Full-body safety harness - blessing or bane?

It is well known that working at height is the most hazardous of all activities at workplaces around the world, with the maximum rates of accidents and fatalities. At industrial worksites in Singapore, a common method of addressing the risk of falling from heights is to issue a full-body safety harness to workers performing duties at heights above 2 m.

Prof N Krishnamurthy, a Safety Consultant in Singapore, discusses the background to this practice, and analyses the pros and cons as well as the essential auxiliary controls that are critical to the successful use of this piece of equipment.

HISTORICAL BACKGROUND TO SAFETY HARNESS

In early days, up to the 1960s and 1970s, there was no personal protective equipment (PPE) for working at height. Workers who, in the 1930s, built the world-famous Empire State Building in the US, did not even wear a helmet.

However, in San Francisco's Golden Gate Bridge project, built around the same time, safety nets were used quite effectively. These were collective (passive) controls, not individual (active) PPE.

By the 1970s, waist belts were mandated for work at heights (Figure 1, adapted by the author http://nasdonline.org/document/1918/3/d001864/safe-grain-and-silage-handling.html).

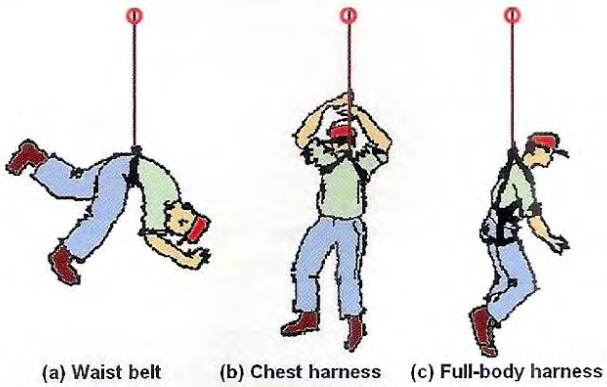

Figure 1: PPE for fall arrest.

While these did arrest (stop) the fall before the worker hit the ground or other bases, it also caused major injuries to the internal organs and spine, because the suspension was around the structurally weakest part of the human body, with all forces being resisted by a few centimetres width of spine.

By the mid-1990s, it was confirmed that waist belts caused more harm than good. Belts were banned for fall arrest in 1998 in the US. Singapore followed suit a year later.

However, waist belts are still in use for fall prevention as 'work (or travel) restraint'. A lanyard of proper length attached to the worker's waist belt at one end and to an anchor at the other end would limit the worker's travel to a safe zone within the edges of a reliable work platform. The Singapore Code of Practice for Working Safely at Height [Reference 1] describes this and other current methods of fall control.

Meanwhile, research and development resulted in the creation of the 'full body safety harness' which basically consisted of two sets of suspenders — one pair for the arm-shoulder joints and the other pair for the thigh-hip junctions.

The aim was that the impact forces of stopping at the end of the cable would be borne by the massive bone structures at these two locations. Additional straps connected the bearing belts and held them close to the body. The full-body safety harness has proven to be a life-saving PPE for falls.

A compromise between the waist belt and the body harness is the 'chest harness' (Figure 1) which encircles only the upper half of the body with a pair of straps under the arms. This was used for 'work positioning' which provided the worker a strap (sit harness) for bottom support and a lean-back cable for stability. It had the disadvantage that if loosely worn, the person could slip through the harness when the arms were lifted.

The use of safety nets has prevailed and in fact increased, particularly in the steel erection industry, as a collective measure still vastly preferred over individual PPE.

It must be reiterated that the safety harness is an individual (active) fall protection control and the last resort for fall control in the recommended order of hierarchy. Hence its use needs special attention.

Further discussion in this article will be limited to the full body safety harness.

FULL-BODY SAFETY HARNESS

The basic safety harness simply consists of two straps at the shoulders and two straps around the thighs, connected together with two or more straps vertically or diagonally at front and back, and horizontally at the waist and possibly around the chest, as in Figure 2.

The suspension was by a 'D-ring', called thus because of its shape, which served as the common connecting point for the support straps, and to which the suspension cable (or lanyard) from an anchor could be attached.

When a person falls, he quickly picks up speed due to gravitational acceleration. When the fall is terminated either at

Figure 2: Full-body safety harness with accessories.

the cable end or by crashing to the base, the impact force on the body can be quite high, resulting in major injury or death.

