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Post-tensioned Multistrand Anchorage Capacity Deterioration Due To Corrosion: John Day Lock Project

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BACKGROUND: A Research Work Unit (WU) has been initiated in the Navigation Systems Research Program to investigate post-tensioned multistrand anchors. A significant number of COE projects have installed multistrand high-capacity post-tensioned foundation anchors over the last three decades. These anchors are embedded and access is limited to the top anchor head for inspection purposes. Due to the evolution of corrosion protection criteria for ground anchors, the early installed anchors may have inadequate corrosion protection that does not meet current corrosion protection standards. The older anchors are approaching the end of their design life and are showing various degrees of deterioration, corrosion, and broken strands. Current load capacity and remaining life of the anchors are unknown. One procedure used to test post-tensioned tendons involves lift-off tests, which are both dangerous and expensive. The applicability of lift-off testing to most existing ground anchorage is severely restricted to the very few existing ground anchors that were not grouted for corrosion protection along the free length of the anchor and which also have special provisions for the connection of the jacking equipment to the anchor head. This severely restricts the practical use of lift-off testing of existing ground anchorage as a viable testing procedure. Additionally, testing deteriorated anchors has been avoided in the past because of greater danger of breaking anchors. To meet reliability analysis required for major rehabilitation studies, estimates of load capacity, rate of decrease, and remaining life are required.

PURPOSE OF WORK UNIT: A research Statement of Need (SON) was submitted by the Corps' Research Area Review Group (RARG) to the Navigation Systems Research Program. In response to this SON, a work unit (WU) was established to develop a procedure to assess post-tensioned anchorage capacity deterioration using nondestructive testing/nondestructive evaluation (NDT/NDE) types of field techniques combined with results from corrosion, deformation, and strength laboratory measurements that are input to PC-based software for analyzing the stability of hydraulic structures that have been retrofitted by ground anchorage and suffer anchorage capacity deterioration due to corrosion. Statistical uncertainties in laboratory and field measurements leading to an assessment of anchorage capacity deterioration are to be formally addressed in the probabilistic stability evaluation procedure.

John Day Lock. The John Day Lock and Dam Project is 216 miles upriver from the mouth of the Columbia River near the city of Rufus, OR. The authorized primary project purposes are navigation and power generation. The project consists of a navigation lock, spillway, powerhouse, and fish passage facilities. John Day Lock was designed and constructed in the 1950's and 1960's simultaneously with the four Snake River locks and dams. The lock is 650 ft long by 86 ft wide and possesses the highest single lift (113 ft) in the Corps of Engineers. The project design was based on the Snake River locks with about 100 ft lifts and scaled to the John Day project conditions. Construction of John Day Lock and Dam was completed in 1971. Structural cracks in the south filling/emptying culvert were first noticed in 1975 and continued to

grow. No significant reinforcement steel was included within the concrete that formed the culvert, and the culvert wall between the lock and culvert is only 7-ft thick. The monoliths were observed to move with each lockage.

Multistrand Anchors at John Day Lock. An investigation was performed in 1979 which led to the installation of 73 post-tensioned anchors in 1981. Each anchor contained 37, 7-strand (0.6 in. diameter) wires and was oriented to pass through a window (about 7 ft) between the emptying/filling culvert and the lock chamber. Spacing and inclination was varied to pass between laterals in the chamber. Figure 1 shows a schematic section view of the anchors. Load transfer takes place at the ends of the post-tensioned anchorage; at the top of an anchor head and at the other end, along the bonded zone contained within the basalt below the base of the lock.

