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REGIONAL STUDY OF MILITARY BULK POL DISTRIBUTION SYSTEMS AND STORAGE FACILITIES, HAWAII
AMENDMENT 3

RED HILL COMPLEX FIRE, LIFE SAFETY, AND ENVIRONMENTAL RISK ASSESSMENT / ANALYSIS VOLUME II OF II

FINAL SUBMITTAL

Critical Infrastructure

APPENDIX D
Structural Analysis Tunnel Bulkheads and Oil-Tight Doors

Critical Infrastructure

Critical Infrastructure

Prepared for

DEPARTMENT OF THE NAVY
PACIFIC DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
Pearl Harbor, Hawaii

Prepared by

WILLBROS ENGINEERS, INC.
Tulsa, Oklahoma

August 1998

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APPENDIX D1
DRAWINGS AND CORE INFORMATION

D1-1 General

This Appendix contains schematics and isometric sketches of the Red Hill Complex, core sample information and a compression test report on the cores.

D1-2 Drawings

A schematic of the Red Hill Complex is given on Figure D1-1. Enlargement of schematic sections are provided on Figure D1-2.

An isometric sketch of the Red Hill Complex is given on Figure D1-3. This sketch shows the location of Critical Infrastructure in the Lower Access Tunnel and Critical Infrastructure in the Harbor Tunnel.

D1-3 Core Information

Information on the six cores taken in the Lower Access Tunnel and Harbor Tunnel are provided on Tables D1-1 and D1-2.

Table D1-1 gives the Door Designation, Specimen Number, Location and Description of each core. The results of compression test performed on the core samples are given in Table D1-2.

Critical Infrastructure

Critical Infrastructure

WILLBROS ENGINEERS, INC.

RED HILL COMPLEX
SCHEMATIC

DRAWING APPROVALS		
DRAWN KLW	DATE 06-19-98	
CHECKED	DATE	
ENGINEER CT/JR	DATE 06-22-98	
APPROVED		

SCALE	PROJECT NO.	DRAWING NO.	REV.
NTS	50253	FIGURE D1-1	0

Critical Infrastructure

Critical Infrastructure

WILLBROS ENGINEERS, INC.

RED HILL COMPLEX
ENLARGED SCHEMATIC

DRAWING APPROVALS		
	DRAWN KLW	DATE 06-19-98
	CHECKED	DATE - -
	ENGINEER CT/JR	DATE 06-22-98
	APPROVED	

SCALE	PROJECT NO.	DRAWING NO.	REV.
NTS	50253	FIGURE D1-2	0

RDHLCC0025062

Critical Infrastructure

Critical Infrastructure

WILLBROS BUTLER ENGINEERS, INC.

RED HILL COMPLEX
ISOMETRIC SKETCH

DWN.	DATE
CHKD.	DATE
ENGR. JWR	DATE 6/12/98
APPROVED	

SCALE	PROJECT NO.	DRAWING NO.	REV.
NTS	50253	FIGURE D1-3	0

TABLE D1-1

CORE INFORMATION

Door Designation	Specimen Number	Location	Core Description
Critical Infrastructure	1	Critical Infrastructure	
	3		
	4		
	5		
	2		
	6		

