

Automated Monitoring System used to Support Drydock Operations at Electric Boat

John E. Regan, P.E.¹, P. Sean Davies², Marvin E. Valdez³ and Bradford W. Roberts, P.E.⁴

ABSTRACT: The Electric Boat facility in Groton, Connecticut consists of three Graving Docks, each supported by interlocking circular and diaphragm cofferdam structures. Owned and operated by the General Dynamic's subsidiary Electric Boat Corporation, these graving docks are used for the construction and maintenance of the United States Navy's submarine fleet. Graving Docks 1 and 2 were constructed between 1961 and 1968, followed by Graving Dock 3, known as the Land Level Construction Facility, which was constructed from 1975 to 1977.

In May 2004, sheetpile cofferdam cell S-2 at Graving Dock 3 experienced an interlock failure during a routine dewatering evolution performed to drydock the USS Jimmy Carter. This event rendered Dock 3 unavailable for submarine construction and launched a series of initiatives at the facility to investigate the cofferdam failure, stabilize and repair cell S-2, and monitor and evaluate the condition of all three Graving Docks. As routine submarine maintenance continued at Graving Docks 1 & 2, geotechnical instrumentation played a pivotal role in restoring confidence in the ability of the aging cofferdam structures to support the construction and maintenance of nuclear powered submarines.

A total of ninety-four (94) vibrating wire piezometers were installed near the base of each cofferdam cell to monitor hydrostatic levels. These instruments were automated using a customized data acquisition system (ADAS) to provide real-time changes of in-situ pore pressures. This data is used during routine but critical dewatering activities to monitor hoop stress conditions in each cofferdam cell and provide the basis for controlling the rate of flooding and dewatering at the Facility. This automated system has demonstrated that pore pressures can be controlled within individual cells to remain within operating range and therefore restore confidence in the Facility so that time sensitive construction and maintenance activities can continue.

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INTRODUCTION

Since the early 1900's, Electric Boat Corporation, a subsidiary of General Dynamics Corporation, has been at the forefront of submarine technology, serving the United States Navy throughout the two World Wars, as well as the Cold War. Located in Groton, Connecticut on the eastern shore of the Thames River, Electric Boat is recognized as the nation's premier designer and builder of nuclear powered submarines. To help construct and maintain the submarines, Electric Boats 8,000 employees utilize three (3) Graving Docks (GD), each capable of docking and launching individual submarines.

GD-1 was designed between in 1960 and construction was completed in 1963. GD-2 was later designed in 1965 with construction completed in 1968. These two graving docks are used for overhaul and repair of delivered submarines. Graving Dock No. 3, formally known as the Land Level Construction Facility, was constructed from 1975 to 1977. This dock is used for launching newly constructed submarines. GD-3 supports sectional construction of submarines whereby assembly and erection of individual hull sections is performed on the inboard and outboard platforms and drydocking and launching is performed using a floating launch pontoon.

Graving docks GD-1 and GD-2 project out into the Thames River in the southwest direction approximately 180 to 230 meters, respectively, whereas GD-3 projects out in the westerly direction, approximately 245 meters. Each Graving Dock is supported by parallel rows of interlocking steel sheetpile cofferdams. The docks are surrounded by the Thames River on three sides to form rectangular dry dock structures, each approximately 30 meters wide.

Overall, the Graving Docks are a critical component of Electric Boat's operations, facilitating maintenance and construction of the submarines while protecting the workers and the US Navy's multi-billion dollar nuclear powered submarines. An incident which occurred in May of 2004 showed just how critical these Graving Docks are to their operation.

BACKGROUND

General Construction

The Graving Dock walls consist of a series of circular and diaphragm cofferdam structures constructed from interlocking 1 centimeter thick, flat steel sheet piles and backfilled with well graded granular soils. Each row consists of a combination diaphragm and circular cofferdam cells which connect with circular cofferdam end cells installed onshore. The diaphragm cells are typically installed approximately 11.5 meters on center and vary in width from approximately 10 to 13.5 meters.

