U.S. Department of the Interior
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A GEOTECHNICAL INVESTIGATION OF THE STRESS HISTORY AND SETTLEMENT POTENTIAL OF SEDIMENT SUPPORTING THE USS ARIZONA MEMORIAL, PEARL HARBOR , HAWAII.

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U.S. Geological Survey
Menlo Park, CA 94025

TECHNICAL REPORT 2004-10

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ABSTRACT: In November of 2003, The National Park Service contracted a private drilling company, Ernest K. Hirata & Associates, Inc., to sample sediment at three or four borehole sites surrounding the USS Arizona Memorial. During a one-week drilling effort, from November 13-20, 52 meters of sediment were sampled at three locations. This report documents the sediment sampling effort and subsequent geotechnical investigation of sediment properties and their implications for continued settlement of the USS Arizona Memorial. We present the lithology of sediment sampled from the three boreholes; an analysis of the sediment stress state and stress history; an estimate of the added stress imparted by the USS Arizona on the floor of Pearl Harbor, and an estimate of the likely settlement of the vessel due to self weight on the seafloor. The USS Arizona, after sixty-three years of settlement, rests almost entirely submerged listing harbor-ward. The submergence and tilting of the vessel is due to differential settlement of the seafloor beneath the vessel.

INTRODUCTION:

In November of 2003, The National Park Service contracted a private drilling company, Ernest K. Hirata & Associates, Inc., to sample sediment at three borehole sites surrounding the USS Arizona Memorial. During a one week drilling effort, from November 13-20, 52 meters of sediment were sampled.

The three boreholes are located as follows: B1A is located midship between the USS Arizona and Ford Island (E608813, N2362945) in 8.5 meters of water at the time of drilling; B2 is located directly northeast of the vessel (E608943, N23662957) in 11.9 meters of water at the time of drilling; B3 is located directly southwest of the vessel (E608749, N23662811) in 11.3 meters of water at the time of drilling (Figure 1). The boreholes B1A, B2, and B3 have sub-bottom drill depths of 15.2, 21,3, and 15.2 meters. The USS Arizona is currently resting on the floor of Pearl Harbor, submerged and tilting away from Ford Island. Immediately following the attack, on December 7, 1941, portions of the deck and railing were sub-aerially exposed, along with the superstructure and guns removed during salvage operations. The superstructure and guns were removed in 1942. Photos taken in the winter and spring of 1942 clearly show much of the vessel deck at, or above, water level (Figures 3-5). Today, sixty three years later, the deck of the vessel is submerged in up to approximately 2 meters of water.

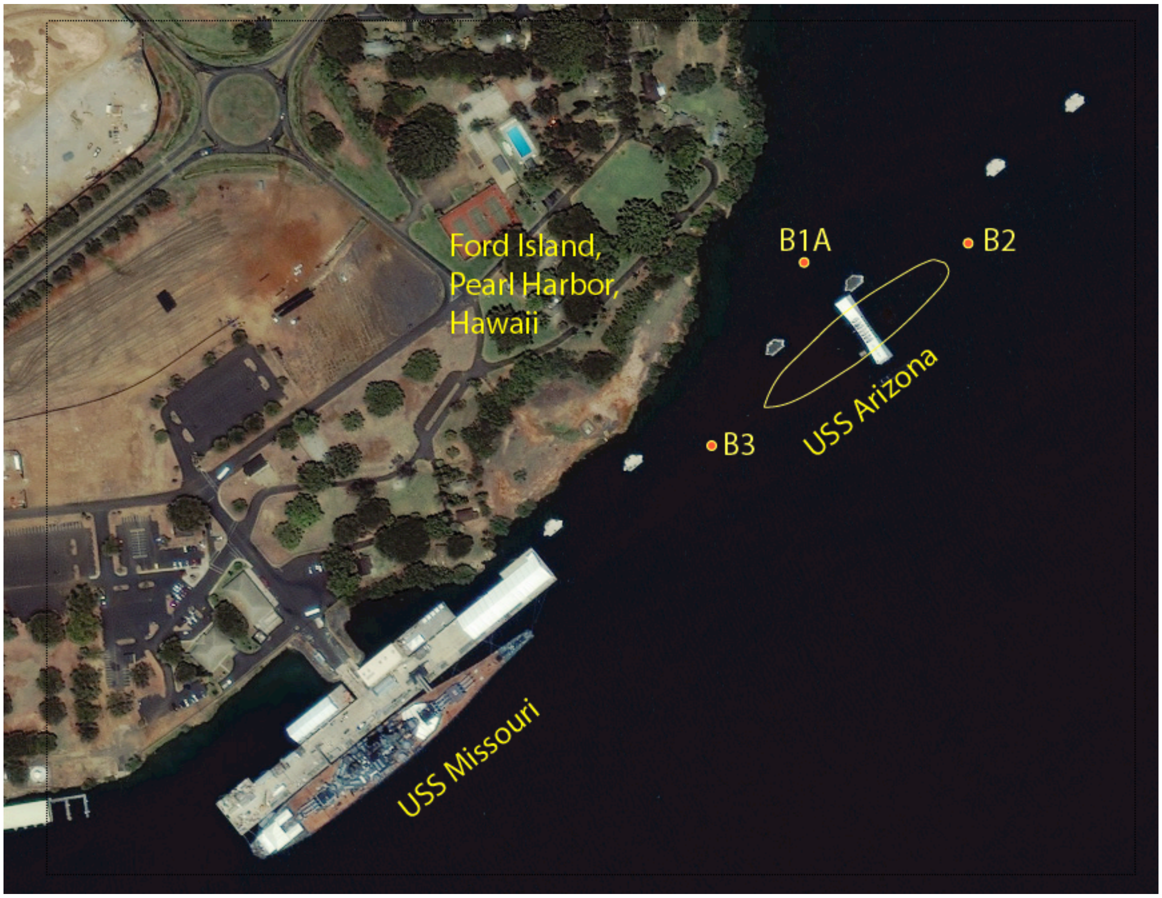

Figure 1. Boreholes B1a, B2 and B3 located around the hull of the USS Arizona, west of Ford Island.

