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Application of Human Systems Engineering Guidelines to Improve Safety, Access and Maintainability in Aircraft Carrier Storage Tanks

ABSTRACT

Applying human systems engineering/ergonomics guidelines to the design of large shipboard storage tanks provides a cost-effective means of reducing safety risks and labor costs during maintenance operations. Suggested design guidelines to enhance access and improve safety were developed in support of the CVN 21 Future Aircraft Carriers Program. Potential labor savings in the range of 30% for tank cleaning and maintenance could reduce the cost of shipyard availability (involving 30 tanks) by approximately $200,000 and/or decrease the time required to perform these operations.

INTRODUCTION

The Bureau of Labor Statistics, BLS, (2003) reports that falls from heights (above 6 feet) are the second leading cause of occupational fatalities, and accounted for 808 of the 5900 occupational fatalities recorded in the US during 2001. Shipyards are among the most hazardous US industries with a non-fatal injury rate of 22.0 per injuries and illness per 100 full time workers (BLS data for 2000) compared to a general average of 6.1 per 100 for private industries[1]. Ship construction and repair operations have a significant range of fall hazards that contribute to these statistics and to the total risk inherent in ship maintenance and construction.

The design of deep tanks and voids on large vessels can create intrinsically hazardous environments combining fall hazards in locations with potential confined space atmospheric hazards, restricted access and typically poor illumination.

REGULATORY REQUIREMENTS AND DEFINITIONS

Protection from falling from heights during operations conducted at elevation is one of the most intuitively clear safety requirements. The regulatory definition of an *elevated work location* varies slightly by industry from 4 to 10 feet[2]. The requirement of five feet within the maritime industry is linked to the typical height of scaffolding sections.

The hierarchy of controls described in Military Standard 882 and accepted safety practice stipulates that, if feasible, the hazard will be eliminated by avoiding the need for entry; or controls such as fixed barriers (such as railings) will be used. If other preferred alternatives are not feasible, personal fall arrest systems are required.

OSHA regulations and consensus standards (ANSI Z359) stipulate *assured fall protection* for elevated work locations that provides a fixed barrier or use an approved personal fall arrest system. An *assured fall protection system* is defined as a

[1] Shipyard work has generally been reported as the second most hazardous work setting in the US, second only to commercial fishing.

[2] OSHA Regulatory requirements by industry are five (5) feet for shipyard employment (29 CFR 1915.159 and 29 CFR 1915.77c); Six (6) feet for construction (29 CFR 1926.501 (b); and Four (4) feet for General Industry (29 CFR 1910.23 b). fifteen (15) feet for Steel Erection (29 CFR 1926.760 (a)); (29 CFR 1926.Subpart R 1926.750 to 760)

combination of equipment and work practice that either prevents falls by measures such as fixed barriers (preferred) or alternatively fall arrest systems.

The latter provides a means to arrest and reduce the impact of a fall through a *personal fall arrest system*. [3]

MISHAP DATA

OSHA (1998) reports that 150 to 200 workers are killed annually in the construction industry while, 100,000 are seriously injured as a result of falls from height. Several high-risk industries suffer the greatest fraction of their occupational fatalities from falls. These include general construction (34%); residential construction (45.5%), carpentry and floor work (53%) and steel erection (81.7%). [Bureau of Labor Statistics, BLS, 2001 data]. Shipyards are categorized within the construction industry, making it difficult to extract fall data for the maritime industry. Review of the narratives from OSHA fatality data between 1991 and 2001 indicated that 20 of 120 shipyard fatalities recorded appeared consistent with falls from height, but often provided limited detail.

The Center for Naval Analysis' evaluation of Navy mishap data, using three databases, showed that falls ranged from 15% to 28% of reported total injuries and illness. (Mintz and Giovachino, 2001). This evaluation also identified several shipyards as Navy locations with the higher injury rates and compensation costs.

Deep tank falls are less frequent than the configuration of these spaces might lead the external observer to predict. This may be due to an acute awareness of the hazard and the use of extraordinary precautions by maintenance and/or access personnel. However the severity of a fall into these spaces is generally high, often resulting in either death and/or significant disability. The Safety Department at Newport News evaluated the risk associated with falls in deep tanks according to Military Standard 882C (Paragraph 4.5) criteria as consistent with the hazard probability level "occasional" but having potentially critical consequences (Category IC or II C). (Nelson 2001). Concurrently, shipboard inclined ladders were evaluated as creating a high probability of injury but with "marginal" (minor injury) consequences, (Category IIB).

There are also the indirect costs of the incident and requirements for emergency rescue, i.e., a high angle rescue team and the extraordinary expense associated with the necessary equipment, time, materials and highly skilled rescue personnel necessary to extricate a victim of a fall. OSHA Fall-Protection regulations requiring provision for such rescue (29 CFR 1915.159 (c) (7)) are extremely difficult to meet with present space configurations.

Testimony provided by workers and personnel in two shipyard safety departments suggested that some mishaps, not reported as falls, resulted when workers "caught" themselves to avert a serious fall at the cost of a lesser injury, such as strained shoulder. Concurrently, the category of "slips/twist/not falling" accounted for 35% of the Navy-wide summary of fall related injuries reported by Mintz and Giovanchino (2001).

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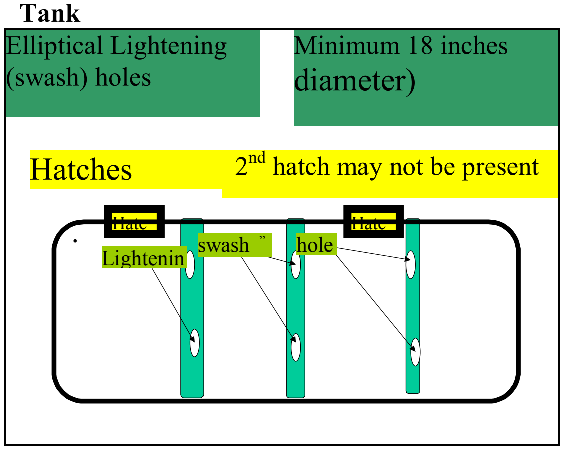
[3] A personal fall arrest system includes an approved full body harness, device(s) designed to provide controlled expansion that limits the impact forces created by a the fall on the victim (to 1800 pounds) and an assured anchorage point (3600 lbs). The device providing controlled deceleration may include a lanyard, deceleration device, lifeline, or suitable combinations of these. The use of body belts for fall arrest has been prohibited since January 1, 1998.