Based on available as-built drawings, sheeting for the cofferdam cells was installed through overburden soils to a final penetration criteria or refusal on bedrock. The sheeting was driven to final depths ranging from approximately El. -21m to El. -36m where bedrock was not encountered. In general, the outboard sheets were driven to 6 meters deeper than inboard. Granular soils were used to backfill the cofferdam cells in all three rows up to approximately El. 2m. GD-1 and GD-2 share a common center wall and common dewatering pumping station. Locking steel bulkhead doors provide access for the submarines into the graving docks. Refer to Figure 1 for a plan view of GD-1 and 2.

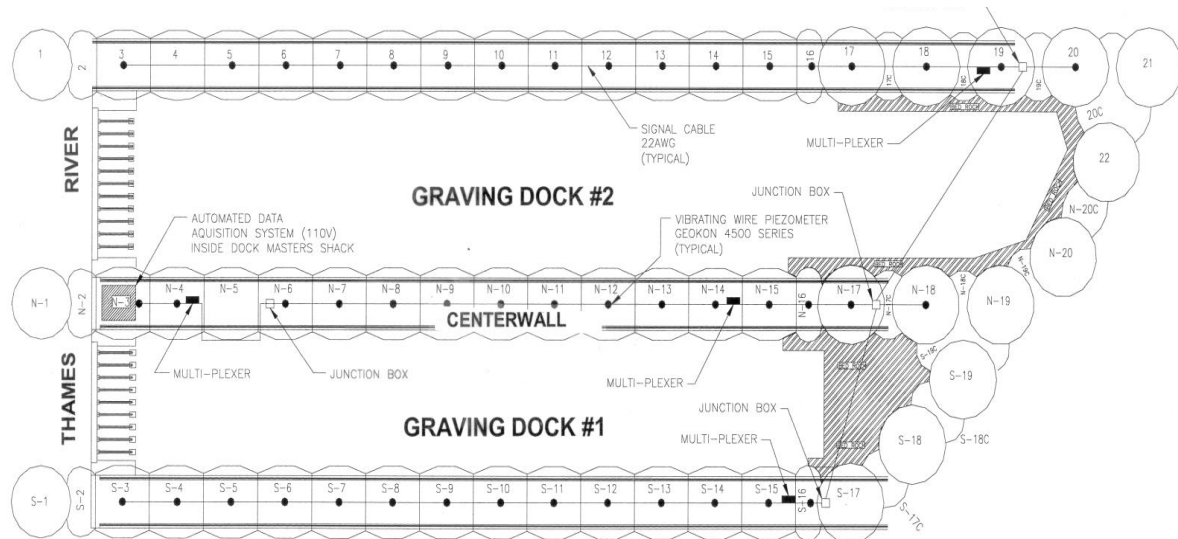


Figure 1 – Plan view of GD 1 & 2 with Centerwall

Graving Dock No. 3 – USS Jimmy Carter

Similarly, GD-3 was constructed by installing sheeting for the cofferdam cells through overburden soils to refusal on top of bedrock. Recent borings encountered bedrock on the north wall of GD-3 sloping east to west from 12 to 18 meters below the top of wall. Bedrock was encountered on the south wall sloping east to west from approximately 21 to 27 meters below the top of deck grade. Electric Boat photo archives indicate that granular soils were used to backfill each cofferdam. GD-3 operates on an independent under drain and dewatering system and also has a steel bulkhead to provide access for submarines into the dock. Refer to Figure 2 for an aerial view of GD-3.

In 1999, Electric Boat was awarded a contract with the US Navy to modify the USS Jimmy Carter (SSN23), the third and final Seawolf-class nuclear powered attack submarine. Valued at over \$4 billion (US), the Jimmy Carter it is arguably the fastest, quietest, most heavily armed attack submarine built in the world. Modifications included the installation of a 30-meter hull extension known as a Multi-Mission Platform (MMP) to provide advanced technology for naval special warfare.

