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In the Spotlight

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

by Mark B. Geiger, M.S.E., CIH, CSP, Arlington, Virginia

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Falls from height are the second leading cause of occupational fatalities, behind only traffic-related fatalities, and account for approximately 700 occupational fatalities annually in the United States [Ref. 1]. The number of such fatalities has continued to rise during the past decade, while most work-related injuries are declining in number. Table 1 summarizes this data. Approximately half of these deaths occur in the construction industry.

Year	Fatal Falls	Total Fatalities
2001	810 (14%)	5,915
2002	714* (13%)	5,524
2003	662 (12%)	5,575
2004	783 (14%)	5,764
2005	735 (13%)	5,734
2006	771* (13%)	5,703*
2007	806* all industry (14%)	5,703

Table 1 — Fatal Falls in U.S. Private Industry

* Data regarded as preliminary at the time of review (Nov. 2007) http://www.bls.gov/news.release/pdf/cfoi.pdf

Falls from height accounted for 288,500 (6%) of the 4,700,600 OSHA-recordable[1] mishaps occurring in 2001 and 2002 tracked by the Bureau of Labor Statistics (BLS) in 2004. In 2006, falls accounted for 234,450 (20%) of 1,183,500 non-fatal mishaps in private industry recorded by the BLS. The general reduction in fall injuries is likely to be related to regulatory requirements and their more stringent enforcement.

Statistics in England are similar, but show fall-related mishaps, rather than traffic-related accidents, as the leading cause of occupational fatalities (Health & Safety Executive, 2003b). Falls accounted for 73 (25%) of 291 occupational fatalities in 2000/2001, but dropped to 46 (22%) of 212 fatalities in 2005/2006.

The 46 fatalities and 3,300 major injuries sustained in 2005/2006[2] represent some of the lowest figures on record and include a 50% reduction in the rate of fall injuries among workers from 1991/1992 to 2005/2006. This reduction appears consistent with the aggressive campaign undertaken by the Health and Safety Executive to reduce workplace injuries, particularly falls. The English Health and Safety Executive made prevention of fall injuries a top priority in the 2001/2004 strategic program (see http://www.hse.gov.uk/statistics/overall/fatl0506.pdf).

European statistics show a similar trend. Falls from height accounted for approximately 40% of construction industry accidents [Ref. 2].

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In 1998, OSHA reported that 150 to 200 workers are killed and 100,000 are seriously injured annually in the construction industry 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 indicates that 20 (16%) of 120 shipyard fatalities recorded appeared consistent with falls from height, but often provided limited detail. Scaffolding and fall protection are the two most commonly cited OSHA violations and garnered the highest penalty amounts in Fiscal Year 2007[3].

Typical costs for a fatality range from $800,000 to $2,400,000, while the average cost of serious injury is more than $30,000 [Ref. 3]. 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 illnesses [Ref. 4]. 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 a strained shoulder. Concurrently, the category of "slip/ twist/not falling" accounted for 35% of the Navy-wide summary of fall-related injuries [Ref. 4]. 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 on use of personal protective equipment and fall-arrest systems retrofitted into existing facilities, often at considerable cost. There has been less focus on 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[4]. The requirement is five feet or greater within shipyard employment and eight feet or greater within the maritime industry.

OSHA regulations stipulate *assured fall protection* for elevated work locations that provides a fixed barrier or use as 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.[5]

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1 OSHA Regulations (Standards - 29 CFR 1906) regulate reporting of occupational injury and illness statistics. OSHA-recordable injuries typically involve a loss of greater than one day of work time.

2 U.K. Health and Safety Executive - A Guide to the Work at Height Regulations, http://www.hse.gov.uk/pubns/indg401.pdf

3 Information courtesy of Keller Online (http://www.jjkeller.com/)

4 OSHA Regulatory requirements by industry are five feet for shipyard employment (29 CFR 1915.159 and 29 CFR 1915.77c); six feet for construction (29 CFR 1926.501b); four feet for General Industry (29 CFR 1910.23b); 15 feet for Steel Erection (29 CFR 1926.760a); and eight feet for Marine Terminals and Longshoring , 29 CFR 1918 (See http://www.osha.gov/ for regulations).

5 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 fall on the victim (to 1,800 pounds) and certified anchorages (3,600 pounds). The device providing controlled deceleration may include a lanyard, deceleration device, lifeline or a suitable combination of these. The use of body belts for fall arrest has been prohibited in the U.S. since January 1, 1998.