DESIGN AND CONFIGURATION

Aircraft carriers (CVN class vessels) require approximately 150 large tanks for storage of fuel, waste liquids, water and ballast. Tanks typically span several frames, each frame in the range of 4 to 6 feet wide, and can be as deep as the molded depth of the ship. Bulkheads at each frame have elliptical openings of approximately 20 inches minimum diameter called swash, sometimes referred to as lightening holes, that allow movement of fluids between compartments, thereby decreasing the free surface area of the ships lightweight (damping the sudden bulk movement of large volumes). The configuration of a "typical" deep tank is illustrated in **FIGURE 1.**

FIGURE 1. Configuration of a Typical Deep Tank



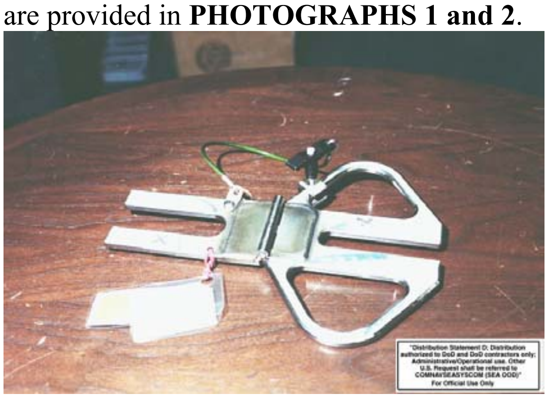
Shipboard space limitations contribute to tank location in areas that are otherwise difficult to use, such as along the side of a steeply sloping hull. Many tanks and voids are irregularly shaped, because of the hull configuration. Impediments to safe and efficient access include; small manholes (top entry ports); passage through bulk heads provided by narrow elliptical swash holes as little as 15" minimum diameter; foot holds limited to "D-ring hole" penetrations in transverse bulkheads, minimal anchorage points for hoisting, scaffolding and securing of personal fall arrest equipment; and irregular space configuration such as steeply angled bases. Shipyard workers report the irregular placement of D-Ring holes in certain tank locations with distances as great as 3 feet between the tank innerbottom and first climbing point.

Evaluation Process and Participants

The combined efforts of several groups were instrumental in elucidating the issues and developing an approach to address the issues of fall hazards. The approach is consistent with the multi-disciplinary integrated process action team (IPT). Several multi-disciplinary process action teams support the Naval Sea System Command (NAVSEA) program manager for future aircraft carriers (CVN 21, previously CVNX-1), including one addressing environmental and safety considerations. The Chief of Naval Operations, Occupational Safety and Health Branch (Code N454) funds a Naval Occupational Safety and Health (OSH) Quality Management Board (QMB) on fall protection. Members of the two groups cooperated in a review of potential risk factors, process evaluation and development of draft guidelines for improved access to confined spaces. The Safety Departments at Puget Sound Naval Shipyard (PSNS) and Newport News Shipbuilding (NNS) participated in this effort. Supporting data was provided by the Naval Safety Center. The evaluation reviewed current practices for tank entry with the intent of identifying potential changes in procedures and additional equipment that might enhance safety. Space configuration and minor modifications in layout that might reduce the hazard and improve worker efficiency in entry and maintenance operations were also considered.

Alternative Approaches

The Safety Branch (Code 106) at Puget Sound Naval Shipyard (PSNS) acts as the lead shipyard for fall protection in the Navy. Their earlier evaluation concluded that D-ring hole footholds in the transverse bulkheads, used for access into the hull's infrastructure (in wing deep tanks and voids), did not qualify as either safe or acceptable ladders since they did not provide for any fall protection. (Vertical ladders more than 15 feet high are required to provide fall protection, typically through a climbers safety rails or ladder cages). PSNS initiated measures to provide assured fall protection that include; development of an anchorage assembling that fits into D-Ring holes and provides an assured anchorage; erection of scaffolding inside many tanks undergoing repair or maintenance; and requirement for fall protection to be used in all jobs conducted at elevation, with the potential exception of the “first man up” in certain situations. PSNS also provides worker training that includes practice inside a mock-up of a carrier deep tank. Photographs of the anchorage device and deployment in a “D-ring” in a training “mock-up” of a shipboard confined spaces are provided in **PHOTOGRAPHS 1 and 2**.



PHOTOGRAPH 1. Anchor Point Assembly

PHOTOGRAPH 2. Anchor Point Assembly Deployed in Training Mock-up

The anchorage assembly for scaffolding and personal fall protection has not been widely used outside PSNS. Other facilities are reportedly reluctant to erect scaffolding inside tanks because of the additional labor costs.

SUMMARY OF ACCESS ISSUES AND POTENTIAL CONFIGURATION CHANGES

There are many pace configurations and issues that increased the difficulty and risk of access. Initial access can be complicated by the distance between manholes or other entry points and secure ladders; limited anchor points above the entry point (manhole); and lack of anchor points at the top level of the climbing location to support the use fall protection. Movement within the tank can be made more difficult by location of the lowest lightening holes (often reportedly 4 to 6 feet above the deck) and position of the lowest climbing D-ring hole (sometimes reportedly greater than three feet above the lowest level). **FIGURE 2** illustrates the locations and access points of potential concern.

Current configurations were reviewed with reference to recommended criteria for human systems integration (ASTM F1166 and American Bureau of Shipping (ABS 1998). **Annex A** summarizes these criteria.

Evaluation of existing configurations, approaches to installing scaffolding and secure anchor points developed by Puget Sound Naval Shipyard and discussion with workers and technical experts suggested that relatively minor changes might reduce the risk of entry and improve access. Alternative designs suggested by application of human systems engineering criteria are summarized in **ANNEX A** (**Table of Recommended Criteria for Shipboard Confined Space (Tank) Entry and Access Aids)** and illustrated in **ANNEX B** **(FIGURES 1 through 5).**

