Some design principles of horizontal fall protection systems

Pages from an engineer's notebook

By David Riches

*Our planet spins around at one revolution per 24 hours. Physically, we cannot sense this, but we do experience one effect which we call day and night. There are other associated phenomena which can be **difficult** to sense. Gravitation (the force of gravity) is a classic example. It is a force of attraction between objects, which we cannot feel, hear, smell or see. Yet we experience its effects when we drop something.*

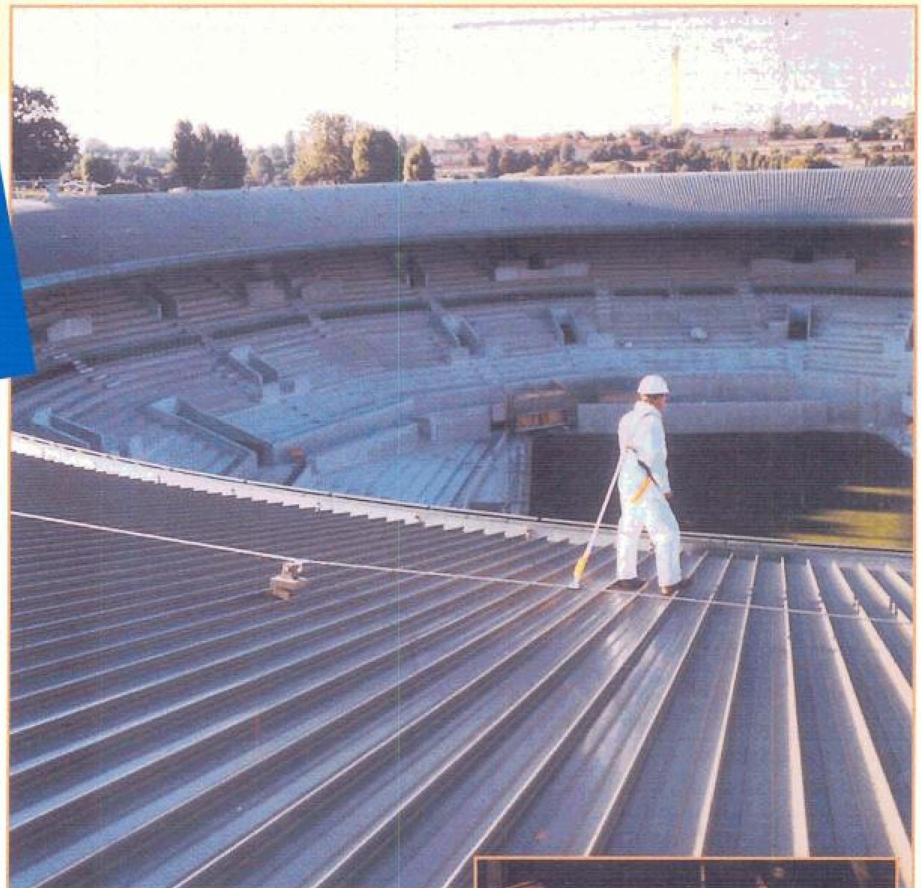

FIGURE 1

WHAT GOES UP MUST COME DOWN

Gravitation can be a welcome friend, because it keeps us well and truly on the ground! But as soon as we leave ground level and move to a higher point we can place ourselves in danger. The attraction between ourselves and the Earth (which we call 'weight') is so great that if we became unsupported, we will plummet back towards ground level. A 3.05 metre fall (ten feet) takes just 0.8 seconds, giving hardly any time to react, and results in an impact velocity of 7.74 metres per second (17.3 miles per hour).

Gravitation is one of the mast critical hazards that industry has to face in its everyday operations. It is a life threatening naturally occurring phenomenon. Being a cosmic quantity, it cannot be isolated, minimised or segregated, so engineering controls must be devised to protect workers at height from its effects. Such controls are known as 'protection from falls from a height', or the less

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unwieldy phrase 'fall protection' and can usually be divided into two main categories:

(i) fall prevention (or fall restraint as it is commonly known) - prevents or restrains someone from entering an area from which they could fall; and

(ii) fall limitation (or the more accepted term, fall arrest) - should a person fall, limits the extent of the fall or 'arrests' the fall.