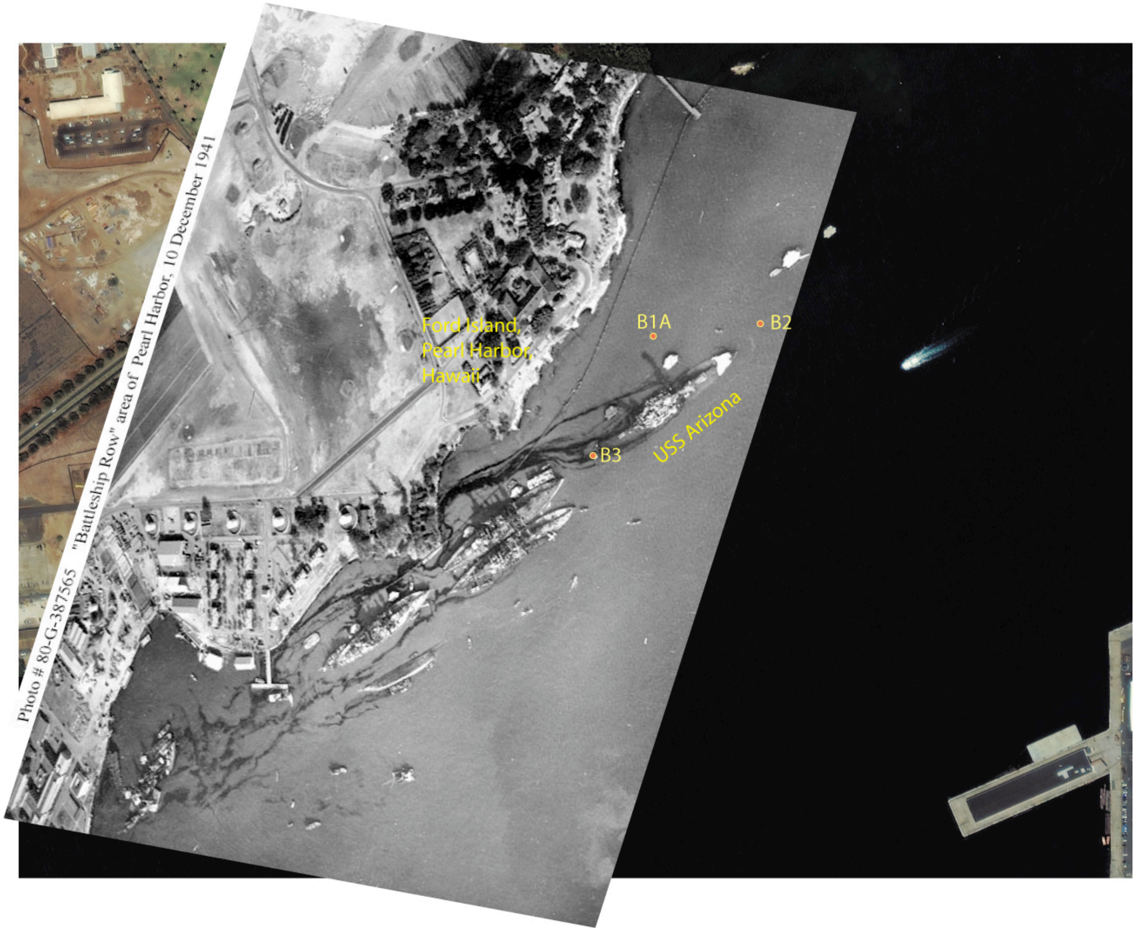

Figure 2. Boreholes and location information from 2003 from Figure 1 with an underlay of DOD photo 80-G-387565, taken December 10, 1941 showing the location of the vessel. It can be seen that most of the vessel was still sub-aerially exposed after the attack.

Figure 3. Gunnery Deck and Deck railings visible above the harbor water in 1942.

Figure 4. A photograph taken of the damage to the exposed deck of the USS Arizona, 2/17/1942.

Figure 5. Salvage crews in 1942 were able to work on the deck above water and cut entry-ways into the vessel for recovery operations.

This report investigates the settlement and tilt of the vessel through a geotechnical analysis of sediment drilled around the stern, shoreward mid-ship, and bow of the vessel. We characterize the state of stress within the sediment; the relation between that stress state and the effective overburden load placed on the sediment due to the existing sediment load and the added stress of the submerged USS Arizona.

CORING OPERATIONS

Field sampling operations, taken from a small drill barge were focused on collecting soil samples with several coring devices. In general, the drillers sampled sediment with either 100 mm Shelby tubes or 75 mm steel pipe (Figure 6). The Shelby tubes are enameled, non-reactive, sample tubes designed for acquiring sediment with saline pore water. The recovered samples are encased in whole-round steel liner tube and capped by the drillers, and then were transported to an onshore laboratory near the drill site.

Figure 6. A small anchored barge was used to advance the borehole. The deck and railings of the USS Arizona are completely submerged in 2003, with the vessel tilting several degrees to the southeast.