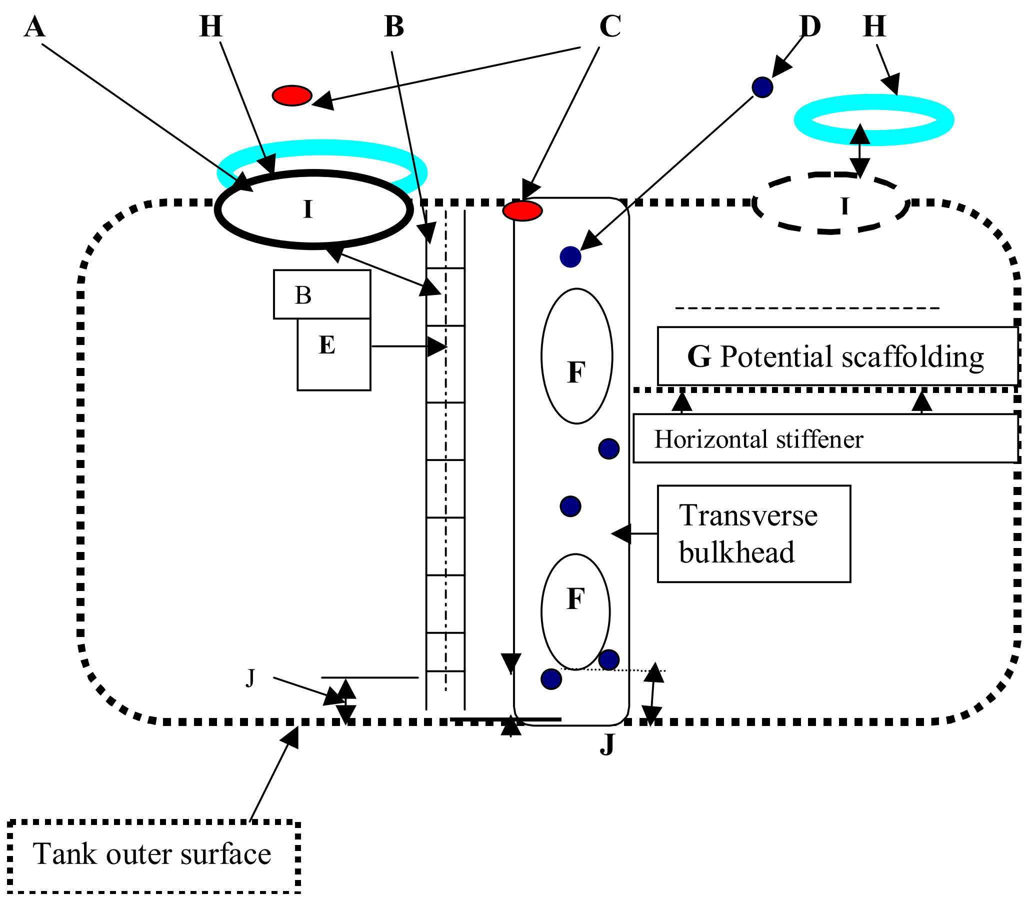


FIGURE 2 (Key). Summary of Parameters for Confined Space Access

Item	Description
A	Access manhole (or hatch) dimensions
B	Space between entry and secure foothold
C	Location and capacity of anchorage points
D	Size, spacing and configuration of footholds
E	Ladder type, configuration and associated fall protection safeguards
F	Size and orientation of swash (lightening) holes
G	Hardware and anchorage points supporting scaffolding
H	Perimeter protection for deck opening
I	Number and location of hatches/manholes
J	Maximum distance from innerbottom (base of tank) to swash hole and first ladder tread or other foothold.

IMPACT OF PROSPECTIVE DESIGN CHANGES ON LAYOUT AND CONSTRUCTION OF VESSELS

Recommended changes were developed with the intent of limiting the extent of modifications necessary to layout of new designs. ***Any such change to existing designs or new structures requires the involvement of a Naval Architect or other professional to evaluate potential impact on structural integrity, stability and stiffness and other critical design parameters.***

The intent and basic dimensional recommendations of each characteristic are summarized in **Annex A**.

Recommendations include:

- Locating manholes within safe (reachable) distance of secure entry footholds. This might involve locating a manhole within one to two feet of the bulkhead versus at the center of a compartment that might be two to three feet from a ladder.

- Providing engineered anchor points above manholes, when feasible, to avoid the need to utilize mobile need to utilize mobile tripods. These might be provided by padeyes (welded anchor points) located on key lifting points or use of mobile beam clamps on I-beams located above manholes. (Benefits of ready availability would need to be weighed against the time and cost for installation and periodic testing of lifting points).

- Providing certified anchor points for personal fall arrest systems at the top of transverse bulkheads. This could be done by providing an "extra" D-Ring hole near the top of the bulkhead for use with an anchor point adaptor. (Anchorage devices are also available that utilize a smaller penetration). The modification would support regulatory compliance by providing an approved anchorage.

- Ensuring that D-Ring climbing holes are located at "reasonable" distances from the base of the compartment, within suitable proximity of "swash" holes to support scaffolding at the top level and provide for effective transfer for personnel passing through adjacent "swash" holes.

- Locating the swash hole closest to the innerbottom of the compartment at the lowest level consistent with structural integrity (typically 2-3 feet from the base) to allow personnel transiting between bulkheads to "walk" through as opposed to climbing up through and down between passages that have been as high as 4-6 feet above the tank bottom.

- Providing swash holes as large as permitted by structural considerations and the need to reduce uncontrolled movement of fluids.

- Identifying methods to provide anchor points for scaffolding at the highest level of swash holes in each compartment. Providing scaffolding at the highest level allows space for deployment of fall protection[4]. Scaffolding at the highest level

[4] At least 17 feet must typically be allowed from the walking surface to the "floor" level because of the additive distances of the lanyard, expansion of shock absorbing device on the lanyard, stretching the harness and the need to allow for a small margin of error.

inside the tank also supports movement of supplies and equipment.

HISTORICAL PERSPECTIVE AND THE ROLE OF LIFE CYCLE COST AND MANPOWER

The next carrier, initially designated CVN 77, was anticipated to be the 10th and the last of the Nimitz class of Aircraft Carriers. The vessel has now been re-designated as CVN 21 because of the anticipated extent of design changes. The redesigned vessel will allow for reconfiguration of many current functional areas and related spaces within the existing hull shape. The modifications suggested for improved tank access will be made possible because of the extent of changes.

The Nimitz Class Carriers were designed for a 30-year service life. CVN 77's performance objectives extended this to 50 years, a goal retained by the CVN 21. DoD also identified a need for a less expensive ship. CVN 77's concept projected approximately 80% of ship life cycle costs for O&M with 50% of this expense derived from manpower and staffing requirements. A primary goal of CVN 77/CVN 21 acquisition is to reduce these cycle cost drivers. The secondary goal is serve as a bridge for the next class of Aircraft Carrier. CVN 21 (previously CVNX-1) will use an evolutionary acquisition approach of phasing-in improvements over each build or design-build evolution. This approach spreads the budget impact over time while reducing developmental risks in the Carrier's evolution.

