Application of System Safety to Prevention of Falls from Height in Design of Facilities, Ships and Support Equipment for Weapons Systems

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Abstract

The construction, operation and maintenance of varied systems, buildings/facilities, aircraft, ordnance and weapons, and ships often involve work at elevated locations. Falls from height account for significant numbers of occupational injuries and fatalities. System safety evaluation of risks should consider and mitigate the hazards of work at elevated locations to manage risk and life cycle costs of systems, vessels and facilities. Early identification and management of these risks reduces the cost of control measures and the effectiveness of their employment. Concurrent application of ergonomic/ human factors engineering criteria reduces risk and lower maintenance costs.

Injuries and Fatalities of Falls from Height

Falls from height are the second leading cause of occupational fatalities, and account for approximately 700 occupational fatalities annually in the United States (Bureau of Labor Statistics, BLS, (2003, Ref. 1). (Traffic-related fatalities remain the leading cause of occupational deaths in the United States). The number of such fatalities has continued to rise over the past decade while most work-related injuries are declining in number. Table 1 summarizes this data.

Table 1: Fatal Falls in US Private Industry

Year	Fatal Falls	Total Fatalities
2001	810 (14%)	5915
2002	714 p (13%)	5524 p

P data regarded as preliminary at the time of reporting (March 2004)

Falls from height accounted for 288,500 (6%) of the 4,700,600 OSHA-recordable[1] mishaps occurring in 2001 and 2002 tracked by BLS in 2004.

Total fall injuries recorded in U. S. private industry have declined with regulatory attention from 374,831 in 1992 to 288,500 in 2001. However, the average number of fatalities has risen from 479 in 1992 to 607 in 2002. Approximately half of these deaths occur in the construction industry. The general reduction in fall injuries is likely to be related to regulatory requirements and their more stringent enforcement.

Experience in England is similar, but showed fall related mishaps, rather than traffic related accidents, as the leading cause of occupational fatalities (Health & Safety Executive 2003b). Falls accounted for 25% (73/291) of occupational fatalities in 2000/2001. Table 2 summarizes English data.

Table 2: Common Causes of Fatal Injuries in the UK 2000-2001 (All industries n=291)

Category of injury	Total
Falls from height	73 (25%)
Struck by moving vehicle	64 (22%)
Struck by object	52 (18%)
Trapped by something collapsing or overturning	37 (13%)
Total	291

European statistics show a similar trend. Falls from height accounted for approximately 40% of

[1] 29 CFR 1906 regulates reporting of occupational injury and illness statistics. OSHA recordable injuries typically involve a loss of greater than one day of work time.

the construction industry accidents (Stemsol 2004).

OSHA (1998) reported 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 (16%) of 120 shipyard fatalities recorded appeared consistent with falls from height, but often provided limited detail.

Typical costs for a fatality range from $800, 000 to $2,400,000, while the average cost of serious injury is more that $30,000 (DON 2003).

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.

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). It is likely that similar types of mishaps in other industries account for many other events that were actually averted falls.

Much of the attention has been upon use of personal protective equipment and fall arrest systems retrofitted into existing facilities, often at considerable cost. There has been less focus upon initial design and preliminary risk evaluation in design. System safety practitioners have not consistently addressed risks associated with work at elevated locations as a consideration in preliminary hazard assessments or in design requirements.

U.S. Regulatory Requirements and Definitions

Protection against falling from heights during operations conducted at elevation is one of the more 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 (5) feet within shipyard employment and eight (8) feet within the maritime industry .

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

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

Risk Review and Management Approaches in the Maritime Industry

[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); eight (8) feet for Marine Terminals and Longshoring , 29 CFR 1918 (See http://www.osha.gov/ for regulations).

[3] A personal fall arrest system includes an approved full body harness and other equipment designed to provide controlled expansion that limits the impact forces created by a the fall on the victim (to 1800 pounds) and certified anchorages (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.

Shipyards are the among the most hazardous U.S. 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[4]. 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 National Shipbuilding Research Project (NSRP 2002) reviewed falls in shipyards addressing both falls from height and at the same level. The evaluation considered engineering and procedural approaches to reducing risks. Participants included eight (8) shipyards representing about half of the U.S. workforce. Falls represented approximately

•20% total injuries

•30% of lost time injuries

Experience in the United Kingdom is similar. Review of records form 2001/2002 indicated that shipyard falls from height account for 23% of serious injuries (defined as three or more days away from work). Slips, trips and falls at the same level accounted for 25% of such mishaps (Health and Safety Executive 2003).

