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Best practices in concrete construction safety

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Reinforced concrete is possibly the most commonly used structural material today. In this respect, Singapore in particular and Asia, in general, are no exceptions. With its wide use come many accidents causing injuries and fatalities. Hazards exist in both the materials and the processes that go to make plain and reinforced concrete, either in situ or pre-cast, as well as prestressed. The risks arising from these hazards must be identified, assessed and controlled according to standard procedures and established hierarchy. In recent years, Singapore has taken the lead in workplace safety with its WSH Act of 2006, and its proactive stance in improving good practices in construction sites. Its success is documented by the reduction in fatality rate from 4.9 per 100,000 in 2004 to 2.9 per 100,000 in 2012.

INTRODUCTION

Construction has been and continues to be the most hazardous industry from time immemorial and in all parts of the world. The number of accidents, severity of accidents and fatality rates are highest in construction, among all industries. Figure 1 compares fatality rates for the Singapore construction industry with that for all industries and for the UK construction industry. It may be seen that:

(a) Singapore construction fatality rates are much higher than fatalities in other industries.

(b) Singapore construction fatality rates are decreasing overall, although they are still higher than those for the UK construction industry.

These are the reasons that safety in the construction industry is extremely important. Concrete and reinforced concrete being a very common construction material in Singapore as in most other countries, safety in concrete construction should take a prime place in our workplace safety concerns.

Concrete has been with us for a very long time, but safety, as a professional concern, is much more recent - it is about a half century old. Concrete, for all its usefulness to mankind, is made with materials and by processes which are inherently hazardous to human health and well-being. It is only fair that workers in that area are protected from ill-health and injury.

With reinforcement added, concrete became a magical material for engineers to build any structure they desired in any configuration they liked. Reinforced concrete is possibly the most widely used structural material today all over the world, easily understood and used by developing and developed, small and big countries alike.

The article examines various hazards that are involved in concrete construction and discusses safeguards and controls in its materials and processes. Safety aspects will be discussed under the following heads:

- MATERIAL HAZARDS
- COMMON PROCESS HAZARDS
- REBAR IMPALEMENT
- MISCELLANEOUS HAZARDS AND SAFEGUARDS

CONCRETE AND REINFORCED CONCRETE

Reinforced concrete (RC) consists of the following essential components:

1. Cement
2. Coarse aggregate
3. Fine aggregate
4. Water, for setting

(1–4) → Concrete

5. Admixtures → For various specific purposes
6. Reinforcement → Reinforcement, most commonly of steel bars, embedded in plain concrete makes up for the low tensile strength of plain concrete.

Each of the above materials fulfils vital functions in RC, but they bring with them hazards to the workers and other personnel handling them.

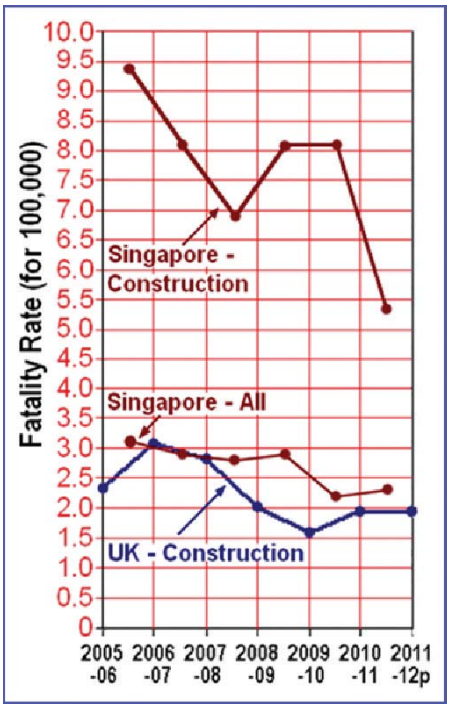


Figure 1: Construction fatalities.

Figure 2: Cement burns. Left (top) - fingers. Left (bottom) - legs. Right - pH chart.

MATERIAL HAZARDS

Cement hazards

Cement is very harsh to human skin. Cement is up to 1,000,000,000 times more alkaline than human skin [1]. Figure 2 shows fingers and legs affected by cement burn, as well as a pH chart. Cement hazards may be referred to as 'chemical hazards' also.

Handled over a long time or with allergic skin, it can destroy the skin and cause very painful burns which are difficult to cure.

Concrete workers deal with cement every step of the way until curing. Apart from hands and legs, knees come into contact with cement during floor screeding. Workers opening cement bags, measuring cement, cleaning containers and storage areas, and stacking empty cement bags are particularly at risk of inhalation and skin contact.

Inhaling cement dust while measuring or transferring it is a terrible hazard, because it will set and harden inside the lungs and effectively destroy big chunks of breathing capacity in due course. Even with gloves, boots, and kneepads, cement dust or wet cement gets in and on to other parts of the body, and quickly starts its attack on exposed skin and air passageways lined with mucous membrane. Eyes are quite vulnerable too.

OSHA [2] recommends the following safety measures against cement burns:

For cement dust:

- Rinse eyes with water if they come into contact with cement dust and consult a physician.
- Use soap and water to wash off dust to avoid skin damage.
- Wear a suitable respirator to minimise inhalation of cement dust.
- Eat and drink only in dust-free areas to avoid ingesting cement dust.

For wet cement:

- Wear alkali-resistant gloves, coveralls with long sleeves and full-length pants, waterproof boots, eye protection, and, if knees and elbows are involved, knee and elbow pads.
- Wash contaminated skin areas with cold, running water as soon as possible.
- Rinse eyes splashed with wet concrete with water for at least 15 minutes and then go to the hospital for further treatment.

Although not a major hazard, even dust from cured and dry concrete can, in quantity and over a period of time, cause skin, eye, and respiratory disease.

Coarse aggregate hazards

Compared to cement hazards, aggregates can cause relatively less harm because most of their effects are more physical than chemical. The stones, in varying sizes, or other hard material are rough to handle, and heavy in bulk containers. Handling them raises fine dust which can get into the lungs and physically irritate and infect parts of the body if and when it gets into eyes, nose etc or between the clothes and the body. Too much shifting around will raise fine powder, with its own hazards.

Workers must wear dust masks, gloves, and high boots. In addition, they are advised to wear long-sleeved shirts and full pants, whose loose ends can be banded and shoved into the gloves and boots, respectively. If some particles do get in contact with the skin, it is worthwhile to take time off to remove the offending particles and wash and dry the contact surface. It is important not to let a small scratch develop into a raw wound.

