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Some Design and Safety Aspects of Formwork Structures

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Introduction

Reinforced concrete being possibly the most common structural material in use today, the topics of design and safety of formwork and associated activities command more attention than the structures they help create.

Formwork for concrete structures has always one of the most hazardous temporary structures, leading to hight numbers of accidents, major injuries, and fatalities around the world.

In this paper, author highlights certain features of formwork structures that are relevant to their design and safety, and shares his findings and opinions on some common misconceptions and deficiencies, mainly based on his experience in Singapore and elsewhere.

Definitions

Some definitions will be presented to establish common terminology with reference to Fig. 1. These are the definitions used in Singapore's revised Code of Practice for Formwork, SS580:2012 [Ref. 1], on whose Committee the author was a Workgroup member.

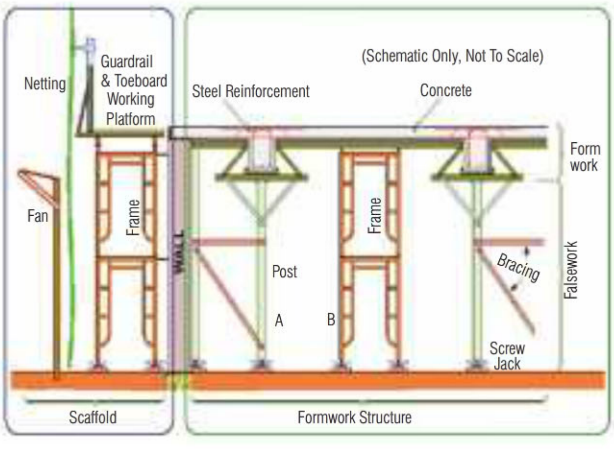

Fig. 1. Scaffold and Formwork Structure Terminology

'Scaffold' is the structure that provides the working platform for workers, their tools, and some materials to facilitate the erection of the permanent structure like a building or bridge.

'Formwork' is the mould into which concrete and steel reinforcement are placed and allowed to harden and cure. Once the concrete has gained sufficient strength to support its own weight and other construction loads, the formwork may be removed, unless it is designed to be left in place to constitute part of the permanent structure.

'Falsework' is the support for the formwork, transferring loads to the ground or other base in the same manner that scaffold transfers the worker loads.

'Formwork Structure' is the combination of formwork and falsework. In casual use, the term 'formwork' or simply 'forms' may be used to refer to the formwork structure.

Design of Formwork

Design Modes for Formwork

Basically, formwork is like any other structural member subjected to various loads, having to eventually transfer them to the base, usually the ground or a higher floor via articulated (stick-like) horizontal beams and vertical or inclined shores (meaning supports). The main load on falsework is from the wet concrete that is cast into moulds of required shapes and sizes.

The design may be classified broadly into three modes.

(a) Generic:

Entire formwork structure is built from generic (i.e. basic) components like planks, beams, and posts of timber, steel etc. These require detailed design of all members and connections from theory, by geometrical properties of cross-sections, mechanical properties of materials, and structural analysis, aided by tests, to satisfy all applicable Codes.

(b) Modular

The structure is put together from standard components such as tubes or other rolled sections of fixed dimensions and shapes. They are made of approved materials with known material properties, and their geometric properties are known and tabulated.

Connection components are also manufactured under strict quality control, and their capacities to match manufactured component sizes and capacities are also listed.

These will involve design of the assembly of components to take the anticipated loads, and checking to ensure assembly does not violate structural or regulatory limits.

(c) System

This comprises a ready-made collection of members and connections of various patented 'proprietary' designs, with ca-

Design Mode →	(a) Generic	(b) Modular	(c) System
Country, environment	Developing, rural	All	Developed, urban
Design effort	100%	1/3 to 2/3	Almost zero
Initial Cost	Minimal	Moderate	High
Productivity	Minimal	Moderate	High
Optimal application	One-off or few, low budget, complex	Limited numbers, medium budget	Multiple use, high budget, simple, repetitive
Time	Maximum	Medium	Minimum
Safety of product	Full checking	Assembly checking	Supplier responsibility
Safety in use	Full checking	Full checking	Full checking

Table 1: Parameters for the Design Modes

pacity tables, and assembly instruction manuals, with which the entire falsework structure can be speedily and efficiently erected.

These do not involve any design, and are suitable for repetitive use of standard or specific complex configurations. They cannot (and must not) be altered as needed at site.

A very broad listing of relevant parameters for the three design modes is given in Table 1.

Modular formwork offers the best compromise between the two extremes, offering a combination of economy and flexibility for general use. Advanced (and 'rich') countries focussing on productivity will prefer system formwork.

