

Appendixes A–J

Appendix A. Gamma Bulk Density Plots for All USS *Arizona* Memorial Recovered Cores.

Plots A-1 and A-2 are from boring B1. Plots A-3 to A-8 are from boring B1A. Plots A-9 to A-24 are from boring B2. Plots A-25 to A-36 are from boring B3. Sections of density curves highlighted in red are considered to be disturbed values or composed of out-of-place materials.

The location of intervals for incremental consolidation (CON) tests are indicated by arrows next to some of the density profiles. The color of the arrows indicates the quality of test result as designated in table 5: green, excellent to good; orange, fair; red, poor.

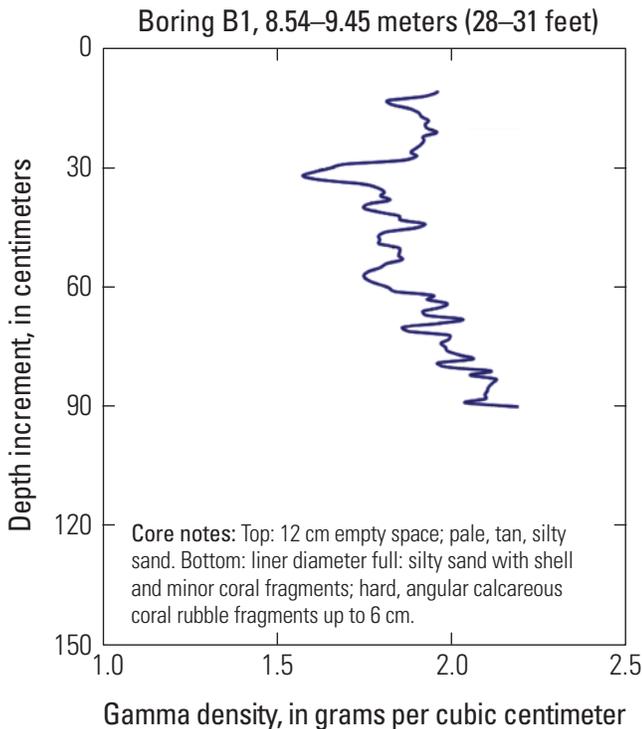
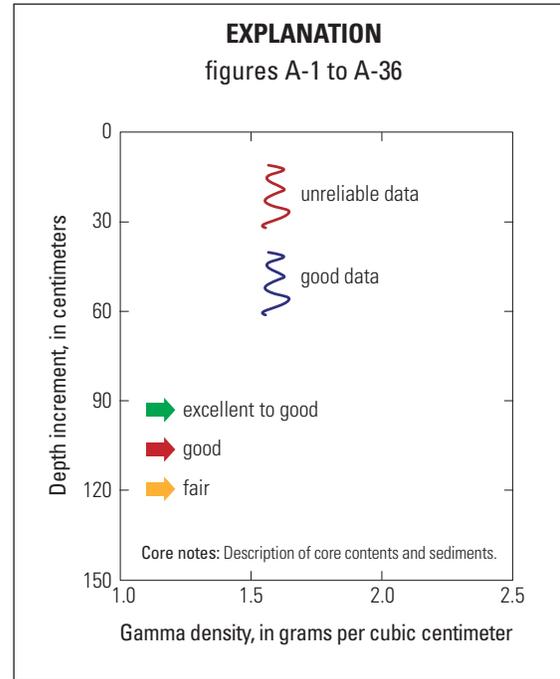


Figure A-1. Plot of gamma density vs. depth in core, Boring B1, 8.54–9.45 m (28–31 ft).

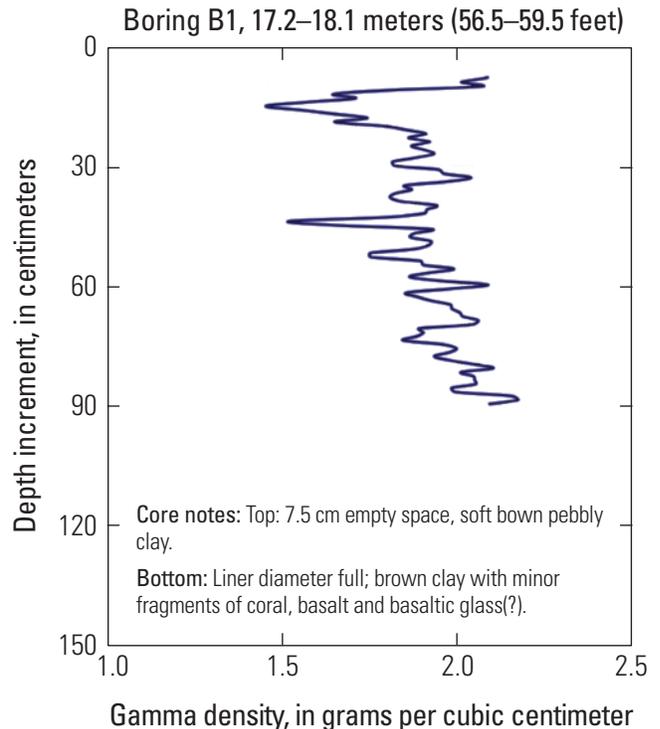


Figure A-2. Plot of gamma density vs. depth in core, Boring B1, 17.2–18.1 m (56.5–59.5 ft).

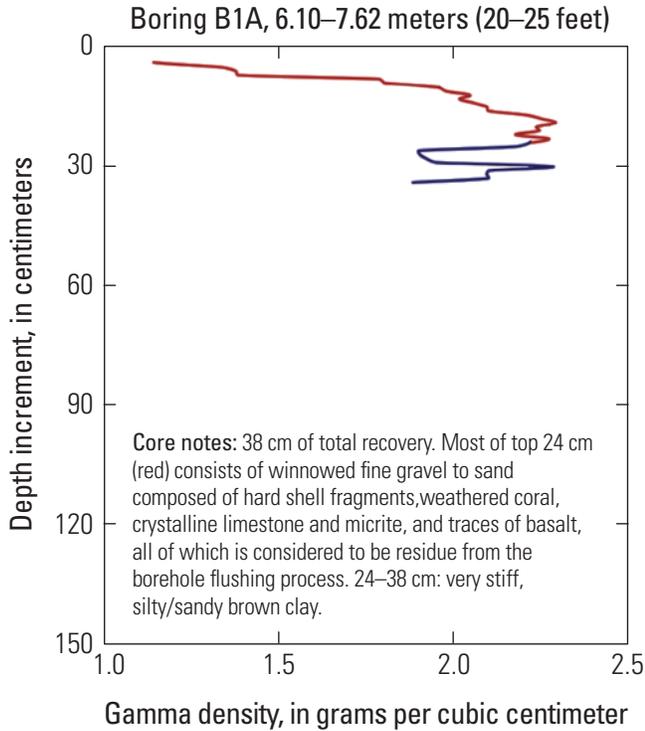


Figure A-3. Plot of gamma density vs. depth in core, Boring B1A 6.10–7.62 m (20–25 ft).

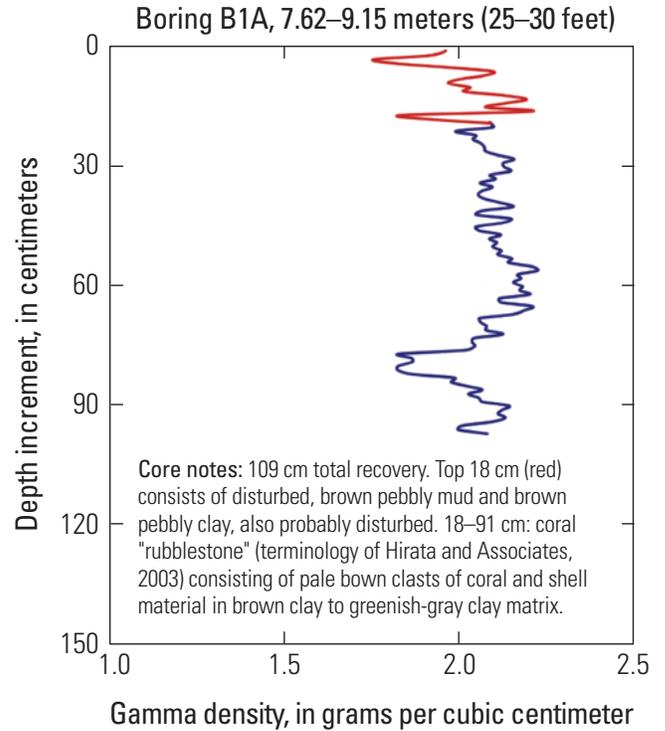


Figure A-4. Plot of gamma density vs. depth in core, Boring B1A 7.62–9.15 m (25–30 ft).

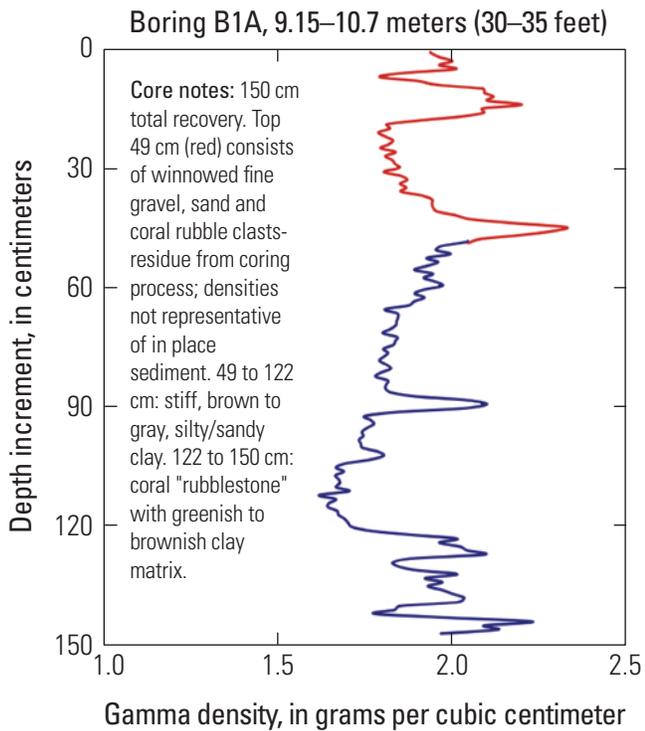


Figure A-5. Plot of gamma density vs. depth in core, Boring B1A 9.15–10.7 m (30–35 ft).

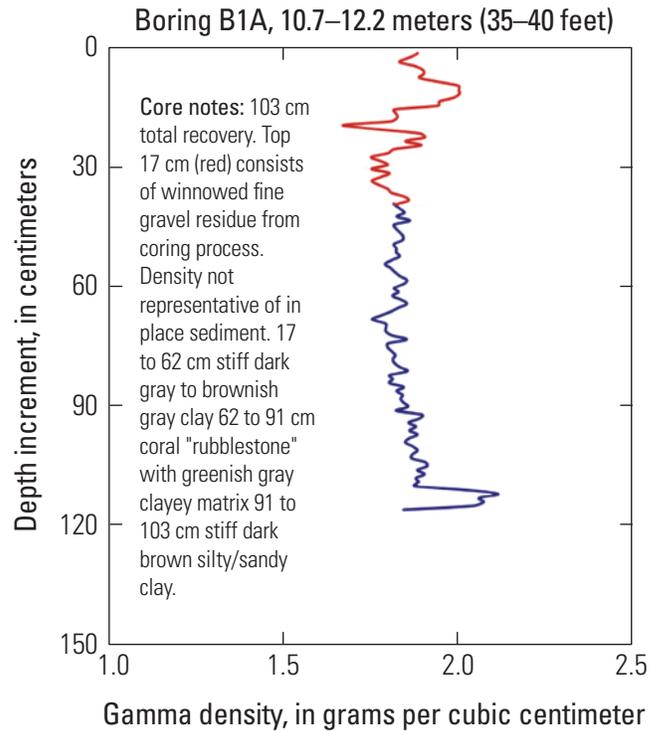


Figure A-6. Plot of gamma density vs. depth in core, Boring B1A 10.7–12.2 m (35–40 ft).

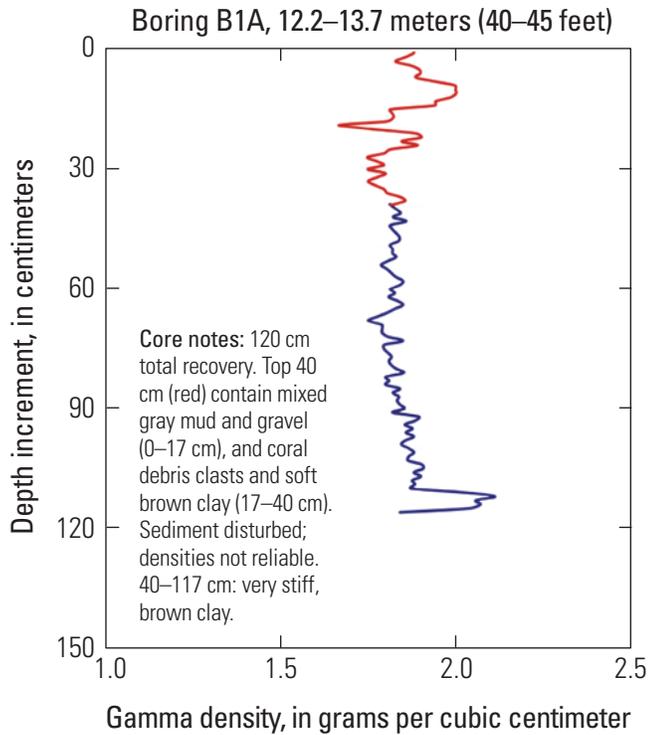


Figure A-7. Plot of gamma density vs. depth in core, Boring B1A 12.2–13.7 m (40–45 ft).

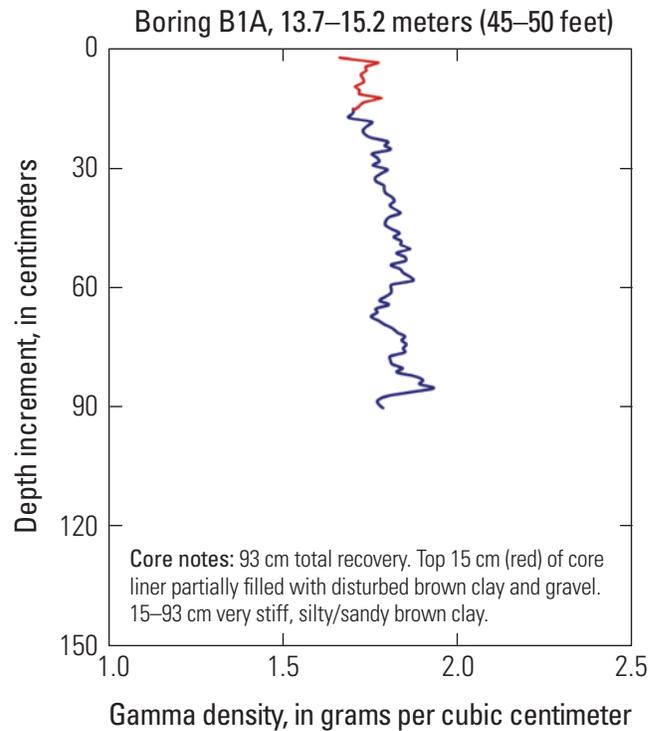


Figure A-8. Plot of gamma density vs. depth in core, Boring B1A 13.7–15.2 m (45–50 ft).

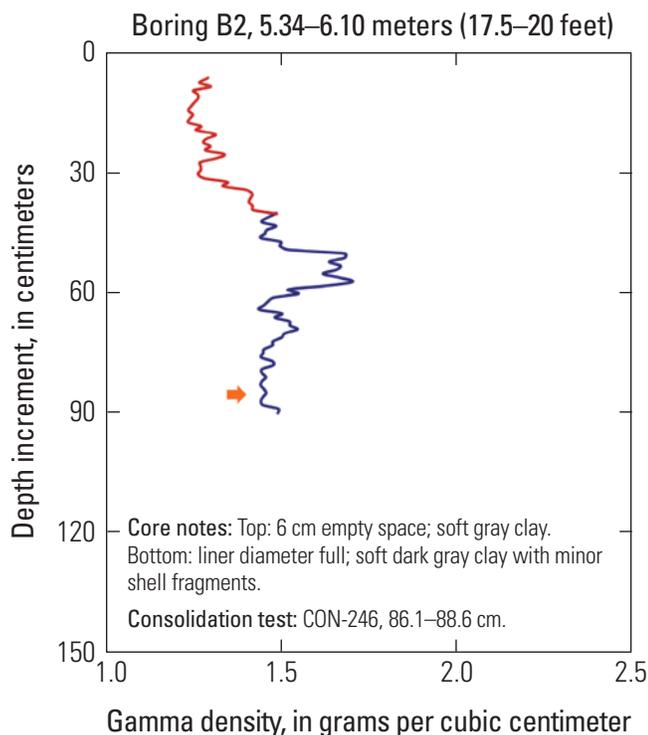


Figure A-9. Plot of gamma density vs. depth in core, Boring B2 5.34–6.10 m (17.5–20 ft).

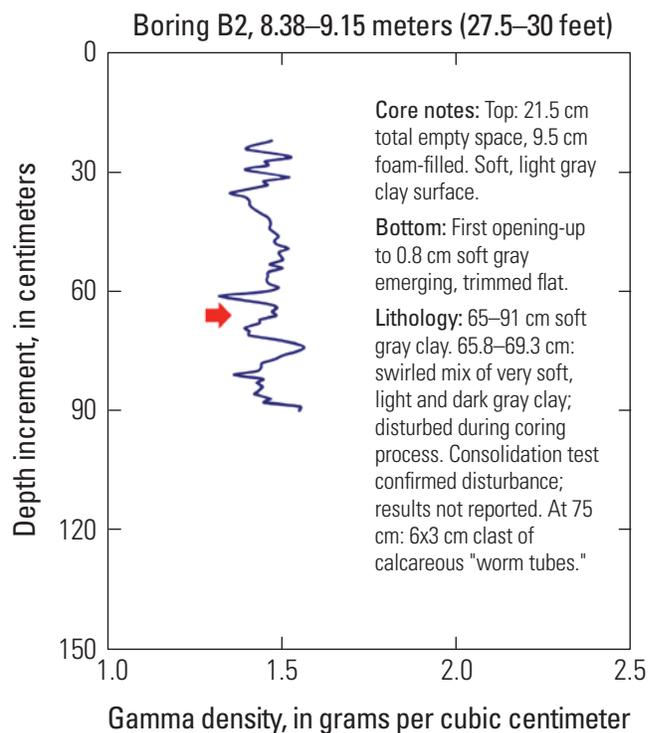


Figure A-10. Plot of gamma density vs. depth in core, Boring B2, 8.38–9.15 m (27.5–30 ft).

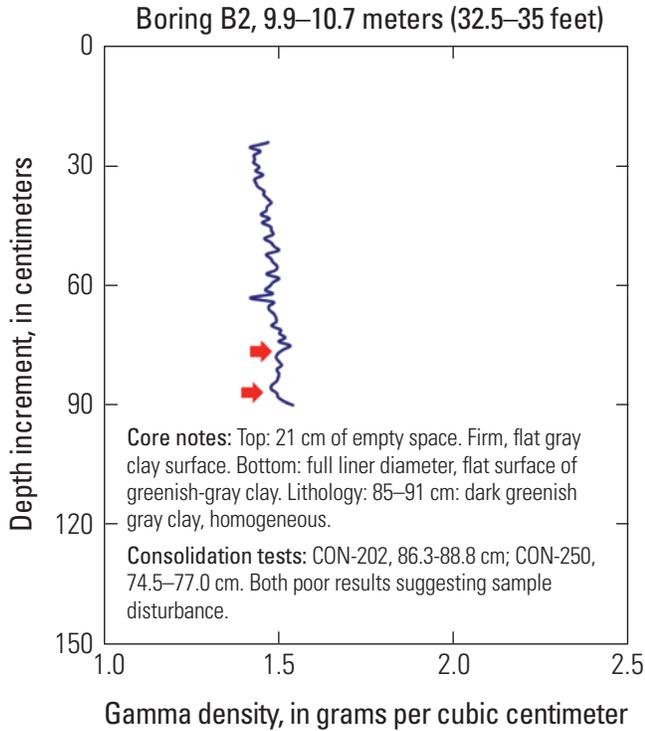


Figure A-11. Plot of gamma density vs. depth in core, Boring B2, 9.9–10.7 m (32.5–35 ft).

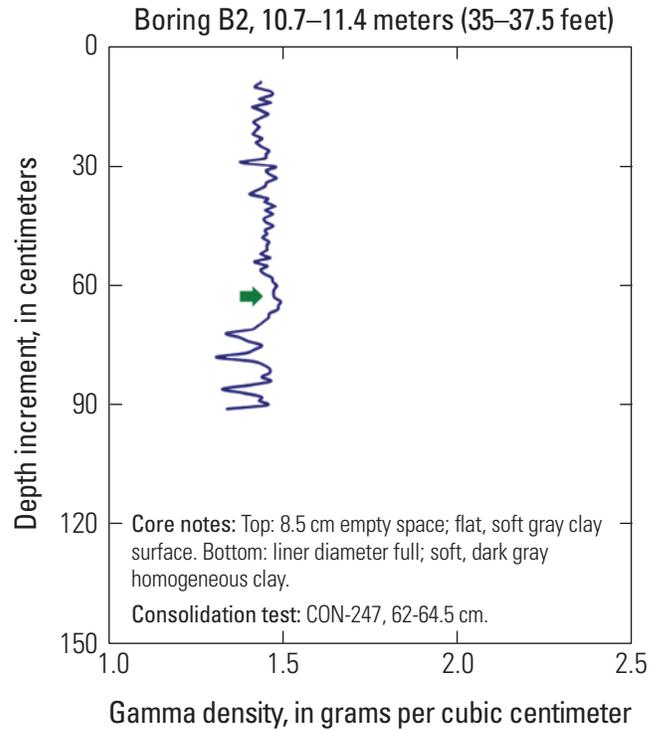


Figure A-12. Plot of gamma density vs. depth in core, Boring B2, 10.7–11.4 m (35–37.5 ft).

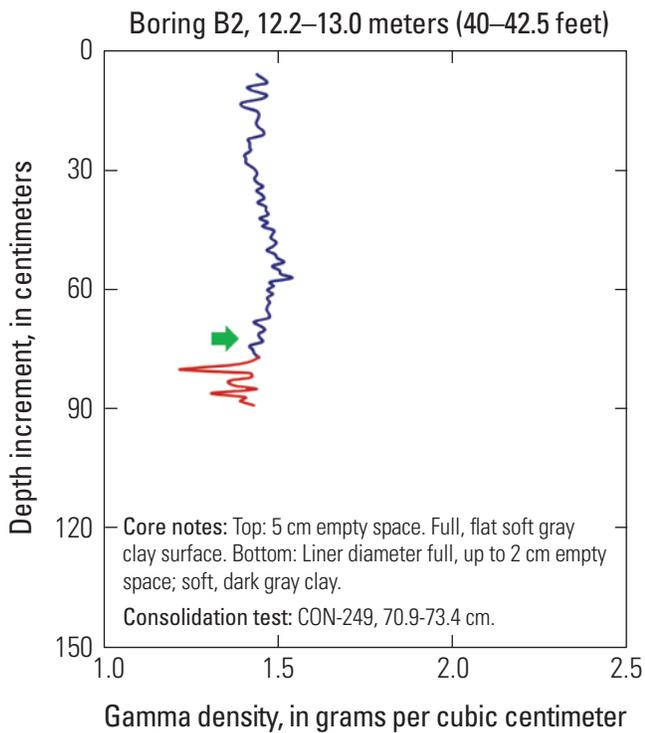


Figure A-13. Plot of gamma density vs. depth in core, Boring B2, 12.2–13.0 m (40–42.5 ft).

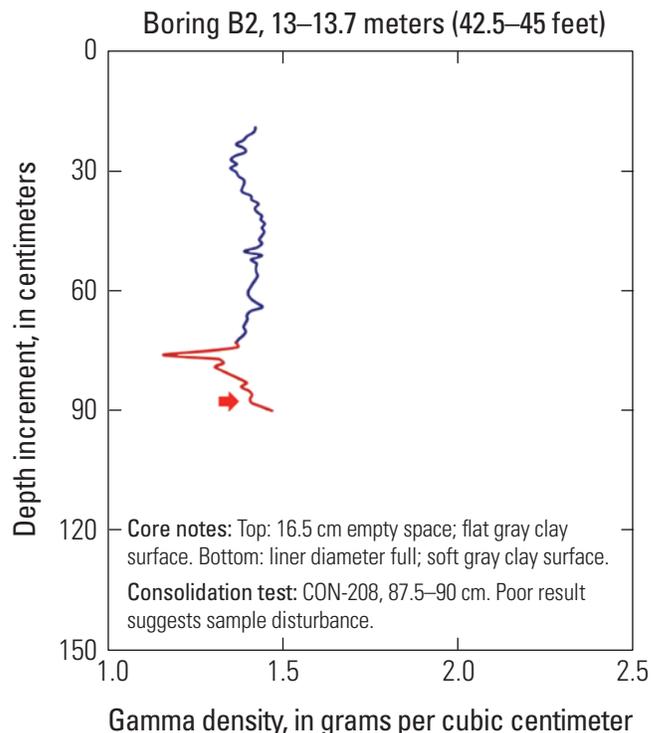


Figure A-14. Plot of gamma density vs. depth in core, Boring B2, 13–13.7 m (42.5–45 ft).

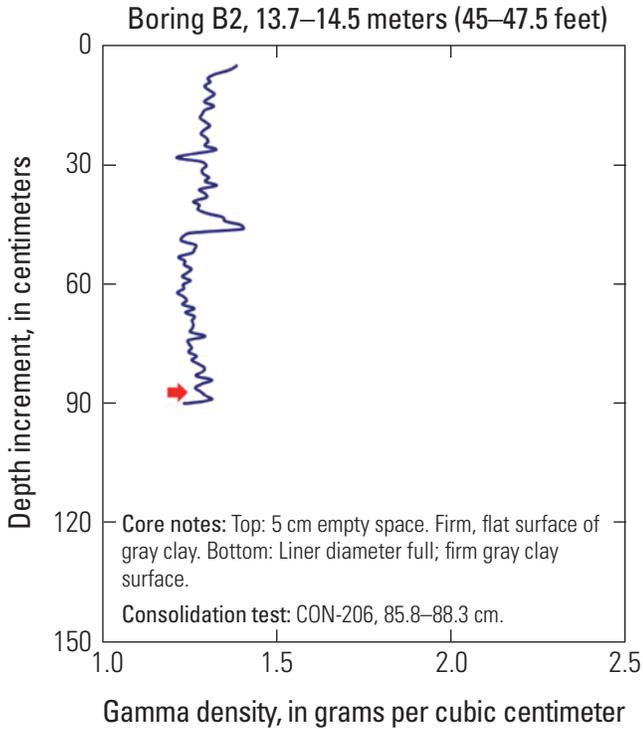


Figure A-15. Plot of gamma density vs. depth in core, Boring B2, 13.7–14.5 m (45–47.5 ft).

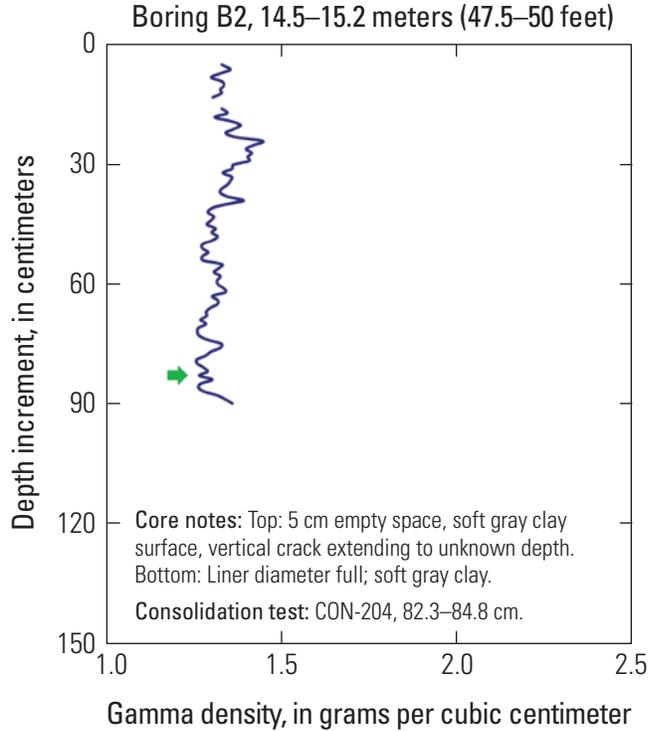


Figure A-16. Plot of gamma density vs. depth in core, Boring B2, 14.5–15.2 m (47.5–50 ft).

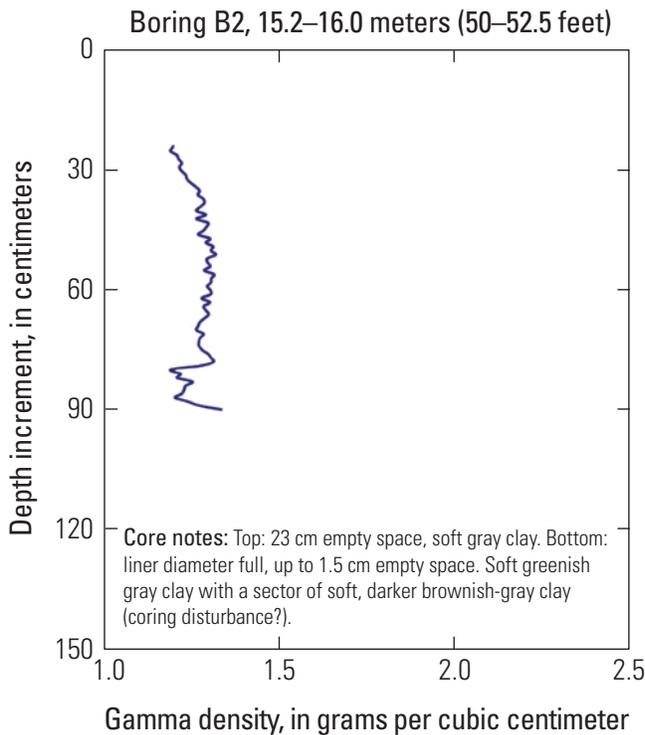


Figure A-17. Plot of gamma density vs. depth in core, Boring B2, 15.2–16.0 m (50–52.5 ft).

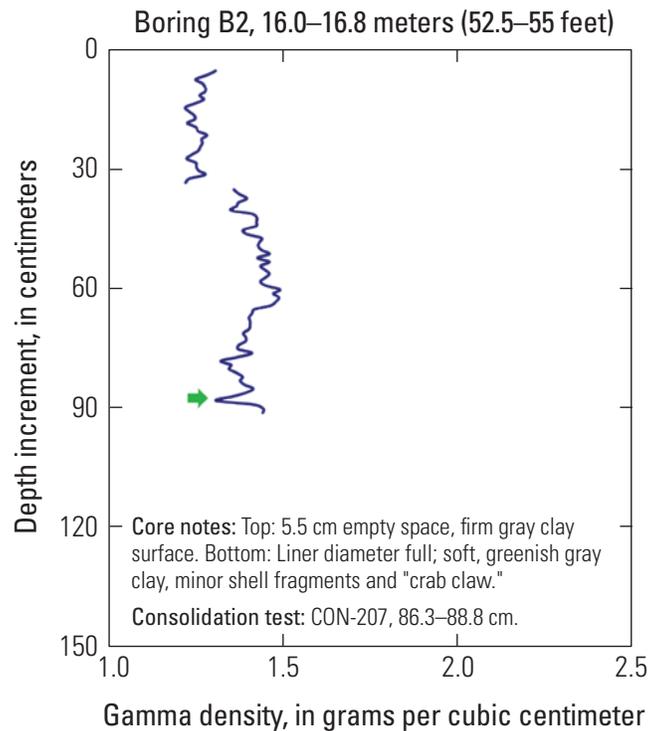


Figure A-18. Plot of gamma density vs. depth in core, Boring B2, 16.0–16.8 m (52.5–55 ft).

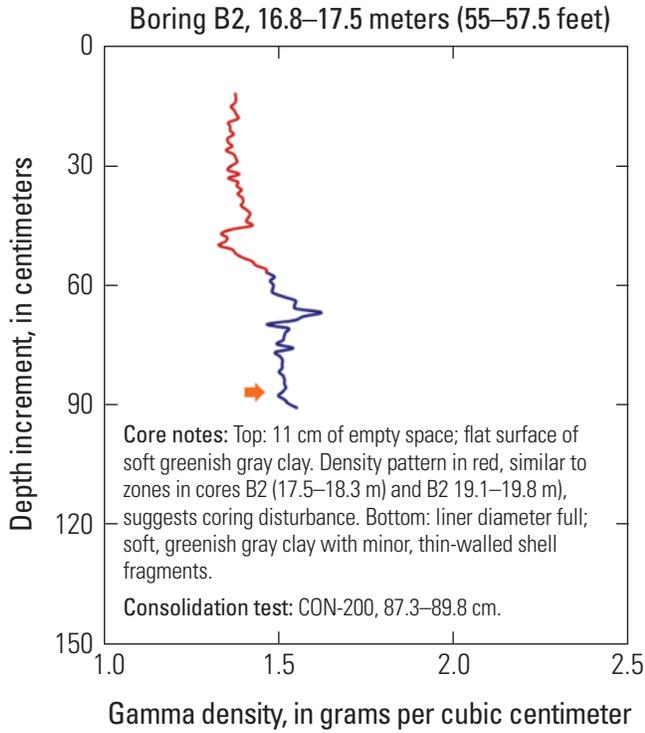


Figure A-19. Plot of gamma density vs. depth in core, Boring B2, 16.8–17.5 m (55–57.5 ft).

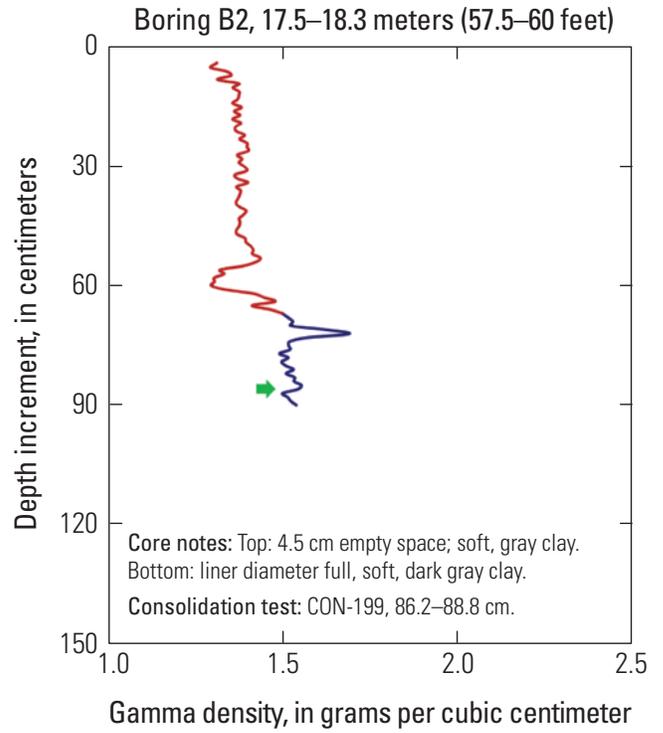


Figure A-20. Plot of gamma density vs. depth in core, Boring B2, 17.5–18.3 m (57.5–60 ft).

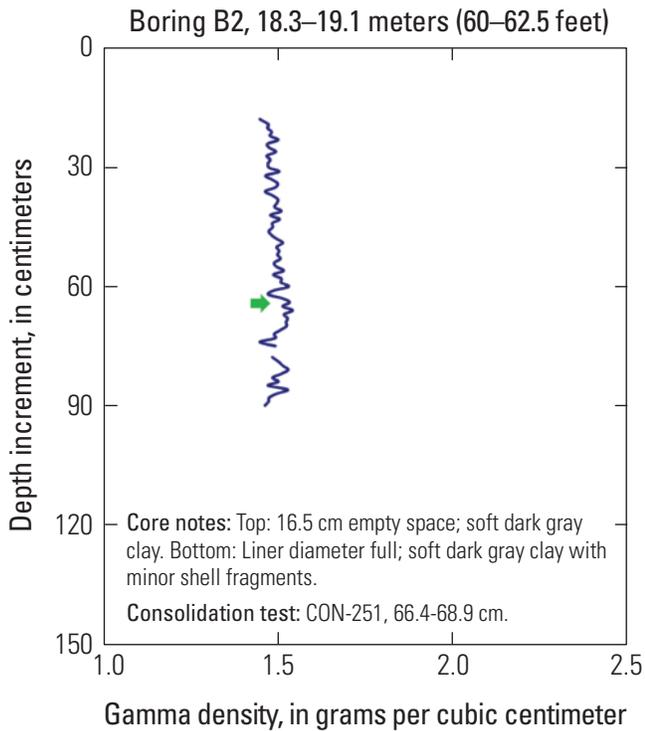


Figure A-21. Plot of gamma density vs. depth in core, Boring B2, 18.3–19.1 m (60–62.5 ft).

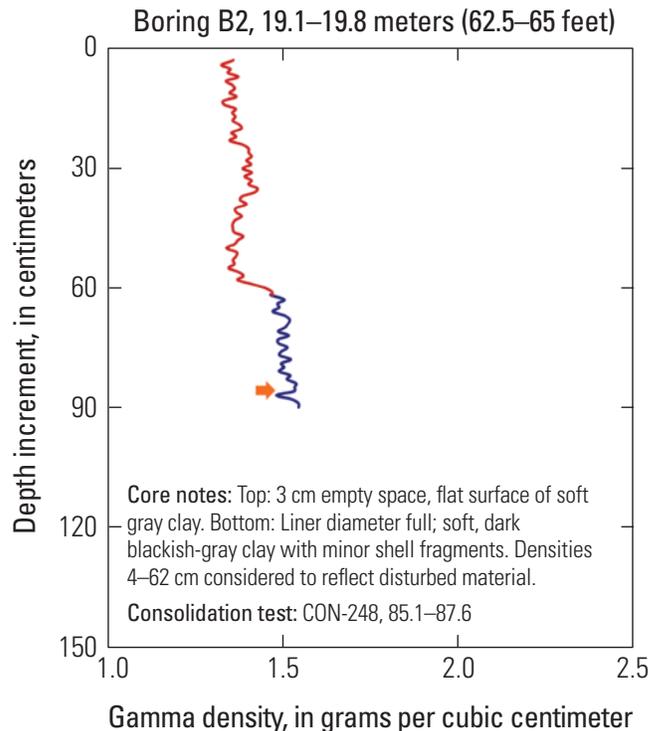


Figure A-22. Plot of gamma density vs. depth in core, Boring B2, 19.1–19.8 m (62.5–65 ft).

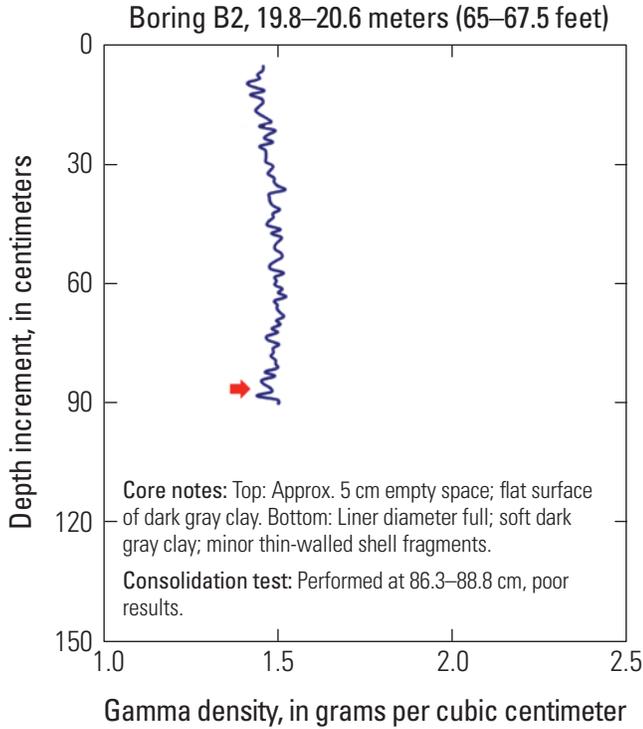


Figure A-23. Plot of gamma density vs. depth in core, Boring B2, 19.8–20.6 m (65–67.5 ft).

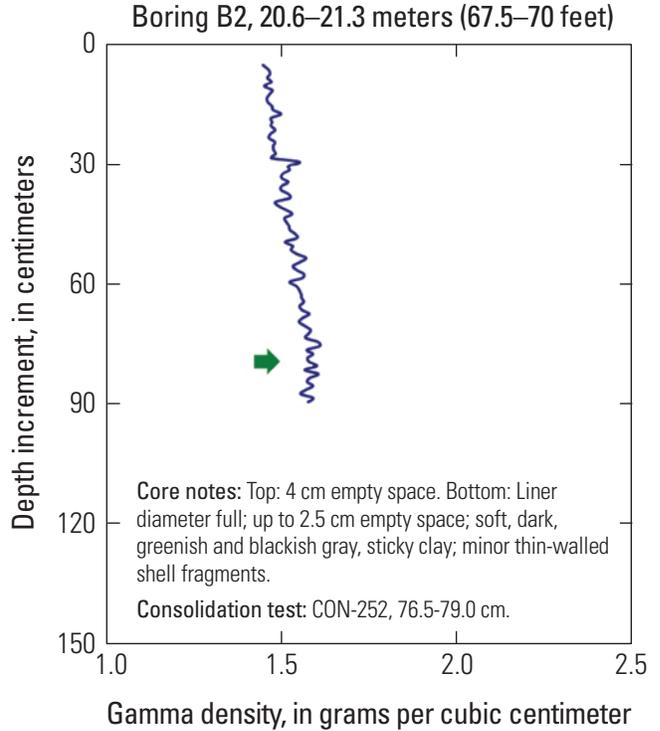


Figure A-24. Plot of gamma density vs. depth in core, Boring B2, 20.6–21.3 m (67.5–70 ft).

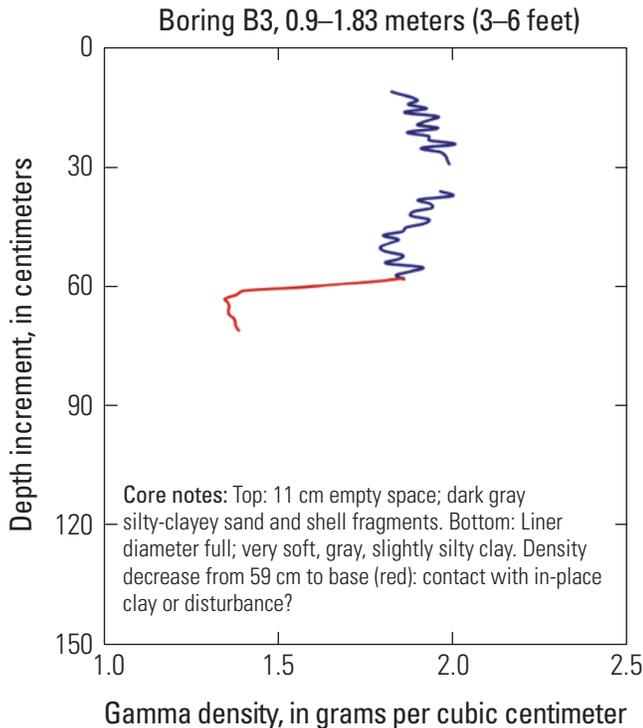


Figure A-25. Plot of gamma density vs. depth in core, Boring B3, 0.9–1.83 m (3–6 ft).

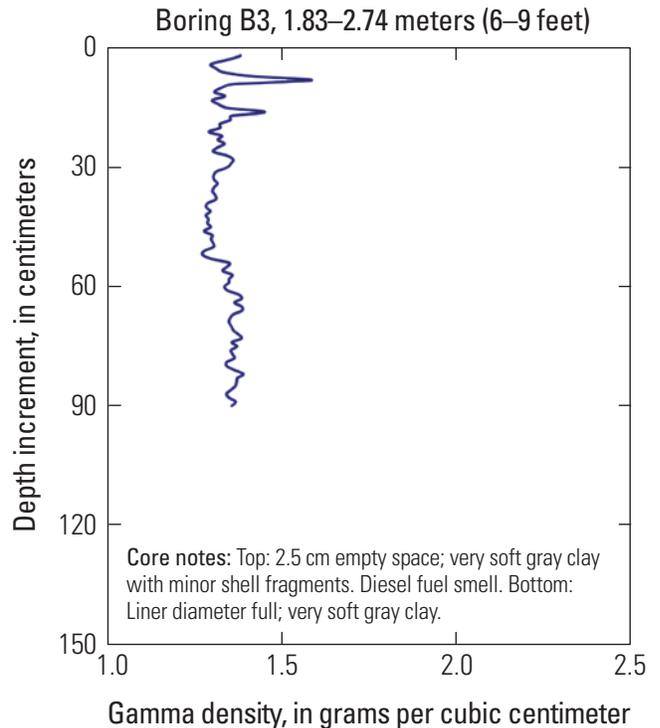


Figure A-26. Plot of gamma density vs. depth in core, Boring B3, 1.83–2.74 m (6–9 ft).

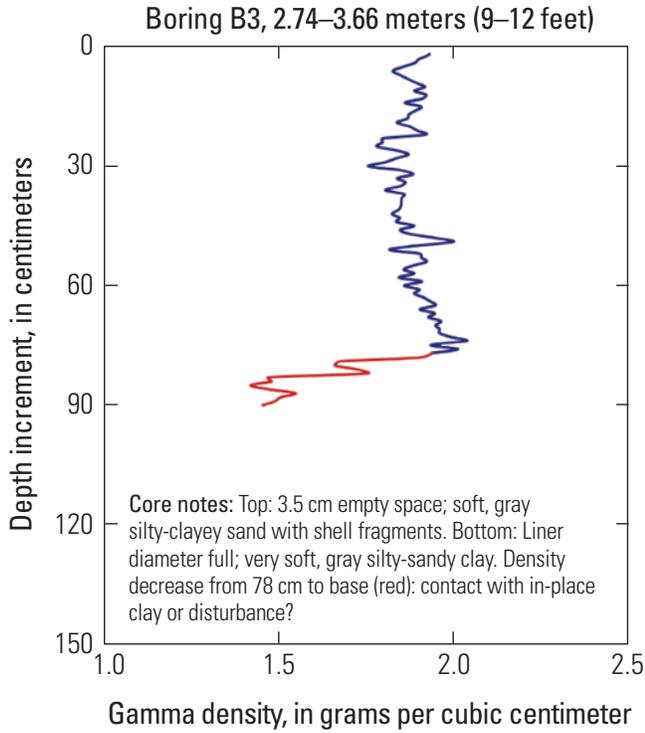


Figure A-27. Plot of gamma density vs. depth in core, Boring B3, 2.74–3.66 m (9–12 ft).

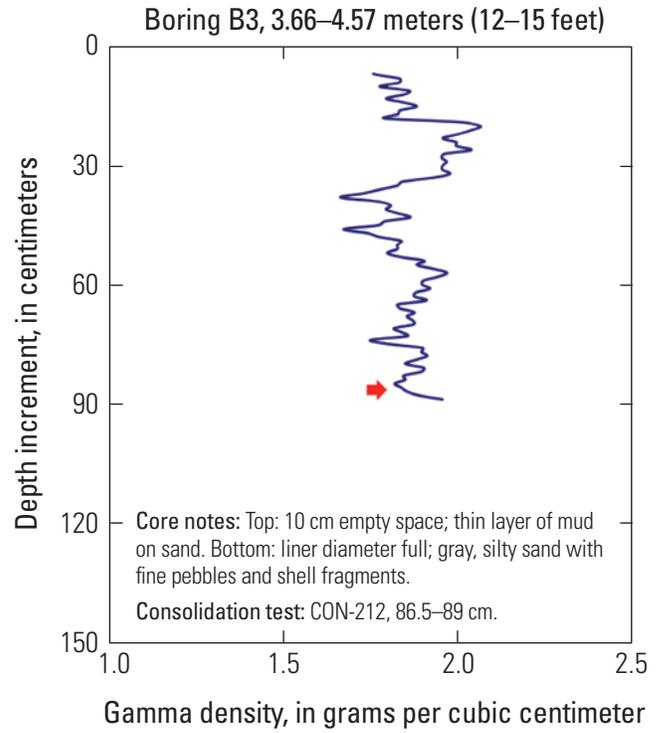


Figure A-28. Plot of gamma density vs. depth in core, Boring B3, 3.66–4.57 m (12–15 ft).

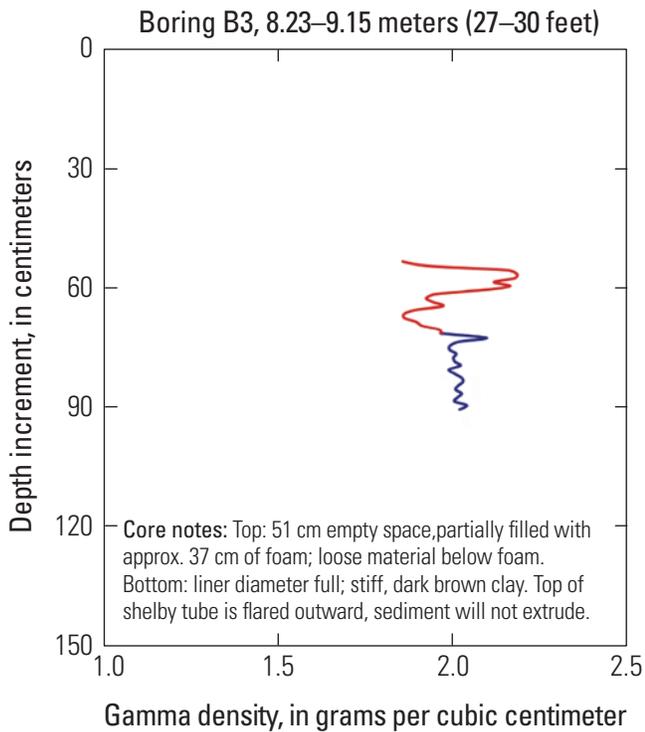


Figure A-29. Plot of gamma density vs. depth in core, Boring B3, 8.23–9.15 m (27–30 ft).

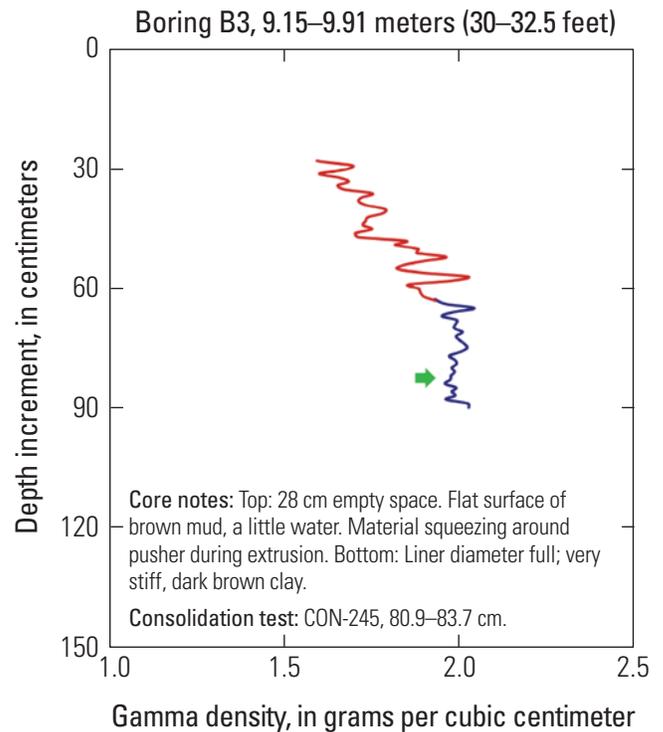


Figure A-30. Plot of gamma density vs. depth in core, Boring B3, 9.15–9.91 m (30–32.5 ft).

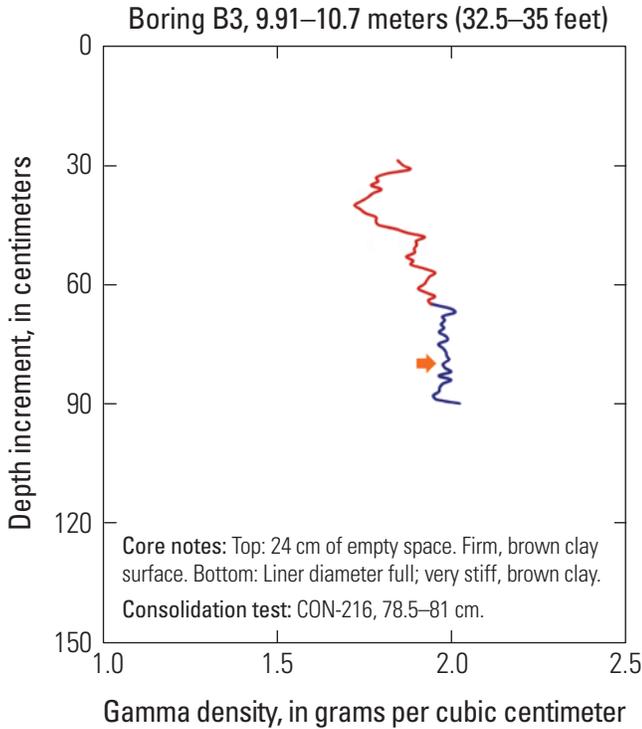


Figure A-31. Plot of gamma density vs. depth in core, Boring B3, 9.91–10.7 m (32.5–35 ft).

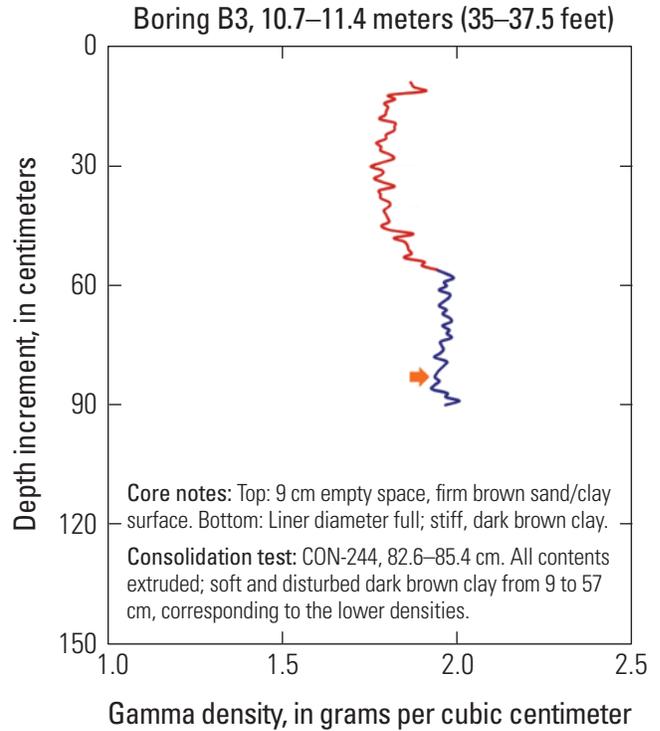


Figure A-32. Plot of gamma density vs. depth in core, Boring B3, 10.7–11.4 m (35–37.5 ft).

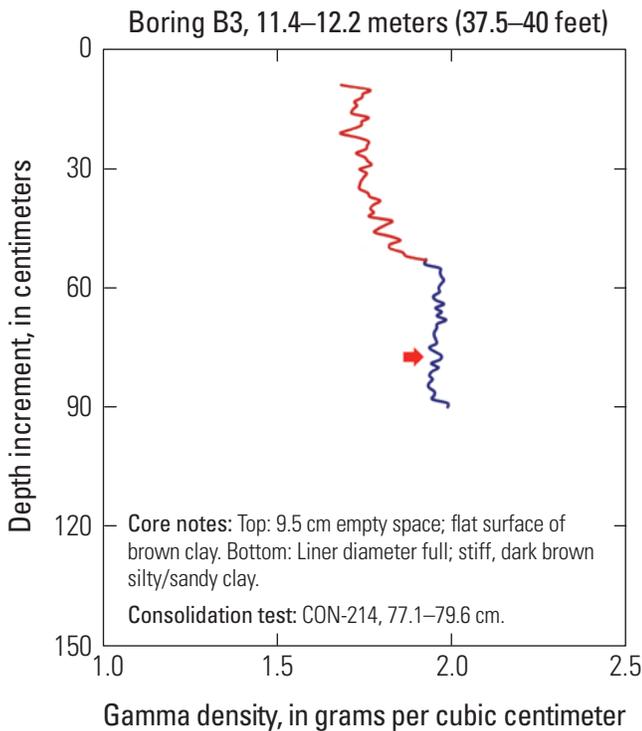


Figure A-33. Plot of gamma density vs. depth in core, Boring B3, 11.4–12.2 m (37.5–40 ft).