The lithology of the samples and drill cuttings are presented in the appendix. The uppermost unit in all three boreholes is a silty sand / sandy silt (SM/ML) with shell fragments (upper yellow unit Figure 7, 8, and 9). Beneath this is a silty sand unit (gray) that thickens toward the north stern area. Borehole B1A is shoreward of the vessel and the silty clay there is interbedded with a coralline rubble and sand. Likewise, the silty sand near the stern is interbedded with silt and sandy silt that coarsens down core. What is most noteworthy regarding the cross-sections in Figures 7, 8, and 9, is the heterogeneity of the sediment beneath the vessel. A relatively stiff profile of silty sands and sandy silts is found near the bow section at B3, whereas, soft deformable fine-grained deposits thicken toward the stern (B2) with a corresponding thinning of stiffer silty sand and sandy silt deposits. Midship on the starboard, shoreward, side, a coraline rubble may provide some stiffening element to the sediment deposit that is not present at the stern, bow, or port side. A seaward thickening wedge of silty-sand is present in the bow (B3) area, whereas, a seaward thickening wedge of finer grained clay is found near the stern.

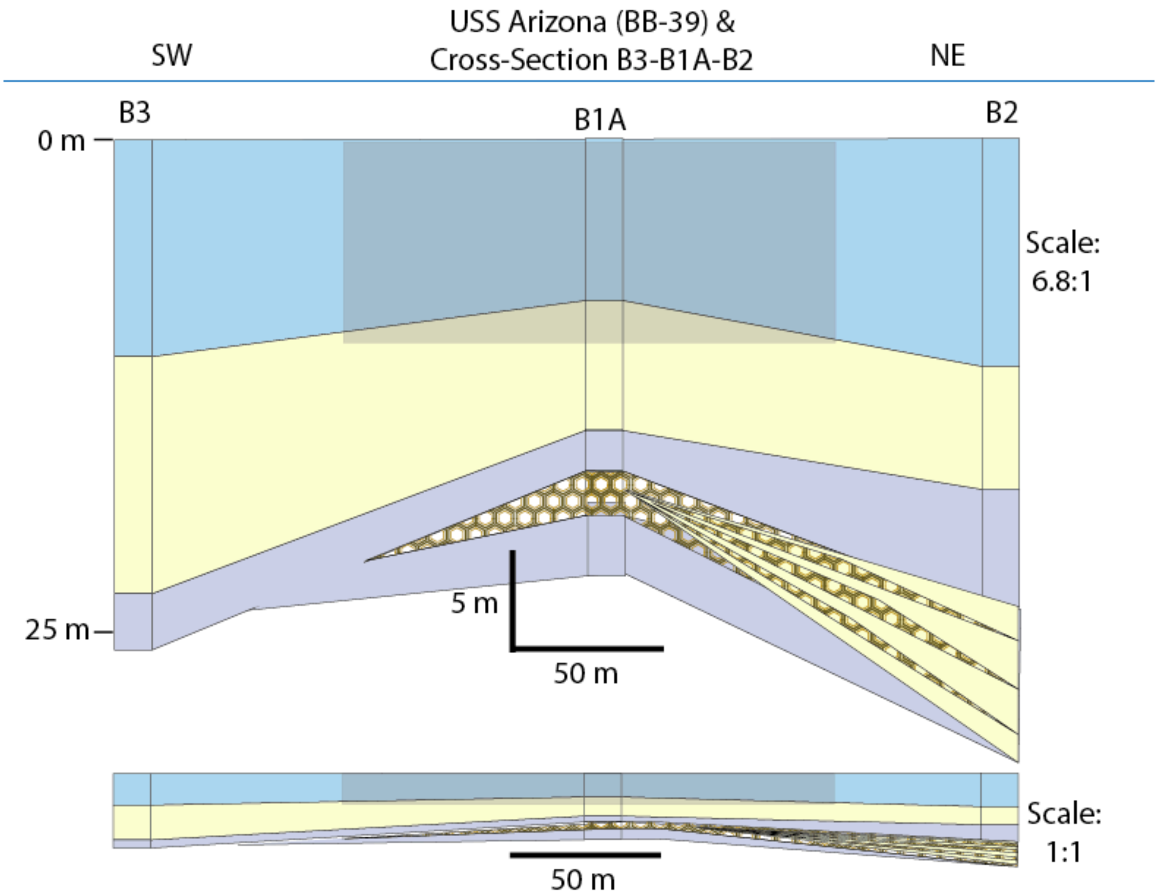

Figure 7. Cross-section from bow area (B3) to stern area (B2) through the shoreward midship boring (B1A). The upper blue unit is the water column. The seafloor is a silty sand and sandy silt underlain by a silty clay. The B1A clay unit is interbedded with a coralline rubble. B2 is a silty clay that transitions into a clayey silt with interbedded sandy silt. The gray shaded area is the USS Arizona.