Fine aggregate hazards

Silicosis is a progressive lung disease caused by breathing respirable particles of silica dust over a period of time. Although individuals vary in their susceptibility, even prolonged skin contact can be harmful. Chronic silicosis may develop after 10 or more years of exposure to crystalline silica at relatively low levels. Accelerated silicosis may result from exposure to high concentrations over 5 to 10 years. Acute silicosis occurs where exposure concentrations are the highest and can cause symptoms to develop within a few weeks to 5 years [3].

In any case, fine dust can be a slow poison, and all precautions should be taken to prevent long-term damage to lungs. Apart from particulate masks, gloves and boots, dustless methods (such as a vacuum or water hose) must be used for cleanup and not the dry sweep method. Dust must not be allowed to collect on walls, floors, and ceilings.

Water hazards

Water, which is essential for the hydration of cement, must of necessity be pure, so there is no health risk from the water per se. However, once it mixes with cement, very aggressive chemical reactions start, and then, even water that looks clear is dangerous as in the case of wet cement. Workers handling and standing around in wet cement and concrete for hours must take special care to wear water-proof (hole-less) gloves and boots and ensure that none of the water gets into them.

On the other hand, a good supply of water under some pressure must be available close to the work area, to enable workers to wash off any cement or concrete coming into accidental contact with eyes, nose, skin etc.

Admixtures hazards

Admixtures are chemicals which are added to concrete at the mixing stage to modify some of the properties of the mix, mainly to increase workability with reduced water, but also as air entrainers, accelerators or retarders. Admixtures should never be regarded as a substitute for good mix design, good workmanship, or use of good materials [4].

While most admixtures are not hazardous to health, certain admixtures are caustic in nature and some may be flammable. As it may not be always clear which ones are flammable, it is safer to treat all chemicals as flammable.

Likewise, all chemicals should be regarded as toxic and corrosive, ad hence, eye, mouth and skin contact should be avoided. Contamination should be washed off immediately with plenty of fresh water. Contaminated clothing should be removed and washed. Medical help should be sought in cases of serious eye contamination, ingestion or excessive inhalation of fumes. Admixture spillage will cause floor areas to become slippery and unsafe. Spillage should immediately be hosed down with water to prevent accidents.

Reinforcement hazards

Reinforcement is so critical a counterpart to concrete that without it there would be no progress in structural engineering as we know it today. It usually consists of steel of various strengths, in the form of circular rods, 6 mm to 60 mm in diameter. Except for the smallest few sizes, the rods have projections or indentations for mechanical grip inside concrete. They are referred to as 'rebars'. Welded wire fabric is also used for reinforcement.

Steel is the heaviest of common building materials, and its movement and handling involve considerable risks to humans and equipment alike. Further, the tasks involved in rebar movement and placement are also among the most hazardous of construction site activities.

The heavy weight can lead to manual lifting problems. A 40 mm diameter rod 10 m long will weigh about 100 kg. Difficulties in handling include the large lengths affecting manoeuvrability in tight spaces, bending them to required shapes, and arranging them within the formwork which forms the mould for casting the concrete around the rebars. Additional hazards include projecting rebars impaling people during transportation or presenting sharp spikes in storage or partially completed RC work.

COMMON PROCESS HAZARDS

Reinforced concrete faces the following hazardous processes in its preparation and utilisation:

1. Erection of scaffold, falsework and formwork
2. Working from scaffold and formwork
3. Preparation of concrete
4. Transportation of concrete to site, and from site to the formwork
5. Preparation of reinforcement
6. Transportation of reinforcement to site, and from site to the formwork
7. Arranging and fixing of reinforcement in the formwork
8. Pouring concrete into formwork
9. Vibration of concrete in the formwork
10. Curing of the concrete
11. Screeding of slab
12. Dismantling of scaffold, formwork and falsework

Each of these processes carries hazards, and needs specific safeguards to eliminate or mitigate their effects. Common to most of them are a few major and high-frequency hazardous activities, namely:

1. Working at height
2. Manual handling of heavy loads
3. Ergonomic problems

These are first discussed and then applied to various processes involved in concrete construction. Recently, the writer had reviewed certain safety aspects of formwork in the Indian context and had highlighted the above three hazardous activities [5].

Working at height hazards

Working at height is inevitable in a modern urban setting like Singapore as most of the structures are high-rise or high above the ground. Even developments deep below ground will have similar hazards and must be included in the discussion. Any work at height (WAH) above 2 m (or less if surrounding hazards warrant it) is considered unsafe without appropriate safeguards according to Singapore Code of Practice for Working Safely at Height [6]. All the WAH hazards must be managed properly.

The most common hazard from working at height is fall from height, amounting to 36% of all fatal accidents as shown in Figure 3, for 2009. Closely associated with it is the danger of objects falling from height to injure persons below (26% in Figure 3).

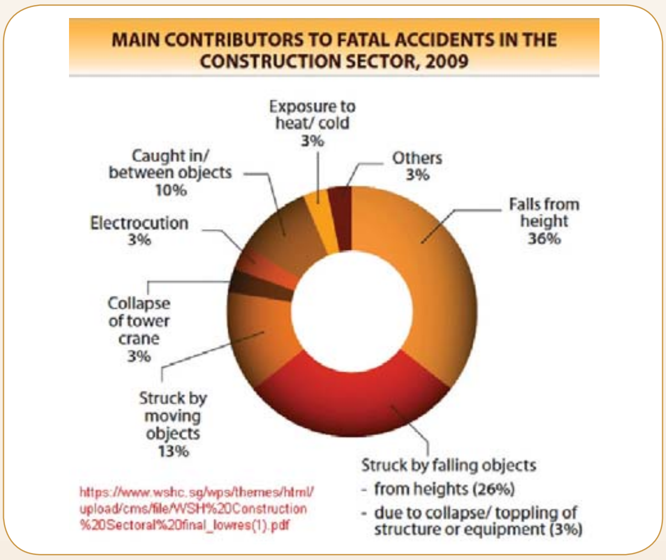


Figure 3. Contributors to fatal construction accidents.

The writer is intimately involved in safety training for (and conducting field research into) WAH. He finds that because of the relatively recent introduction of many safety measures and certain new technologies, parts of the Singapore construction industry are still coming to terms with the demands made by the regulations and safeguards. In particular, from his interaction with his course participants, he has identified inadequate appreciation of the ramifications of WAH, and misperception or misinterpretation of the regulations, as obstacles to faster progress.