What is needed is a 'deceleration distance', sufficient to reduce the arrest force to a safe tolerable level for the human body, which is generally taken as 6 kN. The effect of such cushioning can be easily understood by comparing what happens when an egg is dropped from say 1 m height over a concrete floor and over a foam cushion about 10 cm thick.

To provide this deceleration distance, a 'shock absorber' was developed to be attached to the wearer. In the form of a spring-like element, the shock absorber would stretch to its full length (about 1.5 m) when the pull on the harness D-ring exceeded a certain human tolerance level. This element would bring the body to a gradual stop rather than a sudden one, much like the normal braking of a car.

The combination of shoulder-hip support and shock absorber was, of course, a miraculous solution to the problem of injuries caused at the end of a fall stopped by the waist belt.

AUXILIARY SAFETY CONSIDERATIONS

With the main problem of human injury at fall arrest solved, attention was directed towards fresh concerns introduced by the safety harness with shock absorber. Many of these concerns go beyond the human injury due to impact. Nine of these are discussed in the following sections.

Cost

While collective passive measures such as guard-rails or safety nets will be a one-time cost for an entire work group of any size, individual safety harness cost will be incurred for as many workers as are expected to work at height, which may run to dozens to hundreds of workers.

As a body harness may cost more than a hundred dollars, investment in body harnesses can amount to many thousands of dollars.

Correct fit and correct wearing

More than any other PPE, the safety harness must be of the right fit. Because of the many straps and the large variations in body sizes, expecting a single size to fit the entire population at the workplace would be unrealistic.

When the implications of improper fit are not well known, no special attention is paid to proper fit. It is a common sight in Singapore to see small-statured foreign workers wearing safety harnesses, obviously many sizes too large for them, which hang loose from their shoulders, with the bottom of the harness reaching halfway to their knees and the tongues of the belt buckles not finding holes for a tighter fit. At least two sizes should be stocked so that all can have a reasonable chance of achieving proper fit from either one.

Even with the correct size of safety harness, it is critical that a worker wears it correctly, all the time that he is occupied in work at height. It is not uncommon to find new workers (even in the West!) putting on the harness the wrong way around, namely with the gap for the private parts at the back rather than at front, with rather uncomfortable consequences!

What is the right way to wear it? If too tight, it will constrain the blood supply and cause problems. But if too loose, as is worn by most improperly trained or inadequately supervised workers, it can become ineffective and, in fact, downright dangerous. Workers have fallen out of very loose harnesses. Even otherwise, when the suspending cable jerks to a halt, loose straps at the groin will deliver a massive blow to sensitive male genitals, damaging them permanently.

The right way to wear any fall harness is 'snug tight' which is best checked by the 'two-finger' test, in which the worker tightens all the harness buckles to such an extent that his forefinger and middle finger can slide with very little effort between each strap and his body. Most trained Western workers will automatically conduct the test themselves while putting on their harness. It is the easiest and simplest precaution against incurring at least one particular serious injury.

Swing-back or swing-down effect

Slipping at an edge from the end of a cable will invariably result in the worker swinging backwards and downwards, as in Figure 3 [Reference 1, 2].

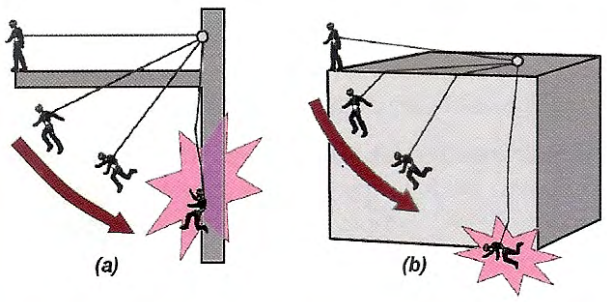

Figure 3: (a) Swing-back, (b) Swing-down.

If the cable or rope is too long and the anchor point is not vertically above the worker, the fall may swing the worker's body either (a) back, to hit the wall or other vertical support or obstruction; or (b) down to hit the ground or other base — both of which are generally fatal.

It is equally important that if and when there is a fall, there are no projections that would injure the person during the fall.

Fall factor

The height of actual fall will depend upon where the anchor for the harness lanyard is located in relation to the person wearing it.