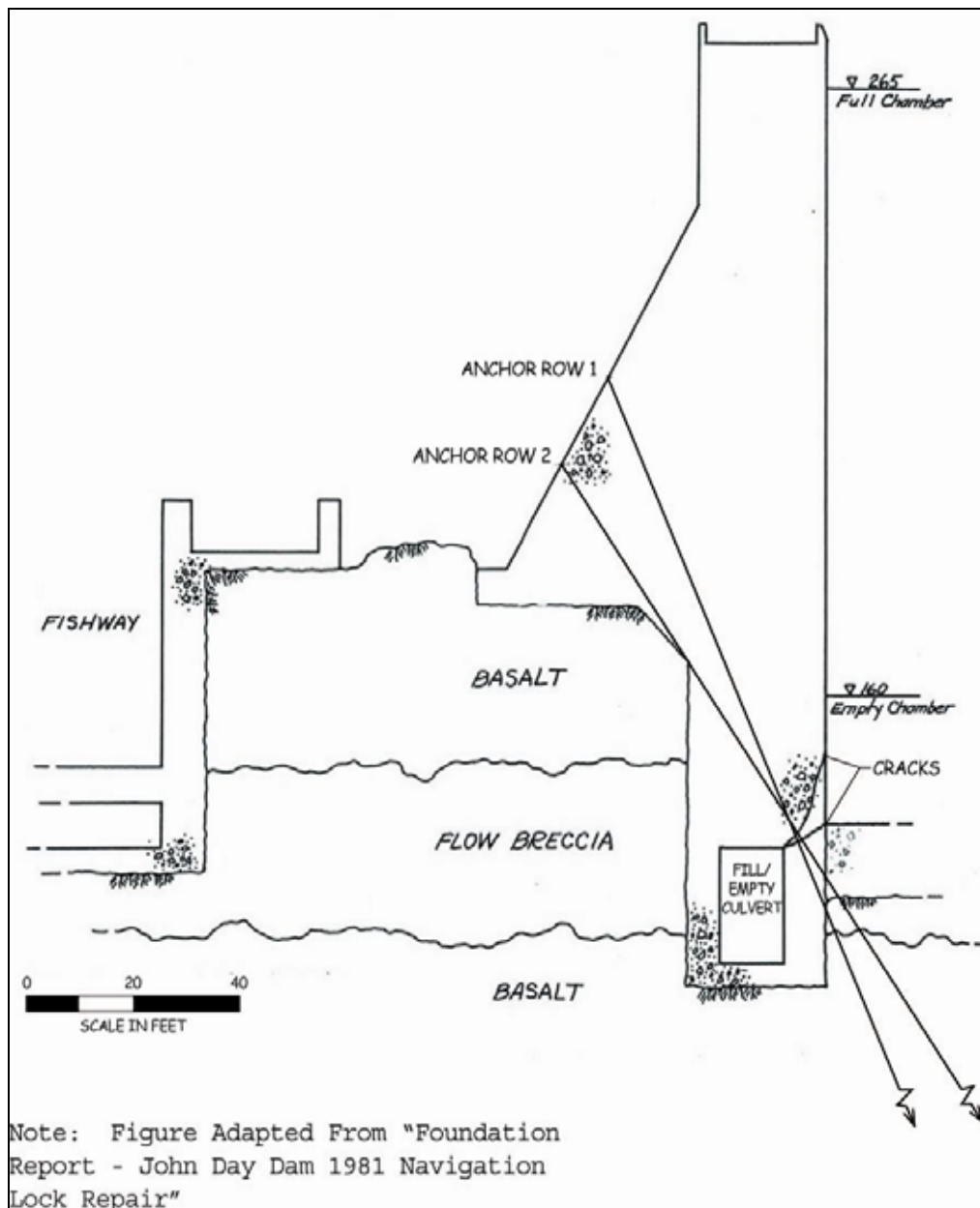


Figure 1. Schematic of John Day Lock crack repair using multistrand anchors.

The original lock-off load for the anchors at the time of installation (1981) was 1,518 kips per anchor. Three-stage grouting was used at the time of installation. Single-stage grouting is preferred today. Figure 2 shows some of the details of the anchors used at John Day Lock. There are individual sheaths around each strand in the free length (i.e., stretch zone of the anchor) in which load transfer does not take place. It is important to observe that the anchor wire was bare strand in the bonded zone contained within the basalt rock below the lock (detail 11 in Figure 2). At the time of initial anchor installation, seepage was observed coming out the top(s) of some anchors. The anchor heads were inspected from 1981 through 1995 and no broken strands were found. The inspections were halted in 1995.