Role of Design in Failure

In general, one may assume that any Code that is followed for design would result in a structure that is safe within a normal range of use for the purpose intended. If followed correctly, the only way one can attribute any subsequent failure to the design process would be if:

- All anticipated actual service loads had not been used for design
- Higher than appropriate material properties had been used in the design
- Support conditions and connection details had been assumed unrealistically, and/or
- Certain factors such as dynamic action, fatigue, or earthquake had been ignored.

On this premise, author will not get into design procedures further in this paper.

Often, while over-loading is the real culprit, under-design is claimed as a failure cause, laying the blame on the designer.

At the same time, author will caution that the designer better discuss with owner and contractor details of loadings, materials, and other pertinent factors before submitting the design, and be sure to document all input data and assumptions along with the design submission so that any failure may not be traced to him.

In fact, Singapore has legislated that from 1 August 2016 when the Design for Safety Regulation comes into force [Ref. 2], the designer must work closely with other parties upstream and downstream to address all relevant considerations that would enable the design to cater to all anticipated loadings and modes of use.

Special Cases for Design

Certain situations in design as well as erection require special attention. SS580 lists the following as typical:

- Cantilever spans
- Heights exceeding 9 m
- Slabs thicker than 300 mm or as per Regulation whichever is more stringent
- Beams exceeding cross-sectional area of 0.5 m^2 or as per Regulation whichever is more stringent
- Columns or walls exceeding 2 m in height
- Formwork structure in two or more tiers
- Layer casting of concrete, for which, unless the sharing of subsequent layer loads by supporting columns is justified by calculations, the entire layer load shall be borne by the formwork structure
- Working platforms for formwork shall be designed and erected independently of the formwork and the reinforcement on it
    - However, where working platforms form part of integrated formwork systems such as climbing forms or table forms, scaffold regulations in force will apply to the working platform extensions

Erection Procedures

Even today, generic formwork is common in countries where there is plentiful supply of naturally occurring structural materials such as timber.

One prime example is USA which produces and uses a lot of timber 'manufactured' to meet rigid specifications by planting and nurturing timbers of various grades over wide expanses. Another example is Hong Kong (and China) where bamboo is such a widely used formwork material that there is a Code of Practice for bamboo formwork. With generic formwork, erection is as critical as design.

Modular formwork is quite common in fairly developed countries where component pipes and other manufactured members and connections of dependable quality are readily available.

When it comes to system formwork, formwork erection procedures have been automated to the extent that they not only speed up erection, but also facilitate reuse of minimal number of units. These are very efficient and cost-effective. The two most common procedures are:

(a) Climbing Formwork

As the name implies, the formwork literally 'climbs' with the structure, being separated from the cast and cured layer (A to B in Fig. 2), shifted up to the next higher layer level B', fixed to the previous level, and readied with reinforcement and casting of the next layer as at C.

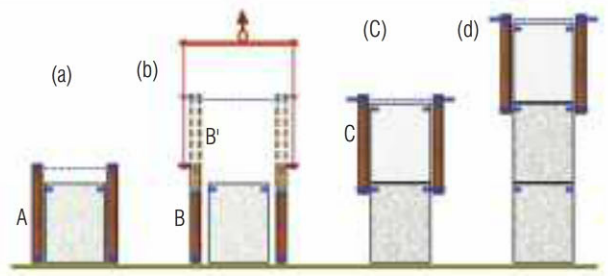

Fig. 2. Procedure for Climbing Formwork

Obviously this is restricted to prismatic – or easily modifiable – vertical structures such as columns, walls, lift cores etc., with many identical lifts.

(b) Table (or Flying) Formwork

These are the horizontal counterparts of climbing formwork, suitable for slabs with or without beams.

Similar to climbing formwork, after one floor has been cast and cured, the formwork 'table' is lowered as at (b) in Fig. 3, pushed out beyond the floor edge as at (c), lifted by crane to the next higher level as at (d), manoeuvred inside the floor domain and lowered on to the previous floor as at (e), and raised to the proper elevation to receive the reinforcement and ready for casting as at (f).

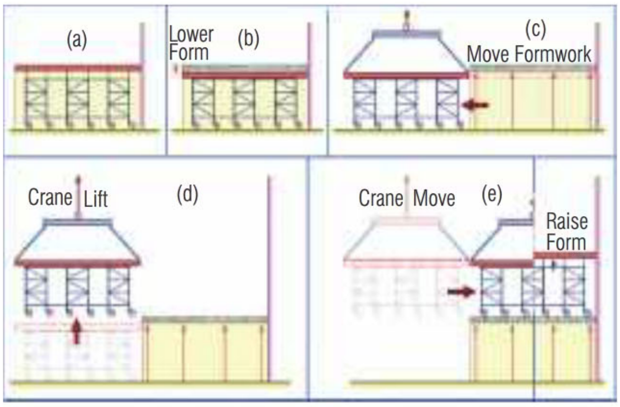

Fig. 3. Procedure for Table Formwork

Need for Extra Care for Formwork

There is a common perception that formwork structures being 'temporary' and not a line item in client charges, do not need and cannot afford as much attention or investment as the permanent structures that they help to build.