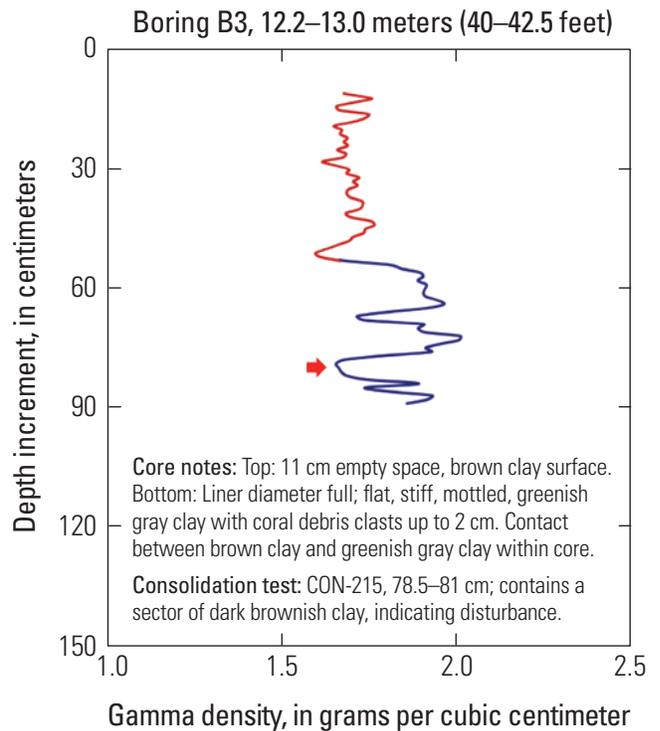


Figure A-34. Plot of gamma density vs. depth in core, Boring B3, 12.2–13.0 m (40–42.5 ft).

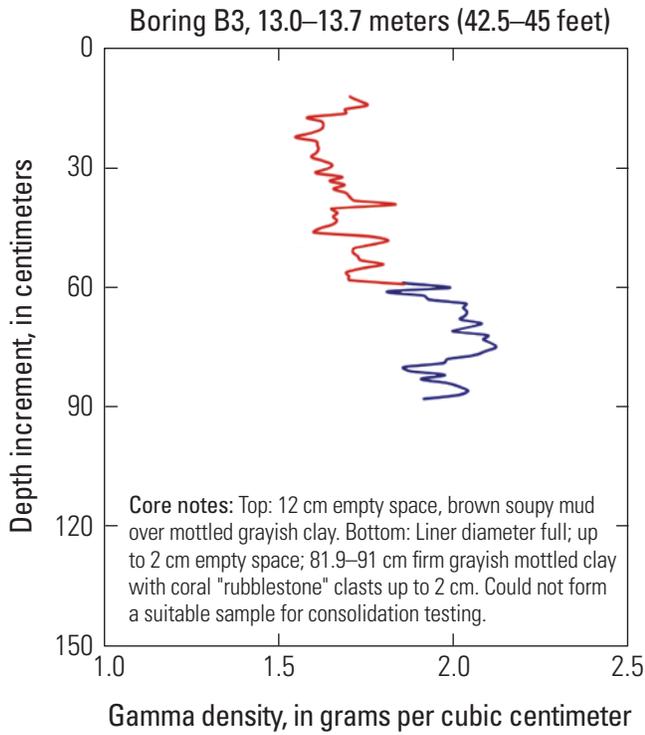


Figure A-35. Plot of gamma density vs. depth in core, Boring B3, 13.0–13.7 m (42.5–45 ft).

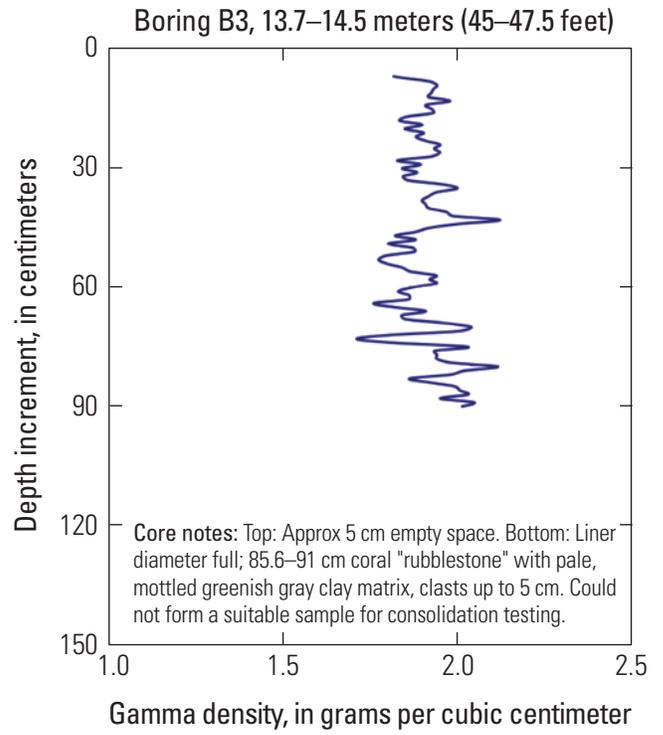
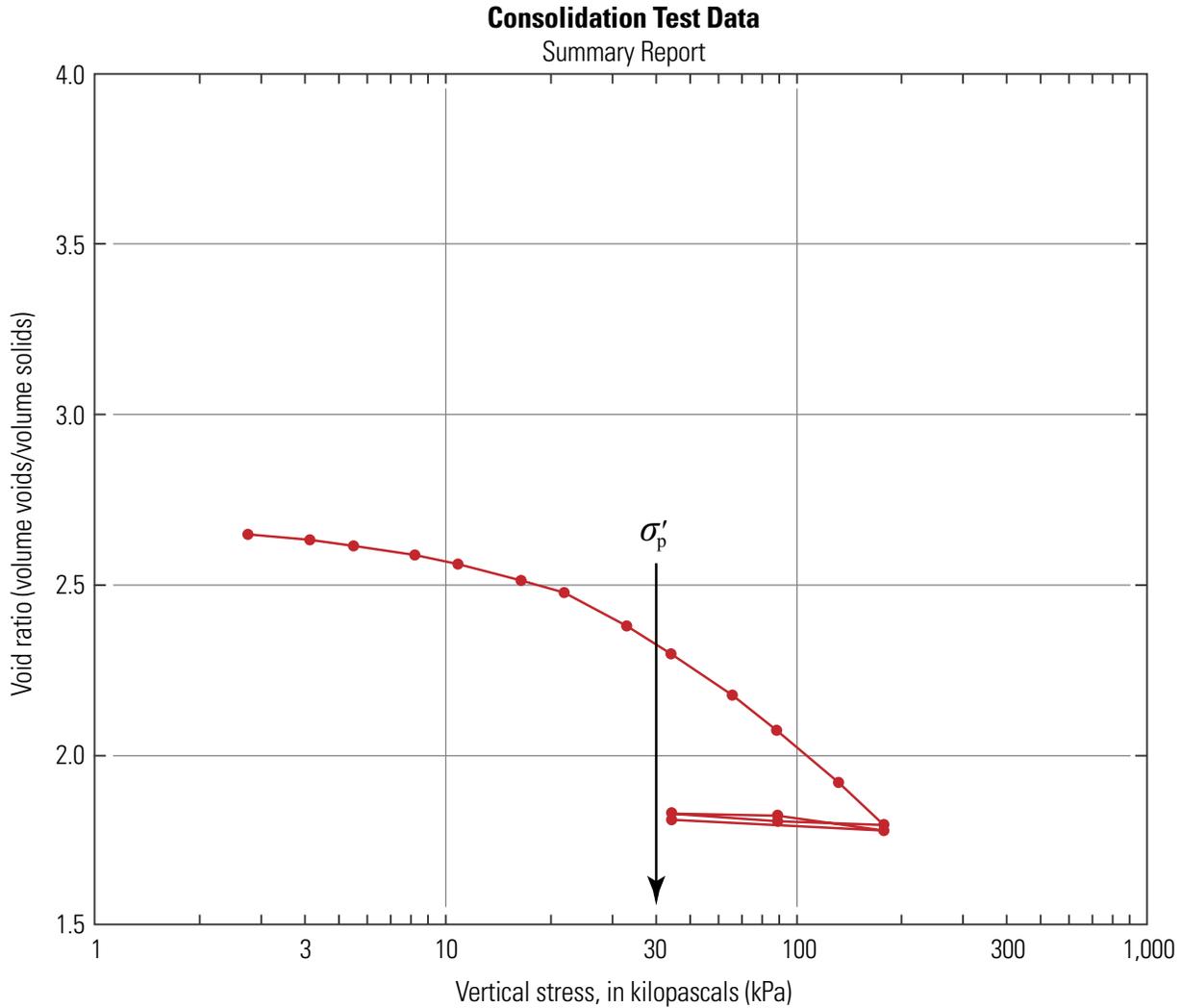


Figure A-36. Plot of gamma density vs. depth in core, Boring B3, 13.7–14.5 m (45–47.5 ft).

Appendix B. Void Ratio vs. Vertical Effective Stress Plots for Incremental Consolidation (CON) Tests for Samples from USS Arizona Borings B2 and B3

Liquid limit (LL), plastic limit (PL) and plasticity index (PI) were not determined and are represented by zero values.

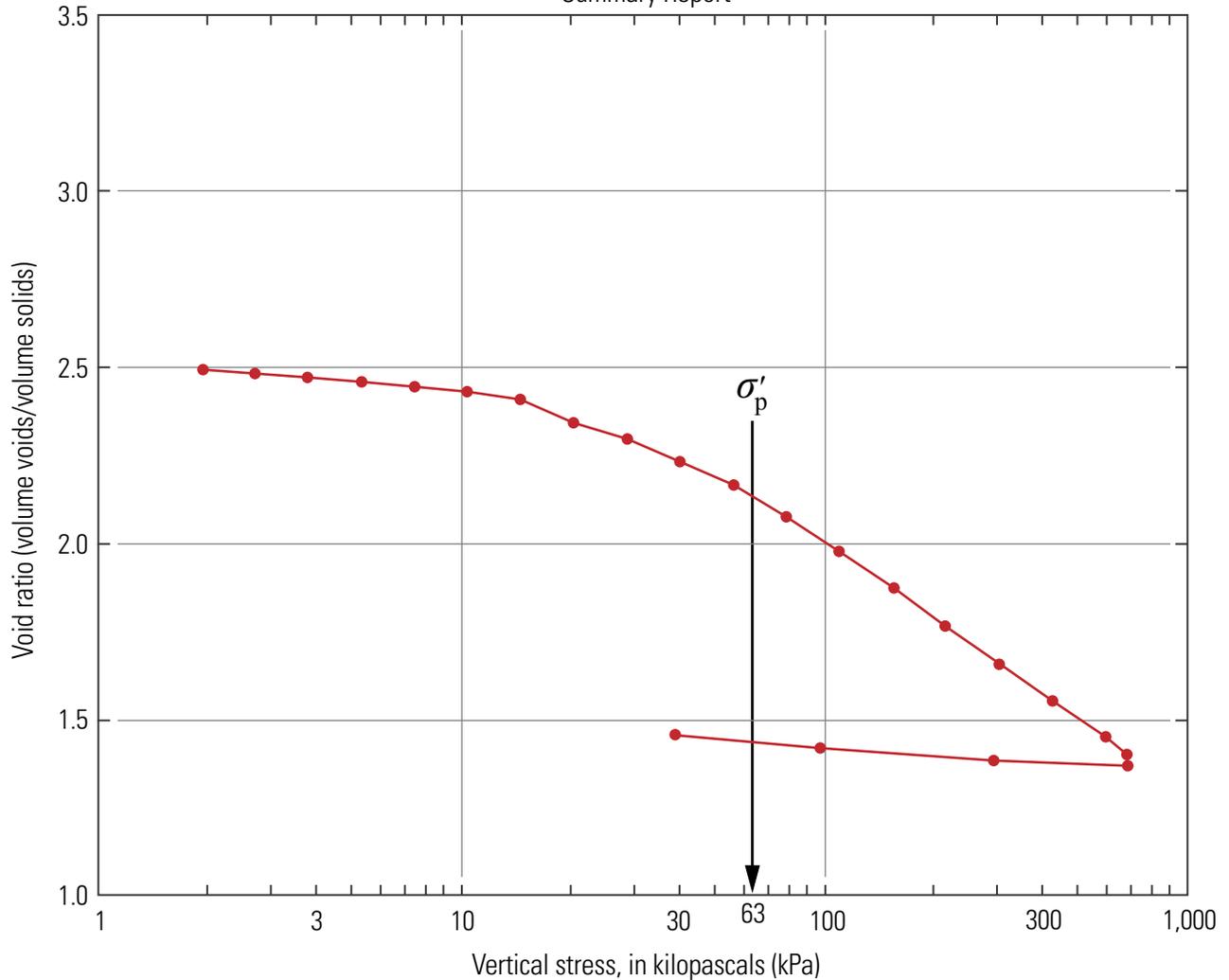


Overburden pressure: 13.3 kPa				Before test		After test	
Preconsolidation pressure: 30 kPa				Water content, %		101.04 70.36	
Compression index: 1.21				Dry unit weight, N/m ³		7201 9420	
Diameter		Height: 25.4 mm		Saturation, %		102.01 104.91	
LL	0	PL:	0	PI:	0	GS:	2.70
Void Ratio				2.68		1.81	
Project: HW Arizona		Location:		Project no.:			
Boring no: B2		Tested by: BC		Checked by: RK			
Sample no.		Test date: 9/12/07		Depth: 17.5–20 ft			
Test no. ICON 246		Sample type: Shelby		Elevation: 86.1–88.6 cm			
Description: Soft, dark gray clay.							
Remarks: 500 lb load cell #74957, Load trac II, System C.							

Figure B-1. Plot of void ratio vs. vertical effective stress for CON-246 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

Summary Report

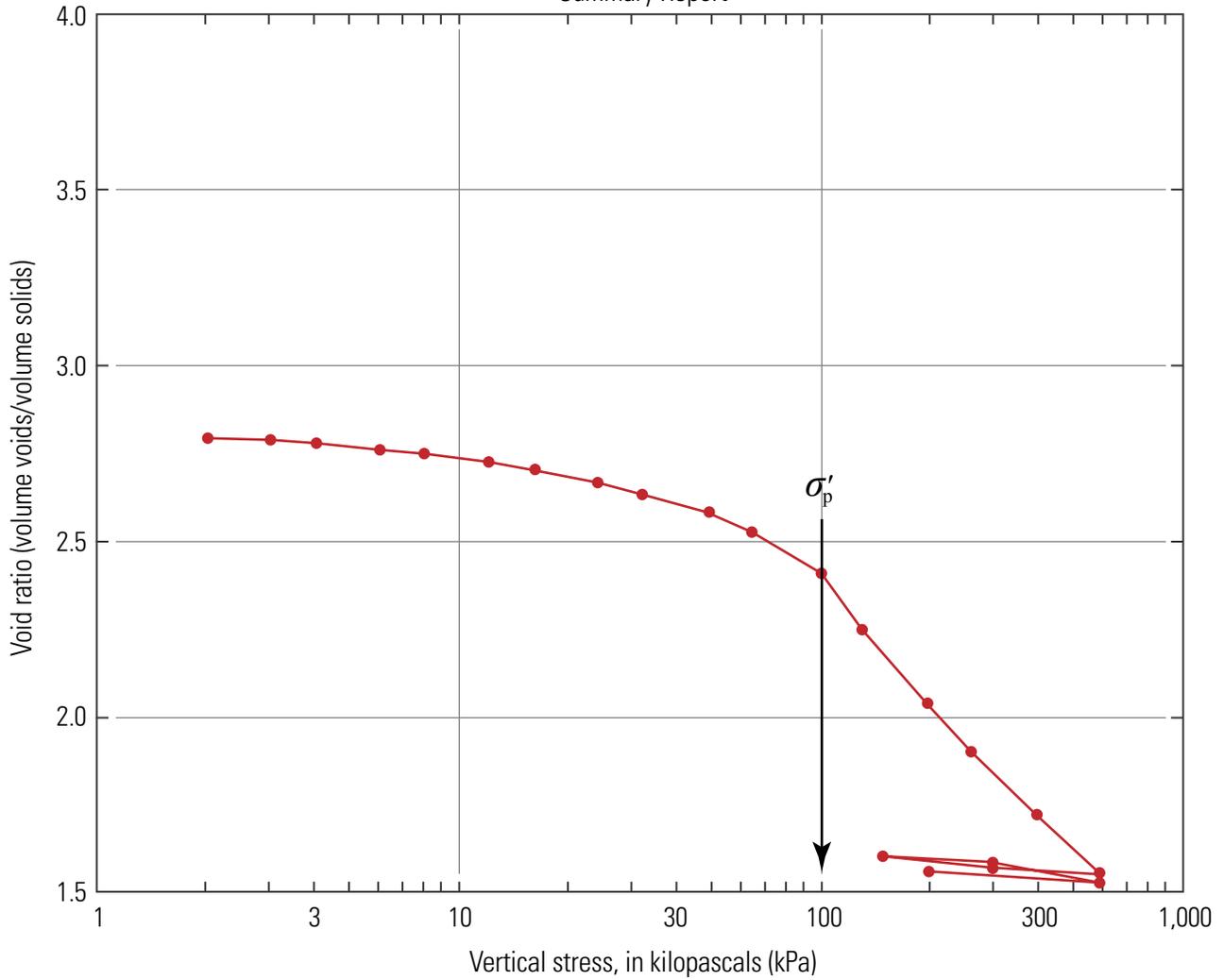


Overburden pressure:	63 kPa				Before test	After test	
Preconsolidation pressure:	63 kPa				Water content, %	95.75 / 57.62	
Compression index:	0.96				Dry unit weight, N/m ³	7564 / 10,780	
Diameter		Height:	25.4 mm		Saturation, %	103.39 / 106.84	
LL	0	PL:	0	PI:	0	GS:	2.70
					Void Ratio	2.50 / 1.46	

Project:	HW Arizona	Location:		Project no.:	
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	5/26/04	Depth:	32.5–35 ft
Test no.	ICON 202	Sample type:	Shelby	Elevation:	86.3–88.8 cm
Description:	Soft, dark gray clay.				
Remarks:	500 lb load cell #74957, Load trac II, System C.				

Figure B-2. Plot of void ratio vs. vertical effective stress for CON-202 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data
Summary Report

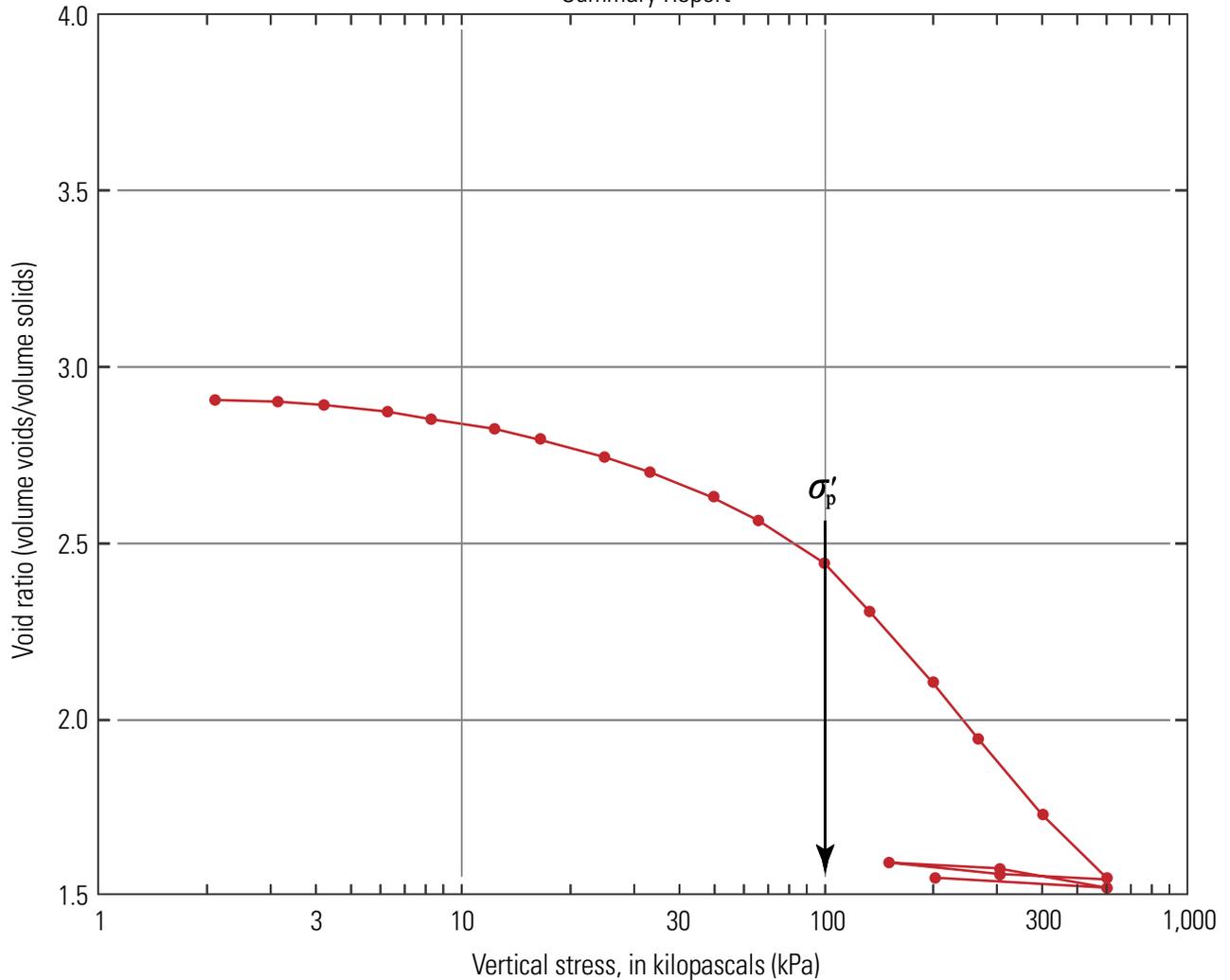


Overburden pressure:	65 kPa		Before test	After test
Preconsolidation pressure:	100 kPa	Water content, %	106.00	62.79
Compression index:	1.65	Dry unit weight, N/m ³	6972	10,350
Diameter	Height: 25.4 mm	Saturation, %	102.30	108.84
LL 0	PL: 0	PI: 0	GS: 2.70	Void Ratio
				2.80
				1.56

Project:	HW Arizona	Location:	Project no.:
Boring no:	B2	Tested by:	BC
Sample no.		Test date:	9/18/07
Test no.	ICON 247	Sample type:	Shelby
Description:	Soft, gray clay; nonhomogeneous.		
Remarks:	500 lb load cell #74957. Old style LVDT on Sustum C.		

Figure. B-3. Plot of void ratio vs. vertical effective stress for CON-247 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data
Summary Report



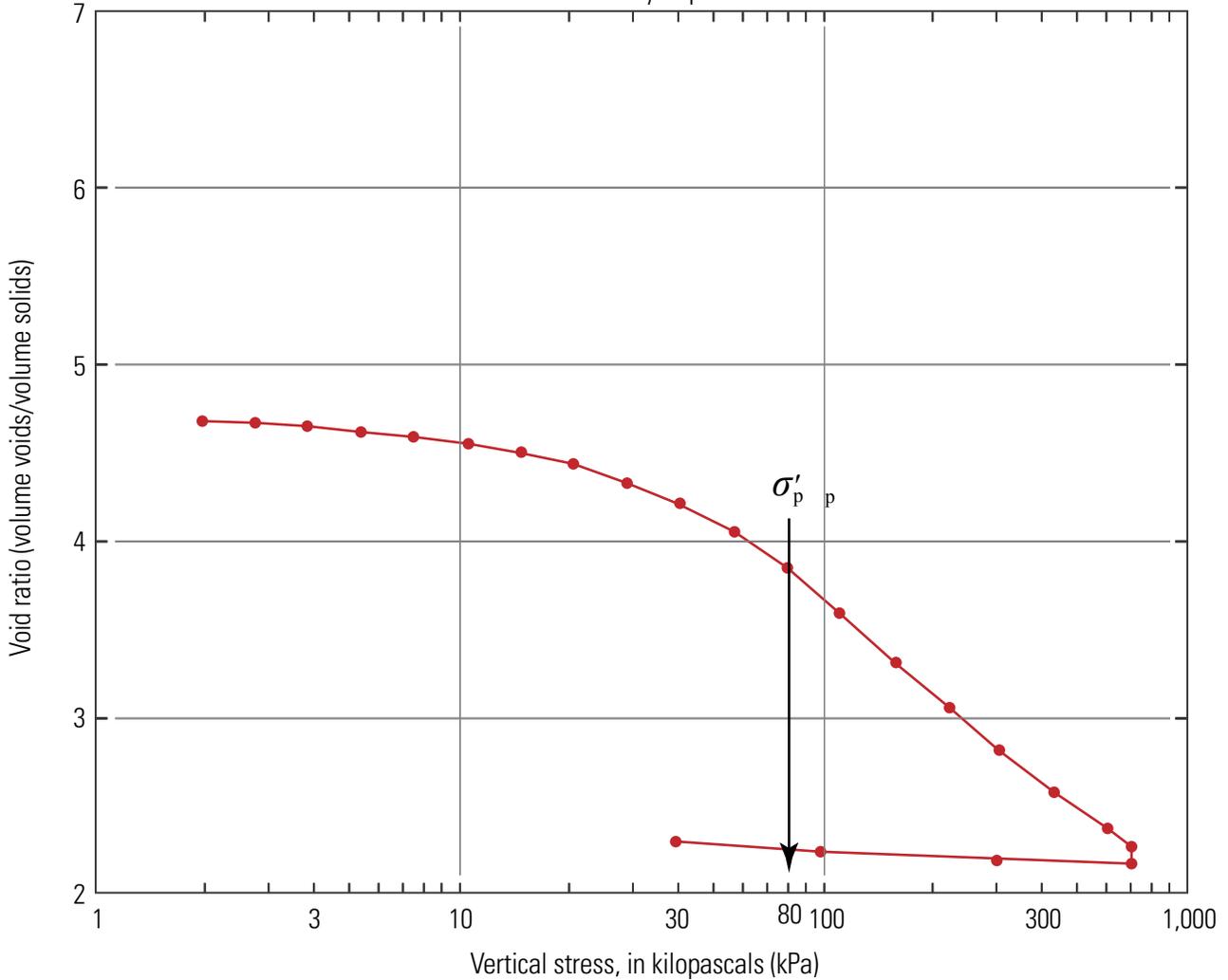
Overburden pressure:	72 kPa		Before test	After test
Preconsolidation pressure:	100 kPa	Water content, %	108.60	62.91
Compression index:	1.53	Dry unit weight, N/m ³	6751	10,380
Diameter	Height: 2.54 mm	Saturation, %	100.34	109.59
LL 0	PL: 0	PI: 0	GS: 2.70	Void Ratio
				2.92
				1.55

Project:	HW Arizona	Location:	Project no.:
Boring no:	B2	Tested by:	BC
Sample no.:	40-42.5 ft	Test date:	9/11/07
Test no.:	ICON 249	Sample type:	Shelby
Description:	Soft, dark gray clay.		
Remarks:	500 lb load cell #74957. Old style LVDT on Sustum C.		

Figure B-4. Plot of void ratio vs. vertical effective stress for CON-249 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

Summary Report



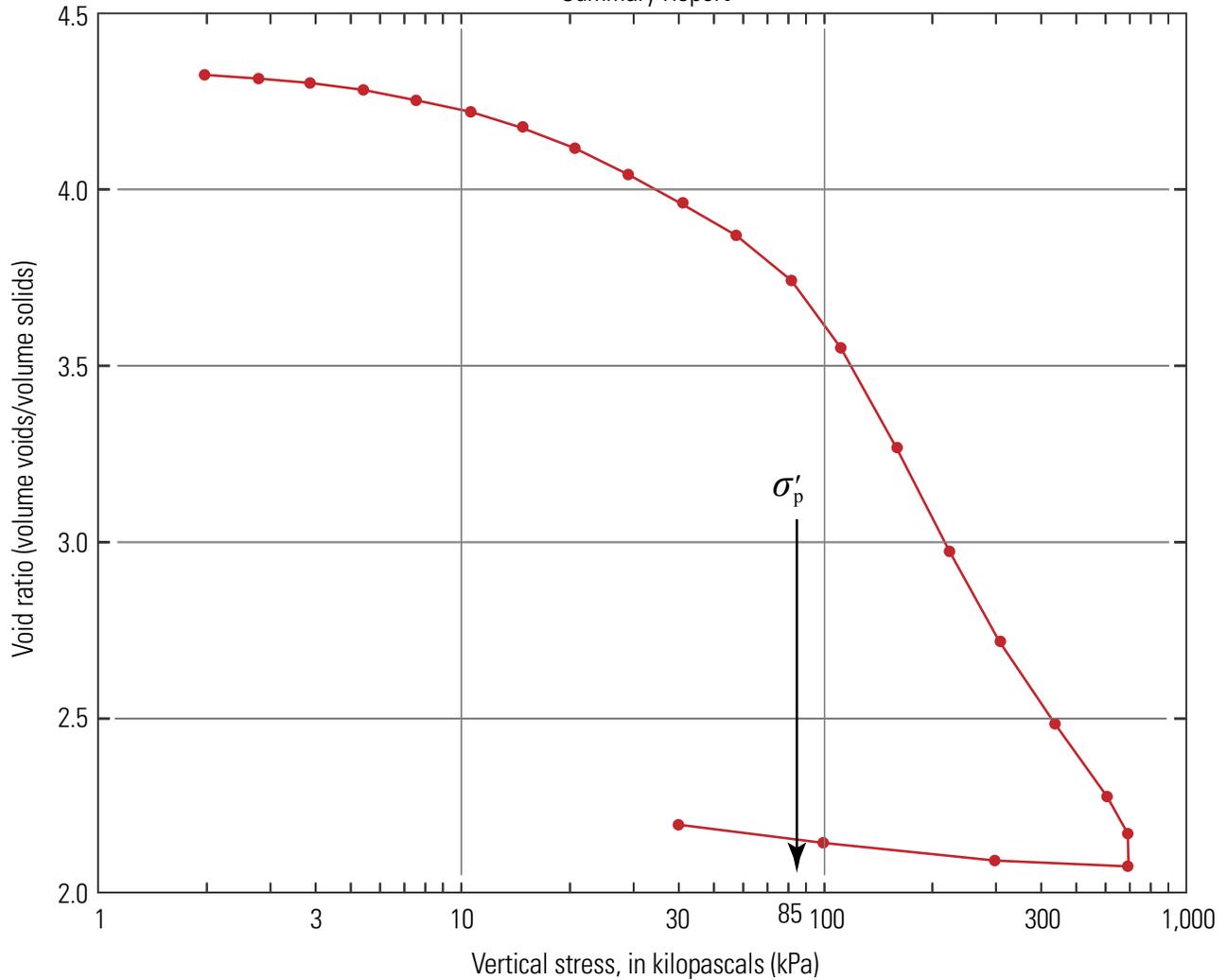
Overburden pressure:	77 kPa		Before test	After test						
Preconsolidation pressure:	80 kPa		Water content, %	172.49	89.16					
Compression index:	2.67		Dry unit weight, N/m ³	4650	8.59					
Diameter	63.4 mm	Height:	25.4 mm	Saturation, %	99.21	105.34				
LL	0	PL:	0	PI:	0	GS:	2.70	Void Ratio	4.69	2.29

Project:	HW Arizona	Location:	Project no.:		
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.	40-42.5 ft	Test date:	7/13/04	Depth:	45-47.5 ft
Test no.	ICON 206	Sample type:	Shelby	Elevation:	85.8-88.3 cm
Description:	Uniform, soft, gray clay.				
Remarks:					

Figure B-5. Plot of void ratio vs. vertical effective stress for CON-206 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

Summary Report



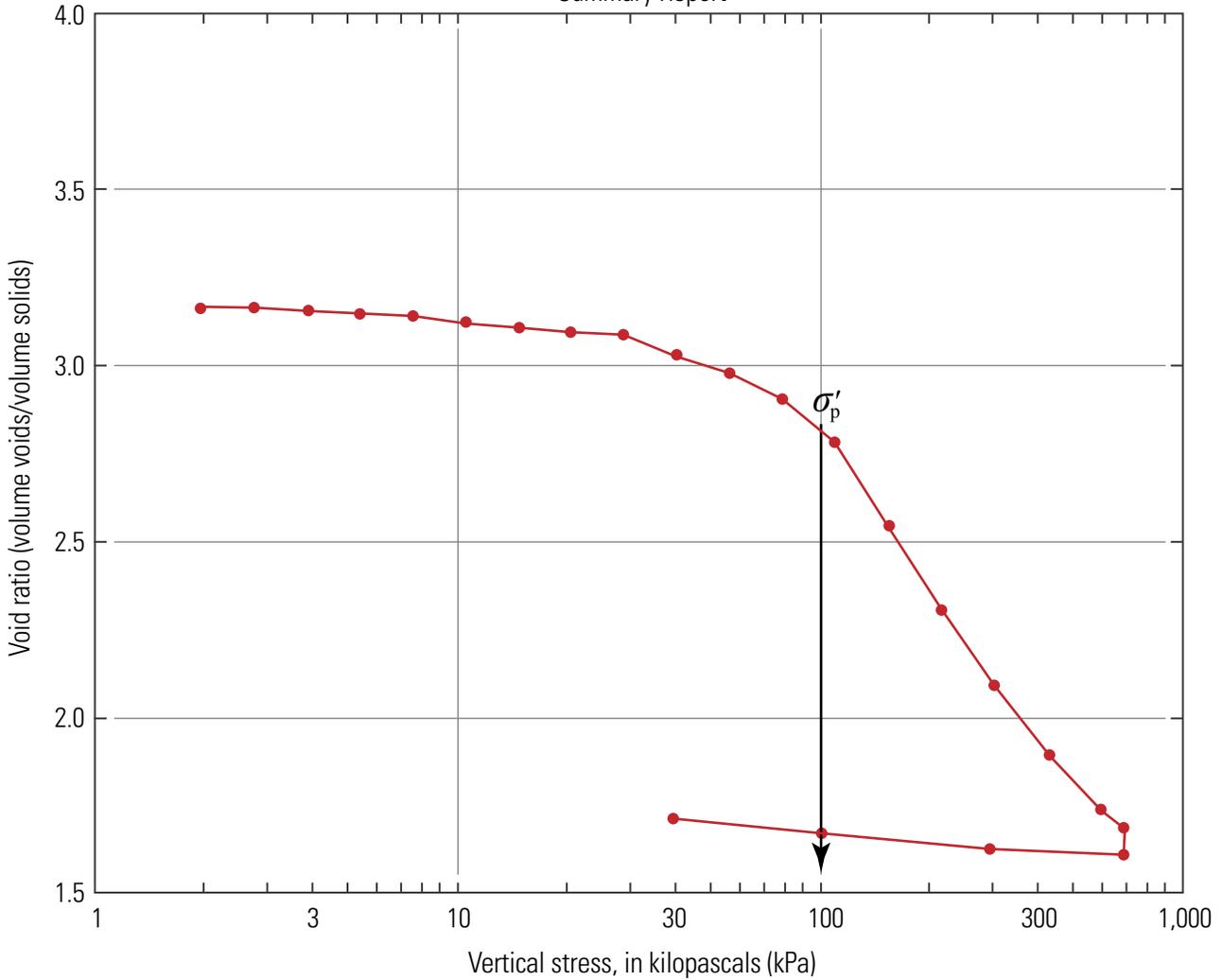
Overburden pressure:	79 kPa		Before test	After test						
Preconsolidation pressure:	85 kPa		Water content, %	172.49	89.16					
Compression index:	2.5		Dry unit weight, N/m ³	4650	8.59					
Diameter	63.4 mm	Height:	25.4 mm	Saturation, %	99.21	105.34				
LL	0	PL:	0	PI:	0	GS:	2.70	Void Ratio	4.69	2.29

Project:	HW Arizona borings	Location:	HW Arizona	Project no.:	50
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	6/04/04	Depth:	47.5–50 ft
Test no.	ICON 204	Sample type:	Shelby	Elevation:	82.3–84.8 cm
Description: Soft, gray silty clay.					
Remarks: Repeat of Icon 203					

Figure B-6. Plot of void ratio vs. vertical effective stress for CON-204 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

Summary Report

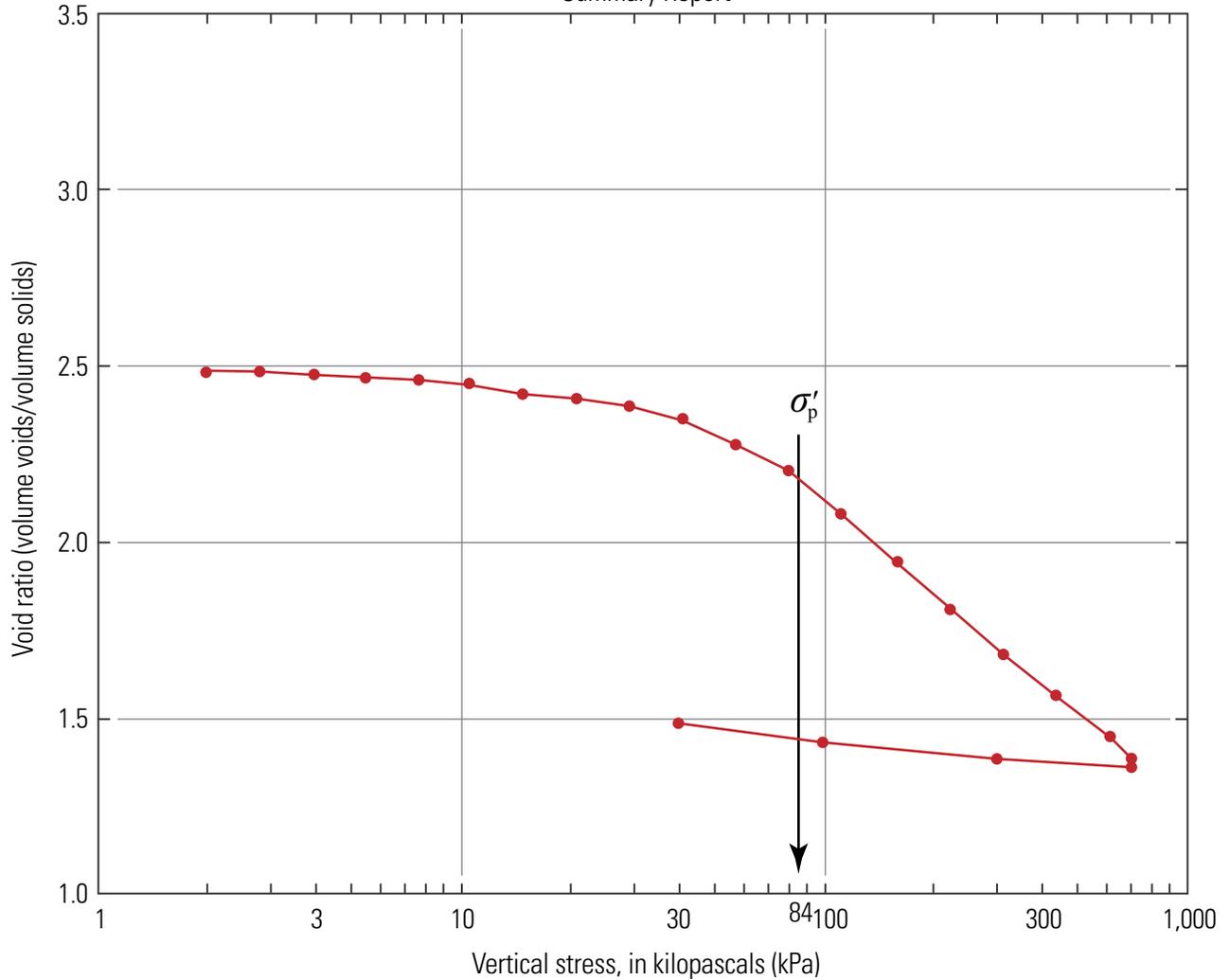


Overburden pressure:	83 kPa		Before test	After test						
Preconsolidation pressure:	101 kPa	Water content, %	119.43	67.25						
Compression index:	2	Dry unit weight, N/m ³	6340	9,761						
Diameter	63.4 mm	Height:	25.4 mm	Saturation, %	101.51	106.02				
LL	0	PL:	0	PI:	0	GS:	2.70	Void Ratio	3.18	1.71

Project:	HW Arizona borings	Location:	USS Arizona	Project no.:	
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	7/19/04	Depth:	52.5–55 ft
Test no.	ICON 207	Sample type:	Shelby	Elevation:	86.3–88.8 cm
Description:	Soft greenish gray clay.				
Remarks:	Minor shell fragments, crab claw.				

Figure B-7. Plot of void ratio vs. vertical effective stress for CON-207 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data
Summary Report

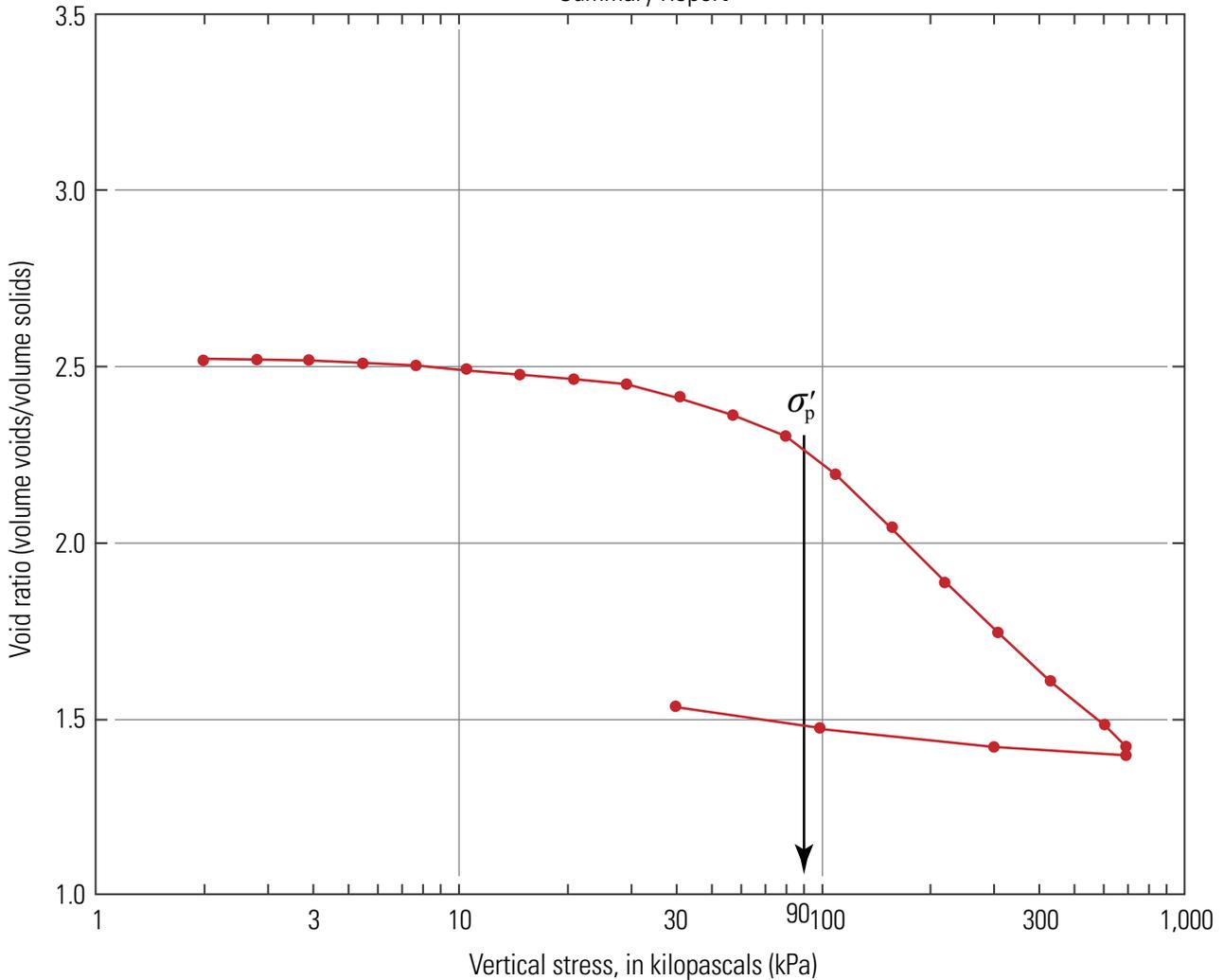


Overburden pressure:	87 kPa				Before test	After test		
Preconsolidation pressure:	84 kPa				Water content, %	81.04	55.02	
Compression index:	1.18				Dry unit weight, N/m ³	7593	10,650	
Diameter	63.4 mm	Height:	25.4 mm		Saturation, %	87.99	100.00	
LL	0	PL:	0	PI:	0	GS:	2.70	
						Void Ratio	2.49	1.49

Project:	HW Arizona	Location:	USS Arizona	Project no.:	
Boring no.:	B2	Tested by:	BC	Checked by:	RK
Sample no.:		Test date:	5/11/04	Depth:	55-57.5 ft
Test no.:	ICON 200	Sample type:	Shelby	Elevation:	87.3-89.8 cm
Description:	Uniform, soft, olive-gray clay. Minor thin shell fragments.				
Remarks:					

Figure B-8. Plot of void ratio vs. vertical effective stress for CON-200 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data
Summary Report



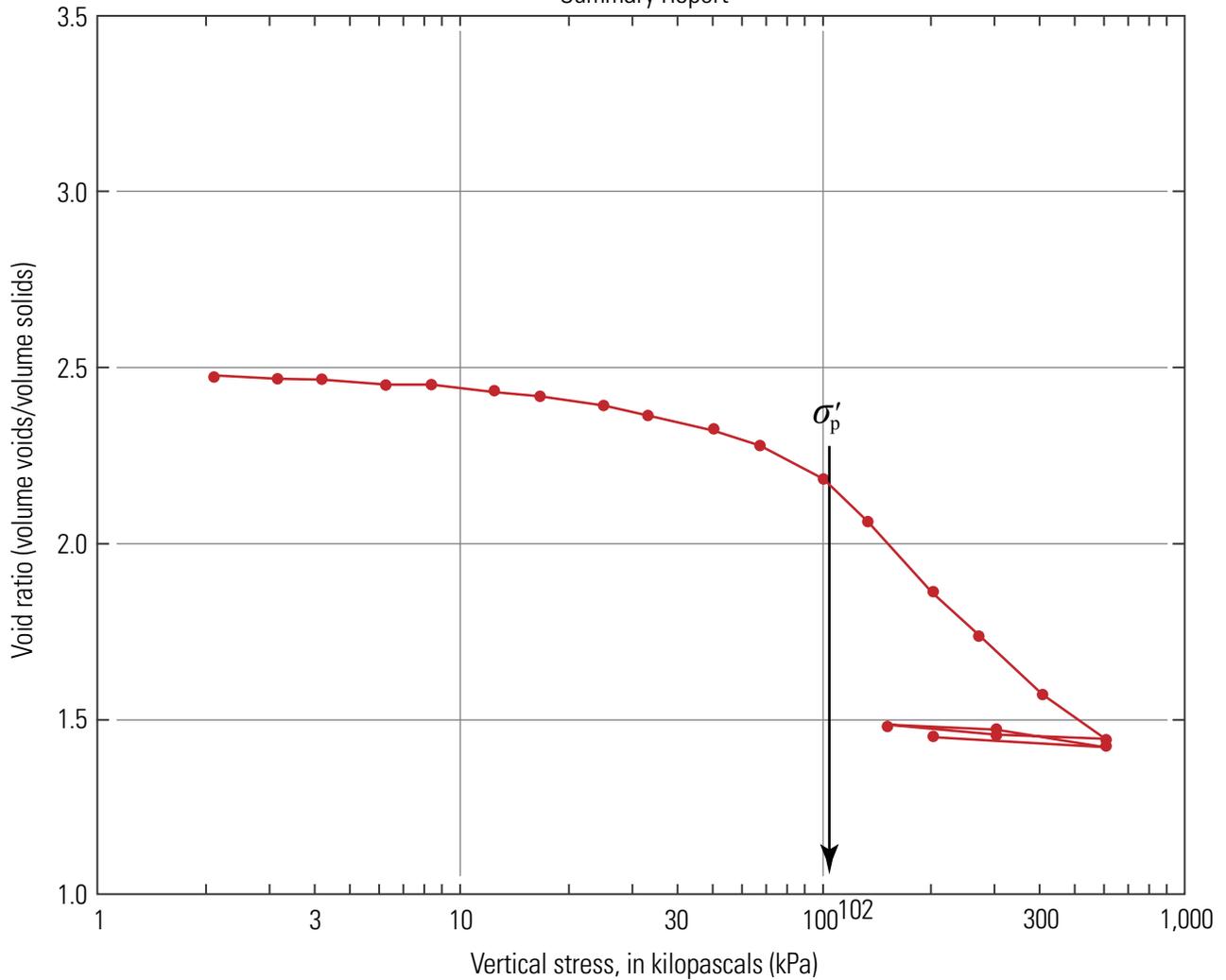
Overburden pressure:	91 kPa				Before test	After test		
Preconsolidation pressure:	90 kPa				Water content, %	93.59	57.01	
Compression index:	1.23				Dry unit weight, N/m ³	7541	10,450	
Diameter	63.4 mm	Height:	25.4 mm		Saturation, %	100.63	100.41	
LL	0	PL:	0	PI:	0	GS:	2.70	
						Void Ratio	2.51	1.53

Project:	HW Arizona	Location:	USS Arizona	Project no.:	
Boring no.:	B2	Tested by:	BC	Checked by:	RK
Sample no.:		Test date:	5/4/04	Depth:	57.5–60 ft
Test no.:	ICON 199	Sample type:	Shelby	Elevation:	86.2–88.8 cm
Description:	Olive gray, sticky clay.				
Remarks:	minor thin walled shells				

Figure B-9. Plot of void ratio vs. vertical effective stress for CON-199 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

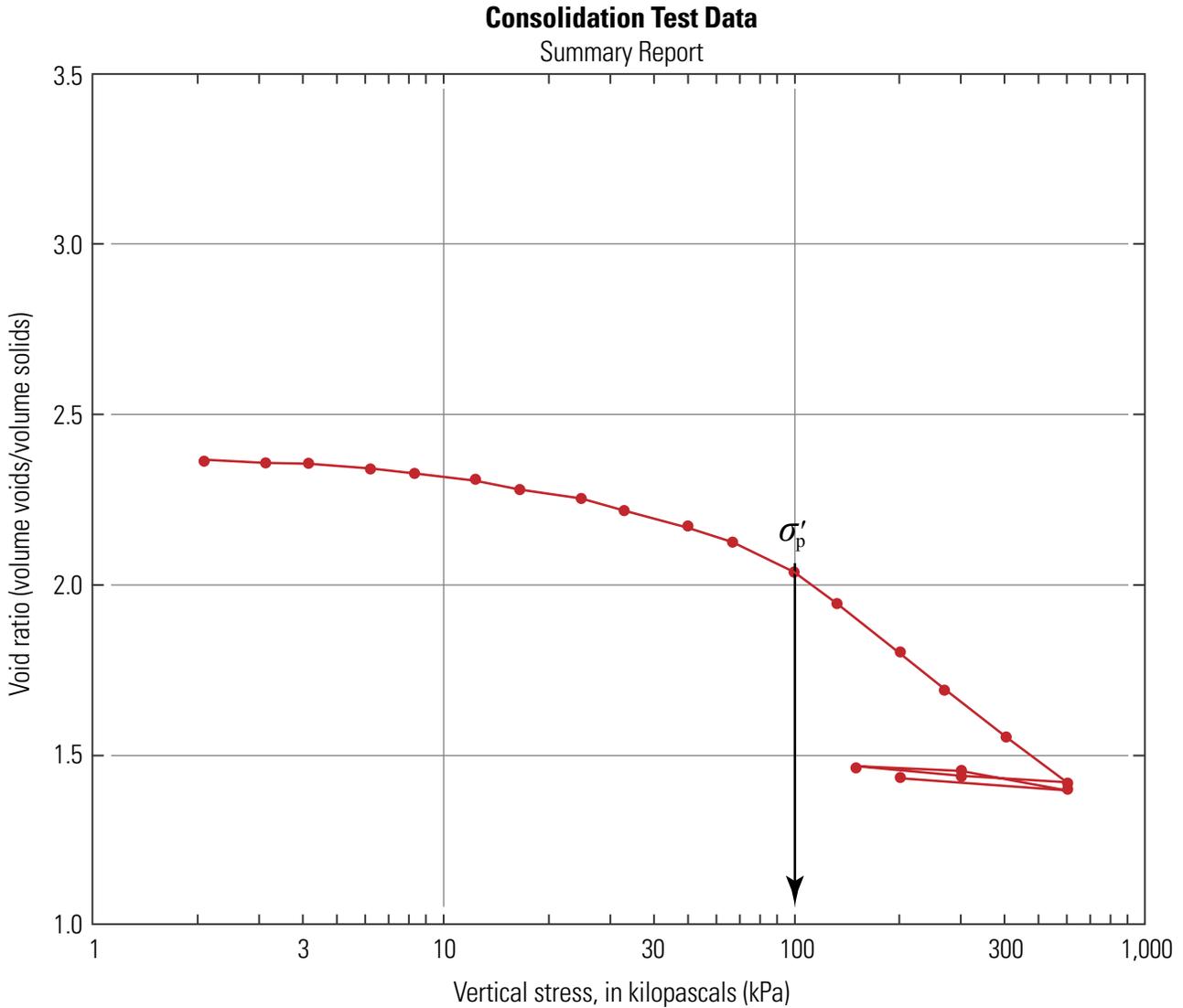
Summary Report



Overburden pressure:	93 kPa				Before test	After test		
Preconsolidation pressure:	102 kPa				Water content, %	93.33	59.16	
Compression index:	1.4				Dry unit weight, N/m ³	7613	10,800	
Diameter	63.5 mm	Height:	25.4 mm		Saturation, %	101.70	110.12	
LL	0	PL:	0	Pl:	0	GS:	2.70	
						Void Ratio	2.48	1.45

Project:	HW Arizona	Location:	USS Arizona	Project no.:	
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	10/5/07	Depth:	60–62.5 ft
Test no.	ICON 251	Sample type:	Shelby	Elevation:	66.4–68.9 cm
Description:	Soft, mottled, dark gray clay with shell fragments.				
Remarks:	500 lb load cell #74957, Old style LVDT on System C.				

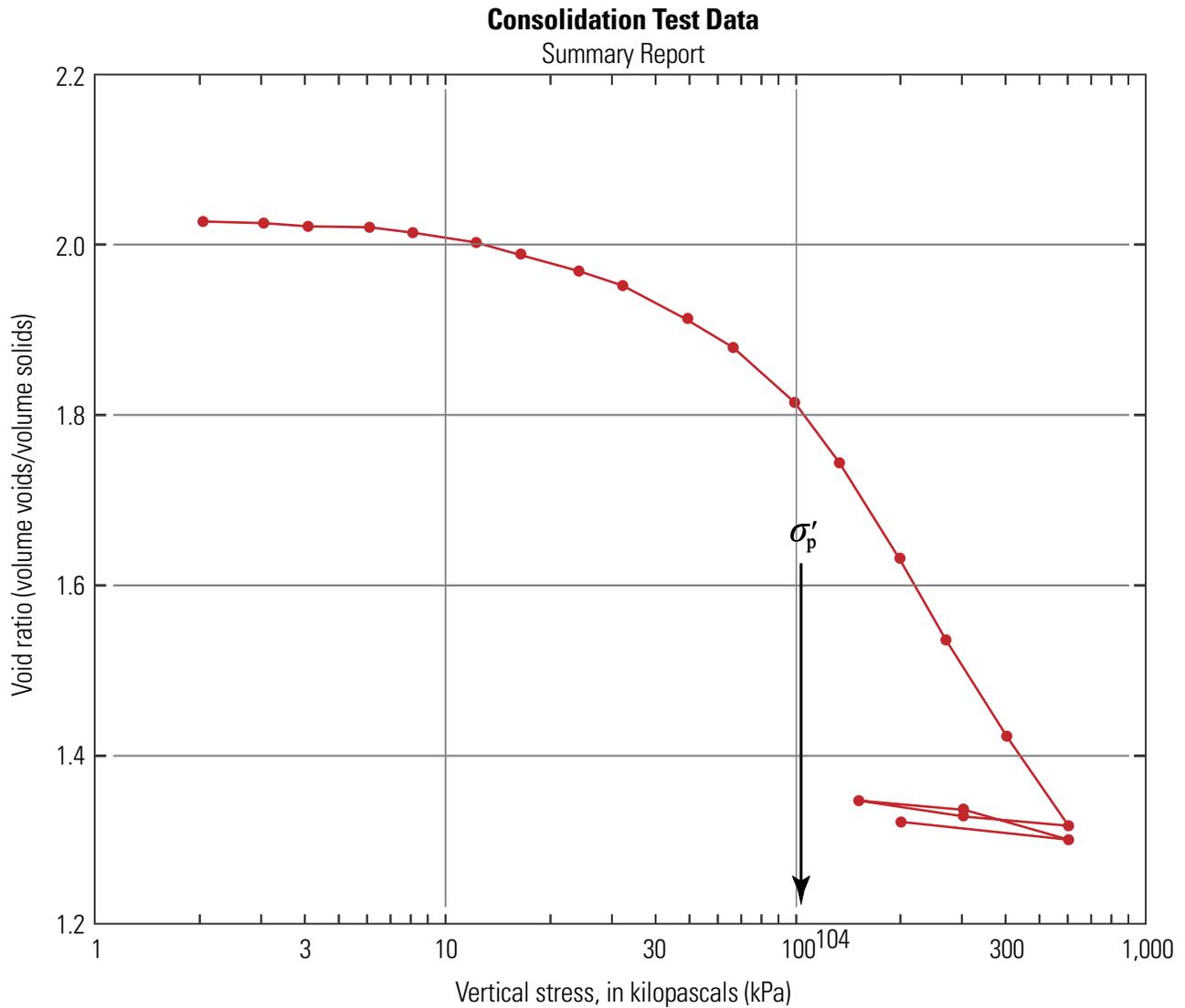
Figure B-10. Plot of void ratio vs. vertical effective stress for CON-251 test. Arrow indicates the maximum past stress/preconsolidation pressure.