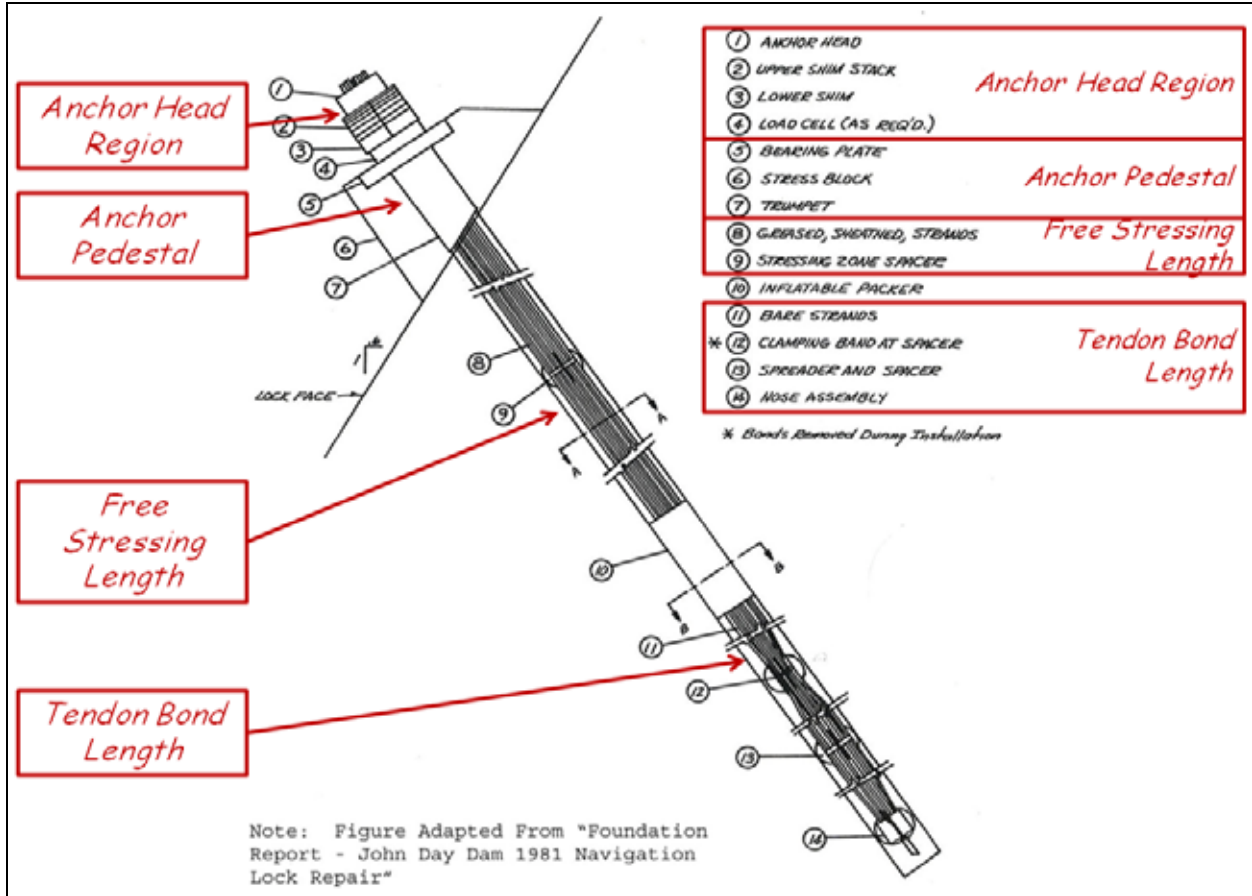


Figure 2. Three stage anchorage system used at John Day Lock.

A foundation investigation at the project was conducted between 2001 and 2004, and in 2003 an outside peer review recommended that several anchors be tested to confirm load capacity. Upon opening anchor covers in 2003, broken strands were discovered. All anchors were visually inspected and the anchors designated as good were tested. In 2008, visual inspection of all anchors was done and representative samples of both good and those with some “loss of tension” were subjected to lift-off testing. Three lift-off tests were conducted on competent anchors in 2003. They showed a range in lift-off load of between 1,340 and 1,390 kips. Twenty one lift-off tests were conducted in 2008 on anchorages in varying states; from no broken strands and no broken anchor head wedges to those possessing 25 broken strands and three broken wedges in the anchor head. It was observed that one anchor head did not possess a single unbroken strand. Excluding data for

any 2008 lift-off test on an anchor possessing seven or more broken strands, the average lock-off load equals 1,304 kips (for 16 tests; values ranging from 1,163 to 1,373 kips); a 14 percent reduction from the initial lock-off value. Interestingly, the lock-off tests conducted on the same three anchors tested in 2003 and in 2008 showed a 4.2 to 5 percent reduction in lift-off force for this time frame. Another key finding was that the number of anchors with visibly damaged strands increased by 11 percent over this five-year time span.