LAW ENGINEERING, INC.
1540 N. 107TH EAST AVENUE
TULSA, OKLAHOMA 74116
(918) 834-4700

REPORT NUMBER 03508 TABLE D1-2

REPORT DATE May 23, 1994

REPORT OF COMPRESSION TEST OF CONCRETE CORES

DATE RECEIVED _____ AUTHORIZED BY _____ LABORATORY NO. 396-40083-01

CLIENT Willbros Butler Engineers

PROJECT Building pad concrete cores

CONTRACTOR Not indicated

SOURCE Not indicated CORED BY Not indicated

TEST RESULTS

SPECIMEN NUMBER	1	2	3	4	5	6
DATE PLACED						
DATE CORED						
DATE TESTED						
AGE WHEN TESTED-DAYS						
DIAMETER IN INCHES	1.742	1.741	1.734	1.735	1.742	1.741
HEIGHT IN INCHES	3.859	3.754	3.756	4.841	3.757	3.712
L/D RATIO	2.215	2.156	2.166	2.790	2.157	2.132
CORRECTION FACTOR	N/A	N/A	N/A	N/A	N/A	N/A
AREA IN SQUARE INCHES	2.383	2.381	2.362	2.364	2.383	2.381
TOTAL LOAD IN LBS.	13,600	12,300	5,840	6,700	9,000	15,350
COMPRESSIVE STRENGTH-PSI	5,710	5,165	2,470	2,835	3,775	6,445
STRENGTH REQUIRED DAYS						
CURING CONDITIONS						
STRUCTURE LOCATION	5-1	1-2	3	6-4	5-3	2-1
TOTAL HEIGHT BEFORE TRIM						

REMARKS:

COPIES: Willbros Butler Engineers
File

ENGINEERING TECHNICIAN

RDHLCC0025065

APPENDIX D2
STRUCTURAL ANALYSIS OVERVIEW
TUNNEL BULKHEADS AND OIL-TIGHT DOORS

D2-1 General

This Appendix contains a structural analysis of Critical Infrastructure due to the hydrostatic pressure in Scenario One. If Critical Infrastructure is full and discharge begins through Critical Infrastructure and Critical Infrastructure is closed before fuel reaches it, the final liquid level would create a hydrostatic head of Critical Infrastructure Critical Infrastructure when a 10% impact factor is added. Using the same logic, if Critical Infrastructure is closed, the resulting hydrostatic head would be Critical Infrastructure The tunnel volumes and elevations used are provided in Appendix D3.

D2-2 Critical Infrastructure

This bulkhead is constructed of gunite that is 24 inches thick with 1-inch square bars at 6-inch centers each way in each face. The bulkhead has an opening 6'-6" by 4'-4" for a door which allows the train to pass plus the Critical Infrastructure penetrate the bulkhead between the opening and the tunnel wall. The pipes have diameters Critical Infrastructure

The bulkhead had two 2-inch diameter cores drilled during the site visit in May of 1994. One of the cores was drilled at a 45-degree angle to determine if the bulkhead is keyed into the rock as shown on the drawings. The cores indicate that the gunite is keyed into the rock as shown on the drawings. The cores were tested for compressive strength. They broke at 2,835 psi and 3,775 psi.

The drawings show a 5-foot thick pipe anchor that is integral with the bulkhead. However, the bulkhead does not have any pipe anchors. The 24-inch reinforced gunite transfers the load to the tunnel wall and rock key.

The bulkhead was analyzed using the finite analysis portion of STAAD-III structural program which uses the ultimate strength design of concrete that has a load factor of 1.7 for hydrostatic loads. The 24-inch thick wall was divided into 133 elements that are approximately 1.0 to 1.25 square feet. The hydrostatic loads from the door were applied as point loads around the perimeter of the opening at the joints of the elements.

The analysis showed that the 1.0 inch square bars at 6-inch centers are adequate to resist the bending forces from the hydrostatic load of 68.38 psi, but the shearing forces exceed the allowable stresses of ACI 318-89, "Building Code Requirements for Reinforced Concrete". The reinforcing was assumed to be an intermediate grade billet steel with a yield point of 40,000 psi which was available in the 1940s.

Using an average compressive strength of 3,500 psi, the allowable shear in the concrete is 118 psi. There are 12 elements that have shear stresses greater than 118 psi, the largest over stress is 180 psi.

The structural analysis of the Critical Infrastructure is provided in Appendix D5.

D2-3 Critical Infrastructure

Critical Infrastructure is integral with the anchors which give it a thickness of 60 inches, except at the top which is 18 inches thick, and the maximum hydrostatic head would be Critical Infrastructure Critical Infrastructure

This bulkhead had two 2-inch diameter cores drilled during the site visit in May of 1994. One of the cores was drilled at a 45-degree angle to determine if the bulkhead is keyed into the rock as shown on the drawings. The core indicates that the gunite is keyed into the rock as shown on the drawings. The cores were tested for compressive strength. They broke at 5,165 and 6,445 psi.