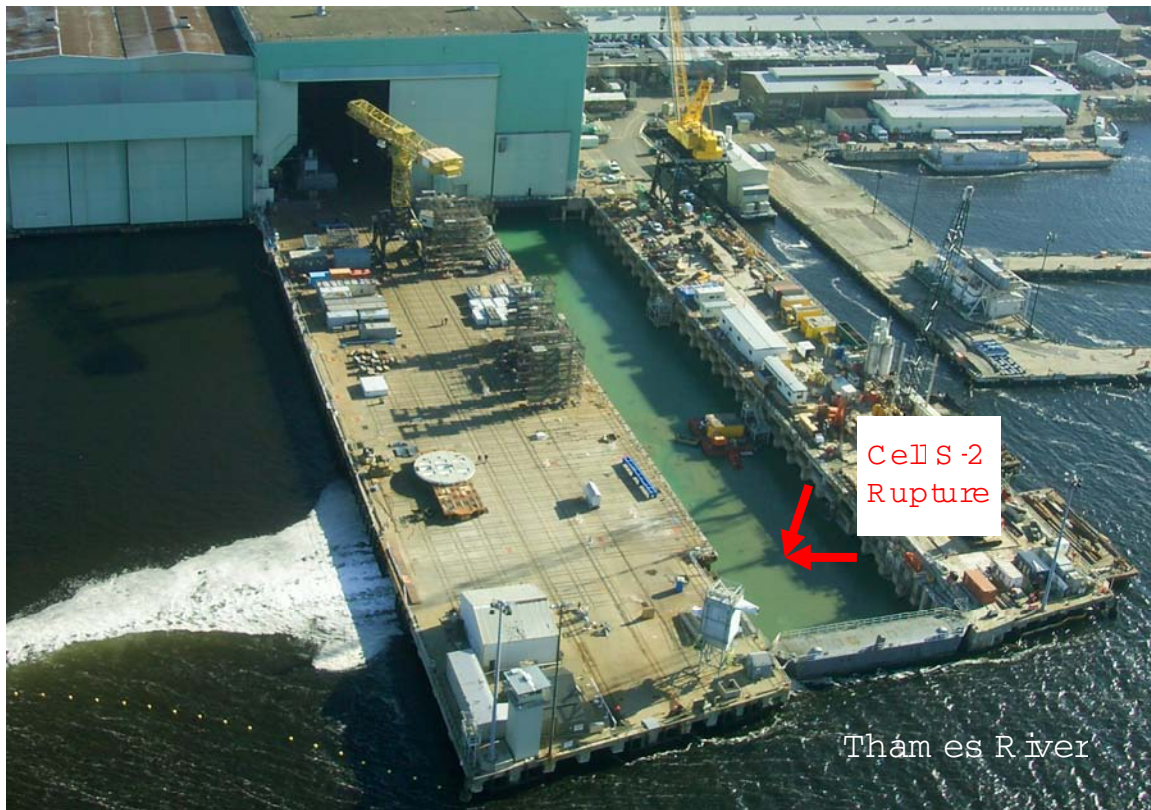


Figure 2 – Aerial view of GD-3 partially flooded to stabilize ruptured Cell S-2.

The MMP has an ocean interface which will be able to launch and recover Remotely Operated Vehicles (ROV), retrieve and deploy weapons and Navy Seal Special Operations forces.

Electric Boat employed GD-3 to execute the work under this contract and by the spring of 2004, work on the SSN23 was nearing completion. In May 2004, the SSN23 was transferred from the outboard platform to the pontoon within GD-3 and the Graving Dock was dewatered to securing the pontoon in-place on the basin floor.

On Wednesday, May 12, 2004, shortly after the pontoon was secured, sheetpile cofferdam cell S-2 on the south wall of GD-3 experienced an interlock failure. The cell failure left approximately 225 cubic meters of granular cell fill material on the basin floor, partially covering the pontoon, and rendered GD-3 unstable. Please see Figure 2. With mounting concern over the stability of the south wall and the potential for a catastrophic failure of the dock, GD-3 was flooded to stabilize the dock walls. Subsequently, the SSN23 was launched early to complete final outfitting within the Thames River.



Figure 3 – Inboard side of GD-3 Cell S-2 showing backfill from ruptured interlock

GD 1 & 2 INVESTIGATION PROGRAM

The failure at cell S-2 in GD-3, the newest of the three graving docks, launched a series of initiatives at the facility to investigate the cofferdam failure, stabilize and repair cell S-2, and monitor and evaluate the condition of GD-3 and re-establish its operational capabilities. Electric Boat contracted with Kiewit Construction Company (Kiewit) of Omaha, Nebraska to repair cell S-2 at GD-3, perform subsurface investigations monitor pore pressures within each cell to evaluate stability. In addition, Electric Boat elected to investigate the existing conditions at the older Graving Docks, GD-1 and GD-2, and monitor the cofferdams as an initial step toward upgrading their service life.