Nothing could be further from the truth! Time and again, it has been proved that temporary structures deserve at least as much consideration in design and safety as permanent structures, and often even more. The argument will be along the following lines:

Why Temporary Structures Need More Care than Permanent Structures

Unlike permanent structures, temporary structures ...

- Do not have assured or well-prepared foundations
- Are not designed as well or in as much detail
- Are not used – or even seen – by the ultimate customer
- Have often built-in compromises in quality and strength
- Are put together at site from numerous components
- Most components are already used and some damaged
- Are erected generally by less skilled temporary workers
- Are not checked as rigorously or as frequently
- Are not inspected as meticulously
- Are not supervised as strictly
- Are not maintained as well
- Do not have their faults rectified as promptly or fully
- Are the first to compromise on safety when time or budget presses hard

So temporary structures need more care, more supervision!

Justification for increase in factor of safety

Many sources justify increase of factor of safety for temporary structures. Eng-Tips Forum [Ref. 3] summarises main reasons as follows:

- Design by site staff who may not have the necessary design background to be doing it
- General view that temporary work should be designed by junior staff (such structures being seen as 'Second class citizens', not deserving attention of 'real' structural engineers)
- Design-in-a-hurry or design-by-guess
- Insufficient consideration of accidental loads (striking falsework strut with a full concrete skip can cause collapse)
- Careless assembly
- Lack of proper quality control, or quality control by personnel with insufficient experience of temporary work and the realities of site operations
- Overloading of temporary work by personnel who do not understand these matters

Recently, Singapore revised its Code of Practice for Formwork from CP23 to SS580, with the major change being increase of the factor of safety for design from about 1.5 including varying load factors, to a flat 2.0 for all loads and all methods and testing. It adopted EuroCode for steel formwork structures, with the stipulation that all load factors be maintained at 2.0.

Why Formwork Structures Need More Care than Scaffolds

Further, it is also true that formwork structures require greater attention than scaffolding. Although formwork and scaffolding are both temporary structures, there are basic functional differences between the two that compel greater attention towards formwork structures. Principal differences are as follows:

- Scaffolds are generally for workers and tools while falsework is for formwork, and concrete casting loads
- Scaffold live loads are of the order of 1.5 to 2 kN/m^2, while falsework live load is mainly concrete weighing 25 kN/m^3, which even for a 300 mm depth slab is 7.5 kN/m^3.
- Scaffold work is generally dry, static work, while falsework is subject to wet, dynamic activities of concrete casting and vibration, with very hazardous materials which will set hard within a short time.
- Scaffold erection is relatively better organised and more visible at all times than falsework which involves more components and variable sizes, and more adjustments and actions.

- Scaffold failures may generally be localised while form-work/falsework collapse can be massive and progressive.

Unfortunately the common reaction is that formwork will be used for a few weeks at most before being taken down, so why worry and spend time, effort and money on it?

Causes of Formwork Failures

Many studies have been made on the hazards in formwork erection and use, and on the causes of formwork accidents and failure. Surprisingly, many of the findings expose common deficiencies and misperceptions regardless of the country's wealth and technical competence.

Author has studied the root causes of accidents in various countries and come to the conclusion that in spite of all the advances in technology, it is ultimately the human, individual worker who faces the risks and ends up triggering (though not causing) accidents, due to a multiplicity of causes ranging all the way from unsafe conditions by top management to ignorant misuse of PPE by the lowest worker.

In other words, a formwork may look crude or high-tech, may be cheap or expensive, the worker may wear no PPE or have the best, and yet, accidents may happen, with very similar outcomes!

On this basis, author lists common risks and causes of failure as follows, without citing specific sources, but giving overall references [Ref. 4, 5, 6]. The word 'deficiency' and its variants will be used to cover the entire range of possibilities from complete lack to inadequate or erroneous compliance with regulations and good practice.

(a) Formwork collapse, causing personal injuries, property damage, etc.