D2-4 Critical Infrastructure

The plans called for the oil-tight doors to be fabricated from 3/8-inch thick plate stiffened with wide flange beams, one on the vertical centerline and on the 1/3 points horizontally. The wide flange section called for on Critical Infrastructure was a W6 x 20 and on Critical Infrastructure was W8 x 33. Both oil-tight doors were fabricated using the W6 x 20 wide flange sections. Critical Infrastructure has one W6 x 20 vertically on the centerline and two W6 x 20s horizontally at the third points. Critical Infrastructure Critical Infrastructure has two W6 x 20s, both vertically and horizontally located approximately on the third points.

The doors were analyzed using the finite element portion of STAAD-III. The 3/8 inch plate was modeled with 600 elements and 651 joints, the wide flange sections were connected to the centerline joints under the flanges so that the plate and wide flanges acted together. The elements were 2.7 inches by 2.5 inches and 2.7 inches by 2.9 inches. The door edges on the centerline of the seal were modeled to allow rotation, translation was restrained.

ASTM-A7 steel was a common steel during the era in which the tunnel was constructed. The yield point of this steel is 27,000 psi which is multiplied by 0.66 to obtain the allowable bending stress of 17,820 psi and 0.4 to obtain an allowable shearing stress of 10,800 psi.

The stresses in the W6 x 20 in the Critical Infrastructure exceed the AISC allowable in shear and bending. The stresses in the plate were also exceeded. The stresses in the plate exceed the allowable bending stress by Critical Infrastructure

The plate stresses from the finite element program were checked using classical methods in Timoshenko's "Theory of Plates and Shells" to verify the stresses and deflections given by STAAD-III. Element 205 and 206 were used to verify the results. These elements are in center of the door with the edges clamped at the beam. The moment and stresses of the classical solution and the program results are within 2.2 percent of each other. The deflection from the classical solution is 0.137 inches and from the program the relative deflection from the beam is 0.16 inches. The variations of moments, stresses and deflection between the classical and program results were greater for element 6 which has 3 beams with clamped edge conditions and one edge free to rotate, the classical solution assumed four edges clamped. The results are close enough to confirm the validity of the program solution.

Critical Infrastructure was also analyzed using the W8 x 33 section, two horizontal at the third points and one vertical at the center as designed. The deflections were greater than the door with the two vertical W6 x 20 stiffeners but the beams did not have any overstresses in bending. There were a few places near supports that had shear overstresses. The 3/8-inch thick plate is overstressed in bending, the stresses are greater than the door with the two vertical W6 x 20 stiffeners because of the greater plate span.

Critical Infrastructure was checked using a Critical Infrastructure without any impact. This simulates the maximum head and pressure that the Harbor Tunnel oil-tight door would sustain. The beams are not overstressed, but he 3/8 inch thick plate has elements that exceed the allowable bending stress. The original may have used a higher strength steel plate or assumed that the plate would deflect and act like a membrane.

The structural analysis of Critical Infrastructure based on W8 x 33 stiffening beams is given in Appendix D6 and the structural analysis using W6 x 20 stiffening beams is provided in Appendix D7. The structural analysis of Critical Infrastructure using W6 x 20 stiffening beams is given in Appendix D8.

To be safe in the event of a catastrophic failure of a tank Critical Infrastructure should be redesigned to withstand the potential pressures from a full tank failure. The design should use updated materials, controls with the bulkhead keyed into solid rock.

APPENDIX D3
TUNNEL VOLUMES AND ELEVATIONS

D3-1 General

The accumulative volumes of the tunnel were computed using the sections shown on the original drawings, not as-built drawings. The elevations of the tunnel roof and floor are recorded along with the volumes to facilitate computations to obtain the hydrostatic head in the Lower Access Tunnel or Harbor Tunnel due to the failure of Critical Infrastructure

The accumulated volumes and heads were also used to determine if fuel will flow out of existing exits.