Overburden pressure: 97 kPa				Before test	After test
Preconsolidation pressure: 100 kPa				Water content, %	91.64 57.98
Compression index: 1.08				Dry unit weight, N/m ³	7835 10,890
Diameter	63.5mm	Height:	25.4 mm	Saturation, %	103.98 109.45
LL	0	PL:	0	PI:	0
		GS:	2.70	Void Ratio	2.38 1.43

Project:	HW Arizona	Location:	USS Arizona	Project no.:	
Boring no:	B2	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	9/24/07	Depth:	62.5–65 ft
Test no.	ICON 248	Sample type:	Shelby	Elevation:	85.1–87.6 cm
Description:	Soft, dark gray clay. Thin-walled shell fragments.				
Remarks:	500 lb load cell #74957, Old style LVDT on System C.				

Figure B-11. Plot of void ratio vs. vertical effective stress for CON-248 test. Arrow indicates the maximum past stress/preconsolidation pressure.

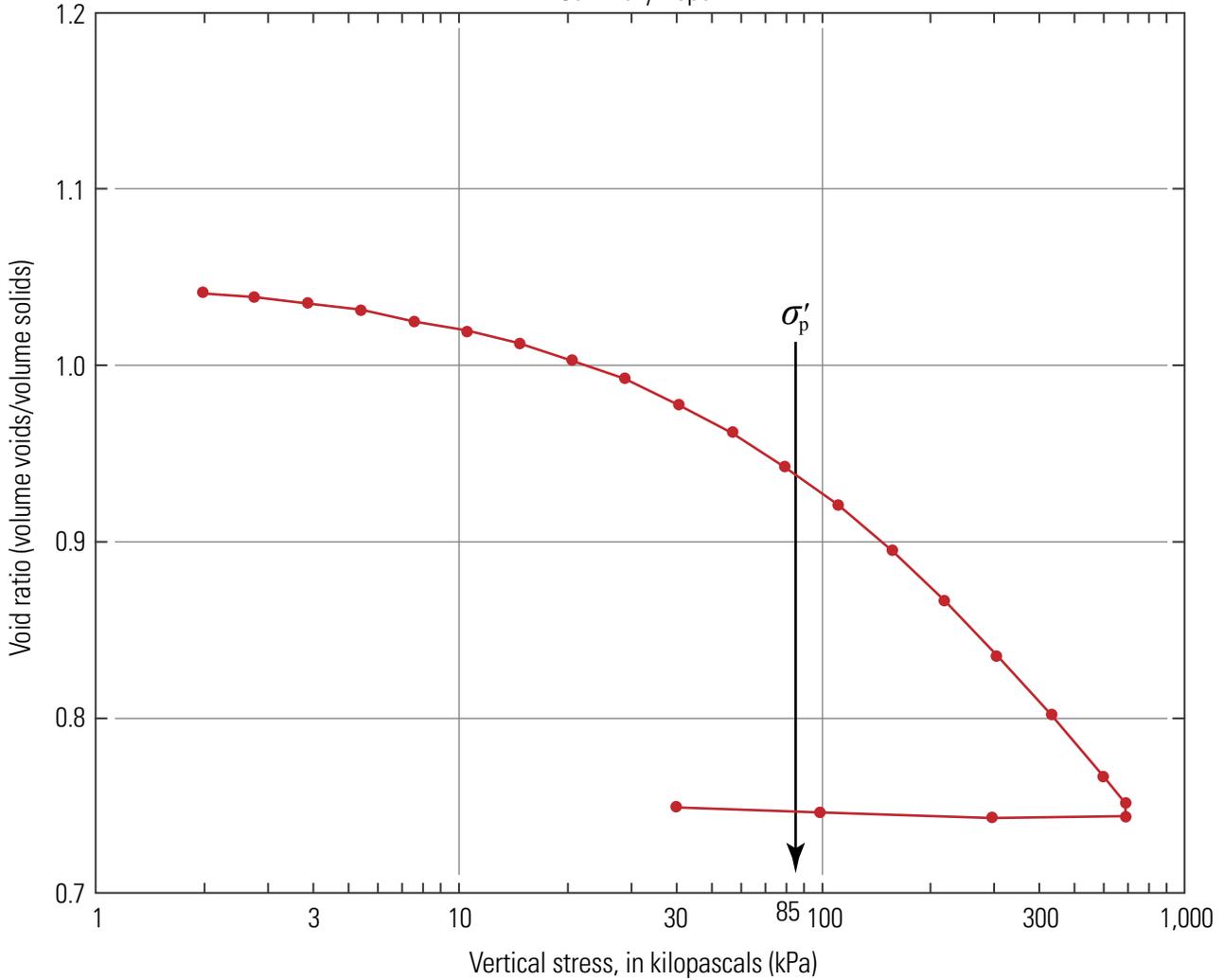


Overburden pressure:	104 kPa				Before test	After test	
Preconsolidation pressure:	104 kPa				77.74	52.92	
Compression index:	0.84				8737	11,420	
Diameter	6.35 mm	Height:	2.54 mm		Saturation, %	103.37	
LL	0	PL:	0	PI:	0	GS:	2.70
					Void Ratio	2.03	
						1.32	

Project:	HW Arizona	Location:		Project no.:	
Boring no.:	B2	Tested by:	BC	Checked by:	RK
Sample no.:		Test date:	9/11/07	Depth:	67.5–70 ft
Test no.:	ICON 252	Sample type:	Shelby	Elevation:	76.5–79 cm
Description:	Soft, dark gray clay with minor shell fragments.				
Remarks:	500 lb load cell #74957. Old style LVDT on Sustum C.				

Figure B-12. Plot of void ratio vs. vertical effective stress for CON-252 test. Arrow indicates the maximum past stress/preconsolidation pressure.

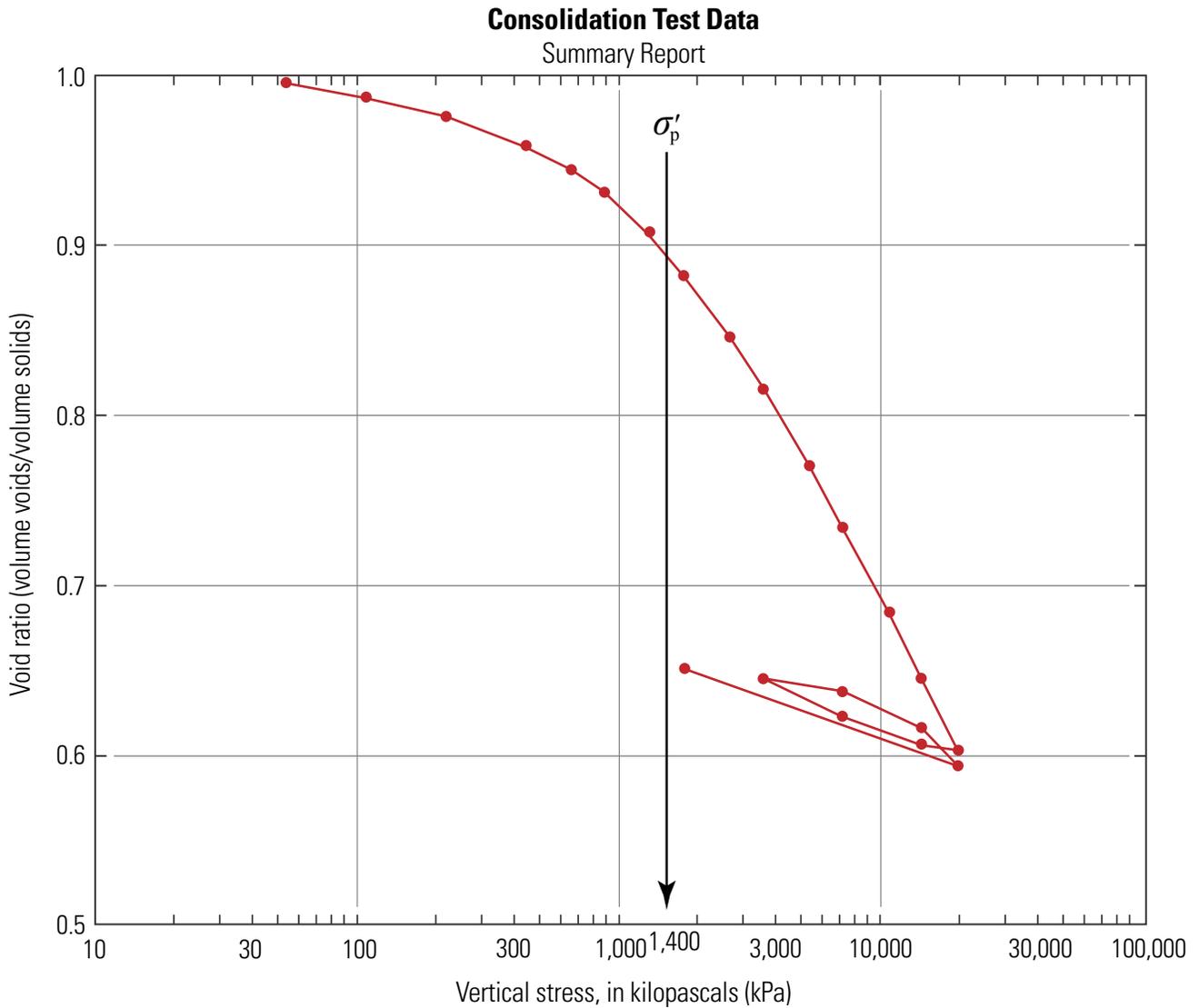
Consolidation Test Data
Summary Report



Overburden pressure:	31 kPa		Before test	After test
Preconsolidation pressure:	85 kPa	Water content, %	40.34	29.51
Compression index:	0.28	Dry unit weight, N/m ³	12,930	15,130
Diameter	63.4 mm	Height:	25.4 mm	Saturation, %
LL	0	PL:	0	PI:
		GS:	2.70	Void Ratio
				1.05
				0.75

Project:	HW Arizona	Location:	Project no.:
Boring no:	B3	Tested by:	BC
Sample no.		Test date:	12/08/04
Test no.	ICON 212	Sample type:	Shelby
Description:	Gray, slightly silty sand with fine pebbles and granules.		
Remarks:	Shell fragments. System B.		

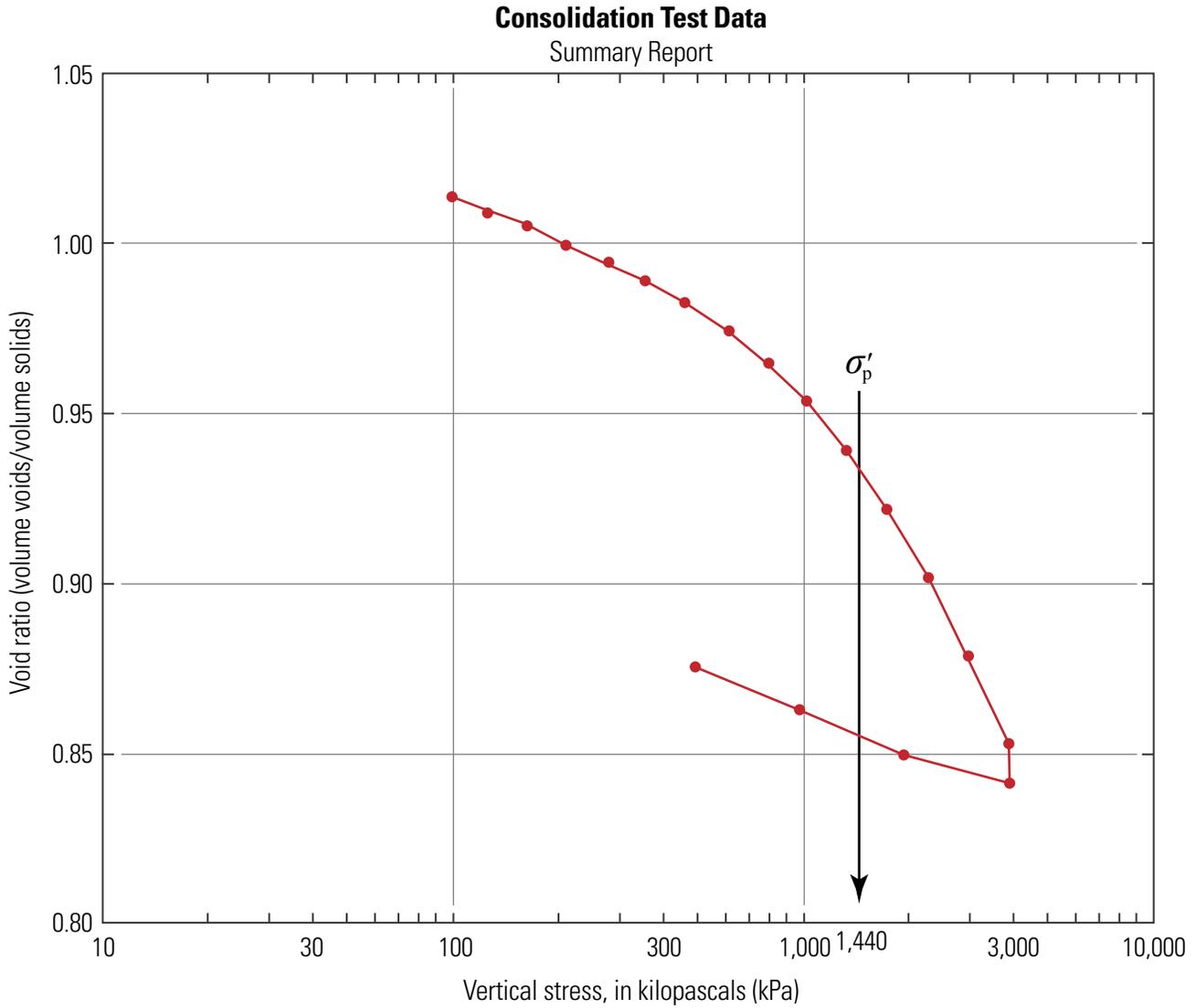
Figure B-13. Plot of void ratio vs. vertical effective stress for CON-212 test. Arrow indicates the maximum past stress/preconsolidation pressure.



Overburden pressure:	79 kPa			Before test	After test
Preconsolidation pressure:	1,400 kPa			Water content, %	39.56 28.04
Compression index:	0.32			Dry unit weight, N/m ³	13,210 16,050
Diameter	38.1 mm	Height:	27.94 mm	Saturation, %	106.26 116.44
LL	0	PL:	0	PI:	0
		GS:	2.70	Void Ratio	1.01 0.65

Project:	HW Arizona	Location:	USS Arizona	Project no.:	5,000 lb c
Boring no.:	B3	Tested by:	BC	Checked by:	RK
Sample no.:	30–32.5 ft	Test date:	9/09/07	Depth:	30–32.5 ft
Test no.:	ICON 245	Sample type:	LEXAN	Elevation:	80.9–83.7 cm
Description:	Very stiff, dark brown, silty/sandy clay. Minor blk granules up to 2mm.				
Remarks:	5,000 lb load cell #C88706. Old style LVDT on System C.				

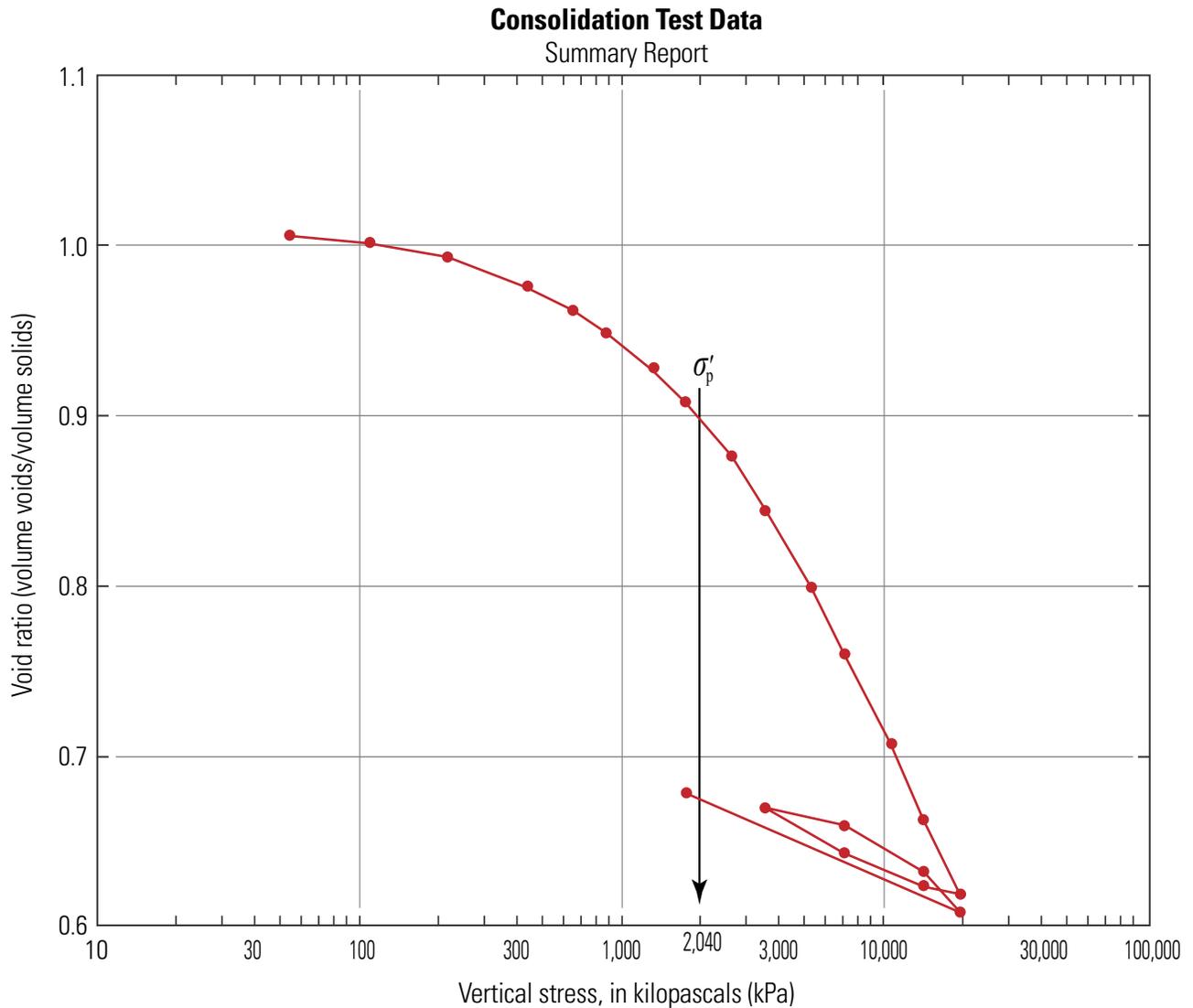
Figure B-14. Plot of void ratio vs. vertical effective stress for CON-245 test. Arrow indicates the maximum past stress/preconsolidation pressure.



Overburden pressure:	85 kPa				Before test	After test			
Preconsolidation pressure:	1,440 kPa				Water content, %	39.99 35.10			
Compression index:	0.25				Dry unit weight, N/m ³	13,110 14,120			
Diameter	63.5 mm	Height:	25.4 mm		Saturation, %	105.96 108.26			
LL	0	PL:	0	PI:	0	GS:	2.70	Void Ratio	1.02 0.88

Project:	HW Arizona borings	Location:	USS Arizona	Project no.:	5,000 lb c
Boring no.:	B3	Tested by:	BC	Checked by:	RK
Sample no.:		Test date:	1/07/05	Depth:	32.5–35 ft
Test no.:	ICON 216	Sample type:	Shelby	Elevation:	78.5–81 cm
Description: Very stiff, dark brown, silty clay.					
Remarks:					

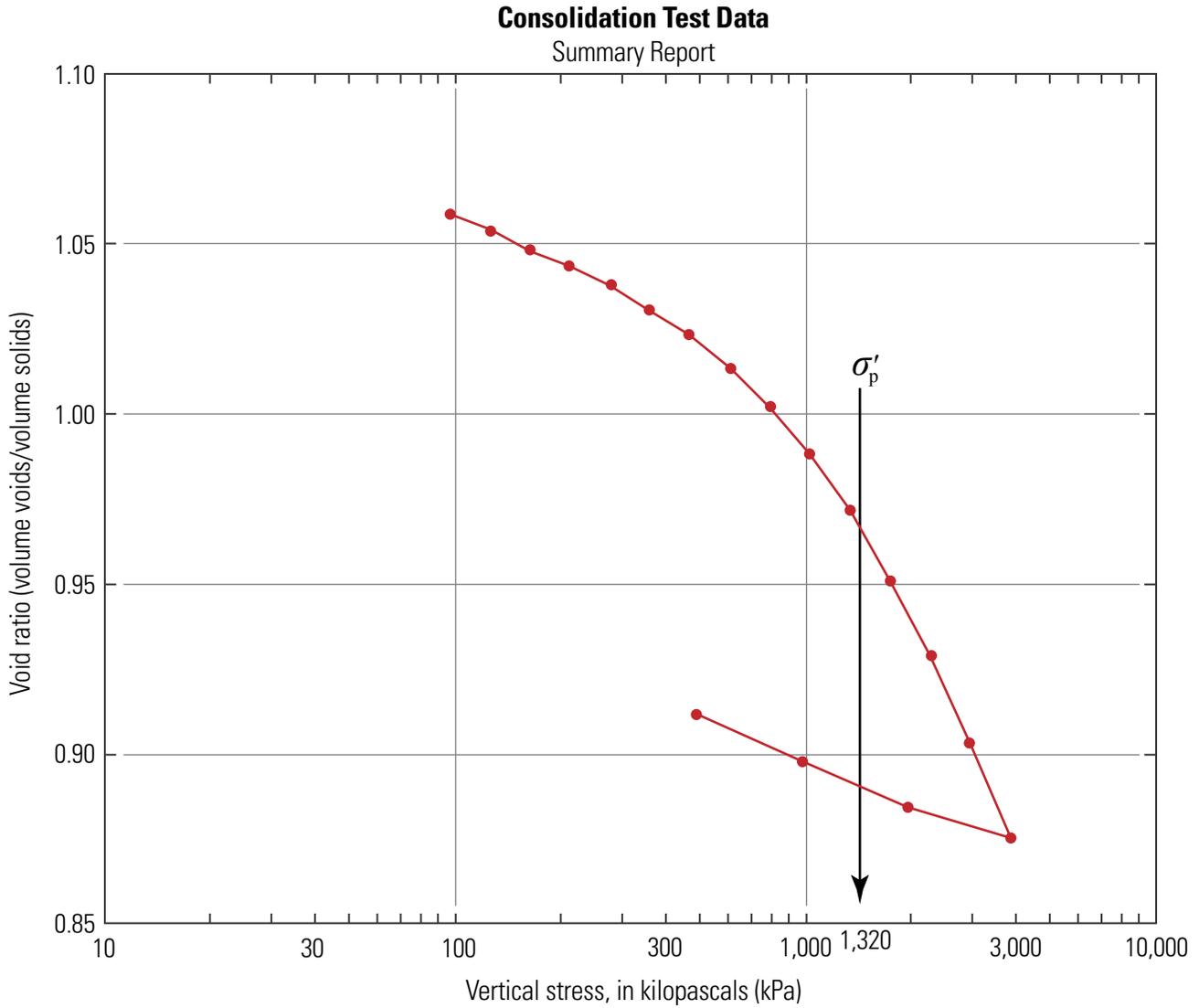
Figure B-15. Plot of void ratio vs. vertical effective stress for CON-216 test. Arrow indicates the maximum past stress/preconsolidation pressure.



Overburden pressure:	93 kPa		Before test	After test			
Preconsolidation pressure:	2,040 kPa		Water content, %	40.52	30.27		
Compression index:	0.54		Dry unit weight, N/m ³	13,150	15,790		
Diameter	38.1 mm	Height: 27.94 mm	Saturation, %	107.97	120.70		
LL	0	PL: 0	PI: 0	GS: 2.70	Void Ratio	1.01	0.68

Project:	HW Arizona	Location:	USS Arizona	Project no.:	5,000 lb c
Boring no:	B3	Tested by:	BC	Checked by:	RK
Sample no.	35–37.5 ft	Test date:	9/5/07	Depth:	35–37.5 ft
Test no.	ICON 244	Sample type:	LEXAN	Elevation:	82.6–85.4 cm
Description: Very stiff, dark brown, slightly silty clay. Mottled mix of grayish clay. (Disturbed?)					
Remarks: 5,000 lb load cell #C88706. Old style LVDT on System C.					

Figure B-16. Plot of void ratio vs. vertical effective stress for CON-244 test. Arrow indicates the maximum past stress/preconsolidation pressure.



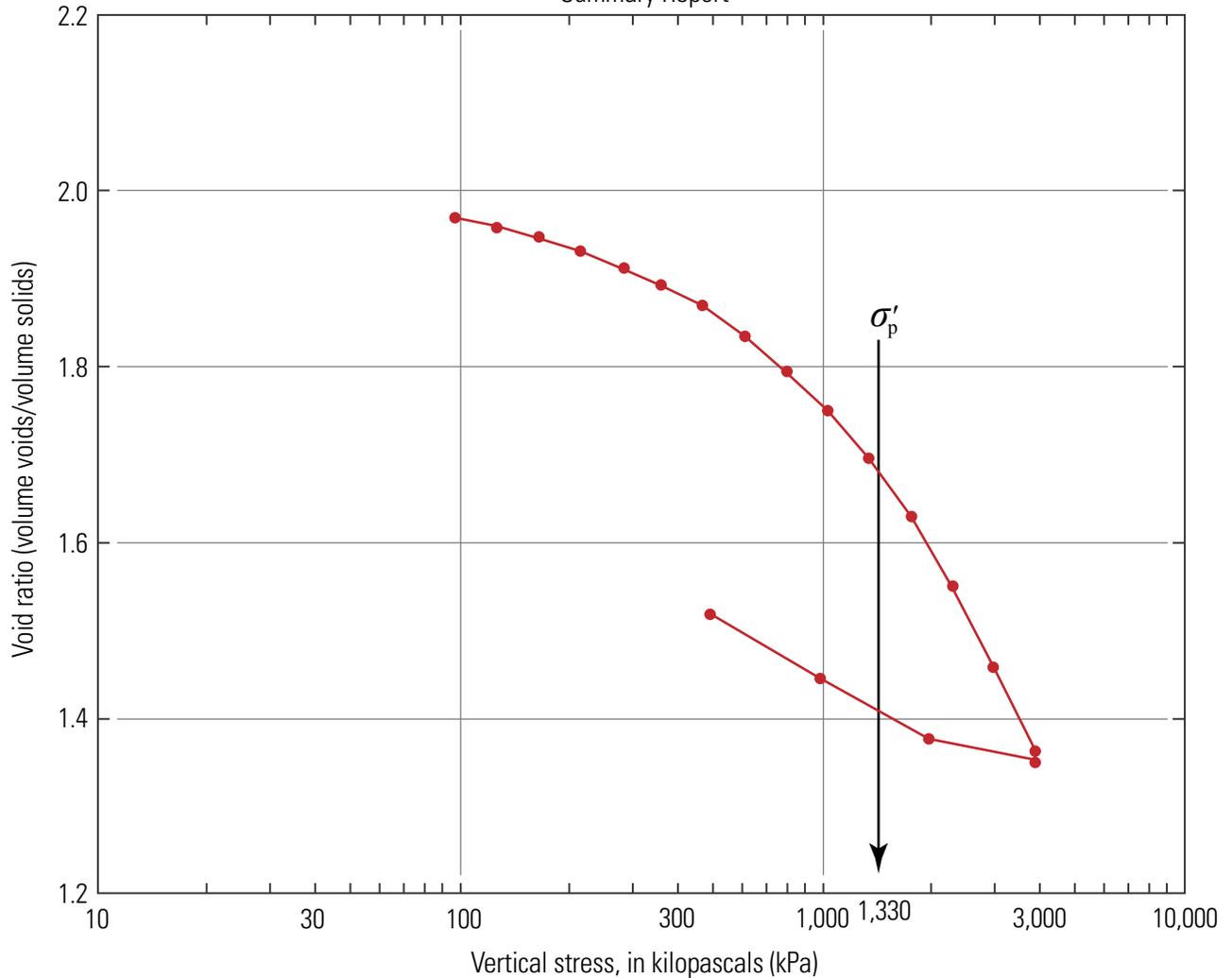
Overburden pressure:	99 kPa			Before test	After test
Preconsolidation pressure:	1,320 kPa			Water content, %	41.62 / 36.72
Compression index:	0.28			Dry unit weight, N/m ³	12,820 / 13,850
Diameter	63.5 mm	Height:	25.4 mm	Saturation, %	105.42 / 108.76
LL	0	PL:	0	Pi:	0
		GS:	2.70	Void Ratio	1.07 / 0.91

Project:	HW Arizona borings	Location:	USS Arizona	Project no.:	5,000 lb c
Boring no:	B3	Tested by:	BC	Checked by:	RK
Sample no.		Test date:	12/22/04	Depth:	37.5–40 ft
Test no.	ICON 214	Sample type:	Shelby	Elevation:	77.1–79 cm
Description: Very stiff, dark brown, silty clay with soft dark and rusty granules.					
Remarks:					

Figure B-17. Plot of void ratio vs. vertical effective stress for CON-214 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Consolidation Test Data

Summary Report



Overburden pressure:	105 kPa				Before test	After test	
Preconsolidation pressure:	1,330 kPa				74.73	58.16	
Compression index:	1.1				8,867	10,510	
Diameter	63.5 mm	Height:	25.4 mm		Saturation, %	101.58	103.41
LL	0	PL:	0	PI:	0	GS:	2.70
					Void Ratio	1.99	1.52
Project:		HW Arizona borings		Location:		USS Arizona	
Boring no.:		B3		Tested by:		BC	
Sample no.:				Test date:		12/28/04	
Test no.:		ICON 215		Sample type:		Shelby	
				Project no.:		5,000 lb c	
				Checked by:		RK	
				Depth:		40–42.5 ft	
				Elevation:		78.5–81 cm	
Description: Stiff greenish gray clay with whitish diffuse patches, minor granules.							
Remarks: A sector of brownish clay (disturbance?)							

Figure B-18. Plot of void ratio vs. vertical effective stress for CON-215 test. Arrow indicates the maximum past stress/preconsolidation pressure.

Appendix C. Report from Ernest K. Hirata and Associates, Inc., Dated December 17, 2003, Concerning the Drilling They Performed for the USS *Arizona* Project



99-1433 Koaha Place
Aiea, Hawaii 96701
Ph: 808-486-0787 Fax: 808-486-0870
Email: eha@hawaii.rr.com

LETTER OF TRANSMITTAL

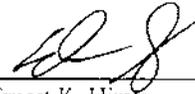
December 18, 2003
W.O. 03-3832

TO: Mr. Richard Frey
Engineering Solutions, Inc.
98-1268 Kaahumanu Street, Suite C-7
Pearl City, Hawaii 96782

SUBJECT: National Park Service
USS Arizona Project

<u>COPIES</u>	<u>DATE</u>	<u>DESCRIPTION</u>
1	12/17/03	Drilling Services Report
<u> x </u>		For your information and use
<u> </u>		As Requested
<u> </u>		For your review and comment
<u> </u>		Other

REMARKS:

FROM: 
Ernest K. Hirata

cc: Matthew Russell, National Park Service

Figure C-1. The letter of transmittal and full drilling report from Ernst K. Hirata and Associates (2003).

**DRILLING SERVICES FOR
NATIONAL PARK SERVICE
USS ARIZONA PROJECT**

for

ENGINEERING SOLUTIONS, INC.

ERNEST K. HIRATA & ASSOCIATES, INC.
W.O. 03-3832
December 17, 2003



99-1433 Koaha Place
Aiea, Hawaii 96701
Ph: 808-486-0787 Fax: 808-486-0870
Email: eha@hawaii.rr.com

December 17, 2003
W.O. 03-3832

Mr. Richard Frey
Engineering Solutions, Inc.
98-1268 Kaahumanu Street, Suite C-7
Pearl City, Hawaii 96782

Dear Mr. Frey:

**Re: Drilling Services for National Park Service
USS Arizona Project**

This letter summarizes the work performed for the project. Drilling services were conducted in general conformance with the scope of work presented in our proposal dated September 16, 2003. Our work scope for this study included the following:

- Coordinate entry and obtain approval from Naval authorities for the proposed borings.
- Mobilize men and equipment to construct a floating barge and mount drilling equipment.
- Drill and sample 3 exploratory borings at selected locations to depths ranging from 15.2 to 21.3 meters, measured from harbor bottom. Four borings were originally proposed, but one was eliminated by the National Park Service during the time of our fieldwork. The general location of the project site is shown on the enclosed Location Map, Plate 1.1. The approximate boring locations are shown on the USS Arizona Core Location Plan, Plate 1.2, prepared by the National Park Service.
- Provide a field engineer to log all borings and handle soil samples. The boring logs are presented on Plates 3.1 through 3.7. The Boring Log Legend is presented on Plate 2.1, and the Unified Soil Classification System is presented on Plate 2.2.
- Demobilize men and equipment from the project site.
- Preparation of this letter and the attached boring logs.

Drilling Services

Three borings were drilled to depths ranging from 15.2 to 21.3 meters below the harbor bottom. The borings were drilled using portable drilling equipment mounted on a temporary barge. In general, 100 mm O.D. steel casing was driven down to selected sampling depths and cleaned out with a rock-bit. Samples were recovered using thin-walled shelly tubes driven with a 63.5 kg hammer dropped from a height of approximately 760 mm inches. Continuous sampling was performed from the harbor bottom down to the

ERNEST K.
HIRATA & ASSOCIATES, INC.

December 17, 2003

W.O. 03-3832

Page 2

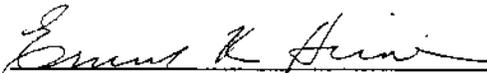
maximum depths drilled in all borings. Some Shelby tubes were damaged by the granular material present in the soil layers. Therefore, Shelby tubes were placed in 1.5 meter long by 75 mm O.D. schedule 40 steel pipe during sampling to protect the thin-walled tubes. The steel pipe was used from harbor bottom down to the maximum depth drilled in boring B1A and to a depth of about 7.6 meters in boring B2. The blow counts presented on the boring logs are those required to drive the Shelby tube or 75 mm steel pipe sleeved Shelby tubes 300 mm, unless noted otherwise. Zero blow counts are indicated in areas where the weight of the extension rods were enough to drive the sampler through the soil. Therefore, no hammer energy was required.

During drilling operations, the soils were continuously logged by our field engineer and classified by visual examination in accordance with the Unified Soil Classification System. The boring logs indicate the depths at which the soils or their characteristics change, although the change could actually be gradual. Only the ends of the Shelby tubes were visible to our field engineer. Therefore, if the change occurred within the 0.76 meter sample tube, the depth was interpreted based on field observations. Classifications and sampling intervals are shown on the boring logs.

We appreciate this opportunity to be of service. Should you have any questions concerning this letter, please feel free to call on us.

Respectfully submitted,

ERNEST K. HIRATA & ASSOCIATES, INC.

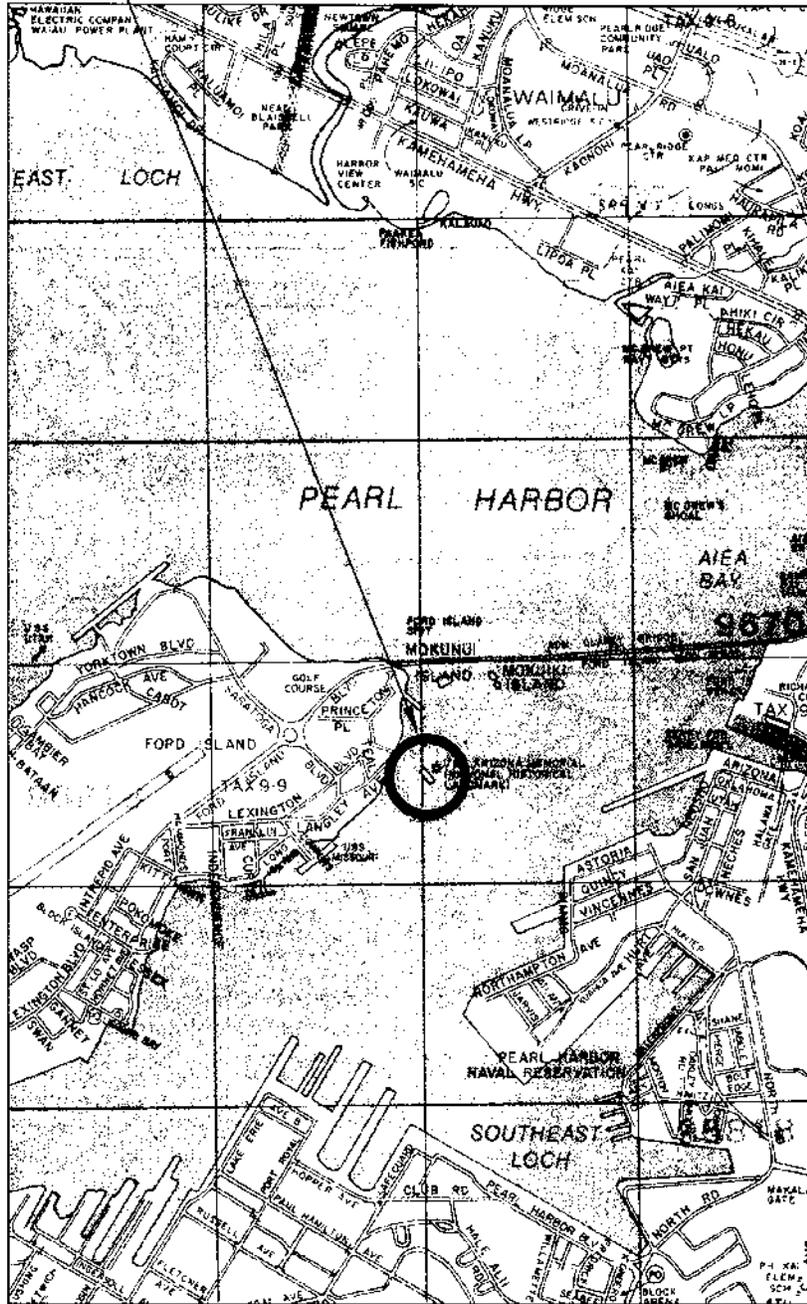

Ernest K. Hirata, President

EKH:EHS:ph

Attachments:

Location Map	Plate 1.1
USS Arizona Geological Core Locations	Plate 1.2
Boring Log Legend	Plate 2.1
Unified Soil Classification System	Plate 2.2
Boring Logs	Plates 3.1 through 3.7

PROJECT SITE



Reference: Bryan's Sectional Maps, 2003 Edition
 (Copyright J.R. Clere, used with permission)

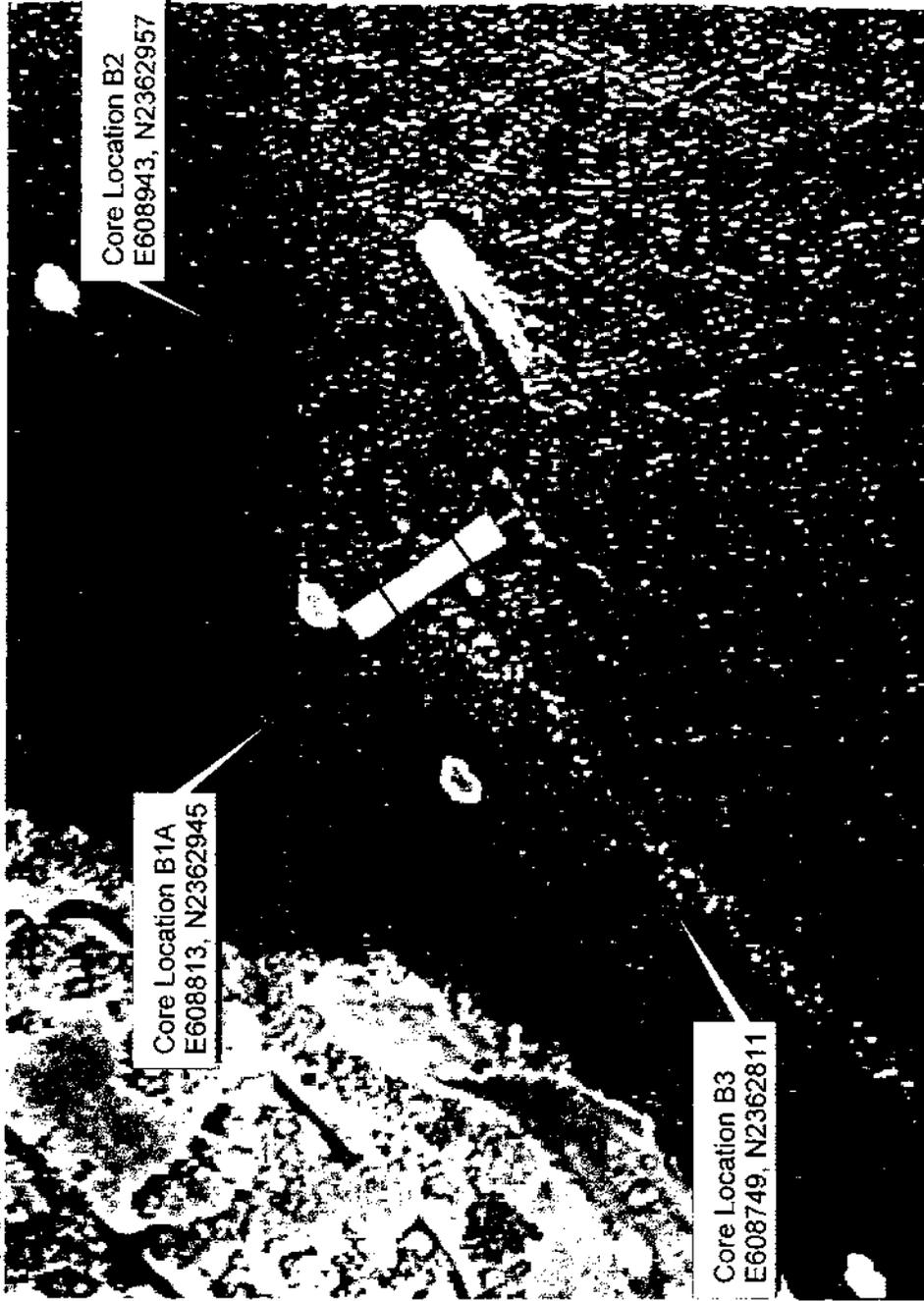
Scale: 1:24,000

<p>W.O. 03-3832</p>	<p>USS Arizona Project - Drilling Services</p>
<p>Ernest K. Hirata & Associates, Inc.</p>	<p>LOCATION MAP</p>

Submerged Resources Center
New Mexico

National Park Service
U.S. Department of the Interior

USS Arizona Geological Core Locations November 2003



20 0 20 40 Meters

 A horizontal scale bar with markings at 0, 20, and 40 meters.

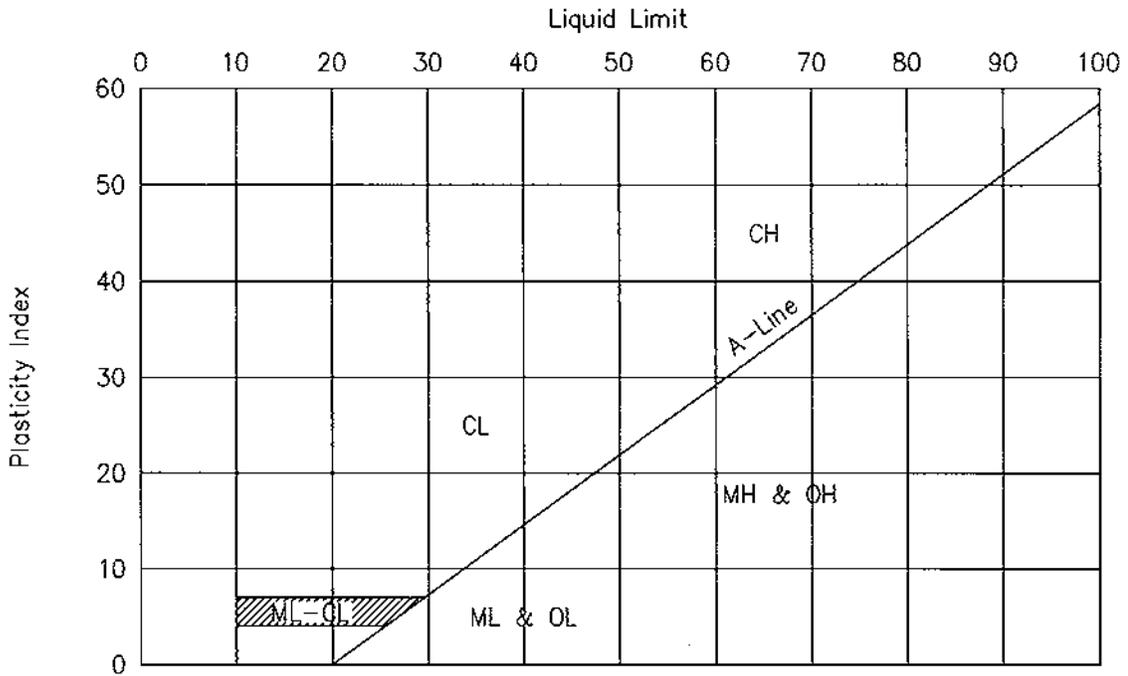
All Coordinates UTM Zone 4, NAD83

Produced by NPS Submerged Resources Center

12/03

MAJOR DIVISIONS		GROUP SYMBOLS	TYPICAL NAMES
COARSE GRAINED SOILS (More than 50% of the material is LARGER than No. 200 sieve size.)	GRAVELS (More than 50% of coarse fraction is LARGER than the No. 4 sieve size.)	CLEAN GRAVELS (Little or no fines.)	GW Well graded gravels, gravel-sand mixtures, little or no fines.
		GRAVELS WITH FINES (Appreciable amt. of fines.)	GP Poorly graded gravels or gravel-sand mixtures, little or no fines.
			GM Silty gravels, gravel-sand-silt mixtures.
			GC Clayey gravels, gravel-sand-clay mixtures.
	SANDS (More than 50% of coarse fraction is SMALLER than the No. 4 sieve size.)	CLEAN SANDS (Little or no fines.)	SW Well graded sands, gravelly sands, little or no fines.
		SANDS WITH FINES (Appreciable amt. of fines.)	SP Poorly graded sands or gravelly sands, little or no fines.
			SM Silty sands, sand-silt mixtures.
			SC Clayey sands, sand-clay mixtures.
FINE GRAINED SOILS (More than 50% of the material is SMALLER than No. 200 sieve size.)	SILTS AND CLAYS (Liquid limit LESS than 50.)	ML Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	
		CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	
		OL Organic silts and organic silty clays of low plasticity.	
	SILTS AND CLAYS (Liquid limit GREATER than 50.)	MH Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	
		CH Inorganic clays of high plasticity, fat clays.	
		OH Organic clays of medium to high plasticity, organic silts.	
HIGHLY ORGANIC SOILS		PT Peat and other highly organic soils.	
LAB/FIELD TEST ABBREVIATIONS		FRESH TO MODERATELY WEATHERED BASALT	
TV = Torvane LL = Liquid Limit DS = Direct Shear PI = Plasticity Index CT = Consolidation Test UC = Unconfined Compression Test		VOLCANIC TUFF / HIGHLY TO COMPLETELY WEATHERED BASALT	
		CORAL	
SAMPLE DEFINITION			
 2" O.D. Standard Split Spoon Sampler		 Shelby Tube	
 3" O.D. Split Tube Sampler		 NX / 4" Coring	
		 RQD Rock Quality Designation	
		 Water Level	
W.O. 03-3832	USS Arizona Project - Drilling Services		
Ernest K. Hirata & Associates, Inc.	BORING LOG LEGEND		

PLASTICITY CHART



GRADATION CHART

COMPONENT DEFINITIONS BY GRADATION	
COMPONENT	SIZE RANGE
Boulders	Above 12 in.
Cobbles	3 in. to 12 in.
Gravel	3 in. to No. 4 (4.76 mm)
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 (4.76 mm)
Sand	No. 4 (4.76 mm) to No. 200 (0.074 mm)
Coarse sand	No. 4 (4.76 mm) to No. 10 (2.0 mm)
Medium sand	No. 10 (2.0 mm) to No. 40 (0.42 mm)
Fine sand	No. 40 (0.42 mm) to No. 200 (0.074 mm)
Silt and clay	Smaller than No. 200 (0.074 mm)

W.O. 03-3832

USS Arizona Project - Drilling Services

Ernest K. Hirata
& Associates, Inc.

UNIFIED SOIL CLASSIFICATION SYSTEM

Plate 2.2

ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B1A DRIVING WT. 63.5 kg START DATE 11/13/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/14/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			7			Silty SAND/Sandy SILT (SM/ML) – Gray to brownish gray, soft to firm, with shell fragments. Increase in sand content from 1.2 to 2 meters. Increase in sand content from 3 to 3.5 meters.
			5			
1			5	1	0	
			7			
			16			
2			22			
			18			
			4	2	5	
3			0			
			0			
			52			Grade with coralline gravel from 6 meters.
			23			
4			6	3	0	
			2			
			0			
5			32			
			51			
			8	4	0	
6			4			
			4			
			59			Silty CLAY (CL-CH) – Grayish brown, medium stiff to stiff, with coralline gravel and sand.
7			47			
			33	5	30	
			44			
			42			
8			26			
			35			
			37	6	40	
			51			
9			68			
			44			
			23			
10			31	7	100	

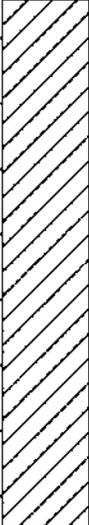
ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B1A (Continued) DRIVING WT. 63.5 kg START DATE 11/13/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/14/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			44			
			55			
			101			
11			29			
			38	8	77	Silty CLAY (CL-CH) - Grayish brown, medium stiff to stiff, with coralline gravel and sand.
			59			
12			76			
			20			
			41			
13			83	9	68	
			86			
			104			
14			14			
			26			
	54	10	83			
15	76					
	124					
						End boring at 15.2 meters.
16						Depth to mudline measured at 8.5 meters below water at 11:24 am on 11/13/03.
17						
18						
19						
20						

ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B2 DRIVING WT. 63.5 kg START DATE 11/18/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/20/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			0			Silty SAND/Sandy SILT (SM/ML) – Gray to brownish gray, soft to firm, with shell fragments.
			0			
			0	1	0	
			0			
1			0			
			0			
			0	2	5	
			0			
2			0			
			0			
			0	3	0	Grade with coralline gravel from 6 meters.
			0			
3			0			
			0			
			0			
4			0			
			0			
			0			
5			4			
			6	4	0	
			7			
6			2			
			6			
			35			Silty CLAY (CL-CH) – Grayish brown, medium stiff to stiff, with coralline gravel and sand.
			47	5	0	
7			95			
			118			
			58			
			121	6	100	
8			87/150mm			
			35			
			65	7	90	
9			44/150mm			
			41			
			97	8	90	
			73/150mm			
10			39			

Plate 3.3

ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B2 (Continued) DRIVING WT. 63.5 kg START DATE 11/18/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/20/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0						
			47	9	100	
			31/150mm			
11			20	10	80	
			32			
			26/150mm			
			22			
12			43	11	93	
			29/150mm			
			102			
			160	12	100	Silty SAND/Sandy SILT (SM/ML) – Tan, loose to dense, with coralline gravel and sand, and shell fragments.
13			96/150mm			
			46			
			70	13	100	
			16/150mm			
14			81	14	93	
			110			
			14/150mm			
			39			
15			126	15	60	
			84/150mm			
			44			
			17	16	70	
16			16/150mm			
			11			
			17	17	100	
			15/150mm			
17			14			
			18	18	63	
			9/150mm			
			20			
18			43	19	77	
			29/150mm			
			11			
			17	20	67	
19			15/150mm			
			27			
			11	21	93	
			9/150mm			
20			0			

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BORING LOG

W.O. 03-3832

BORING NO. B2 (Continued) DRIVING WT. 63.5 kg START DATE 11/18/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/20/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			0	22	10	
			0/150mm			
			0	23	80	
			0/150mm			
-21						
-22						End boring at 21.3 meters.
-23						Depth to mudline measured at 11.9 meters below water at 8:38 am on 11/18/03.
-24						
-25						
-26						
-27						
-28						
-29						
-30						

ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B3 DRIVING WT. 63.5 kg START DATE 11/15/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/15/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			0			Silty SAND/Sandy SILT (SM/ML) – Gray to brownish gray, soft to firm, with shell fragments.
			0	1	0	
			0/150mm			
1			0			
			0	2	0	
			0/150mm			
			0			
2			0			
			0/150mm			
			0	3	0	
			0			
3			0/150mm			
			0	4	0	
			0			
4			0/150mm			
			0	5	0	
			0			
5			0/150mm			
			0	6	0	
			0			
6			0/150mm			
			0	7	0	
			0			
7			0/150mm			
			0	8	100	
			0			
8			0/150mm			
			0	9	0	
			0			
9			2	10	0	
			0/150mm			
			0			
8			1	11	0	
			0/150mm			
			0			
9			4	12	77	
			2/150mm			
			2			
			4	13	0	
			2/150mm			
10			4			

ERNEST K. HIRATA & ASSOCIATES, INC.

Geotechnical Engineering

BORING LOG

W.O. 03-3832

BORING NO. B3 (Continued) DRIVING WT. 63.5 kg START DATE 11/15/03
 SURFACE ELEV. N/A DROP 760 mm END DATE 11/15/03

DEPTH	GRAPH	SAMPLE	BLOWS PER 0.3 m	SAMPLE NO.	RECOVERY (%)	DESCRIPTION
0			4	14	0	
			0/150mm			
11			4	15	100	
			2/150mm			
			0			
12			0	16	0	
			0/150mm			
			0			
			0	17	100	Silty CLAY (CL-CH) - Grayish brown, soft to firm.
13			0/150mm			
			0			
			0	18	100	
			0/150mm			
14			0			
			0	19	100	
			0/150mm			
15			0	20	100	
			0/150mm			
						End boring at 15.2 meters.
16						Depth to mudline measured at 11.3 meters below water at 11:25 am on 11/15/03.
17						
18						
19						
20						

Appendix D. Discrepancies in Sediment Stratigraphy Between the Hirata and Associates Drilling Report and This Report for Recovered Cores from The USS Arizona Borings B1A, B2, and B3

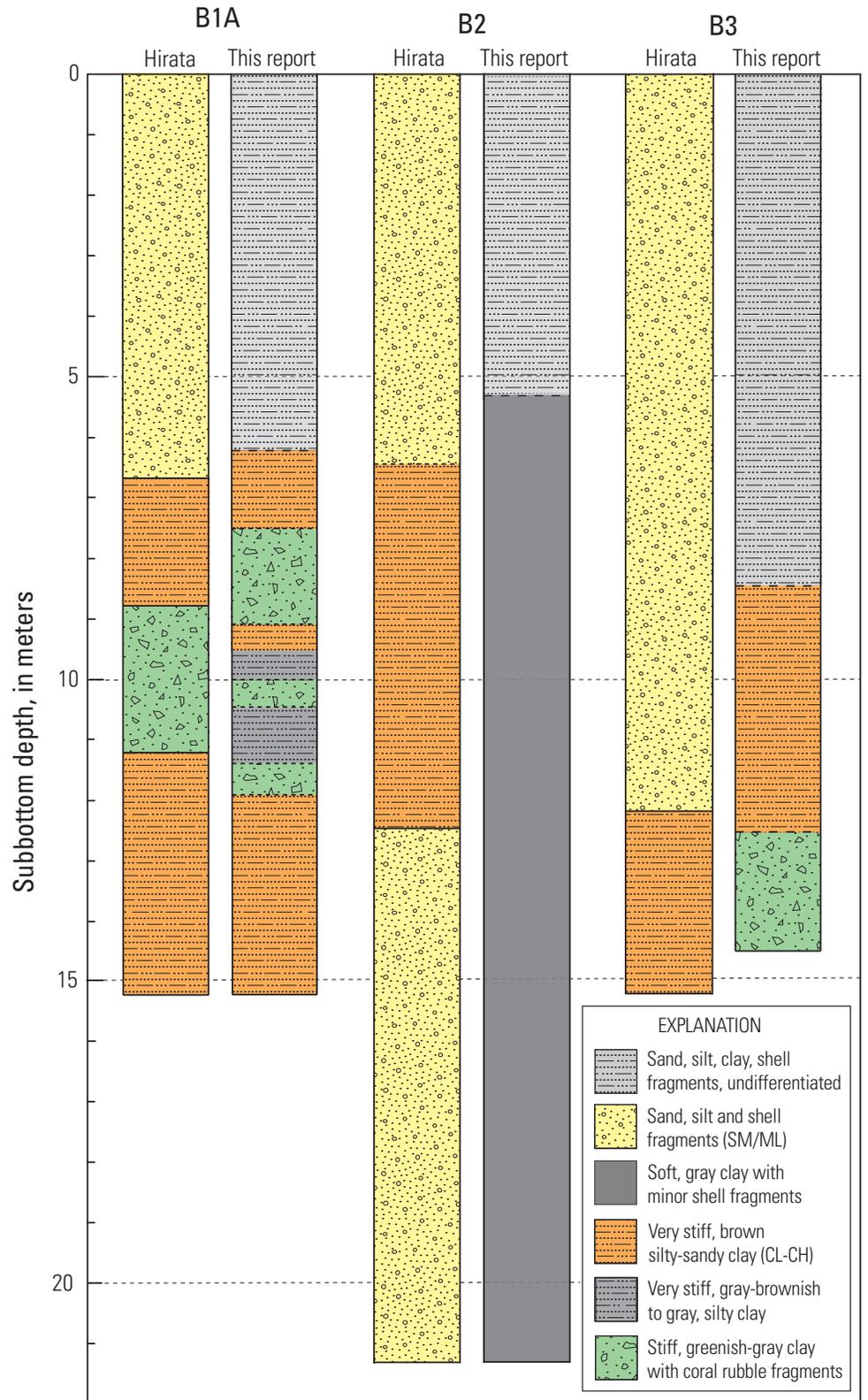


Figure D-1. Comparison between the stratigraphic columns of the USS *Arizona* borings as shown in the Hirata and Associates report (2003) and those determined in this report.

