

Temporary Works Toolkit

Part 17: Falsework for the support of *in situ* concrete to horizontal surfaces

The Temporary Works Toolkit is a series of articles aimed primarily at assisting the permanent works designer with temporary works issues. Buildability – sometimes referred to now as ‘construction method engineering’ – is not a new concept and one always recognised as vital to the realisation of one’s ideas; it ought to be at the forefront of an engineer’s mind.

www.twforum.org.uk



Andrew Jones
BEng, CEng, MICE

Chief Engineer, RMD Kwikform Ltd (UK)

Introduction

Falsework is defined in BS 5975¹ as a temporary structure used to support a permanent structure while it is not self-supporting. The definition is broad and encompasses different situations such as:

- the support of fresh concrete
- the support of permanent works during refurbishment
- needling of openings
- horizontal support of walls
- facade retention
- heavy propping to retaining walls.

This article focuses on the use of proprietary equipment for the support of fresh concrete to horizontal surfaces. The principles and methods described are broadly applicable to all falsework.

Falsework equipment

In the UK, the majority of falsework utilises proprietary equipment which is designed and supplied either by an equipment supplier or by a subcontractor responsible for concrete works. Proprietary falsework equipment is manufactured from specially engineered materials that fit together in different configurations and can be reused multiple times. It is designed to:

- have a high strength-to-weight ratio

- be quick and straightforward to use
- incorporate safe access
- be robust and easy to maintain
- pack down neatly so that it is safe and economical to transport.

Common components are:

- steel or aluminium adjustable props
- steel soldiers (lightweight beams formed of thin folded back-to-back channels)
- aluminium beams (with or without a nailing insert to attach plywood)
- laminated timber beams
- formwork panels (a metal frame with plywood or plastic facing)
- steel scaffolding
- aluminium towers.

The three most common layouts of equipment for concrete slabs in the UK are:

- prop and panel (Figure 1a)
- partially braced aluminium towers (Figure 1b)
- fully braced steel birdcages (Figure 1c).

With the latter two, the formwork can either be panels or a grillage of beams faced with plywood. Note that a birdcage falsework is a fully braced scaffold falsework with multiple legs in both directions.

Design

Although the design of falsework uses the same principles as permanent works, there are significant differences necessitating special consideration during design. The main differences are that:

- the maximum design loading is likely to

- occur every time the falsework is used and not rarely over the structure’s design life
- falsework tends to have less redundancy and lower stiffness than permanent works
- elements and components can be reused numerous times
- commonly, a relatively short timescale is allocated for the design and procurement of elements and components
- falsework is more likely to have assembly errors, resulting in initial imperfections such as lack of fit and eccentricities that have not been accounted for
- falsework often relies on the permanent works for lateral stability.

Like permanent works, all falsework design should include design checks for:

- structural strength and stiffness of individual members
- lateral stability
- overturning
- positional stability.

Structural strength

Traditionally, falsework in the UK has been designed using a permissible stress approach; despite the advent of limit state design codes, this still dominates. This is partly because the benefits of limit state design are less obvious for proprietary falsework. In falsework design, there is higher load certainty and fewer loading combinations, the design cost as a proportion of the total can be high, design periods are short, there is a limited range of available equipment, and the geometry and other external requirements often dictate the

layout. The focus is more on providing a quick and safe solution with available equipment than optimising the design. Producing efficient solutions is important, but is not always the primary driver. To tie in with this, the vast majority of technical data for proprietary equipment is given in terms of safe working loads.

Unless specified in the contract, the designer can choose to carry out a permissible stress design in accordance with Section 3 of BS 5975 or to carry out a limit state design in accordance with the relevant Eurocode, BS EN 12812², and PAS 8812³.

Designers familiar with the process of European harmonisation of design standards will notice the anomaly that a British Standard and European Standard for falsework exist in parallel. This was allowed as the European Standard excludes falsework that is categorised as Class A, which, in the UK, BS 5975 is taken to cover. Additionally, BS 5975 contains essential procedural controls which are not in the European Standard.