Falls from height

The WSHC Code [6] spells out clearly what needs to be done under various fall circumstances, in particular, when safety harnesses must be used. It prescribes the hierarchy of controls as collective (for all workers) before individual, and prevention before protection.

On this basis, the writer affirms that evaluation and implementation of WAH controls should be in the following order:

(a) Safe work zone, defined as stable platform and specified guard-rail.

(b) When no edge protection → travel (work) restraint.

(c) When no platform → work positioning by rope access (or MEWP).

(d) When platform or work zone is not stable → fall arrest by safety net.

(e) Same as (d) and when only a few individuals are involved → safety harness.

The writer has developed a schematic matrix to reflect the hierarchy above, as shown in Figure 4.

Figure 4. Fall control hierarchy.

However, it is very common practice for occupiers and contractors to hand out safety harnesses as the single solution for all WAH scenarios, even when they have platform and guard-rail, regardless of whether or not the worker runs the risk of falling in the normal course of work.

A reason cited for this excessive redundancy is that some workers climb the guard-rail, presumably in the course of their work, and fall off as a consequence. Why is this so? Remembering that the vast majority of construction workers is immigrant, the writer is convinced that this apparently irrational unsafe act of climbing handrails on the part of the few immigrant workers is because:

(i) They had been assigned tasks beyond their vertical reach.

(ii) They were not advised on safe work procedures (SWP) or given instructions and/or facilities (such as a short ladder and work restraint for use when they climbed the ladder from the platform) to carry out their assignment.

(iii) They were too language-challenged and even too frightened to ask for instructions and help.

(iv) There probably was nobody around to check them from doing wrong or give them guidance.

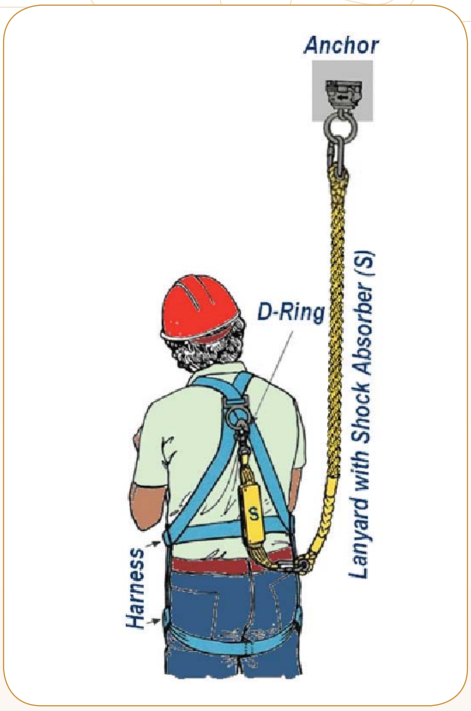
So in truth, such behaviour would be a logical result of an unsafe condition created by the management rather than an unsafe act by the worker. Of course, it would be wrong for a worker to ignore the risk, but the management could and should have easily avoided this hazard by anticipating the special circumstances and providing not only the facilities needed, but also more continuous and closer supervision to eliminate the possibility of such involuntary violations.

Logically, to protect against such transgression of safe bounds (a), as listed above, travel (work) restraint (b) would have been the control of choice. Why the industry has not taken to this is because in many cases, the regulatory statement that belts are banned for fall arrest is often mistaken to mean that belts are banned for anything to do with a fall, overlooking the recommendation that belts and lanyards as work restraint for fall prevention are better than fall arrest devices.

Even for fall arrest, the collective solution (d) for all workers by a soft landing like a safety net would be preferable. But unfamiliarity and lack of experience with this drive employers away from it, leading them to Personal Protective Equipment (PPE) (e) to save individual workers. That is how, once confidence has been lost in the worker's ability to remain within the safe zone, the safety harness becomes the only 'logical' solution!

Even if this habit of giving safety harnesses (though unnecessarily) can be accepted as expedient, the reality is that the body harness is not a self-contained PPE but part of a system. It will become functional and effective if and when (and only if and when) a number of other requirements are met, the most essential of which, as the writer has discussed in detail elsewhere [7], are as follows:

- Proper fit of harness, to avoid injury due to jerk within the slack, at the end of the fall.
- Sufficient fall clearance to avoid hitting bottom at the end of the fall, of about 5.5 m + sag (Figure 5).
- Strong enough anchor (16 kN to 22 kN), to take the impact at the end of the fall.
- 100% tie-off with a twin lanyard, so that the worker is always protected from a fall.
- Prompt rescue system, to avoid 'suspension trauma' due to being suspended too long.



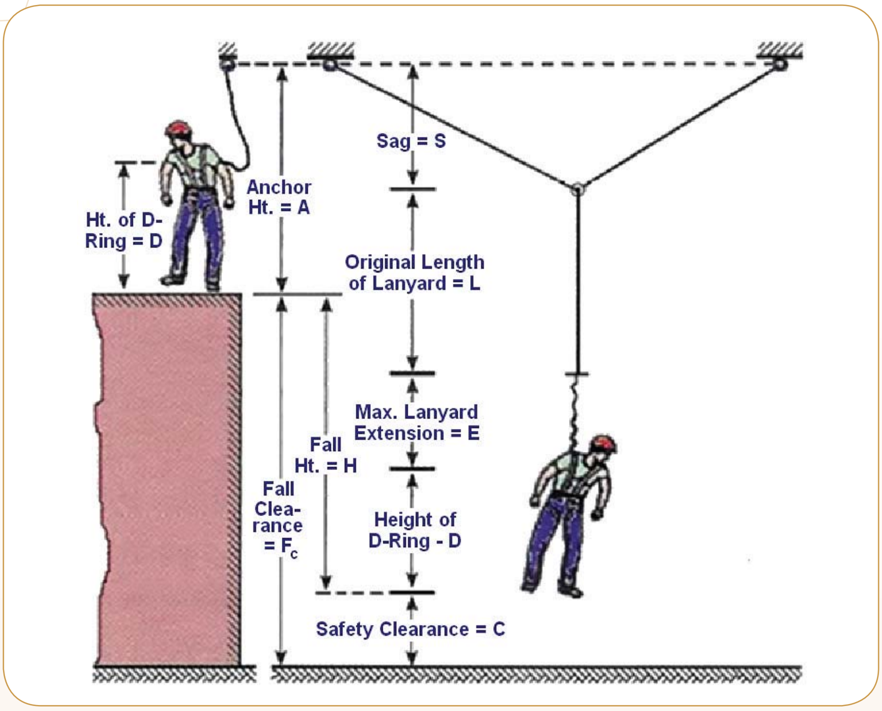


Figure 5: Fall arrest system. Left, safety harness, lanyard with shock absorber (S) and anchor. Right, fall clearance required (S+L+E+D+C-A).