Engineered control implies design, so how does one design a fall protection system? First of all we have to consider some basic fall protection system requirements:

(i) it must facilitate operations at height and must allow work to proceed through an ergonomic, safe and secure means;

(ii) in the case of a fall restraint system it must prevent a person entering an area from which they could fall;

(iii) in the case of a fall arrest system it must be capable of automatically arresting a person who accidentally falls;

(iv) it must ensure that the deceleration forces imposed upon the faller's body during the arresting phase are kept to a minimum and maintained at levels below physiological and legal limits;

(v) it must ensure that the arrest distance through which the faller falls is kept to a minimum to reduce the risk of ground/obstacle collision and in order to meet legal limits;

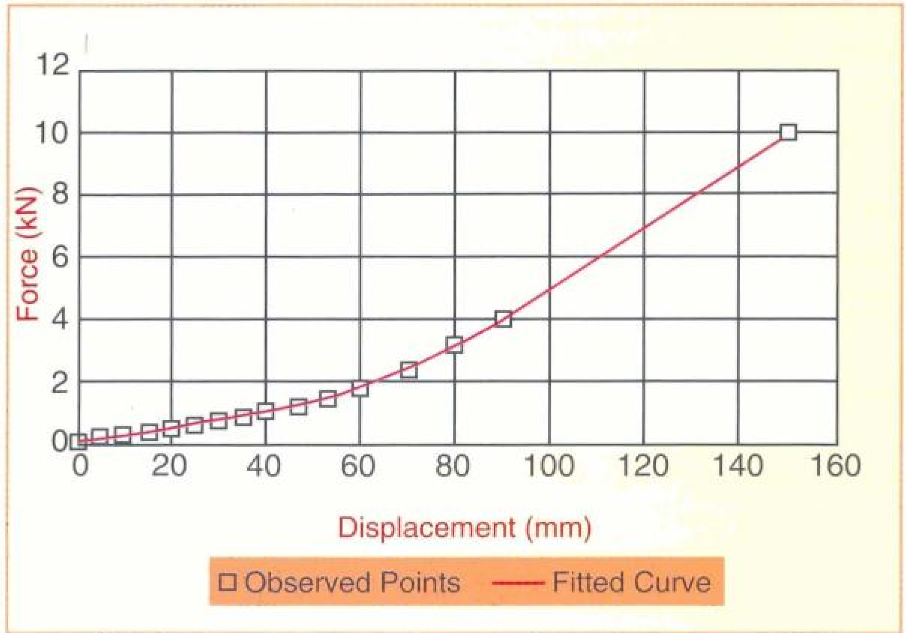

DIAGRAM I: Elasticity relationship of a typical 7 x 7 construction cable.

(vi) it must minimise the trauma that the faller could experience as a result of being rapidly decelerated in a safety harness;

(vii) it must facilitate and expedite the rescue and recovery operation after the fall is arrested; and

(viii) it must be capable of being attached to a suitable and reliable anchorage, which in itself must be capable of sustaining the dynamic forces generated during the arrest and the ensuing forces generated during the suspension and rescue phases, with an adequate factor of safety.

Secondly, we need to consider the basic components of the system:

(ix) the person(s) for whom protection is required;

(x) some kind of safety harness which the person wears;

(xi) a connecting line between the harness and the supporting structure, (a lifeline or lanyard);

(xii) an anchorage which is securely attached to the supporting structure;

(xiii) connections between the harness, lifeline, and anchorages; and

(xiv) some kind of energy absorption capability, which can dissipate the energy generated as the result of a fall, so that the arrest forces imposed upon the faller are kept to a minimum.

HORIZONTAL LIFELINES

The international term 'Horizontal Life Line' (HLL) describes one type of system which attempts to incorporate all these considerations. It provides a continuous attachment for a safety harness in an operator's place of work. It consists of a horizontally mounted cable which runs the entire length of the area to be protected, and is attached to the building or structure by intermediate anchorages at pre-set intervals, and two anchorages at the extremities. If a person falls while attached, they will be arrested in the same way as an aircraft

FIGURE 2: SIMREL test preparation.