Post Tensioning Institute Updates. In the 1980 updated “Recommendations” document, Post Tensioning Institute, PTI, (1st Edition) recommended corrugated sheathing or epoxy coated strand in the dead end anchor zone and greased and sheathed tendons in the free stressing length zone. The latter sheathing was intended both as a bond breaker and for corrosion protection. Two-stage grouting was the standard practice.

In the 1986 updated “Recommendations” document, PTI (2nd Edition) placed emphasis on chemical analysis as a means for selecting the appropriate level of corrosion protection. Encapsulated tendons, although no details were provided, were only required for aggressive ground. One-stage grouting was relatively new.

In the 1996 updated “Recommendations” document, PTI (3rd Edition), Class I Protection (sometimes referred to as double corrosion protection) and Class II Protection (sometimes referred to as single corrosion protection) were introduced. Clear encapsulation details were provided by PTI along with a decision tree where engineers could base the selection of Class I or Class II on factors such as ground aggressivity, consequences of failure.

Class I protection is the current standard for post-tensioned hydraulic structures. Previous corrosion protection methods were considered to be inadequate from the viewpoint of past performance.

John Day Lock Multistrand Anchor Meeting 30-31 August 2011. A meeting and site visit were held at the Portland District Headquarters and the John Day Project on 30-31 August to discuss status of John Day anchors and the current research plans. The meeting participants are shown below:

David Scofield, Portland District
Ralph Strom, Consultant
Gerry Heslin, Cornforth Consultants
Dr. Robert Ebeling, ERDC
Richard Haskins, ERDC
Dr. John Hite, ERDC

Pat Hunter from the John Day Project led the tour on 31 August. Figure 3 shows the anchor pedestals (i.e., reinforced concrete reaction blocks) and anchor head protective covers protruding from the outside face of the south lock wall. These are some of the upper anchors shown in Figure 1. Figure 4 shows the original anchor head installed in 1981. This anchor head was specially manufactured for this project with a threaded head (refer to Figure 4). This special provision facilitates the connection of a specially manufactured “coupler” to the jacking equipment used for lift-off testing. This feature is unique to the John Day anchorage.



Figure 3. Anchor head pedestals and protective covers along the south lock wall access deck.



Figure 4. Original 1981 threaded anchor head with spacers and wedges resting on the anchor pedestal.

CORROSION OBSERVATIONS: Issues affecting the current plan forward involving John Day Lock in ERDC's research effort to assess and quantify multistrand anchorage capacity deterioration due to corrosion are shown below. The issues contributing to corrosion induced deterioration of the post-tensioned anchors at John Day are:

- a. The bonded zone is situated below the base of the lock in the Basalt and in proximity to the permeable flow breccia.
- b. Piezometers located below the base of the culvert indicate the Basalt in this zone is fractured and provides a conduit for water during lock operations.
- c. In addition to item (b), significant bond damage occurs as the tendon is prestressed and load is transferred to the grouted anchor zone and surrounding rock. The large tensile strains induced in the load transfer zone lead to crack formation in the surrounding grout and foundation rock.
- d. The culvert was constructed using minimal reinforcing steel to accommodate tensile strain due to flexure in the culvert wall and volume change effects. The reinforcement provided was inadequate for crack control. Fracture of some reinforcing bars was observed during periodic inspections. Lock wall cracking in this region allows access to lock chamber water.
- e. Quality assurance issues with the contractor resulted in large rounded river-run aggregate with lots of variability in concrete compaction and tensile strength. Bond between the aggregate and cement paste is a key to tensile stress-strain capacity and large quantities of rounded river-run aggregate meant the tensile stress-strain capacity would be low.
- f. Water on the Columbia is characteristically soft which further contributes to corrosiveness.
- g. It was noted that there are extreme seasonal temperatures and the pedestals containing the anchor heads (Figure 3) are exposed to these conditions.