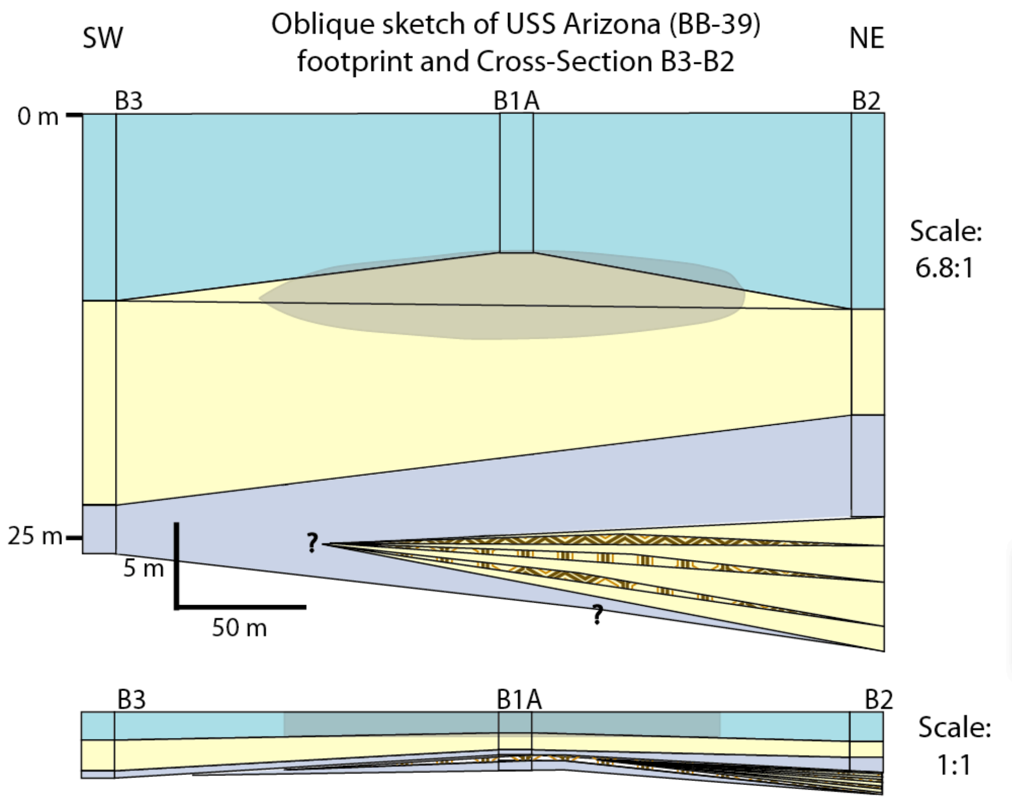

Figure 8. A proposed model of the lithology directly beneath the USS Arizona between B3 and B2. The silty clay unit thickens toward the northeast (stern). A coraline rubble may be beneath the vessel midship, offshore of B1A.

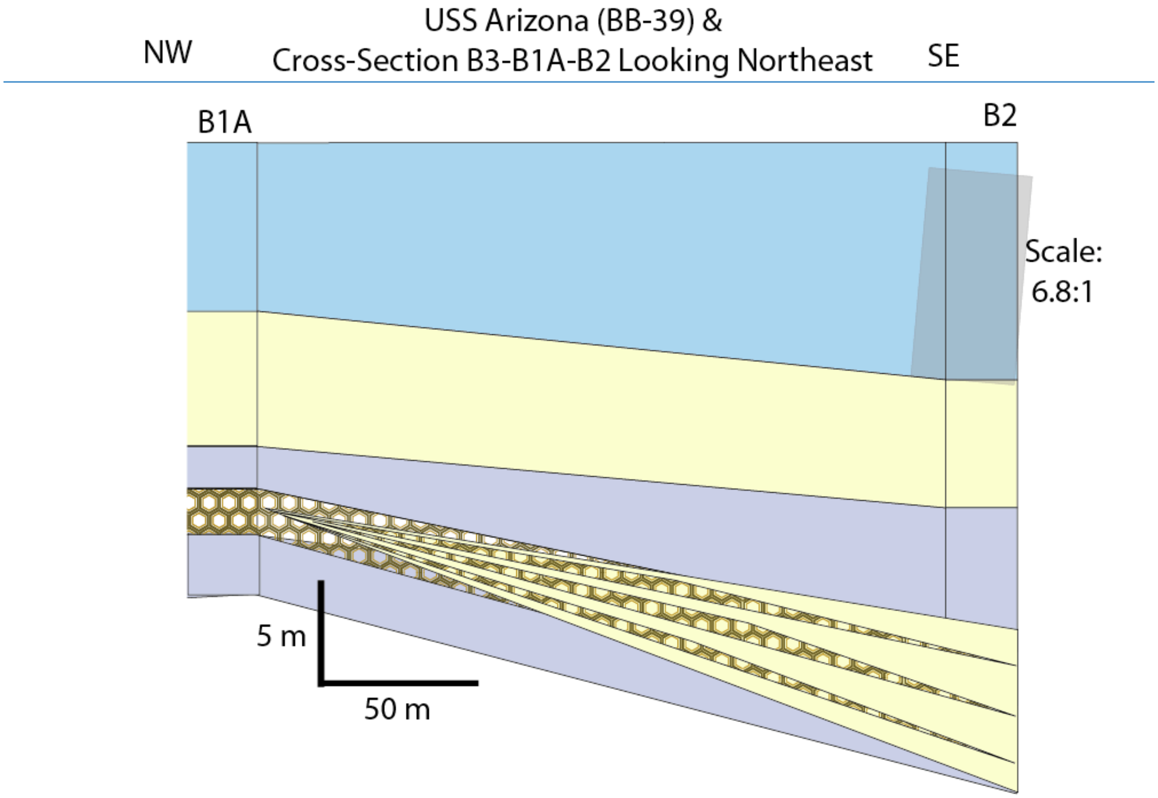

Figure 9. A proposed model of the downslope lithology between B1A and the USS Arizona based on the B2 borehole to the northeast. The silty clay unit and the clay silt-to-sandy silt thickens toward the southeast (port side). A coralline rubble may be beneath the starboard side of the vessel midship, offshore of B1A.

USGS Multi-Sensor Core Logger

At the lab in Building 42, on Ford Island, samples in Shelby tubes were logged for their geotechnical properties on the USGS multi-sensor whole core sediment-logging device, built in Great Britain by Geoteck, Ltd. Sealed cylindrical sediment cores were placed horizontally upon a transport sled and moved by a computer-controlled stepper motor through a frame supporting three sensors (Figure 10). In a sequence, the logging device measures core diameter and attenuation of gamma rays from a ^{137}Cs source to compute soil wet bulk density. Measurements of density were typically taken at 1-centimeter increments, often within the first hour after the cores are sampled. The transport sled is capable of carrying individual core sections up to 1.5 meters in length. Because the core liner is steel, we are able to only characterize the bulk density of the sediment, but not the magnetic susceptibility of p-wave velocity.