The CVNs maintenance cost cycle is based on an incremental maintenance plan (IMP). A CVN will undergo one refueling and complex overhaul (RCOH) of 32-month duration at its approximate mid-life cycle. Interim maintenance availabilities occur within an 18- month operational period outside each boundary of the RCOH. These availabilities are referred to as Planned Incremental Availabilities (PIAs) or dry docking Planned Incremental Availabilities (DPIAs). PIAs are generally last 6 months. DPIAs require 10.5 months.

In RCOH, virtually all the tanks and voids are inspected, cleaned, blasted and painted. In PIA, or one six-month pier side availability, about 50 tanks are cleaned, blasted, painted or otherwise maintained. In DPIA, which usually occurs about every six years, this number of tanks increases from 50 to 120.

There are a total of about 800 tanks and voids on a typical CVN. About 100 spaces are cleaned every two years, in addition to the DPIA. Of those 800 total spaces, approximately 120 tanks hold fuel and/or ballast water.

Painting on Navy Ships accounts for 15-25% of the maintenance cost of a CVN during its availability and requires the equivalent of 30 full time sailors when the ship is in service. Painting and related maintenance are among the single most expensive items in the life of a CVN; responsible for 2.7% of the life cycle cost of the ship or 12% of all maintenance costs. The correction of corrosion failures related to an improper paint application raises these values to 25% of maintenance cost, or a life cycle net present value of 4.3% of the value of the ship.

Manpower Requirements

Deep tanks are not occupied spaces. However, job analysis indicates that during inspection and maintenance operations, a wide range of trades are obligated to enter these spaces during shipyard availability (ROH or RAV). Personnel requirements associated with a "typical" tank cleaning and repainting operation are summarized in **TABLE 3**.

TABLE 3. Shipyard Trades Involved in Tank Maintenance

Personnel and tasks	Number in work crew
Gas free initial evaluation	2
Periodic gas free inspections	2
Shipwrights	3-4
Tank Cleaners	6-8
Abrasive Blasters	6-8
Inspectors	2-3
Welders and Fire watch	2 welders, 1 fire watch
Marine Machine Shop	2-3
Temporary Services	2-3
Riggers	2-3
Technical support	Varies

Notes: 40-50 tanks at 8 deck levels with about 1/3 or 14 of them being available for an inspection at any given time.

1. Initial entry may require longer due to lack of scaffolding and entry locations. Shipwrights install all scaffolding for the tank cleaners and painters.

2. Abrasive blasting during dry dock availability as follows: DPIA every 3-4 years, PIA every 2 yrs and for pier side maintenance (limited hull areas) every 6 months.

3. Shipwrights may do limited repairs during pier side availability.

4. Pipe fitters repair and replace pipes, and associated fittings. Machine shop repairs valves and other equipment including: valve seats, jacking and reduction gears.

5. Temporary services (TSI) include ventilation, lighting, airline manifolds, and other utilities as needed. Occupancy is not consistent, but extensive revisits are required to relocate lights, ventilation and are power as needed (often occurs concurrently with shop 51).

6. Riggers are involved in the movement of heavy equipment, such as valves. They may erect chain falls and temporary staging to extract large materials out of the tank voids

7. Technical support is not a formal term but includes various oversight and engineering groups including ship safety (ships force), shipyard safety (code 106), varied engineering support and planning codes and inspection (non-destructive testing) code 138 and QA for welding code 135.

During maintenance painting, up to 12 different trades may enter deep wing tanks in teams of no less than two persons. Labor rates are in the range of $50/hr. Considering the frequency and duration of fall hazard exposure and the difficulty for access to many locations; any enhancements to improve deep tank configuration will not only minimize or mitigate fall hazards, but also increase productivity. Easier and safer access may reduce maintenance problems (such as corrosion from improper painting and preparation).

ESTIMATED MANPOWER SAVINGS

Equipment designs that require higher manpower for operation or maintenance may be both unsafe and inefficient. As an example, Simpson (1990) described the case of a highly dangerous drilling machine used in the mining industry. This device was designed to drill holes in the working face, but afforded the operator a very restricted view of the operation. Its design was described as "an accident waiting to happen". However, the available mishap statistics did not support this contention. Further evaluation indicated that the presence of spotter was needed to effectively operate the machine nominally intended for use by a single individual. Documenting the additional labor requirement provided the necessary stimulus for redesigning the machinery to provide an inherently safer and less labor-intensive product.

Available shipyard accident records show a similar limitation in data directly linking confined space work with fall injuries. There are two concurrent explanations; limitations in the specificity of existing information and the great care exercised by those entering confined spaces.

A worksheet was developed to compare the labor requirements associated with current and suggested configurations. It was validated through informal review by the planning and estimating department at Puget Sound Naval Shipyard and by others involved in this project. **TABLE 4** compares current the labor costs of a "typical" tank cleaning and repainting job with the labor costs anticipated from a project conducted in a similar tank with improved access.

TABLE 4. Tank Maintenance Costs for Current and Suggested Configurations.

*** Assuming $60 man-hour plus miscellaneous costs for materials**

Tank Description (of the case used in this example)			
Depth (feet)	**50**		
Number frames	**4**		
Dist between frames (feet)	**5**		
Tank length (feet)	**20**		
Width at tank top (feet)	**10**		
Width of tank at inner bottom (feet)	**5**		
Estimated maintenance time and costs			
Factor	**Present**	**Proposed**	**Change**
Man-hours Job	**88**	**55**	**-33**
Job cost *	**$21,528**	**$13,640**	**$ 8,188 (37%)**
Number of similar tanks **	**30**	**30**	**-**
Total cost per yard period	**$645,840**	**$409,200**	**$236,640 (37%)**

* Aspects reducing time and risk (a)-padeye &/or anchor point at top (b) improved access at top level (c) reduced time to move equipment (d) reduced time to set up scaffolding (e) reduced time at base with less difficulty going between frames.
**** Maintained in a "typical" yard period**

The information was prepared in a spreadsheet **(ANNEX C)** that allowed for description of the dimensions of the tank, its condition, the work to be done and calculation of estimated time and labor costs. Additional columns projected the labor requirements for a tank that had a similar configuration but was designed for improved access. It provided notes explaining the rationale for differences on the basis of parameters such as reduced time to erect scaffolding or provide anchor points for personal fall arrest systems. An accompanying diagram explained the dimensions to be utilized when putting information into the spreadsheet.

Evaluation of common scenarios showed a labor savings in the range of 30% associated with improved tank access. Extrapolation of this savings suggests that the present "typical" cost of $22,000 (88 man hours) associated with cleaning and repainting of a representative tank could be reduced by approximately 30% or $13,640 (55 man hours) by improved access. If thirty tanks of similar configurations were involved, the cost could be reduced from $654,000 to approximately $409,000.