The investigation program at GD-1 and GD-2 included visual inspections of sheetpile web and interlocks, approximately 50,000 ultrasonic thickness (UT) measurements to quantify the level of corrosion in the webs of sheet piling, subsurface investigations in each cell to classify and evaluate draining characteristics of cell fill material, and cofferdam stability analyses. Based on the interlock failure at GD-3 and the age of the GD-1 and GD-2, Electric Boat determined that bursting of the sheet pile interlocks was the critical failure mode with critical driving forces resulting from changes in hydrostatic pressure within the cells.

A limited testing program was initiated in which 9 pairs of interlocks, which were removed from cell S-2 at GD-3, were pull-tested in Electric Boat's materials testing laboratory. The pull tests indicated that the strength of the sampled interlocks had decreased approximately 25% due to corrosion. Based on hoop stress analyses performed by Electric Boat, the available interlock strength corresponded to a minimum factor of safety (FOS) of 1.5 against bursting provided that hydrostatic pressure across each cell did not exceed a 2:1 phreatic surface.

The investigation program concluded that controlling hydrostatic static pressures within each cell was critical to maintaining stability of the dock walls during docking and undocking evolutions. Based on their findings, Electric Boat's primary objective was to measure and monitor pressure within each cell to restore confidence in the facility and maintain US Navy certification.

INSTRUMENTATION PROGRAM

GZA GeoEnvironmental, Inc (GZA) of Norwood, Massachusetts subcontracted with Kiewit to perform forty-six (46) geotechnical borings within each cell to characterize cell fill material at GD-1 and GD-2. In concert with the cofferdam investigation program performed by Electric Boat, the scope of the exploration program was expanded to include the installation of vibrating wire piezometers installed in each circular cell to measure and monitor hydrostatic pressure. GZA installed Model 4500 S vibrating wire piezometers, manufactured by Geokon of Lebanon, NH, approximately 12 meters below the top of the cells, corresponding to the dock basin floor grade.

Automated Data Acquisition System

A total of forty six (46) vibrating wire piezometers were initially installed within exploratory borings performed as part of the investigation program. Each VWPZ was installed near the base of each cofferdam cell in GD-1 and GD-2 to monitor hydrostatic levels. After initializing the VWPZs, GZA spliced each instrument using 3M model 82-A splice kits and installed approximately 3,050 meters of direct burial signal cable to intermediate junction box locations located along the east end of each wall. Each junction box consisted of buried manhole structure used to protect a multiplexer (a switchbox used to control up to 32 instruments). From these buried structures at each wall, GZA installed approximately 1,200 meters of Multiplexer (MUX) cable, through protective conduit along the centerline of GD-1 & GD-2 centerwall to a central monitoring station at cell N-3, located at the west end of the centerwall. Each MUX cable was routed into the Dockmasters shack, located at Cell N-3, and connected to an Automated Data Acquisition System (ADAS).

The ADAS consists of a Geokon Model 8020 Micro-10 Datalogger which uses the Campbell Scientific CR10X MCU computer with six (6) intermediate multiplexers controlling 46 VWPZs in the cofferdams and one (1) VWPZ installed within the Thames River. Utilizing Windows based Multilogger software for programming; the ADAS

provides continuous real-time monitoring of in-situ pore pressures. Refer to Figure 4 and 5 for a generalized layout of the ADAS and the instrumentation schematic.