Data provided privately by a large American shipyard (Table 3) demonstrates the relative proportion of falls occurring at both the same level and from height. Direct compensation and medical costs for “simple” injuries involving back, knees or other individual injuries were reportedly in the range of $20,000 per event. Those involving multiple injuries such as back and shoulder cost in the range of $30,000.

The NSRP data identifies the location of falls and their general common causes and recommended control measures.

Table 3: Review of Falls in a Major American Shipyard

•Falls at same level (slip-trip-fall)	54%
•Fall through opening or other space	24%
•Fall from ladder or scaffold	19%
•Fall between different levels	16%
•Falls on stairs/steps	9%
(Does not equal 100 %. Some categories are overlapping)	

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

Table 4 summarizes the categories of falls recorded and the average time lost linked with each category in the NSRP study.

Table 4: Shipyard Fall Accidents*

Accident type	**Average Lost Days**	**Number of recorded mishaps**
Scaffolds	50	117
Bicycles	43	140
Into holes or open surface	37	230
Tripping or stumbling over obstructions	33	1045 (30%)
Stairs	28	400
Ladders	22	380
From buildings or structures	22	320
Slipping due to slippery surfaces	21	701
Other	20	30
Average	28	
Areas most likely to be influenced by design**		

*Include both falls from height and at same level.
Based on 2707 injuries in a population of approximately 45,000 sustained over a period of four (4) years (1998-2001)
** Evaluation of reviewer (Mark Geiger)

Losses associated with these injuries were estimated to account for direct costs in the range of $25.2 million with indirect costs of approximately $100.8 million for a total loss of $134 million (NSRP 2002).

A high fraction of these mishaps were influenced and might be controlled by factors associated with good engineering design and effective process management. **Table 5** links the order of precedence used in system safety (Military Standard 882) with control and mitigation measures advised in the NSRP report on shipyard falls.

Table 5: Application of Order of Precedence to Control/Mitigation of Shipyard Falls from Buildings or Structures *

Control Method	Key factors and prevention
Elimination of the hazard	Design to limit need for access
Substitution	Replacing the hazard with a less hazardous operation. This include modular construction with pre-fabrication of large sections on shore and then hoisting the modules into place as an alternative to assembly in the dry-dock.
Isolation including Fixed Barriers	Lack of guarding and secure ladders for climbing (especially cranes). Unguarded deck edges – guard all edges (using railing if feasible)
Procedures (excluding maintenance)	Training –and use of approved harness (include design for secure and accessible anchorage points)
Maintenance procedures	Ladders unguarded from crane movement (need to be guarded)
Warnings	Improved labeling and contrast painting at edges.
Training	Training –and use of approved harness (include design for secure and accessible anchorage points)
Protective equipment	Approved fall protection harness (requirement for use should be minimized by fixed barriers and supported by approved anchor points where alternatives are not feasible.

* Includes mobile cranes and manlifts.

The design of ships includes many serious potential fall hazards that can be most efficiently addressed in design. Areas of concern include; deep tanks and voids; inclined ladders (the term used to describe shipboard "stairs"); vertical ladders; masts; vertical passageways (including emergency escape and access trunks; deck or other edge protection during shipyard periods[5]; working over the side both in shipyard periods and inspection at other times (Geiger 2003a). The Naval Facilities Engineering Command (2003) provides criteria for facility fall hazard assessments that can be used to develop a preliminary hazard list (PHL) and site-specific (or platform-specific) hazard evaluation. These general criteria may be adapted to maritime applications by persons familiar with the related operations and process hazards.

Shipboard storage tanks, double bottoms and voids (empty spaces that do not routinely carry fluids) are confined spaces with difficult access and locations that create severe fall hazards as well as serious atmospheric hazards.

Review of fall statistics provided by the Naval Safety Center documented relatively few, but very serious fall mishaps associated with confined space entry for military personnel. A more common fall issue was that of falls on shipboard ladders, particularly inclined ladders (shipboard "stairs"). The Safety and Health Department at Newport News Shipbuilding reported a similar concern for shipboard inclined ladders with concerns about ladder angles, and design of a more secure handrail for use in port periods. Efforts are being made to address design and maintenance issues for inclined ladders by cooperative efforts between the Naval Safety Center and Naval Sea Systems Command.