Appendix E. Photographic Analysis of Historical and Recent Photographs of the USS *Arizona* Barbette 3 Port-Side Vent.

Note that all elevations are not adjusted for sea level rise. MLLW stands for mean lower low water.

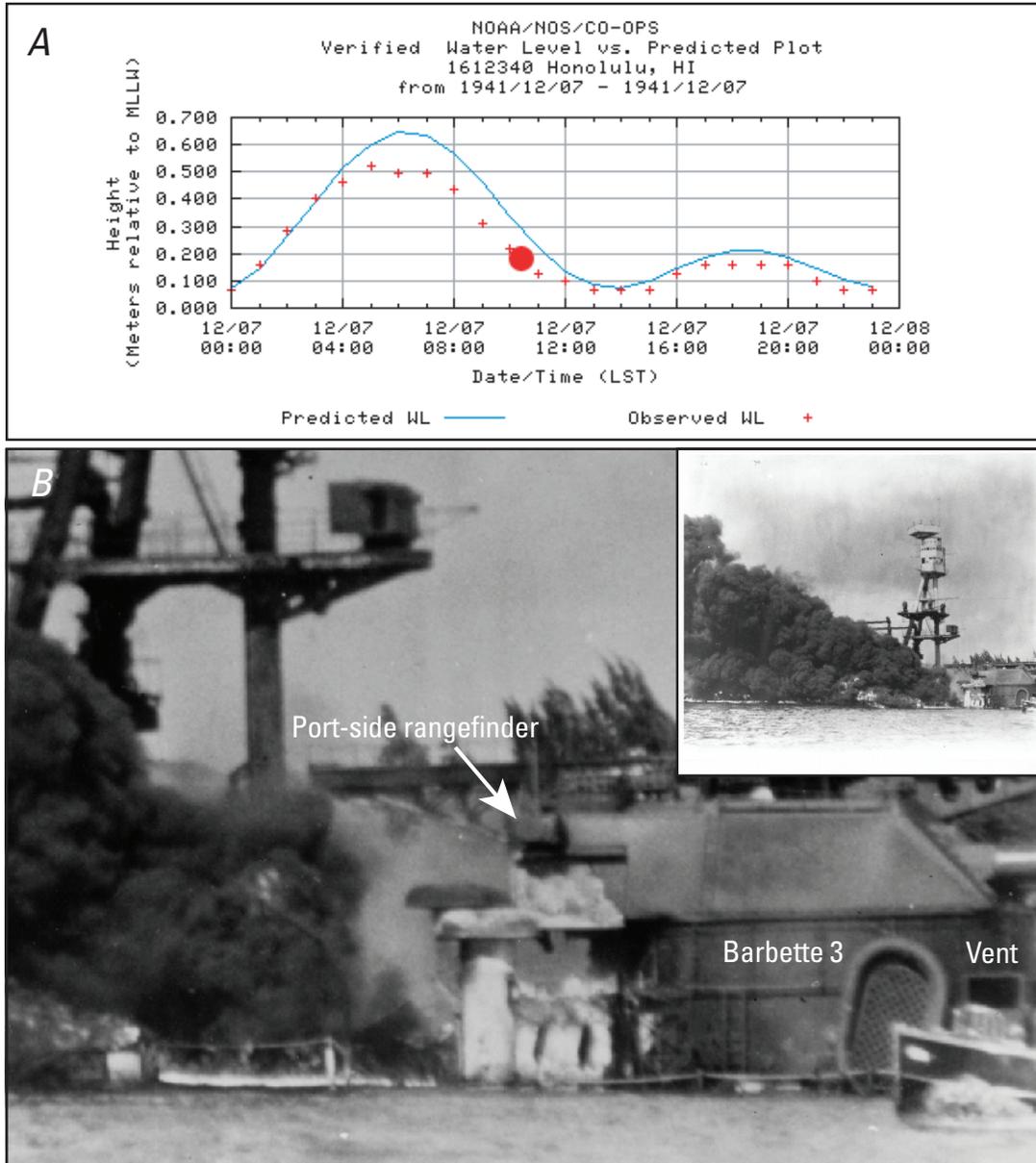


Figure E-1. Photo analysis for December 7, 1941, 10:21. *A*, Tidal cycle for December 7, 1941; red mark indicates estimated time and tide of photo. *B*, Photo PR-54A from the USS *Arizona* Memorial Museum Archives. The turrets are assumed to be oriented parallel to the axis of the ship and the azimuth of the port-side rangefinder on barbette 3 is assumed to be 144°. The shadow of the rangefinder lies directly beneath the rangefinder indicating a sun azimuth of 144°, a time of 10:21 and a tide level of 0.19 m MLLW. Plus/minus 5° in azimuth is ± 0.03 m in tide level. This is the earliest photo found following the explosion of the USS *Arizona*, approximately 2.25 hours after the sinking of the ship. The rectangular opening of the vent on the barbette is 0.74 m high and the top of the vent is 1.52 m below the top rim of the barbette, as determined on March 4, 2008. The water level is projected horizontally to a point below the vent. The top of the vent is calculated to be 2.8 ± 0.04 m above the water level, corresponding to a height of 3.00 ± 0.08 m MLLW. The top rim of the barbette is inclined 2.6° forward and the main mast 3.0° forward. Day 1.

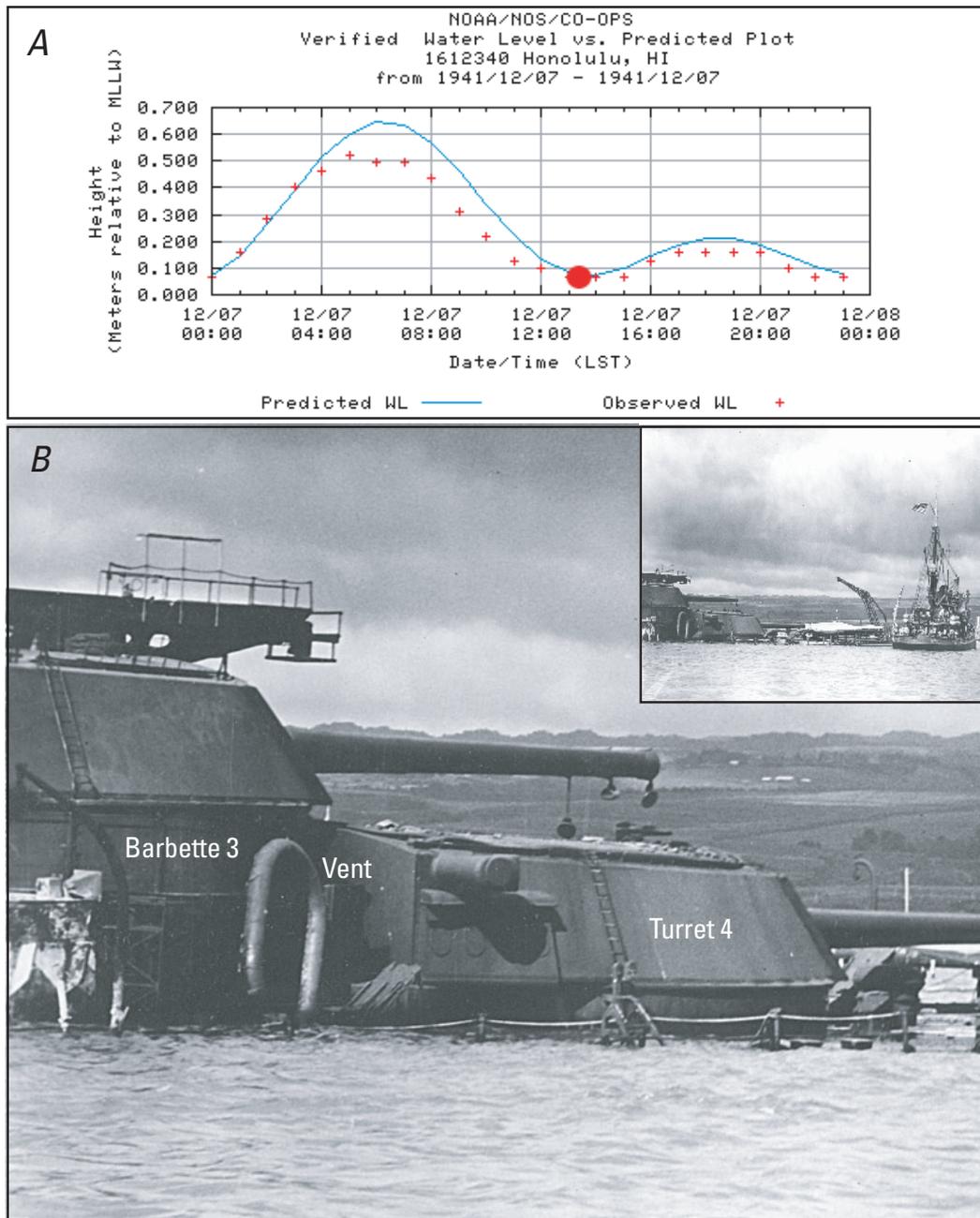


Figure E-2. Photo analysis for December 7, 1941, 13:23. *A*, Tidal cycle for December 7, 1941; red mark indicates estimated time and tide of the photo. *B*, Photo PR-52 (undated) from the USS *Arizona* Memorial Museum Archives. This image is also identified as #80-G-32761 at <http://www.history.navy.mil/>, where the caption states “USS *Widgeon* (ASR-1) alongside the stern of the sunken USS *Arizona* (BB-39), probably on or about 8 December 1941.” Photo PR-67A (undated) from the USS *Arizona* Memorial Museum Archives provides a wider view which shows the USS *Arizona* burning vigorously forward of barbette 3, indicating a December 7 date. Calculations based on the shadow of the rangefinder on turret 4 provide an estimated sun azimuth of $201 \pm 2^\circ$, and time of $13:29 \pm 7$ minutes. The verified tide level is 0.07 m MLLW for 13:00–15:00. The top of the vent is calculated to be 2.58 ± 0.06 m above the water level, corresponding to an elevation of 2.65 ± 0.06 m MLLW. From this viewing angle, the main deck is estimated to be inclined 2.15° forward. See text for more discussion of this photo. Day 1.1.

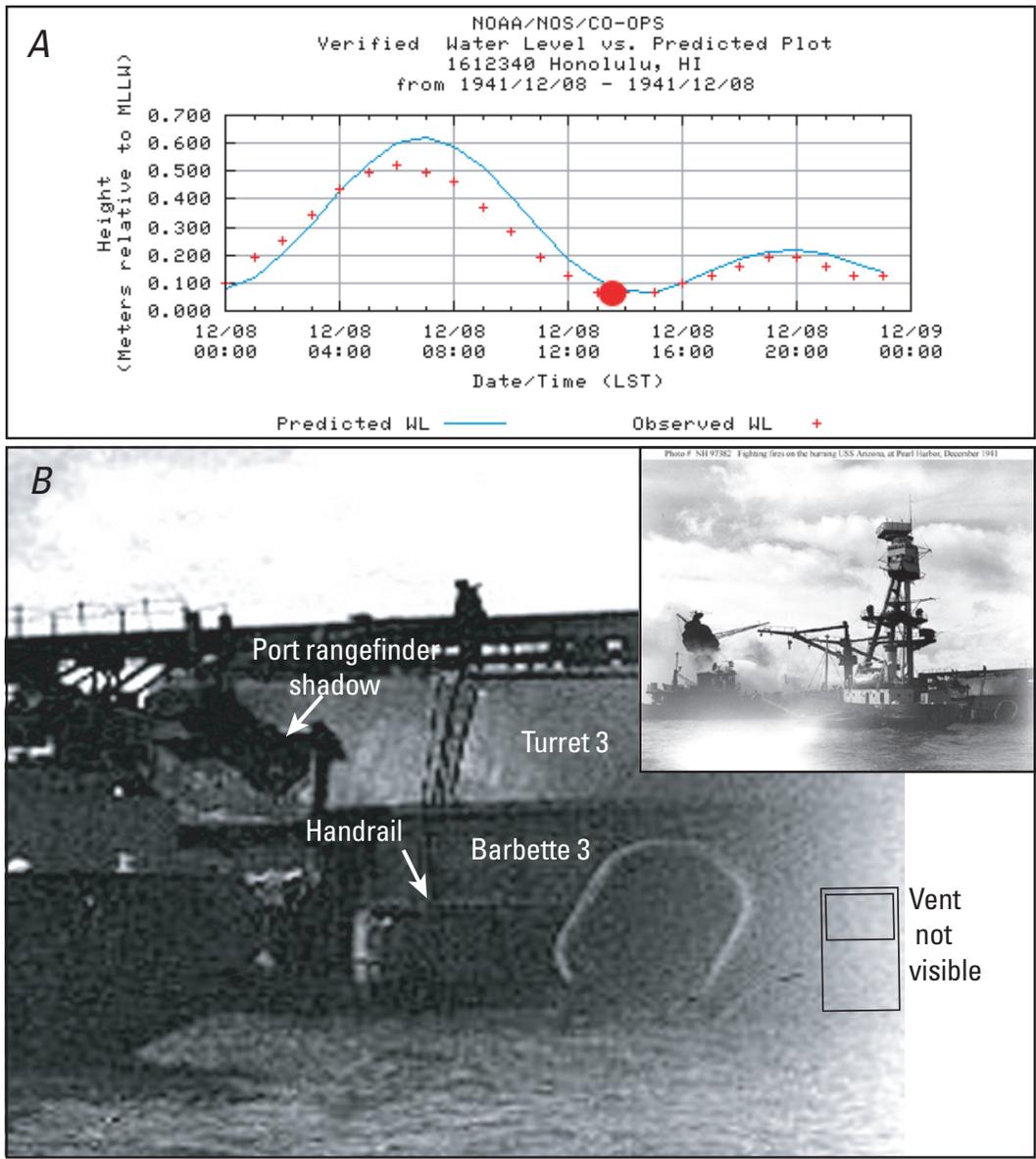


Figure E-3. Photo analysis for December 8, 1941. *A*, Tidal cycle for December 8, 1941; red mark indicates estimated time and tide of the photo. *B*, Photo NH 97382 from <http://www.history.navy.mil/>. The caption for the image states: “A harbor tug (YT) and a garbage lighter (YG) fighting fires on the battleship, after she was sunk at Pearl Harbor by Japanese bombs on 7 December 1941. This photograph may have been taken on the following day.” The much-diminished state of the fire and the lack of evidence of firefighting at the USS *Arizona* in other photos dated December 7 suggest this is December 8. The USS *Tern* would arrive at 14:30. The port side vent on barbette 3 is not visible; the height of its top is calculated based on its position relative to the top of the barbette and the position of the hand rail at approx. mid-height on the barbette. The handrail is estimated to be 1.70 m below the barbette rim and the vent top is 0.21 m above the handrail. Vent outline here is approximate. The port-side rangefinder shadow is nearly identical to that on December 7 (fig. E-2); a time of 13:30 is assumed. The verified tide level is flat at 0.07 m MLLW from 13:00 to 15:00. The vent top is calculated to be 2.37 ± 0.1 m above the water level. The height of the vent is calculated to be 2.37 ± 0.10 m MLLW. The barbette rim is tilting approx. 2.2° forward. Day 2.

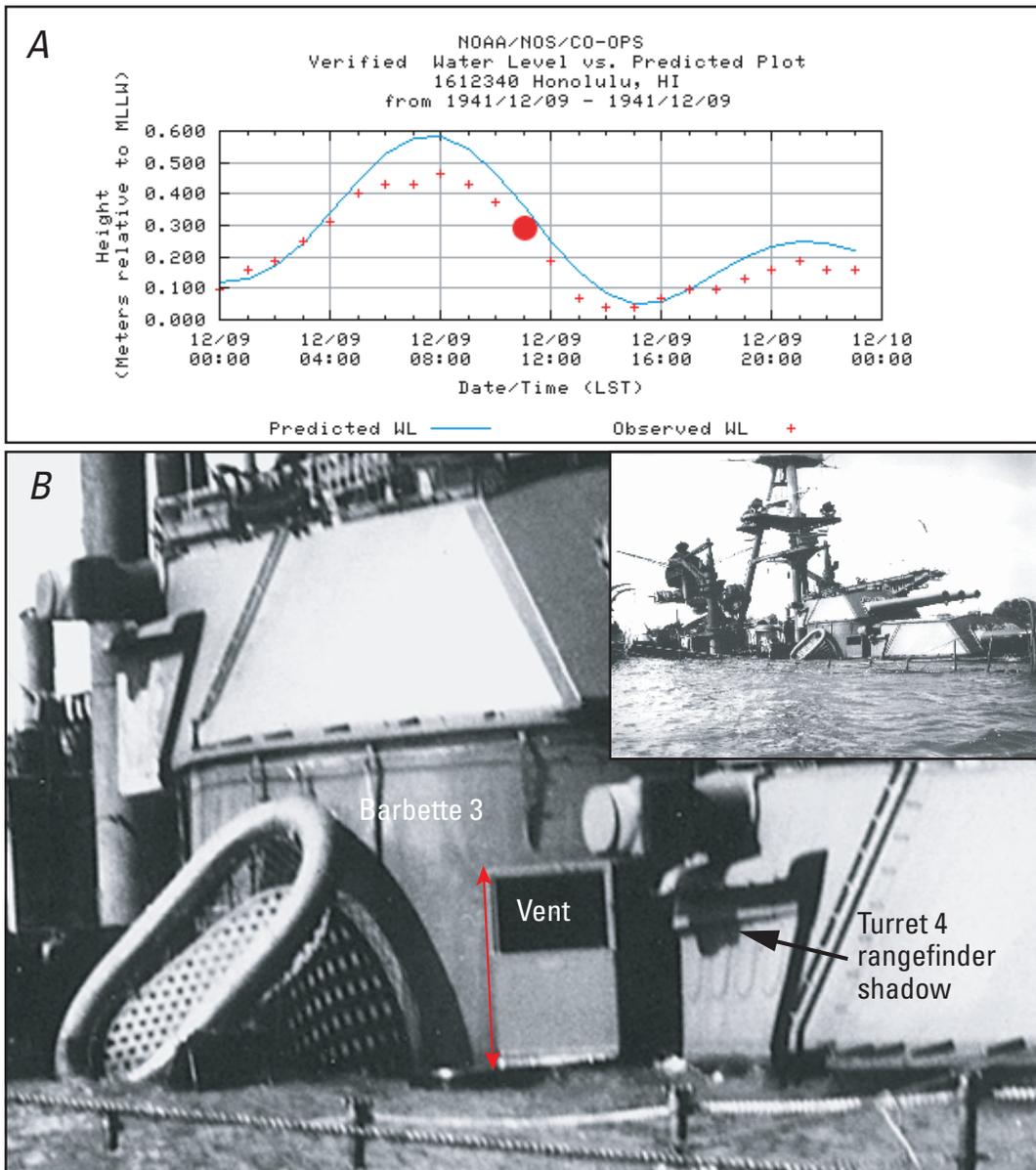


Figure E-4. Photo analysis for December 9, 1941. *A*, Tidal cycle for December 9, 1941; red mark indicates estimated time and tide of photo. *B*, Photo PR-66 from the USS *Arizona* Memorial Museum Archives. A similar photo, NH 83064, at <http://www.history.navy.mil/> is dated December 9, 1941, showing the USS *Navajo* and USS *Tern* spraying water on the USS *Arizona*. This photo is also designated 80-G-32612. The photo is slightly smeared from camera motion. Deck logs from the USS *Tern* (<http://www.history.navy.mil/docs/wwii/pearl/ph118.htm>) indicate that the fire was declared to be out and the USS *Tern* departed from the USS *Arizona* at 12:35 on December 9. Port-side rangefinder shadows are interpreted to indicate an estimated sun azimuth of 154° , a time of 11:00 with a tide height of 0.28 m MLLW. Plus/minus 5° in azimuth is approx. ± 18 minutes in time and ± 0.03 m in tide level. The top of the vent is 1.82 m (red arrow) above a horizontal projection at its base containing a fan, as measured on March 4, 2008, and is visible above the water level here. The vent top is estimated to be 1.97 ± 0.04 m above the water level. The height of the vent top is estimated to be 2.25 ± 0.06 m MLLW. Day 3.

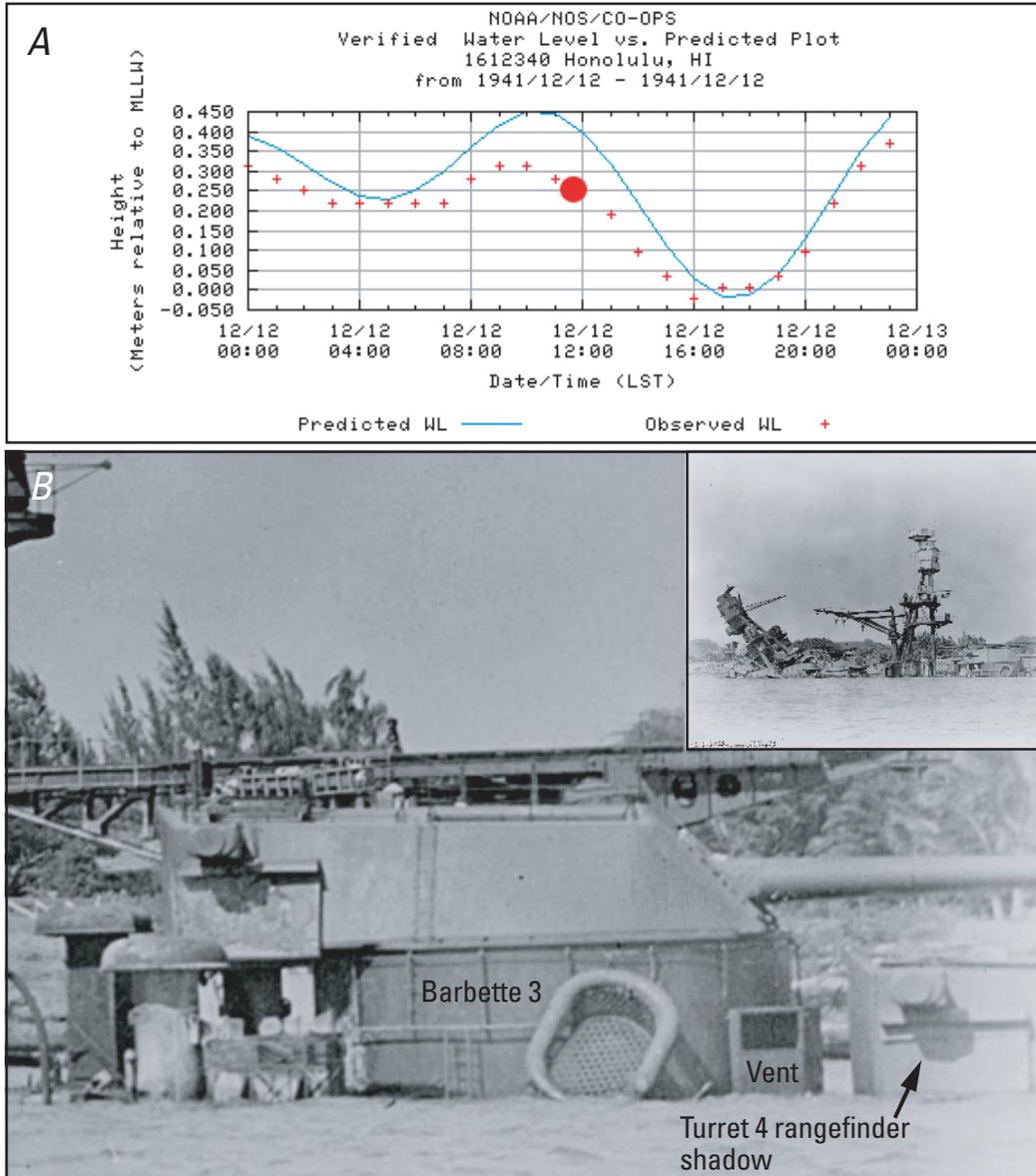


Figure E-5. Photo analysis for December 12, 1941. *A*, Tidal cycle for December 12, 1941; red mark indicates estimated time and tide of photo. *B*, Photo PR-16A from the USS *Arizona* Memorial Museum Archives; also designated NH 64473 at www.history.navy.mil/. The port-side rangefinder shadows indicate an estimated sun azimuth of $170 \pm 2^\circ$, a time of $11:55 \pm 6$ minutes and corresponding tide height of 0.25 m MLLW. Plus or minus 10° in azimuth amounts to approx. ± 33 minutes in time and approx. ± 0.02 m in tide height. The vent opening is 0.74 m high as measured from the starboard side vent and the top rim of barbette 3 is 1.52 m above the top of the port-side vent, as measured on March 4, 2008. The vent top is estimated to be 1.81 ± 0.03 m above the water level. The calculated elevation of the vent top is 2.06 ± 0.05 m MLLW. The barbette rim and the upper deck are inclined $1.45 \pm 0.1^\circ$ forward; the main mast is inclined 1.75° forward. Day 6.

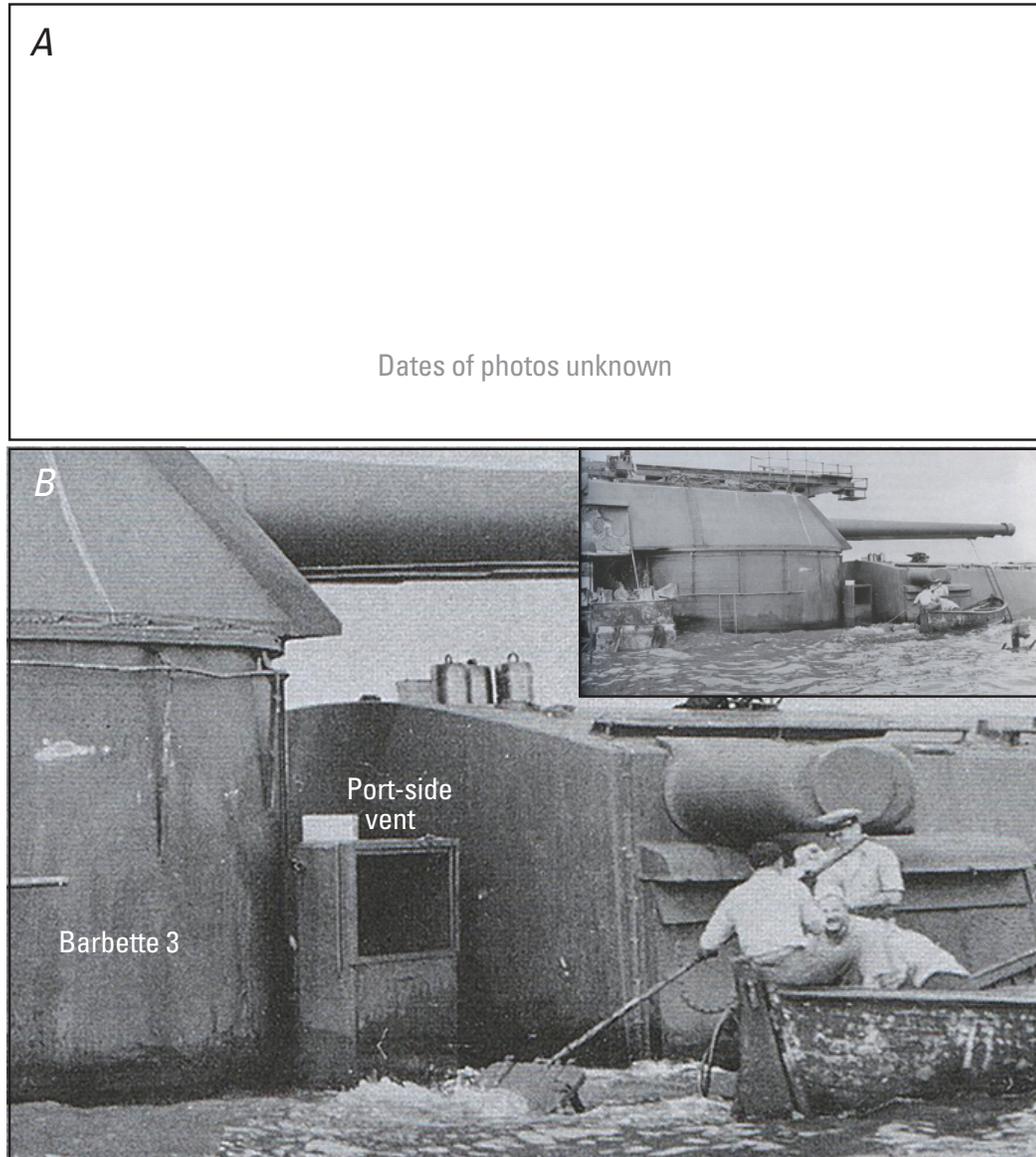


Figure E-6. Photo analysis for undated image. *A*, Tidal cycle and date of photo are unknown. *B*, Photo from page 253 of Stillwell (1991). Another version appeared in the February 21, 1942 edition of the Illustrated London News (ILN), from <http://history.sandiego.edu/cdr2/WW2Pics/82409b.jpg> (no longer available). The available photos examined in this study bracket the date between December 12, 1941 and February 17, 1942. Turret 3 had not yet been rotated toward Ford Island. The best suggestion of time is seen in the ILN version, a shadow at the upper corner of the attachment near the port-side rangefinder of turret 3, resembling the shadow in the December 7 and 8 images taken in the early afternoon (approx. 13:30). A time of 13:30 is assumed for this image. The top of the vent is 1.81 ± 0.02 m above the water level. The tide range for all of the dates between December 12, 1941 and February 17, 1942 at 13:30 is 0.287 (February 12–13) to -0.033 (January 21–22) m MLLW. The average tide level is 0.14 m MLLW with a range of $+0.15/-0.17$ m. The tide-corrected elevation of the vent is estimated to be $1.95 \pm 0.15/-0.17$ m MLLW. The point is plotted at the mid-point in time between December 12 and February 17, which is day 40.

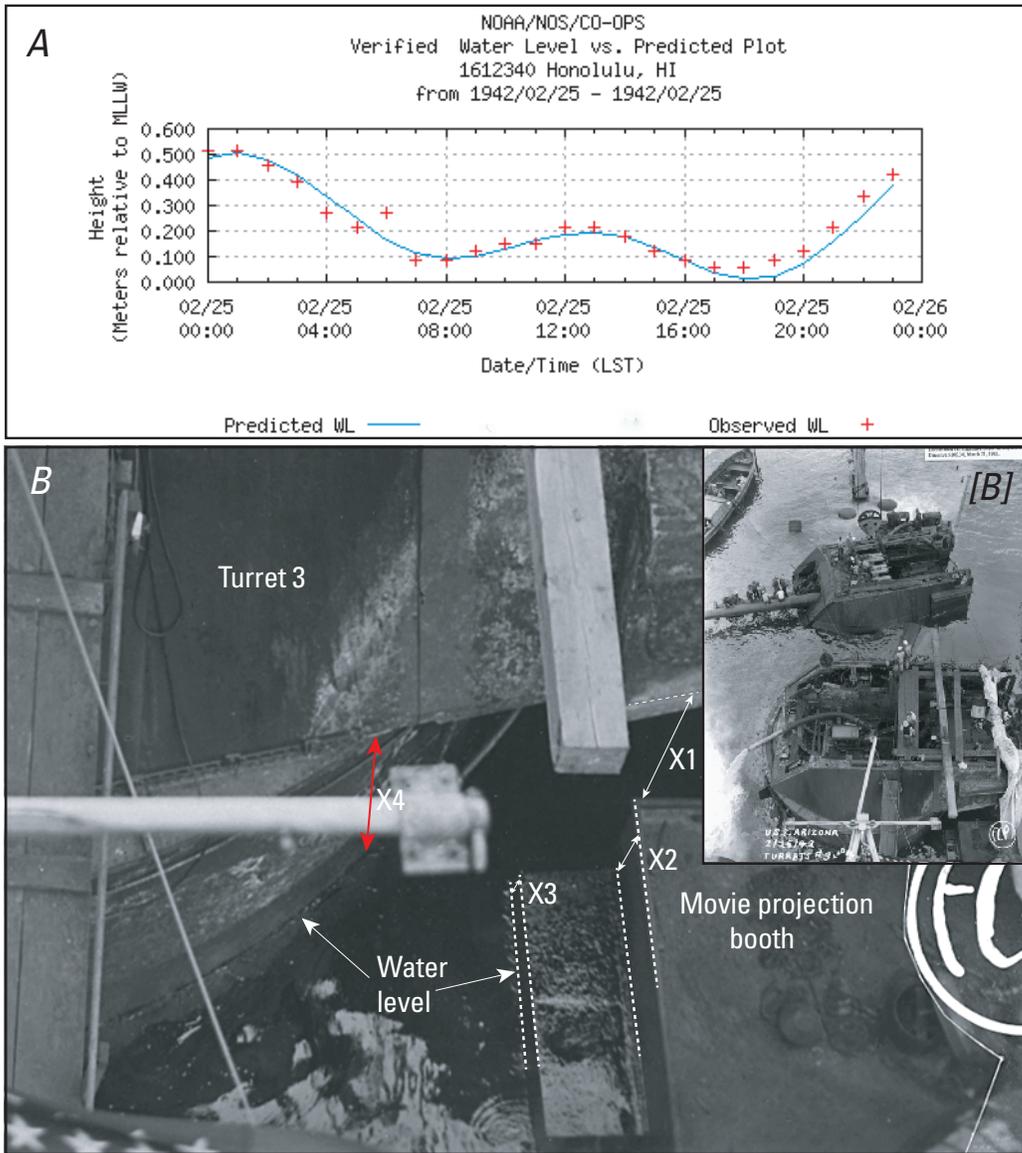


Figure E-7. Photo analysis for February 25, 1942. *A*, Tidal cycle for February 25, 1942. *B*, Photograph dated February 25, 1942 with caption “USS Arizona; Turrets 3 and 4” located at <http://narademo.umiacs.umd.edu/>. The view is looking down on turret 3, which is rotated toward Ford Island. The bottom edge of the turret can be seen relative to the water level and is approximately directly above the aft side of the movie projection booth. There are no shadows in the image and the time is unknown. By bridging between features within photos PR-16A (fig. E-5), the June 8, 1942 image (fig. E-8), and this one, the bottom edge of the turret (rim of the barbette) is estimated to be 2.65 m (X4) above the water level in this image, obtained from heights X1, X2 and X3 (1.72, 0.61 and 0.3 m, respectively). A deck tilt correction from the forward side of the turret to the vent location is estimated to be 0.14 ± 0.03 m. The top of the port-side vent is 1.52 m below the bottom edge of the turret/barbette rim. The vent top is therefore estimated to be 1.33 meters above the water level. The tide range for the daylight hours for this date is 0.058 (18:00) to 0.211 (12:00–13:00) m MLLW. The mid-day tide level is 0.21 m MLLW, which corresponds to an elevation of 1.48 m MLLW. The elevation range is estimated to be 1.48 ± 0.1 – 1.23 m MLLW. Day 81.

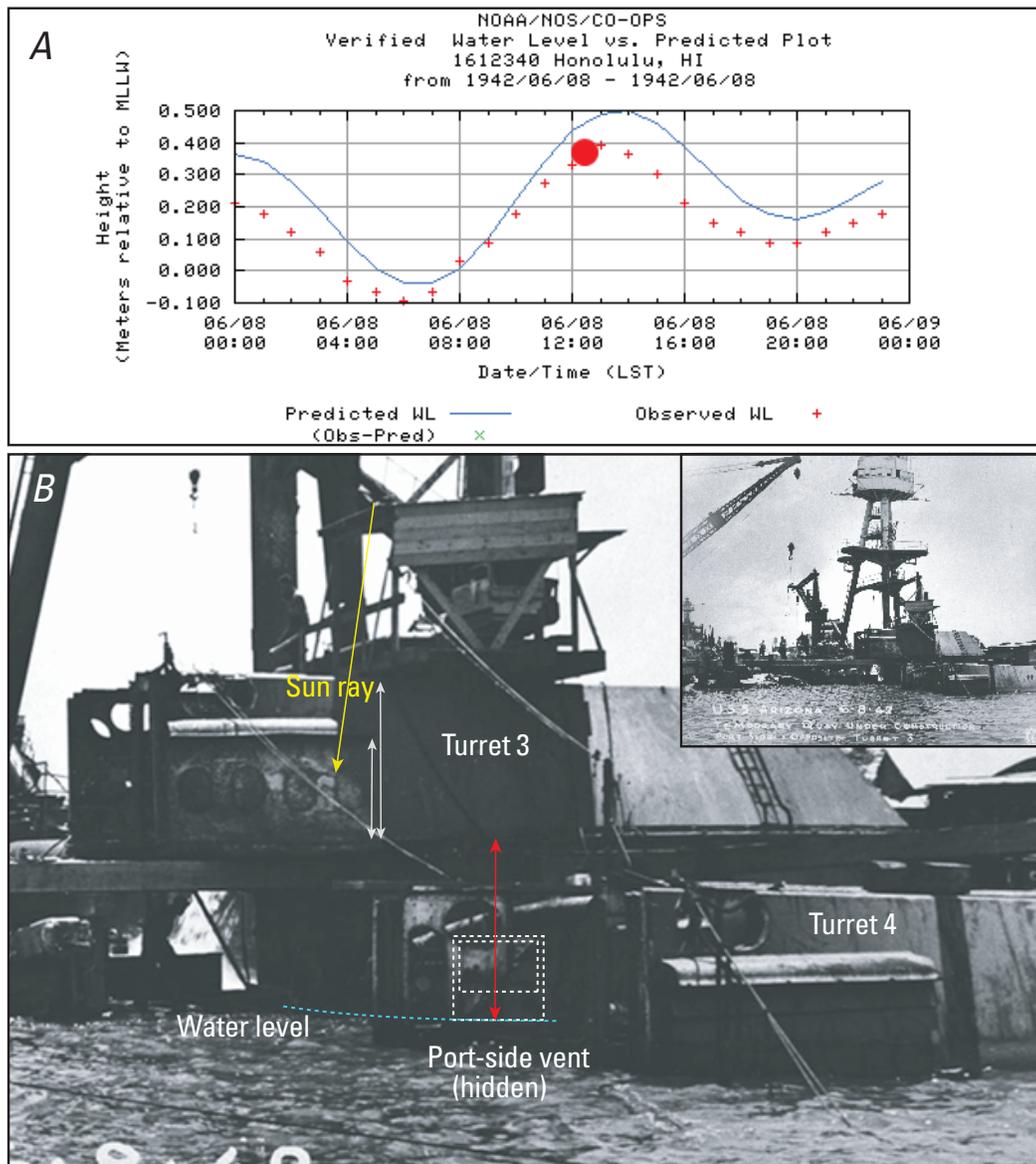


Figure E-8. Photo analysis for June 8, 1942. *A*, Tidal cycle for June 8, 1942; red mark indicates the estimated time and tide of photo. *B*, An unidentified photo dated June 8, 1942 obtained from the Submerged Resources Center, National Park Service. The caption written on the photo reads: "U.S.S. *Arizona*, 6-8-42, temporary quay under construction port side-opposite turret 3." The port-side vent on barbette 3 is not visible behind turret 4. Scale is derived from two dimensions on turret 3, 1.53 m and 2.46 m (arrows) and the water level is projected to the vent location. The top rim of barbette 3 at the vent is estimated to be 2.75 ± 0.05 m (red arrow) above the water level. The top of the vent is 1.52 m below the rim of the barbette and the vent top is calculated to be 1.23 m above the water level. The sun azimuth, estimated from the shadows made by the platform on the top of turret 3, is $< 54^\circ$, possibly in the range $40 \pm 10^\circ$ with corresponding times of 12:23 to 12:27 and tide elevations of 0.35 and 0.36 m MLLW, respectively. The time is assumed to be 12:25. The top of the vent is calculated to be 1.59 ± 0.06 m MLLW. Day 184.

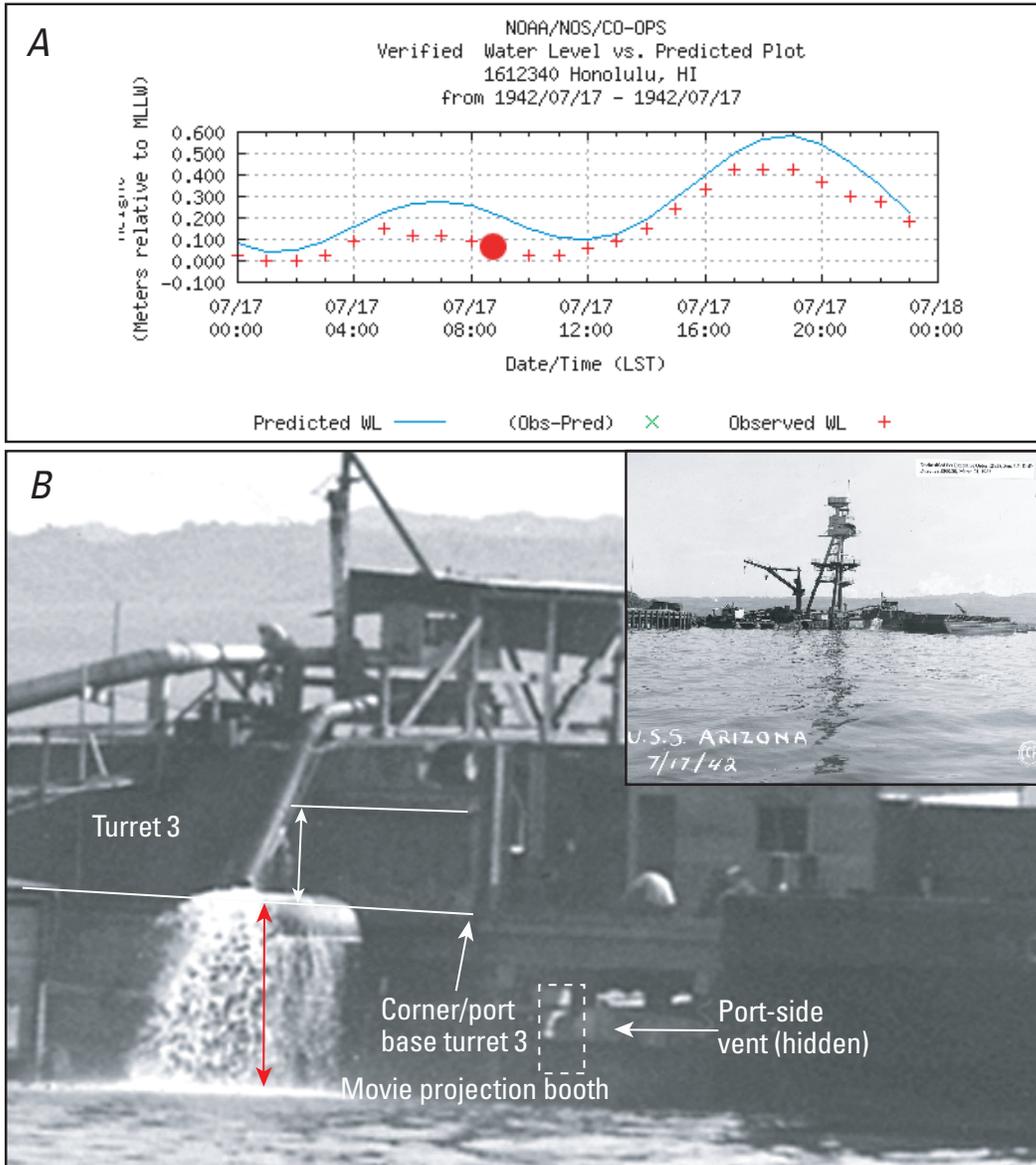


Figure E-9. Photo analysis for July 17, 1942. *A*, Tidal cycle for July 17, 1942; red mark indicates the estimated time and tide for the photo. *B*, Photo bearing the “FCP” icon dated July 17, 1942 obtained from <http://narademo.umiacs.umd.edu/> which shows the port side of the USS *Arizona* and the remaining superstructure. Turret 3 is rotated toward Port Island. As determined in figure F-5, the time is 8:45 with a tide level of 0.07 m MLLW. Plus/minus 15 minutes equals ± 0.01 m in tide level. The port side vent is hidden from view, but is within the highlight box on the far side of the turret. The white arrow on turret 3 provides a scale of 1.53 m. The red arrow indicates a height of the barbette 3 rim 2.77 ± 0.05 m above the water. A tilt correction of 0.14 m is added over a distance of 8 m due to a forward deck slope estimated to be about 1° to transfer the measurement from the forward side of the barbette to the aft side. The port vent top is 1.52 m below the barbette rim. The estimated height of the vent top is 1.46 ± 0.1 m MLLW. Day 223.

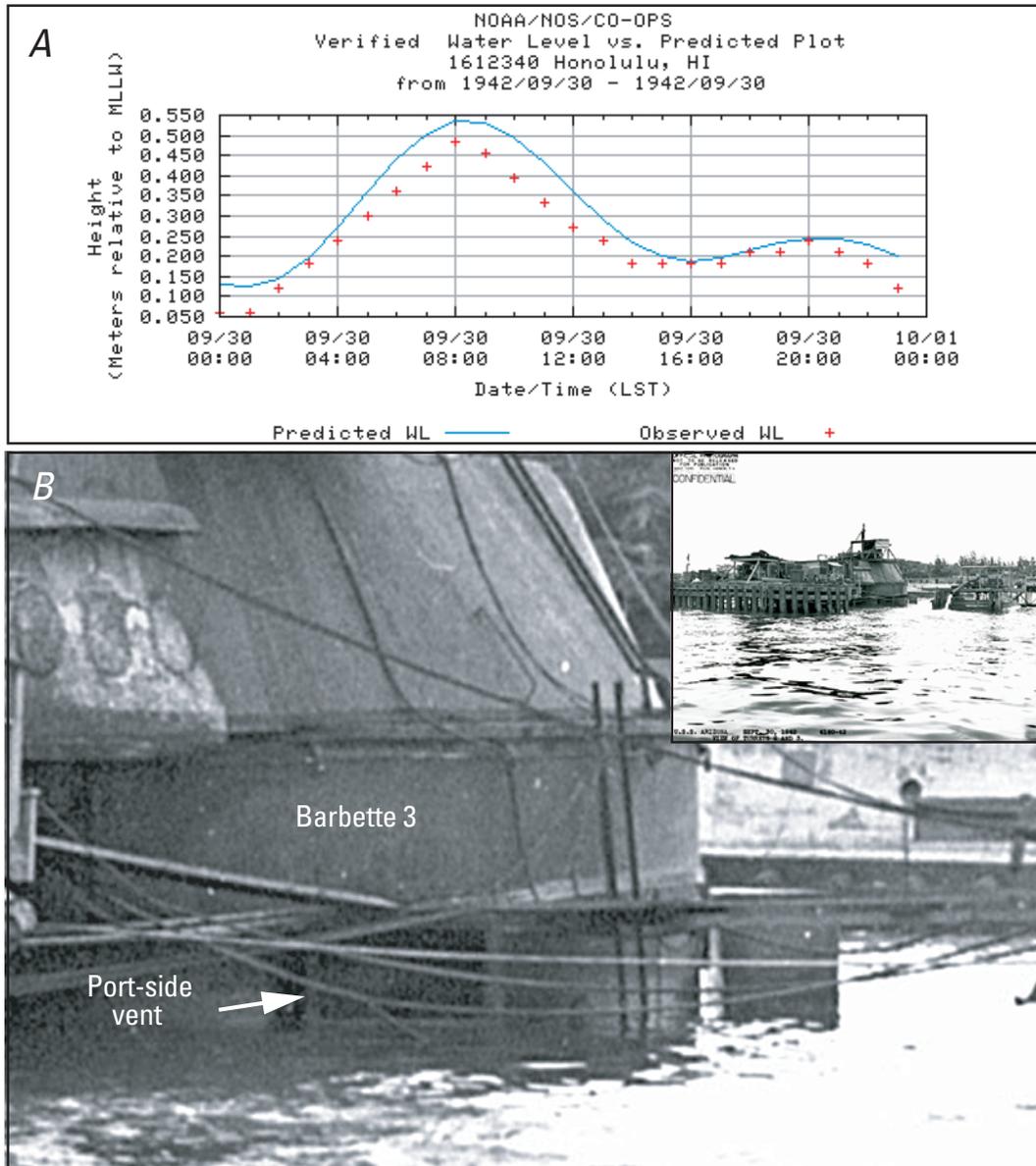


Figure E-10. Photo analysis for September 30, 1942. *A*, Tidal cycle for September 30, 1942. *B*, Photo 4160-42 dated September 30, 1942 obtained from the Submerged Resources Center, National Park Service. There are no useful shadows in the photo and the time is unknown. The vent opening height is 0.74 m, its external width 1.47 meters and the height of the barbette rim above the vent top 1.52 m, as measured on March 4, 2008, all producing a consistent scale. The top of the vent is calculated to be 1.02 ± 0.02 m above the water level. The tide range for daylight hours on this date is 0.485 (8:00) to 0.180 (14–17:00) m MLLW. The average tide height for this range is 0.33 meters, resulting in a height of 1.35 ± 0.15 m MLLW. The mid-day (12:30) tide level is 0.26 m MLLW, resulting in a height of $1.28 \text{ m} + 0.23 / - 0.08$ MLLW. Day 298.

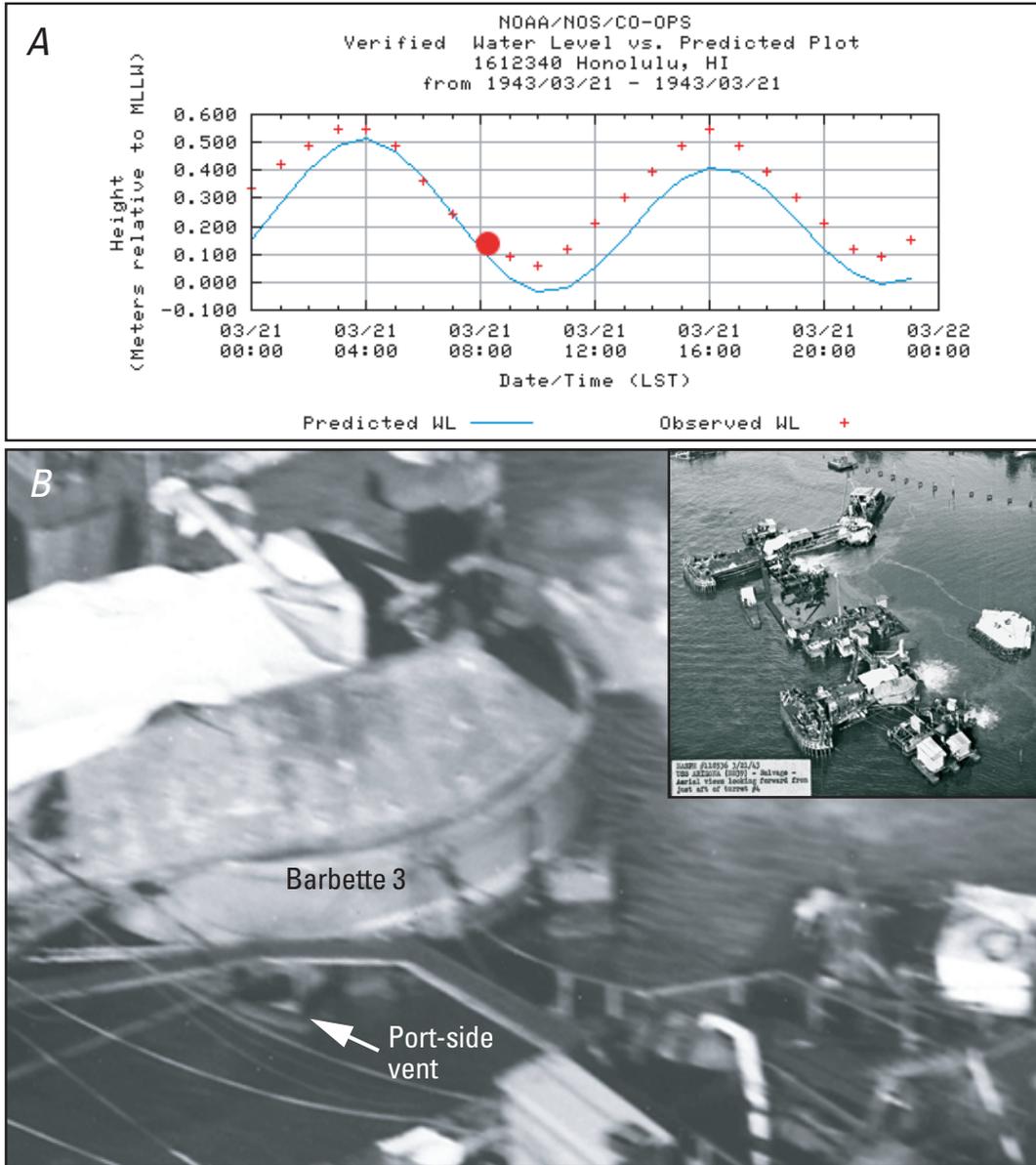


Figure E-11. Photo analysis for March 21, 1943. *A*, Tidal cycle for March 21, 1943; red mark indicates the estimated time and tide for the photo. *B*, Photo NASPH 118536 dated March 21, 1943 obtained from the Submerged Resources Center, National Park Service; also available at <http://narademo.umiacs.umd.edu/>. The photo is smeared from camera motion in a generally upper right to lower left trend. The waterline and top and bottom of the port-side vent opening are not highly distorted, being parallel to the smear direction. The sun azimuth, estimated from shadows on the remaining deck and salvage-related structures, is $99 \pm 1^\circ$, with a corresponding sun elevation of 22° . The estimated time for the image is 8:14. The tide level for this time is 0.14 m MLLW. The port side vent top height is calculated to be 1.14 ± 0.05 m above the water level and at a height of 1.28 ± 0.07 m MLLW. Day 469.