Figure 10. USGS core sediment logger set up in Navy Building 42 during the drilling operations. An enameled steel Shelby tube is being scanned.

The USGS developed an Apple HyperTalk™ driven software program called HYPERSCAN to automate the logger system and support a number of user and system tailored scanning options (Kayen and Phi, 1997). The program includes a suite of sub-routines for system calibration and permits the sensors to be activated or disabled. For example, at Pearl Harbor the cores retained sediment within metal core liner (e.g. Shelby tube samples) that not allow for measurement of magnetic properties: in this case we disables the magnetic susceptibility sensor to increase the efficiency of the system. Computer automation also allows the technician to maintain some physical distance from the Cesium (^{137}Cs) gamma ray source. During automated scanning, an un-split sediment core is driven down a track system in user-prescribed increments and the Macintosh computer interrogates sensors. As data enter the computer, the bulk density, and p-wave velocity and magnetic susceptibility if they were logged, are calculated, logged into a matrix data file, and presented in real-time on a 3-plot graphics display window.

Wet Bulk Density

Bulk density is the ratio of the total soil weight, to the soil volume. The configuration of our device allows for a core to pass between a scintillation counter and a vessel emitting a one-centimeter columnated beam of gamma rays from a radioisotope Cesium-137 source. Sediment bulk density (ρ_b) is calculated from the gamma ray attenuation characteristics of the cores according to Lambert's law. For a user-defined time period, the number of gamma decays emitted from the Cesium-vessel, passing through the core and received at the scintillation detector is counted. To address the health and safety concerns of technicians and satisfy the requirements of our radiation use permits and NRC license, we use lead shielding to reduce the amount of gamma ray emission away from the scintillation counter sensor to nearly background levels.

The number of scintillation's transmitted from the source to the scintillation counter through air, is referred to as the unattenuated gamma count, I_o. For the case where a homogeneous material of some thickness, d, lies between the Cesium source and sensor, the attenuated gamma ray count, I, can be related to the unattenuated number of gamma decays, I_o, the material thickness, d, the soil bulk density, ρ_b, and the soil Compton scattering coefficient, μ_s, by Lambert's Law (CRC 1969):

$$I = I_o \exp\{-\mu_s \rho_b d\} \qquad (1)$$

The bulk density of the soil can be determined as follows:

$$\rho_b = \frac{1}{\mu_s d} \ln\left(\frac{I_o}{I}\right) \qquad (2)$$

For recovered whole sediment cores encased in liners, we must account for the influence of the core liner to get an accurate estimation of the soil density. The liner correction accounts for liner attenuation of the gamma-ray beam through absorption and scattering, effects controlled by 1) the liner Compton scattering coefficient, μ_l, 2) liner wall thickness, l, and 3) liner wall density, ρ_l. For sediment contained within a core liner of outer diameter, D, and double-wall thickness, 2l, equation (2) can be rewritten as:

$$I = I_o \exp\{-\mu_s \rho_b (D-2l)\} \bullet \exp\{-\mu_l \rho_l 2l\} \qquad (3)$$

Equation 3 relates the attenuated gamma-ray count to the partial scattering influences of the liner and soil, and can be used to assess the density of material contained within a variety of liner-types, both plastic and metal. To determine the bulk density of soil, equation 3 must first undergo transformation to base-e logarithm.

$$\rho_b = \frac{\ln\left(\frac{I_o}{I}\right) - \mu_l \rho_l 2l}{\mu_s (D-2l)} \qquad (4)$$

Calibrations

Density measurements of soil contained within intact core-liner are calibrated to the known standards of water (ρ_w=1.00 g/cc) and aluminum (ρ_{al}=2.70 g/cc). These two standards serve as end-members that fully-bound the limits of soil density found at Pearl Harbor. The added advantage of using these materials is that their respective Compton scattering coefficients, μ_w and μ_{al}, are similar to those of soil pore water and soil alumina-silicate particles, although we determine these parameters empirically. To account for the influence of the liner, a water-aluminum standard is prepared by inserting a solid-cylinder of 6250 or 1100F aluminum into an unsplit section of core liner identical to the liner used for soil sampling. The length of milled aluminum fills one-half the total length of the "calibration standard"-core liner and distilled water fills the remaining portion. Caliper measurements of the liner diameter and wall thickness are made to determine the travel path-length through the liner and interior space.

During the density calibration, the numbers of scintillation's-per-second are logged for transmission of gamma rays through air to give a measure of I_o. Similar measurements are made for the "calibration standard" to determine the scintillation count for water-filled liner, I_w, and aluminum-filled liner, I_{al}. We determine the attenuation ratios for water and aluminum (I_o/I_w and I_o/I_{al}) and solve for the remaining unknowns, $\mu_l\rho_l$ and μ_s, by setting up two simultaneous equations and eliminating one of the variables. For each soil-core, we scan the whole-round sections using the same Compton scattering parameters that correct the calibration-standards water and aluminum to their known values of density.

Calibration standards are run repeatedly during testing programs. Typically, to calibrate the sediment-core profiles for density, measurements are made from our calibration-standard after every core is logged on our device. The empirical Compton scattering coefficient for soil that is determined by this method tends to be approximately 40% lower than the published value for water, and at present the reason for this is unknown. The circular cross-section of soil cores, as compared with an idealized tabular cross-section may be the cause of the lower μ_s, and future experiments are planned to assess the influence of core liner geometry on the scattering of gamma-rays.