<u>Case Study of Aircraft Carrier Deep Tanks</u>

Environmental Protection Integrated Process Team (IPT) for the Future Aircraft Carriers Program conducted in a special study of fall hazards in aircraft carrier storage tanks.

The design of deep tanks and voids on large vessels can create intrinsically hazardous environments combining fall hazards in locations with potential confined space

[5] Certain military vessels are addressing the issue of radar signature and designing their hull forms and superstructure to reduce detection. Railings used on the side of the vessels may be eliminated or made retractable. It is anticipated that automation and reduced manning will limit the time and tasks required of sailors on deck. However, measures such as retractable railing and tether lines will be needed to protect individuals working on deck.

atmospheric hazards, restricted access and typically poor illumination.
Detailed evaluation of work process in aircraft carrier storage tanks identified significant labor savings associated with potential minor design changes in configuration. (Geiger 2003b).

Aircraft carriers (CVN class vessels) require approximately 150 large tanks for storage of fuel, waste, 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 effect of the ships lightweight (damping the sudden bulk movement of large volumes). The configuration of a "typical" deep tank is illustrated in **Figure 1.**

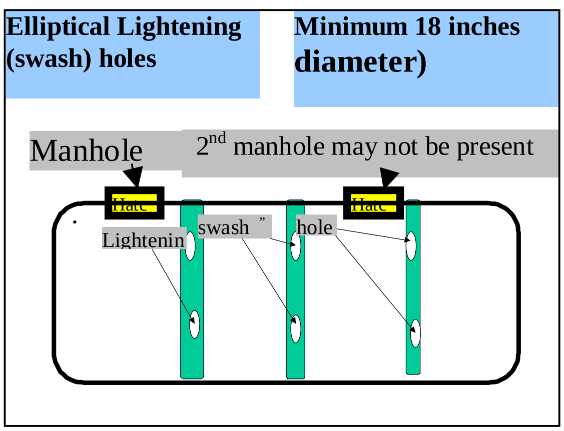
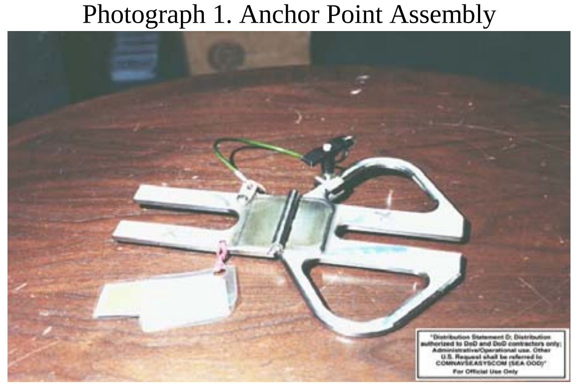


Figure 1. Configuration of a Typical Deep Tank

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-inch minimum diameter; foot holds limited to "D-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 inner bottom and first climbing point.

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-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

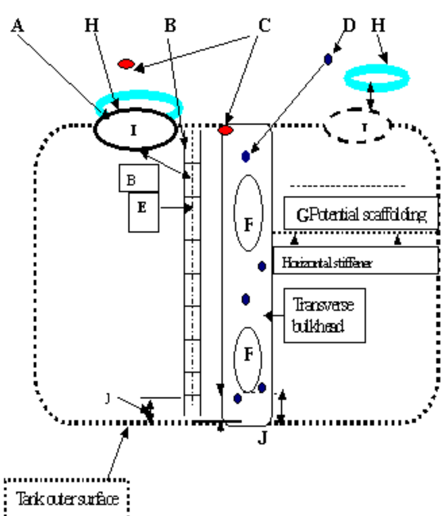


Photograph 2. Anchor Point Assembly Deployed in Training Mock-up

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

Space configurations and issues that increased the difficulty and risk of access include the distance between manholes or other entry points and secure ladders; limited anchor points above the entry point (manhole); lack of anchor points at the top level of the climbing location to support the use fall protection, location of the lowest lightening holes (often reportedly 4 to 6 feet above the deck) and location 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 F1166-1995) and American Bureau of Shipping Guidelines for Human Systems Integration (ABS 1998).