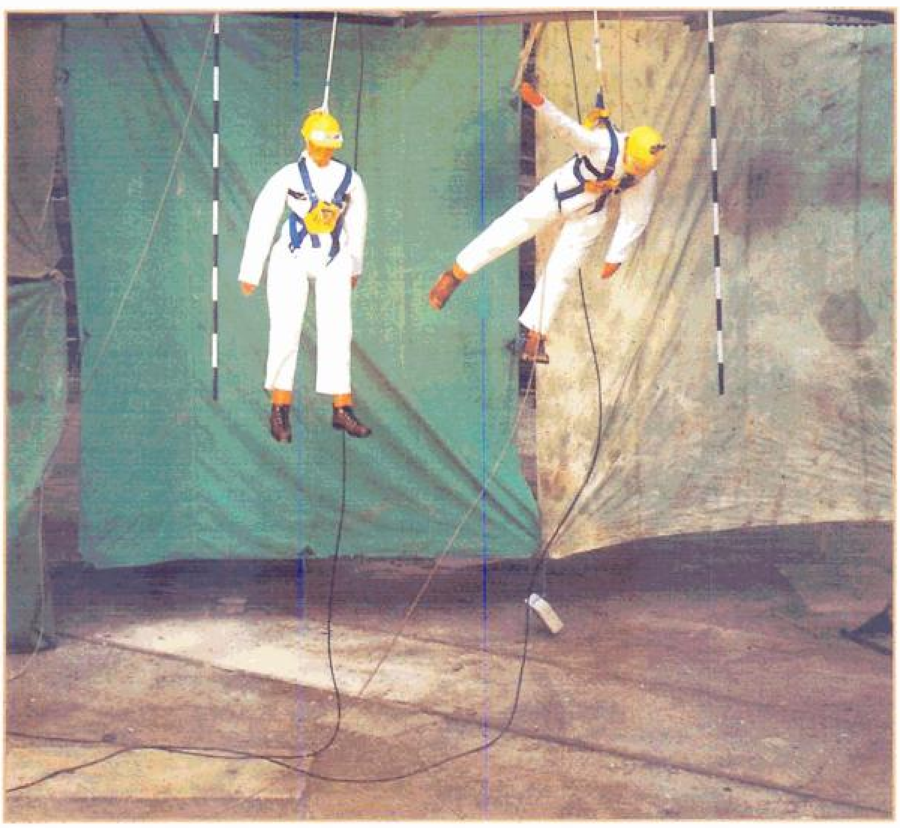

FIGURE 3: George catches his arm on the way down.

catches the arrester wire when landing on an aircraft carrier.

A special travelling device connects to and runs along the HLL, and has an integral link for connection of a safety lanyard and harness. During attachment, a worker can walk the course of the cable and the travelling device will trail behind the worker automatically, enabling both hands to be free for the task at hand. The device is able to pass through the intermediate anchorages without disconnection.

Where work is to be carried out horizontally at height the HLL can be a versatile solution when considering the fall protection options (e.g. *figure* 1).

DESIGNING FOR USE, FOR SAFETY AND FOR PEOPLE

It is important to stress that the secret of successful design is not so much to focus on system configuration, selection of materials, factors of safety or other criteria, but is crucially to facilitate the work of the people connected to the system, and to protect them from injury during and after an accidental fall. Let's not forget about the people who have to use these things! The European Standards set the maximum arrest force allowed on a person at 6kN, but this is a minimum requirement, not a target. In fact many designers aim to reduce this figure to between 2-3kN, so a faller experiences half the arrest force currently permitted. This also means that the resulting forces in the whole system and on the anchorages are correspondingly less.

The best safety system in the world will not be used if it is found too difficult or inconvenient. Ergonomics therefore play an important part in the use of a system, and insufficient attention to this often spoils a system's overall performance.

It is vital that the system can be attached to the structure where it is needed, by having anchorages installed. Apart from structural integrity, the installation process contributes to the performance of the system. Poor installation means poor protection, irrespective of the merits of the system.

If an anchorage is not available, a worker may utilise part of a building structure for an anchorage which is incapable of sustaining the fall forces. A common example is where workers attach to guard rails for convenience. Generally these rails are not designed to withstand the dynamic forces generated in arresting a fall. The importance of having properly designated and rated fall protection anchorages cannot be over-emphasised.

What about rescue? After an accident, a faller will be suspended by the straps of the safety harness, some distance below the system (post-fall suspension). This can have a worsening effect on the circulatory, respiratory and metabolic performance of the body. It is imperative that the post-fall suspension time is kept to a minimum and that the faller is brought back to a position of safety as soon as possible. Having a rescue plan is vital.