After system calibration is complete, soil cores are run through the logger system and calibration corrected densities and velocities are presented, along with magnetic susceptibility, on a real-time graphics display. Typical run-time for driving a 150 centimeter core through the sensor array is approximately 35 minutes.

System Quality Assurance and Quality Control

Several approaches are taken to assess the quality of our non-invasive measurements of bulk density and sound speed velocity through a core liner. After extensive use of our system at sea and in our shore-based laboratory, several hundred calibration log files containing 30 or more data points were separated into individual files for water-filled and aluminum-filled core liner. These material dependent sub-sets of the calibration files were then used to calculate the mean and standard deviation for the measured density and velocity and compared with the known values for water and aluminum presented in parenthesis (Table 1).

TABLE 1-- *Data quality for gamma-ray bulk density (Known values are shown in parentheses).*

Density Statistics	Distilled Water	Aluminum
Mean Density (g/cc) (Known ρ_b)	1.004 (1.00)	2.700 (2.70)
Density Std. Dev. (g/cc)	0.010	0.016

The mean value of the calculated and measured density of distilled water was within 0.4% of the known value and the mean value for aluminum was exactly the known value. It was found that the standard deviation for density measurements is on the order of 0.6-1.0% of the measured value.

Results from the USGS Multi-Sensor Core Logger

Whole round core samples were scanned using the logger device within 24 hours of their initial sampling. Sediment recovery varied widely depending upon lithology type. Almost no recovery occurred in the uppermost silty sand, sandy silt, gravel, and coralline rubble deposits of the three borings. Beneath the coarse upper unit are silty-clay and sandy-silt deposits that had recovery of 68-100% of the length of the sample tube. The wet bulk density profiles are intermittent sections through the sediment column with gaps of unknown density properties in-between, although the lithologies of these gaps are recorded. The tops of the tubes are only partly filled, such that the computed density falls off due to the large water filled void. This void is eliminated in our stress calculations, but presented here in Figure 11

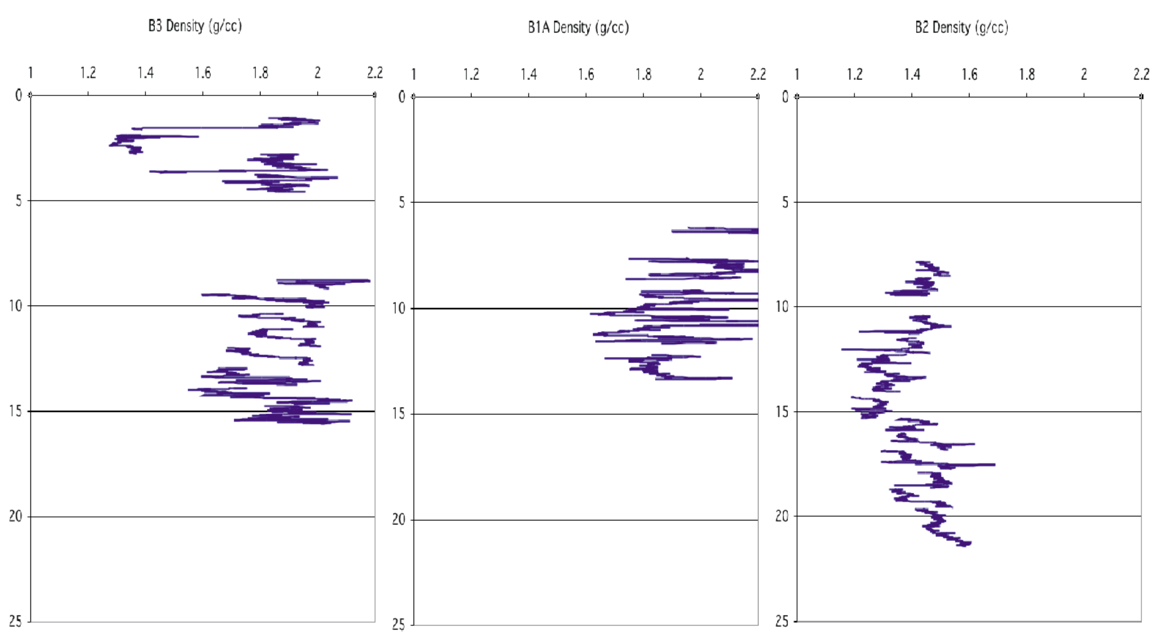

Figure 11. Wet bulk density of samples taken at borings B1A, B2, and B3.

Consistent with the lithologies noted in the Hirata and Assoc. report (see appendix), a higher density deposit, typical of coarse grained sediments is found toward the bow of the vessel (B3): a low density deposit, typical of finer grained sediment is found near the stern of the vessel (B2). At B1A, mid-ship and shoreward of the hull, a coarse higher density deposit fines downward through the sampled section. The density profile for B2 was used to compute the natural seafloor effective overburden stress above consolidation test samples.

CONSOLIDATION TESTING FOR STRESS HISTORY

A suite of 12 consolidation tests were performed on sediment samples from borehole B2, the thickest accumulation of fine grained sediment among the three boreholes (Table 1). Consolidation tests are performed to determine the settlement characteristics and the maximum past pressure felt by the sediment (σ'_{vm}). Twelve consolidation tests were performed within a triaxial cell using either a constant rate of strain-loading technique developed by Wissa and others (1971) or the traditional incremental loading method of Casagrande (1936). In preparation for this procedure, a thin wafer of sediment was confined within a cylindrical ring and placed at the base of a fluid filled cell. After the cell was filled with de-aired water the sediment was uniaxially loaded either at a constant rate of compressive strain or incrementally loaded with static weight. During this procedure pore water pressure, axial deformation, and axial load were continually monitored and automatically computer-logged at predetermined intervals.