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 Appendix A. Details are provided in (Geiger 2003b).

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 inner bottom (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 Architects and Professional Engineers to evaluate potential impact on structural integrity,***

stability and stiffness and other critical design parameters.

Manpower Costs and Their Link to Safety

Operations that are unsafe are also often inefficient. Workers are often capable of overcoming hazardous situations through extreme care and labor-intensive, specialized procedures. Thus, mishap statistics may be lower than would be predicted by the configuration of the work area, Simpson (1990). This may be the case for falls in confined spaces.

Because available statistical information about falls in shipyard confined spaces was incomplete, an evaluation of work-tasks was used to identify relative efficiency provided by alternative configurations. A detailed review of work process, man-hours and labor costs involved in maintenance of aircraft carrier deep tanks allow a comparison of costs and time associated with the present and a proposed configuration (Geiger 2003b). Operations were reviewed for a "typical" shipyard maintenance involving entry and refurbishing 30 large storage tanks. Table 6 summarizes the relative cost and time required by the present and proposed tank configurations. Savings of approximately 30% or $250K per shipyard period are projected. This is estimated to amount to approximately $2.5 million over the life of an individual ship.

TABLE 6. Tank Maintenance Costs for Current and Suggested Configurations.

* Based on $50 hour loaded labor costs

Tank Description (of the case used in this example)			
Depth (feet)	**50**		
Number frames	**4**		
Distance 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%)**

General Application of System Safety Principles to Design of Shipboard Confined Spaces

Application of system safety principles to shipboard confined spaces provides the following order of precedence for hazard mitigation; *

1. Hazard Elimination

Design and maintain to avoid or minimize the need for access to hazardous locations by measures such as:
–Long life paint systems
–Isolated tanks not needing routine painting
- Location of controls and sensors outside the tank where feasible.

2. Substitution

Replacing the hazard with a less hazardous operation. This includes modular construction with pre-fabrication of large sections on shore and then hoisting the modules into place as an alternative to assembly in the dry-dock.

3. Fixed Barriers - where Feasible

These include temporary barriers around manholes, scaffolding erected inside tanks prior to major work such as blasting and painting.

4. Hazard Mitigation via Design for Safe and Efficient Access - stressing application of human factors engineering criteria

–Access ports
–Ladders (include safety rails)
–Appropriate location of anchor points for scaffolding and fall arrest systems*.
*Initial access and inspection is often the most difficult task

5. Procedures and Warnings: Evaluation of Special Hazard Areas

–Redundant fall arrest (Ladders may be corroded).
–Preliminary and ongoing purging and atmospheric testing
–Consideration of emergency rescue in planning and procedures

6. Protective Equipment (and related training and enforcement). Design engineers should support the effective application of this measure by
- Design to provide appropriately placed anchor points for fall arrest systems and scaffolding.
- Design for access

**Some control measures are overlapping and concurrently applied such as design of effective anchorage for fall protection harnesses and procedures involving use of this protective equipment*

A general system safety review of common shipboard fall hazards is proposed in **Table 7**

Table 7: System Safety Evaluation of Common Shipboard Fall Risks and Mitigation

Risk Area	**Potential severity**	**Anticipated Probability**	**Remarks**
Falls (tanks) present design	Catastrophic	Moderate to high	Likely to occur in system life
Falls (tanks) proposed design	Catastrophic	Moderate low, if fall protection can be used	Likely to occur in system life. Alternative design reduces life-cycle costs
	Severe to moderate	Moderate low, if fall protection can be used	
Falls inclined ladders	Moderate	Moderate to High – Depending upon design	Influenced by design. **Poor design likely to create un-acceptable risk.**
Falls on deck (with edge protect-ion)	Moderate	High	May be acceptable risk
Falls on deck (no edge protect-tion)	Catastrophic	High	Critical, if ships are designed for low radar signature. **Alternative controls required.**

Approaches to Evaluation and Control

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.

References on design for safety and fall protection (Ellis 1999), (Schilder 1999), (DON 2003) address implementation of protective measures employing the hierarchy of controls consistent with Military Standard 882. The Department of the Navy, Fall Protection Guide for Ashore Activities (developed by the Naval Facilities Engineering Command) (DON 2003) provides a detailed matrix for evaluation of potential fall hazards and application of control measures.