CONCLUSIONS

Reasonable and limited configuration changes, affecting access in CVN 21 deep tanks, are advised to reduce manpower requirements for entry, while lowering safety risks. Manpower requirements for tank/void entry are reviewed in terms of the additional time, materials, labor and access related risks. These create significant ownership costs associated with the legacy designs. Future design changes could be justified solely on the basis of controlling these risks with associated reductions in acquisition life cycle costs and in the acquisition's total ownership costs.

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<table>
<tr><th colspan="3">ANNEX A: Criteria for Shipboard Confined Space (Tank) Entry and Access Aids
Refer to FIGURE 2 for diagram summarizing parameters</th></tr>
<tr><th>Item</th><th>Description</th><th>Suggested Design Objective and Criteria</th></tr>
<tr><td>A*</td><td>Access hatch (manhole) dimensions.

Related issues: Type of hatch; size and weight of hatch; closing, securing and sealing mechanisms for the hatch.
Examples: spring loaded, self-closing, hydraulically dampened, dogs-latches, OS&Y handset, positive locking latches, pressurization/ depressurization applications (below water)</td><td>Primary objective: Safe and efficient access for workers and equipment during routine entry.

<u>(Gen. Spec 071-3 par. 3.2) Manholes</u>
Manholes of 15” x 23” except where structures or space considerations require reduction to a minimum 15” x 18”

Secondary objective: Access with SCBA for rescue (at least one access per space)

Nominal 36" diameter for person outfitted with a SCBA

ASTM F1166-95

Table 33 Mobile Work Space Dimensions (partial copy)
<table>
<tr><td>Vertical Entry Hatch</td><td>Minimum.. (inches)</td><td>Preferred (inches)</td></tr>
<tr><td>Square</td><td>18</td><td>22</td></tr>
<tr><td>Round</td><td>22</td><td>24</td></tr>
</table>
<u>ASTM-1142-90</u>
Deck cut size (Table 1)
15 inches x 23inches (Minimum)
18 inches x 24 inches (maximum)
<u>ASTM F1142-90</u>*
Deck cut size (Table 1-Rectangular)
15 inches x 23 inches (Minimum)
18 inches x 24 inches (Maximum)
(Table 2-Oval) 15 inches x 23 inches (minimum)
18 inches x 24 inches (maximum)</td></tr>
<tr><td>B*</td><td>Maximum space between entry point and secure foothold/ladder diameters, distance, angle of inclination, transitioning space requirements to first transverse bulkhead</td><td>Objective: Limit transition distance so that a secure footing is maintained (by one foot) at all times.

Design Criteria:
Perimeter of hatch to be located no more than 8” from vertical plane of ladder. (ASTM F 1166 Fig 85).

Footrests or steps provided at 12 inch intervals if step-down access > 27 inches,

Horizontal grabrods to be provided at key transition points as described in NAVSEA guidance (Gen. Spec 623-7)

Note: This may require ancillary hardware during entry.</td></tr>
<tr><td>C *</td><td>Location and capacity of anchorage points: Supporting entry access to space at manhole (above deck/below deck), under deck, and integral to the transverse bulkhead.</td><td>Objective: Anchorage locations meeting OSHA/ANSI load criteria at all access and climbing points needed for deployment of PFAS.
Support fall protection anchorage (5,000 pounds) dynamic load and access for lifting reasonably anticipated loads into the space and (3,500 pounds) engineered for static loads
Access routes, size and quantity of support locations based on installed equipment. Padeyes provided in number, location and capacity as required (General Specifications Section 602)

<u>Author’s recommendation</u>:
Padeye/ anchorage points
(1) Above hatches and manholes
(2) At top of bulkheads with D ring climbing holes or ladders
(3) Above equipment such as pumps installed in spaces.
(4) Avoid locations between hatches and bulkheads to minimize the potential for swing falls.

Portable anchor points

ANSI A 10.14
ANSI 359.1
(Source for OSHA criteria)</td></tr>
</table>

Item	Description	Suggested Design Objective and Criteria
D*	Size, spacing and surface configuration of the D holes or other access points on bulkheads where installation of fixed ladder is not feasible; angle in ascent /descent for narrow angle high pitched exterior hull where a "level" walking surface (perpendicular to tank bottom) cannot be achieved **This does not eliminate the need for fall protection systems.**	Objective: Foothold is large enough to accommodate foot (in safety boot) and deep enough to support footing (not "sharp"). Steeply sloped sides* (walking surface) require additional footholds or anchorage points. The contacting surface should provide an adequate coefficient of friction to provide a safe foothold. (Guidance OSHA standard for walking and working surfaces 29 CFR 1910.22 and the criteria of slip resistance cited in the OSHA Steel Erection Standard 29 CFR 1926.754 (c) (3)[5] • Tentative definition of steeply sloped $\geq$ 20 degrees. • Author's recommendation: Bethlehem Steel Std 129-00-01 for footholds (minimum criteria); must have concurrent provision for fall arrest such as a climbing rail or other Personal Fall Arrest Systems (PFAS).
E*	Ladder type and configuration with an associated fall-protection safeguard (such as a Ladder Climbing Assist Device (LCAD) or other PFAS).	Objective: Ladder design meeting current ASTM criteria for rung spacing and other configuration. Design criteria: Include 15 foot maximum distance without climbing rail or other protective device. ASTM F-1166 Sec 31.8 (Gen. Spec 623.3 Par. 3.5) Ladders - Climber's safety rail required on mast, yardarm, and stack vertical ladders. Treads on rungs of vertical ladders shall be 12 inches (or less) apart, tread bottom shall not be more than 15" above the level deck (623.3 par. 3.9). Authors recommend use of these criteria if alternative specific standards are not available. Also consult 29 CFR 1926 Subpart X Ladders (1926.1051 to 1926.1060)
F*	Dimensions /orientation of Swash or lightening holes intended for passage, e.g. coaming type dimensions	Objective: Safe access for routine entry with provision for emergency rescue requiring use of SCBA. Suggest standard: (Gen. Spec 071-3) with one set of holes in each space should permitting emergency rescue (36-inch diameter). Other holes should be at least 18" x 23" and be unobstructed. Preferred criteria is to meet ASTM F1166 Criteria for side hatch entry 28" x 32" Supporting requirements include stable foothold 26-28 inches below lightening hole(s) and anchor points for PFAS on bulkhead above passage. Anchor points should be reachable manually or with available extension devices for positioning anchorage points.