The ratio of the distance fallen to the length of the cable is defined as the 'fall factor'.

Figure 4 shows three common locations for the anchor, with the corresponding fall factors.

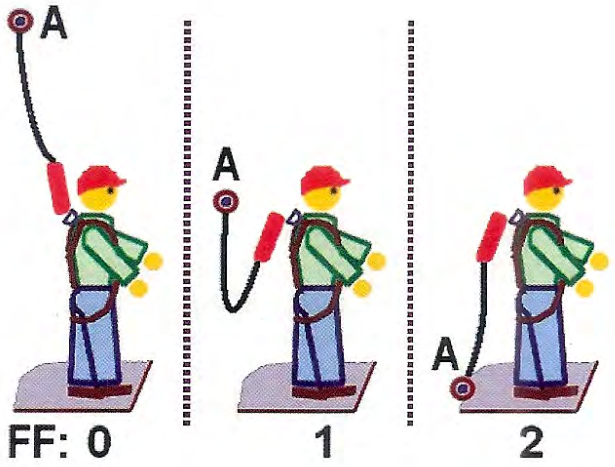

Figure 4: Fall factors 0, 1, and 2 (A - anchor).

With anchor overhead and not much slack in the cable, there will almost be no fall, and fall factor will be zero. When anchor is at shoulder (D-ring) level, the fall will equal the length of the cable, and fall factor will be 1. When anchor is below the wearer (also with not much slack) total fall will be twice the length of cable, and fall factor will be 2.

Obviously, the higher the anchor point above the person, the better it is. Some formulas for impact force at the end of a fall with lanyard involve this fall factor as a parameter.

Fall distance and fall clearance

When a worker is given a body harness, the assumption is that if he falls, he will be stopped before hitting the ground or other base.

This implies that the available distance for the fall must be more than the distance by which the worker can fall.

The fall distance (or fall height) over which a worker with safety harness will fall is the sum of a number of contributions as shown in Figure 5 (adapted by the author from Reference 2):

$$H = S + L + E + D - A \ldots (1)$$

where,

- S = Sag in horizontal life line or slack in any other support to which the anchor is attached (= zero if anchor is fixed to a stationary point).
- L = Length of cable, lanyard and shock absorber.
- E = Extension (due to stretch of cable and shock absorber assembly).
- D = Height of D-Ring above worker foot level.
- A = Height of anchor above worker foot level (negative if below).

Obviously, there should be some safety margin C (about 1m) below the feet of the fallen person, to allow for loose fit of harness, variable body position etc, so that he will not 'bottom out' and hit the base. Fall distance plus safety margin is 'Fall Clearance', F_c.

For example, for a worker with D-ring height 1.4 m, 2 m lanyard, cable and shock absorber stretch of 1.2 m, safety clearance of 1 m, and fixed anchor at foot level, F_c is 5.6 m from worker foot level.

The Singapore Code [Reference 1] gives two formulas to calculate the fall clearance (from anchor level) required for two cases, in Sec 17.2.

Obviously then, giving such a body harness to workers on the second floor of a building or on top of a container, is not only dangerous, but it can also give an impression of safety that is actually non-existent, thereby indirectly increasing the risk of falling.

All too often, workers are given a fixed length of lanyard at the start of the work day and left to themselves with assignments at various heights above the base, without checking the different fall clearances required for different locations.

Anchor of sufficient strength

As has been pointed out earlier in the article, the impact force on the body due to fall arrest can be quite high.

As a result of considerable industry experience and research, OSHA of the US, as well as authorities in many other countries, recommend a minimum required anchor capacity for a safety harness of 5000 lb, which is equivalent to 22.2 kN. The Singapore Code [Reference 1] makes many references to the need for adequate anchorages, and even mentions the required capacity as 22.2 kN in Clause 17.1.2.

Strictly, anchors of adequate capacity are expected to be part of the fall protection plan, and mandated for every workplace where there is work at height, with the anchor locations and capacities clearly marked.