Tunnel volumes and elevations are provided on Table D3-1 following this page.

Critical Infrastructure

Critical Infrastructure

Critical Infrastructure

TABLE D3-1
TUNNEL VOLUMES AND ELEVATIONS

Critical Infrastructure

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APPENDIX D4

STRUCTURAL ANALYSIS OF Critical Infrastructure

D4-1 General

The 24-inch thick gunite bulkhead is reinforced with 1-inch square bars at 6-inch centers each way in each face. There are Critical Infrastructure that project through the bulkhead as well as electrical conduits. The Critical Infrastructure The electrical conduits were ignored due to their small diameter.

The 6'-6" by 4'-4" opening for the railroad was modeled into the bulkhead. The loads from the door were applied as point loads at the joints of the elements around the door perimeter.

The bulkhead was checked using a Critical Infrastructure which includes the impact factor of 10 percent.

The bending stresses in bulkhead are within the limits set forth in "Building Code Requirements for Reinforced Concrete", ACI 318-89. The allowable shearing stresses of this code are exceeded in 12 elements.

The reinforcing was assumed to have a yield point of 40,000 psi which is an intermediate grade. The gunite was assumed to have a compressive strength of 3,500 psi.

D4-2 Liquid Level, Pressure and Load Calculations

Calculations for determining the liquid level, pressure and load on the Critical Infrastructure are provided in Exhibit D4-1.

D4-3 STAAD-III Computer Stress Calculations

STAAD-III computer stress calculations for Critical Infrastructure are given in Exhibit D4-2.

EXHIBIT D4-1

LIQUID LEVEL, PRESSURE AND LOADING CALCULATIONS: Critical Infrastructure (*b*) Three bend and three flattening tests shall be made from each size in each lot of rivets offered for inspection, each of which shall conform to the requirements specified.

II. WORKMANSHIP AND FINISH.

20. **Workmanship.** Rivets shall be true to form, concentric, and shall be made in a workmanlike manner.
21. **Finish.** The finished rivets shall be free from injurious defects.

III. INSPECTION AND REJECTION.

22. **Inspection.** The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the rivets ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the rivets are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.
23. **Rejection.** Rivets which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

STANDARD SPECIFICATIONS FOR BILLET-STEEL REINFORCEMENT BARS

OF THE

AMERICAN SOCIETY FOR TESTING MATERIALS.

ADOPTED AUGUST 25, 1913; REVISED 1914.

1. **Classes.** (*a*) These specifications cover three classes of billet-steel concrete reinforcement bars, namely: plain, deformed, and cold-twisted.
(*b*) Plain and deformed bars are of three grades, namely: structural-steel, intermediate and hard.
2. **Basis of Purchase.** (*a*) The structural-steel grade shall be used unless otherwise specified.
(*b*) If desired, cold-twisted bars may be purchased on the basis of tests of the hot-rolled bars before twisting, in which case such tests shall govern and shall conform to the requirements specified for plain bars of structural steel grade.

I. MANUFACTURE.

3. **Process.** (*a*) The steel may be made by the Bessemer or the open-hearth process.
(*b*) The bars shall be rolled from new billets. No rerolled material will be accepted.
4. **Cold-twisted Bars.** Cold-twisted bars shall be twisted cold with one complete twist in a length not over 12 times the thickness of the bar.

II. CHEMICAL PROPERTIES AND TESTS.

5. **Chemical Composition.** The steel shall conform to the following requirements as to chemical composition:

Phosphorus { Bessemer. . . . . not over 0.10 per cent
Open-hearth . . . . . . " " 0.05 "

6. **Ladle Analyses.** An analysis to determine the percentage of carbon, manganese, phosphorus and sulphur, shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified in Section 5.
7. **Check Analyses.** Analyses may be made by the purchaser from finished bars representing each melt of open-hearth steel, and each melt, or lot of ten tons, of Bessemer steel, in which case an excess of 25 per cent above the requirements specified in Section 5 shall be allowed.