- Deficient foundations:
  - Inadequate information on soil or sub-structure to enable proper design or safe erection
  - Improper design
  - Inadequate provision of sole plates and base plates, improper erection of props
- Deficient design:
  - Incomplete in detail such as connections
  - Incomplete analysis of buckling and sway of vertical supports
  - Missing or inadequate bracing design
  - Lack of guidance in material selection, component installation, dismantling, etc.
  - Lack of design for heavy and special loadings
  - Lack of attention to minimise variations in slab thicknesses, and other variations
  - Lack of attention to minimise 'risky' formwork as for cantilevers
- Deficient materials such as by:
  - Sub-standard materials
  - Non-conformance to design specifications
  - Components damaged by wrong or over use
- Poor erection and workmanship such as:
  - Non-conformance to design
  - Ad-hoc unapproved changes
  - Omission of essential components such as bracing
  - Inadequate attention to placement of heavy loads
  - Inadequate attention to supporting still-curing lower levels of recently cast concrete
- Deficient maintenance
- Deficient dismantling such as by:
  - Premature removal
  - Aggressive removal that may induce shock or reverse stresses
  - Wrong sequence of removal

(b) General Deficiencies in Planning and Management:

- Deficient access/egress such as missing, poorly designed and/or erected ladders or steps
- Violation of Regulations such as:
  - Deficient risk assessment and risk control [Ref. 7]
  - Not designed or erected by authorised/competent personnel
  - Erected formwork not checked and approved
  - Formwork in use not certified at specified intervals
  - Drawings and SWPs not available at site for reference
  - Drawings and SWPs not followed by erectors and users
- Deficient inspection and certification
- Deficient supervision in quantity and quality
- Deficient training of workers
- Deficient communication between and among various stakeholders
- Deficient transmission of information and instructions
- Mix of incompatible or different proprietary systems or components
- Deficient signage for safety information, safe load capacity etc.
- Deficient watcher or other hazardous activity monitoring system

(c) Difficult working environment:

- Extreme heat or cold weather
- Deficient control of noise, dust, lighting etc.
- Deficient provision of shade, rest, toilet and eating facilities
- Deficient control of poor ergonomics
- Deficient control of manual handling
- Deficient control of rebar impalement (piercing) hazard
- Deficient management of chemical, mechanical, electrical and other hazards
- Deficient guidance at site
- Deficient house-keeping, leading to trip and fall hazards

(d) Working at height:

- Deficient planning, design or implementation of safety measures for prevention of or protection after falls from height [Ref. 8.]
- Deficient provision, implementation, monitoring or supervision of co-requisites for:
  - Edge protection for fall prevention
  - Work (or travel) restraint for fall prevention
  - Fall arrest by soft landing
  - Fall arrest by safety harness, in particular fall clearance, anchor, etc. [Ref. 9]
  - Prevention of debris, tools, or other objects falling from height
- Deficient SWP for fall prevention or protection
- Deficient PPE for fall prevention or protection
- Deficient inspection and supervision of work at height

7. Prevention of Formwork Failures

In one sense, prevention of formwork failures and accidents can be quite straightforward: Simply eliminate or correct all the deficiencies that were listed in the previous section!

A human factor often forgotten is that although everyone, including workers, is responsible for one's own safety, the safety of workers should be the concern of higher-ups from supervisors to top management.

Given below is a partial list of rules that can be used to reduce the potential of formwork failures [Ref. 10 to 13].

1. Conduct a detailed risk assessment (RA) of the particular job and develop controls relevant and feasible to the particular environment and workforce
2. Prepare a formwork plan that includes detailed drawings and written specifications for fabricating, erecting, and dismantling of the formwork. The plan should be prepared by a person who is competent in the design of formwork.
3. Follow all applicable codes, ordinances, and regulations pertaining to formwork, shoring, and scaffolding.
4. Develop detailed Safe Work Procedures (SWPs) for every task, particularly those that are unusual and infrequent.
5. Post guidelines for shoring and scaffolding in a conspicuous place and ensure that all persons who erect, dismantle, or use shoring are aware of them.
6. Follow all instructions, procedures, and recommendations from manufacturers of formwork components used.
7. Survey the jobsite for hazards, such as loose earth fills, ditches, debris, overhead wires, and unguarded openings.
8. Ensure adequate fall prevention or protection measures for workers during formwork erection, concrete pouring, and formwork dismantling.
9. Inspect all shoring and scaffolding before use, and ensure that workers are using the equipment properly.
10. Make a thorough check of the formwork system after it is erected and immediately before a pour, in particular connections between formwork components. Most catastrophic accidents occur during the concreting stage.
11. Never take chances. If in doubt regarding the safety, contact a safety officer and the management.
12. Where the workforce is not sufficiently organized or trained to take care of itself, increase and improve supervision so as to be continuously available during all site operations involving formwork. Supervisors must ensure that the workers follow all SWP and use all PPE at all times during the task.

Bracing of Compression Members

Buckling capacity

Many failures of formwork have been traced to buckling failure of slender compression members which may include both vertical columns and inclined or horizontal struts.