From the consolidation data the void ratio (e) (volume of the voids/volume of the solids) was plotted versus the log of the vertical effective stress. With such a plot, a curve similar to that in Figure 10 is usually produced. The right side of the curve defines a straight line called the "virgin compression line." The slope of this line is the compression index (Cc). The compression index indicates the amount of void ratio change for a tenfold increase in vertical stress beyond σ'_{vm}. Extrapolating the virgin curve to higher void ratios and employing the Casagrande (1936) graphical construction, the maximum past stress can be calculated. A measure of the consolidation state is the overconsolidation ratio, the ratio of the maximum past pressure felt by the sample (σ'_{vm}) by the in-situ effective (buoyant) overburden stress (σ'_{e}). The individual test plots for each consolidation test is presented in the Appendix with calculations of initial void ratio and the coefficient of compression.

An OCR of 1.0 indicates normally consolidated sediment, meaning that the sediment is in equilibrium with the current thickness of overburden of sediment. For OCR of less than 1.0, the sediment has not yet fully consolidated to the in-situ overburden stress, whereas for OCR greater than 1.0 indicates that the sediment has experienced pressures in excess of current overburden loads. Overconsolidation of near-surface sediment is caused by, among other factors, electro-chemical bonds, overburden erosion, cementation, and current reworking. Often, overconsolidation is a near surface phenomenon and is lost at depth. Another measure of consolidation state is the effective excess pressure, σ'_{e} that is σ'_{vm}- σ'_{vo}. This parameter is useful for estimating the amount of stress equivalent of material removed above a sediment deposit.

Core	Depth ft.	Interval cm	Icon #	σ'_{vm} (ksc)	C_c	e_o	σ'_{vo} (ksc)	OCR	σ'_e (ksc)	Quality	Sample lith type
B2	27.5-30	65.8-68.3	Icon 205			3.23	0.45466071			Unusable	soft clay , swirled disturbed mix
B2	32.5-35	86.3-88.8	Icon 202	0.64	0.97	2.5	0.530125574	1.207261132	0.109874426	Poor	soft, darkgreenish-blackish gray clay, homogeneous
B2	42.5-45	87.5-90	Icon 208			3.11	0.681055301			Poor/Unusable	soft, sticky, dark greenish gray clay
B2	45-47.5	88.3-85.8	Icon 206	0.52	2.3	4.69	0.718787732	0.723440282	-0.198787732	Poor	uniform, soft gray clay
B2	47.5-50	82.3-84.8	Icon 203	0.82		2.31	0.756520164	1.083910302	0.063479836	Good	gray silty clay
B2	47.5-50	87.3-89.8	Icon 204	0.86	2.5	4.34	0.756520164	1.136783976	0.103479836	Fair	soft, gray silty clay, homogeneous; wood fragment?
B2	52.5-55	86.3-88.8	Icon 207	0.93	1.89	3.18	0.831985028	1.117808577	0.098014972	Very Good	soft, greenish gray clay
B2	55-57.5	87.3-89.8	Icon 200	0.86	1.19	2.49	0.86971746	0.988826878	-0.00971746	Very Good	soft, uniform, olive gray clay; minor thin shell fragments
B2	57.5-60	86.2-88.8	Icon 199	0.9	1.2	1.49	0.907449891	0.9917903	-0.007449891	Fair	olive gray sticky clay
B2	65-67.5	86.3-88.8	Icon 201			2.44	1.020647187			Poor/Unusable	soft, dark gray, sticky clay; minor thin-walled shell fragments
B2	67.5-70	81.8-84.3	Icon 197	0.82	0.71	1.98	1.058379618	0.774769266	-0.238379618	Fair	grayish black sticky clay
B2	67.5-70	85-88	Icon 196	0.55	0.71	2.18	1.058379618	0.519662312	-0.508379618	Poor	soft, dark greenish gray, sticky clay
B3	40-42.5	84.6-87.3	Icon 198			1.43				Poor/Unusable	stiff, mottled, yellowish-greenish gray clay

Table 1. Consolidation test results from fine-grained samples. Listed are the borehole (core); sub-bottom depth (ft); depth in the Shelby tube (cm); test number; maximum past pressure; compression index; initial void ratio; estimated effective overburden pressure (ksc); OCR; excess effective stress; test quality; and sediment characteristics.

The results of the consolidation test suite strongly indicate that the sediment surrounding USS Arizona is normally consolidated. Overall, the samples lack excess effective stress: that is, they are in equilibrium with the overburden sediment. Thus any application of new stress will drive the sediment into the virgin compression regime, initiating new settlements of the loaded sediment.

STATIC SEDIMENT STRESS EXERTED BY THE SINKING OF THE USS ARIZONA

The USS Arizona was commissioned in 1916 at the Brooklyn Navy Yard, New York. The full weight displacement of the vessel, assumed here to be the vessel weight in December of 1941, was approximately 37, 600 Tons. The total and buoyant density of steel is 7.85 and 6.82 g/cc, respectively, thus the submerged weight of the vessel beneath the waterline is approximately 33,000 Tons (30.5M kg). The Length and beam, at the waterline, of the vessel are 185m and 29.6m, respectively, and we estimate the area of the flat bottom to be 4300 m^2. Thus the effective stress of the vessel acting uniformly on the seafloor directly beneath the centerline of the vessel is approximately 30.5M kg/43M cm^2, or 0.70 kg/ cm^2. This stress level is equivalent to approximately 9 meters of deposited sandy sediment with a bulk density of 1.8 g/cc.