Many in the industry have not kept up with the details that should go with the body harness. Most workers wear it loose. As for fall clearance, it is not generally checked, and it is not uncommon to find workers at second storey level (less than about 4 m) or on top of containers (less than about 2.5 m) wearing safety harnesses, while a safety harness would not be functional or effective within about 5.5 m, without counting lifeline sag and loose harness slack. Anchors, where indicated, are often not specifically designed. Rescue is generally initiated by a call to the Civil Defence.

Sadder still is the fact that even when workers are given safety harnesses, shown anchors and instructed to use them properly, it may happen that a worker has not understood the instructions fully or realised the implications of his not following them strictly, and leaves the harness on the work platform and keeps doing his work and moving around dangerously.

The technique of 100% tie-off of anchoring the second lanyard before unclamping the first to move on to another adjacent location may be confusing to those who are unfamiliar with the fall arrest system in spite of being trained, and so one of the lanyards ends up wrapped around the waist and tucked in, as if it is a spare!

All this adds up to an invitation to disaster when somebody falls. This can be remedied of course and is being officially tackled by improved education and training, and increased inspection and enforcement. As the writer has repeatedly stated, better and closer supervision will help a lot.

The general principle should be, during erection or dismantling of scaffold, falsework and formwork, without edge protection or safety net, safety harnesses should be used. Once the scaffold or formwork is up, edge protection or work restraint should suffice. Beyond this, unless mandatory, safety harnesses should be considered only when safety nets are infeasible. Ladders may be used for short-term usage for low heights (less than about 4 m), mainly for access, and not as work platforms.

Hit by falling objects

As stated earlier, a close second to people falling from height is the hazard of objects falling from height on people below. Usual objects are debris, construction materials, and tools. Even a small object like a 30 g steel bolt would hit like a bullet if it fell from 10 storeys high.

Debris is usually managed with vertical debris nets along the open sides. Safety helmets, with chin straps worn, will be the individual PPE. Toe-boards along the edge protection are essential to prevent fall out of debris and tools. Workers must protect themselves and their co-workers from falling objects, by securely fastening the materials they are working with to the loading equipment or to the structure, before they remove supporting cables. Lanyards will ensure that their tools will not fall if misplaced or dropped.

Manual handling of heavy loads

Cement is heavy, concrete is heavy and steel rebars are heavier still. The scaffold and formwork structure components, pipes (tremies) carrying wet concrete, vibrators, almost everything connected with concrete construction, happen to be very heavy. Workers often have to handle them manually, by lifting them most of the time. This leads to spinal strain which falls under the common problem of musculo-skeletal disorders (MSD) which, according to to the HSE [8], affects 1 million people a year as the most common reason for occupational ill health in Great Britain, costing its society £ 5.7 billion. A cement bag weighs 50 kg. Steel decking 2 m long and 200 mm wide with 4.8 mm thick metal weighs 50 kg. A 10 m long 40 mm diameter rebar weighs 100 kg — which amounts to 50 kg per worker if two carry it.

It is a fact that for every kg a person bends and picks up, his backbone is subjected to about 12 kg force (as shown in Figure 6) and that for normal Asians, picking up more than about 24 kg on a regular basis over the long-term, magnified as stated, will damage the fibro-cartilage cushions (discs) between the vertebrae. Pushing, pulling, or pivoting or climbing with heavy loads places an equal or larger strain on vertebrae. Unfortunately, damage to discs and vertebrae are irreversible, and lower back pain is a lifelong suffering.

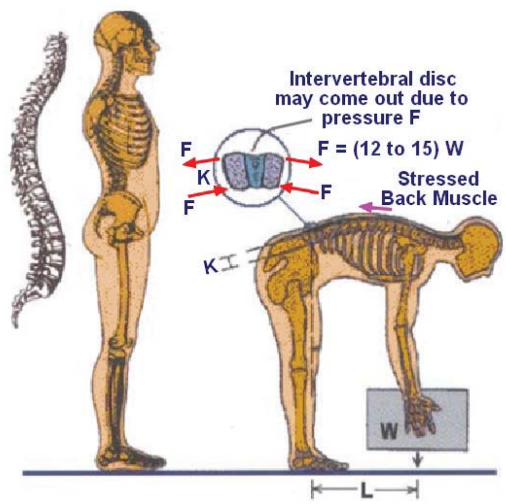


Figure 6: Force on spine when lifting.

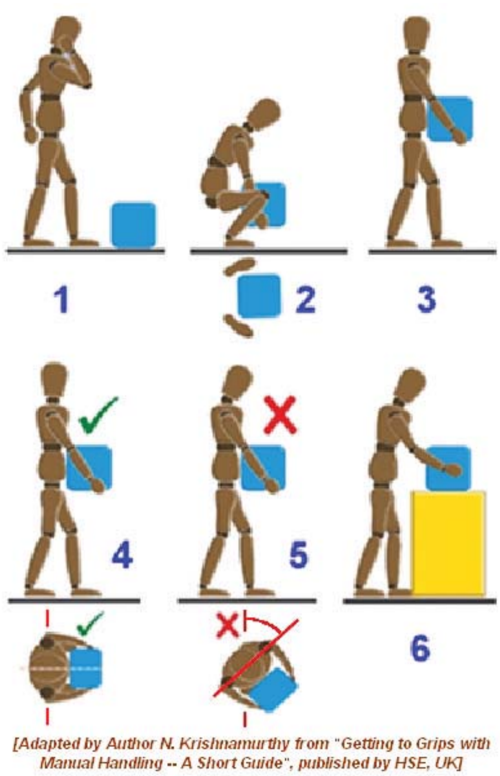


Figure 7: Lifting heavy weights.

Needless to say, this is a well-known classical problem. Many advanced nations have mandatory or recommended limits on how much a worker may carry on a regular basis as part of his assigned work. Australian laws limit it to 20 kg; their cement bags too must not be more. The UK limit is 25 kg. Singapore has recommended 25 kg in its Code of Practice for Manual Handling [9] and a few other regulations.

Even the 25 kg is only the upper limit in ideal cases. When a worker lifts it high, or carries it far from his body, or twists at an angle with it, the effect on the backbone worsens and the load carried must be correspondingly reduced, as described in detail in the Code [9].