Note that BS EN 12812 states that Class A falsework is 'for simple constructions such as *in situ* slabs and beams' which can be designed 'using established good practice'. This is further defined as falsework of overall height less than 3.5m and slab thicknesses of less than 300mm. In the UK, the view is that all falsework should be designed and that BS 5975 should be used.

BS EN 12812 is not complete within itself, but gives advice on how the Eurocodes should be applied to falsework. The advice is not always clear and PAS 8812 has been written to assist in its interpretation and to provide UK designers with a common framework. To provide a safe limit state falsework design, the relevant Eurocodes, BS EN 12812 and PAS 8812 should be used together.

The Eurocodes cover the design of permanent and temporary works. However, designers need to be careful when applying these standards to temporary works, due to the differences between them, as listed above.

Although both BS 5975 and BS EN 12812 state in their scopes that they cover all falsework, they mainly cover traditional birdcage-type falsework. Although this can be extended to cover other types, the advice is less thorough.

Loading

Loadings applicable to falsework are: self-weight, imposed loads and environmental loads. For falsework covered by this article, this will generally consist of: self-weight of the equipment, weight of the fresh concrete, access/construction operations and wind loading. These loadings are specified in BS 5975 and BS EN 12812, which in turn are

based on BS EN 1991-1-6⁴ and BS EN 1991-1-4⁵ and provide identical values.

A weight of 25kN/m³ is allowed for fresh concrete, which assumes normal concrete with up to 2% reinforcement. Although BS 5975 gives advice for concrete with higher percentages, in practice 25kN/m³ is taken as a standard value.

A minimum access load of 0.75kN/m² is applied to the whole area of work. Where fresh concrete is placed, an additional load is applied to a 3m × 3m area to allow for some heaping of concrete and a small amount of equipment. This additional load varies between 0.75kN/m² and 1.75kN/m² depending on the slab thickness. In areas where other light work is being carried out, storage of tools is likely or it is used as an access route, the minimum loading is increased to 1.5kN/m².

For wind loading, both falsework standards allow probability to be used to take into account the short duration of the falsework when calculating the dynamic wind pressure. BS 5975 uses a probability factor of $(C_{prob})^2 = 0.83^2 = 0.7$. While the main text of BS EN 12812 leaves it to the judgment of the engineer, the UK National Annex gives a C_{prob} value of 0.83. Although, historically, there was blanket use of the probability factor in falsework design, in recent years a risk-based approach has been adopted based on the consequence of failure.

Analysis

The detailed analysis of falsework structures with multiple members pinned together, with joints of various stiffnesses, is complex and often does not lend itself to elastic analysis software. Traditionally, simplifications have been used to calculate the internal forces, with the effects of vertical and horizontal forces being considered separately and then added together.

If elastic analysis is carried out, then it will generally be first-order, with the minimum horizontal load acting as a significant amplification factor to allow for any second-order effects. The engineer should recognise when structures may be affected by second-order effects and, if this is the case, carry out appropriate analysis.

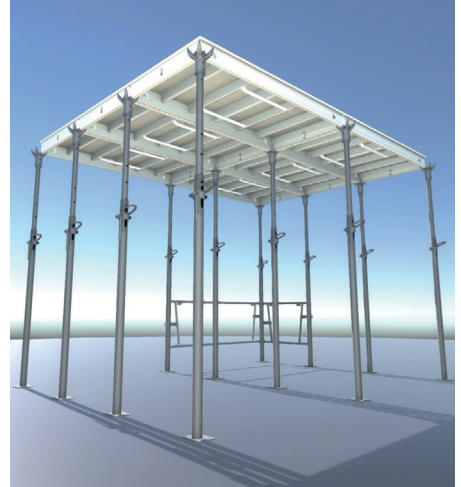
Factor of safety

The permissible stress global factor of safety within BS 5975 is generally 1.65 on yield and 2.0 on failure. The factor of safety against overturning is given as 1.2.