Fall Protection in Building Design and Construction

Falls from height account for approximately 40% of English construction industry accidents (Steemson 2004). OSHA reports that 32% of construction deaths (335 of 1048 fatalities in 1995) are linked to falls from height http://www.osha.gov/SLTC/constructionfallprotection/index.html. OSHA provides extensive guidelines and links to regulations (OSHA 1995) http://www.osha.gov/SLTC/constructionfallprotection/recognition.html.

Safety should be incorporated into design in order to reduce both risk and cost (Christensen and Manuele 1999). In the construction industry, safety includes both design of the facility against failure and protection of the workers involved in that process (Schilder 1999). Work at elevated heights and the associated need for fall protection are key elements of building construction and maintenance. Schilder (1999) addresses fall protection for both construction and maintenance in the context of system safety and cites the Construction Industries Institute (CII) software program "Design for Safety Toolbox" available at www.construction-institute.org, addressing design issues. He also provides a general checklist for building design review that includes fall protection. The Naval Facilities Engineering Command, NAVFAC (DON 2003) provides one of the most detailed guidelines for addressing fall prevention during planning and design. This reference specifically addresses the responsibilities of designers and construction managers and facility owners to create and maintain a safe working environment with particular reference to potentially lethal hazards addressed by fall protection programs.

Steemson (2003) addresses planning, regulatory enforcement and design issues associated with prevention of falls. The European Senior Labor Inspectors Committee has focused upon this issue in cooperation with the UK's Health and Safety Executive (Details are provided at http://europe.osha.eu.int/good_practice/sector/construction/slic/).

Many of the more progressive construction firms and process-engineering consultants have begun to address fall protection as a design element in design and operations. For example, an FAA Contractor, Horne Engineering, broadened the concept of safety operations of the FAA air traffic control and communications network to include operator safety and fall protection for maintainers of communications towers and related equipment (Umbaugh, 2003).

Requirements for life-cycle cost and risk management within Government Defense Systems and Facilities

The role of the Federal government should be addressed because of the leadership role and economic influence it provides. Many systems acquired and maintained by the Department of Defense such as ships, aircraft[6], cranes, large vehicles[7] and related support equipment and facilities include significant potential fall hazards. Additionally, the Federal government and contractors who support federal acquisition efforts employ a high fraction of system safety practitioners.

[6] Aircraft fall hazards addressed in this discussion are related to primarily to maintenance and occasionally to egress.

[7] Access to cranes and many large vehicles includes operator movement to and from elevated locations for operation and maintenance.

Regulatory requirements relevant to federal and defense systems and supporting facilities include DoDI 5000.1 and DoDD 5000.2 acquisition regulations that specifically require cost and risk management throughout a programs life cycle to include design, testing, production fielding, maintenance and ultimate demolition/disposal or recycling. The general rule is that approximately 60% of life cycle costs are incurred in operation, maintenance and disposal. These costs and many of the associated risks are most effectively addressed in the initial design phase. System development is broadly addressed to include the primary system and support equipment by references such as Military Standard 881 (Work Breakdown Structure). The work breakdown structure process also coordinates subsystem development and process management.

Federal Acquisition Regulations (FAR), Clause 52.236-13, requires that ***contractors performing construction and demolition work on Department of Defense contracts are required to comply with the latest version of USACE EM385-1-1*** (USACE 2003). This reference provides specific, enforceable programmatic requirements for *Safe Access and Fall Protection (Section 21)* and addresses the issue throughout other sections.

Early planning is documented as a key cost-control measure. The Naval Facilities Engineering Command's fall protection group has documented cost increases of a factor of ten for each stage of fall protection design (DON 2003). For example, application of fall protection measures that would cost $1X at the drawing stage will increase to $10X if fall protection must be included after roof mounted equipment is located and $100X if considered during the construction phase.

<u>Prioritized Approaches to Management of Fall Hazards in Facility Design, Construction and Maintenance</u>

Guidelines for fall protection have been most comprehensively addressed in facilities design, construction and maintenance. Approaches described in the Department of the Navy Guidance (DON 2003) are summarized below. Evaluation and engineering control during the planning phase is strongly emphasized. Risk assessment should include review of prior injuries in related facilities or operations and evaluation of the current designs.