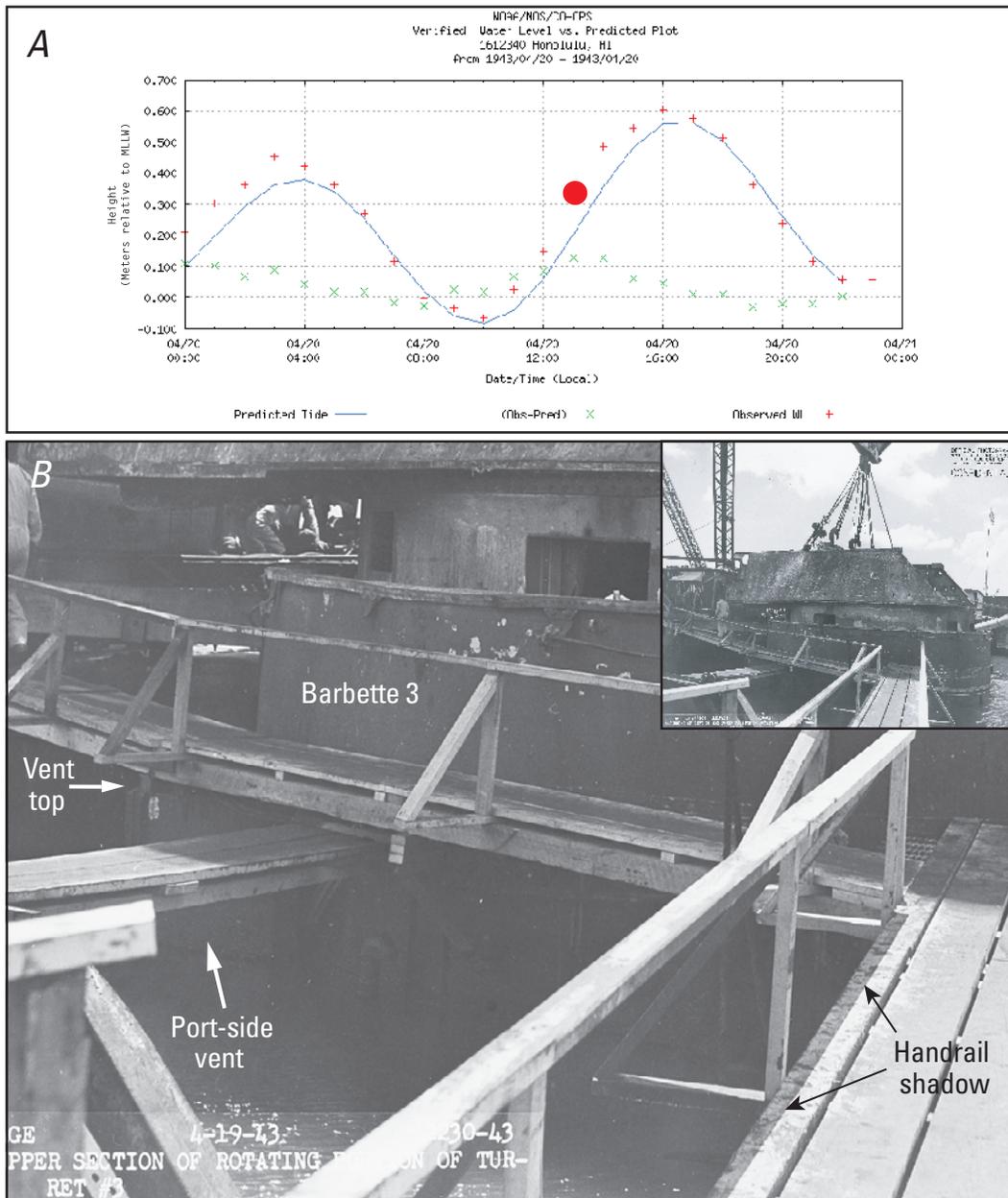


Figure E-12. Photo analysis for April 20, 1943. *A*, Tidal cycle for April 20, 1943; red mark indicates the estimated time and tide for the photo. *B*, Photo 2230-43 dated April 19, 1943 obtained from the Submerged Resources Center, National Park Service. The Salvage Diary indicates a date of April 20 for the event in the photo. The sun azimuth is best seen in the shadow produced by the handrail on the left side of the wooden walkway. The shadow is almost directly beneath the railing. The azimuth is in the range of 218 to 220° with associated times of 13:02 and 13:04, respectively. The tide range during this time is less than 0.01 m. The sun azimuth is estimated to be $219 \pm 2^\circ$, the time for the image is 13:03 and the tide level is 0.34 m MLLW. The sun elevation is best estimated from the shadows and dimensions of the handrail vertical supports. Dimensional uncertainties limit the estimated elevation to 77 to 81°. The vent top is 1.52 m below the rim of the barbette, as measured on March 4, 2008. The vent top is calculated to be 1.00 ± 0.03 m above the water level. The vent top elevation is calculated to be 1.34 ± 0.04 m MLLW. See text for more discussion of this photo. Day 500.

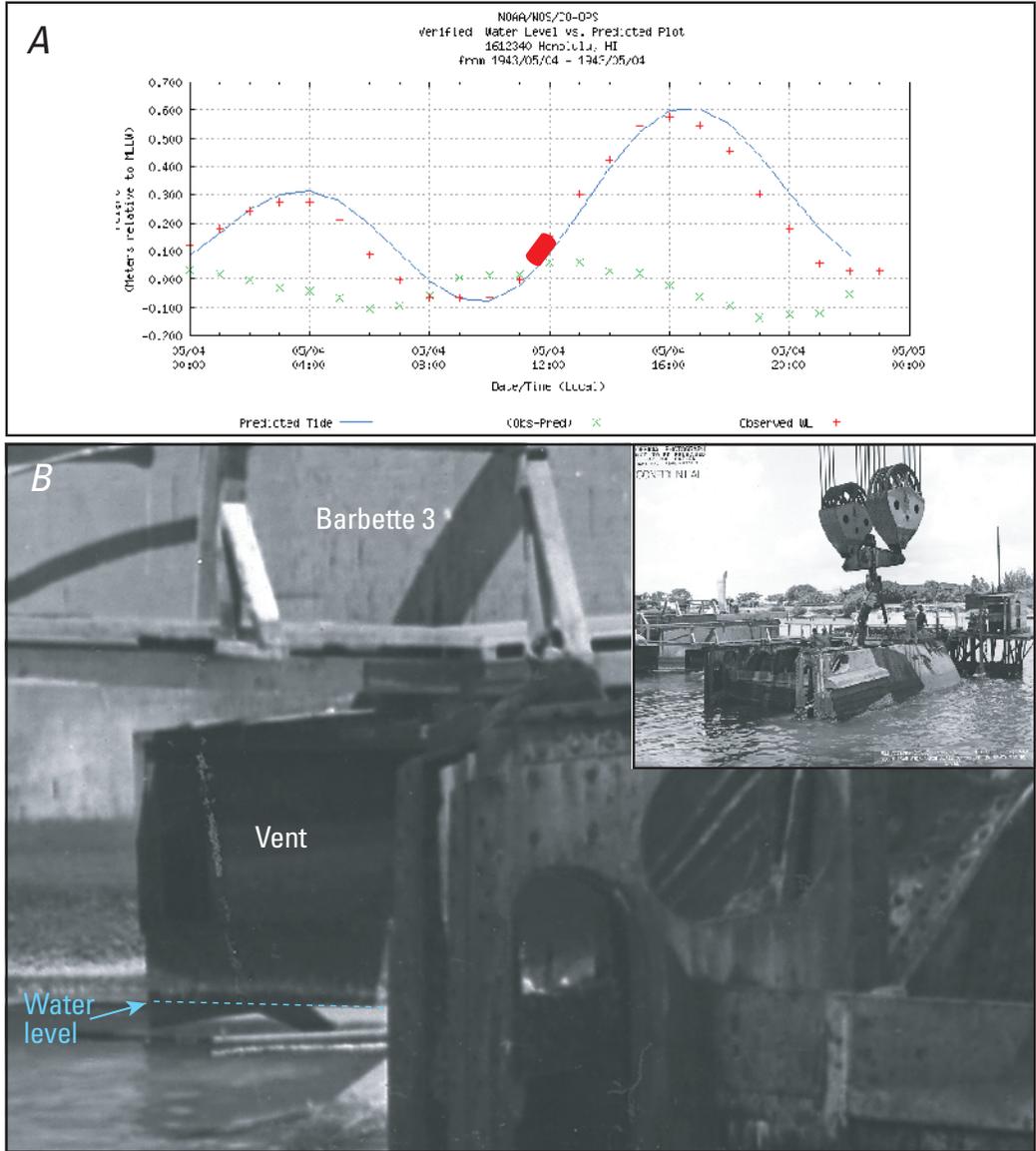


Figure E-13. Photo analysis for May 4, 1943. *A*, Tidal cycle for May 4, 1943; red mark indicates the estimated time and tide for the photo. *B*, Photo 2540-43 dated May 3, 1943 obtained from the Submerged Resources Center, National Park Service. According to the Salvage Diary, the activity in the photo happened on May 4, 1943. In the enlargement, part of the port-side vent is obscured behind the corner of turret 4. The vent opening is 0.74 m high, as determined in March 2008. This photo and another, 2540-38, allow a vent top height calculation of 1.22 ± 0.01 m above the water level. The sun elevation is very high, probably >75 to 80° ; for example, see shadows from rivets on the lifting block in original scan. The maximum elevation for this date is 84.55° at 12:29. The sun azimuth is estimated to be in the range of 104° to 124° , with corresponding time and tide levels of 11:14 (0.03) and 11:56 (0.14) m MLLW, respectively. Assuming an azimuth of 114° , time of 11:41 and tide level of 0.10 results in a vent top elevation of $1.32 \pm 0.04 / -0.07$ m MLLW. See text for more discussion of this photo. Day 514.

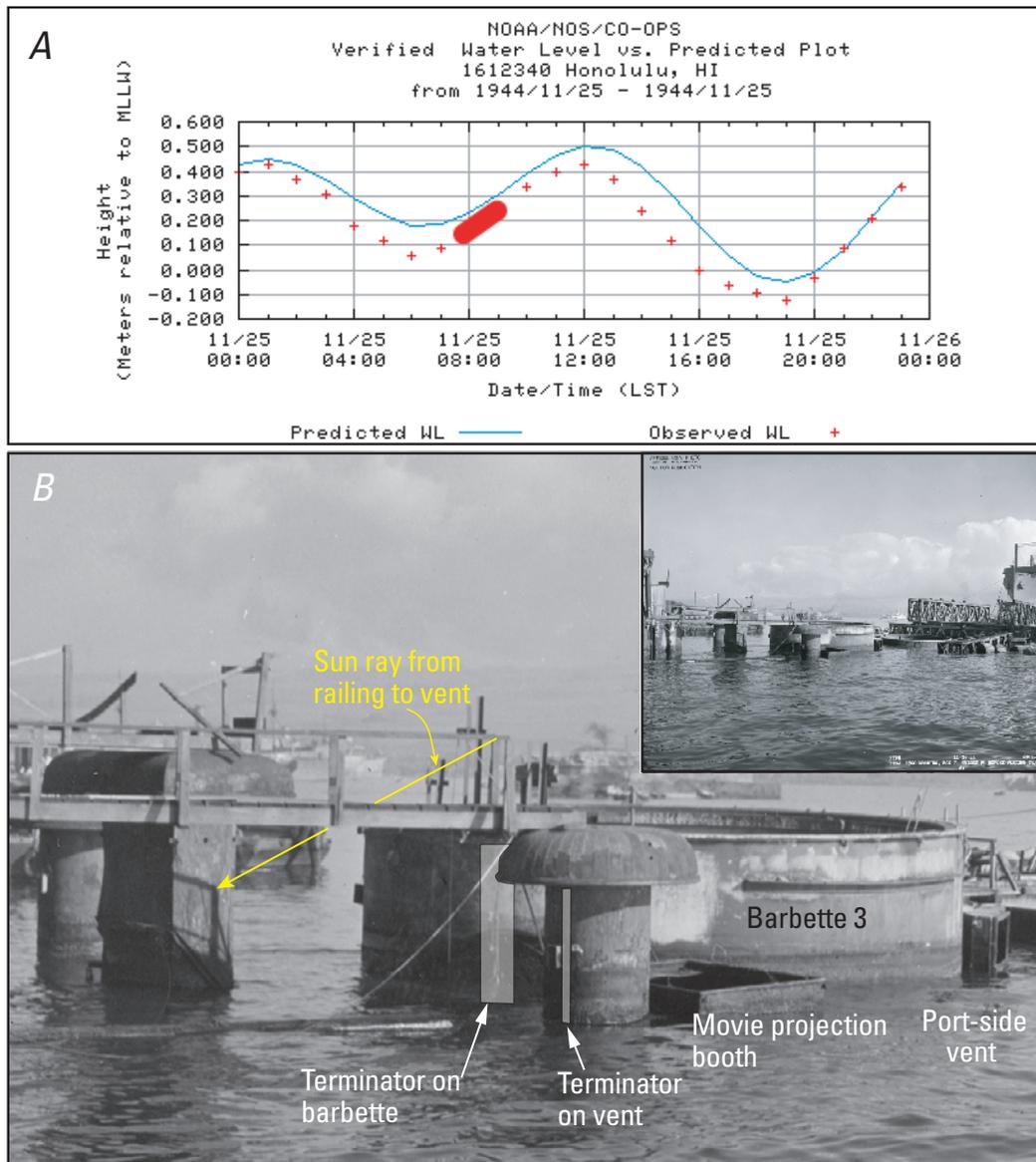


Figure E-14. Photo analysis for November 25, 1944. *A*, Tidal cycle for November 25, 1944; red band indicates estimated time of the photo. *B*, Photo PH6801-44 from the USS *Arizona* Memorial Museum Archives dated November 25, 1944. The caption reads: "Proj. 1320 mooring, Fox 7. Turret #3 before placing truss #3." The viewing angle is about 60° from the sun azimuth. The sun elevation is determined at several points on barbette 3, barbette 4 cofferdam and the foreground mushroom-shaped vent. The elevation is estimated to be $25 \pm 1^\circ$. One sun azimuth is estimated by transferring the terminator on the cylindrical base of the mushroom-shaped vent to the barbette by the same ratio of shadow to illumination, then plotting and measuring angles on a diagram of the ship. The azimuth is estimated to be $123 \pm 3^\circ$ as depicted within the highlighted zones above. The sun azimuth producing the railing shadow is $124 \pm 2^\circ$. The port-side vent opening is 0.74 m high and the vent top is estimated to be 1.00 ± 0.07 m above the water level. The time and tide level based on a 123° sun azimuth are 8:28 and 0.19 m MLLW. The time and tide level based on the sun elevation are 8:56 and 0.24 m MLLW. The vent top elevations for these two times are 1.19 ± 0.07 and 1.24 ± 0.07 m MLLW, with an average of 1.22 ± 0.07 . See text for more discussion of this photo. Day 1,085.

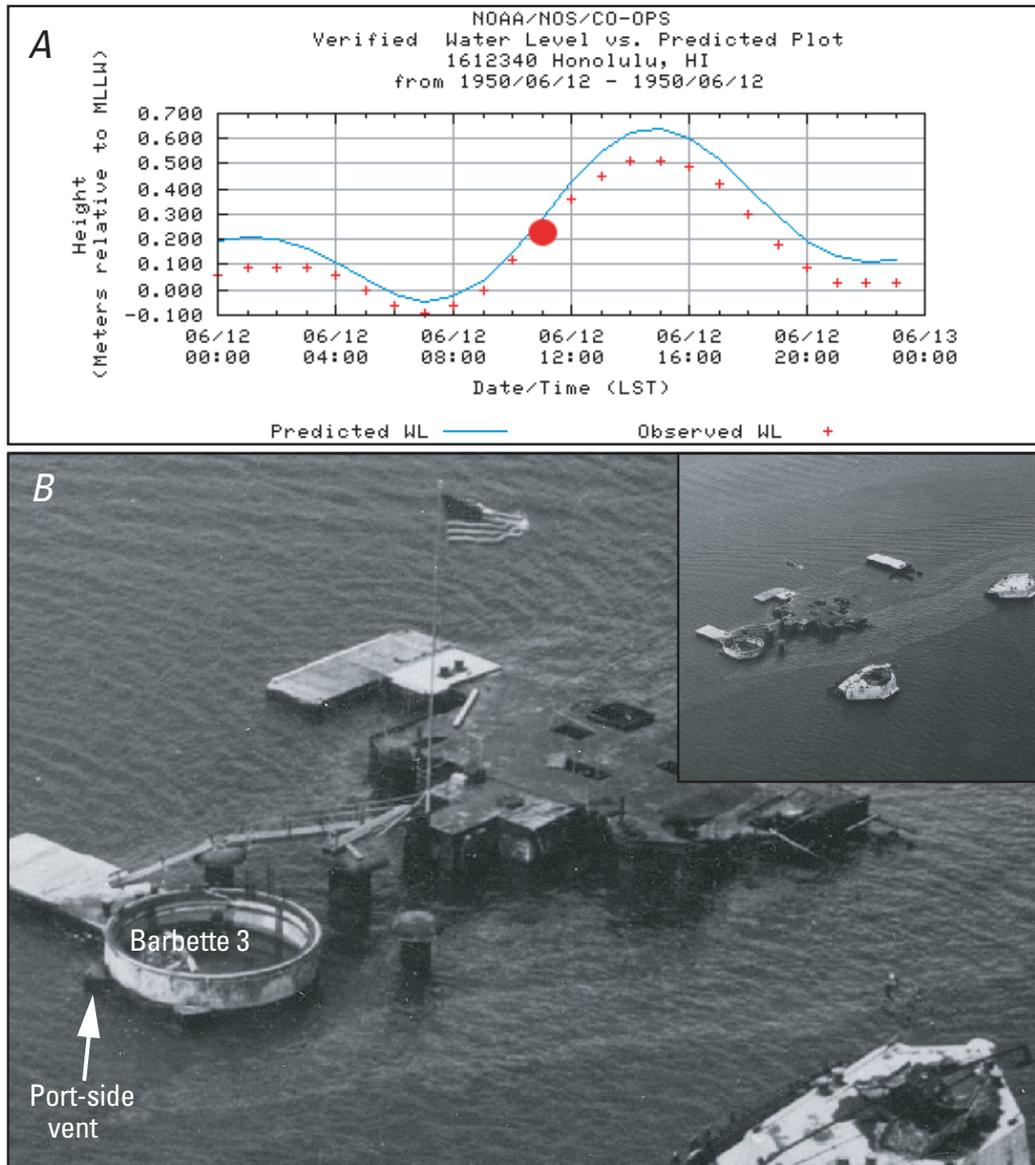


Figure E-15. Photo analysis for June 12, 1950. *A*, Tidal cycle for June 12, 1950; red mark indicates the estimated time and tide for the photo. *B*, Photo TEMP NO. 733 dated June 12, 1950 from the USS *Arizona* Memorial Museum Archives. The earliest photo found of the original memorial, still retaining wooden walkways constructed across the tops of the various vents prior to the end of 1945. The flag was returned to the *Arizona* on March 7, 1950 (<http://www.ussArizonafacts.us/memorial.htm#>). The maximum azimuth for the AM hours for this day is 80.83° at 10:55. An apparent flagpole and associated ruffled flag shadows on the remaining USS *Arizona* deck have an azimuth approximately at this maximum azimuth. The flagpole, based on this and several other photos, is estimated to be 17.7 m tall. Based on this height, the sun elevation is in the range 66 to 71°, which would restrict the time and tide to between approx. 10:45 (0.188) and 11:10 (0.236) m MLLW, respectively. The time is assumed to be 11:00 and corresponding tide level is 0.21 m MLLW. The port-side vent top height is estimated to be about 0.54±0.08 m above the water level, corresponding to an elevation of 0.75±0.1 m MLLW. Day 3,110.

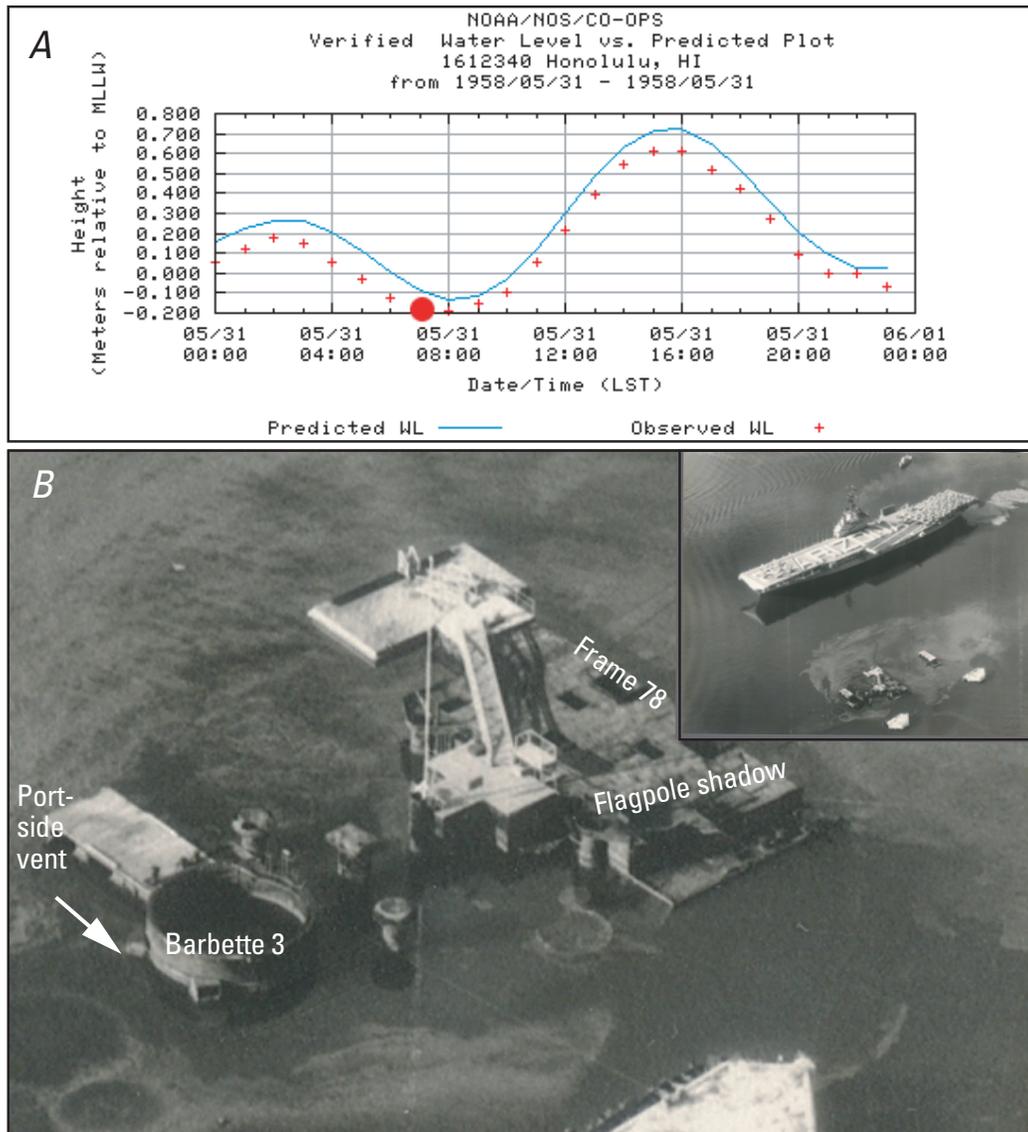


Figure E-16. Photo analysis for May 31, 1958. *A*, Tidal cycle for May 31, 1958; red mark indicates the estimated time and tide for the photo. *B*, Photo obtained from <http://www.uss-bennington.org/phz-58-ben-az.html> showing the USS *Bennington* (CV-20) passing by the USS *Arizona* on Memorial Day, May 31, 1958. The flagpole shadow on the remaining deck indicates a sun azimuth of 72° , a time of 7:03 and a tide level of -0.19 m MLLW. The water level is most easily measured at the starboard side vent on barbette 3 where the vent opening is visible. The opening height (0.74 m) and distance from the vent top to the rim of the barbette (1.52 m) provide scale. An average of the two heights obtained by these scales leads to an estimated height of the vent top above the water of 0.99 meters. A tilt correction is applied for transferring this height to the port side. The difference in height between the two vent tops is 0.254 m measured on March 4, 2008. The tilt of the mooring platform on the port side of the barbette is approx. 0.9 degrees measured on March 4, 2008. An expression developed for the tilt of the platform from its construction (assumed flat in early 1945) to the present results in 0.5° on day 6,020. The change in height difference between the two vent tops between 2008 and day 6,020 is approx. 0.05 m, leading to a height difference in 1958 estimated to be 0.21 m. The calculated elevation of the port-side vent top for May 31, 1958 is 0.59 ± 0.05 m MLLW. Day 6,020.

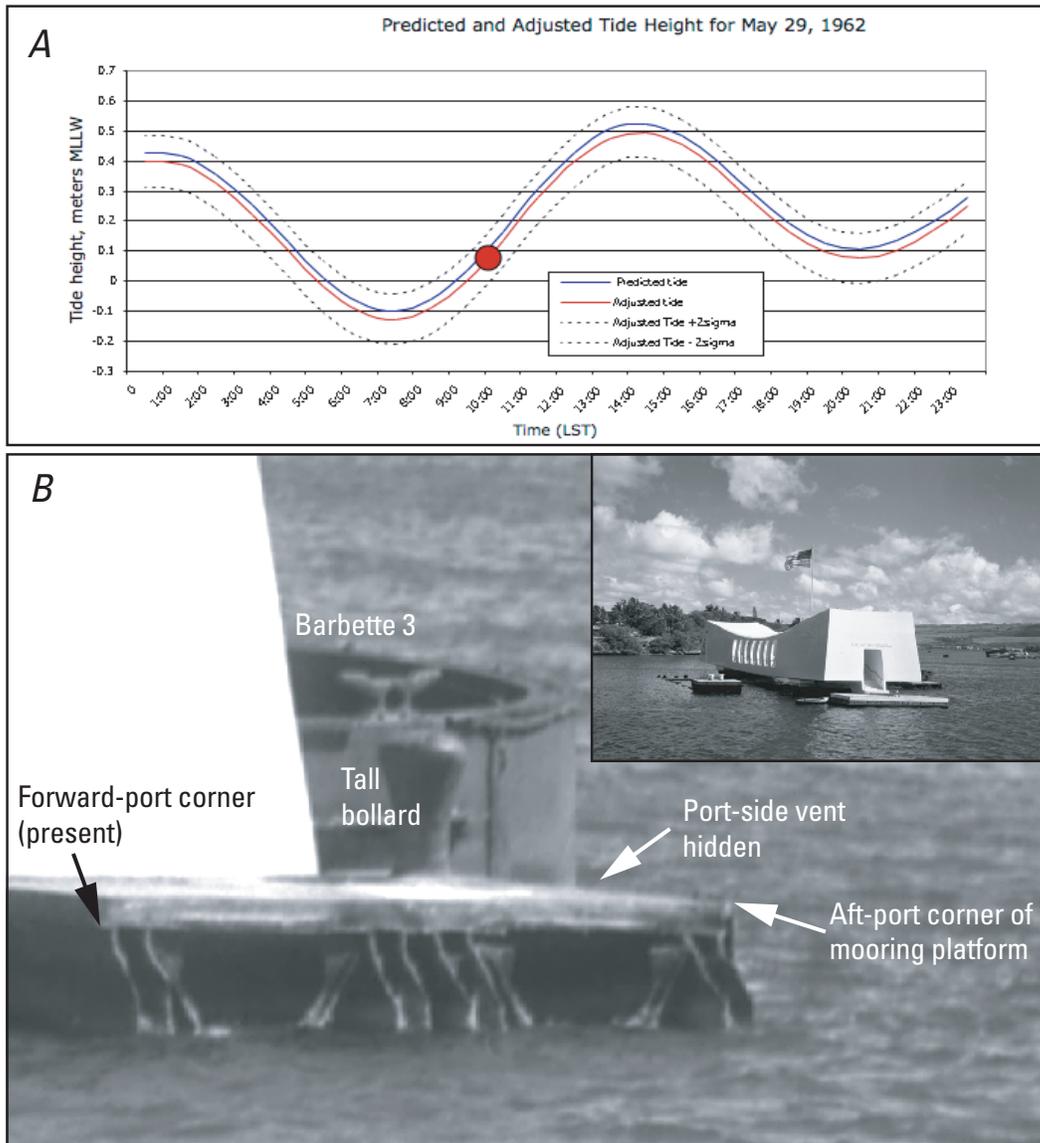


Figure E-17. Photo analysis for May 29, 1962. *A*, Tidal cycle for May 29, 1962; red mark indicates the estimated time and tide for the photo. The blue (upper) solid line is the predicted tide from the WWW Tide and Current Predictor at <http://tbone.biol.sc.edu/tide/tideshow.cgi>. The red (lower) solid line is the adjusted tide 0.03 m lower. The dashed lines are $\pm 2\sigma$. *B*, Photo USN1061040 (428-N-1061040 at the National Archives) dated May 29, 1962, the day before the dedication of the Memorial. The flagpole shadow on the Memorial roof has an azimuth of approx. $81 \pm 1^\circ$ and the forward mooring bitt on the midship port-side mooring platform shows a sun elevation of 50° , indicating a time of approx. 9:35. The predicted tide height at 9:35 is 0.11 m MLLW; the adjusted tide height is 0.08 m, with a 2-sigma standard deviation for the estimated tide height of ± 0.084 m. The port-side vent on barbette 3 is hidden behind the mooring platform. For scale, the tall bollard is 1.07 m tall and the concrete at the aft-port corner of the mooring platform is 0.20 m thick. On March 4, 2008, the aft-port corner of the mooring platform was 0.31 m above the vent top; the present forward-port corner was 0.14 m above the vent top. After a tilt correction back to 1962, the aft and forward corners are 0.34 and 0.17 m above the vent, respectively. Based on these scales, the vent top is estimated to be 0.46 ± 0.02 m above the water level. The vent top elevation is estimated to be 0.54 ± 0.14 m MLLW. Day 7,113.

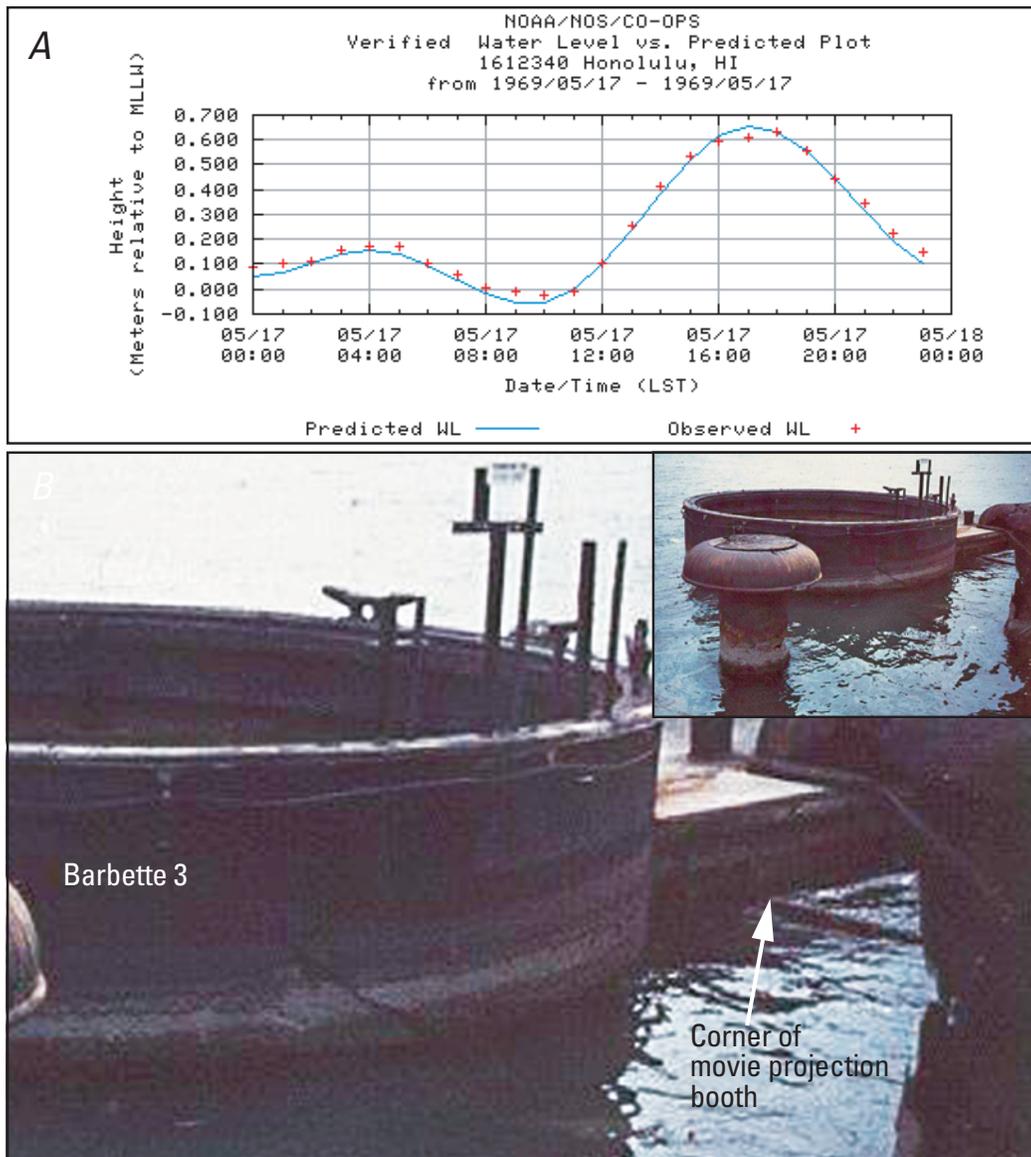


Figure E-18. Photo analysis for May 17, 1969. *A*, Tidal cycle for May 17, 1969. *B*, Photo dated May 17, 1969 from <http://www.navsource.org/archives/01/39d.htm> showing barbette 3 and mooring platform. The port-side vent is not visible. There are no useful shadows in the image and the time is unknown; features are at the limit of useful resolution. The water level on the forward side of the platform indicates a rather low tide condition, suggestive of the morning hours for this date. The top edges of the movie projection booth are above the water level on the forward side of the platform. Based on another photo, the inside corner of the booth is estimated to be 0.7 m below the top of the platform. The concrete thickness between the bits and the barbette is about 0.29 m, and the forward edge of the mooring platform in line with the mooring bits is estimated to be 0.83 ± 0.02 m above the water level. The forward edge was 0.343 m above the vent top on March 4, 2008. The port side vent top is estimated to be 0.49 ± 0.05 m above the water level. The tide range for daylight hours varies from -0.024 (10:00) to 0.631 (18:00) m MLLW. The average tide level between 7:00 and 11:00 is 0.01 m MLLW with a range of $0.05/-0.03$ m. The vent top height is estimated to be 0.50 ± 0.1 m MLLW. Day 10,023.

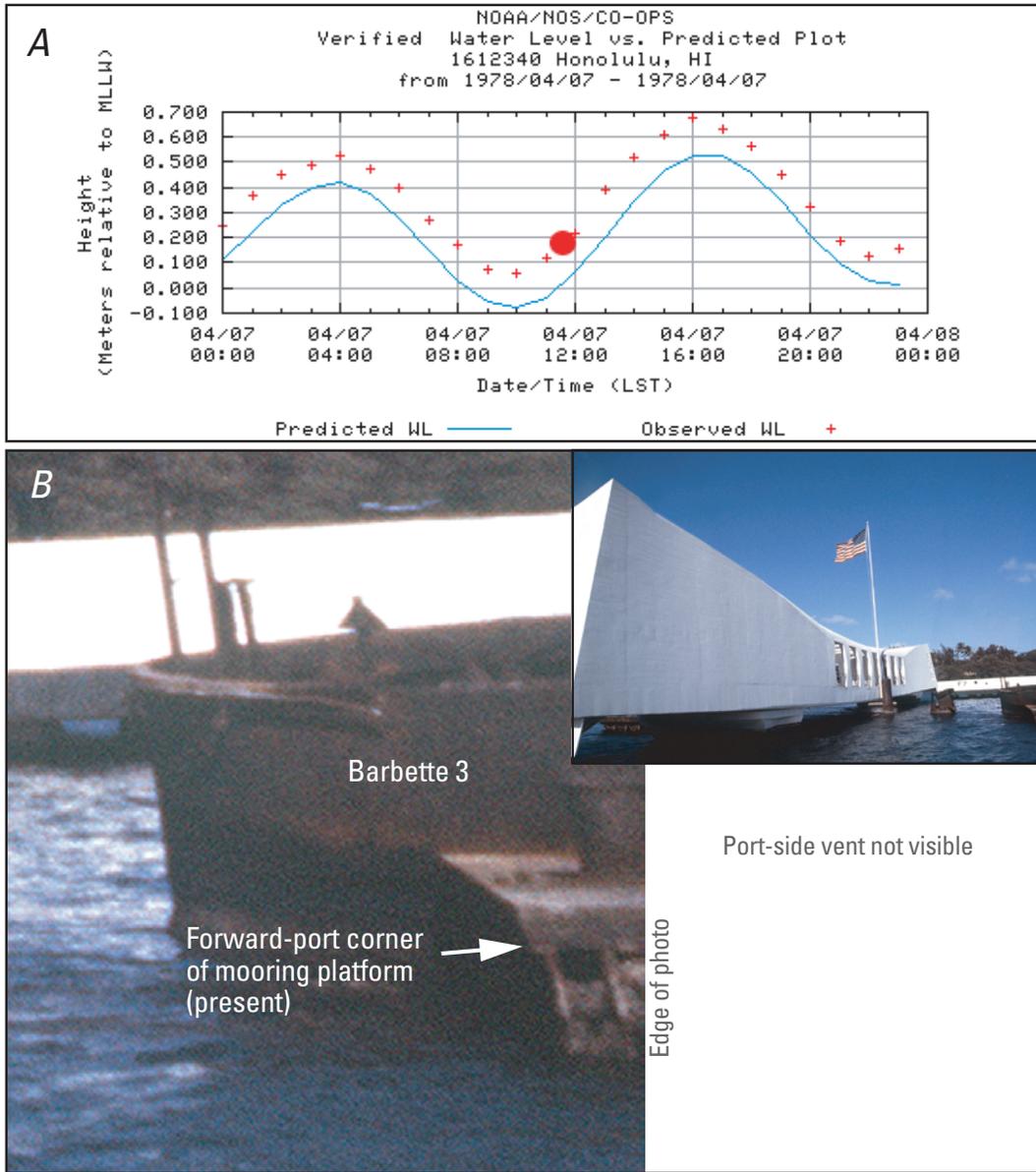


Figure E-19. Photo analysis for April 7, 1978. *A*, Tidal cycle for April 7, 1978; red mark indicates the estimated time and tide for the photo. *B*, Photo DF-ST-84-08027 dated April 7, 1978 from <http://www.defenseimagery.mil/index.htm>. The port side vent on barbette 3 is not visible. The flagpole shadow on the Memorial roof has an estimated azimuth of 135° corresponding to a time of 11:38 and a tide of 0.18 m MLLW. Plus or minus 5° of azimuth corresponds to ±9 minutes and ±0.014 m in tide level. The vent height is calculated from the water level at the forward port corner of the mooring platform. In 1978 the concrete slab was still present above the metal at the forward port corner. On March 4, 2008, the metal surface at the forward port corner was 0.14 m above the vent top and the concrete is 0.29 m thick. The top of the metal is estimated to be 0.56±0.02 m above the water in the image. The vent top is calculated to be 0.60±0.03 m MLLW. Day 13,271.

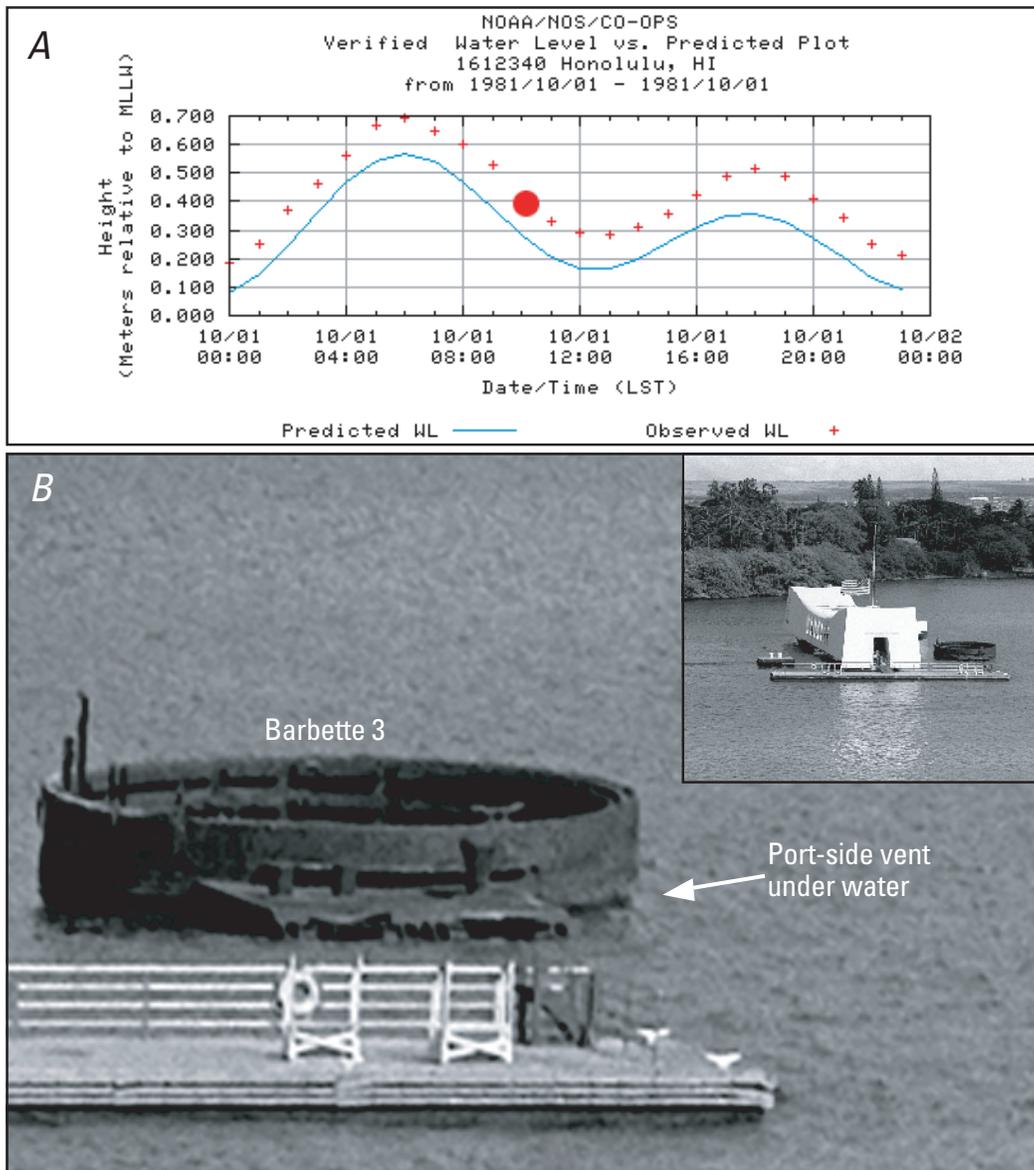


Figure E-20. Photo analysis for October 1, 1981. *A*, Tidal cycle for October 1, 1981; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SN-82-01556 dated October 1, 1981 from <http://www.defenseimagery.mil/index.htm>. Despite the image appearing somewhat distorted, a flagpole shadow on the Memorial roof suggests a time of 10:11 with an associated tide height of 0.39 m MLLW. Plus or minus 1° in azimuth corresponds to ± 4 minutes in time and ± 0.005 m in tide height. As a potential verification of the date, a reason for the flag at half-mast on this date could not be identified. The port side vent is not visible, indicating that it is at or just below the water level and therefore the vent top has a maximum height of 0.39 ± 0.02 m above MLLW. The water level relative to features at the port aft corner of the mooring platform suggests that the vent top must be just below the water surface. The vent top height is calculated to be 0.39 ± 0.02 m MLLW. Day 14,544.

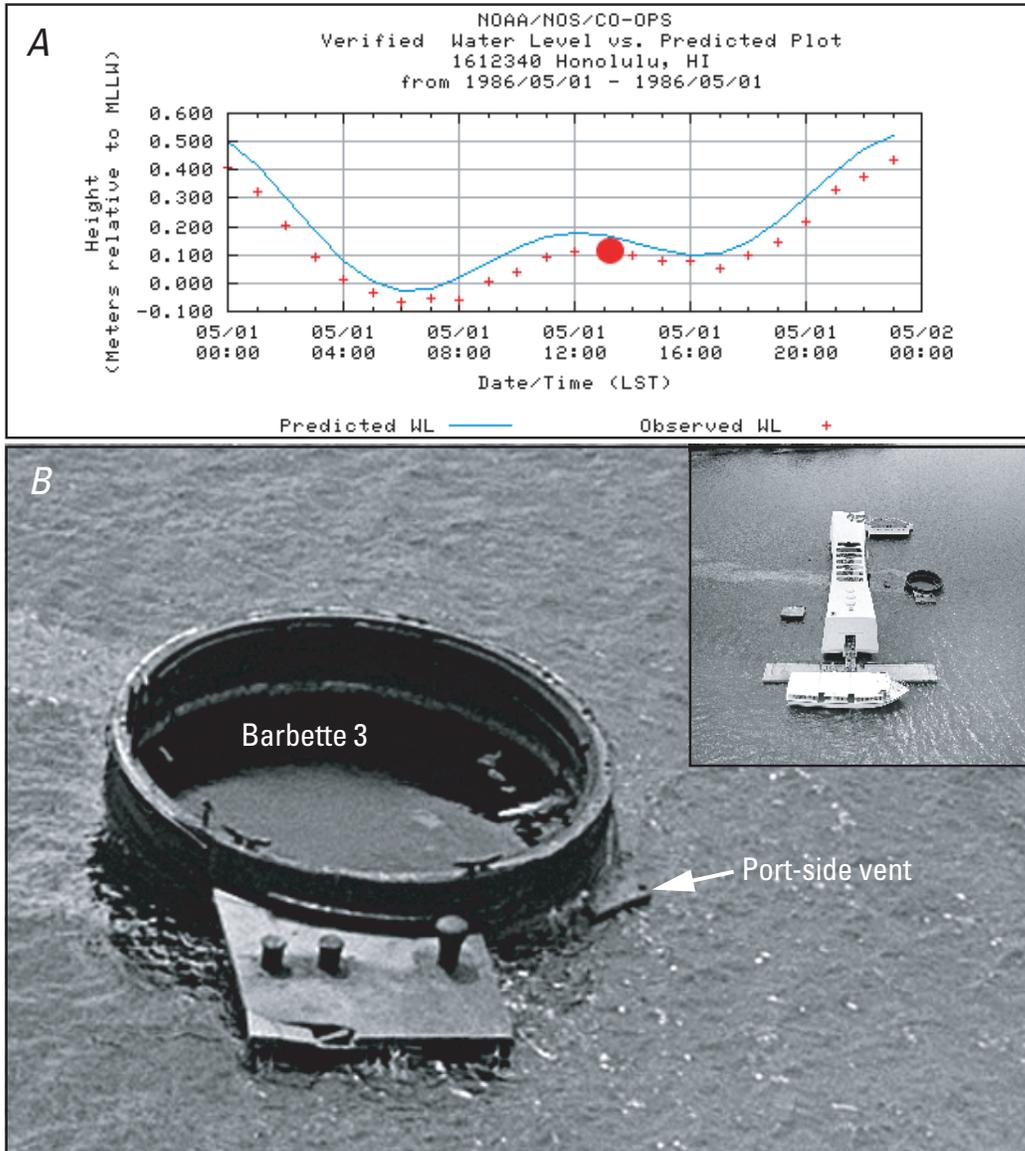


Figure E-21. Photo analysis for May 1, 1986. *A*, Tidal cycle for May 1, 1986; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SN-86-08980 dated May 1, 1986 obtained from the former Defense Visual Information Center (no longer available at <http://www.defenseimagery.mil/index.htm>). The bits on the mooring platform and the railing on the floating dock provide useful shadows, indicating a sun azimuth in the range 237 to 243°, with corresponding times of 13:07 to 13:16, respectively. An azimuth of 240°, time of 13:11 and a tide of 0.12 m MLLW are assumed. Plus/minus 2° in azimuth is ± 0.001 m in tide level, that is, the tide level is not very sensitive to azimuth around this time period. The estimated height of the vent top above the water level is 0.28 ± 0.02 m, suggesting about 0.18 meters of open space height within the vent opening. The calculated vent top elevation is 0.39 ± 0.02 m MLLW. Day 16, 217.

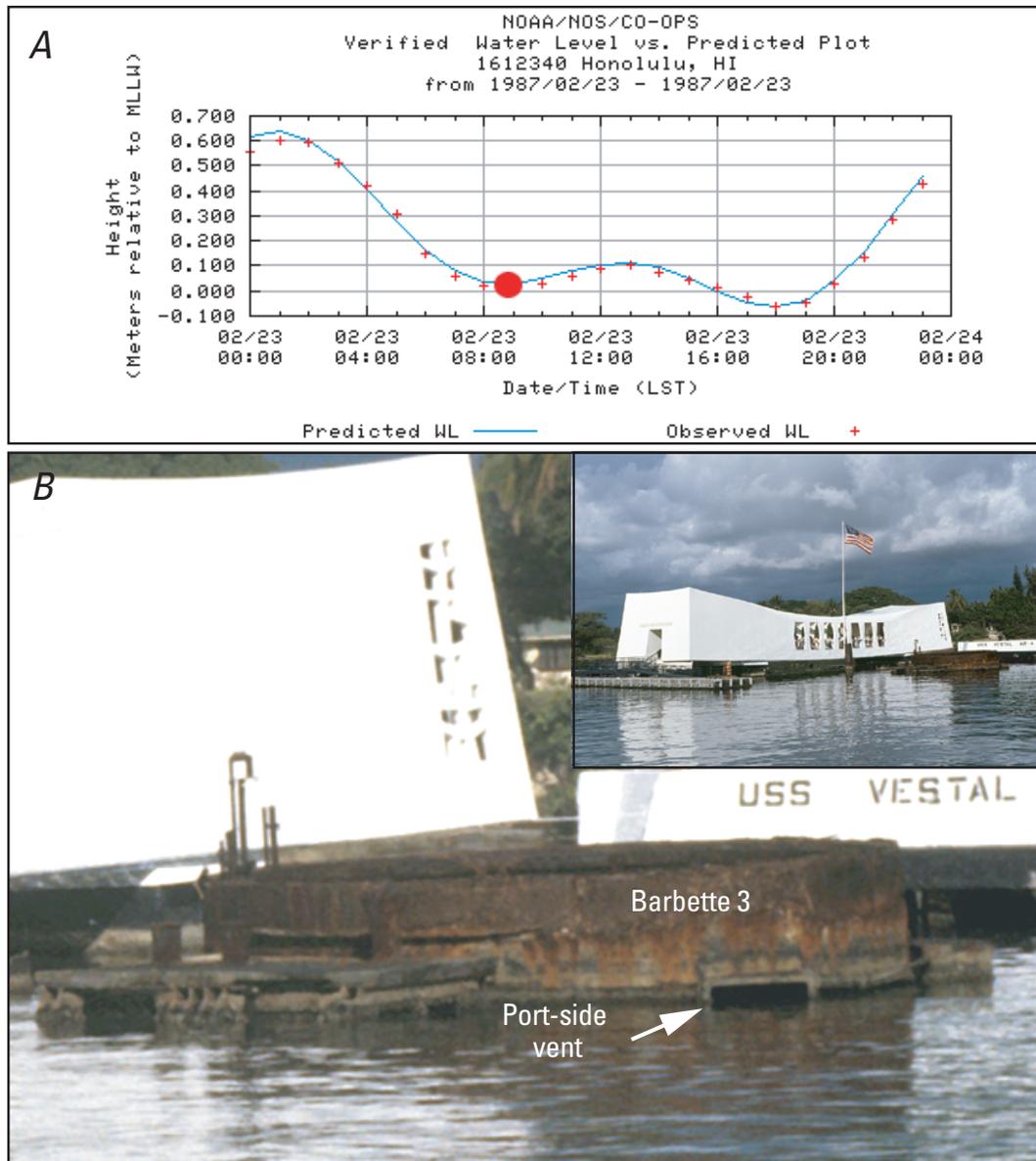


Figure E-22. Photo analysis for February 23, 1987. *A*, Tidal cycle for February 23, 1987; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-ST-87-03920 (photos -03921 and -03923 also examined) obtained from the former Defense Visual Information Center (no longer available at <http://www.defenseimagery.mil/index.htm>). The flag and flagpole shadows on the Memorial suggest a sun azimuth in the range 109 to 115° with a time range of 8:24 to 9:10, respectively. An azimuth of 112°, a time of 8:48 and a tide of 0.015 m MLLW are assumed. The vent top is estimated to be 0.35 ± 0.02 m above the water level based on several images, resulting in an elevation of 0.37 ± 0.03 m MLLW. Day 16, 515.

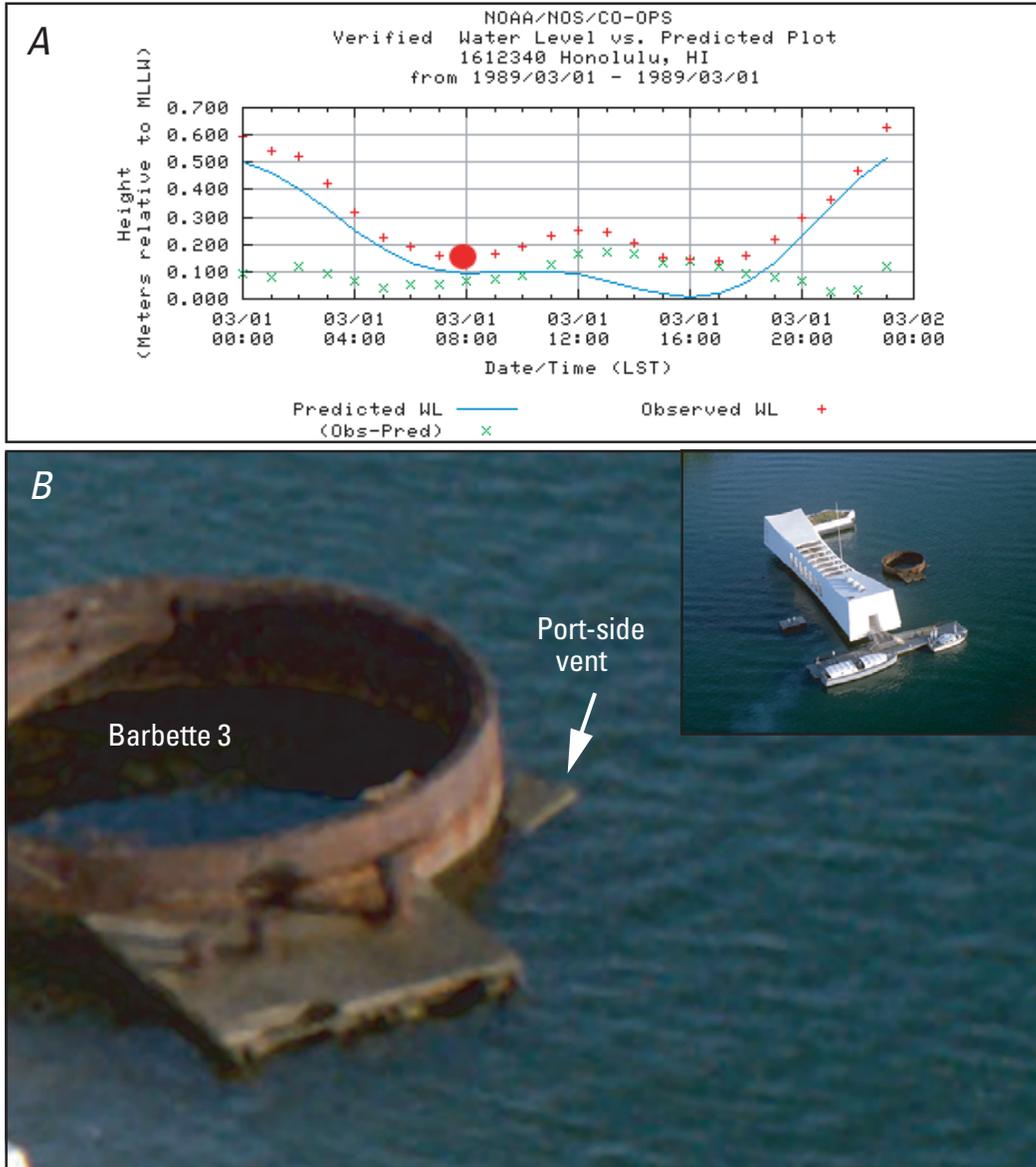


Figure E-23. Photo analysis for March 1, 1989. *A*, Tidal cycle for March 1, 1989; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SC-94-00459 dated March 1, 1989 obtained from <http://www.defenseimagery.mil/index.htm>. The flagpole shadow on the Memorial and the bitt shadows on the mooring platform indicate a sun azimuth in the range 100 to 103°. The sun elevation estimated from the tall bollard on the mooring platform is approx. 11°. An azimuth of 103° and a time of 7:49 are assumed. The tide level for 7:00 and 8:00 is 0.16 m MLLW. Details at the vent are at the limit of resolution. The vent height is estimated from the water level at the port aft corner of the mooring platform. The port aft corner was measured to be 0.307 meters above the top of the vent on March 4, 2008. Here, the port aft corner is estimated to be 0.51 m above the water level, resulting in a vent top elevation of 0.36±0.02 m MLLW. Day 17,252.