Unfortunately, this well-documented fact is not as well-known to workers and supervisors or the management. Often the trauma develops gradually and over a period of time, unlike the dangers of falling from height which are a visible, obvious, and are an immediate threat. Here again, the immigrant workers are not in the best position to understand and manage the situation on their own. They probably do not connect the cause and effect relationship in this matter, and if they do, they do not use available venues to rectify it.

These could be the reasons the problem has not surfaced as a major problem in Singapore. Like violations of the safe zone in working at height, workers volunteering or accepting to carry any load assigned is more an unsafe condition than an unsafe act.

Actually, the situation can easily be managed by one or a combination of the following measures:

- Training workers to squat and carry instead of bend and lift as in Figure 7, on or off the site.
- Wherever possible, to divide the loads into 25 kg or lighter parcels.
- Assigning more workers to share the load.
- Providing mechanised aids such as dollies (carts) for the actual movement.

Ergonomic problems

Ergonomics is the science of proper posture in relation to work. Apart from the wrong way to lift heavy loads, as discussed in the previous section, MSD afflicts workers carrying out tasks continuously in the wrong posture, or performing long-term repetitive motion. The writer recently published an article on this subject in a local magazine [10].

Even without overload, many tasks in concrete placement, vibration, and finishing involve bending and twisting postures (as shown in Figure 8, except for the worker on extreme right), which if continued for too long, without sufficient rest and compensatory exercise, could very adversely affect the worker's health.

Repetitive work is the hallmark of most concrete work. Common examples of tasks involving poor ergonomics are handling, moving and mixing materials; mixing, placing and finishing concrete including floating and screeding, ie levelling and smoothing horizontal surfaces; binding rebars with wire within or on formwork (centre, Figure 8); vibrating fresh concrete, curing etc.

Figure 8: Left - 'bull-floating' with an awkward posture. Centre - squatting and wire binding rebars. Right - bending down and wire binding versus standing up and wire binding, using a mechanical aid.

A typical reinforcement set-up, fabricated in a workshop or assembled from individual components at site will involve thousands of operations of the same kind, such as arranging bar-chairs under rebars, tying rebars with binding wire, and so on, each of which requires concentration and physical effort of the same kind over hours and days.

The muscles involved in these are mostly of the fingers, wrist, hand, and elbow, plus the knee when squatting down, and the back muscle when bending down. Repetitive use of these muscles and nerves will lead to such disabling conditions as 'carpel tunnel syndrome'.

The most common consequence of such bad work posture is MSD, which, if not relieved by rest, medication, physiotherapy etc, may result in permanent muscle and nerve damage, leading to paralysis, gangrene etc. In the US, MSDs are the most common injuries in the construction industry, accounting for over one-third of all lost workday injuries and about half of all compensation claims in spite of considerable mechanisation of many repetitive and ergonomically arduous tasks, as for instance the use of the mechanical wire binder by the standing worker on the extreme right in Figure 8.The situation in other advanced countries is no less critical.

In Asia, the problem has not made itself felt, mainly because culturally Asians are more used to bending and squatting than Westerners. But habits and lifestyles have been changing and Asians too have (or soon will) become more vulnerable to MSD. Singapore authorities are promoting awareness of this recently recognised hazard and its consequences, and it is necessary for the industry to address this concern pro-actively before it becomes a problem.

MSD can be taken care of with a combination of various safeguards including but not restricted to:

- Raising the job to a level not requiring bending of the back.
- Providing lighter tools, with easier controls.
- Replacing hand tools with mechanical tools.
- Planning work and arranging materials to avoid unnecessary movement.
- Giving workers more breaks during the task.
- Increasing the number of workers — they do not cost that much, but in Singapore, availability may be a problem.
- Rotating workers in such tasks as vibration with pokers.
- Decreasing speed and/or rate of work.
- Changing posture frequently.
- Minimising the amount of such work by substitution, automation, pre-fabrication etc.

REBAR IMPALEMENT

There is a special problem with steel rebars, that under certain circumstances, they can impale (ie pierce through) a person, causing great agony and possibly death. One is during transportation, and the other is in a construction site or precast concrete factory.

Transportation and moving of rebars

Rebars are heavy and when they are in motion and something gets in their way, the impact will be extremely high. In the case of a human, the effect will be literally deadly. Hence in any and all movement of rebars, whether on the road or by a crane at a site, or even by workers shifting them around, great care must be exercised. All movement must be continuously and strictly supervised.

The effect of sudden stopping of a truck carrying long rebars (Figure 9) is either not known or not remembered. When the truck travelling at say 80 kmph on the expressway brakes suddenly, the rebars are still travelling forward at that speed, which makes them Olympic style javelins, puncturing through glass, wood, or even metal backs of the truck cabs, let alone whatever human tissue may happen to be in the way. Special baffles must be interposed between the bars and the cab before starting on the trip.

Figure 9: Rebar transportation hazard.

The other scenario is when a car or motorcyclist is following too close to the truck. When the truck stops, its baffle may protect the cab, but the car occupants or motorcyclist behind get thrown on to the projecting bar at the speed of the following vehicle, and get skewered regardless of the red rag at the end!

At a construction site, with so many heavy objects moving around under mechanical and human power over a restricted area, with so many workers each focussing on their individual or small team work, even with the best of supervision, there would be occasions for workers to strike against objects or vice versa.

Common situations are:

- When the rear worker in a two-worker operation does not stop when the front worker stops, and this pushes the latter against some sharp hard object.
- When a worker is dragging something and moving backwards in a bent position, and then straightens up without checking if he is under some sharp or hard object.

Impalement on rebar projections

By far, the most horrendous and not so rare an accident at a reinforced concrete worksite is that of workers falling on to a lower level with a vertical set of uncapped rebars, and getting themselves impaled on them, generally leading to slow and painful death. Figure 10 (left) depicts one example of the hazard.

Because of the fairly high likelihood of its occurrence and the very high severity of the consequence, specific SWP and special safety devices have been developed and are being used in most countries. Figure 10 (centre) shows an example of a plastic cap with a broad and stiffened impact surface to protect against injury during a fall. A better solution is the protective shield of a 2 by 4 or a plank for a row of vertical rebars as in Figure 10 (right).

Figure 10: Left - rebar impalement hazard. Centre – plastic cap. Right - plank shield.

In Singapore, the practice of providing safety cover for exposed rebar ends does not yet appear to be common or specifically required. The protection most observed is the ad-hoc capping of exposed rebar ends with thin throw-away plastic shells which came with the threaded ends of rebars to protect them until they were ready to be coupled.