III. PHYSICAL PROPERTIES AND TESTS.

8. **Tension Tests.** (*a*) The bars shall conform to the following requirements as to tensile properties:

TENSILE PROPERTIES.

Properties Considered.	Plain Bars.			Deformed Bars.			Cold-twisted Bars.
	Structural-Steel Grade.	Intermediate Grade.	Hard Grade.	Structural-Steel, Grade.	Intermediate Grade.	Hard Grade.	
Tensile strength, lb. per sq. in.	55,000 to 70,000	70,000 to 85,000	80,000 min.	55,000 to 70,000	70,000 to 85,000	80,000 min.	Recorded only
Yield point, min., lb. per sq. in.	33,000	40,000	50,000	33,000	40,000	50,000	55,000
Elongation in 8 in., min., per cent. . . .	1,400,000[a] / Tens. str.	1,300,000[a] / Tens. str.	1,200,000[a] / Tens. str.	1,250,000[a] / Tens. str.	1,125,000[a] / Tens. str.	1,000,000[a] / Tens. str.	5

[a] See Section 9.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.
9. **Modifications in Elongation.** (*a*) For plain and deformed bars over $\frac{3}{4}$ in. in thickness or diameter, a deduction from the percentages of elongation specified in Section 8 (*a*) of 0.25 per cent shall be made for each increase of $\frac{1}{32}$ in. of the specified thickness or diameter above $\frac{3}{4}$ in.
(*b*) For plain and deformed bars under $\frac{7}{16}$ in. in thickness or diameter, a deduction from the percentages of elongation specified in Section 8 (*a*) of 0.5 per cent shall be made for each decrease of $\frac{1}{16}$ in. of the specified thickness or diameter below $\frac{7}{16}$ in.
10. **Bend Tests.** The test specimen shall bend cold around a pin without cracking on the outside of the bent portion, as follows:

BEND-TEST REQUIREMENTS.

Thickness or Diameter of Bar.	Plain Bars.			Deformed Bars.			Cold-twisted Bars.
	Structural-Steel Grade.	Intermediate Grade.	Hard Grade.	Structural-Steel Grade.	Intermediate Grade.	Hard Grade.	
Under $\frac{3}{4}$ in.	180 deg. d = t	180 deg. d = 2t	180 deg. d = 3t	180 deg. d = t	180 deg. d = 3t	180 deg. d = 4t	180 deg. d = 2t
$\frac{3}{4}$ in. or over.	180 deg. d = t	90 deg. d = 2t	90 deg. d = 3t	180 deg. d = 2t	90 deg. d = 3t	90 deg. d = 4t	180 deg. d = 3t

Explanatory Note: d = the diameter of pin about which the specimen is bent;
t = the thickness or diameter of the specimen.

11. **Test Specimens.** (*a*) Tension and bend test specimens for plain and deformed bars shall be taken from the finished bars, and shall be of the full thickness or diameter of material as rolled; except that the specimens for deformed bars may be machined for a length of at least 9 in., if deemed necessary by the manufacturer to obtain uniform cross-section.
(*b*) Tension and bend test specimens for cold-twisted bars shall be taken from the finished bars, without further treatment; except as specified in Section 2 (*b*).
12. **Number of Tests.** (*a*) One tension and one bend test shall be made from each melt of open-hearth steel, and from each melt, or lot of ten tons, of Bessemer steel; except that if material from one melt differs $\frac{3}{8}$ in. or more in thickness or diameter, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.
(*b*) If any test specimen shows defective machining or develops flaws, or if a tension test specimen breaks outside the middle third of the gage length, it may be discarded and another specimen substituted.

IV. PERMISSIBLE VARIATIONS IN WEIGHT.

13. **Permissible Variations.** The weight of any lot of bars shall not vary more than 5 per cent from the theoretical weight of that lot.