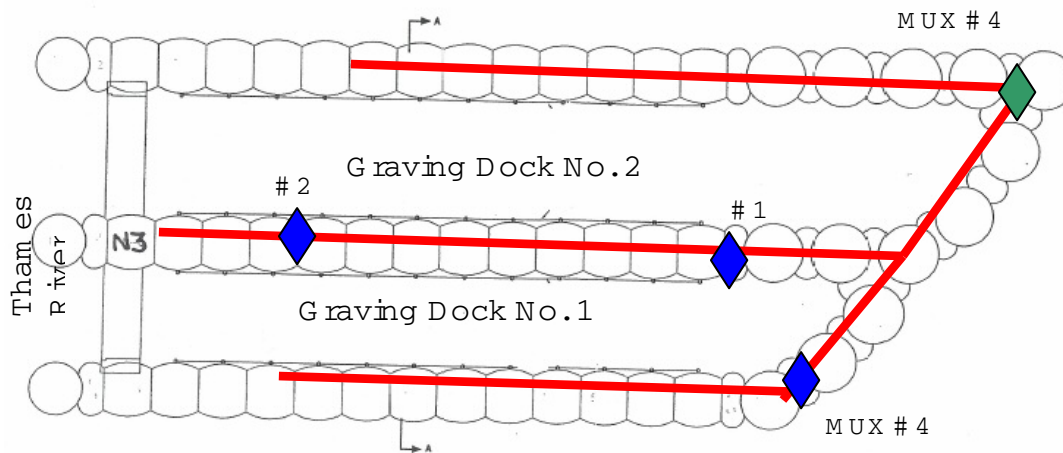


Figure 4 – Layout of ADAS system showing intermediate multiplexers and buried signal cable along each wall terminating at the datalogger in the Dockmaster Shack (Cell N-3)

ELECTRIC BOAT-GRAVING DOCKS 1/2 DATALOGGER SYSTEM SCHEMATIC

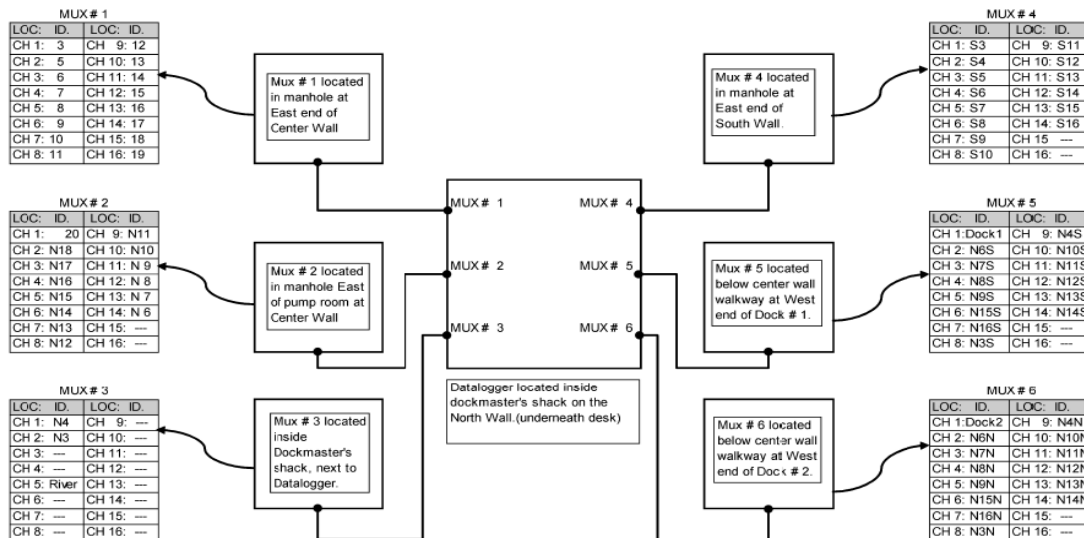
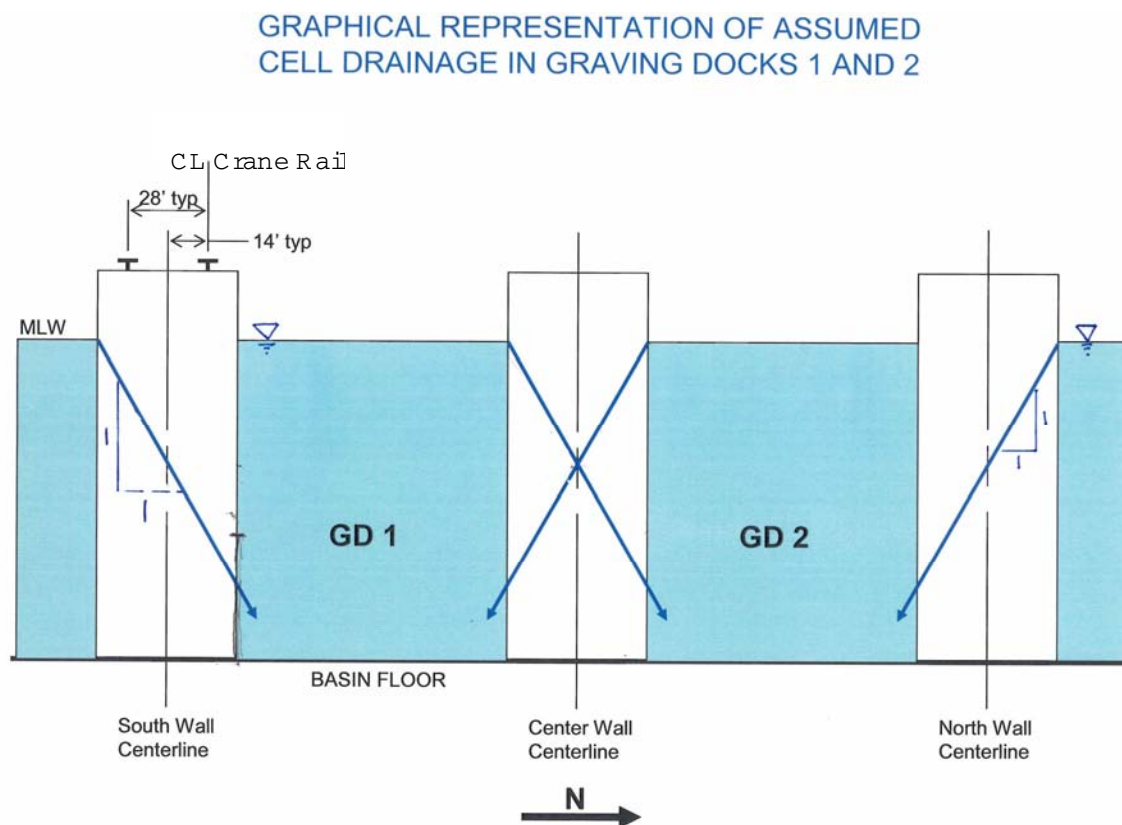