It is often misunderstood that once such caps are provided, the worker is safe if he falls on them or hits them. This is not necessarily so. Unless the caps have been specially designed with a large enough contact area and strong enough material — or made of plastic reinforced with steel plate — to resist human body impact from fairly large heights, the bar may pierce through the cap, or, if the cap top is not wide enough, the bar and cap together can deliver the death blow. These are known to be only 'scratch protectors'. But providing these is better than ignoring the whole problem!

Another ad hoc alternative to shielding would be to simply bend the bars by 90° or more so that the sharp ends are pointing horizontally or downwards. But then, these create fresh hazards namely they present a danger for horizontal movement of people in the area (although mushroom shaped caps could be used on the sharp ends to good effect) and straightening them later for concrete casting is troublesome, and with thick rods, not fully effective.

It must also be noted that not only vertical rebars but inclined or even horizontal rebars are an equal threat for impalement, because all it takes is for a worker to bump into an exposed sharp end of a rebar with sufficient force to puncture his skin, before the momentum carries him to heavy internal damage. Even careless handling of (or being near) rebars projecting from pre-cast or already cast members can cut and mutilate limbs.

MISCELLANEOUS HAZARDS AND SAFEGUARDS

Apart from the major hazards and controls in reinforced concrete work that have been listed in preceding sections, there are a number of controls which are common to many construction sites. Common to all these controls are the required compliance regime of strict maintenance, regular inspection, and pro-active supervision in all such situations.

In addition to effective and up-dated training, frequent reminders and specific briefings must be given to the workers, particularly under the prevailing conditions of immigrant labour diversity in Singapore. Risk assessment and management are mandatory.

Collapse of scaffold or formwork structure

Collapse of scaffold or formwork structure used in concrete construction may happen either due to overload or under-design. The main problem that leads to either of these conditions is the mindset that scaffolds and formworks are temporary structures and so are not as deserving of investment of money or time in regard to their stability and safety.

In theory, formwork must be designed so that they will be strong and stable under construction loads, which should rightly include concrete delivery and movement. Heavy loads must be placed only at specially designed, designated zones.

In practice, due to lack of clear instructions, the design may not cover all construction loads. At site, SWP may not cover alternative means to keep loads within safe bounds. Arrangements might have been made to open the bundles at ground level or on strong bases and distribute them on formwork, but these may not always be followed.

Under these conditions, it is quite likely that a half cubic metre concrete hopper, weighing more than 12 kN, may accidentally rest on a formwork designed for 1.5 kN per m^2 plus a concentrated load of 2 kN. Or a heavier than permitted load of concrete may be dropped from a larger than permitted height. To prevent these, all rules for placement of concrete on formwork must be strictly followed.

A contentious issue in temporary structure design has been the factor of safety. Until major accidents such as the Nicoll Highway collapse and Fusionopolis collapse, and design rules were tightened up, temporary structures were designed like permanent structures for average load factors of 1.5.

The international enquiry committee for the Nicoll Highway disaster and the writer who was assigned to investigate the Fusionopolis collapse [11] strongly recommended a minimum factor of safety of 2.0 for temporary structures. The industry is gearing up to the higher benchmark. The new Code of Practice for formwork, SS580:2012 [12], with the writer having the privilege to serve on its committee workgroup, has mandated a minimum 'load safety factor' of 2.0 for all methods of formwork design and testing.

Formwork is at its most unstable and vulnerable condition during the concrete casting and early stages of hardening and curing while the concrete is still soft and weak. Multi-storey work requires the additional consideration of the danger of shoring of new work on to recently completed work which may not have attained adequate strength, or which may not itself be adequately shored. Finally, premature or wrong striking of formwork is a real hazard also. These require expert advice and strict implementation of SWP.

Tripping and falling hazards and safeguards

All too common in concreting work are:

- Tripping on formwork projections, depressions, or rebars, cable entanglements etc, and falling.
- Abrasions and cuts during the handling of reinforced concrete materials and tools, some of which may slice through the palm to the bone.
- Pinching and crushing of fingers, toes, hands, wrists, caught between materials and components, which sometimes may necessitate amputation.

To prevent such harm, PPE such as steel-toed shoes, thick gloves, and thick full body clothing must be worn, backed by the compliance regime already mentioned.

Mechanical hazards and safeguards

In concreting work, all the processes listed in the section 'COMMON PROCESS HAZARDS' are likely to involve machines of some kind or the other, be it cranes, forklifts, pumps, vibrators, bar benders, saws etc. These will pose a wide range of hazards from cuts, bruises and pinched limbs, to eye injuries, amputations, fractures etc, leading to even death, sometimes.

Controls must follow the usual hierarchy of risk management to deal with these hazards. These will include machine guards, safety interlocks for machine operation, up-to-date training, appropriate PPE, and an effective compliance regime.

Electrical hazards and safeguards

Concreting involves more mechanical and manual operations than electrical. But, as most machines are operated by electricity, and electrically operated hand tools are involved, or even something as innocent as night work has to be done, electricity becomes an additional source of danger to the workers.

Possible consequences of frayed insulations, contact with water, ungrounded circuits etc could range from a simple electric shock to fatal electrocution. Although ELCBs are mandatory, grounding and short-circuits can still happen under unfavourable circumstances.

Even though a simple shock may not injure the worker, the instantaneous unexpected jerk may throw him off balance and make him drop things. He and/or co-workers whom he may knock against, may also fall and get hurt. Electric shorts can result in fires and explosions. Risk-wise, 110 v is much safer than 220 v. Many companies with foresight are investing in 110 v tools to be used with a 110 v supply.

Noise hazards and safeguards

Among the health hazards in Singapore, noise-induced deafness (NID) has been identified as by far the biggest culprit, contributing to 88% of all occupational diseases in the country. Most of it has been traced to manufacturing and marine industries, and construction accounted for only about 5% of it in 2011 [13]. Still, the topic is significant because of the permanent adverse effects of excessive noise even on a small group of people, and because the lessons learnt and controls recommended in other sectors are easily transferrable to construction.

Construction sites are notoriously noisy a lot of the time, with digging, piling, moving, grinding, sawing, jack-hammering, welding, and all kinds of machinery including cranes, motors etc going full power. Figure 11 depicts the writer's presentation of data from the WSH Report [13] on the variations in occupational diseases from 2001 to 2011, which dramatically shows the dominance of NID in the country as well as the relative insignificance (quantitatively) of MSD.