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Risk Review and Management Approaches in the Maritime Industry
Shipyards are 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[6]. 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) [Ref. 5] 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 shipyards. Falls represented approximately 20% of total injuries and 30% of lost-time injuries.

Statistics in the United Kingdom are similar. Review of records from 2001/2002 indicate 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 [Ref. 6].

Data provided privately by a large American shipyard (Table 2) 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 recommends control measures. 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 [Ref. 5].

Table 2: Review of Falls in a Major American Shipyard

Category of fall	Fraction of falls*
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 overlap.)*	

A high fraction of these mishaps were influenced, and might be controlled by, factors associated with good engineering design and effective process management.

Case Study of Aircraft Carrier Deep Tanks

The Environmental Protection Integrated Process Team (IPT) for the Future Aircraft Carriers Program conducted 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 atmospheric hazards, restricted access and typically poor illumination. 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 bulkheads provided by narrow elliptical swash holes as little as 15-inch minimum diameter, footholds limited to "D-hole" penetrations in transverse bulkheads, minimal anchorage points for hoisting, scaffold erection and the securing of personal fall arrest equipment; and irregular space configurations, such as steeply angled bases. Shipyard workers report the irregular placement of D-ring holes in certain tank locations with distances as great as three feet between the tank inner bottom and the 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. Its 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 any fall protection[7]. PSNS initiated measures to provide assured fall protection that includes 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.

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.

Current configurations were reviewed with reference to recommended criteria for human systems integration [Refs. 7, 8].

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 suggest that relatively minor changes might reduce the risk of entry and improve access[8] [Ref. 9].

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6 Shipyard work has generally been reported as the second most hazardous work setting in the U. S., second only to commercial fishing.
7 Vertical ladders more than 15 feet high are required to provide fall protection, typically through a climber's safety rails or ladder cages.
8 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 Naval architects and professional engineers to evaluate potential impact on structural integrity, stability and stiffness, and other critical design parameters.

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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 [Ref. 10]. 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.

By conducting a detailed review of work process, man-hour costs and time associated with the present and a proposed configuration [Ref. 9], operations were reviewed for a "typical" shipyard maintenance involving entry of and refurbishing 30 large storage tanks. Savings of approximately 30% or $250,000 per shipyard period were projected. This is estimated to amount to approximately $2.5 million over the life of an individual ship.

Fall Protection in Building Design and Construction

Falls from height account for approximately 40% of English construction industry accidents [Ref. 2]. OSHA reports that 32% of construction deaths (335 of 1,048 fatalities in 1995) are linked to falls from height[9].

Safety should be incorporated into design in order to reduce both risk and cost [Ref. 11]. In the construction industry, safety includes both design of the facility against failure, and protection of the workers involved in that process. Work at elevated heights and the associated need for fall protection are key elements of building construction and maintenance. In a chapter written by Craig B. Schilder in the book *Innovations in Safety Management: Addressing Career Knowledge Needs*, Schilder 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,"[10] addressing design issues. He also has provided a general checklist for building design review that includes fall protection [Ref. 12]. The Naval Facilities Engineering Command (NAVFAC) [Ref. 3] provides one of the most detailed guidelines for addressing fall prevention during planning and design. This reference specifically addresses the responsibilities of designers, 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. The European Senior Labor Inspectors Committee has focused upon this issue in cooperation with the U.K.'s Health and Safety Executive.[11]

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 [Ref. 13].

Requirements for Life-Cycle Cost and Risk Management within Government Defense Systems and Facilities

The role of the U.S. 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[12], cranes, large vehicles[13] 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 number of system safety practitioners.

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 program's life cycle to include design, testing, production fielding, maintenance and ultimate demolition/disposal or recycling. Federal Acquisition Regulations (FAR), Clause 52.236-13, states 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 10 for each stage of fall protection design [Ref. 3]. 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.

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[9] http://www.osha.gov/SLTC/fallprotection/construction.html. OSHA provides extensive guidelines and links to regulations (OSHA 1995) http://www.osha.gov/SLTC/fallprotection/recognition.html.
[10] Available at http://www.construction-institute.org.
[11] Details are provided at http://europe.osha.eu.int/good_practice/sector/construction/slic/).
[12] Aircraft fall hazards addressed in this discussion are related primarily to maintenance and occasionally to egress.
[13] Access to cranes and many large vehicles includes operator movement to and from elevated locations for operation and maintenance.

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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 (e.g., railings) will be used. If other preferred alternatives are not feasible, personal fall-arrest systems are required.