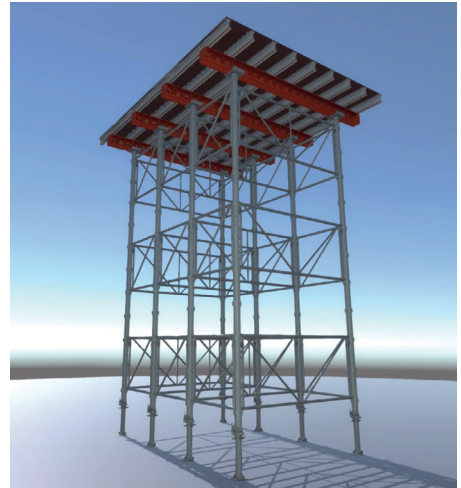
For limit state design, BS EN 1991-1-6 states that, during execution, all supported loads should be treated as variable actions; which for falsework effectively means that only its own self-weight can be considered as a permanent action. This means that the majority of loads will have a partial load factor

 **Figure 1**
Common configurations of falsework equipment for concrete slabs

a) Prop and panel



b) Partially braced aluminium towers



c) Fully braced steel birdcages

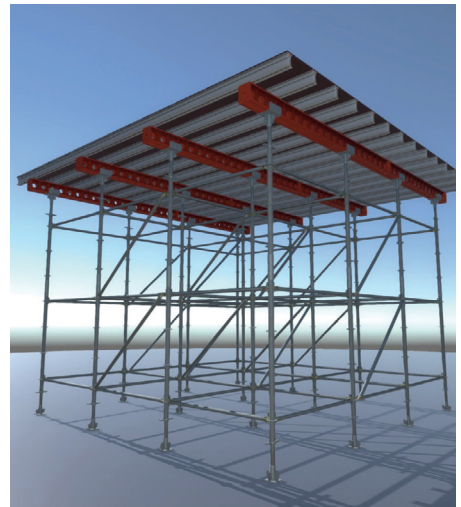
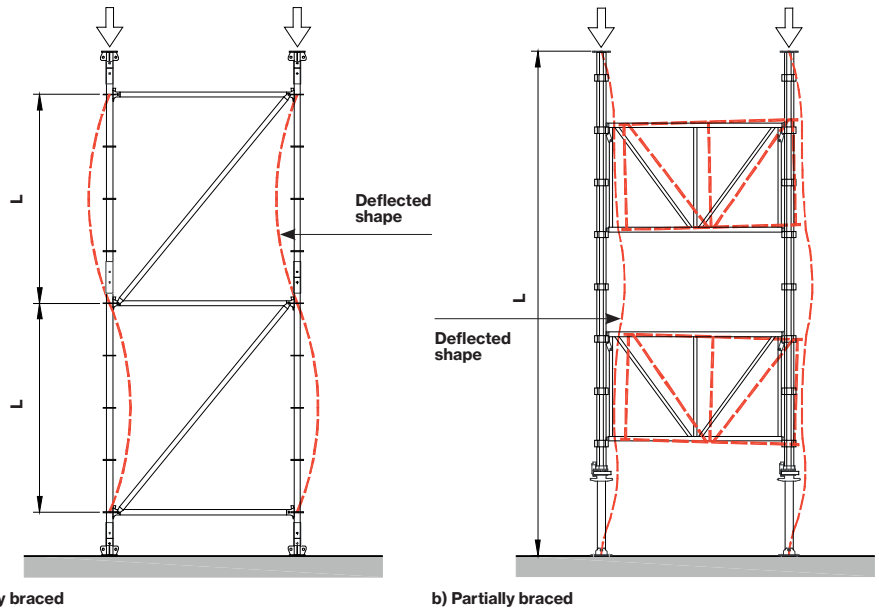


Figure 2
Braced falsework



of 1.5. This is an important difference from the permanent works load case, where the supported concrete would be taken as a permanent action. This is supported by BS EN 12812, which also provides an increase to the partial material factor for aluminium and steel, with a minimum value of 1.1. Multiplying these two partial factors together gives an overall factor of 1.65, which is comparable to that of BS 5975.