SETTLEMENT ANALYSIS

A preliminary analysis of the vertical settlement of sediment beneath the vessel assumes that the hull is a rigid mat that is uniformly loading the ground beneath the centerline of the vessel. The initial void ratio (volume of the solid particles/volume of the void space) of the soil deposit can be estimated from the core sediment logger profiles assuming a grain specific gravity for the solid particles, and from the initial state and consolidation characteristics of the consolidation test samples. Table 2 lists the initial void ratio estimates for each of the Shelby Tube soil samples tested, and the individual test results are presented in the Appendix. Based on the observation of normal consolidation (OCR ~ 1.0) in all the test samples, the void ratio and full consolidation under an additional load of 0.70 kg/ cm^2 is computed as follows:

$$e = e_O - C_c \text{ LOG } \{P/P_o\} \qquad (5);$$

here, P is the effective overburden stress of the overlying soil (P_o) plus the added stress of the vessel pressure on the seafloor (assumed to be 0.7 kg/ cm^2). The fine-grained portion of the sediment column, susceptible to the majority of the settlement was subdivided into individual layers represented by the Shelby tube sample taken within it. These layers have variable thicknesses $H_{inc.}$ depending on the sampling depths. We compute the individual layer settlement as:

$$\Delta H_{inc.} = H_{inc.} *(e_O - e)/(e_O + 1) \qquad (6),$$

And the total settlement ΔH beneath the vessel as the sum of the incremental settlements, or

$$\Delta H_{.} = \Sigma \Delta H_{inc.} \qquad (7).$$

The addition of the USS Arizona pressing on the seafloor exerts 0.7 kg/cm2 on top of the prior stress level of the sediment effective overburden (Table 2). We estimate that near the borehole area B2, these loads resulted in ~1.6 meters (5') of settlement of the foundation sediment beneath the vessel. This slow process of consolidation followed the abrupt initial impact of the vessel on the seafloor. These settlements, unlike the initial loading of the seafloor on December 7 that likely resulted in some bearing failure of the near surface sediment, would need years or even decades to complete before equilibrium was reached between the new loads. Thus, portions of the vessel sub-aerially exposed in the 1942 salvage operations are now submerged beneath approximately1-2 meters of water. The tilt of the vessel, seaward is likely due to the seaward thickening wedge of fine-grained sediment. In a future analysis we will estimate the amount of total predicted tilting that can be expected at the memorial site. The heterogeneity of the soil deposits beneath the vessel indicates that the stern overlies a large wedge of soft-fine-grained sediment capable of large settlements, whereas the bow is founded on stiffer deposits of sandy silt and silty sand, with less clay near the surface. It is likely that this sediment variability has resulted in the stern settling to a greater extent than the bow.

CONCLUSIONS

The study presented here, addresses the potential for normal settlement processes to affect the orientation and elevation of the USS Arizona, with respect to the seafloor and the waterline. Three boreholes around the vessel indicate that the vessel rests upon highly variable sediment. The settlement potential of the vessel is greater toward the stern, and toward the port side (bay side). A coralline rubble layer observed at boring B1A midship on the shoreward side may act to prevent settlement of the vessel there and may amplify tilting toward the bay. The presence of the stiffer rubble zone may also enhance differential settlement beneath the vessel that can result in hull stresses that deform the underbody of the vessel. In the area of maximum settlement potential, we compute a estimated settlement at full consolidation of approximately 1.6 m. Future measurement of the stiffness properties of the sediment, and monitoring of the settlement of the vessel is recommended. A 2-dimensional settlement analysis is needed to estimate the final degree of seaward tilting that is expected to occur.

Core	Depth ft.	σ'_{vm} (ksc)	C_c	e_o	σ'_{vo} (ksc)	e	H_{inc} (m)	Δh (m)	$\Delta h/H$
B2	27.5-30			3.23	0.455	2.650	2.846	0.391	0.137
B2	32.5-35	0.64	0.97	2.5	0.530	2.145	0.762	0.077	0.101
B2	42.5-45			3.11	0.681	**2.670**	3.049	0.327	0.107
B2	45-47.5	0.52	2.3	4.69	0.719	**4.011**	0.762	0.091	0.119
B2	47.5-50	0.82		2.31	0.757	**1.902**	0.762	0.094	0.123
B2	47.5-50	0.86	2.5	4.34	0.757	**3.629**			
B2	52.5-55	0.93	1.89	3.18	0.832	**2.679**	1.524	0.183	0.120
B2	55-57.5	0.86	1.19	2.49	0.870	**2.185**	0.762	0.067	0.087
B2	57.5-60	0.9	1.2	1.49	0.907	**1.192**	0.762	0.091	0.120
B2	65-67.5			2.44	1.021	**2.115**	2.287	0.216	0.095
B2	67.5-70	0.82	0.71	1.98	1.058	**1.823**	0.762	0.040	0.053
B2	67.5-70	0.55	0.71	2.18	1.058	**2.023**			
						Total Settlement	TOTAL H (m)	**1.576**	

Table 2. Settlement analysis of sediment beneath the hull of the USS Arizona. A load of 0.7 kg/ cm^2 was used in addition to the effective overburden pressure to represent the new application of loads of the USS Arizona and overburden sediment on the seafloor directly beneath the centerline of the vessel. At the edges of the hull, and away from the vessel, the load exerted by the hull diminishes as a function of depth and lateral distance.

ACKNOWLEDGEMENTS

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APPENDIX

Drilling report by Hiarata and Assoc.

Consolidation test results for Borings B2 and B3 samples.