[5] The steel erection proposed rule was published in the **Federal Register** on August 13, 1998. It contained a provision covering slip-resistance for skeletal structural steel (§1926.754(c)(3) of the proposed rule). The proposed rule also identified (in an Appendix) two ASTM approved test methods for testing the surfaces (ASTM F1677-96 and ASTM F1679-96).

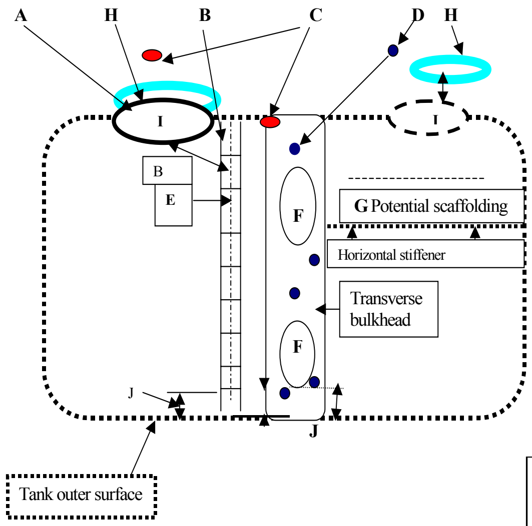
Item	Description	Suggested Design Objective and Criteria
G*	Hardware to support scaffolding. Where feasible, modular scaffolding integrated scaffolding, use of horizontal "T" stiffeners as point of attachment for the scaffolding planking. Provisions for running scaffolding planking through swash holes and access for movement and setup of scaffolding.	Objective: Design for installation of scaffolding at top transit level of deep tanks. Anchorage locations for scaffolding suitable for required maintenance in compartment. Suggested design approach: Hardware such as horizontal stabilizers (currently in place) and possibly complementary anchorage points on opposite side of compartment meeting ANSI A 10.8. Identify anticipated anchorage for scaffolding in each compartment in design documents. Remarks: Deployment of PFAS requires about 17 feet. Secure scaffolding on top level provides a work that allows use of sensors to monitor gases at lower levels; hoisting of equipment to lower levels and climbing access to other levels with PFAS.
H*	Safety requirements for perimeter protection, deck and bulkhead holes, openings, railings and toeboards	Objective: Protect all openings and perimeters that present a plausible risk of falling or tripping. Suggested design criteria: 29 CFR 1915.73 for manholes and other deck openings. (Requires guarding of opening to height of at least 30 inches except when work in progress would interfere with this protection) All access trunks 17 ft or deeper (except machinery escape trunks or fuel tanks) should have these nylon nets installed starting at uppermost deck and then installed at alternate deck levels. These nets need to be installed within 24 " of a fixed vertical ladder top rung. Nets (without weight being applied) should sag no more than 4". After the nets fabrication/installation nets should be weight drop tested and attach a stamped tag to document the test.
I*	Number and position of hatches	Objective: Design to optimize access and ventilation. Recommended design: Meet Gen. Spec. 071 criteria. Consider design modeling of anticipated airflow pattern and ventilation methods during design. Provide description with diagrams in maintenance documents. Certain isolated locations will require guidelines for movement of exhausted air out of the compartments adjacent to the tank.
J	Maximum distance between tank innerbottom (deck) and first lightening (swash hole) and associated foothold	Swash (lightening) hole should be 25 to 32 inches above base of tank. (All dimensions and distances subject to structural considerations as determined by marine architect). Footholds should be 12 inches apart with first D-ring hole or ladder rung 12 to 15 inches above the innerbottom (base of tank).

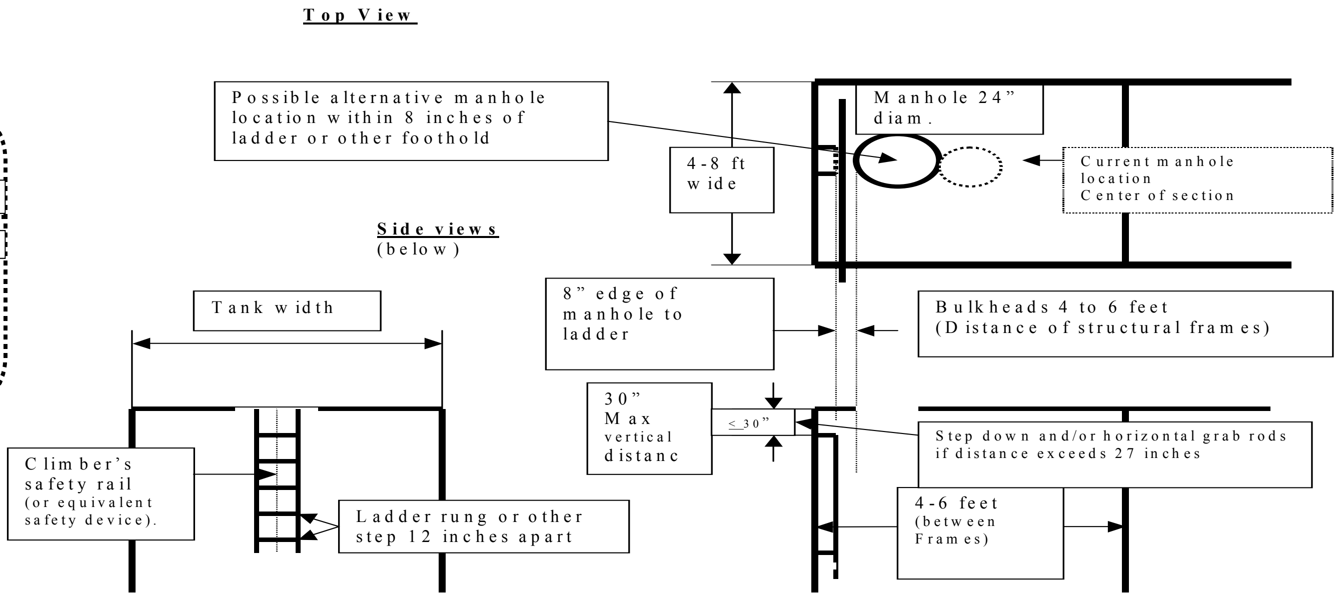
Annex B Figures 1 and 2 Access Manhole and Distances between Entry and Secure Foothold