Tall and slender compression members buckle – that is snap into a curved shape, shed load, and collapse – suddenly and without warning when loaded to their critical value. The critical loads fall sharply with increasing slenderness.

Often, the material remains elastic so that when he load is removed the column may spring back to its original shape.

Theoretical critical buckling load on a column is given by the Euler Formula:

$$f_{cr} = \pi^2 \cdot E \cdot r^2 / L_E^2 = \pi^2 \cdot E / \lambda^2 \le f_y,$$

where,

λ is Slenderness ratio = (L_E/r), L_E being unbraced length, r the radius of gyration = $\sqrt{(I/A)}$, I being moment of inertia of cross-section, and A being cross-sectional area;

E is the Young's Modulus of Elasticity for the steel; and,

f_y is the yield stress for the steel.

Practical values of P_{cr} $(=A.f_{cr})$ further depend on:

- End support conditions
- Intermediate bracing

Figure 4 depicts theoretical and practical stress levels in columns for various slenderness ratios. Most permanent columns are designed to take 60% to 80% of permissible stress, while temporary struts, being long slender elements with no in-fills or moment resistance at the connections, can take only 40% to 60% of the permissible stress. These zones are shown as shaded ovals in the figure.

While ends of struts may be free, pinned or fixed, only the both ends pinned condition is the feasible and economical support for temporary structures.

The influence of intermediate lateral bracing on column capacity is indeed awesome, as depicted in Fig. 5. When one lateral support is provided splitting the total height into two equal parts, the capacity increases to four times. With two lateral supports dividing the height into three equal parts, the capacity increases to nine times. Capacity increases as the square of the number of braced parts into which the member is divided.

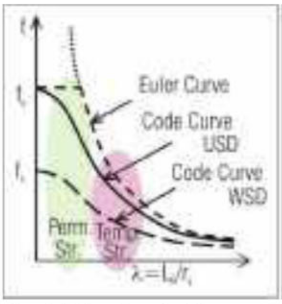

Fig. 4. Euler, Practical Curves

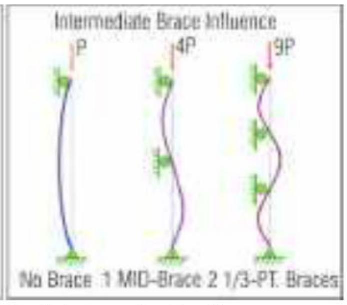

Fig. 5. Intermediate Bracing

What should be frightening is the reverse argument: If a single mid-height support is removed, the capacity drops by 75% of designed value. If one out of the two intermediate supports is removed, the capacity drops by about 55%.

Higher strength materials (especially steel) lead to two penalties on buckling: One, the higher strength will naturally lead to smaller areas which generally increase the slenderness ratio resulting in lower capacity. Two, yield strength of the steel itself shows up as an adverse factor in increasing the slenderness effect.

So, beyond a certain point (such as 460 MPa) higher strength would make the buckling situation worse, as the slenderness factor is found to vary directly as a function of yield stress.

Without going into details, the following may be said about slenderness ratios:

- Hollow sections are better than solid sections
- Best to worst cross-sections: Circle → Square → Rectangle → 'I' → 'T' → Channel → Angle
- Unsymmetrical sections have a strong axis and a weak axis (Fig. 6), with quite large differences in the radii of gyration about these axes, so that the weak axis capacity may be many times smaller than the strong axis capacity

- To increase the weak axis capacity, one or more intermediate supports may be provided to resist buckling about the weak axis (as shown in Fig. 6)

It is worth mentioning that in beams with thin-walled sections such as 'I' beams, the compression flanges behave like axially loaded compression members and their lateral torsional buckling must be considered in design. Design codes usually specify the appropriate procedure for this.

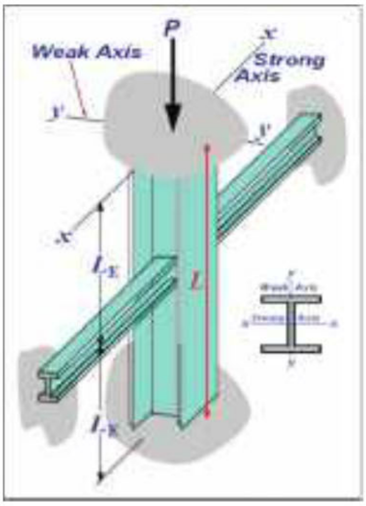

Fig. 6. Weak Axis Support

Sway

Sway is the lateral shifting away from the original designed position under vertical and/or horizontal loads, again causing failure. Although in theory a vertical member should be under pure compression when subjected to a central vertical load, in practice, even very small deviations from verticality or of load application can trigger a drastic lateral movement which if unrestrained, can lead to collapse.