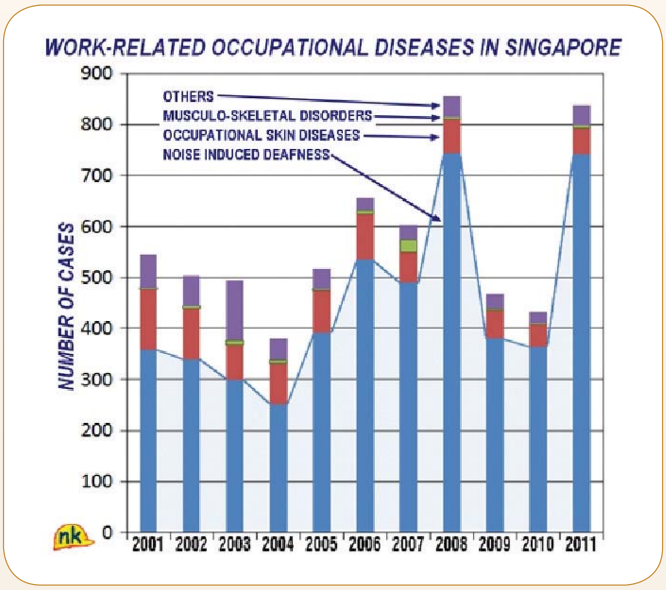


Figure 11: Occupational diseases in Singapore.

Like low back pain due to MSD, NID is also not obviously harmful. It is also slow and gradual in development, and when endured over a long period (like a couple of years) is also irreversible. A noise level of 85 dB(A) is defined as the upper limit of comfortable and safe noise for adult humans. Any noise louder than this will begin to affect the hearing and if it persists, may result in permanent damage.

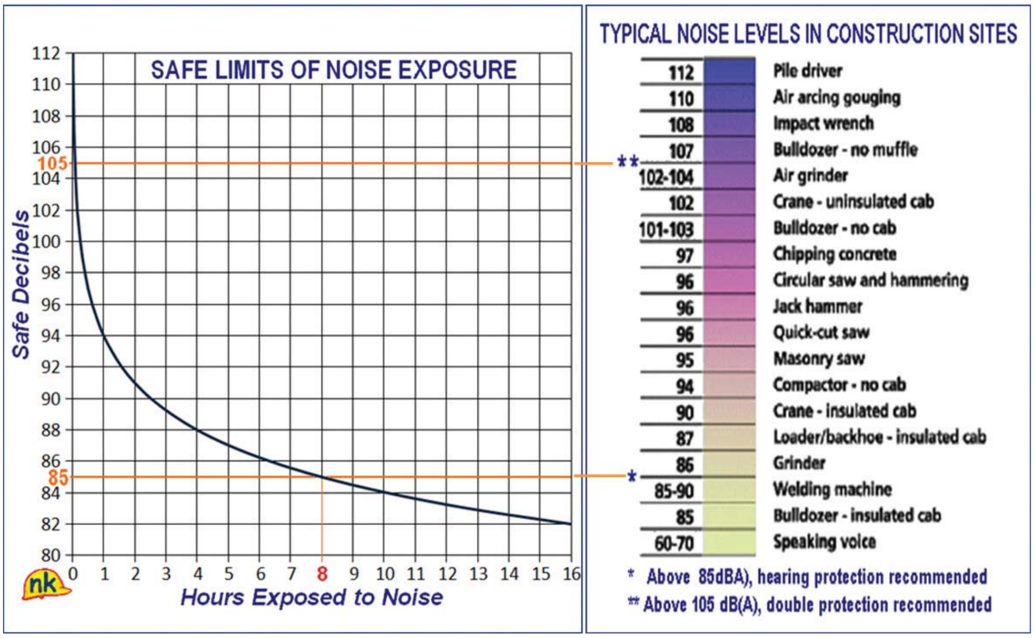


Figure 12: Left - safe limits of noise. Right - noise levels of various activities.

Figure 12 (left) shows the curve plotted by the writer from data presented in tabular form in the Noise Regulations [14]. In addition to the 85 dB(A) safe level, it also indicates a second danger threshold at 105 dB(A), when the person exposed is expected to use 'double protection'.

Obviously, the damage will depend not only on the noise level but also on the total duration of the noise. The curve shows that noise levels higher than 85 dB(A) may be tolerated for shorter periods than 8 hours, eg 94 dB(A) may be tolerated for 1 hour. The 105 dB(A) limit is reached in 5 minutes! Even a small reduction below 85 dB(A) can extend the tolerance duration considerably; 82 dB(A) can be tolerated for 16 hours which is twice the tolerance duration for 85 dB(A). So it is imperative all efforts be made to reduce the noise levels at construction sites.

Aligned with this curve is the chart on the right of Figure 12, which depicts the typical noise levels from various sources in construction sites [15]. Together, the two figures can predict the safe duration of exposure for a worker exposed to noise from various tasks.

Of course, there are conventional preventive solutions for NID, as detailed in the regulations. Permanent solutions are to eliminate the offending source if possible, or to mitigate the hazard by noise barriers, mufflers etc. Where such collective mitigation is not possible, individual protection by hearing protectors such as earplugs and/or earmuffs should be adopted. The regulations lay down clear guidelines on testing, training, and supervision for hearing protection.

Hearing protectors however are an example of a hazard control which mitigates one danger but brings in another new hazard. A worker wearing a hearing protector cannot hear the supervisor's instructions or warning sounds and signals. 'Active headphones' are available, of course, at a cost, which would allow normal conversation and sounds to be transmitted to the ear while louder noises are blocked.

Psychological hazards and safeguards

Not much importance has been given to psychological hazards in Singapore. This is also the case in other Asian countries, if only because the need for it has not been demonstrated. However, the largely immigrant workforce suffers under extreme communication and cultural handicaps, and the heavy manual and mechanical handling and the highly repetitive nature of concreting tasks can induce a lot of mental stress on top of major physical labour. The normal outlets for stress relaxation and the conventional venues of redress, even if available, are not comfort zones for the immigrant labour. It is therefore worth relieving psychological stress by providing good site facilities and rest breaks, frequent liaison with the workforce through supervisors and foremen, and if needed, counselling before the stress escalates into serious problems.

Precast concrete hazards and safeguards

Precast concrete has many well-known advantages over cast-in-situ concrete and it is very strongly recommended in Singapore. At the same time, it carries with it certain unavoidable risks. All the material and process risks at site discussed up to this point carry over to the precast factory, with the difference that the enclosed controlled nature of precast concrete products manufacture eliminates or reduces many hazards. One should focus on hazards of the product after it leaves the manufacturing plant.

