The Innovative Use of High Pressure Jetting of Thin Diaphragm Walls To Construct Hydraulic Control Barriers

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Abstract: Emplacement of hydraulic control barriers and in unstable soils, near foundations, or near underground/overhead obstructions using conventional construction techniques can be problematic. A demonstration project of high pressure jetting was conducted at the National Test Site at the Dover Air Force Base in Dover, Delaware. The demonstration project was sponsored by US Department Of Energy's Office of Science and Technology, DuPont, US Air Force/Armstrong Labs, and the National Environmental Technology Test Sites Programs. This program demonstrated high pressure jetting of thin diaphragm walls to be an effective technique for constructing hydraulic control barriers where conventional techniques would have been problematic. The objective of the program was to demonstrate that high pressure jetting was capable of constructing a thin diaphragm hydraulic control barrier, to verify its continuity, and to develop cost information. To demonstrate the technology, a circular cofferdam roughly 34 feet in diameter comprised of 12 interconnecting thin diaphragm walls was constructed and keyed into the aquitard at a depth of 36 feet. Hydraulic flood tests, pump tests, and impulse tests were then conducted to determine the bulk hydraulic conductivity and the continuity of the cofferdam. Using the data from the flood and pump tests and using Darcey's Law the bulk hydraulic conductivity of the cofferdam was calculated to be 2.52 x 10^{-6} cm/sec which also indicated 98.8 percent of the cofferdam was competent. To delineate the location of the defective zone an innovative pulsed hydraulic test was conducted which clearly showed the location of the defective area of the cofferdam.

High pressure jet grouting has been demonstrated as an innovative and cost effective emplacement method for the construction of subsurface physical containment barriers. The jet grouting process consists of drilling a borehole to the desired depth. Once at depth the drilling fluid is diverted from the drill bit to the jetting nozzles and the pumping of the desired slurry begins. The pump pressure and flow rate are then increased to the desired specifications. Once at pressure the drill string is withdrawn at a predetermined rate without rotating the drill string. As the jet grouting process proceeds excess soils and slurry will be expelled at the surface through the annulus of the borehole and the drill string. The walls are emplaced using high pressure jetting of slurry into native soils to create low permeable zones (Figures 1 and 2) by jetting through two relatively horizontal and opposing nozzles as the drill string is extracted

Figure 1. Photograph of high pressure jet grouted panels (high cement / low bentonite slurry)

Figure 2. Photograph of a high pressure jet grouted panel (high bentonite / low cement slurry)

without rotation. During jet grouting the high pressure jetting action erodes a linear cavity in the soil into which the slurry later sets to form a mixture of mostly slurry and some host soil. Continuous containment barriers are created by jet grouting a series of intersecting panels such that the ends of panels overlap.

In a pilot demonstration project a circular cofferdam was jet grouted with a diameter of 34 feet consisting of 12 inter-connecting panels with an effective tip to tip distance of 9.3 feet (Figure 3). The cofferdam was constructed by jet grouting at roughly 6000 psi and a drill string extraction rate of roughly 64 inches per minute. Based upon lab testing of cores from the nearby test panels the cement-bentonite slurry had an *in situ* hydraulic conductivity of roughly 1.0×10^{-7} cm/sec. The panels of the cofferdam were jetted roughly 7 feet into the underlying confining unit at a depth of 36 feet below ground surface. Based upon down hole inclination measurements of the drill string and the resultant an as-built drawing, several additional panels were jetted to help ensure continuity at the intersections between panels (Figure 3). Three pairs of monitoring wells were installed and screened within the 10 foot saturated zone to monitor water levels inside and outside of the cofferdam to determine the gradient across the panels. The cofferdam was then covered with a geomembrane to prevent precipitation infiltration (Figure 4).

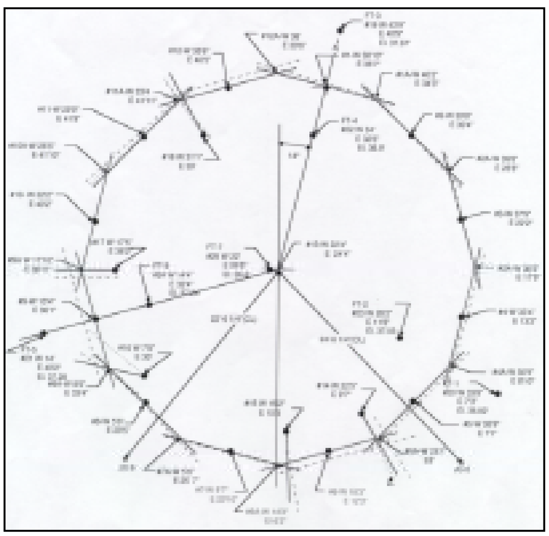

Figure 3. An "as-built" drawing of the cofferdam consisting of 12 panels, 6 monitoring wells and 1 injection well