Here again, a combination of ignorance and negligence results in many safety personnel either not recognising the problem or not implementing the controls. Many companies simply drive

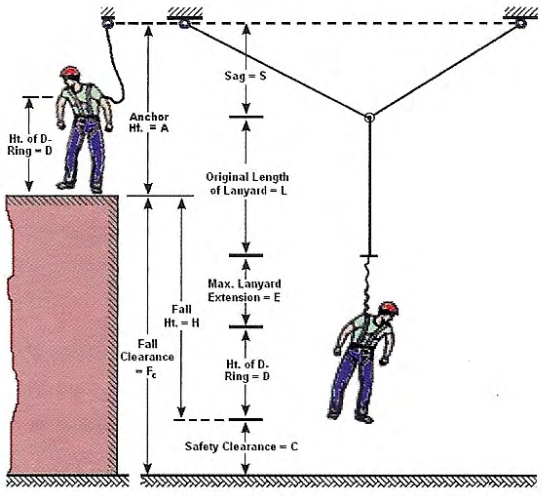

Figure 5: Fall distance and clearance.

some standard eyes into the nearest available support, and leave the site staff to ensure that workers clamp their lanyards to these anchors when accessible, or to any available support when not. Of course, if workers do not find any obvious anchor, many would simply tuck the lanyard around their waist.

Discomfort from continuous long-term use

Only a person who has worn a full-body safety harness snug-tight, for more than an hour or two, at an outdoor worksite, can appreciate the physical strain and resultant mental stress caused by straps chafing around the arms and at the crotch with every movement.

The safety harness industry has devoted considerable effort in developing models which provide better comfort than earlier ones, at some extra expense, of course, to the customer. Yet, the fact remains that after the first couple of hours and the first few days, the workers' movements (and thoughts) are hindered by the constant friction between the body and the snug-tight straps. Having to frequently unclamp and clamp the lanyard to different anchors further aggravates the irritation, literally and figuratively.

Over weeks and months of such repetitive labour, concentration and enthusiasm at work will be reduced — eventually leading to possible reduction in productivity.

The worker is constantly tempted to loosen the straps or to even remove the harness every chance he gets. In this process, when he is actually working at height, he may forget or purposely ignore the re-tightening of the straps or even wearing the harness. Many fatal fall cases are on record, where workers have left their harnesses on the work platform while they work.

Apart from strictly following the recommendations given herein, a practical solution to combat worker discomfort and pain, is to limit the exposure of the worker to safety harness work, by rotation of workers,

Suspension trauma

The worst potential danger arising from the use of full-body safety harness is the physiological problem (termed 'suspension trauma') of being suspended in space from a harness for more than a short while [Reference 1, 3].

This problem arises due to stoppage of blood circulation upward from the legs when the legs are not pressing on some object and not otherwise active for some length of time. The un-oxygenated blood slowly fills up from the feet upward to the heart, after which the heart gently stops functioning, and the victim may die unless rescued and resuscitated promptly.

As this may happen within five minutes to an hour, the general advice is to rescue the person 'as soon as possible', meaning minutes and not hours. Very few workers and supervisors are aware of the enormity of this problem and very few companies have in-house rescue plans, resorting instead to calling Civil Defence for help when a worker has fallen.

The Singapore Code [Reference 1] requires the rescue to be within 10 minutes, under Clause 17.5.2, and this can rarely be achieved without an in-house system.

Training, inspection, and supervision

Last but not least, above and beyond all the high-tech safety harnesses and all the detailed regulations for their use, a worker's safety and survival ultimately will depend on how much he understands the hazards and the safeguards, and how well he personally adheres to the safe work practices.

Most of the preceding problems with and dangers from safety harnesses are already known. Authorities constantly offer guidance by way of codes and regulations, advisories and check-lists. The best way to bring this knowledge to those actually facing the dangers, and ensure that they truly practice the principles to prevent the potential dangers escalating into fatal accidents, is by a proper combination of training, inspection, and supervision.

The Code [Reference 1] states, 'Employees who use these systems should be trained in the correct fitting, anchorage, use and maintenance of the individual fall arrest systems'.

The use of the safety harness requires rigorous and focussed training before a worker enters a work at height job. The training must include teaching the principles and the use of the safety harness and emergency preparednesss, demonstration by an experienced instructor, and testing the worker's ability to wear it and adjust all the straps correctly. Reminders at tool-box meetings, and regular or at least occasional checks on random workers, requiring them to show the supervisor how they will wear it, will be a good idea.