FIELD OBSERVATIONS: A significant number of anchor failures seem to initiate with the failure of the center wire known as the "king" or "core" wire. The center wire has a larger diameter than the outer wires to assure the outer wires bear on the center wire and grip it as there is no other means of keeping tension in the center wire. This failed wire has been observed either retracting into the seven-strand grouping or protruding outwards (and above the tops of the seven-strand wire groups). For those wires protruding, the length has been on the order of six to eight inches. This length likely corresponds to the distance between the tip of the gripping wedge and the top of the wire above the anchor head. Retraction of the center wire could indicate a loss of section due to corrosion where the diameter has reduced enough to prevent the outer wires from bearing on it. Protrusion of the center wire may indicate a corrosion failure. Figure 5 shows flow of water through the anchor from the lock operation, and the loss of the center wires can also be seen. Potential contributing factors to strand failure near the anchor head are listed below:

- a. Temperature,
- b. Wetting and drying action leading to a concentration of dissolved oxygen near the anchor head
- c. Corrosion stress, stress concentration, or loss of cross section at the gripping wedge,
- d. Increased corrosion potentials (electrical potentials).



Figure 5. 2008 inspection (and lift-off testing) of multi-strand tendons showing loss of center wire and flow of water through several of the 7-stand wires.

Other factors that may be contributing to failed strands and other observations are:

- a. If the king wire is straight an argument can be made that the six surrounding wires will have less tension (longer) and add a shearing force;
- b. Water appears to be moving up the length of cable. One fundamental question is what path the water is taking toward the anchor head. For example, is the water moving up around the “king” wire, inside the sheath, or outside the sheath. This question contributes to the motivation for removing an anchor head and recovering and inspecting the subsurface cable;
- c. A secondary question is, where does the sheath terminate and does this additionally contribute to corrosion issues occurring mostly toward the anchor head;
- d. Recovery of a nonfunctional anchor head would allow for a detailed assessment of points of access for insertion of NDE / mitigation technologies.

ERDC Recommended Field Tests for John Day Multistrand Anchors. Field activities will benefit the investigation of the multistrand anchors by helping to determine some of the corrosion, deterioration, and failure issues. Inspection and recovery of the top section of the anchor head, for anchors that have experienced a loss of tension, is desired. The results of the previous lift-off tests can be used to identify these anchors.

The proposed procedure to obtain an anchor would be as follows:

- a. Perform a lift-off test;
- b. Remove shim plates;
- c. Release tension;
- d. Saw cut with wire saw at base of trumpet;
- e. Photograph and recover head, grip wedges, and cables.

Other field activities that could be conducted for assessment of baseline corrosion rates and catalysts are to install a datalogger to monitor four anchor heads. Temperature, pressure, and cathodic potentials data could also be collected.

Accessibility and Scheduling of Field Work. There is a scheduled lock outage for two weeks in March. Any activities performed during this period would need to be closely coordinated with lock maintenance. Any recovery of a long anchorage assembly would have to occur during outage and involve work from within the lock chamber. All activities must be scheduled around fish passage and prior approval is necessary. Overhead wires used for avian avoidance will cause overhead accessibility issues with cranes from the top of the lock wall and will need to be considered for any field work. Some anchors are close to the fish ladder, but there are no activities planned within the fish ladder (shown in the center and to the right of Figure 3). All field activities would need to be coordinated through the Fish Passage Operations and Maintenance (FPOM) workgroup for the project.

SIGNIFICANT FINDINGS: The research performed to date and the investigation into the John Day Project, have revealed several key issues for the multistrand anchors. The unique features of John Day Anchors for lift-off testing capabilities are not common to most all other ground anchors. The threaded anchor head was specially manufactured for this project and facilitates the connection of a custom made “coupler” to the jacking equipment used for lift-off testing. This emphasizes the need to develop NDE testing techniques that will be vital for assessment of anchors at other sites and also the John Day Project. Forensic inspection of a “decomposed” anchor head and pedestal of a corroded John Day anchor should provide useful insight into corrosion behavior of the anchorage system, especially the corrosion stress, stress concentration, or loss of cross section at the gripping wedge. The load transfer zone for the bonded section of the anchors needs to be studied carefully to try and avoid cracking of the foundation and the subsequent flow of water into the anchors.

ADDITIONAL INFORMATION: This CHETN is a product of the Probabilistic Assessment of the Reduced Capacity of Multistrand Post Tensioned Ground Anchorage Due to Tendon Corrosion Work Unit of the Navigation Safety Research Program being conducted at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Questions about this technical note can be addressed to Dr. Robert Ebeling (601-634-3458; email: Robert.M.Ebeling@usace.army.mil). This technical note should be cited as follows:

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