Annex B: Figure 1 (Item A) Manhole Access

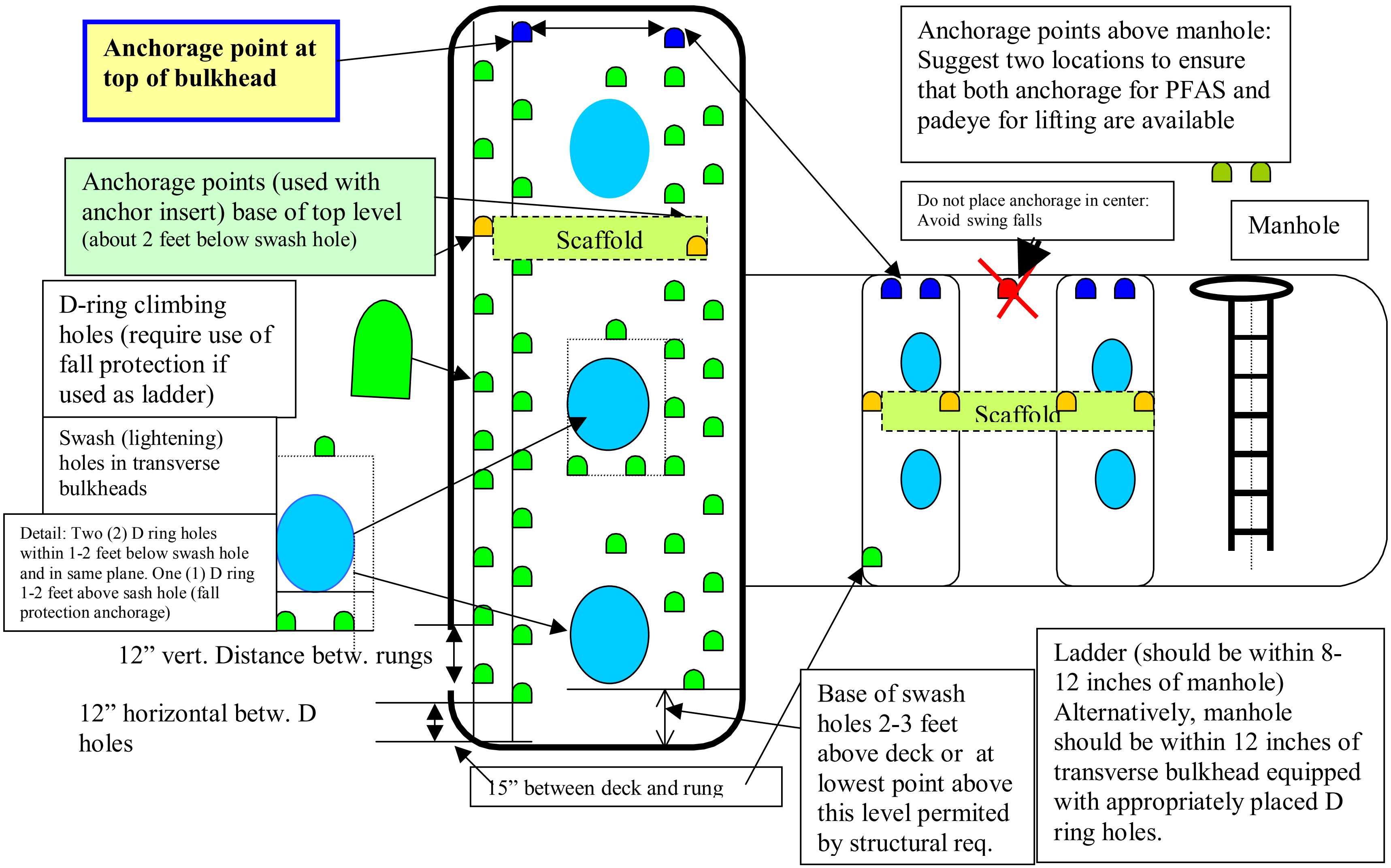
Idealized view of tank with transverse bulkheads and manhole for access

(Actual dimensions will vary with vessel and compartments)