Figure 4. Photograph of the geomembrane cover and seals around the monitoring wells

The integrity of the cofferdam was then characterized using hydraulic flood tests. Flood tests were conducted at 4, 8.5, 10, 12, and 15 gpm and each test run until steady state conditions were observed (Figure 5). In Figure 5, the bottom three curves (FT-1, FT-3, and FT-5) are monitoring wells located outside of the cofferdam, the top curve FT-7 is the injection well and the middle three curves (FT-2, FT-4, and FT-6) are monitoring wells located inside the cofferdam. Based upon the test results, the

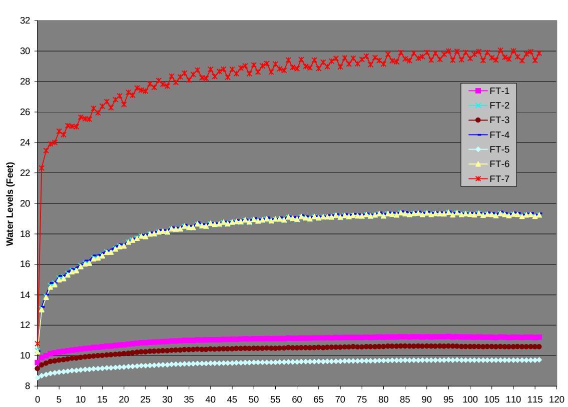

Figure 5. A graph of the water levels in the monitoring wells during a 8.5 gpm flood test

average bulk hydraulic conductivity calculated for the cofferdam using Darcy's Law was estimated to be 2.52 x 10^{-6} cm/sec. To help understand why the hydraulic conductivity was below that of the test panels, hydraulic pulse tests were performed to delineate the location and nature of the potential defect. The intent of the hydraulic pulse test is to create a pressure pulse in the saturated zone within the cofferdam and measure whether or not the pressure pulse is attenuated by the cofferdam's walls. The pressure pulse was generated in the central 4 inch casing (FT-7) using a timing circuit to open and close a solenoid valve connected to a water source. Hard piping was run from the solenoid valve to a packer and foot-valve assembly that was positioned below the water table. High frequency pressure transducers were then installed in all the monitoring wells including the injection well to measure the pressure pulses in the monitoring wells. The pressure pulses were then recorded on a strip chart recorder. Based upon the hydraulic pressure pulse results it is apparent that a defective zone is located near the FT-1 monitoring well (Figures 6 and 7) due to the pressure rise in the monitoring well.

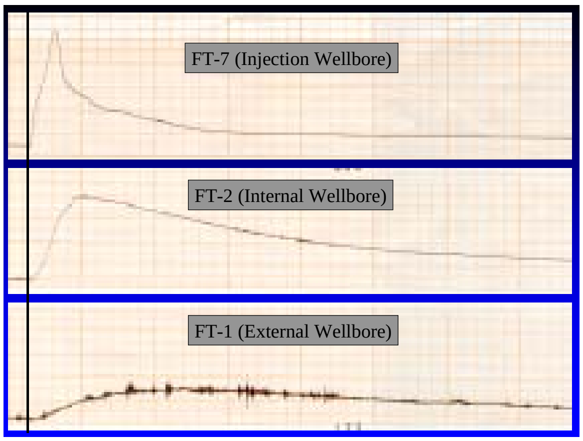

Figure 6. Charts showing the injection pulse, an internal response pulse (FT-2), and an external response pulse near the defective zone

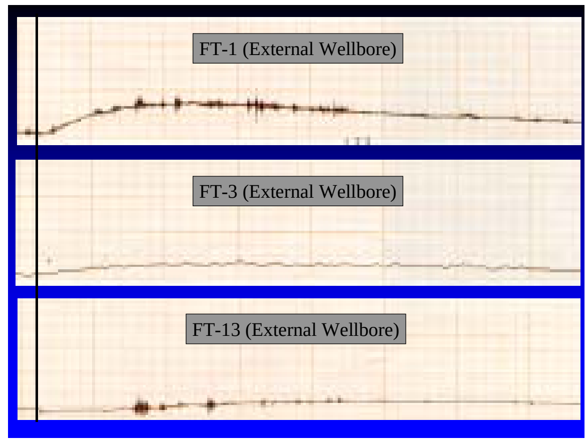

Figure 7. Charts showing the external response pulse near the defective zone and two neighboring external response pulses

Based upon the results of this demonstration, high pressure jet grouting appears to be as cost effective as the more conventional methods to emplace physical hydraulic control barriers. This is especially true for situations where conventional emplacement methods would be problematic cost prohibitive or technically impractical such as in unstable soils, near foundations, or around underground obstructions.