STRETCHING CABLES

Cable is often used in systems, (including the HLL) not only for connection, but also for energy dissipation purposes. The energy generated by falling persons has to be 'lost', or more properly 'converted' into another form, in the arresting process. A cable is not a material as often thought, but rather a complex mechanism in its own right. It does not have a circular cross section, but in the case of the commonly used 7 x 7 constructed cables, has seven strands each containing seven wires, interspersed with many air

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FIGURE 4: Four dummies awaiting SIMREL.

spaces, and is wrapped in a helical form. Energy can be dissipated not only as a function of each of the individual 49 wires extending, but also through internal friction and relaxation of the twist form. Consequently, fall energy can be converted into cable stretch. The capacity for this is determined by the cable size and construction, and its elasticity. The elasticity characteristic of the cable is parabolic, not linear *(diagram 1)* therefore the value of elasticity varies depending on the forces applied. Computer software, used to predict system performance, including the effects on the faller, must take account of such characteristics and not rely on good approximations.

Cables of varying construction and increasing diameter may be specified because greater amounts of energy can be dissipated without the forces getting near to a dangerous level.

Fall arrest system designers have to consider distances and times in conjunction with forces. Detailed analysis and research into these types of system reveal that in the event of a fall, the maximum arrest force on a faller may not occur at the same time as the maximum force generated in the cable. Consequently the mathematical analysis has to be a dynamic one, the computer performing a real time calculation at split second intervals to ensure that the maxima of each parameter is captured.

FACTORS OF SAFETY

Coming down the analysis trail we must take a look at factors of safety. Engineers set this ratio as a comparison between what a system is ultimately capable of sustaining and what it is actually meant to sustain in operation. It provides an adequate reserve of strength to compensate for the more intangible characteristics of engineering. Now one could design with a cable of 100kN mimimum breaking strength, and, for example, allow a maximum cable force of 20kN, giving a factor of safety of five (100 ÷ 20). Or one could allow a maximum cable force of 19kN, to give a factor of safety of 5.26 (100 ÷ 19). But one would not allow a force of 45kN in a 90kN breaking strength rope. A safety factor of two is the minimum set by the European standard but I would argue that designers should allow a greater factor, to account for the weakening effects of in-service degradation, vibration effects of wind etc. and more importantly, the effects in a fall of bending the cable through intermediate brackets and the travelling device. Unfortunately, cable is not specifically designed to be loaded heavily in abrupt bending.

Of course a well-designed system dissipates the faller's energy by applying it to a variety of components in the system. Some designers have incorporated various energy dissipating mechanisms into their systems. There are the 'in-line types', which take energy out of the cable (protecting the cable and anchorages) some have deforming intermediate supports, which take energy from the faller (protecting the cable, anchorages and faller) and there are the integral lanyard types, which take energy from where it is directly generated - from the person falling. It is important therefore that the designer considers how the complete system operates, not just the individual parts.

WHO'D BE A DUMMY?

Testing is vital in this particular field of safety. Designers, manufacturers and installers should be aware of their obligations under the Health and Safety at Work etc Act 1974, Part 1, Section 6. Traditionally in the UK, dynamic simulations of falling workers to test the performance of various fall protection equipment have been accomplished by the use of anthropometric dummies (drop testing). These dummies (e.g. *figure 2*) have their dimensions, mass distribution and anatomy arranged to be statistically representative of certain population groups. Similar test dummies are used in other industries where human impacts are of concern, e.g. aircraft ejection seats, and passenger restraint systems in motor vehicles. Unfortunately in the fall protection industry more modern European test methods are specifying the use of solid cylindrical masses, for testing convenience. I am firmly

FIGURE 5: Four dummies past their maximum drop and starting to rebound.