Critical Infrastructure

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EXHIBIT D4-2

STAADD-III COMPUTER STRESS CALCULATIONS: Critical Infrastructure

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APPENDIX D5
STRUCTURAL ANALYSIS OF Critical Infrastructure
BASED ON USING W8 X 33 STIFFENING BEAMS

D5-1 General

This section analyzes the Lower Access Tunnel oil-tight door as designed with W8 x 33 stiffening beams. The door was fabricated with W6 x 20 stiffening beams, which is analyzed in Appendix D6.

The door was analyzed using the head created by failure of Critical Infrastructure when full. The head of Critical Infrastructure with an impact factor of 10 percent creates Critical Infrastructure The door is assumed free to rotate about the center of the seal but not free to translate.

The finite element analysis shows that the plate thickness is inadequate for this pressure. The W8 x 33 stiffening beams intended for the Lower Access Tunnel are within the allowable AISC stresses in bending, but overstressed in shear in a few places near or at supports.

D5-2 Liquid Level, Pressure and Load Calculations

Liquid level, pressure and load calculations for oil-tight Critical Infrastructure are given in Appendix 4, Exhibit D4-1.

D5-3 STAAD-III Computer Stress Calculations

STAAD-III computer stress calculations for the oil-tight Critical Infrastructure are given in Exhibit D5-1.

EXHIBIT D5-1

STAADD-III COMPUTER STRESS CALCULATIONS Critical Infrastructure

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APPENDIX D6
STRUCTURAL ANALYSIS OF OIL-TIGHT Critical Infrastructure BASED ON USING W6 X 20 STIFFENING BEAMS

D6-1 General

This section analyzes the Lower Access Tunnel oil-tight door as designed with W6 x 20 stiffening beams on the vertical and horizontal third points. The door was designed with W8 x 33 stiffening beams, which is analyzed in Appendix D5.

The door was analyzed using the head created by failure of Critical Infrastructure when full. The head of Critical Infrastructure with an impact factor of 10 percent creates Critical Infrastructure The door is assumed free to rotate about the center of the seal but not free to translate.

The finite element analysis shows that the plate thickness is inadequate for this pressure. The W6 x 20 stiffening beams intended for the Lower Access Tunnel are not within the allowable AISC stresses in bending or in shear.

D6-2 Liquid Level, Pressure and Load Calculations

Liquid level, pressure and load calculations for oil-tight Critical Infrastructure are given in Appendix 4, Exhibit D4-1.

D6-3 STAAD-III Computer Stress Calculations

STAAD-III computer stress calculations for oil-tight Critical Infrastructure are given in Exhibit D6-1.

EXHIBIT D6-1

STAAD-III COMPUTER STRESS CALCULATIONS: OIL-TIGHT Critical Infrastructure

Critical Infrastructure

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APPENDIX D7

STRUCTURAL ANALYSIS OF OIL-TIGHT Critical Infrastructure BASED ON USING W6 X 20 STIFFENING BEAMS

D7-1 General

This section analyzes the Harbor Tunnel oil-tight door as designed with W6 x 20 stiffening beams. The door was designed with W6 x 20 stiffening beams.

The door was analyzed using the head created by failure of Critical Infrastructure when full. The head of Critical Infrastructure with no impact factor creates a pressure Critical Infrastructure. The door is assumed free to rotate about the center of the seal but not free to translate.

The finite element analysis shows that the plate thickness is inadequate for this pressure. The W6 x 20 stiffening beams used for the Harbor Tunnel are within the allowable AISC stresses in bending or in shear.

D7-2 Liquid Level and Pressure

Liquid level and pressure for oil-tight Critical Infrastructure are given in Volume I, Section 6.5.2.3.

D7-3 STAAD-III Computer Stress Calculations

STAAD-III computer stress calculations for oil-tight Critical Infrastructure are given in Exhibit D7-1.

EXHIBIT D7-1

STAAD-III COMPUTER STRESS CALCULATIONS: OIL-TIGHT Critical Infrastructure

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