Figure 5 – Schematic of ADAS system to provide real-time pore pressure monitoring.

Routine operations at Electric Boat apply three (3) primary loading conditions on the GD-1 & GD-2 cofferdams; 1) GD-1 is dewatered leaving full hydrostatic pressure at riverside (south) and within GD-2, 2) GD-2 is dewatered leaving full hydrostatic pressure at riverside (north) and within GD-1, and 3) GD-1 and GD-2 are both dewatered.

Installation of VWPZs within exploratory borings generally left the instruments near the center of each cell. As such, piezometric readings obtained reflected pore pressures at the instrument locations. To correlate piezometric readings from the center of each cell to hydrostatic pressure at the face of each cell, GZA customized the multilogger software to normalize the readings. Using an assumed phreatic line of 1:1 through a cross section of a typical cell to model pore pressure dissipation within the well drained cell fill material, readings were normalized to account for 3-dimensional offsets from centerline of cell using x, y and z vectors provided by Electric Boat. Refer to Figure 6. These adjusted readings were then assumed to represent pore pressure readings at that outer limits of each cell (i.e. face of sheeting) and used to monitor factors of safety against interlock failure.



Further programming efforts were employed to convert pore pressure readings into head of water above the basin floor and provide a real-time graphical interface for users to compare head of water for each cell (i.e. pore pressure at the cell face) to the allowable in-service strength of the interlocks. This relationship is designated the “Go / No Go” criteria and is represented graphically at the ADAS monitor to assist Electric Boat in controlling the rate at which the docking and undocking evolutions may proceed without overstressing individual cells.

Docking of the USS Seawolf (SSN 21)

After a series of QA/QC tests performed by GZA and with the piezometric correlations finalized, Electric Boat prepared to drydock the USS Seawolf in GD-2 by early February 2005. Using the ADAS, piezometric data collected on regular one minute intervals provided the basis for controlling the rate of flooding and dewatering. With GD-2 flooded throughout the docking evolution, VWPZs within the south wall of GD-1, as well as centerwall, provided the primary piezometric measurements.