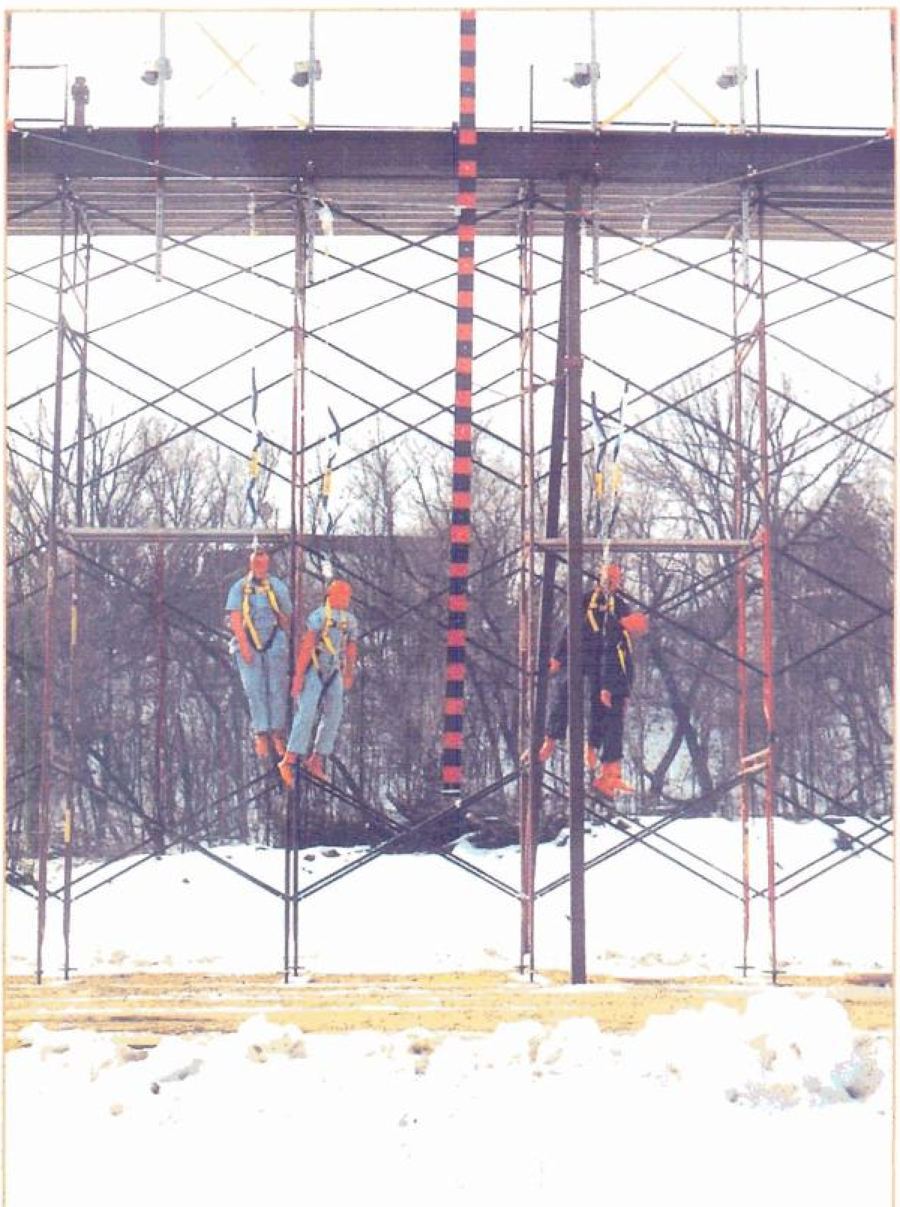

FIGURE 6: Pairs of swinging collisions.

opposed to this since it does not test how the equipment will be used in practice, nor does it reveal how humans might react to the system's method of arrest (e.g. *figure* 3). Whilst it is wrong for ethical reasons to test the equipment with human subjects, I believe the use of anthropometric dummies brings more relevance to the testing.

Several types of test should be performed to confirm the overall performance of the system. The types include: dynamic, static, endurance, environmental, corrosion and functional. Each section may need several tests before a clear result is arrived at. This may be costly. but necessary, before a designer allows equipment to go into production. It is better to have a dummy hit the ground as the result of an unforeseen event in a test and to learn from it, than to learn through a real accident. Several drop tests are needed on HLLs, especially where the system is rated for a number of workers to be simultaneously connected. Simultaneous release (SIMREL) to simulate two persons falling together or staggered release (STAGREL) to simulate persons falling at intervals need to be evaluated. More up to date testing has even considered the effects of a four person SIMREL (see figures *4*, 5 and 6). High speed photography is employed to capture the real time events for post test analysis, because each drop is over in a matter of a few tenths of a second.

Protection from falls from a height is a relatively new safety field and as a consequence documented information and technical expertise is scarce. Statutory regulations and technical standards are vaguely written, but in general are improving. The design and implementation of fall arrest systems is complex, and it has been difficult to adequately deal with many of the issues that it raised in this condensed account. However, we must never lose track of the fact that the principles behind such designs must focus on the person to be protected.

ABOUT THE AUTHOR
David Riches currently practices as a safety engineer in his independent consultancy, Safety Squared. He sits on the national, European and international committees responsible for the technical standards in this field. He has led several safety-design projects from concept to market, and advises companies employing personnel working at height.