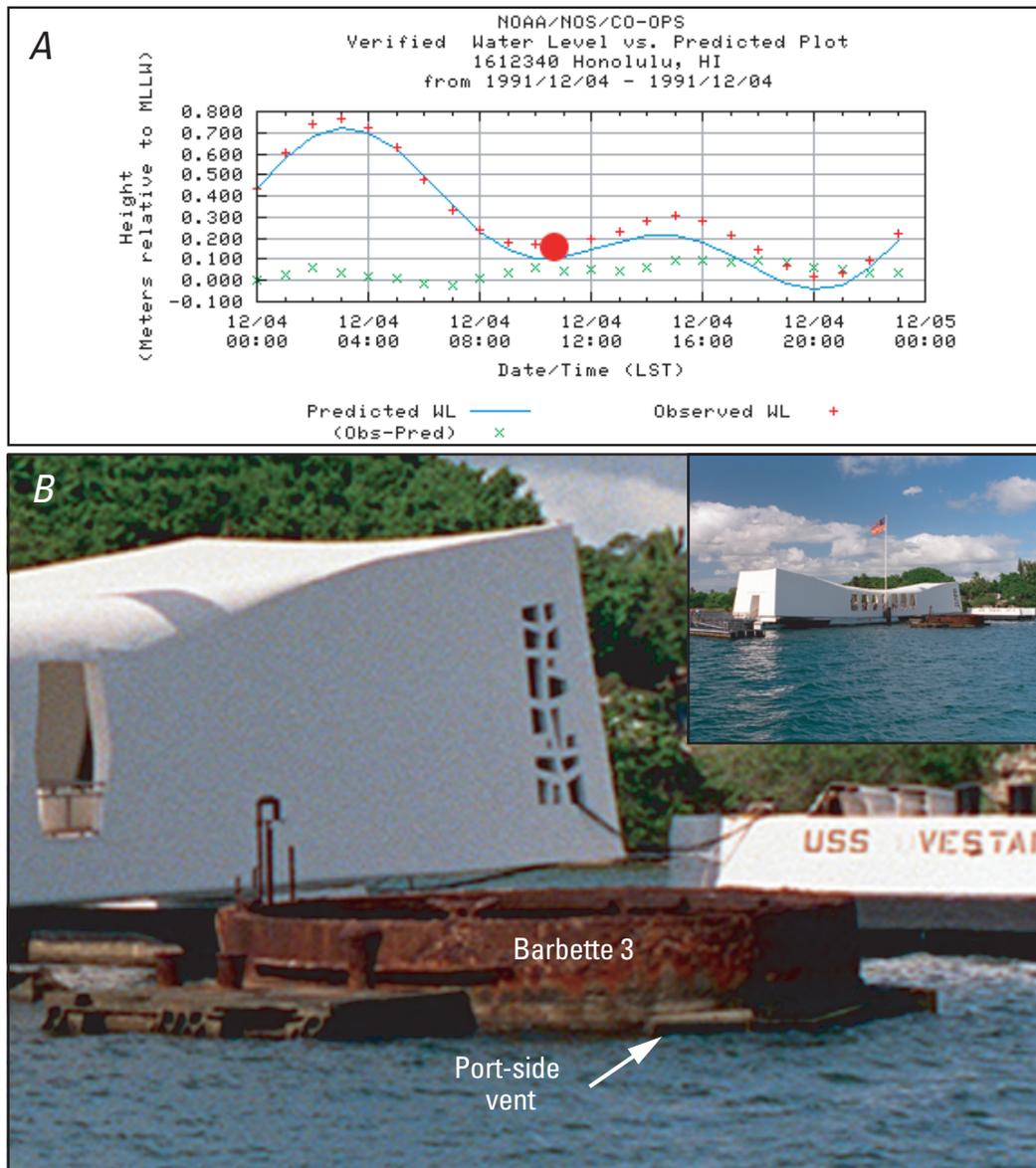


Figure E-24. Photo analysis for December 4, 1991. *A*, Tidal cycle for December 4, 1991; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SC-92-05772 from <http://www.defenseimagery.mil/index.htm> dated December 4, 1991. The flagpole shadow is just beyond the northeast side of the memorial, however the flag shadow is present on the memorial. The sun azimuth is estimated to be in the range of 146 to 150° with times of 10:29 to 10:45, respectively. There is little tidal variation during this time, 0.162 to 0.159 m MLLW. A time of 10:37, sun azimuth 148° and tide of 0.16 m MLLW are assumed. The height of the vent top is calculated to be 0.23 ± 0.02 m above the water level with a corresponding elevation of 0.39 ± 0.02 m MLLW. This elevation is about 0.04 m above that calculated for December 7, 1991 (fig. E-25). Day 18,260.

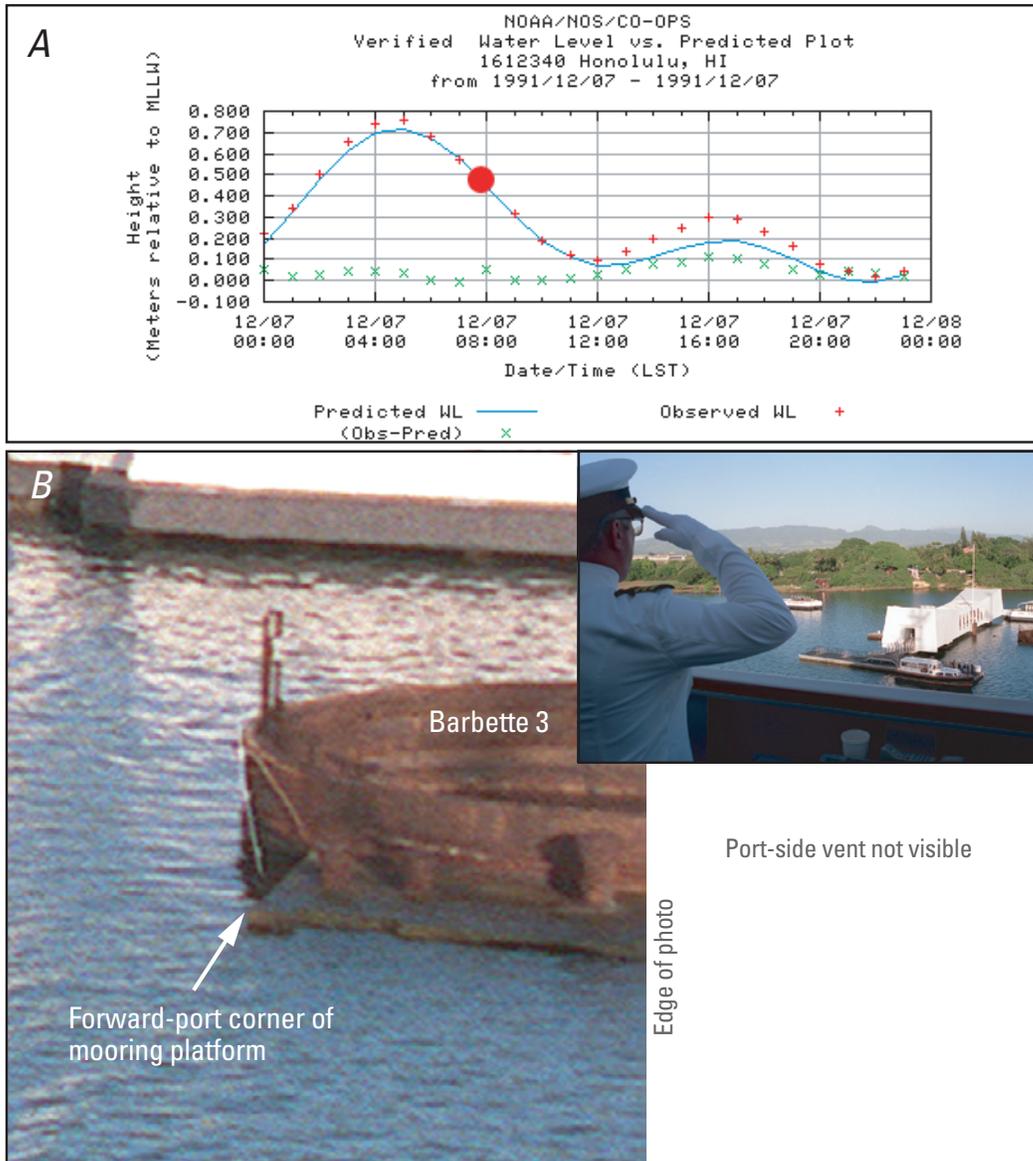


Figure E-25. Photo analysis for December 7, 1991. *A*, Tidal cycle for December 7, 1991; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SC-92-05373 from <http://www.defenseimagery.mil/index.htm> dated December 7, 1991 taken from the USS Chosin during activities on the 50th anniversary of the attack. The flagpole shadow azimuth on the memorial roof is estimated to be 119.5° indicating a time of 7:51. The barbette 3 vent is not visible; its height is calculated from the height of the forward port corner of the mooring platform. On March 4, 2008 the top of the vent was measured to be 0.14 m below the metal corner of the platform. At the time of this image, the concrete had not yet broken away from this corner of the platform. It is estimated that the water depth over the corner would be about 0.02 m resulting in a calculated vent top elevation of 0.35 ± 0.03 m MLLW. This height is 0.04 m below the height calculated for December 4, 1991 (fig. E-24). Day 18,263.

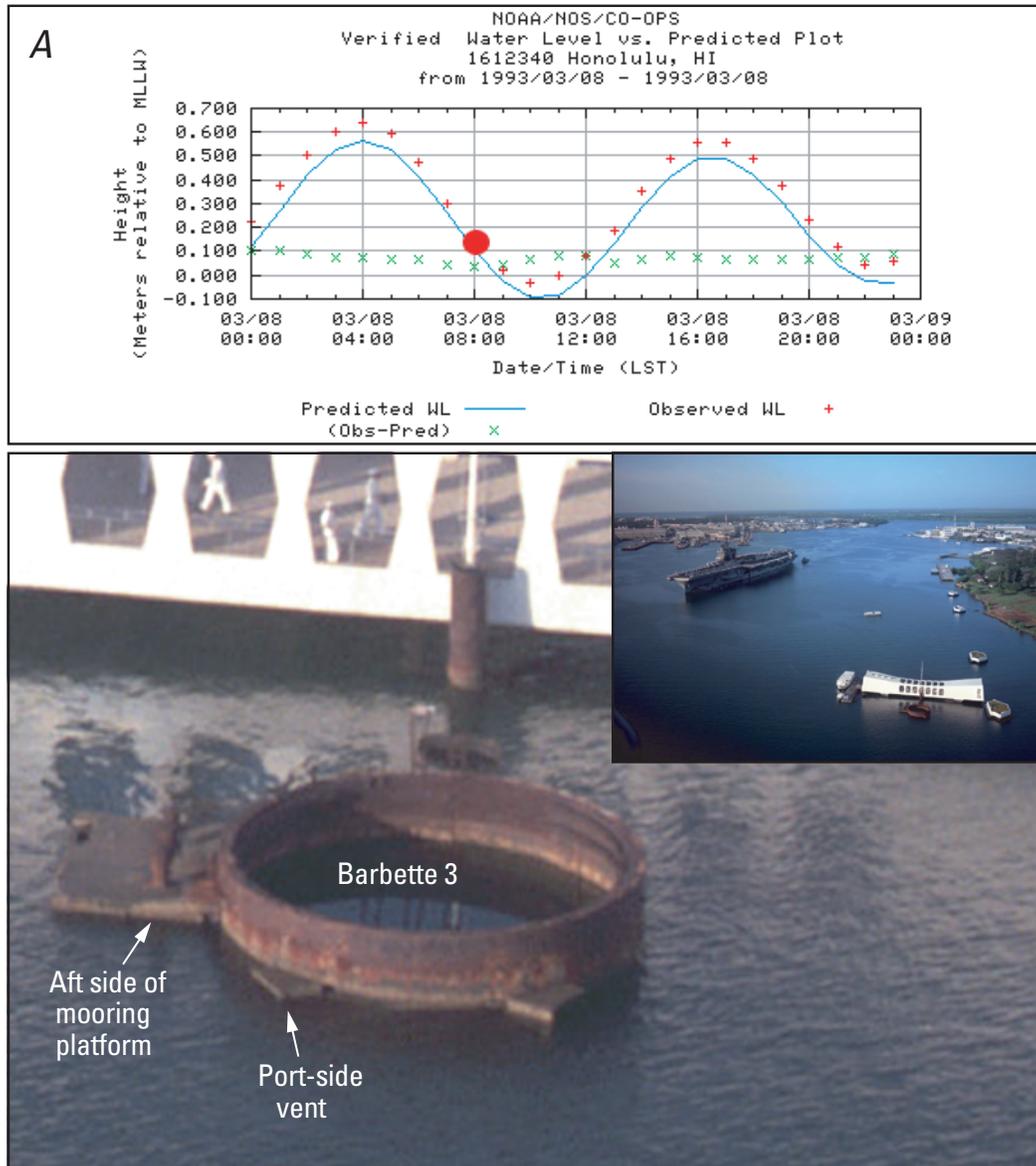


Figure E-26. Photo analysis for March 8, 1993. *A*, Tidal cycle for March 8, 1993; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SC-05-10863 dated March 8, 1993 obtained from the former Defense Visual Information Center (no longer available at <http://www.defenseimagery.mil/index.htm>). The flagpole shadow on the Memorial roof has an azimuth of 102° indicating a time of 8:02. Details in the area of the vent are at the limit of useful resolution. The aft edge of the port-side mooring platform at the bits is estimated to be 0.56 m above the water level. On March 4, 2008 the top of the port vent was measured to be 0.34 m below the platform edge. The top of the vent is therefore about 0.21 m above the water, suggesting about 0.11 m of open space above the water within the vent. The top of the vent elevation is calculated to be 0.35 ± 0.05 m MLLW. Day 18,720.

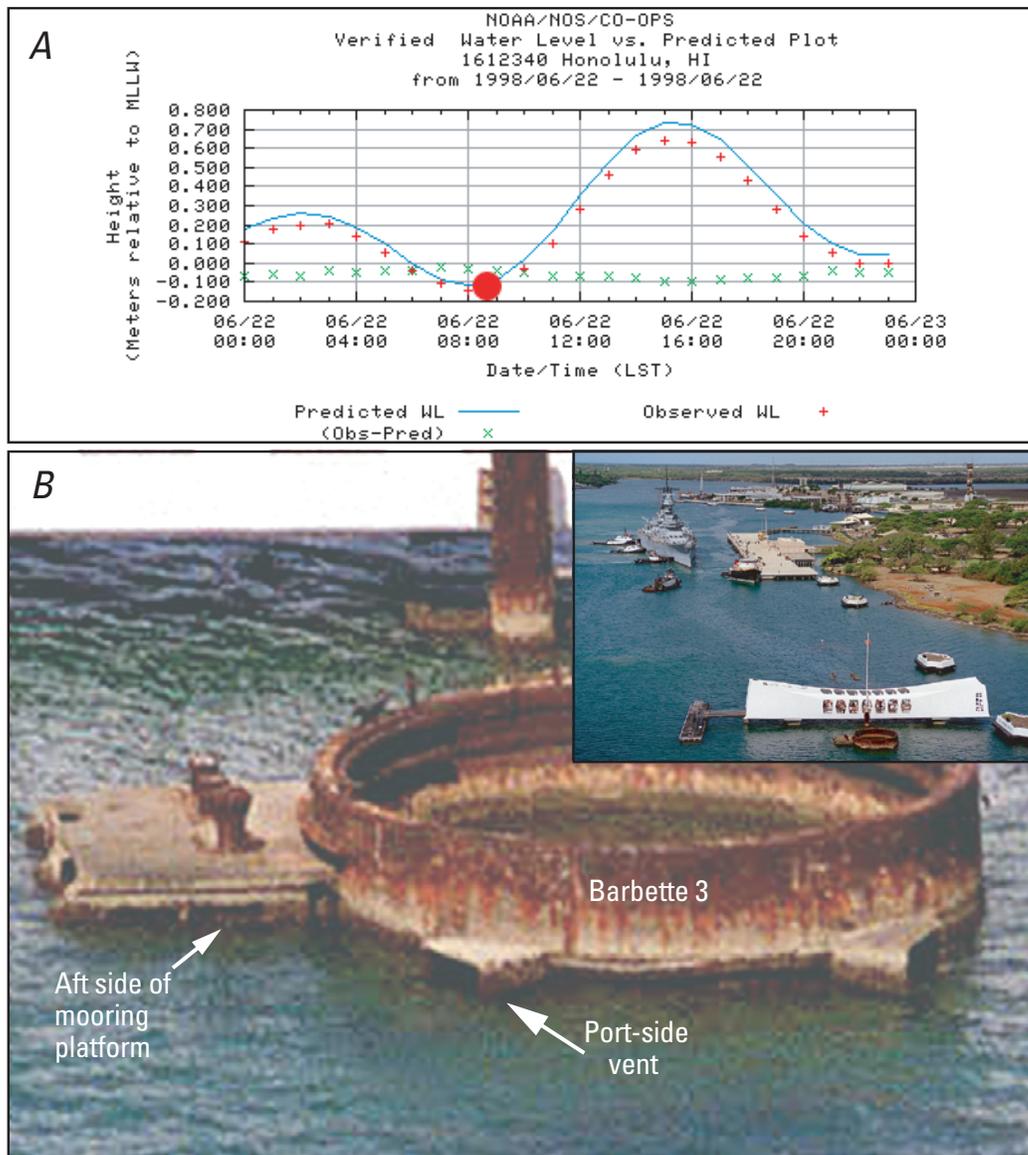


Figure E-27. Photo analysis for June 22, 1998. *A*, Tidal cycle for June 22, 1998; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SD-93-09094 dated June 22, 1998 from <http://www.navsource.org/archives/01/63f.htm> showing the USS *Missouri* being pushed to its new berth in Pearl Harbor. The flagpole shadow on the Memorial has an estimated azimuth of 76° , which occurs at two times: 8:41 and about 11:55, with tide levels of -0.13 and 0.27 m MLLW, respectively. The 8:41 time and tide are assumed to be correct, as the later time produces a vent height dramatically out-of-step with other dates. The water level is most clearly visible along the aft side of the mooring platform, where it is 0.81 ± 0.03 m above the water. The aft edge of the platform surface adjacent to the tall mooring bitt was measured to be 0.34 ± 0.03 m above the vent top on March 4, 2008. The vent top is calculated to be 0.46 m above the water level and at an elevation of $0.33 + 0.08 / -0.03$ m MLLW. Day 20,286.

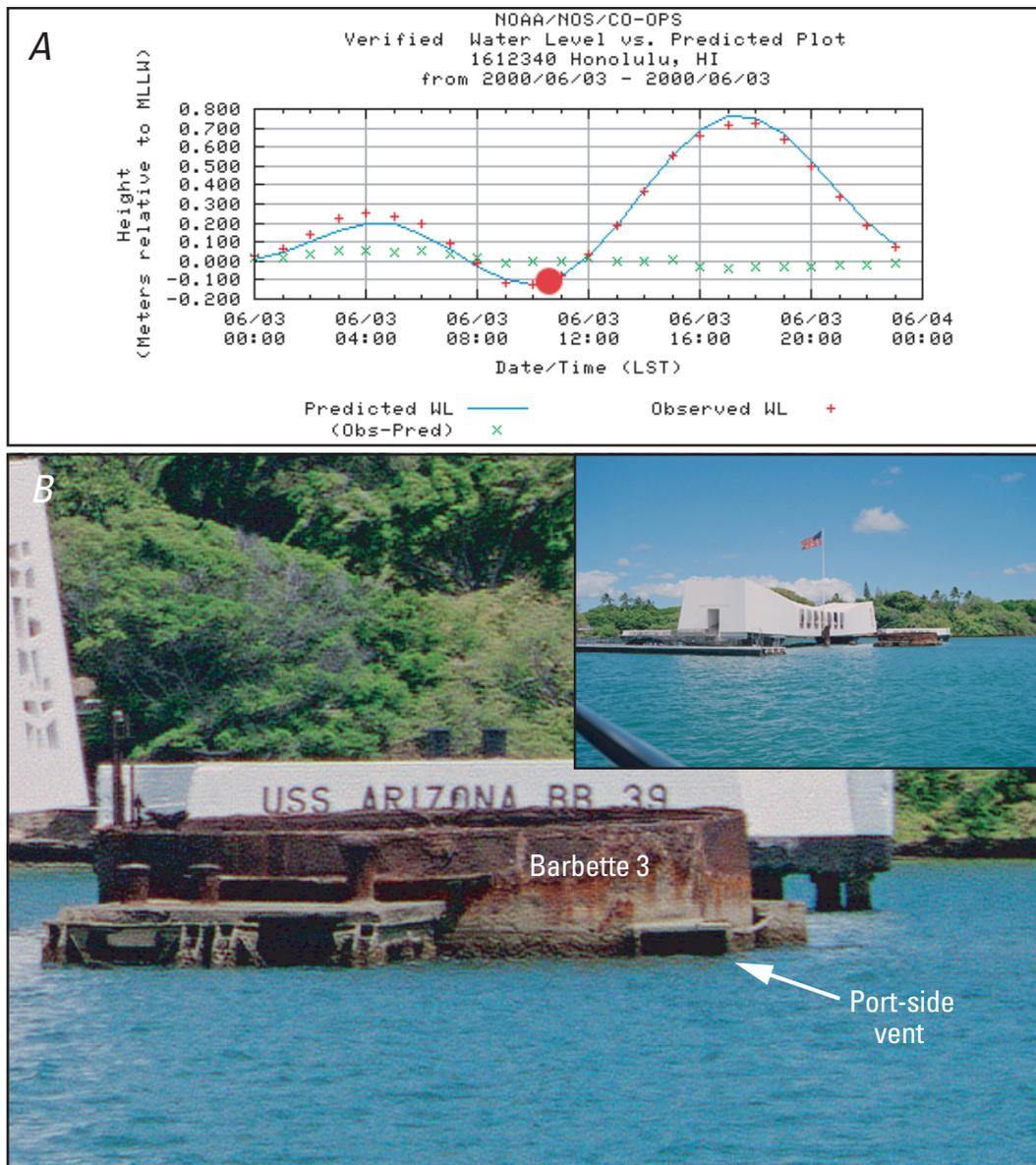


Figure E-28. Photo analysis for June 3, 2000. *A*, Tidal cycle for June 3, 2000; red mark indicates the estimated time and tide for the photo. *B*, Photo 000603-N-4912M-002 (also identified as DN-SC-02-05619) dated June 3, 2000 from <http://www.defenseimagery.mil/>. This is the first image of a series of nine images in numerical order depicting a visit to the memorial; this image seems to show the approach to the memorial structure. A related image, DN-SC-02-05623, taken from inside the memorial, contains features providing an estimated time of 10:42 (fig. F-12). The time for this image would be earlier and is assumed to be 10:30 and corresponding tide level of -0.10 m MLLW. Plus/minus 30 minutes in time is ± 0.02 m in tide level. The exterior width of the vent is 1.47 m. The top of the vent is calculated to be 0.43 ± 0.04 m above the water level and at an elevation of 0.32 ± 0.05 m MLLW. Day 21,364.

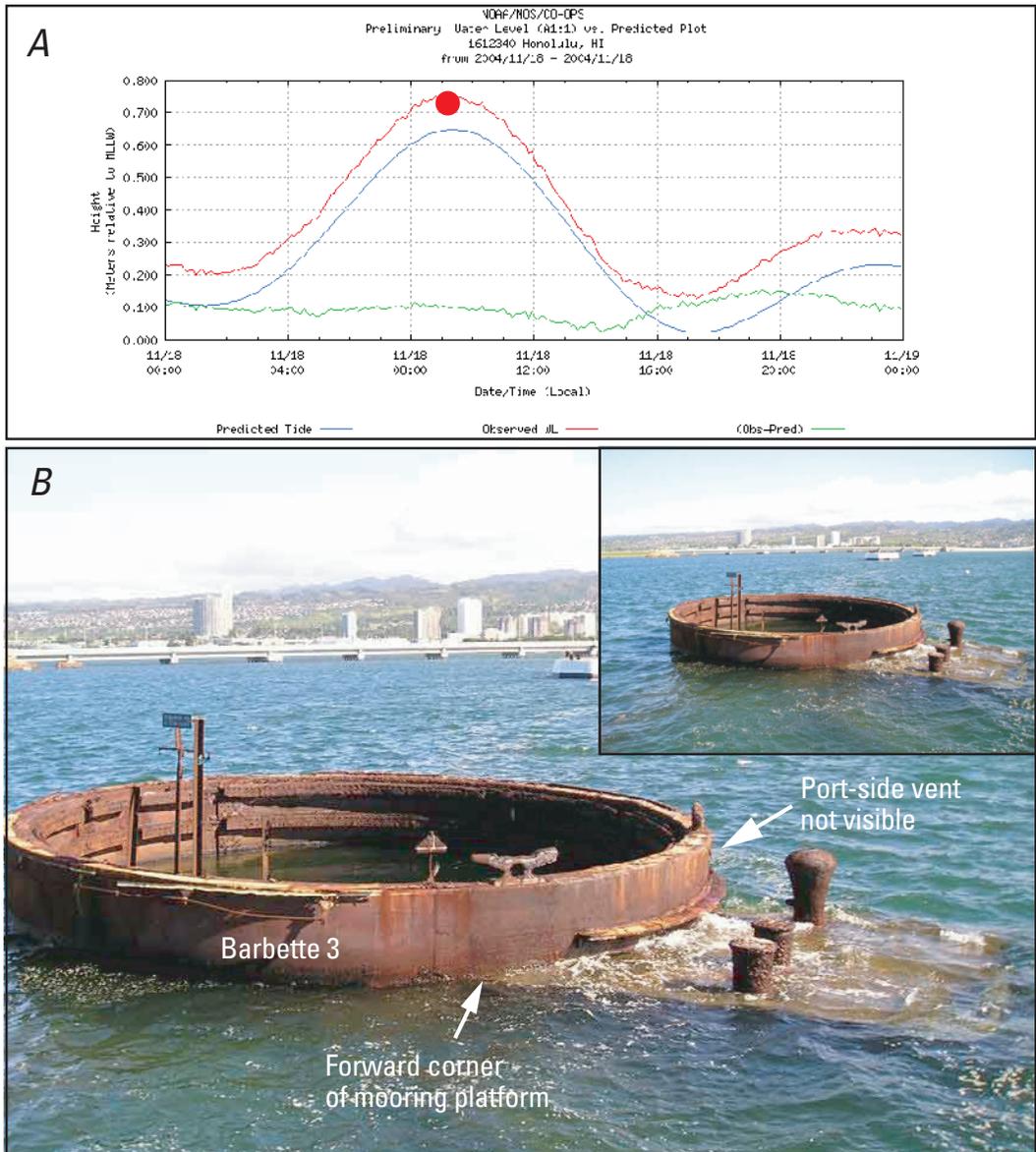


Figure E-29. Photo analysis for November 18, 2004. *A*, Tidal cycle for November 18, 2004; red mark indicates the estimated time and tide for the photo. *B*, Dated photo from a citizen website at <http://www.beoriginal2.com/hawaii2004-7.html> showing the barbette 3 mooring platform completely submerged. The date is considered reliable; the high tide state is consistent with the verified tidal data for this date and time period. The vent is not visible. A photo taken by the visitor from the tour boat at departure from the memorial has a flagpole shadow azimuth of approx. 138°, which corresponds to 10:00 and 0.73 m MLLW. The time and tide level of this photo are assumed to be 9:30 and 0.74 m MLLW, respectively. Measurements on March 4, 2008 show that the forward corner of the platform is 0.38 m above the top of the port side vent and at an elevation of 0.68 m MLLW. The corner appears to be submerged to some depth. For zero water depth at the corner, the vent top would be at 0.36 m MLLW (0.06 m above March, 2008); if the vent top is the same elevation as in 2008 (that is, no settlement), the water depth would be about 0.06 m. The water depth in this image is assumed to be 0.03 m and the vent top elevation is calculated to be 0.33±0.03 m MLLW. Day 22,992.

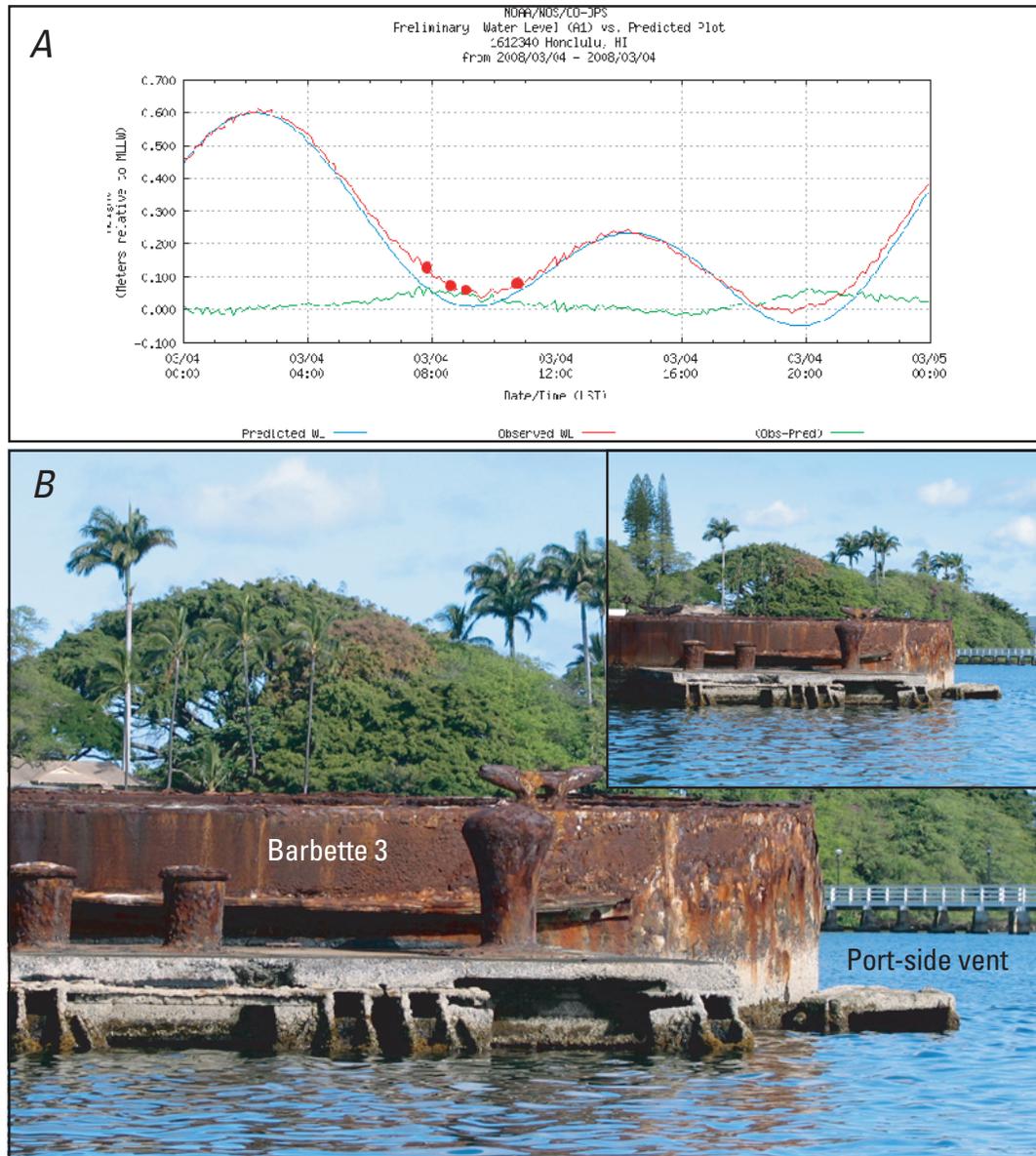


Figure E-30. Photo analysis for March 4, 2008. *A*, Tidal cycle for March 4, 2008 showing 6-minute data from the Honolulu Harbor station #1612340; red marks indicate the times of measurements of barbette 3 vent height. *B*, Barbette 3 photographed on March 4, 2008 at 9:28 local time. The adopted value for the present height of the vent top is the average of four measurements. The local times, height above the water level (m) and smoothed tide levels (m MLLW) are as follows: (1) 7:51, 0.178, 0.118; (2) 8:38, 0.241, 0.073; (3) 9:07, 0.254, 0.057; (4) 10:45, 0.216, 0.077. The average vent elevation is 0.30 ± 0.01 m MLLW. The height of the border above the vent opening is 0.10 m. Applying the method used for older photos, the height of the vent top above the water level measured from this photo is 0.25 m. The tide level (smoothed) at 9:28 is 0.05 m MLLW, resulting in a vent elevation of 0.30 ± 0.01 m MLLW. Day 24,194.

Appendix F. Photographic Analysis of Historical and Recent Photographs of the USS *Arizona* Barbette 3 Port-Side Vent.

Note that all elevations are not adjusted for sea level rise. MLLW stands for mean lower low water.

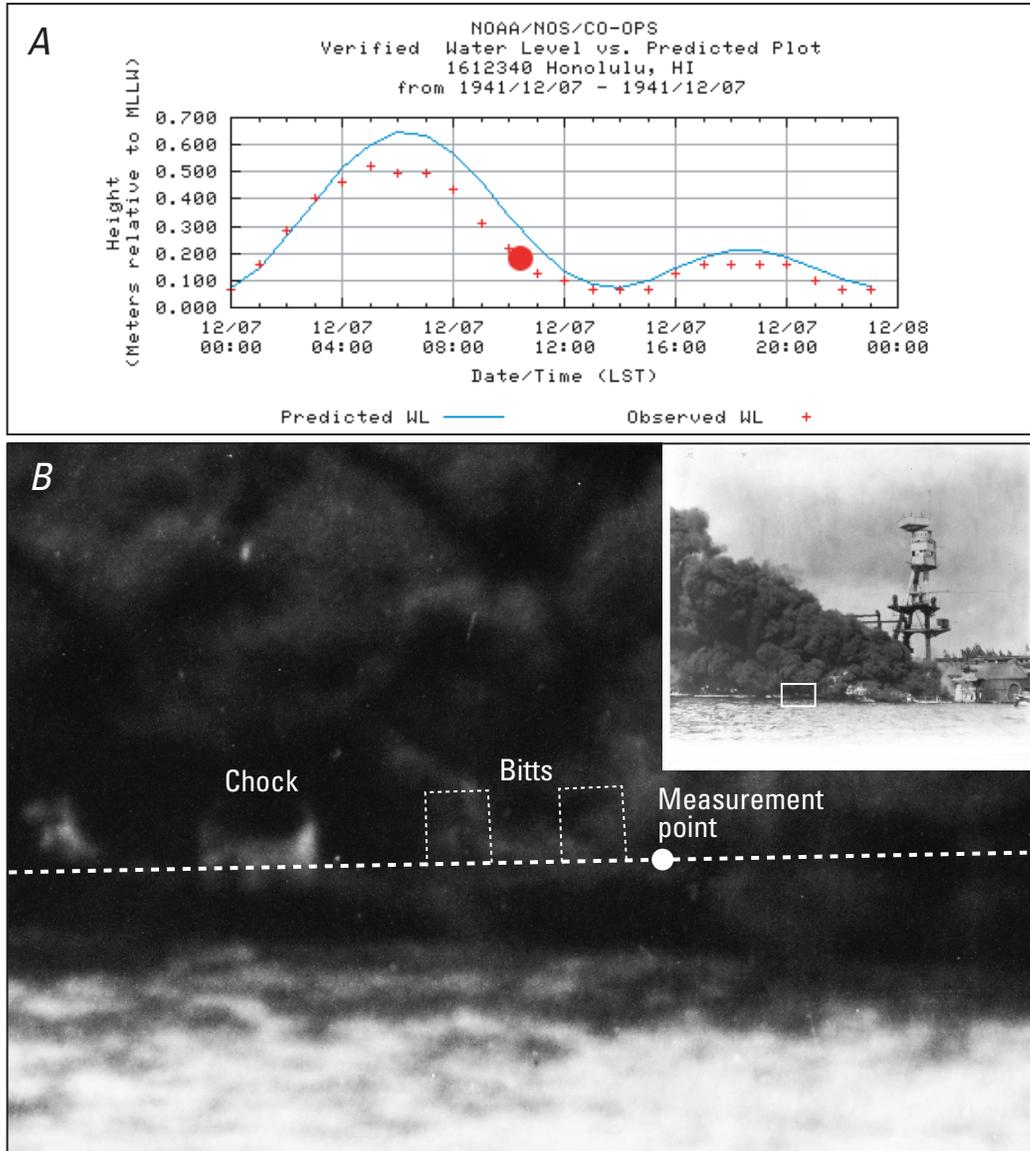


Figure F-1. Photo analysis for December 7, 1941. *A*, Tidal cycle for December 7, 1941. The red mark indicates the estimated time and tide for the photo. *B*, Photo PR-54A from the USS *Arizona* Memorial Museum Archives. The photo shows the midship port side of the USS *Arizona* while burning approx. 2.25 hours after sinking. The location of the enlargement is within the box in the thumbnail. The time is 10:21 and the tide level is 0.19 m MLLW, as determined in figure E-1. The chock is on the upper deck at frame 79; the measurement point is at the aft side of the obscured moorings bitts at approx. frame 83. This point is now at the aft side of the mooring platform forward of the Memorial structure. The largely obscured bulwark top edge is assumed to be tilting 2.6° forward, like barbette 3, as measured in figure E-1. The top of the chock is estimated to be 0.52±0.02 m above the bulwark. The bulwark at the chock is estimated to be 0.65±0.05 m above the water level. The measurement point is 3 frames (3.7 m) aft of the chock and projected to be 0.18 m higher. The bulwark at the measurement point is estimated to be at 1.02±0.08 m MLLW. Day 1.

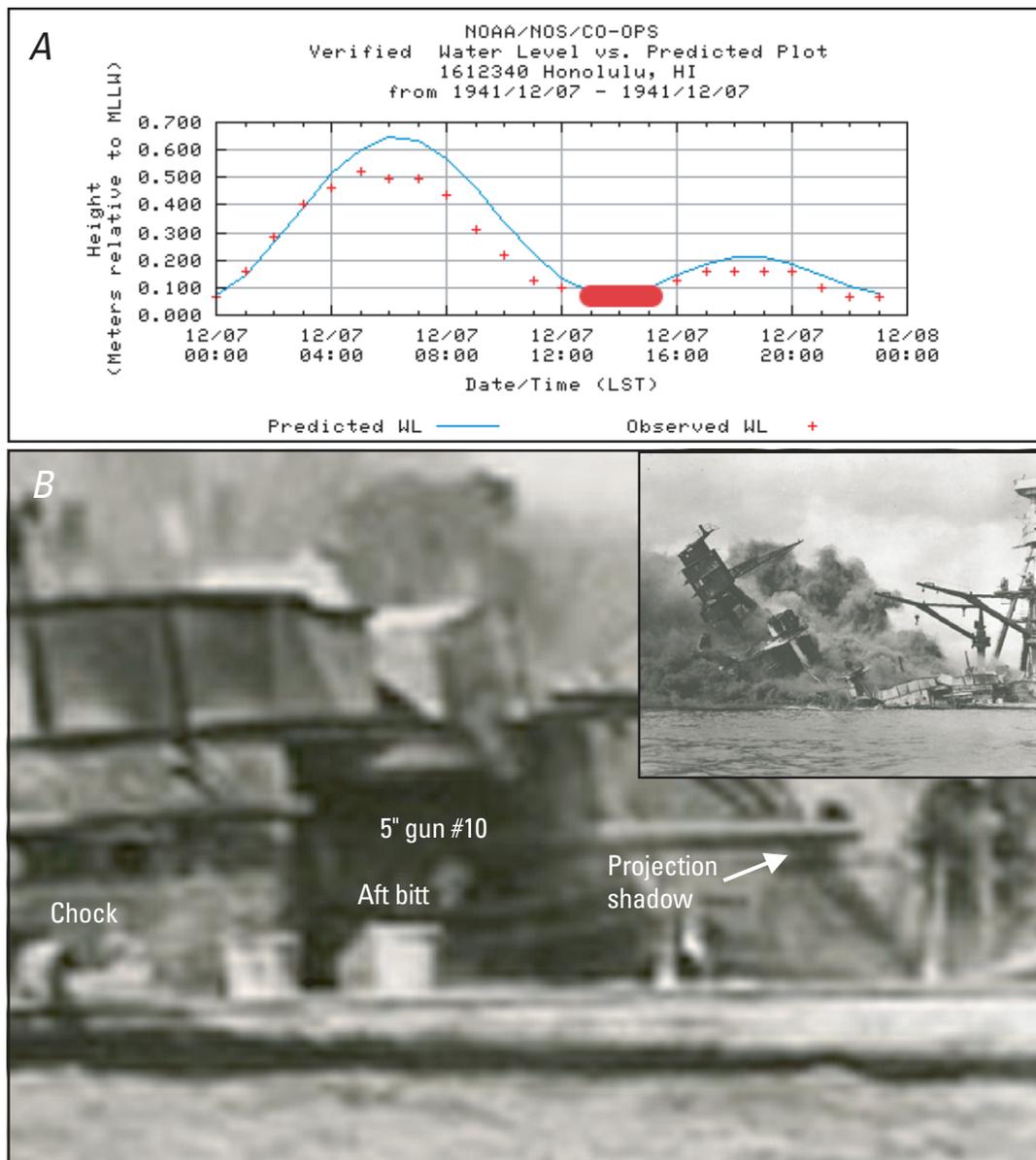


Figure F-2. Photo analysis for December 7, 1941. *A*, Tidal cycle for December 7, 1941. The red band indicates the estimated time range of the photo. *B*, A variant of photo NH 97380 dated December 7, 1941 from <http://www.pearlharbormemorial.com/>. The photo shows the midship port side of the *Arizona* while burning. The point of measurement is the top of the bulwark at the aft side of the two mooring bitts at frame 83. The visible height of the aft bitt is 0.58 ± 0.02 m as estimated from various photos. The bulwark is 0.77 ± 0.03 m above the water level, identical to a level measured from photo PR-67A, a photograph taken close in time to PR-52 (fig. E-2), which has an estimated time of 13:23. A triangular projection just forward of the base of the port side boat crane produces a shadow (arrowed), which indicates an afternoon time in the range of 13:00 to 15:00. The verified tide level for 13:00 to 15:00 is 0.07 m MLLW. The calculated bulwark elevation is 0.84 ± 0.05 m MLLW. The apparent longitudinal bulwark tilt is 1.2° forward. Day 1.1.

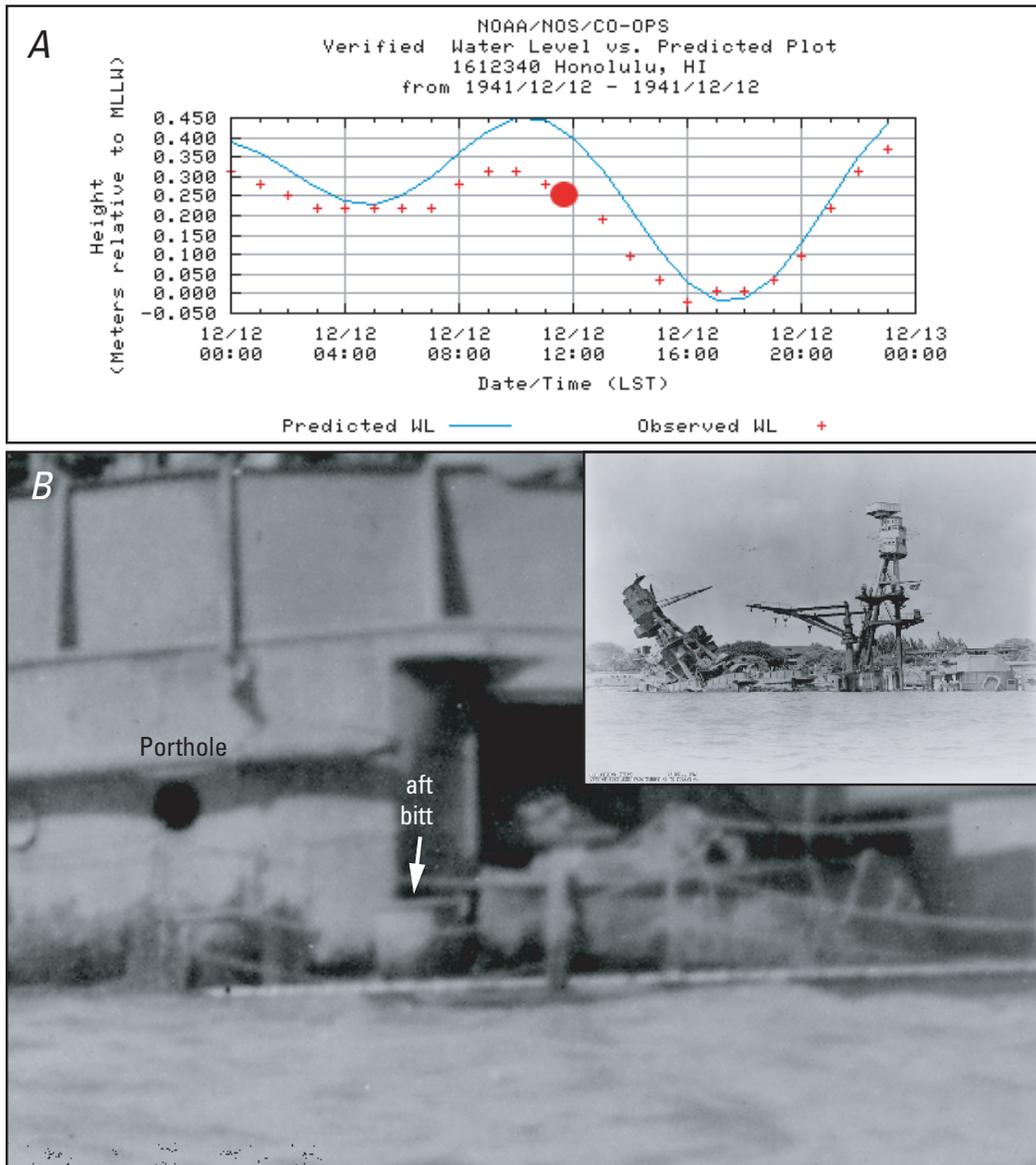


Figure F-3. Photo analysis for December 12, 1941. *A*, Tidal cycle for December 12, 1941; red mark indicates the estimated time and tide for the photo. *B*, Photo PR-16A from the USS *Arizona* Memorial Museum Archives with enhancement showing the port side midship aft bitt. The time is 11:39 and the tide height is 0.26 m MLLW as determined in fig. E-5. The height of the upper deck from the top of the bulwark to the half-round above is 2.59 ± 0.04 m as determined from a ship section in Foecke and others (2010). The height from the top of the porthole to the half-round at the deck above is estimated to be 0.93 m. The visible height of the aft mooring bitt is 0.58 ± 0.02 m and its top width is 0.69 ± 0.01 m. The top of the bulwark just aft of the bitt is 0.17 ± 0.03 m above the averaged water level, resulting in an elevation of 0.43 ± 0.03 m MLLW. Day 6.

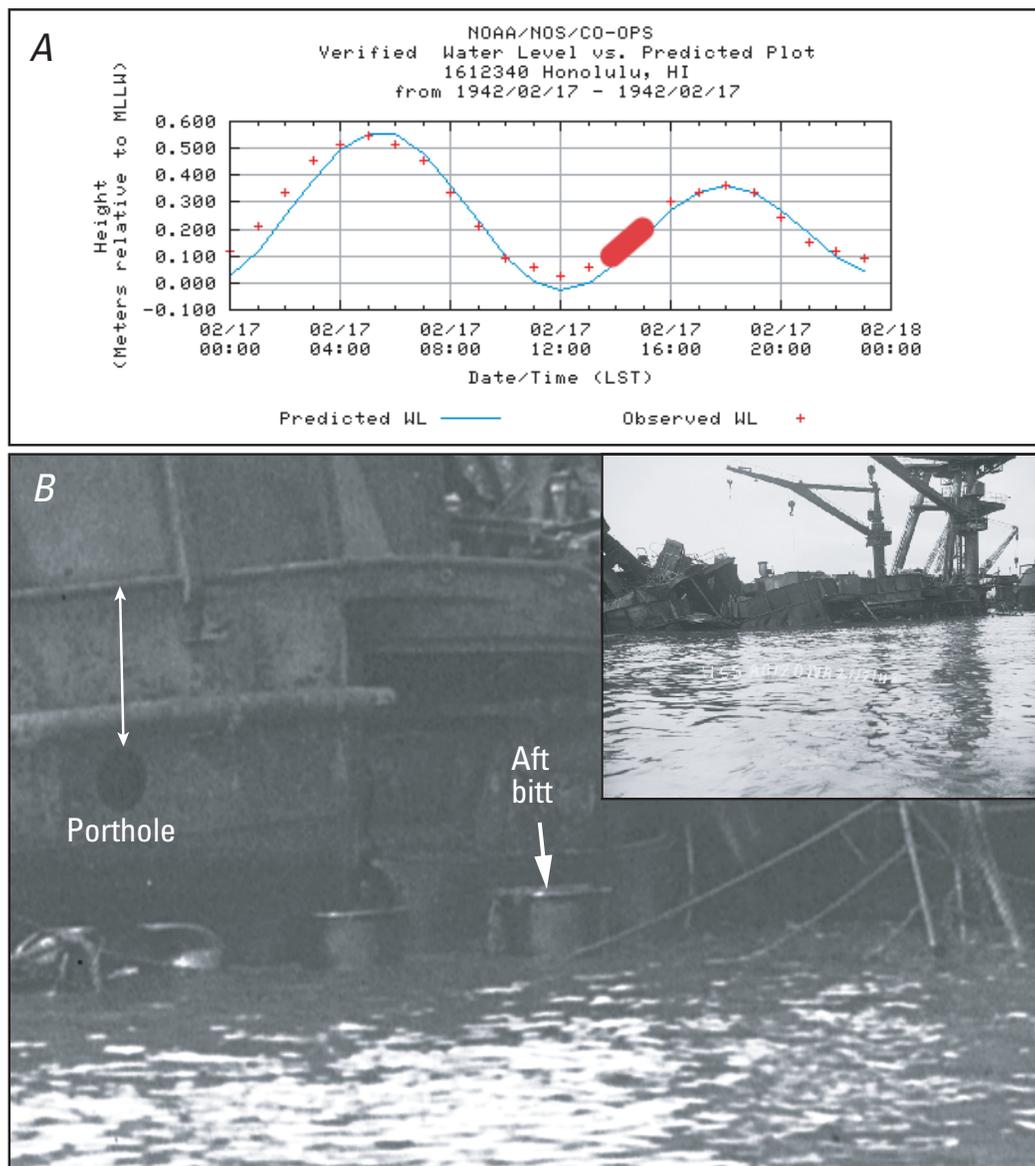


Figure F-4. Photo analysis for February 17, 1942. *A*, Tidal cycle for February 17, 1942. Red band indicates estimated time range for the photo. *B*, Photo dated February 17, 1942 obtained from the Submerged Resources Center, National Park Service. For scale (white arrow), the height from the top of the dark porthole to the half-round edge of the deck above is estimated to be 0.93 meters as stated in figure F-3. Approximately 0.37 m of the aft mooring bitt is emergent above the water level. The top of the aft bitt is 0.58 ± 0.02 m above the bulwark. The top of the bulwark is therefore approximately 0.21 m below the water level. The time is not tightly constrained. The triangular projection referred to in figure F-2 produces a shadow similar to that on December 7. This and other shadows suggest a sun elevation in the range of 54 to 43° , with corresponding times of 13:42 to 15:00 and tide levels of 0.21 and 0.10 m MLLW, respectively. The average bulwark elevation adjacent to the aft bitt for this time period is calculated to be -0.05 ± 0.06 m MLLW. The longitudinal bulwark tilt is estimated to be $0 \pm 0.4^\circ$. Day 73.

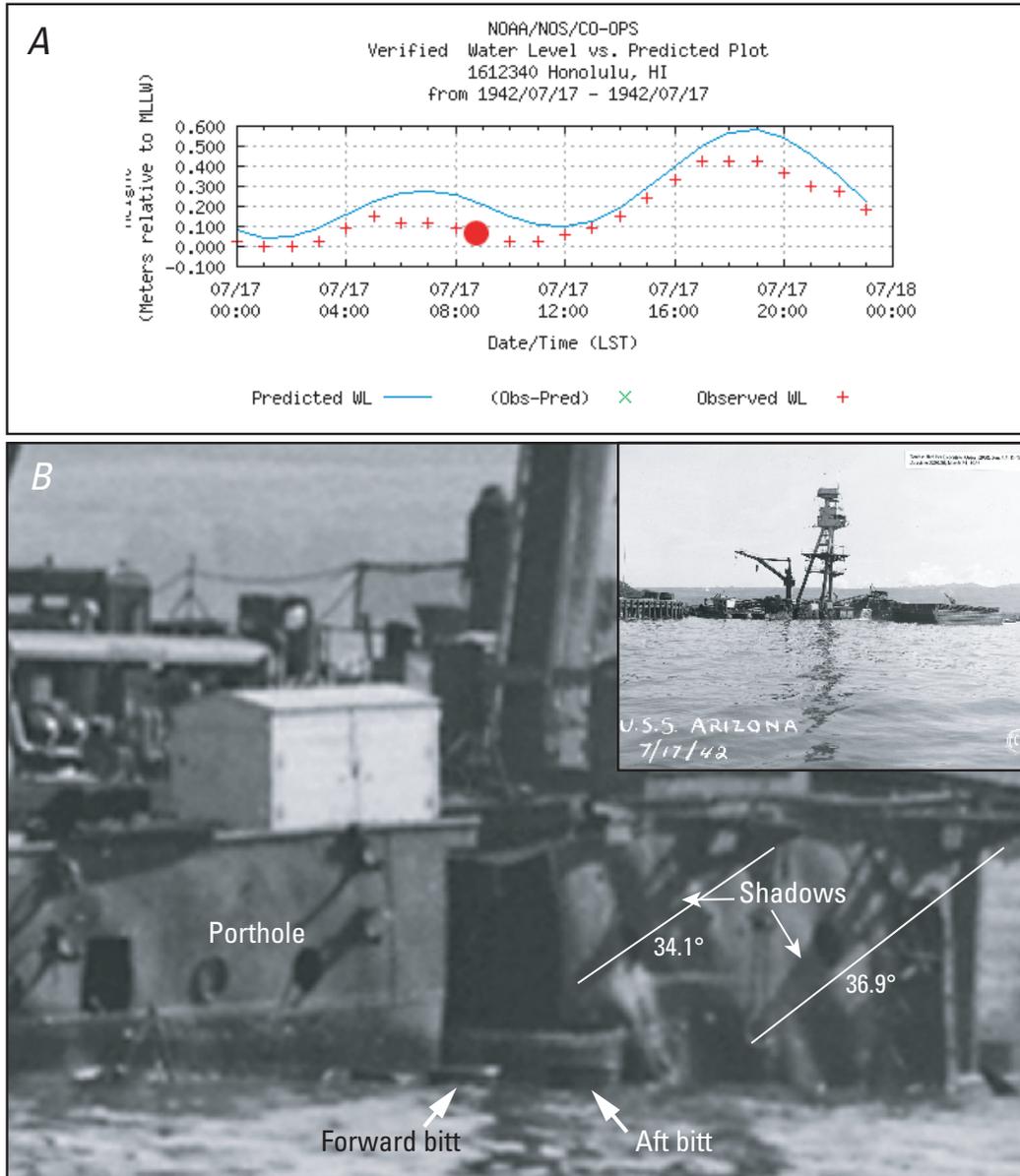


Figure F-5. Photo analysis for July 17, 1942. *A*, Tidal cycle for July 17, 1942; red mark indicates the estimated time and tide for the photo. *B*, Photo bearing the “FCP” icon dated July 17, 1942 obtained from <http://narademo.umiacs.umd.edu/> which shows the port side of the *Arizona* and the remaining superstructure. Shadows (arrowed) from projections indicate an apparent early morning sun elevation of 34.1 to 36.9° and an assumed time of 8:45. The tide elevation is 0.07 m MLLW. The tops of the mooring bitts are emergent above the water; the top of the chock may be just above the water. The top of the porthole is 0.93 m below the half-round of the edge of the deck above. The top of the aft bitt is 0.2 m above the water level, putting the adjacent bulwark top edge approx. 0.38 m below the water level. The elevation of the bulwark at the aft bitt is -0.31 ± 0.05 m MLLW. Based on the heights of the bitts and chock above the water level, the deck on which the bitts are located and bulwark are estimated to be sloping $0 \pm 0.5^\circ$. Day 223.