The hierarchy of control measures and some common measures include;

1. **Elimination**: Designs that avoid the need for work at heights: These include design of equipment that require periodic servicing such aerials and street lamps to rotate at the base for access when maintenance is required. Remote sensors may be used to eliminate or reduce the need for access to hazardous locations.

2. **Substitution:** Substituting or replacing the hazard with a less hazardous operation or process. For example, structures may be prefabricated on the ground rather than assembled at heights.

3. **Isolation:** This involves isolating or separating the hazard from employees or others by measure such as providing a fixed barrier at the edge of a high surface from the work area. Design for access with fixed barriers may include railings, use of mobile platforms or other measures that limit the risk of hazardous access. Schilder (1999) documents examples of window washing platforms that moves around the building and roof penthouses with entry at the inward (rather than overhanging) side.

4. **Engineering Controls:** Engineering controls are required when the hazard can't be eliminated or the need for access to elevated location avoided by other means. Different equipment, such as mobile lifts, or alternative techniques may provide engineering controls. Application of longer lasting paint systems inside shipboard tanks may be considered an engineering control because it reduces the frequency of required access.

5. **Administrative Controls:** This includes identifying and enforcing alternative work practices that reduce the risk of fall injuries by erection of warning signs or restricting access to certain locations.

6. **Personal Protective Equipment:** Personal protective equipment, such as personal fall arrest systems, should be considered when other measures are impractical or not fully effective.

These control measures are not likely to be mutually exclusive. An integrated system of process and risk management employing more than one measure is apt to be required.

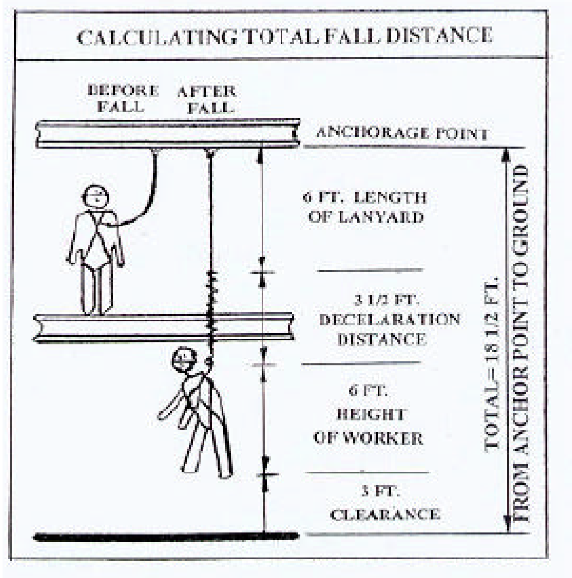
Engineering Considerations in Design and Application of Personal Fall Arrest Systems

Workers cannot safely use personal protective equipment for fall arrest in the absence of general managerial and technical support systems. Personal fall arrest systems are an integrated *system* that includes the physical components of a full body harness, anchorage and lanyard and the managerial and training programs that must be designed, deployed and managed as an integrated unit.

Design (and related documentation) should support application of personal fall arrest systems through measures such as pre-identified accessible anchorages and accessible footing. DON (2003) identifies location of suitable anchor points as the most critical control measure that designers should include to support deployment of fall protection throughout facility life cycle. Engineering expertise is essential to provide anchor points that can provide the 5000-pound capacity required by ANSI Z359.1 and OSHA Standards (29CFR 1926.502 (d) (15)) and 29 CFR 1910.66, Appendix C. Anchorage locations should be as high as feasible to minimize the free fall distance – which cannot exceed six feet - prevent contact with the surface below. Total deployment distance is in the range of 18 feet as illustrated in **Figure 2**. The combination of lanyard length, 6 feet, deceleration distance, 3.5 feet, worker height 6 feet and desired clearance, 3 feet, create a need to secure the anchorage point approximately 18 feet above the ground. Fastening lanyards to guard rails or the floor of a walking surface are not safe because of the increased free fall distances and probable strength limitations of the anchoring points.

