condition. Areas which required grading during the course of the work were returned to original condition by restoring the original contours. Vegetation which was disturbed during the course of the work was replaced with plants of similar type and size. Access was limited to specific areas to minimize the area disturbed. In the event of injury to vegetation or trees, a horticulturist or tree surgeon specialist was required to be retained for determining the repair or replacement required.

5. Clean up and disposal of waste materials.

All rubbish or waste material on the construction site was required to be properly disposed of. Areas were designated for disposal on-site of acceptable waste materials. Materials were classified for proper disposal and all on-site areas were left clean and properly restored upon completion.

Drill cuttings and waste materials appropriate for on-site disposal were buried in the designated areas on-site. Excess stockpiled materials used for required backfill and

grading operations were also disposed of on-site and properly graded during restoration.

Non-hazardous trash and rubbish were collected and stored for disposal off-site in approved landfills. Clean-up was a continuous operation. This avoided litter or rubbish being blown away, and also helped to maintain a safe, clutter-free work area. Trash receptacles were placed in all work areas to collect rubbish. Wastes were tested to ensure they were non-hazardous. If hazardous materials were found they were disposed of or treated in accordance with applicable EPA regulations. In the event of soil contamination, the contaminated soils were removed and treated, or disposed of at an approved site. Any locations where contaminated soils were removed were tested for compliance, and proper documentation was submitted to authorities.

WATER

1. Water used for construction purposes

Any water used had to be removed from the reservoir and returned without a detrimental effect. Water was tested to verify that it was acceptable for the intended use, whether incorporated in the work such as for grout, or for support activities such as washing, and water testing. Water used for washing purposes was collected and treated as necessary. Any chemical imbalance had to be neutralized and foreign particles removed before returning to the water table. An extensive collection and transmission system was installed to allow collection of the flushing water and its pumping to settling areas to allow particles to settle prior to releasing the cleaned water.

2. Prevention of water pollution

Water pollution was avoided by the proper planning and implementation of a Spill Prevention Control and Countermeasure Plan. This plan included measures to reduce the risk of spills, as well as an emergency plan of action in the event of an accidental spill. To ensure the planned safety measures were maintained, the plan also contained a procedure for monthly review by a qualified individual not associated directly with project operations.

Storage areas for diesel fuel and hazardous liquids required secondary containment as well as impermeable liners to ensure that no fuel spilled on the ground during fuel transfers would be allowed to enter groundwater supplies. The project safety plan also outlined handling and storage details and provisions.

In case a spill did occur, the countermeasure plan required that the necessary equipment and trained personnel be readily available at all times. Persons were trained to react appropriately regardless of whether the spill was in water or on land. The plan emphasized the need to first contain a spill to avoid spreading, to then reduce the potential for absorption into the ground and to minimize contamination. Then clean-up of any contamination would start immediately, and the proper authorities notified. Following the containment and clean-up of the contamination, proper classification and disposal in accordance with established procedures was directed.

AIR

1. Air pollution abatement

For prevention and control of air pollution, and to minimize emissions of airborne contaminants, a major area of emphasis for this project was to maintain combustion powered equipment in proper condition. This impacted the routine maintenance schedule. Also, open burning of debris was not permitted in order to avoid smoke or fumes.

2. Dust abatement

Inherent in our plan to avoid air pollution was the control of airborne dust from site access roads. In an arid climate such as Southern Arizona, frequently traveled site access roads can develop dust very rapidly. Therefore, water was utilized to dampen road surfaces, which kept dust to a minimum. This project also utilized drilling with a Down-the-Hole hammer. During its operation, this tool pulverizes the concrete and the rock, using pressurized air as the flushing medium. It was therefore a major potential source of dust and so water was injected through the drill flush to reduce dusty emissions. A rubber skirt was also placed around the foot of the drill rig, just above the hole entry point to further catch the debris. Cement used in grout mixing was bagged to limit the amount of dust created.

WILDLIFE

1. Protected species of wildlife

The construction area contained endangered and protected wildlife species. It was mandatory to avoid any disturbance of these species, and to avoid any further endangerment. For example, it was necessary to work closely with government and environmental agencies to avoid disturbance of bald eagles which nested downstream of the project site. The famous "Gila monster" giant lizards were similarly protected.

2. Protection of wildlife

It was also a requirement that injury to, or damage to habitats, of animals inhabiting the construction area was to be prevented. Deer, javelin, coyotes, wild horses, rabbits and a host of rodents and small animals inhabited the work area. The river and reservoir are both previous sources of water for the desert inhabitants, and fences were erected around the hazardous areas to deter animals from entering.

OTHER CONCERNS

1. Noise abatement

To avoid unsafe and unacceptable sound levels on-site and in the adjacent residential housing and the Sagauro Lake Ranch Resort, the noise levels in the work areas were to be kept below 75 decibels. Equipment used was properly maintained to avoid problems with noise control equipment. Equipment that was not quiet by design was kept a sufficient distance away to avoid sound levels in excess of the specified limit. Also, hearing protection was required for personnel working around equipment producing high noise levels.

2. Light abatement

It was also necessary to control undesirable light pollution in the adjacent residential areas. The primary problem with regard to this was the lighting required for night shift activities. These lights were directed so as not to be a nuisance or cast a beam directly on residences or on specific areas of the surrounding countryside. Welding was also a source of light that was controlled by the use of shields during activities.

3. Preservation of historical or archaeological data

It was also mandated that all objects encountered during construction with historical, archaeological or scientific value be preserved. In the event of a significant discovery, the work was to be immediately suspended until the proper authorities were notified. This proved not to be a concern at this project.

4. Pesticides

It was required that our operations complied with the Federal Environmental Pesticide Control Act of 1972. This was addressed by ensuring that labeling, storage and application of pesticides conformed with guidelines.

5. Personnel safety

This project utilized a comprehensive safety and hazardous materials handling program in compliance with OSHA and other applicable regulations. All employees and visitors on site were required to have a safety orientation meeting prior to entering construction areas. Weekly safety meetings were held to address site specific dangers and to reinforce regulations. Safety meetings also addressed corrective measures for violations noted during job site inspections.

A primary concern in safety was to eliminate the illegal use of controlled substances. A drug screening and substance abuse plan was also necessary to aid in providing a drug free workplace. Pre-employment screening as well as random testing were two commonly used practices.

Another concern related to the extremely high temperatures encountered during the summer months. Work clothing was mandated to completely cover arms and legs while safety glasses with dark lenses were issued to combat glare. Cotton gloves were issued to permit steel surfaces to be touched without causing burns.

In general, it must be confirmed that drilling, grouting and stressing operations are inherently potentially dangerous operations utilizing large, sophisticated equipment and major forces and pressures. Steps were therefore taken to maximize equipment automation and so reduce manual involvement. This was another factor which contributed to this project being totally "accident free".

6. Final remarks

This case history illustrates how an extremely demanding construction effort can be accomplished on a delicate structure, in a sensitive natural environment and in arduous working conditions. One of the keys to this success is applying the principles of "Partnering", wherein all the contracted parties establish a formal system of communication and review, intended to exploit the spirit as well as the letter of the specifications. This attitude was evident at all stages in the Stewart Mountain Dam project, from bidding and award onwards, and is a salutary example to engineers who view their contractual relationships as confrontational and not complementary.

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