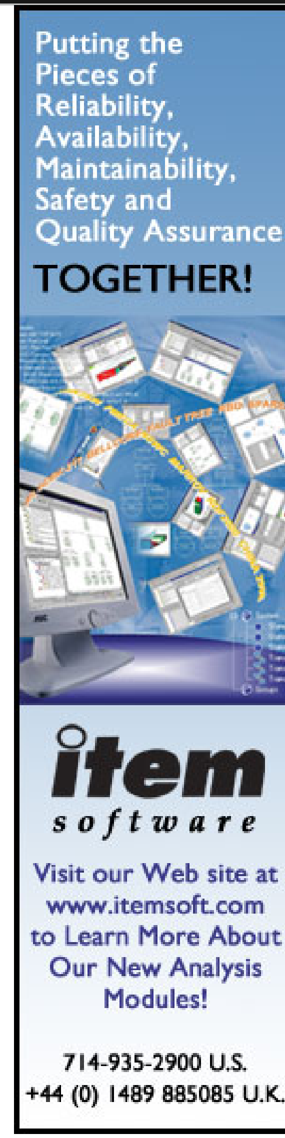
References on design for safety and fall protection [Refs. 3, 12, 14] address implementation of protective measures employing the hierarchy of controls consistent with Military Standard 882. The Department of the Navy, *Fall Protection Guide for Ashore Activities* (developed by the Naval Facilities Engineering Command) [Ref. 3] provides a detailed matrix for evaluation of potential fall hazards and application of control measures.

Guidelines for fall protection have been most comprehensively addressed in facilities design, construction and maintenance. Approaches described in the Department of the Navy Guidance [Ref. 3] are summarized below. Evaluation and engineering control during the planning phase are strongly emphasized. Risk assessment should include review of prior injuries in related facilities or operations and evaluation of the current designs.

Approaches to Evaluation and Control

The hierarchy of control measures and some common measures include:

- **Elimination:** Designs that avoid the need for work at heights. These include design of equipment that requires periodic servicing such as 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.
- **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.
- **Isolation:** This involves isolating or separating the hazard from employees or others by measures 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. An example includes window-washing platforms that move around the building and roof penthouses with entry at the inward (rather than overhanging) side [Ref. 12].
- **Engineering controls:** Engineering controls are required when the hazard can't be eliminated, or the need for access to elevated locations 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.
- **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.
- **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. NAVFAC 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 [Ref. 3]. Engineering expertise is essential to provide anchor points that can provide the 5,000-pound capacity required by ANSI Z359.1 [Ref. 15] and OSHA Standards (29CFR 1926.502 (d) (15)) and 29 CFR 1910.66, Appendix C [Ref. 16, 17].

Anchorage locations should be as high as feasible to minimize the free-fall distance — which cannot exceed six feet — and prevent contact with the surface below. Total deployment distance is in the range of 18 feet. The combination of lanyard length (six feet), deceleration distance (3.5 feet), worker height (six feet) and desired clearance (three feet), creates 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 is not safe because of the increased free-fall distances and probable strength limitations of the anchoring points.

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 to allow for a maximum swing away from the tie-off point of 30 degrees [Ref. 3].

Horizontal lifelines require engineering design because the trigonometry of their deployment can create great stresses on loading that occurs on deployment.[14]

Improper tie off of a rope lanyard or lifeline around an H or I beam can reduce the strength significantly.[15]

A fall-protection program must also include provision for rescue and retrieval of personnel after a fall [Refs. 3, 15, 18]. 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.

Designs to accommodate scaffolding and/or fall netting are very important in the construction process. Early and appropriate selection is critical. Reference 2 documents a case where nets costing £4,000 could have replaced scaffolding that cost £12,000 and added four weeks to a building program[16].

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14 A horizontal lifeline 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 and DON 2003 indicate that force amplification for five degrees sag is about 6:1.
15 See OSHA non-mandatory guidelines, paragraph (i) and DON 2003.
16 Information on a designer initiative can be found at http://www.hse.gov.uk/construction.

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Conclusion

Falls from height are among the most serious and frequent injuries 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 costs 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. The ability of workers to use special care and precautions to reduce the incidence of mishaps may mask the severity of 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 is likely to mitigate hazards while reducing construction and maintenance costs.

Acknowledgments

This effort is dedicated to the many personnel who work under difficult and often hazardous conditions, including the spaces described in this manuscript. It is hoped that this effort will support development of future designs that make their lives safer.

About the Author

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