The safety harness depends, for its effectiveness, on the quality and integrity of every one of its components, and the correct functioning of every one of the many auxiliary safeguards, every time. Inspection in this case is more than quality control — it is a matter of life and death, and just as important as, say, checking one's parachute before leaving on a dangerous aerial mission.

Before every work at height task, the harness must be inspected for any deterioration of rope or wire cable, webbing and buckle; for the integrity of the D-ring, all clamps, and the shock absorber; for anchor locations and capacities; and for the feasibility of the fall protection plan and the rescue plan.

Equally important will be careful and possibly continuous supervision.

Many site personnel may tend to take it for granted that a trained worker can understand and use a body harness. Workers who wear safety harnesses for many hours often loosen their harnesses for comfort reasons. If they move from one task to another frequently, they will not know how to check the fall distance, or will 'forget' to attach their clamps to fresh anchors. A safety harnessed worker is also not supposed to work alone.

Any one or a combination of the above lapses can lead to a fatal fall, and supervision is the key to avoiding them. There have been many instances of fatal accidents where a worker with an expensive, fully functional safety harness has fallen from height and found to have his lanyard wrapped nicely around his waist.

Training, inspection, and supervision are thus the final safeguards in the chain of activities governing the use of the safety harness at a work place.

WHEN IS A SAFETY HARNESS REALLY NECESSARY?

It must be clear by now that just giving a worker a safety harness does not ensure that he will be protected from injury or death if and when he falls. It is only the first step in a series of complex requirements to ensure that the harness will be effective in saving the worker.

The Code [Reference 1] specifically cautions, 'Individual fall arrest systems should only be used if it is not reasonably practicable to use other risk control measures to prevent falls'.

The many fresh problems and additional considerations in the use of a safety harness demand a critical review of when, where, and how a safey harness should be used for protection while working at height. This need can be judged only by risk assessment.

According to the WSH Risk Management Regulations [Reference 4], first the hazards of any dangerous job such as working at height must be identified and assessed by risk assessment, and appropriate controls must be implemented [Reference 5]. More than half of the fall accidents in construction have been traced to lack of or inadequate risk assessment and/or control implementation [Reference 6].

Too many employers who know only that the belt is banned for fall arrest and that safety harness is the recommended alternative, are supplying safety harnesses to their workers without further thought or action to ensure their safety in actual practice.

The first approach to working safely at height when unavoidable, should be to provide a safe work zone consisting of a proper work platform and suitable edge protection by guard-rails and toe-boards.

However, in certain cases, the fall hazard cannot be eliminated because no stable, horizontal, edge-protected safe work zone can be provided. Examples include:

- There is a proper work platform but no edge-protection, either because it is being erected or dismantled, or it has been removed for a reason, or the worker has to work above his reach.
- There is neither work platform nor edge protection, either because the temporary works are being erected or dismantled, or the permanent structure is being demolished.
- The work platform is not stable and/or is likely to move around with the worker in it, as with suspended or slung scaffolds, MEWPs (mobile elevating work platforms) etc.
- The work area is not horizontal, as on sloping roofs.

The solution in such cases is to first consider special fall controls such as:

(i) Individual fall prevention by work restraint, or by work positioning.

(ii) Collective fall protection by soft landings like safety nets or cushions, which will provide sufficient deceleration distance to reduce impact.

Only when all the preceding fall controls have been considered and found unfeasible, should a safety harness be considered.

Singapore codes and regulations reflect these concerns by actually requiring a safety harness in a number of specific situations, as follows:

- Rigging, ie erection or dismantling of temporary structures
- Demolition of permanent structures
- Suspended and slung scaffolds
- MEWPs such as scissor-hoists or boom-hoists
- Sloping roofs

But regulations do not state that safety harnesses need not be used for other situations. That is where employers who worry about falls go overboard in their caution, and issue harnesses even where they are not required, unfortunately without adopting the other concommitant safeguards discussed earlier.

CONCLUSION

Employers and occupiers must seriously consider issuing safety harnessess to workers only after other safer controls are confirmed to be unfeasible.

So then, is the full-body safety harness a blessing or a bane?

When only the individual fall protection by safety harness will cover the fall from height risk, and if and only if all the nine auxiliary considerations discussed above are adequately addressed, can it be considered as a blessing.

In all other cases, it will be a bane!

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