Figure 2 Total Fall Distance

(From DON 2003, Figure 26)



Total Fall Distance
(Figure 26)

Anchor point and access location must also avoid the potential for "swing falls" – a pendulum-like motion that can occur if a worker impacts a horizontal surface while falling or after deployment of his fall arrest system. Tie-off points should be located so as to minimize this potential and allow for a maximum swing away from the tie off point of 30 degrees (DON 2003).

Horizontal lifelines require engineering design because the trigonometry of their deployment can create great stresses on loading that occurs on deployment. [8]

[8] A horizontal life-line is a fall arrest system that uses a line spanning between two end anchorages. The assembly includes necessary connectors, in-line energy absorbers and may include intermediate anchorages. Depending on the angle of sag, horizontal lifelines may be subject to an impact force that is greatly magnified above that of the attached lanyard. The OSHA requirement (see 29 CFR 1910.66 Appendix C) for compliance with fall protection standards indicate that force amplification for 5 degrees sag is about 6:1 and DON 2003.

Improper tie off of a rope lanyard or lifeline around an H or I beam can reduce the strength significantly [9]

A fall protection program must also include provision for rescue and retrieval of personnel after a fall (ANSI Z359.1, DON 2003, 29 CFR 1926.501). Within confined spaces, a co-worker should be able to retrieve the victim using a hoist or other mechanism while located outside the confined space. Maritime confined space applications pose particular challenges, and it is estimated that remote retrieval is not feasible in many current circumstances.

Design to accommodate scaffolding and/or fall netting is very important in the construction process. Early and appropriate selection is critical. Steemol (2004) documented a case where nets costing L 4000 could have replaced scaffolding that cost L 12,000 and added 4 weeks to a building program. Information on a designer initiative can be found at www.hse.gov.uk/construction.

Summary

Falls from height are among the most serious and frequent injury in many of the facilities and weapons platforms/ systems managed by DoD and industry. System safety practitioners must consider work at elevated locations in preliminary hazard assessments and during design and development. Early consideration can reduce risks and cost during construction and over the life cycle of systems, facilities and equipment.

Mishap data from similar venues and evaluation of potential design hazards are essential in identifying and managing risks. However, mishap statistics may be incomplete or inconclusive. This may be due to limitations of data management systems, initial mishap investigation and reporting, particularly with regard to detail and evaluation of design-related issues. Circumstantial information suggests that some averted falls may be characterized in a way that does not indicate their root cause.

[9] See OSHA non-mandatory guidelines, paragraph (i) and DON 2003.

The ability of workers to use special care and precautions to reduce the incidence of mishaps may mask the severity underlying hazards. Because of the link between safety and efficiency, detailed work-process evaluation may identify areas of risk.

Specialized engineering expertise is required to address fall hazards, including design applications where personal fall arrest systems require engineered anchorages. Designs and related engineering management systems should consider walking and working surfaces, materials handling, access and emergency rescue.

Existing occupational safety and health regulations, technical guides, acquisition regulations and the system safety approach should be applied in a complementary framework to mitigate risks of work at elevated locations. Application of system safety evaluation and human factors engineering are likely to mitigate hazards while reducing construction and maintenance costs.

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Section 1915.159 Personal Fall Arrest Systems, Published 61 FR 26321, May 24, 1996
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Biography

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OSHA Regulations and Standards from the OSHA Web Page: http://www.osha.gov

The following are some of the Fall Protection Regulations:

29 CFR Part	1926	Subpart M, Fall Protection
29 CFR Part	1910	General Industry
	1910.23	Guarding floor and wall openings and holes
	1910.66	Powered platforms for building maintenance
	1910.132	General Requirements -- Personal Protective Equipment
	1910.269	Electric Power Generation, Transmission and Distribution
29 CFR Part	1915	Shipyard Employment
	1915.159	Personal Fall Arrest Systems (PFAS)
	1915.160	Positioning Device Systems
29 CFR Part	1918	Longshoring
	1918.85	Containerized Cargo Operations, includes Requirements for Fall Protection

ANSI Standard A10.11-1989 (R1998)-Safety Nets Used During Construction, Repair and Demolition Operations

The ANSI Z359 Standards Committee is drafting three new standards that should be available for review in the near future:

ANSI Z359.0 ANSI Standards on the Fall Protection Program
ANSI Z359.2 Requirements for Positioning and Restraining Systems
ANSI Z359.3 Requirements for Assisted Rescue and Self-Rescue Systems, Subsystems and Components

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