To prevent sway, many codes require all free-standing structures to be designed for a lateral force of 2 to 2.5% of the vertical force on the vertical member.

Bracing against buckling and sway

A major cause of formwork failure is lack of or inadequate bracing against instability and sway. Instability is due to buckling of long, slender compression members discussed in the previous sub-section.

The following points should be read with reference to Fig. 7.

(a) As mentioned in the previous sub-section, tall slender columns buckle and collapse.
(b) Columns under horizontal or eccentric vertical loading tend to sway sideways, unless prevented from sway.
(c) Buckling and sway can combine to collapse one or a set of columns.
(d) Buckling capacity may be increased by providing lateral support at intermediate points along the length of the column. This support may be provided externally from existing permanent structures or other guys and anchors as at A and B in Fig. 7(d). This external support system will also prevent side-sway.
(e) Lateral support against buckling may also be provided internally by diagonal bracings as at C and D in Fig. 7(e). This internal diagonal bracing system will also prevent side-sway, in the rows of panels with diagonal bracing.

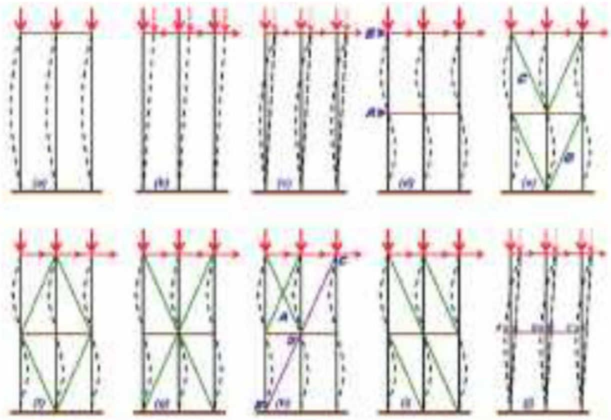

Fig. 7. Buckling and Side-sway in Falsework, and Ways of Addressing them

(f) Internal diagonal bracing may take many forms, with the common characteristic that the diagonals must be in opposite directions in adjacent panels and/or adjacent rows.
(g) An alternate arrangement to (f).
(h) Diagonal bracing in opposite directions may be used within the same panel as at A, especially if adjacent panels or rows cannot be braced. It Is recommended that at least one diagonal bracing such as BC, or preferably a pair of diagonals run from the bottom of one end to the top of another end, crossing two or more bays. The crossings of such long diagonals with horizontal or vertical members may be connected for greater stability.
(i) All diagonals sloping in the same direction is not recommended.
(j) Often, it is wrongly assumed that horizontal bracings can both improve buckling capacity and prevent sway. As shown, even with horizontal bracing ABC, the columns can buckle and sway because these are possible by the braces ABC simply shifting horizontally to the location A'B'C' without any change in length, and hence without introducing any new forces.

It is not necessary to brace all panels or even all bays or rows. Every second or third (or other number) bay or row may be braced, but the shears from the bays or rows with no bracing must be taken at the braced bay or row.

When a bracing is omitted or removed for any unavoidable reason, a competent person must check and confirm that this action does not introduce any instability in any bay or row. If it may, alternative bracings or external supports must be provided to prevent the instability.

Unsymmetrical sections will need more bracing about the weak-axis.

Bracing shall be provided primarily to transfer horizontal forces to ground. Even where horizontal forces are transferred to anchors at formwork level, bracing may be necessary to stabilise connections and reduce unbraced strut lengths.

Bracing shall be provided as necessary in all three planes of the formwork structure: longitudinal, transverse, and horizontal, as displayed in Fig. 8:

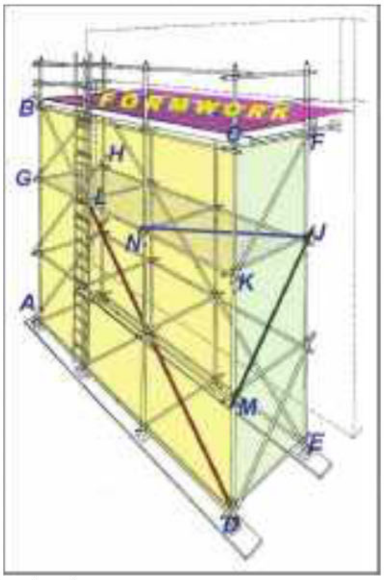

Fig. 8. Three bracing planes

- ABCD is the longitudinal plane for bracing, and LD is a diagonal brace in it
- CDEF is the transverse bracing plane, and MJ is a diagonal brace in it
- GHJK is the horizontal bracing plane, and NJ is a diagonal brace in it.