Figure 13, depicting various activities involved in the erection of a precast building, dramatically points to the many risks involved in the erection. While many of them are familiar ones, the new risks include transportation, lifting, and assembly of the very heavy and very large precast components. Particularly important are site connections, inattention to which, have led to many catastrophic failures.

Figure 13. Left - transportation of unit. Centre - lifting of unit. Right - lifting of tilt-up slab.

The findings and recommendations from a comprehensive study of the precast concrete products industry, conducted by the US Government [16], may be interesting in this regard.

- The injury and illness incidence rates for the precast concrete products industry was 2.5 times the rate for all private sector industries.
- 41% of the fatal accidents occurred due to misuse of hoists and cranes.
- Accident causal factor patterns were identified as follows:

Manual materials handling — 17.6%, Working/Walking surfaces — 12.4% Personal Protective Equipment — 10.7%, Access and egress — 9.8% Mechanical materials handling — 7.6%, Machine guarding — 2.7% Chocking, bracing, and cribbing — 2.6%, Hazardous energy (lockout/tagout) — 1.6%

Singapore might have had very similar experiences, and until a few years ago, the accidents in the precast concrete industry were much higher than in the rest of construction. But BCA has been very pro-active in promoting precast concrete, and improving productivity and safety in the industry [17].

A recent innovation has been the development of Integrated Construction and Precast Hub (ICPH), to integrate the production of precast components with prefabrication and other related construction activities, all housed within a multi-storey complex. This would mean greater safety to the industry.

Prestressed concrete hazards and safeguards

Prestresseed concrete is one step more hazardous than in-situ concrete if post-tensioned and one step more hazardous than precast concrete if pre-tensioned. The additional hazard comes from the fact that the tensioning of high-strength tendons within the site or shop concrete involves very high stresses — 5 to 10 times the value for ordinary steel reinforcement.

During the tensioning and anchoring processes, any mis-step would unleash tremendous energy instantaneously with unpredictable catastrophic results. Consequently the safeguards to this process would involve procedures similar to those for bomb blasts. In production plants, the protective baffles may be of permanent RC or steel. At site, temporary wooden baffles will be necessary, as shown in Figure 14.

Even the dismantling or demolition of prestressed members would need special care, because the cutting of a tendon would release tremendous energy, the tendons hurling debris far and wide and possibly cutting anything in its path. Prestressed members can also explode if they are positioned in such a way that the high tension in certain portions of the concrete in the unloaded member is not balanced by compression due to the self-weight of concrete, as designed.

CONCLUSION

With proper planning, proactive risk assessment and management, and rigorous implementation of controls and the compliance regime of maintenance, inspection and supervision, as recommended herein, best practices in concrete construction safety can be achieved, dependably and economically.

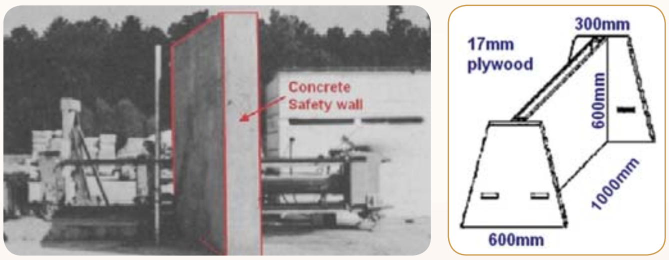


Figure 14: Safety baffles during prestressing. Left - concrete. Right - plywood.

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(This article is based on a Keynote Paper presented by Dr Krishnamurthy at the 38th Conference on OUR WORLD IN CONCRETE & STRUCTURES, organised by CI-PREMIER PTE LTD. The event, which addressed the theme 'The Concrete Infrastructure Strategies', was held from 22 to 23 August 2013 in Singapore).

Workplace safety and health event in May 2014

OS+H Asia 2014, an important regional exhibition and key business platform for all involved in workplace safety and health, will be held in Singapore from 7 to 9 May 2014. Organised by Messe Dusseldorf, this is the ninth presentation of the event, since its inception in 1998. At OS+H Asia 2014 in Singapore, some 160 exhibiting companies and world leading brand names from 20 countries will showcase cutting-edge innovations and solutions for a safer and healthier workplace. OS+H Asia 2014 is expected to attract 6,000 targeted quality visitors from among OSH consultants, engineers, factory and site managers, safety and health officers, inspectors from government and regulatory bodies, HR personnel, occupational physicians, facilities designers and others. As a 'total solutions platform' that is unique to Asia's workplace environment, OS+H Asia 2014 will focus on the dynamic changes surrounding workplace safety and health matters for companies and employees in Asia. The exhibition provides one-stop synergistic sourcing and networking opportunities for all OSH practitioners and professionals, who wish to be updated on the latest developments, trends and technological innovations that are shaping the region's OSH sector.

CONCERENCES AND FORUMS

The various conferences and forums held alongside the exhibition will update delegates on best practices and present solutions to workplace safety and health challenges.

The Singapore WSH Conference 2014

Dates: 7 & 8 May 2014. Organised by WSH Council, Ministry of Manpower, WSH Institute.

Themed 'Integrating Safety and Health: Towards a Holistic Approach', the conference aims to highlight the importance of adopting a holistic approach towards managing both safety and health risks in the workplace.

Forum on Workplace Safety and Health

Date: 9 May 2014. Organised by The Institution of Occupational Safety and Health; The Institution of Engineers, Singapore; Singapore Institution of Safety Officers; and Messe Düsseldorf Asia.

This regional forum will gather WSH experts, professionals and specialist service providers and manufacturers, to share strategic capabilities in workplace safety and health. With two breakout sessions focusing on 'Workplace Safety & Health and 'Design for Safety', participants will gain in-depth knowledge on related issues and concerns.

IPAF Asia Conference 2014

Date: 9 May 2014. Organised by International Powered Access Federation.

Key international speakers will present on core topics such as how to keep the use of mobile elevating work platforms (MEWPs) safe and productive.

THE EXHIBITION

OSH+H Asia 2014 will feature a comprehensive selection of innovative products and enhanced technologies, services and solutions, of relevance to a variety of industries. They will cover:

- Environment control at the workplace
- Fire Protection products and services
- Occupational medicine and hygiene, industrial first-aid
- Personal safety equipment
- Safe handling of dangerous substances
- Safety equipment and safe facilities
- Work safety at high-risk areas
- Workplace ergonomics (industrial and office)
- Safety organisation, services and consultancy