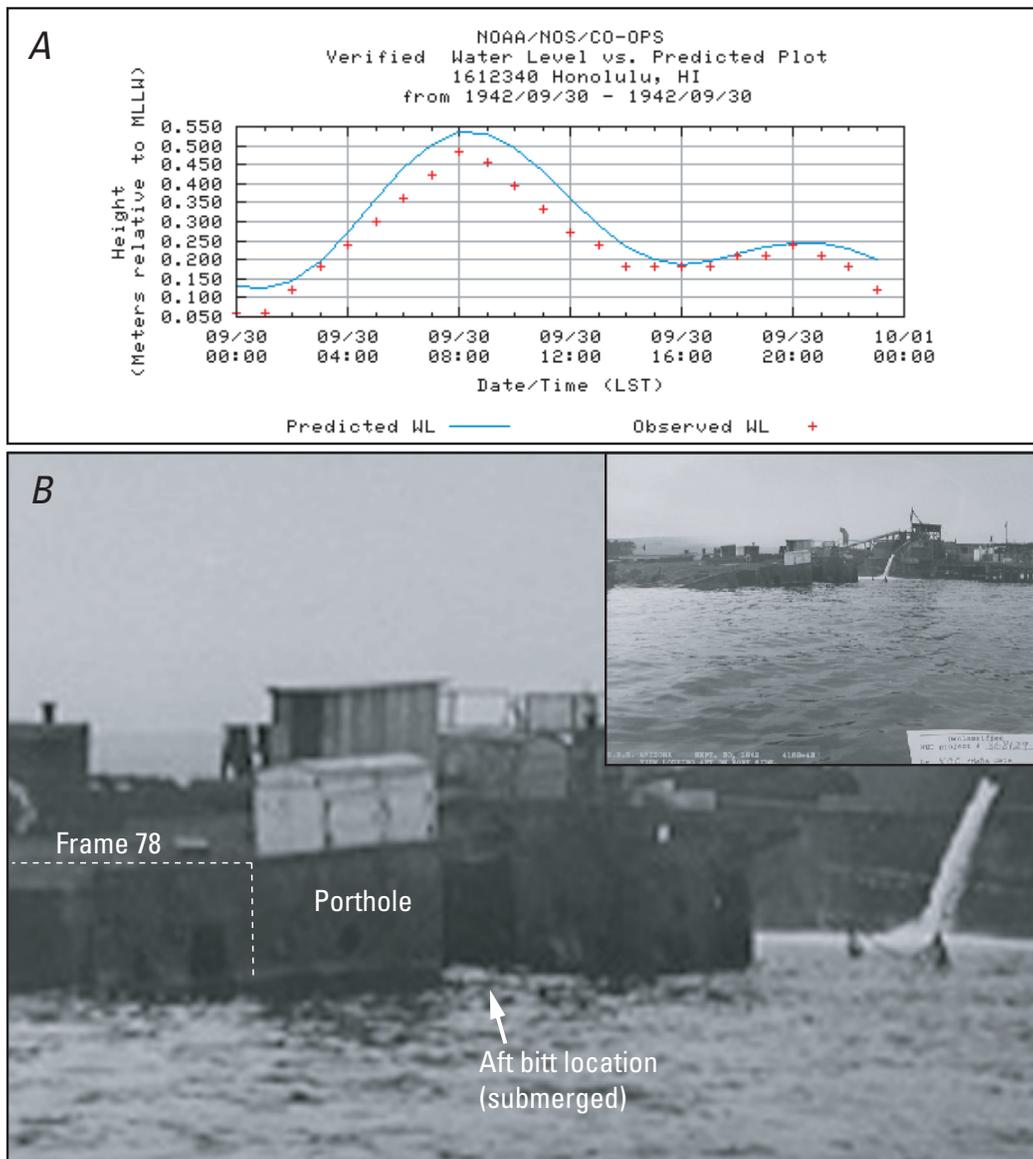


Figure F-6. Photo analysis for September 30, 1942. *A*, Tidal cycle for September 30, 1942. *B*, Photo 4152-42 dated September 30, 1942, which shows the port side of the USS *Arizona* and the remaining superstructure. Like photo 4160-42 (fig. E-10) also dated September 30, 1942, this photo lacks useful shadows and the time is unknown. The principle scale is the 0.93 m height from the top of the porthole to the deck edge above. The deck level is 1.33 m below the bottom of the porthole; the deck is therefore 0.92 m below the water level. The top of the bulwark is 0.66 m below water. The porthole is located about 2 m forward of the aft mooring bitt and the deck is sloping approx. 0 to 0.5° forward. The deck is estimated to be 0.02 m higher at the mooring bits, so the corrected depth to the bulwark is 0.64 ± 0.1 m below the water level. The tide range for the daylight hours is 0.485 (8:00) to 0.18 (14–17:00) m MLLW. Lacking shadows, assuming a mid-day (12:30) tide level of 0.26 m MLLW produces a tide-corrected elevation of -0.38 m MLLW with a daylight range of 0.23/–0.08 m. Day 298.

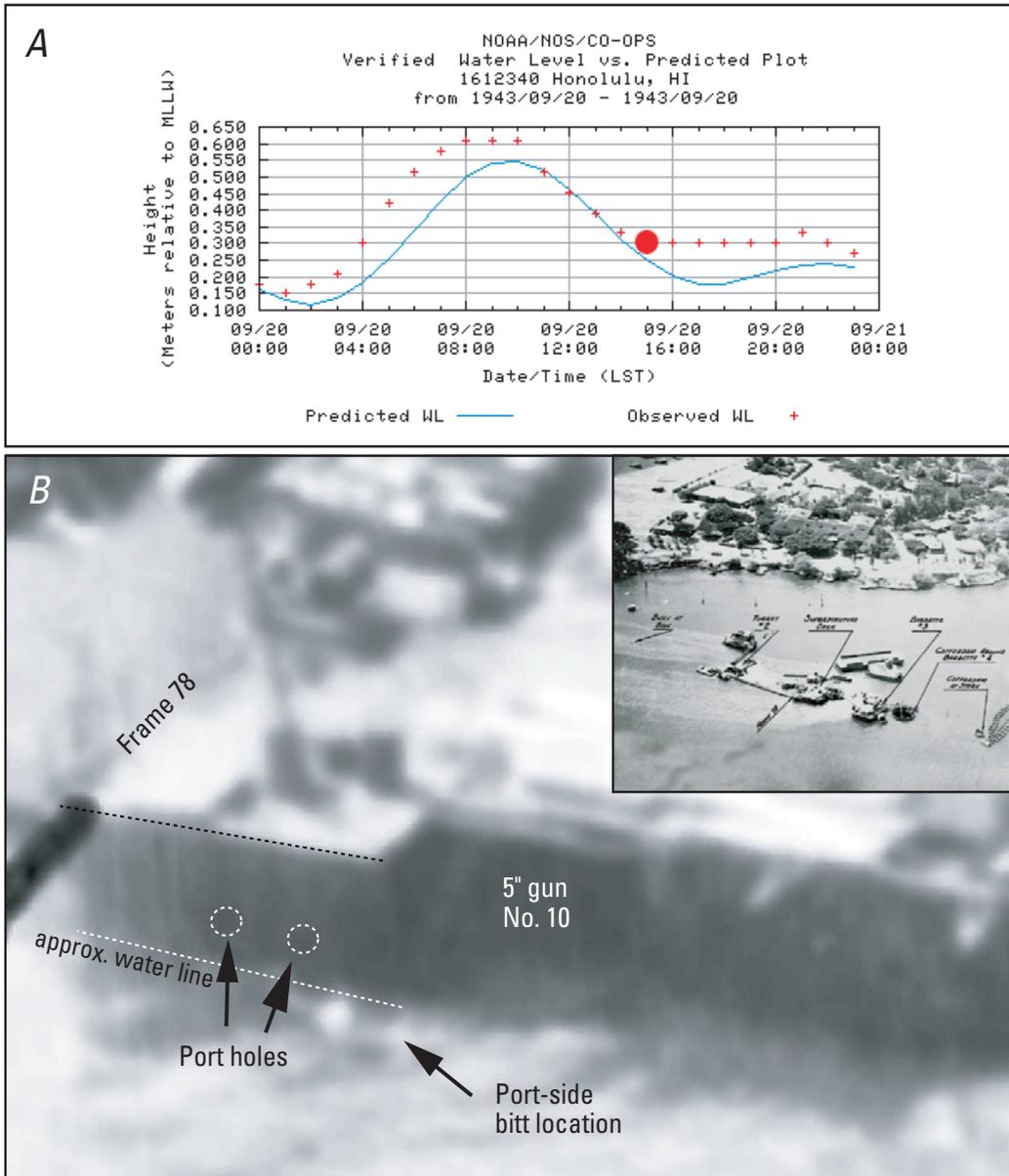


Figure F-7. Photo analysis for September 20, 1943. *A*, Tidal cycle for September 20, 1943; red mark indicates the estimated time and tide for the photo. *B*, Photo NASPH #119574 from USS *Arizona* Memorial Museum Archive dated September 20, 1943. Another version was found at <http://narademo.umiacs.umd.edu>, both of which are at the limit of usability when enlarged. The enlargement shows the location of the pair of bitts on the deck adjacent to the No. 10 5" gun emplacement. Shadows on the deck surface trend a small angle northeast of the axis of the ship, estimated to be about 10°. The sun azimuth is estimated to be 244°, corresponding to a time of approx. 15:00 and a tide height of 0.30 m MLLW. The porthole referenced in previous figures is the vague spot at the aft (right) arrow; visibility on the photo is better before its incorporation into this figure. Scales are as described in figure F-3. The bulwark at the aft porthole is estimated to be 0.76 m under water and 0.03 m higher at the bitt location due to deck tilt; the bitts would be submerged. The bulwark elevation is estimated to be -0.44 ± 0.12 m MLLW. Day 653.

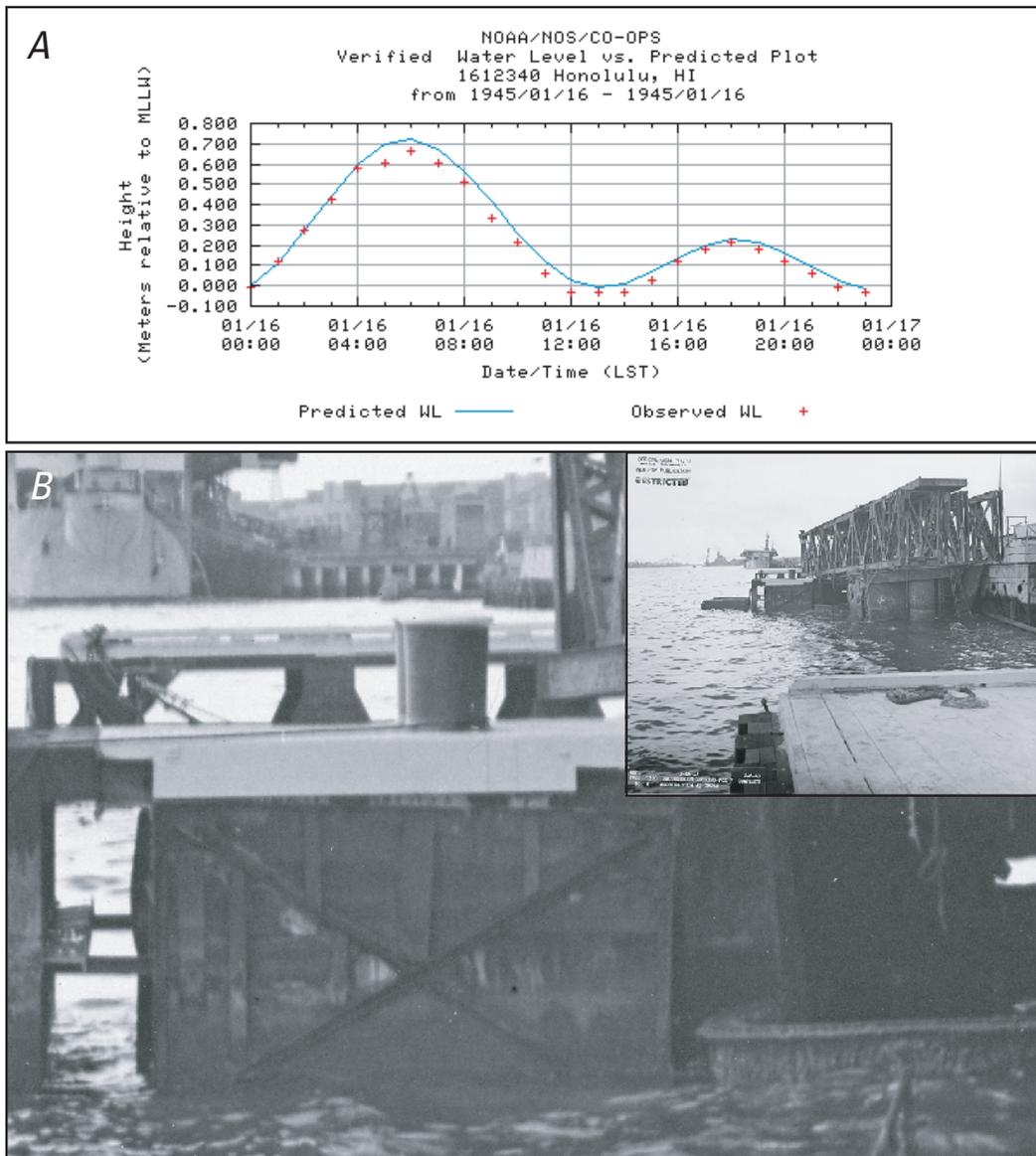


Figure F-8. Photo analysis for January 16, 1945. *A*, Tidal cycle for January 16, 1945. *B*, Photo 246-45 dated January 16, 1945 from the USS *Arizona* Memorial Museum Archives. The location of the pair of mooring bits on the midship port side is now occupied by a platform constructed between November, 1944 and the date of this photo. There are no shadows and the time is unknown. The intersection of the two angled braces (the “X”) on the aft side of the platform is an important reference point in this and later photos. The height from their intersection to the base of the overlying metal beam is estimated to be 0.85 ± 0.03 m. The height from the base of the beam to the concrete surface above is 0.39 ± 0.01 m. The height from the submerged edge of the deck on the bulwark to the concrete surface is estimated to be 2.32 m. The water level is estimated to be 0.49 ± 0.06 m above the bulwark level. The daylight tide variation for this date ranges from a high of 0.58 m (7:14, sunrise) to -0.033 m (12:00–14:00) MLLW. The bulwark elevation at the mid-day tide level would be -0.52 m MLLW, within a range for the day of $0.61/-0.06$ m. Day 1,137.

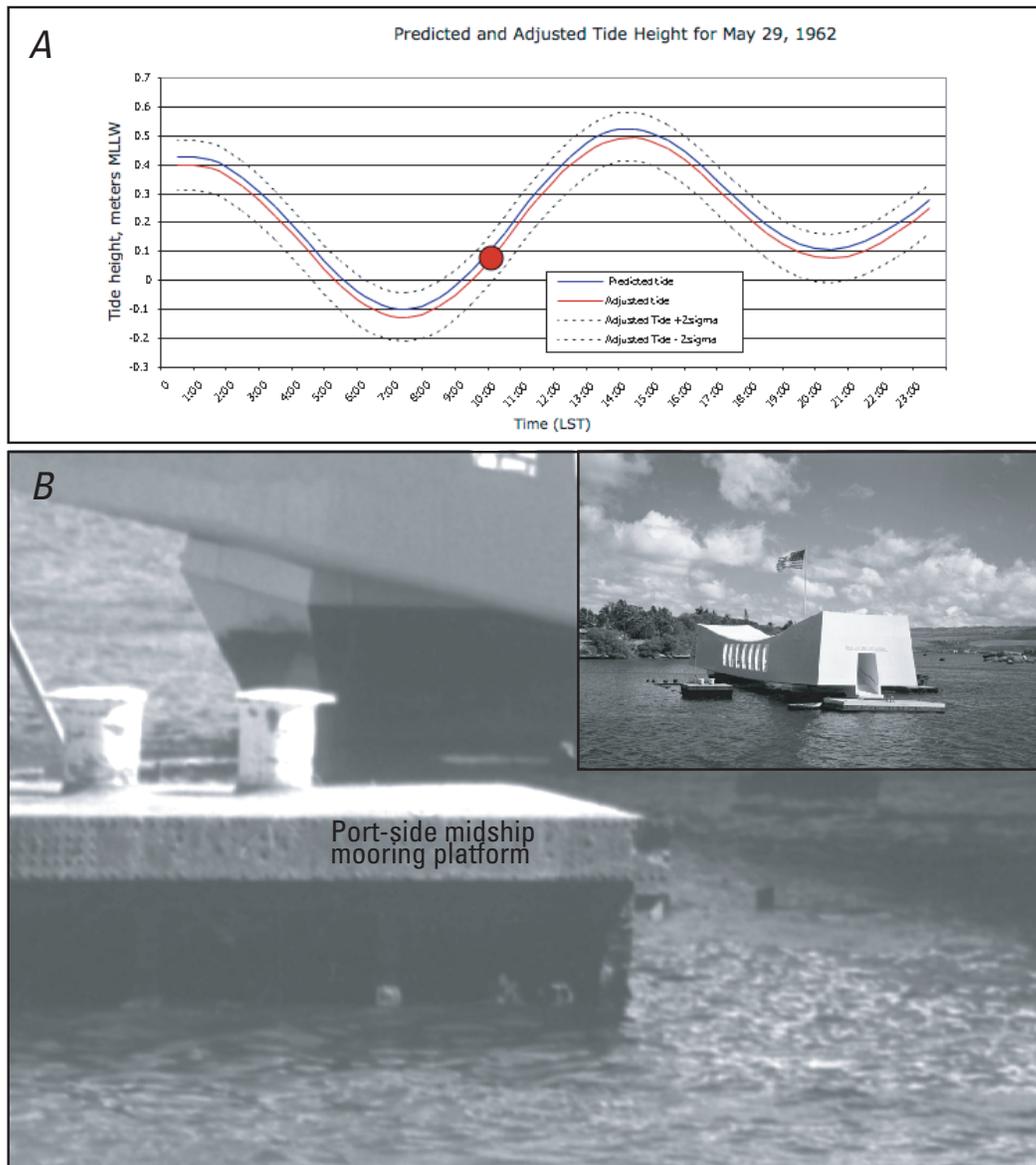


Figure F-9. Photo analysis for May 29, 1962. *A*, Tidal cycle for May 29, 1962; red mark indicates the estimated time and tide for the photo. The blue, upper solid, line is the predicted tide from the WWW Tide and Current Predictor at <http://tbone.biol.sc.edu/tide/tideshow.cgi>. The red, lower solid, line is the adjusted tide 0.03 m lower. The dashed lines are ± 2 sigma. *B*, Photo USN1061040 (#428-N-1061040 at the National Archives) dated May 29, 1962, the day before the dedication of the Memorial. The flagpole shadow on the Memorial roof has an azimuth of approx. 81.3° , indicating a time of 9:35. The adjusted tide height at 9:35 is 0.08 m MLLW. The vertical face of the port side of the platform near the aft end is 0.42 ± 0.01 m high. The water level is estimated to be 0.86 m below the bottom edge of the face. The top of the platform at the aft end is measured to be 2.32 ± 0.03 m above the edge of the hull on the bulwark. The bulwark elevation is estimated to be -0.96 ± 0.1 m MLLW. Day 7,113.

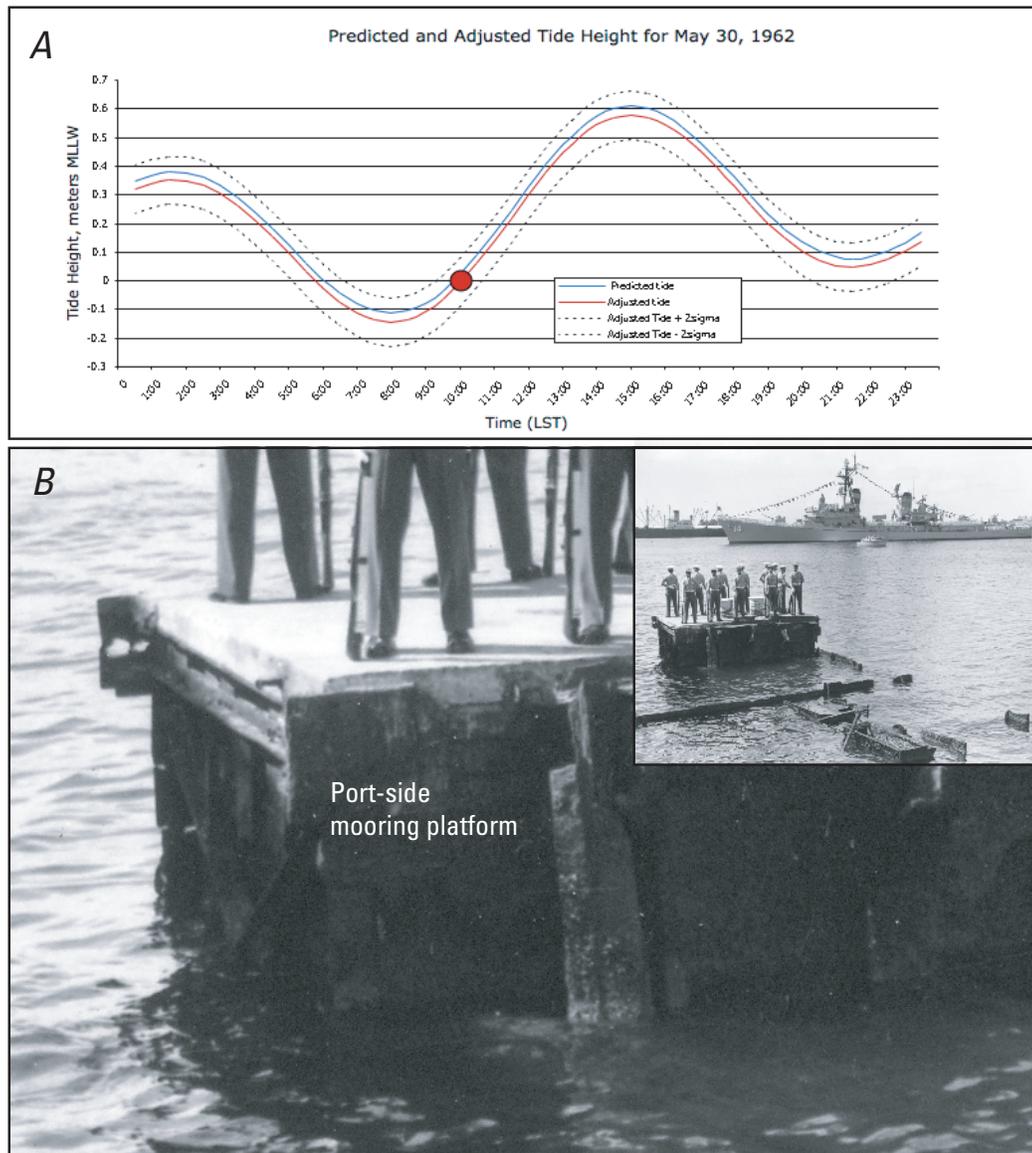


Figure F-10. Photo analysis for May 30, 1962. *A*, Tidal cycle for May 30, 1962; red mark indicates the estimated time and tide for the photo. The blue, upper solid, line is the predicted tide from the WWW Tide and Current Predictor at <http://tbone.biol.sc.edu/tide/tideshow.cgi>. The red, lower solid, line is the adjusted tide 0.03 m lower. The dashed lines are ± 2 sigma. *B*, Photo HIST 1 dated May 30, 1962 from the USS *Arizona* Memorial Museum Archives showing part of the dedication activities for the new memorial. The best time indicator is the shadow from the forward mooring bitt on the platform, which shows a sun elevation of approx. 50° and a time of 9:37. The predicted tide level is 0.04 m MLLW; the adjusted height is 0.012 ± 0.08 m MLLW. The aft end of the platform is 2.32 m above the edge of the hull. The base of the "V" of the angled brace on the aft side, the top of the "X" in figure F-8, is 0.85 ± 0.03 m below the base of the horizontal metal beam. The water level relative to the "V" is vague, estimated to be in the range of 0.1 to 0.14 m below the "V." The water level is assumed to be 0.13 ± 0.02 m below the "V." The edge of the hull at the bulwark is 1.08 m below the "V." The bulwark is estimated to be at an elevation of -0.94 ± 0.11 m MLLW. Day 7,114.

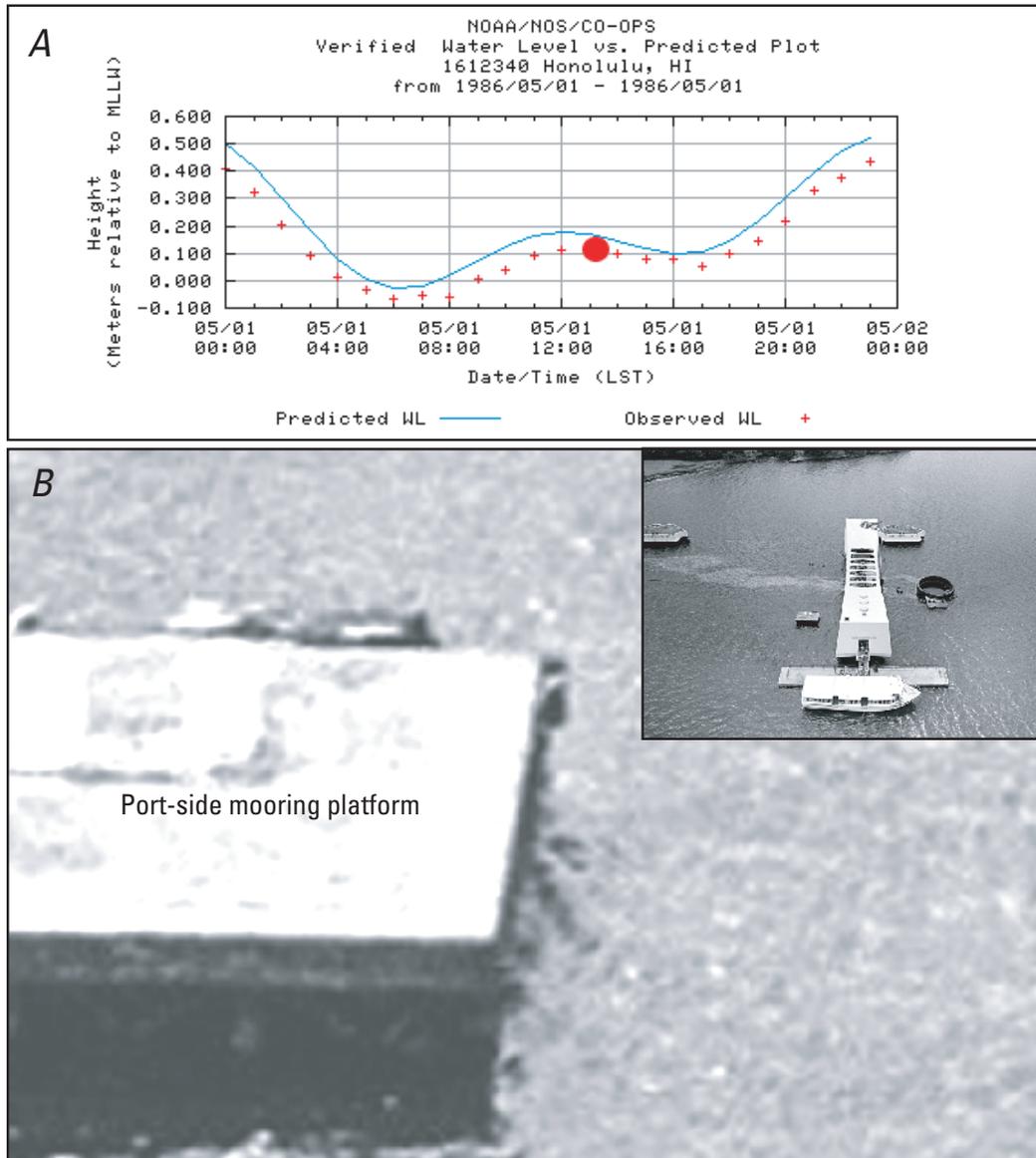


Figure F-11. Photo analysis for May 1, 1986. *A*, Tidal cycle for May 1, 1986; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SN-86-08980 dated May 1, 1986 obtained from the former Defense Visual Information Center (no longer available at <http://www.defenseimagery.mil/index.htm>). The time is 13:11 and tide is 0.12 m MLLW, as determined in figure E-21. The vertical face of the port side of the platform is 0.42 ± 0.01 m high near the aft end. The water level is estimated to be 0.72 ± 0.05 m below the top surface of the platform. The edge of the hull at the aft end of the platform is 2.32 ± 0.03 m below the platform surface. The water is estimated to be 1.6 m deep. The bulwark is at an estimated elevation of -1.07 ± 0.05 m MLLW. Day 16,217.

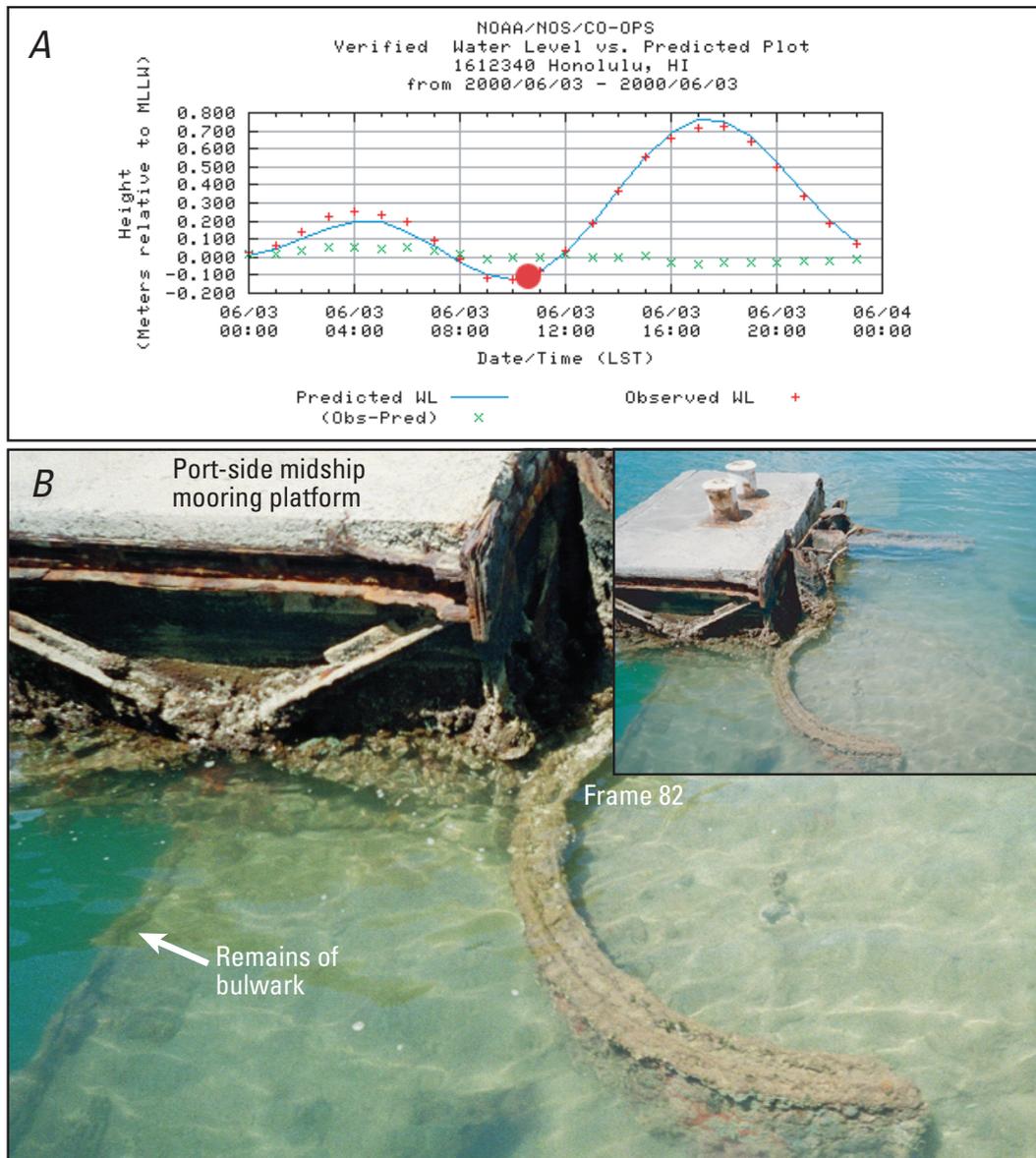


Figure F-12. Photo analysis for June 3, 2000. *A*, Tidal cycle for June 3, 2000; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SC-02-05623 from <http://www.defenseimagery.mil/index.htm> dated June 3, 2000. The shadows of the mooring bitts on the platform indicates a sun azimuth broadly in the range $80 \pm 5^\circ$ and have little sensitivity to time over several hours. The sun elevation is estimated to be 65° , corresponding to a time of 10:42 and a tide elevation of -0.094 m MLLW. Plus/minus 5° in elevation equals ± 22 minutes and ± 0.015 m in tide level. The water level is below the intersection of the X-shaped braces on the aft side of the platform. The edge of the deck and bulwark are visible below water. It is not certain how much of the original height of the bulwark is still present. The bulwark is estimated to be 1.08 m below the X-intersection and the water level is estimated to be 0.08 ± 0.01 m below the x-intersection. The bulwark elevation is estimated to be -1.09 ± 0.05 m MLLW. Day 21,364.

Appendix G. Photograph Analysis of Historical and Recent Photographs of the USS *Arizona* Midship Starboard Side

Note that all elevations are not adjusted for sea level rise. MLLW stands for mean lower low water.

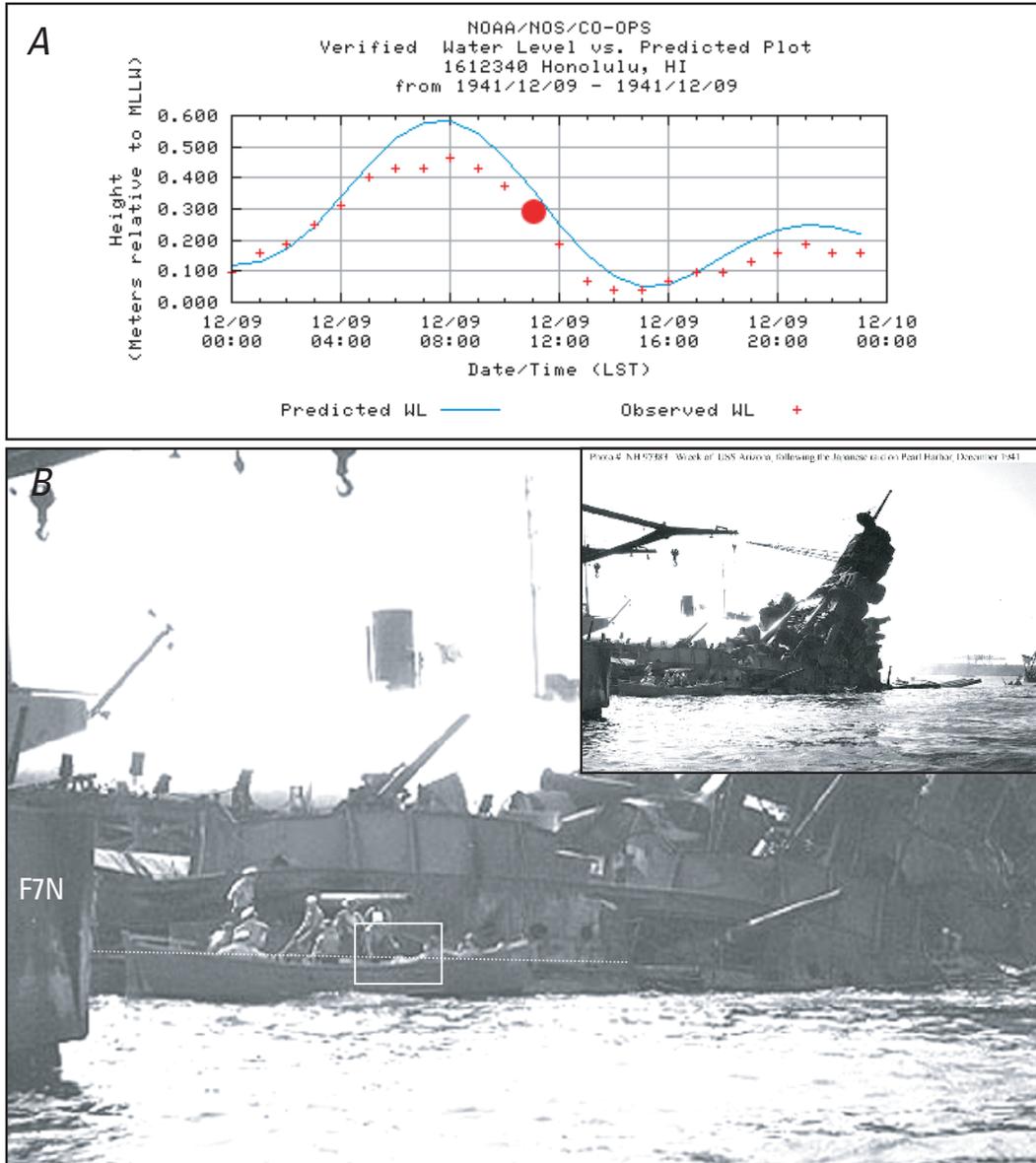


Figure G-1. Photo analysis for December 9, 1941. *A*, Tidal cycle for December 9, 1941; red mark indicates estimated time and tide of photo. *B*, Photo #NH 97383 obtained from <http://www.history.navy.mil/> dated December 9, 1941. The USS *Tern* and *Navajo* are on the port side of the *Arizona* spraying water. This is the earliest useful view found for the starboard side. The pair of mooring bits still visible today on the starboard side of the upper deck is located within the white box behind the small boat. See text for more discussion of this photo; the time for this photo is assumed to be 11:05 (see fig. 32). The tide elevation at 11:05 is 0.27 m MLLW. Plus/minus 30 minutes is ± 0.05 meters in tide level. The distance from the top of the portholes to the half-round at the deck above is estimated to be 0.93 m. The upper deck bulwark, highlighted with dashed line, at the mooring bits is estimated to be 0.67 ± 0.04 m above the water level, corresponding to an elevation of 0.94 ± 0.07 m MLLW. The bulwark has a forward tilt of about 1.1° . The deck edge above the upper deck has a forward tilt of about 3° . Day 3.

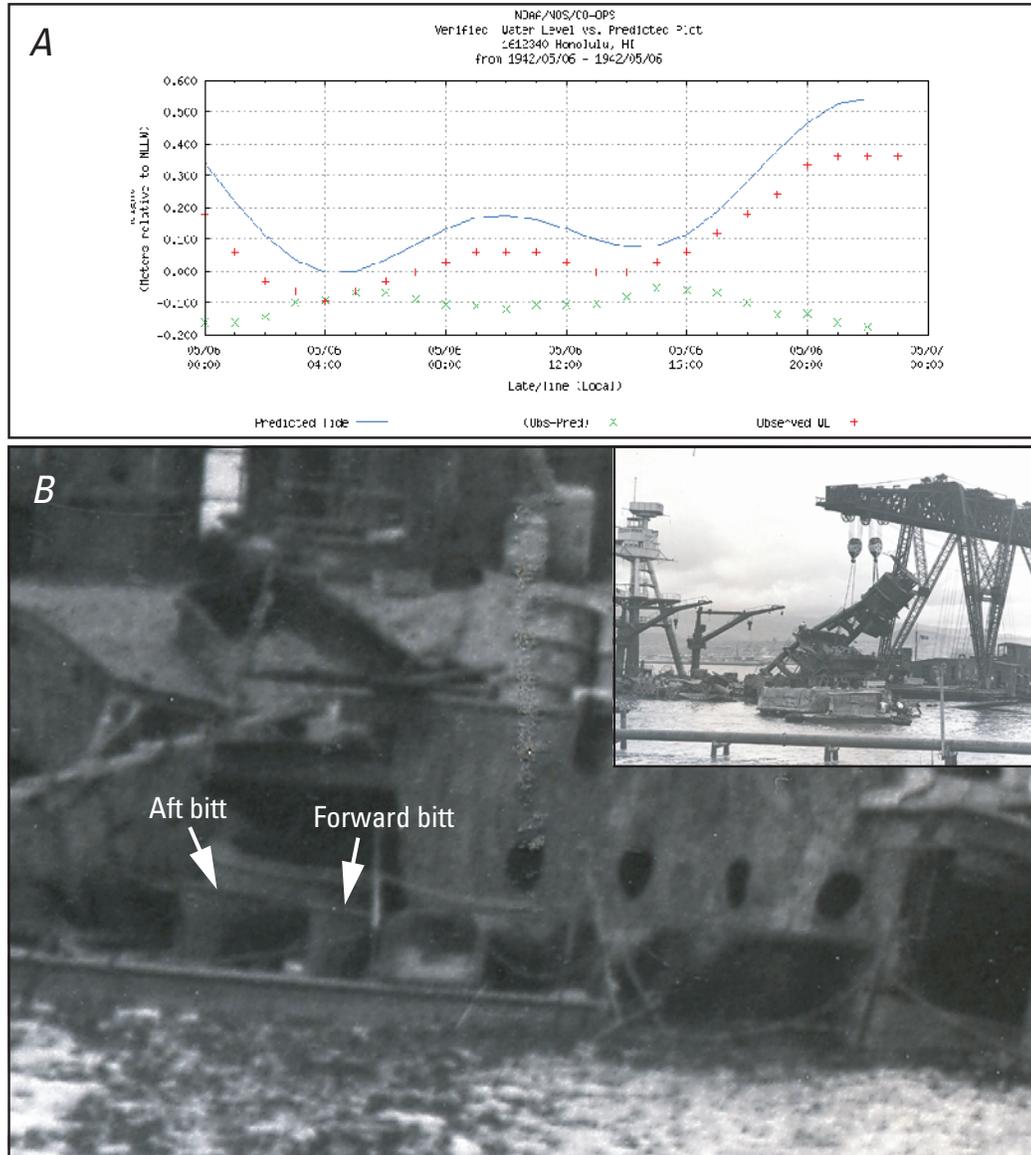


Figure G-2. Photo analysis for May 6, 1942. *A*, Tidal cycle for May 6, 1942. *B*, Unidentified photo obtained from the National Park Service, Submerged Resources Center. The National Park Service (<http://www.pastfoundation.org/Arizona/FAQ.htm>) states that the foremast was cut away and removed on May 5, 1942. This date is cited in Stillwell (1991), p. 278. A photo dated May 6, 1942 at <http://www.navsource.org/archives/01/39b.htm> shows the foremast laying on a barge. The Salvage Diary states that the top half of the foremast was removed on May 6. There are no useful shadows in the image and the time is unknown. The two tilted starboard midship bits are visible at the bulwark of the upper deck at the left side of the enlargement. For scale, the distance from the top of the portholes to the deck above is estimated to be 0.93 m. The diameter of the aft bitt is estimated to be 0.69 ± 0.01 m. These provide a consistent scale to estimate the height of the bulwark above water at the aft bitt to be 0.33 m. The daylight tide range for May 6 is -0.003 (7:00) to 0.18 m (18:00). The midpoint of this tide range is 0.09 m MLLW, corresponding to a bulwark elevation of 0.42 m MLLW and a range of ± 0.1 . Day 151.

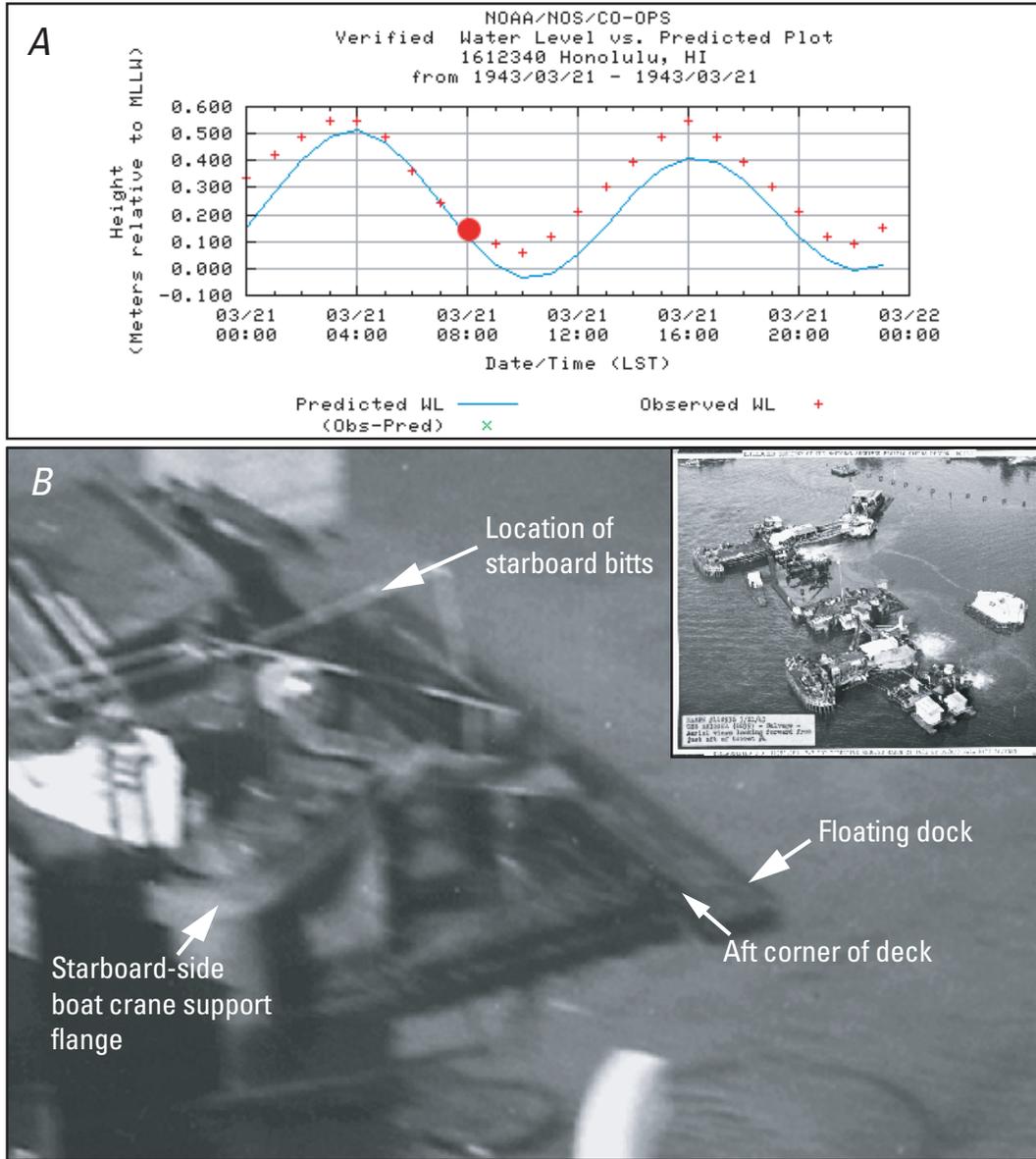


Figure G-3. Photo analysis for March 21, 1943. *A*, Tidal cycle for March 21, 1943; red mark indicates estimated time and tide of photo. *B*, Photo NASPH#118536 dated March 21, 1943 obtained from the Submerged Resources Center, National Park Service. As for figure E-13, the photo quality is near the limit of usability. The time is estimated to be 8:14 and the tide level 0.14 m MLLW. The upper deck near the starboard bitts is above the water level. For scale near the upper deck area of interest, the support flange around the base of the boat cranes, measured from photo PR-16A, is estimated to be 0.53 m wide. The starboard aft corner of the upper deck is estimated to be 0.40 ± 0.05 m above the water surface. The measurement point at the starboard mooring bitts is calculated to be approximately 6.9 m forward of the aft corner of the deck. The starboard upper deck edge slope is low, estimated to be 0.5° forward, similar to the port side, resulting in a height difference of approx. 0.06 m lower than the aft corner. The deck at the bitts is estimated to be 0.22 m above the water and at an elevation of 0.37 ± 0.10 m MLLW. Day 469.

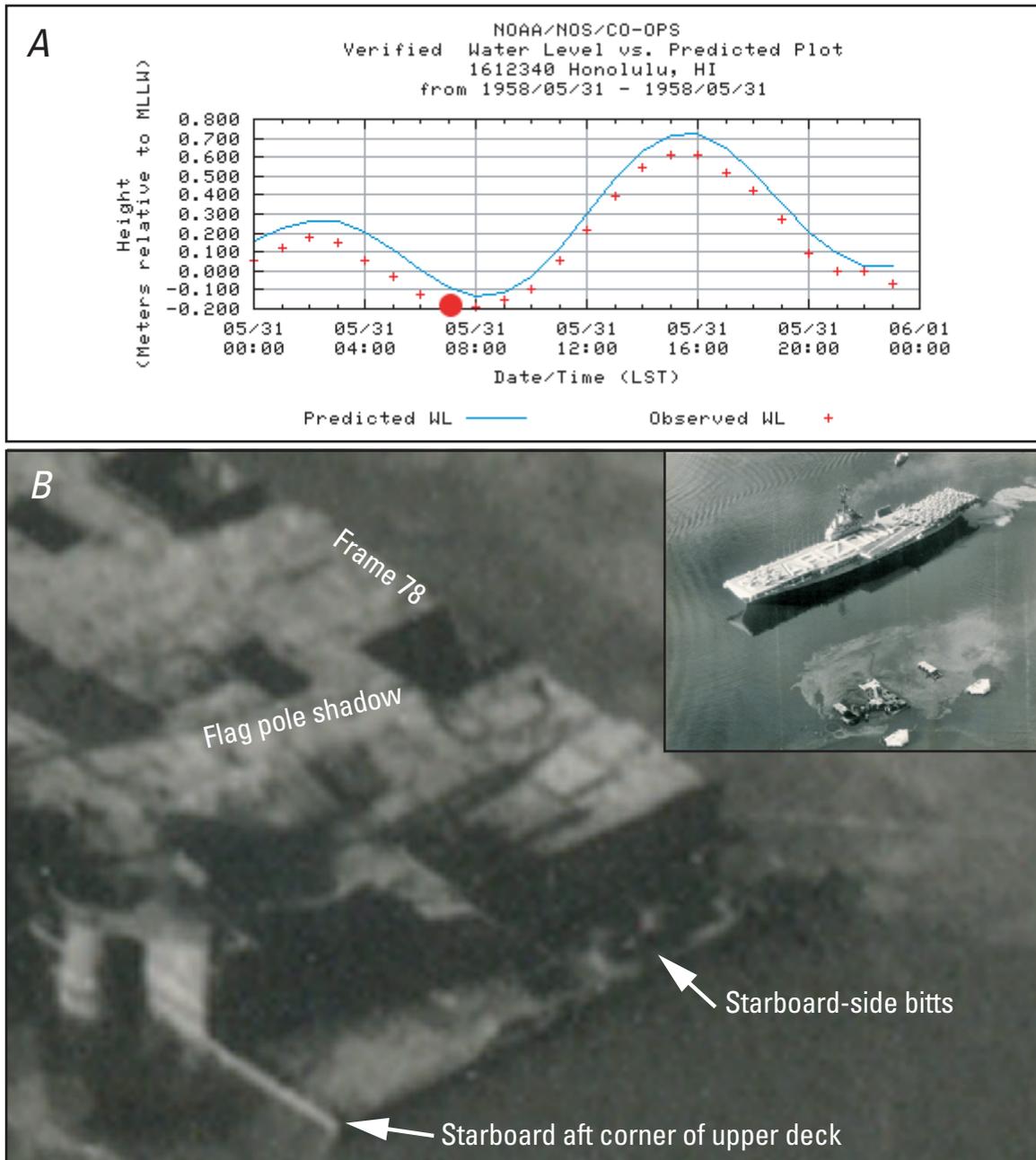


Figure G-4. Photo analysis for May 31, 1958. *A*, Tidal cycle for March 4, 2008; red mark indicates the time and tide for the photo. *B*, Photo obtained from <http://www.uss-bennington.org/phz-58-ben-az.html> showing the USS Bennington (CV-20) passing by the USS *Arizona* on Memorial Day, May 31, 1958. The upper deck at the starboard side bitts is above water and the bitts themselves are marginally visible. Scale for the photo is based on several features of known or estimated dimensions as described in figure E-16. As determined in figure E-16, the time is estimated to be 7:03 and the tide level -0.19 m MLLW. The bulwark at the bitts is estimated to be 0.26 ± 0.07 m above the water level. The calculated bulwark elevation is 0.08 ± 0.07 m MLLW. Day 6,020.

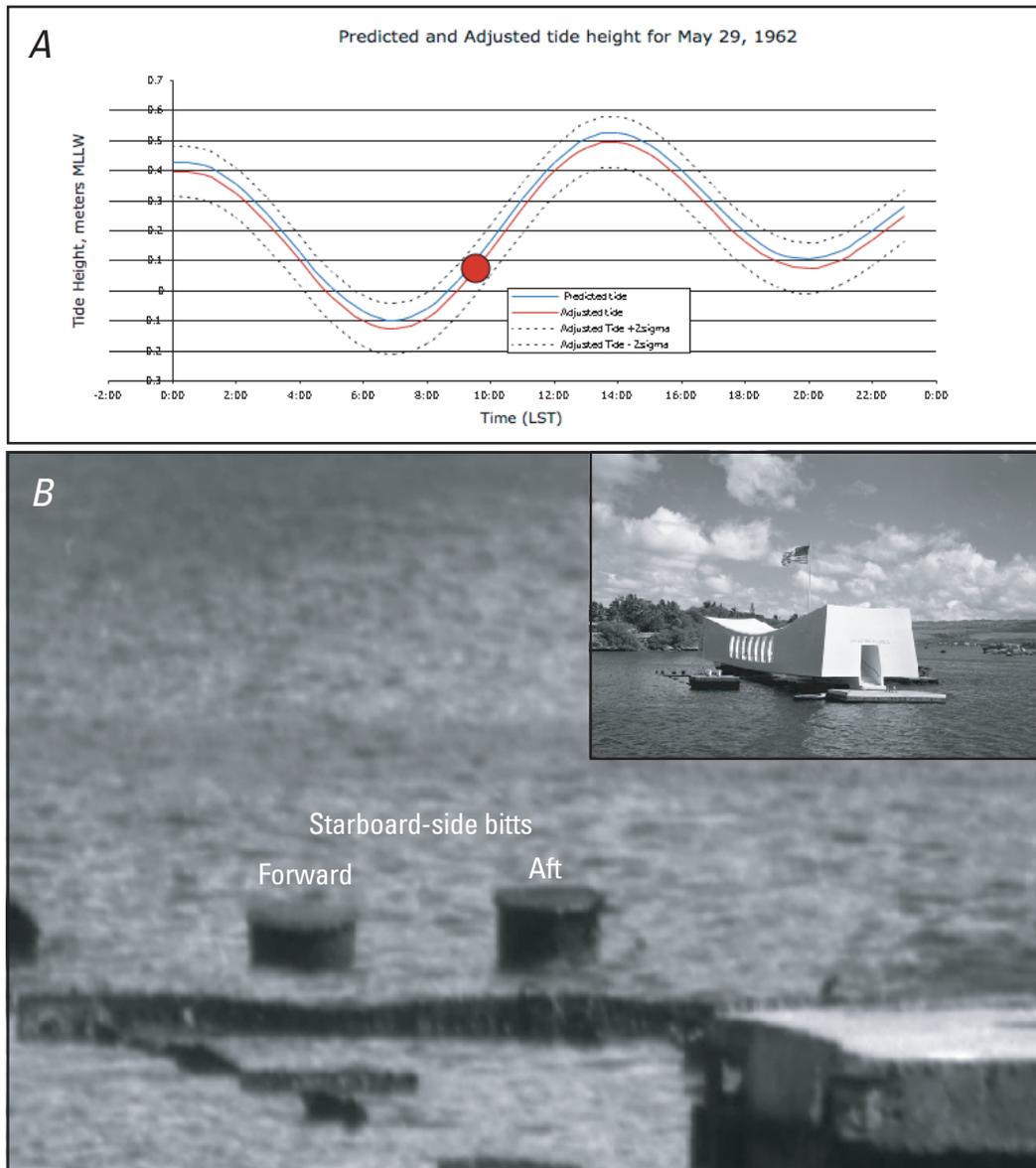


Figure G-5. Photo analysis for May 29, 1962. *A*, No verified tidal data are available for this date. Tidal cycle for May 29, 1962; red mark indicates the estimated time and tide for the photo. The blue, upper solid, line is the predicted tide from the WWW Tide and Current Predictor at <http://tbone.biol.sc.edu/tide/tideshow.cgi>. The red, lower solid, line is the adjusted tide 0.03 m lower. The dashed lines are $\pm 2\sigma$, equal to ± 0.084 m. *B*, Photo USN1061040 (#428-N-1061040 at the National Archives) dated May 29, 1962, the day before the dedication of the Memorial. The two starboard bitts are emergent above the water. The estimated time is 9:35. The unadjusted predicted tide level obtained from the University of South Carolina WWW Tide and Current Predictor is 0.11 m MLLW; adjusted tide level is 0.08 m MLLW. The aft bitt is 0.69 ± 0.01 m in diameter, measured on November 17, 2009. The starboard side (the high side) of the aft bitt is estimated to be 0.52 ± 0.02 m above the water level and at 0.61 ± 0.1 m MLLW. Based on measurements on March 4, 2008, the top of the aft bitt is 0.53 m above the adjacent outer edge of the existing deck. The bulwark is calculated to be at 0.07 ± 0.1 m MLLW. Day 7,113.