Falsework braces should be able to resist a minimum of 2.5% of axial force in the braced strut. For system formwork, documentation should include all bracing.

Temporary bracings may have to be designed and provided during erection and dismantling to cater for unbalanced forces, and to prevent excessive displacement or collapse.

Where bracings span more than one bay, the shears in the bays covered should be collected cumulatively and transferred to end anchors or the ground, with all crossing points being properly clamped.

Braces intended to stabilise multiple bays shall be inclined between 30° and 60° to the horizontal, and shall preferably be in pairs, with each pair being inclined in the opposite direction to the other, to provide for change in the direction of applied forces.

Safety Considerations

SS580 provides extensive guidelines on safety, highlighting many items that can go wrong and suggesting solutions. The following sections summarise guidelines from the Code.

Risk Assessment

In many developed countries, risk management is considered important for all hazardous industries like construction. In Singapore, it is mandatory for all workplaces, and is enforced strictly for high-risk activities such as work at height. Accident investigations by Ministry of Manpower (MOM) often highlight absence of or inadequate risk assessment as a cause.

On the matter of risk assessment, which is very critical for formwork structures, SS580 refers to the Code of Practice for Risk Management [Ref. 7]. MOM, in its Circular of 2013 [Ref. 5] lists the items that should be considered, among others, as follows:

- Formwork structure erection, alteration and dismantling procedures
- Base support capacity
- Formwork structure stability
- Placement of rebar
- Concrete casting
- Working at height
- Monitoring of formwork
- Formwork leakage
- Formwork structural failure
- Settlement of formwork structure
- Repair of formwork structure
- Emergency escape route
- Emergency response plan.

Safe Work Procedures (SWP)

SWP shall be written out soon after RA. Apart from method statements for routine work, SWP should include responsibilities of all stakeholders, PPE to be used, and emergency measures.

SWP should cover all anticipated activities during the work, particularly the infrequent and unusual ones. They shall be strictly followed (and all PPE should be correctly worn) all the time the workers are carrying out their tasks.

Work at height

Work at height is unavoidable in most formwork activity, and special safeguards shall be implemented to avoid accidents by falling from height. All criteria shall be checked and all requirements satisfied as in the Code of Practice for Safely Working at Height [Ref. 8].

Fall prevention plan to be done by occupier of workplace.

Safe Formwork construction related to Design

Safety aspects shall be considered and controls implemented at every stage in life cycle of formwork structure, including planning and inspection, and during construction. Some common measures for good construction practice to ensure safe formwork design, in addition to those already mentioned, are as follows:

- Provide adequate shoring or re-shoring
- Avoid using a prop directly on top of another prop
- Ensure that adequate temporary bracings are in place while setting up the formwork
- Ensure that anchoring of the system formwork can be visually ascertained
- Ensure adequate provision for lateral pressure on forms
- Control lateral pressure on forms by vertical rate of placement by means of slump, type of vibration, admixtures, etc.
- Regulate horizontal sequence and rate of placing concrete to avoid unbalanced loading on the formwork structure
- Control any loadings that may cause vibrations and shock
- Prevent premature removal of supports
- Comply with recommendations of manufacturers of components and keep within limits set by the designer
- Ensure proper field inspection by formwork supervisor to see that form design has been properly interpreted and implemented by the formwork erectors
- Ensure that formwork components not designed by analytical methods or not certified as safe by suppliers are validated for use by appropriate testing

- Ensure that interactions between formwork, falsework and permanent structure are taken into account in planning and construction
- Provide safe means of access, adequate edge protection, perimeter containment screening, etc. to ensure a safe work zone
- Provide temporary catch platforms as fall arrest for fall distances shorter than required for body harnesses
- Disallow any field repair of modular or system formwork components without manufacturer's approval
- Provide cable-guided or supported systems with integral free-fall breaking devices
- Disallow use of form panels from system wall/column formwork, etc. for purposes other than those for which they were designed for, such as ladders, walkway bridges etc.
- Ensure specific industrial standards are observed for hydraulic and electrical equipment used for operating system formwork
- Ensure rotation of workers, rest periods, and other safeguards against fatigue and Musculo-Skeletal Disorders (MSD) due to repetitive work

Safety-related Concerns in Formwork Activities

Among the many hazardous activities and situations in formwork erection, use, alteration and dismantling, the following deserve special attention:

- Movement of vehicles at the entrance to and within the site
- Movement of large and heavy objects, involving cranes, forklifts etc;
- Manual handling of heavy objects conforming to relevant Regulations limiting the load to be lifted by a worker on a regular basis to 25 kg
- Ergonomic hazards in general, which may lead to (MSD)
- Working at height, for which various measures for fall prevention such as edge protection, and work restraint should be adopted first rather than fall arrest measures such as body harness, or catch net
- Working in confined space, in tunnels or other areas where natural light and ventilation are not available, for which various measures such as toxic gas and oxygen deficiency checks and rescue systems should be implemented
- Storage and handling of hazardous materials such as
- Chemicals used in the formwork erection and oiling
- Cement corrosive to the skin and damaging eyes and lungs
- Abrasive or sharp edged objects
- Noise leading to Noise-Induced Deafness (NID)
- Unsafe acts and unsafe conditions arising from extensive human intervention and the simultaneous interaction of many trades, requiring strict and often continuous supervision at every stage of erection, use, alteration, and dismantling of formwork structure
- When various types of works by steel fixers, plumbers, electricians, and other trades are ongoing, strict segregation of formwork construction zone and zone for other trades should be observed
- Impact of vehicles / machinery adjacent to formwork structure

Conclusion

Formwork structures continue to be in the news for the wrong reasons with numerous collapses, injuries and fatalities. While designers are quite aware of the Code requirements they must meet, constructors generally are either ignorant or negligent of the regulations, and end up modifying or bypassing the design.

Author has recently published a few other papers on the subject of formwork [Ref. 14 to 16], which are available from his website [www.profkrishna.com]. Part of this paper is extracted from the third of the papers cited.

He has one last piece of advice for designers and constructors alike: An unwritten but irrevocable law is: "Ignorantia juris non excusat", which simply means, "Ignorance of the law is no excuse".

What this implies is that if after an accident the investigation reveals that it happened due to the violation of law or laws that were required to be followed, the responsible person(s) cannot plead ignorance of those laws as a reason for their not implementing it.

In practical terms it means that managers must procure copies of all relevant regulations, and circulate it to those who must deal with formwork design, erection, use, or dismantling, so that any violation cannot be hidden behind administrative lapses. The investment in obtaining and disseminating applicable regulations is much cheaper than facing penalties!

References

1. SS580:2012, Singapore Standard Code of Practice for Formwork, SPRING, Singapore, 2012, 40 pp.
2. S428, Workplace Safety and Health Act (Chapter 354a), Workplace Safety and Health (Design for Safety) Regulations 2015, Government of Singapore.
3. "AASHTO - Temporary Structures", Eng-Tips Forum, 6 May 2002, retrieved on 14 April 2016 from: http://www.eng-tips.com/viewthread.cfm?qid=22666
4. Preventing Formwork Incidents – Report on Session 28 Mar 2014 Solutioning Session, WSHI, Singapore, July 2015, 8pp.
5. Circular on Safety Requirements for Formwork Structures, 31 Jan. 2013, Ministry of Manpower, 9 pp.
6. Advisory For Professional Engineers On Formwork Safety, 18 Jan. 2014, 4 pp.
7. Code of Practice on WSH Risk Management: 2011, Revised 2015, WSH Council in collaboration with the Ministry of Manpower, Singapore, 31 p.
8. Code of Practice for Working Safely at Heights: 2009, Revised 2013, WSH Council, Singapore, 69 p.
9. Krishnamurthy, N., "Full-body Safety Harness -- Blessing or Bane?", 'The Singapore Engineer' - The Magazine of the Institution of Engineers, Singapore, August 2012, p. 18-22.
10. Guide to Formwork for Concrete, American Concrete Institute, ACI 347-01
11. Industry Guide for Formwork, South Australia, Safework, Government of South Australia, June 2012, 36 pp.
12. Occupational Safety and Health Standards for the Construction Industry, Part 1926, Subpart Q: Concrete and Masonry Construction, U.S. Department of Labor, Washington, DC.
13. Building Code Requirements for Reinforced Concrete, ACI Committee 318, American Concrete Institute, Detroit, MI, USA.
14. Circular on Safety Requirements for Formwork Structures – 31 Jan. 2013, Ministry of Manpower, 9 pp.
15. Krishnamurthy, N., "Certain Safety Considerations in Formwork", 'The Masterbuilder' Chennai, India, Vol. 15, No.4, Apr. 2013, Ministry of Manpower, 9 pp. 88-94.
16. Krishnamurthy, N., "Best Practices in Concrete Construction Safety", 'The Singapore Engineer' - The Magazine of the Institution of Engineers, Singapore, Feb. 2014, Ministry of Manpower, 9 pp. 19-30.
17. Krishnamurthy, N., "SS580:2012 Code of Practice for Formwork and Some Related Issues", 'The Singapore Engineer' - The Magazine of the Institution of Engineers, Singapore, Feb. 2016, Ministry of Manpower, 9 pp. 15-25.◆