Annex B Figure 3 ITEMS C AND D Anchorage Points and Climbing Hole Location

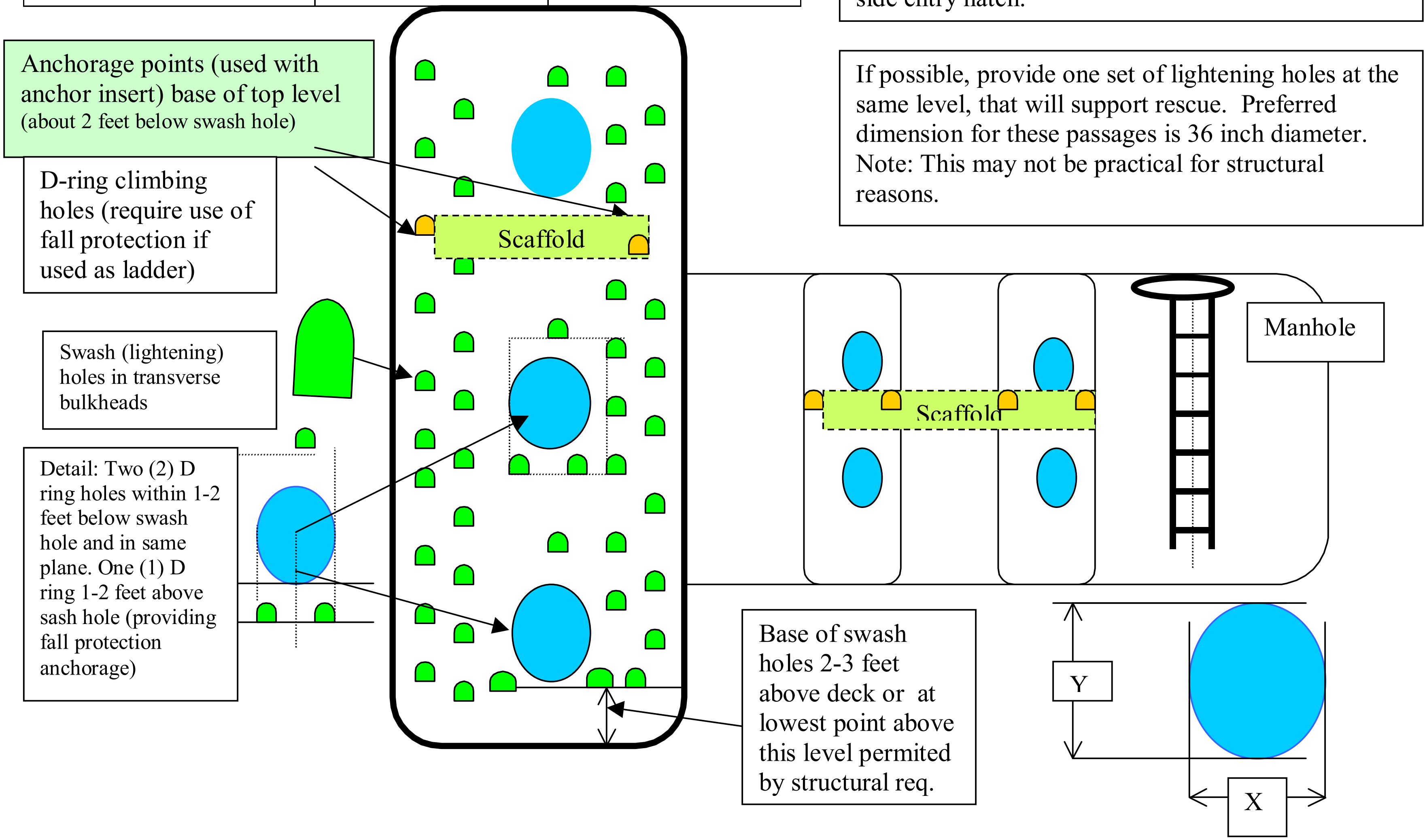


Annex B Figure 4 (Item F) Dimensions of Swash (Lightening) Holes

Swash (lightening hole dimension)	Width (inches) (x)	Height (inches) (y)
Minimum	18	23
Preferred	29	32

Transverse passage (swash or lightening holes) should be 18" x 23" and unobstructed. Preferred criteria is 29' x 32" per ASTM std 1166 criteria for side entry hatch.

If possible, provide one set of lightening holes at the same level, that will support rescue. Preferred dimension for these passages is 36 inch diameter. Note: This may not be practical for structural reasons.



ANNEX C PROJECTED COST CHANGES ASSOCIATED WITH PROPOSED ACCESS CHANGES

Purpose:	This worksheet is designed to identify prospective cost changes associated with design modifications that would improve access and work safety during inspection and repair of deep tanks. The accompanying illustration shows the general layout of a "typical" deep tank and location of features such as swash (lightening) holes, manholes and anchor points (current and suggested).								
How to use this form:	1. Complete the items for tank description including depth (**A2**), number of frames (**B2**), distance between frames (**C2**) or total length (**D2**), width at the top (**F2** and bottom (**E2**). The tank volume and area will automatically be calculated. 2. Complete information on tank condition as related to their influence of required repairs (for example extensive corrosion may require cleaning, blasting and painting) (**A7**). 3.Describe features of current and proposed configurations related to access as influenced by potential design changes in boxes **C5-6, F 5-6, G5-6, H5-6 and I5-6**. 4. Estimate labor requirements for the space(s) as presently configured in terms of manhours for each affected trade. Crew size is shown in columns b3-12. (Modify tasks shown in column c3-12 if needed). Projected worktime should be entered in collumns d3-12. Total labor costs will be calculated in columns e3-13. 6. Estimate labor that would be anticipated from potential design changesin collumns f3-13. Revised estimated costs will be calculated in collumn g3-13. Differences in worktime and labor costs will be automatically calculated in collumns h3-13 and g3-12. Identify features that reduce labor via improved access using the key (a) through (e) in row 22.								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
1	**Depth**	**Number frames**	**Dist btw frames**	**Length**	**Width top**	**Width bottom**	**Rectangular volume**	**Triangular volume**	**Total volume**
2	50	4	5	20	10	5	250	125	7500
3	**Access Description**								
4	**Access Description**		Tank bottom to ullage hole		Scafold anchorage top level @ ullage holes		Anchorage top of frames	Distance betw D holes	Anchorage top of manhole
5	Present configuration		6		no		no	Max 3 ft	no
6	Present configuration		2		yes		yes	Max 1.5 ft	yes
7	Discussion of tank condition:								

ANNEX C PROJECTED COST CHANGES ASSOCIATED WITH PROPOSED ACCESS CHANGES

			Present Configuration		Proposed configuration		Projected effect of changes		
Trade	**Crew size**	**Task**	**Worktime**	**Cost***	**Worktime**	**Cost***	**Worktime**	**Notes***	**Cost***
Gas free techs	2	Gas free initial	4	$ 464.00	3	$ 348.00	1	(a) (b)	$ 116.00
Gas free techs	2	periodic eval	10	$ 1,160.00	6	$ 696.00	4	(a) (b) (f)	$ 464.00
Shipwrights	4	scafold errection	12	$ 2,784.00	8	$ 1,856.00	4	(d), also (a), (b), (c)	$ 928.00
Tank cleaners	6	Cleaning -spray	6	$ 2,088.00	4	$ 1,392.00	2	(a) (b) (c) (e)	$ 696.00
Abrasive blasters	8	blast clean	12	$ 5,568.00	8	$ 3,712.00	4	(a) (b) (c) (e)	$ 1,856.00
Inspectors	2	inspection	4	$ 464.00	3	$ 348.00	1	(a) (b) (e)	$ 116.00
welders & fire watch	3	welding	10	$ 1,740.00	8	$ 1,392.00	1	(a) (b) (e) (g)	$ 348.00
Marine machine	4	repair pump	4	$ 928.00	2.5	$ 580.00	2	(a) (b) (c) (e)	$ 348.00
Riggers	2	remove pump	4	$ 464.00	2	$ 232.00	1.5	(a) (b) (c) (e)	$ 232.00
Tech support	3	general support	4	$ 696.00	2	$ 348.00	2	(f)	$ 348.00
Painters	6	paint	12	$ 4,176.00	6	$ 2,088.00	2	Improved access improves quality	$ 2,088.00
Inspectors	2	inspection post paint	6	$ 696.00	3	$ 348.00	6	(a) (b) (e)	$ 348.00
Total labor	**44**	**Tank eval & refirbishing**	**88**	**$ 21,228.00**	**55.5**	**$ 13,340.00**	**32.5**		**$ 7,888.00**
Misc Materials				$ 300.00		$ 300.00			$ 00
Paints $40gal/300 ft/gal	2250 sq ft			$ 300.00		$ 300.00			$ 00
Job total $$				**$ 21,828.00**		**$ 13,940.00**			**$ 7,888.00**
Number of similar tanks	**per yard period**		**30**		**30**		**30**		**Number of similar tanks**
Total cost difference	**per yard period**		**$654,840.00**		**$418,200.00**		**$236,640.00**		**Total cost difference**

**** Aspects reducing time and risk (a)-padeye &/or anchor point at top (b) improved access @ top level (c) reduced time to move equipment (d) reduced time to set up scaffolding (e) reduced time at base less difficulty going between frames (f) Easier access for re-evaluation (g) Reduced time at base critical**