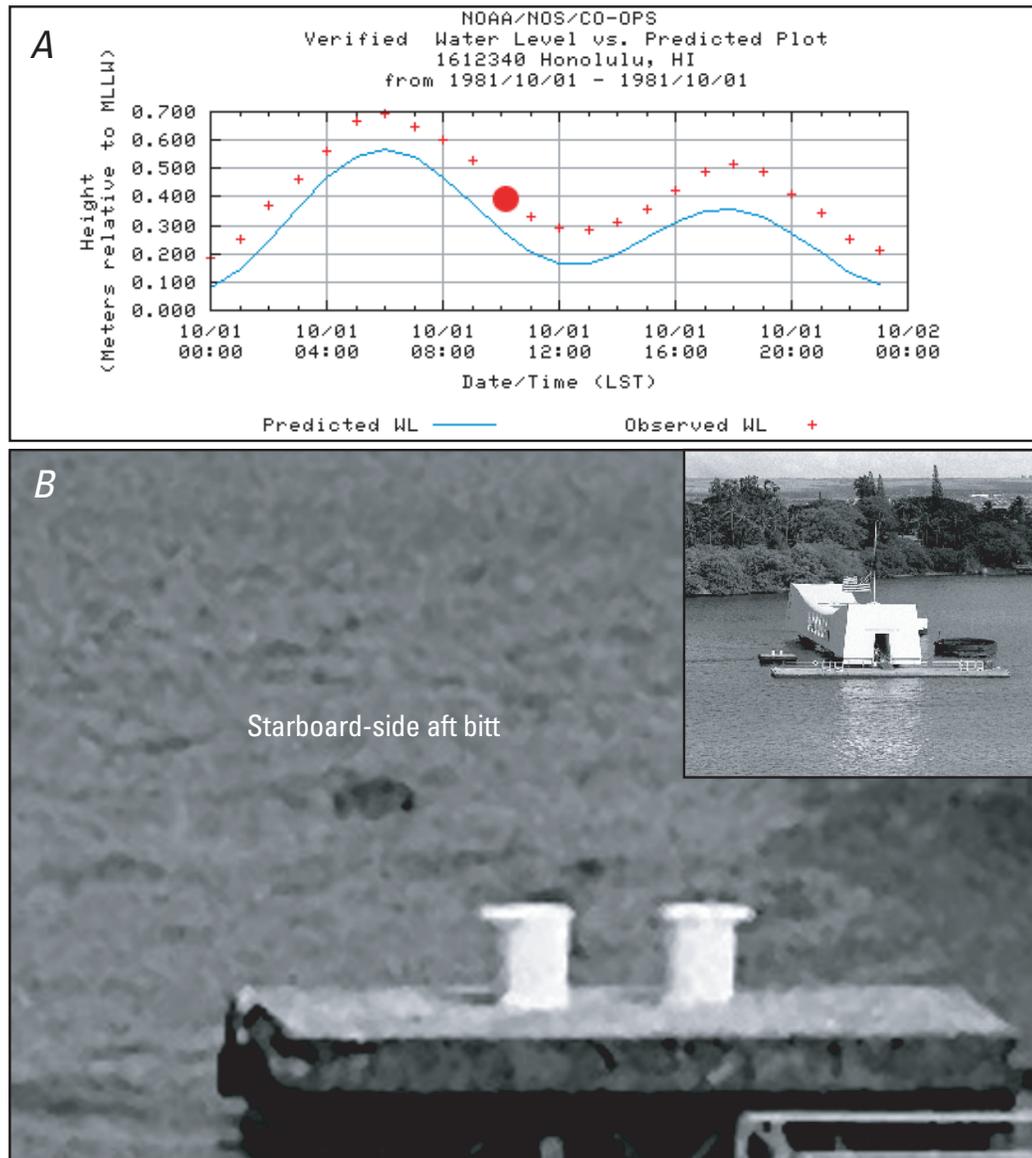


Figure G-6. Photo analysis for October 1, 1981. *A*, Tidal cycle for October 1, 1981; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SN-82-01556 dated October 1, 1981 from <http://www.defenseimagery.mil/index.htm>. The time is 10:11 and the tide level is 0.39 m MLLW. Only the top of what is assumed to be the aft bitt on the starboard side is visible. This is consistent with the relative heights of the forward bitt and the chock. The top of the aft bitt is approx. 0.1 m higher than the top of the forward bit, as measured from recent photographs. The slope of the top surface of the aft bit is approx. 12° to port and the height from the rounded rim on the low side to the highest point is about 0.14 m. If the top of the forward bitt is just under water, the top of the aft bitt is estimated to be 0.10 m above the water level, consistent with the view in the photograph, and giving the top an elevation of 0.49 ± 0.03 m MLLW. The edge of the deck is 0.53 meters below the top of the aft bitt, as measured on March 4, 2008. The deck edge is calculated to be at -0.04 ± 0.03 m MLLW. Day 14,544.

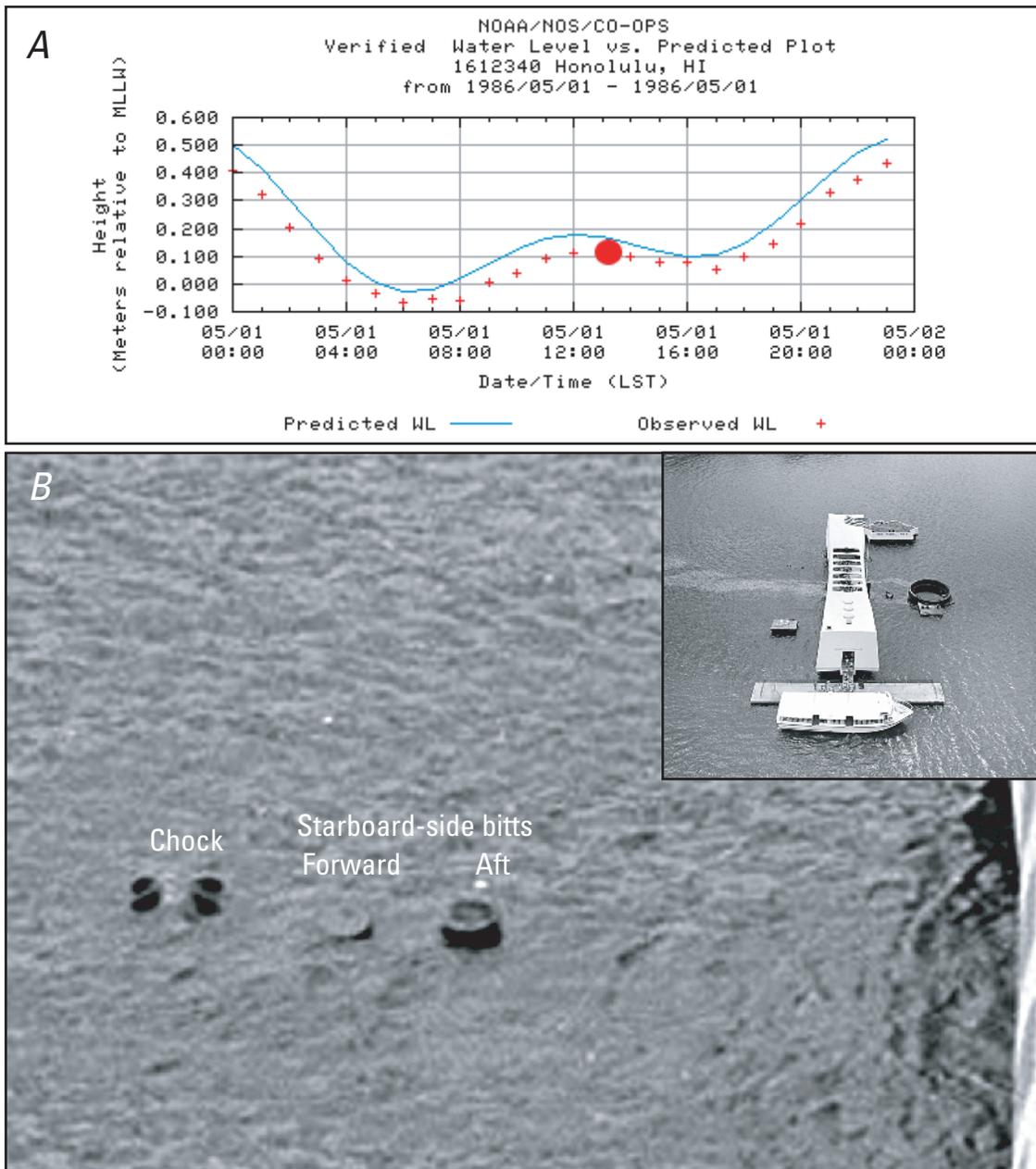


Figure G-7. Photo analysis for May 1, 1986. *A*, Tidal cycle for May 1, 1986; red mark indicates the estimated time and tide for the photo. *B*, Photo DN-SN-86-08980 dated May 1, 1986 obtained from the former Defense Visual Information Center (no longer available at <http://www.defenseimagery.mil/index.htm>). The time is 13:11 and the tide level is 0.12 m MLLW, as determined in figure E-21. The water level is below the rounded edge of the lower (port) side of the forward bitt, the lower of the two bitts. The top of the aft bitt is estimated to be 0.36 ± 0.03 m above the water level and at an elevation of 0.48 ± 0.03 m MLLW. The edge of the deck is 0.53 m below the top of the aft bitt, as measured on March 4, 2008. The deck edge is calculated to be at -0.07 ± 0.03 m MLLW. Day 16,217.

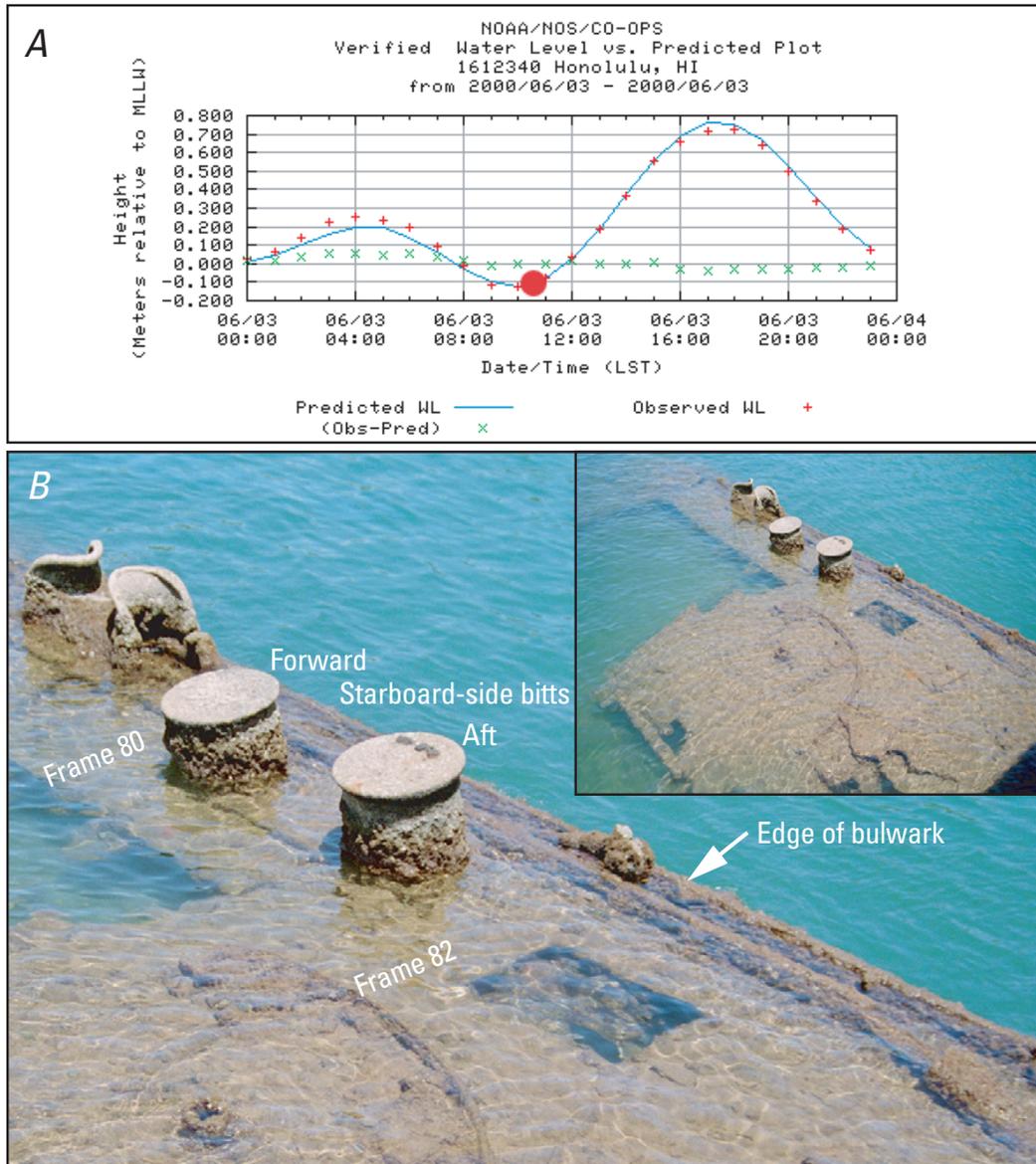


Figure G-8. Photo analysis for June 3, 2000. *A*, Tidal cycle for June 3, 2000; red mark indicates the estimated time and tide for the photo. *B*, Photo 000603-N-4912M-007 (also identified as DN-SC-02-05624) from <http://www.defenseimagery.mil/> dated June 3, 2000. This is one of a sequence of photos taken at the memorial on this date and shows a very low tide state. The time is assumed to be 10:42 as determined in photo DN-SC-02-05623 for the calculations of the port side (fig. F-12). The tide level for this time is -0.094 m MLLW. The water level is variously just above and just below the outer edge of the starboard side near the aft bitt within a range of perhaps ± 0.02 m. The elevation of the edge of the deck is estimated to be -0.094 ± 0.02 m MLLW. The outer edge of the deck near the aft bitt was 0.18 m below the water level at a tide level of 0.61 m MLLW when measured at 10:17 on March 4, 2008. Even assuming no movement of the deck since 2000, a very low tide condition is necessary to match the scene in this photo. These tide levels exist during the morning of June 3, 2000, providing some independent support for the date and time of the image. Day 21,364.

Appendix H. Photographic Analysis of Historical Photographs of the Bow, Stern, and Turret 2 of the USS *Arizona*

Note that all elevations are not adjusted for sea level rise. MLLW stands for mean lower low water.

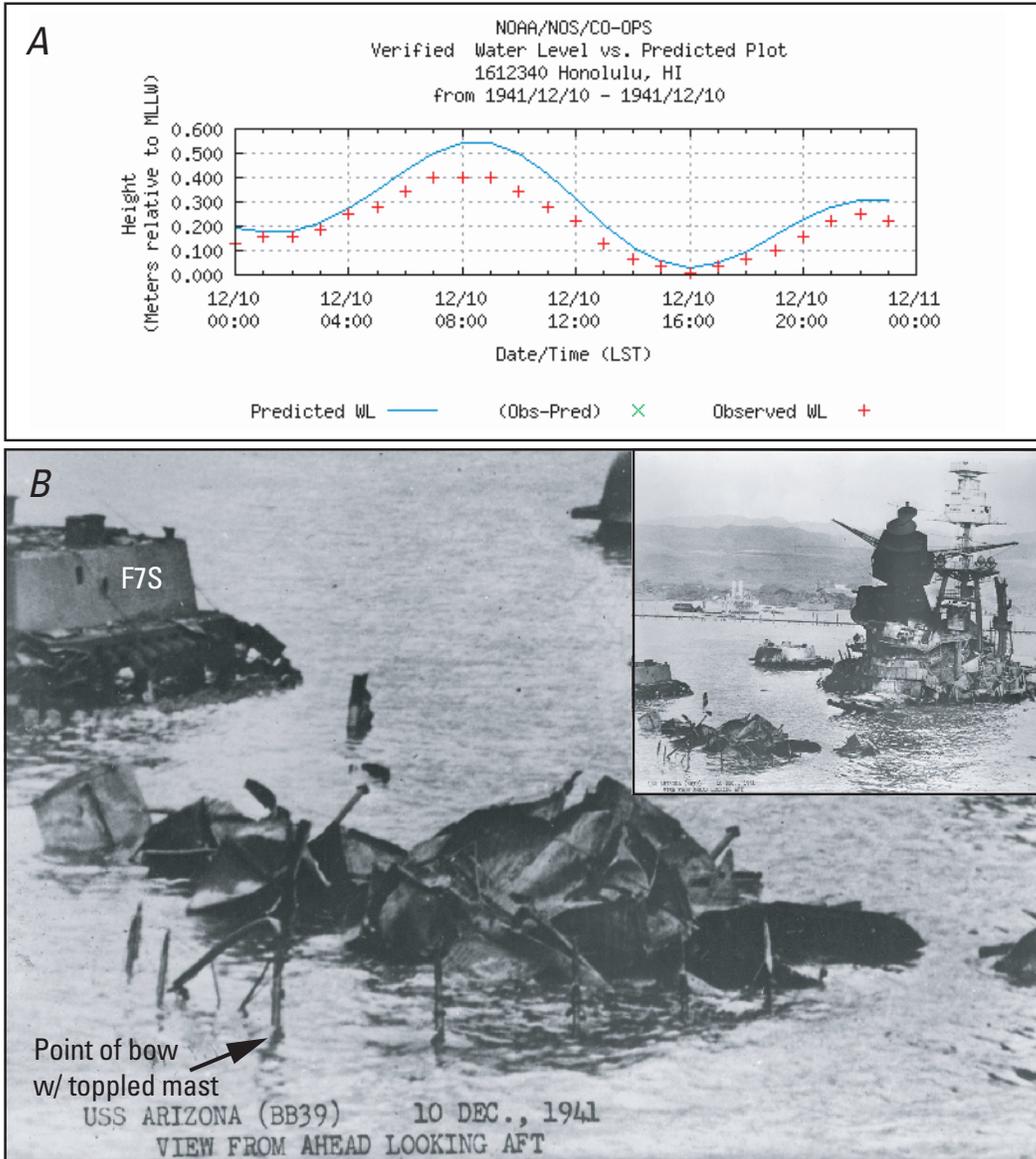


Figure H-1. Photo analysis for December 10, 1941. *A*, Tidal cycle for December 10, 1941. *B*, Photo Temp No. 885 from the Arizona Memorial Museum Archives dated December 10, 1941, also identified as #NH 63918 at www.history.navy.mil/, showing the bow of the USS *Arizona* covered by shallow water. Based on other photos, the base of the railing posts are at the edge of the deck and the tops are estimated to be 1.12 m above the bulwark, based on ship drawings and scaling from photos. Judging from the visible railing post heights, the water depth at the point of the bow is estimated to be 0.25 ± 0.1 m. There are no useful shadows and the time is unknown. The water level at turret 2 in this photo is approx. the same as on December 7 in figure H-2. The tide level for December 7, 13:00 to 15:00, is 0.07 m MLLW, making the bow elevation for December 7 (Day 1.1) approx. -0.18 ± 0.1 m MLLW. Day 4.

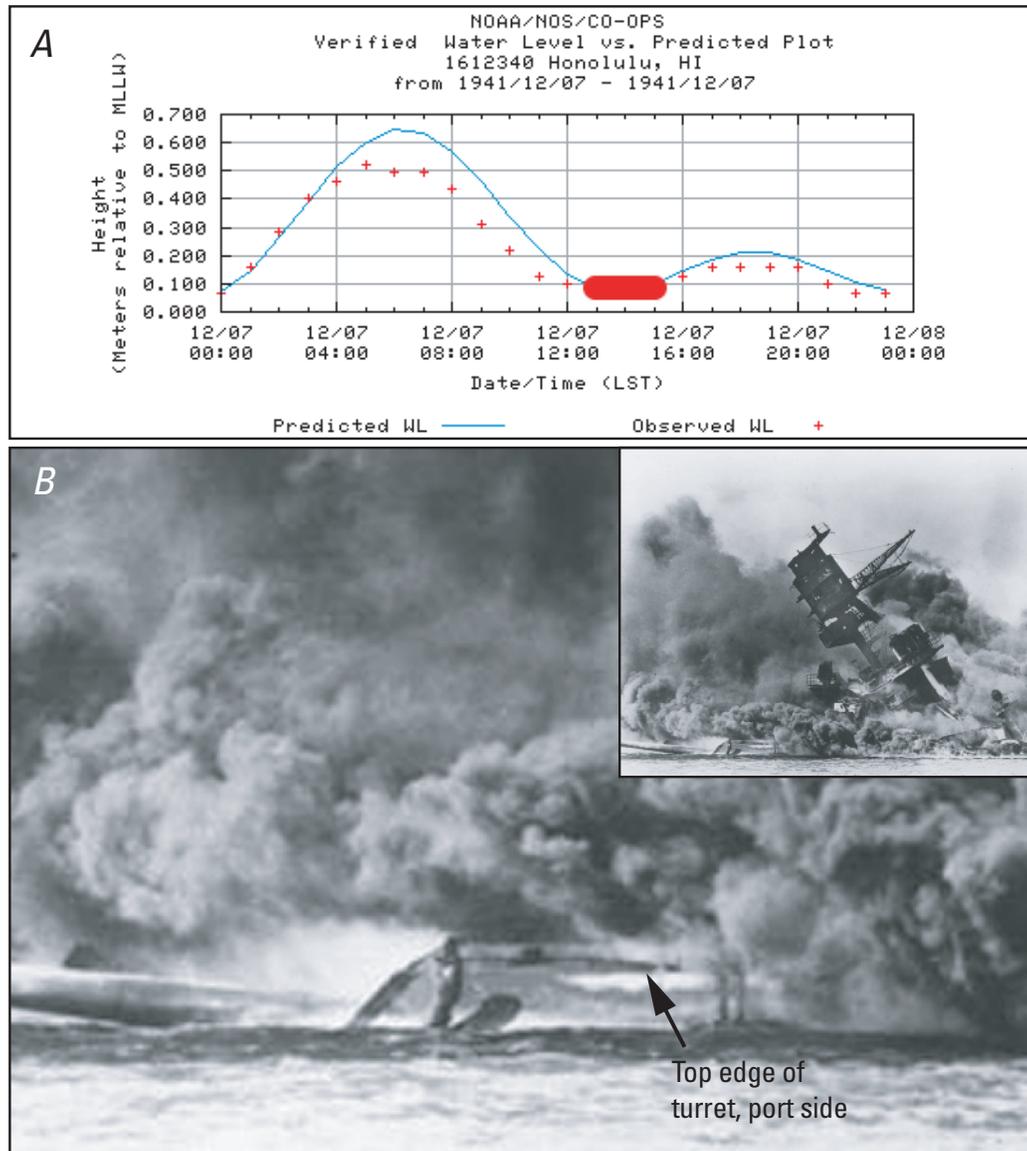


Figure H-2. Photo analysis for December 7, 1941. *A*, Tidal cycle for December 7, 1941. The red bar is the estimated time and tide range for the photo. *B*, Unidentified photo from <http://www.nps.gov/>. The state of the fire is nearly identical to that in photo #NH 97380 on December 7, 1941. The enlargement shows the water level at turret 2 about half-way up the angled, port-side face, with top edge highlighted. The port and starboard faces of the turret are still present today, the tops of which are above or below the water surface, depending on the tide level. Based on PR-16, (fig. E-5) the turrets are slightly tapered, from about 2.26 to 2.46 meters high, forward to aft. The half-height is assumed to be 1.16 m. The time is assumed to be between 13:00 and 15:00, as determined in figure F-1 for photo #NH 97380. The tide level for this time period is 0.07 m, resulting in an elevation of 1.23 ± 0.1 m MLLW for the top edge of the turret. This picture also provides information for the bow at this time (fig. H-3). Day 1.

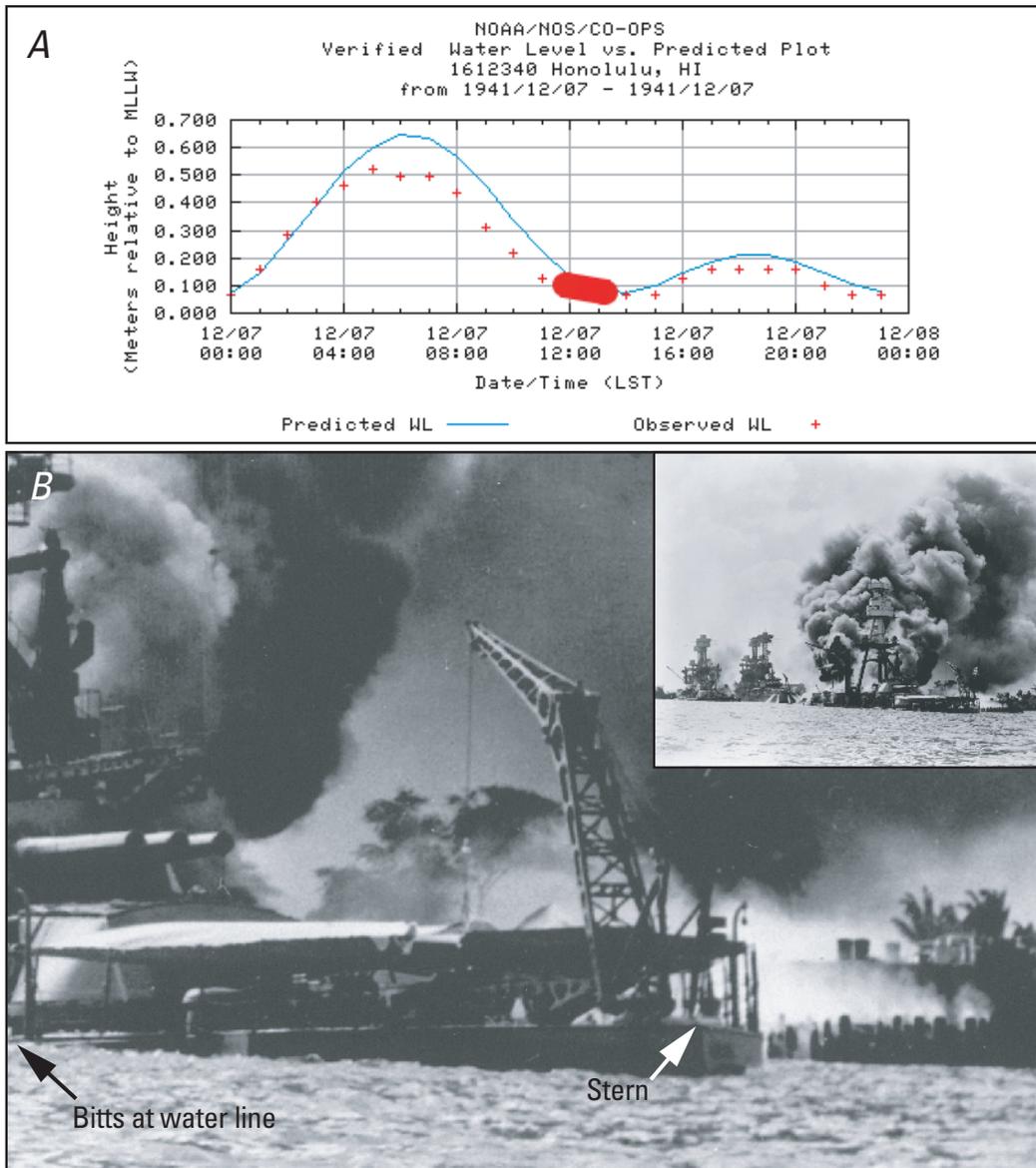


Figure H-3. Photo analysis for December 7, 1941. *A*, Tidal cycle for December 7, 1941. The red bar is the estimated time and tide range for the photo. *B*, Photo #NA80-G-32424 showing the stern of the USS *Arizona* above the water surface. The time for the image, based on vague rangefinder shadows on turrets 3 and 4, is late morning to early afternoon, possibly 11:30 to 13:30. The tide level for this time period is 0.11 to 0.07 m MLLW. The deck slope is approx. 2.6 to 2.2° forward as measured from PR-54A (fig. E-1) and PR-52 (fig. E-2). There is a length of about 27 m from a pair of port-side bits at the water line to the point of the stern. The stern is estimated to be approx. 1.13±0.1 m above the water surface. From photo PR-52, the sun canopy is estimated to be 2.1 m above the deck edge. The stern is 1.15 m above the water based on this scale. The tide level is assumed to be 0.10 m MLLW and the stern elevation is estimated to be 1.2±0.13 m MLLW. Day 1.

Appendix I. Spectral Analysis of Interface Waves (SAIW) Test Result Plots from the USS Arizona

USS Arizona	
Site ID	718ARZ
SEAFLOOR SAIW	
Location USS Arizona Memorial	
POSITION DEGREES	
GPS LAT (N)	21.36469
GPS LONG (W)	-157.95073
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

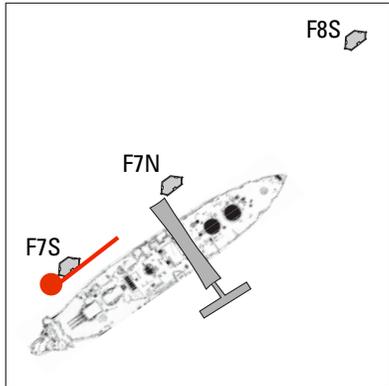
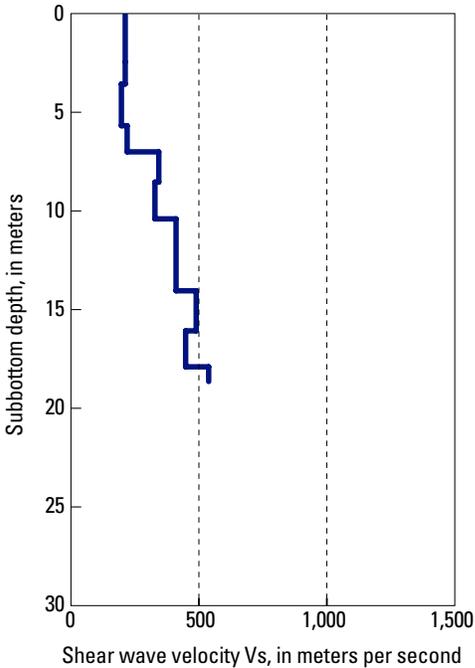


Figure I-1. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 718ARZ located adjacent to the Fox 7 South quay. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS Arizona	
Site ID	719ARZ
SEAFLOOR SAIW	
Location USS Arizona Memorial	
POSITION DEGREES	
GPS LAT (N)	21.36464
GPS LONG (W)	-157.95081
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

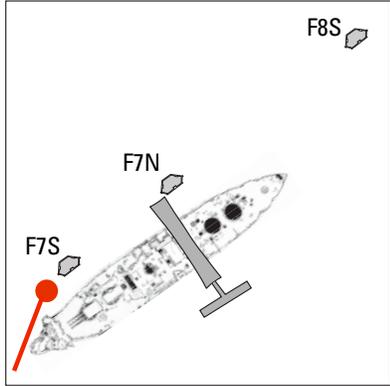
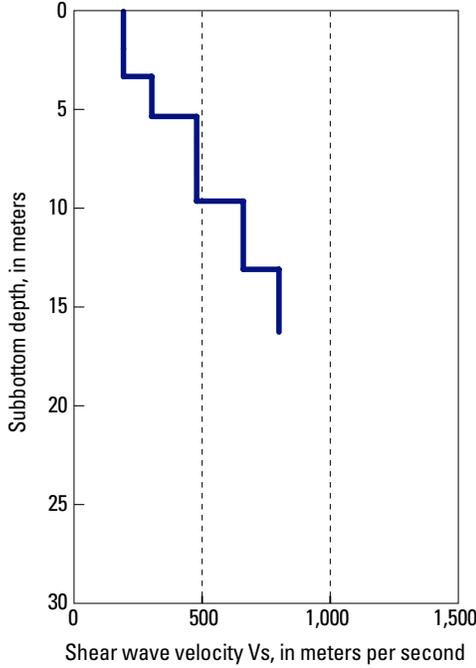


Figure I-2. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 719ARZ located between the Fox 7 South quay and the USS Arizona bow. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS *Arizona*
 Site ID 720ARZ
 SEAFLOOR SAIW

Location USS *Arizona* Memorial

POSITION DEGREES
 GPS LAT (N) 21.36529
 GPS LONG (W) -157.95001

Data Type SWEPT-SINE SAIW
 Investigators KAYEN, MINASIAN
 Date collected 6/7/2005

TEST METHOD SEAFLOOR SAIW

PROJECT NAME USS *Arizona*
 SPONSORS USGS, NPS

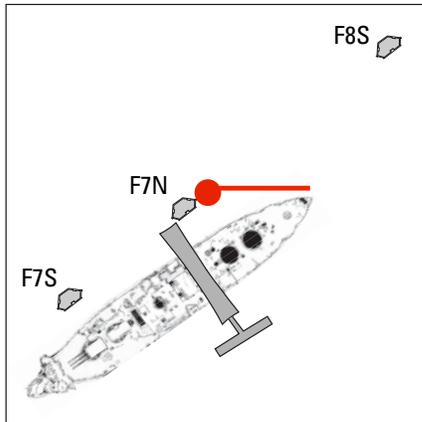
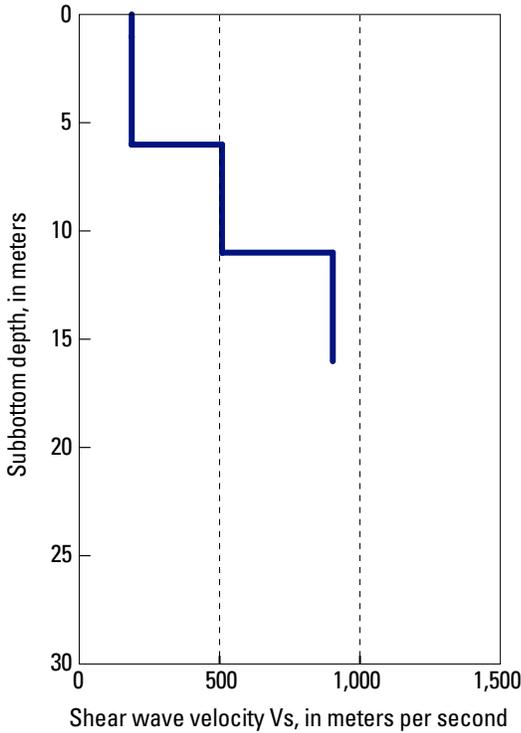


Figure I-3. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 720ARZ located adjacent to the Fox 7 North quay. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS *Arizona*
 Site ID 721ARZ
 SEAFLOOR SAIW

Location USS *Arizona* Memorial

POSITION DEGREES
 GPS LAT (N) 21.36474
 GPS LONG (W) -157.94966

Data Type SWEPT-SINE SAIW
 Investigators KAYEN, MINASIAN
 Date collected 6/7/2005

TEST METHOD SEAFLOOR SAIW

PROJECT NAME USS *Arizona*
 SPONSORS USGS, NPS

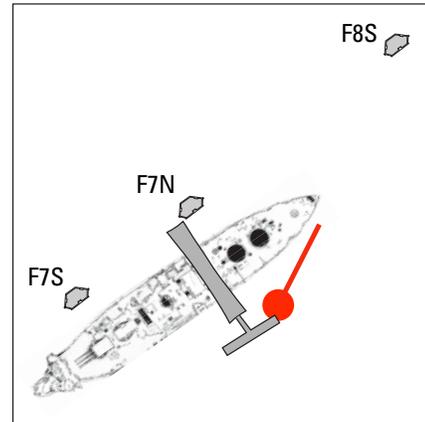
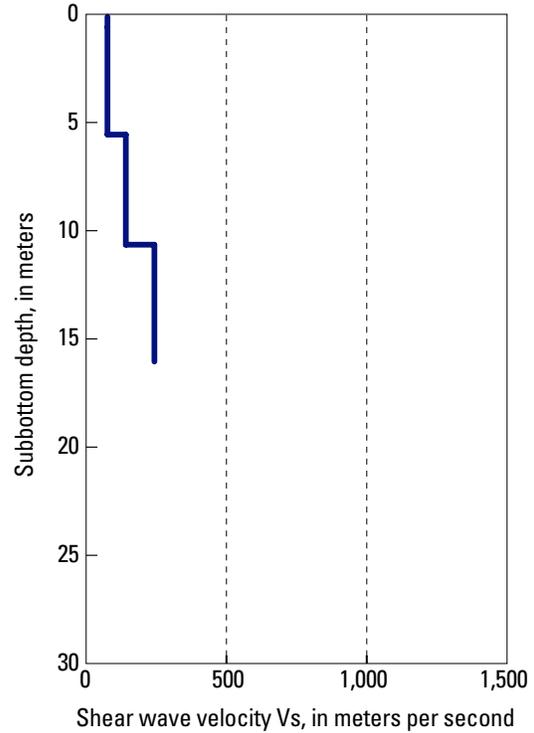


Figure I-4. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 721ARZ located adjacent to the northeast end of the USS *Arizona* memorial floating boat dock. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS Arizona	
Site ID	722ARZ
SEAFLOOR SAIW	
Location	USS Arizona Memorial
POSITION	DEGREES
GPS LAT (N)	21.36474
GPS LONG (W)	-157.94966
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

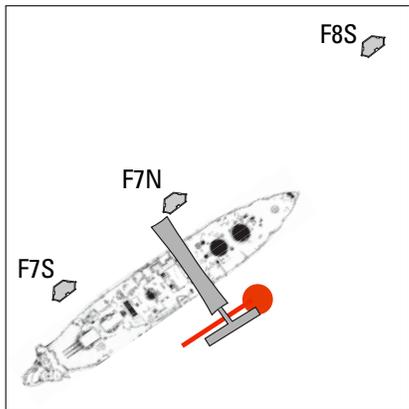
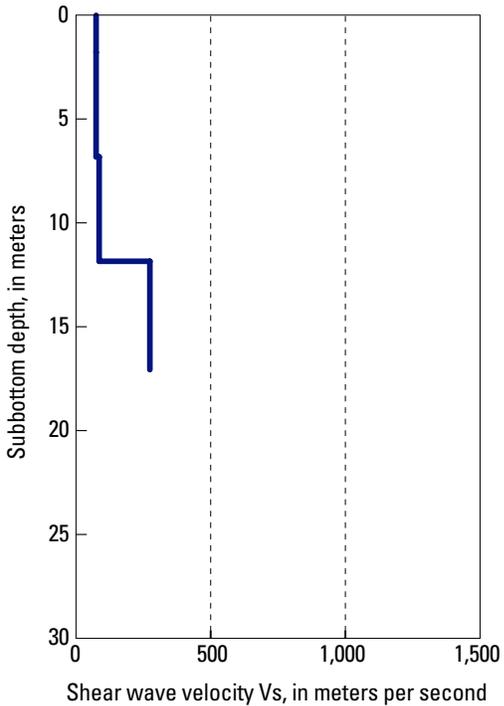


Figure I-5. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 722ARZ located adjacent to the northeast end of the USS Arizona Memorial floating boat dock. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS Arizona	
Site ID	723ARZ
SEAFLOOR SAIW	
Location	USS Arizona Memorial
POSITION	DEGREES
GPS LAT (N)	21.36419
GPS LONG (W)	-157.95096
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

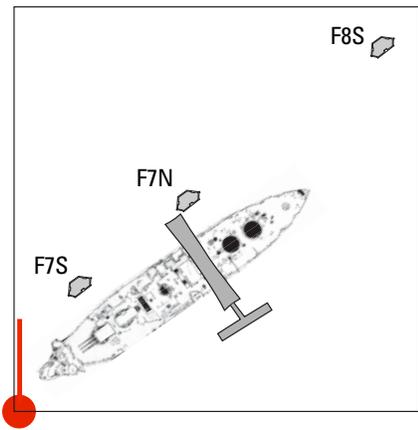
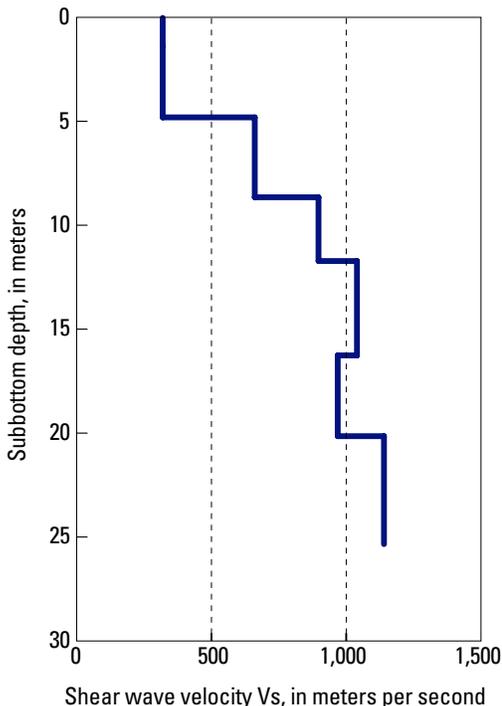


Figure I-6. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 723ARZ located at boring B3 at the bow of the USS Arizona. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS <i>Arizona</i>	
Site ID	724ARZ
SEAFLOOR SAIW	
Location	USS <i>Arizona</i> Memorial
POSITION	DEGREES
GPS LAT (N)	21.36419
GPS LONG (W)	-157.95096
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS <i>Arizona</i>
SPONSORS	USGS, NPS

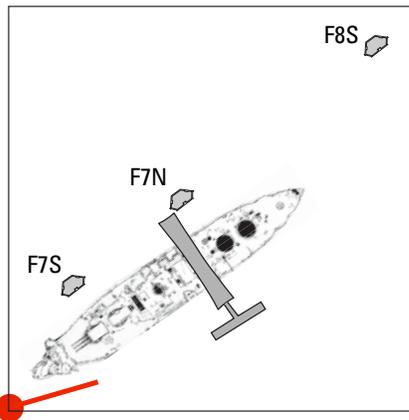
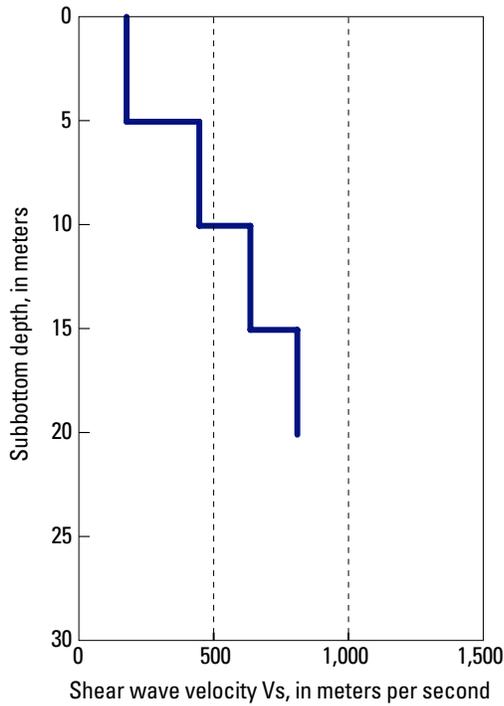


Figure I-7. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 724ARZ located at boring B3 at the bow of the USS *Arizona*. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS <i>Arizona</i>	
Site ID	725ARZ
SEAFLOOR SAIW	
Location	USS <i>Arizona</i> Memorial
POSITION	DEGREES
GPS LAT (N)	21.364528
GPS LONG (W)	-157.949941
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS <i>Arizona</i>
SPONSORS	USGS, NPS

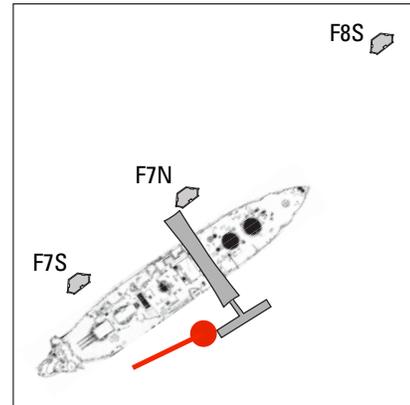
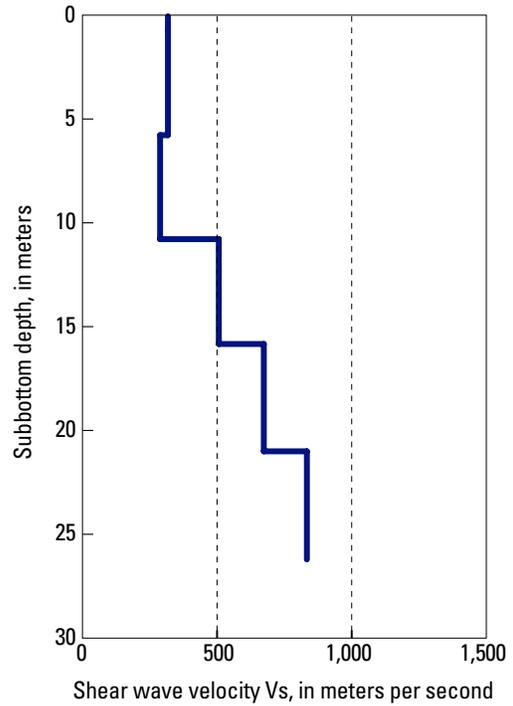


Figure I-8. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 725ARZ located adjacent to the southwest end of the USS *Arizona* Memorial floating boat dock. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS Arizona	
Site ID	726ARZ
SEAFLOOR SAIW	
Location	USS Arizona Memorial
POSITION	DEGREES
GPS LAT (N)	21.3658
GPS LONG (W)	-157.94917
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

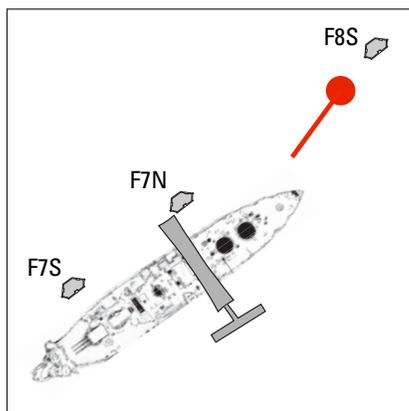
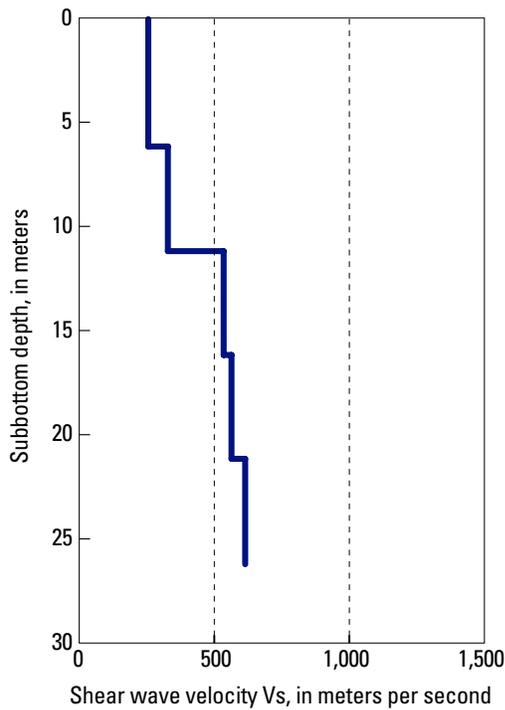


Figure I-9. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 726ARZ located between the Fox 8 South quay and the bow of the USS Arizona. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

USS Arizona	
Site ID	727ARZ
SEAFLOOR SAIW	
Location	USS Arizona Memorial
POSITION	DEGREES
GPS LAT (N)	21.36519
GPS LONG (W)	-157.95
Data Type	SWEPT-SINE SAIW
Investigators	KAYEN, MINASIAN
Date collected	6/7/2005
TEST METHOD	SEAFLOOR SAIW
PROJECT NAME	USS Arizona
SPONSORS	USGS, NPS

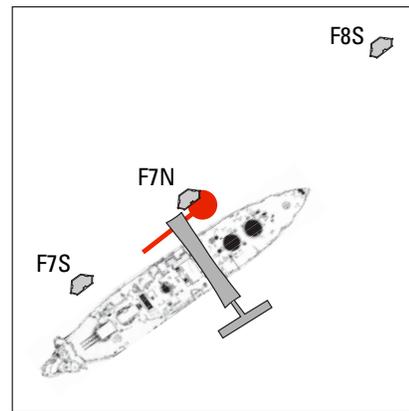
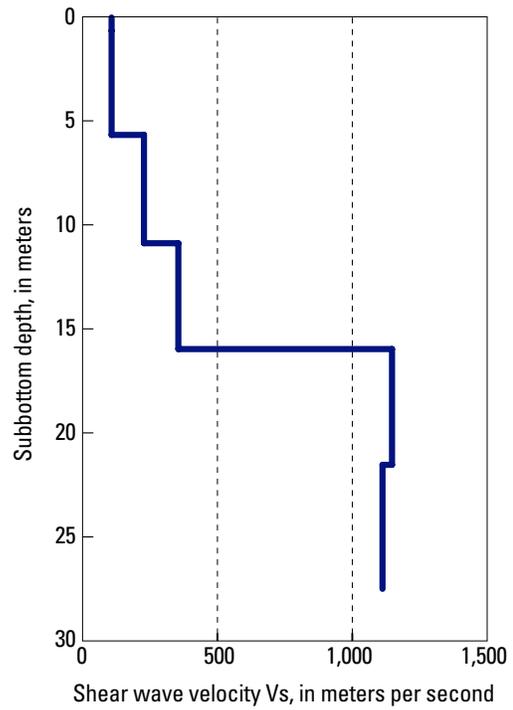


Figure I-10. Plot of shear wave velocity V_s versus subbottom depth for SAIW site 727ARZ located between the Fox 7 North quay and the USS Arizona. The red spot in the diagram marks the location of the shaker; the red line is the seismometer streamer location.

Appendix J. Unpublished USGS Memos Reporting Results of the C1-02-HW Seismic Reflection Survey

These memos are summaries of the results of the C1-02-HW seismic reflection survey provided to the National Park Service by the chief investigators. They are not dated in their original form, but probably originated during the later part of 2002.

MEMO

TO: Larry Murphy and Matt Russell, NPS

FROM: Michael Field and Patrick Hart, USGS

SUBJECT: Subsurface Acoustic Reflectors in Pearl Harbor (C1-02-HW)

This memo complements the data report "Pearl Harbor Chirp Seismic Survey (C1-02-HW)" and provides a brief discussion of the geologic interpretation of the seismic reflection records obtained during the August 2002 survey adjacent to the *USS Arizona* and *USS Utah*.

Over-all Data Quality and Surface Character:

Roughly 20 to 30 % of the seismic reflection records obtained adjacent to Ford Island in the vicinity of the USS *Arizona* provide information on near surface and subsurface structure. The remaining records are obscured by gas and no subsurface information is present. Sediment in estuaries, harbors, and coastal bays typically is gaseous, and the lack of penetration in 70 to 80 % of the records is not unusual. The nature of subsurface reflectors in the "good-penetration" areas is discussed in the next section.

Within the large area of poor or no penetration, we recognized several different types of surface reflectors that may have significance. Several contiguous lines displayed a single bright reflector (referred on maps as SBR). The cause and significance of the SBR are not known from this limited survey. The SBR may indicate a hard sandy surface underlying relatively low-density mud that composes the present-day floor of Pearl Harbor. There is also the possibility that the SBR is caused by high gas content of near-surface sediment, particularly since the deeper structure is obscured by gas.

Two areas were identified as areas displaying point diffractions (PD) on or near the seabed. The two areas are very similar, and only differ by the apparent relative abundance of the point diffractions. Point diffractions are assumed to be caused by single large objects lying on the seabed that diffract energy from the acoustic source. In glacial areas, for example, boulders and other large single objects create point diffractions. It is not known what causes the point diffractions in Pearl Harbor, but it is reasonable to assume that they may be caused by wreckage on the seabed or debris remaining from salvage operations. The fidelity of the patterns on adjoining and crossing lines verify that the point diffractions are real phenomena related to a characteristic of the seabed.

Subsurface Reflectors and Their Significance:

The seafloor beneath Pearl Harbor in the vicinity of Ford Island and the USS *Arizona* is underlain by a series of acoustic reflectors down to subsea depths of about 175 ft that we interpret as sedimentary in origin. Four of the reflectors were distinctive because of their relative strength and persistence and because they convey information about the subsurface history.

Reflector A'

This reflector appears on only about 50% to 60% of the CHIRP records that have good acoustic penetration, and there is some evidence that where missing, it has been

eroded from the sedimentary record. The Reflector lies at about 20 to 27 milliseconds (approximately 49 to 66 feet) below the sea surface. Several lines show Reflector A' abruptly terminated by channel incision. The channels cutting and eroding the reflector were likely last active during periods of lower sea level, and it is possible that Reflector A' therefore predates the last low stand of sealevel at about 20,000 years ago.

Reflector A

This reflector is the shallowest continuous reflector in the area; it lies at about 34 to 40 milliseconds (approximately 84 to 98 feet) below the sea surface. The reflector marks the uppermost surface of a series of stacked, parallel reflectors that define a relatively thick packet of sedimentary strata. Because of the lack of extensive views of Reflector A in the subsurface profiles it is not possible to determine the mode of deposition of the sedimentary strata; most likely it is fluvial/estuarine.

Reflector B

This reflector is a relatively deep acoustic reflector (57 to 64 milliseconds, or approximately 140 to 157 feet, below the sea surface) that exhibits some unevenness and irregularity. It probably marks a change in sediment history from the overlying sediment sequence that is capped by Reflector A. The irregular surface suggests a period of erosion following deposition, and internal stratification indicates deposition as marine sandstone or mudstone.

Reflector C

This reflector is the deepest one that can be mapped with the CHIRP data acquired in August 2002; it lies at about 67 to 72 milliseconds (approximately 165 to 177 feet) below the sea surface. The reflector is uneven and irregular, and shows no evidence of internal stratification. The strength of the signal return from those depths suggests that the surface marks a firm, well-cemented deposit. Based on comparison with other acoustic records, we believe that the surface most likely represents the surface of an eroded reef/limestone deposit. It is possible, but less likely in our view, that it also could be volcanic or volcanoclastic in origin.

MEMO

TO: Larry Murphy and Matt Russell, NPS
 FROM: Patrick Hart and Michael Field, USGS
 RE: Pearl Harbor Chirp Seismic Survey (C1-02-HW)

SUMMARY: This memo summarizes the field operations and data from a one-day chirp seismic reflection survey conducted in Pearl Harbor, Hawaii on August 22, 2002. The purpose of this subbottom survey was to determine the thickness of sediments and depth to coral bedrock in the areas immediately surrounding the USS Arizona Memorial and the hull of the USS Utah. The USGS cruise ID for this work is C1-02-HW. On-line metadata can be viewed and downloaded from: <http://walrus.wr.usgs.gov/infobank/c/c102hw/html/c-1-02-hw.meta.html>

In the area adjacent to the Arizona Memorial, data quality is sufficient in places to identify and map several reflectors, including what is interpreted to be coral bedrock at a sub-sea surface depth of between 165 and 182 feet. There is a widespread zone, however, where subbottom reflections are obscured by what is interpreted to be small amounts of methane gas within the uppermost sediments. A zone of no subbottom reflections surrounds the USS Utah and no useful data were acquired in this area.

The CD that accompanies this memo contains two excel spreadsheet files that summarize trackline numbers, digital SEG-Y data file names (there are several lines per data file), trackline start and end times in GMT, zones of good data, and subbottom reflection depths in milliseconds (two-way time) and feet. Reflection times were converted to depth using a constant velocity of 1500 m/s (4920 ft/sec). There are also two Adobe Illustrator files of a trackline map of each area annotated at one minute intervals.

DATA ACQUISITION: 48 short seismic reflection profiles totaling approximately 20 km of profile data were acquired during 5 hours of reflection data acquisition in two areas:

Arizona	36 lines (AZ 1-36)
Utah	12 lines (UT 37-48)

Lines UT 37 and UT 38 are transit lines between the two areas and do not show on the maps.

The acquisition system consisted of a raft-mounted Edgetech 512 chirp subbottom profiler, a Delph Seismic digital recording pc, and differential GPS navigation deployed from a 26 ft Navy Boston Whaler. The fire rate was 5 chirps per second (except lines UT-47 and UT-48 at 4 chirps per second), with a 160 ms record length digitized at 12.5 kHz and recorded in 16-bit integer SEG-Y format. The acoustic source used was a 20 ms chirp sweeping from 500 Hz to 6000 Hz. Ship speed during data acquisition varied between 2.5 and 3.5 kts. Differential GPS coordinates were recorded on a YoNav navigation system, which was interfaced to the Delph Seismic system and longitude/latitude values were written in the SEG-Y trace headers in arc milliseconds for all lines

There are three data channels recorded in the SEG-Y files. Channels 2 and 3 are conventional seismic traces that oscillate between positive and negative amplitude values. In geophysical terms, they are the real and imaginary components of the seismic trace, with a 90 degree phase shift from one to the

eroded from the sedimentary record. The Reflector lies at about 20 to 27 milliseconds (approximately 49 to 66 feet) below the sea surface. Several lines show Reflector A' abruptly terminated by channel incision. The channels cutting and eroding the reflector were likely last active during periods of lower sea level, and it is possible that Reflector A' therefore predates the last low stand of sealevel at about 20,000 years ago.

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