As shown on Figure 7, piezometric readings within the centerwall indicated an undrained condition developed in cells N-15 and N-16 (each maintaining more than 3 meters of static head). As the depth of water within these cells approached the limit of the Permitted Operating range, as defined by the blue Go-No Go line, Electric Boat was forced to delay each dewatering interval to maintain stability of the centerwall. This condition increased the docking evolution as the USS Seawolf, its crew and equipment, were on standby waiting for cells N-15 and N-16 to drain. The total docking for this evolution double to approximately 18 hours and lasted between 0950 hrs on February 9, 2005 to 0240 Hrs on February 10, 2005. This event and other subsequent docking evolutions led Electric Boat and GZA to develop a final phase of instrumentation system where instruments would be installed to monitor pore pressure at the most critical locations.

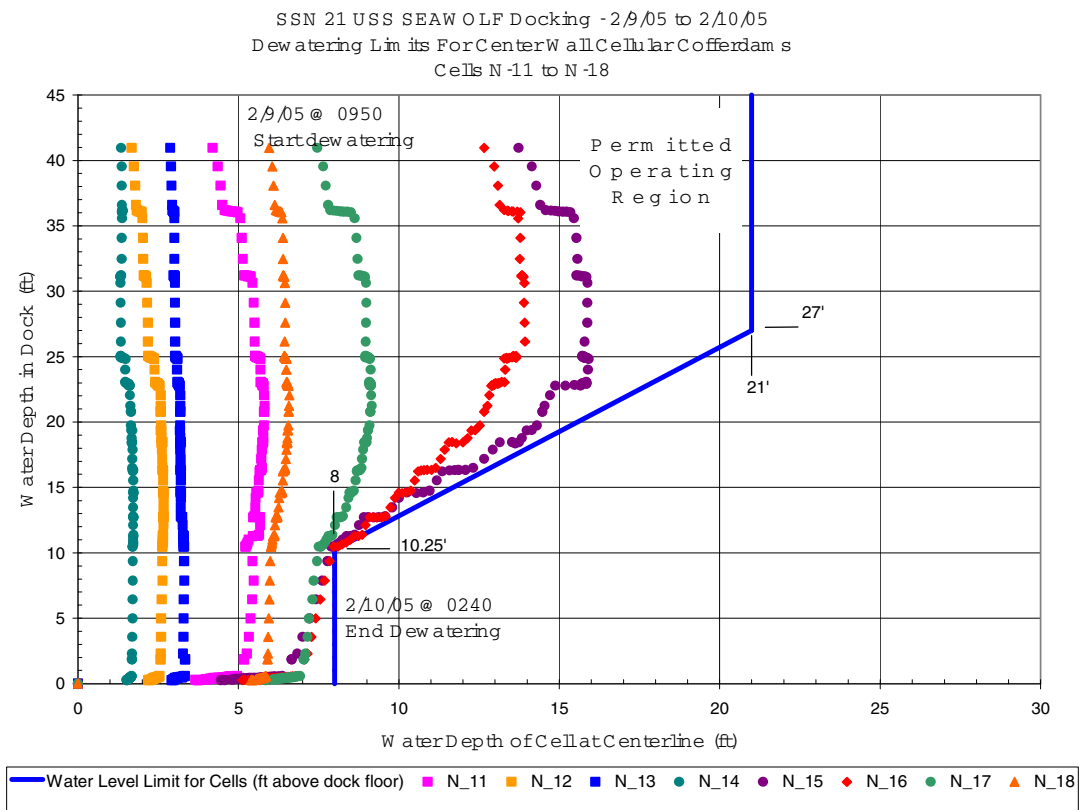


Figure 7 – Docking evolution slowed by relationship of pore pressure vs. flood level

Supplemental Cell Invert Instrumentation

In pursuit of more accurate real-time data, GZA added twenty-eight (28) additional VWPZs at the toe of each cell in the centerwall to obtain direct measurements of hydrostatic pressure at the face of the sheetpiling.

Undocking of the USS Jimmy Carter

By October 2005 the ADAS was again fully operational GZA engineers provided fulltime support to Electric Boat during the undocking of the USS Jimmy Carter from GD-2 on October 8, 2005. With GD-1 completely dewatered throughout the undocking evolution, VWPZs within the invert of the centerwall, provided the primary measurements which Electric Boat used for controlling the flooding rate. By controlling the differential water pressure inside and outside of each cofferdam, the undocking evolution was safely performed and GD-2 was dewatered in approximately 4 hours between 1315 hrs and 1650 hrs. Figure 8 presents the relationship of the pore pressure readings obtained from supplemental invert piezometers within the centerwall vs. the depth of water in the dock. The Permitted Operating region limit (i.e. Go-No Go Line) was revised to account for direct measurement of pore pressure at the sheeting face. The results obtained during this evolution provided further confirmation that pore pressure were well within acceptable limits and demonstrated an adequate factor of safety against bursting.

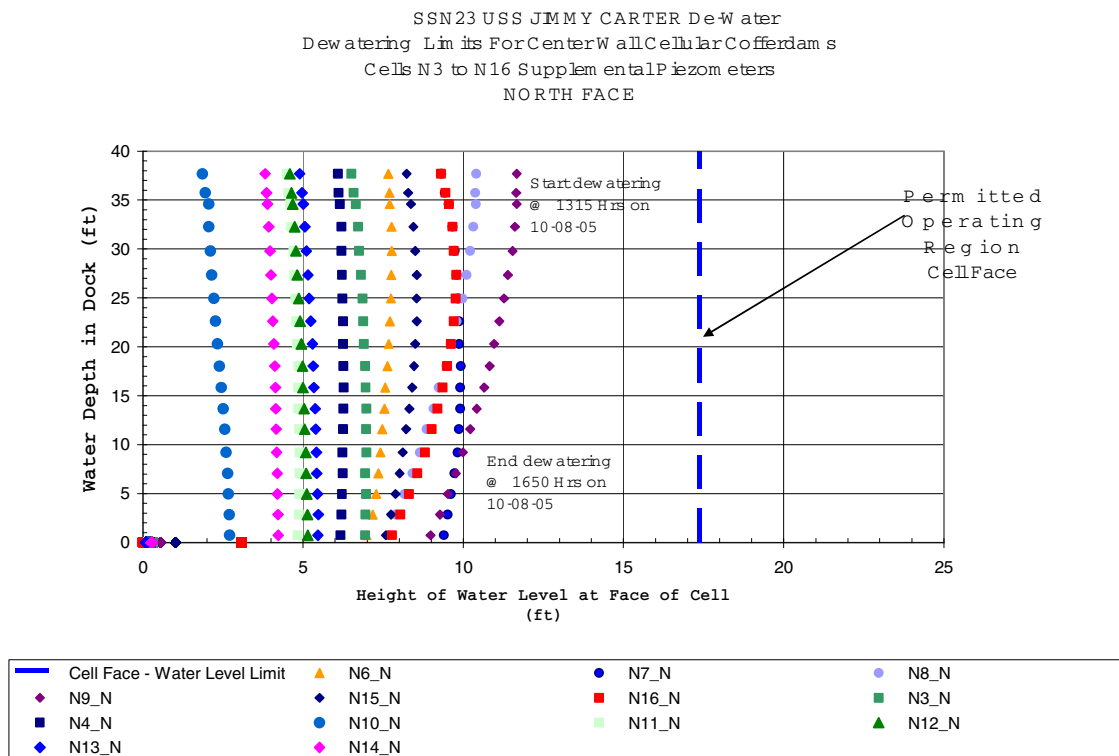


Figure 8 – Graphical relationship of cell pore pressure vs. flood level in GD-2

FINDINGS / CONCLUSIONS

Through use of conventional geotechnical instrumentation and customized programming, piezometer data is now used by Electric Boat and the US Navy to make critical, real time, decisions during docking and undocking of US Navy nuclear submarines. The ADAS has demonstrated that pore pressures can be controlled within individual cells to remain within operating range and therefore restore confidence in the Facility so that time sensitive construction and maintenance activities can continue.

As routine submarine maintenance continued at Graving Docks 1 & 2, piezometric readings obtained were instrumental in evaluating internal pore pressures in each cell and played a pivotal role for Electric Boat to restore confidence in the ability of the aging cofferdam structures to support the construction and maintenance of nuclear powered submarines, maintain US Navy certification for future business, and retain thousands of craftsmen and engineers for future business.

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