The increase in partial factors over those which are commonly used in permanent design takes into account the differences listed above. Where falsework is designed, manufactured and assembled for a single use, using similar details and execution standards adopted for permanent works, the engineer may justify factors similar to those used in permanent works design.

The factor of safety against overturning in BS EN 12812 is the same as in the Eurocodes and necessitates multiplying stabilising forces by a factor less than 1 and destabilising forces by a factor greater than 1. The combination of these for a standard falsework will give an overall factor of safety of around 1.65, which is significantly greater than the value given in BS 5975.

Lateral stability

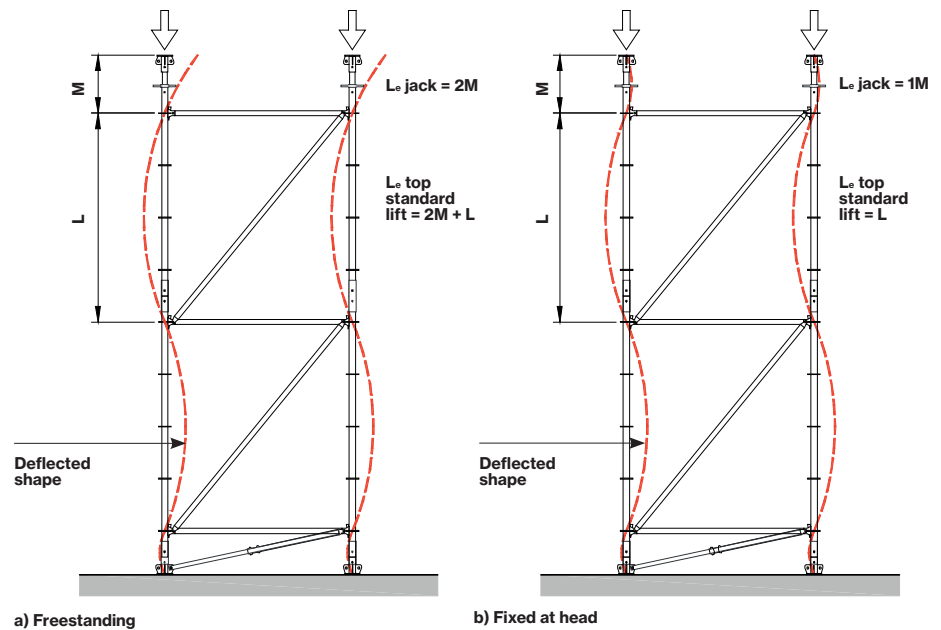
Consideration of the lateral stability of falsework is particularly important and is one of the primary recommendations of the Bragg Report⁶. This was published in 1976 after a number of significant collapses in the UK. The report recommended that all falsework be designed to withstand a minimum horizontal destabilising force of 3% of the total vertical forces applied at the point of application of the force. This was subsequently incorporated into BS 5975, where it was reduced to 2.5%. The reduction in falsework collapses since then is widely attributed to the implementation of this recommendation.

In the design of falsework, an important distinction is made between falsework which is restrained at the top and falsework which is freestanding. Top-restrained falsework does not provide its own lateral stability, but relies on external support. This will normally be provided by the permanent structure that is being built or altered. In the construction of a flat slab for a building, the soffit formwork will be fitted tightly around the permanent columns, walls and building cores and will often rely on this to prevent itself falling over. Many of the common falsework systems – prop and panel and partially braced towers, in particular – are almost exclusively designed

a) Fully braced

b) Partially braced

Figure 3
Effective length of top standard lift



a) Freestanding

b) Fixed at head

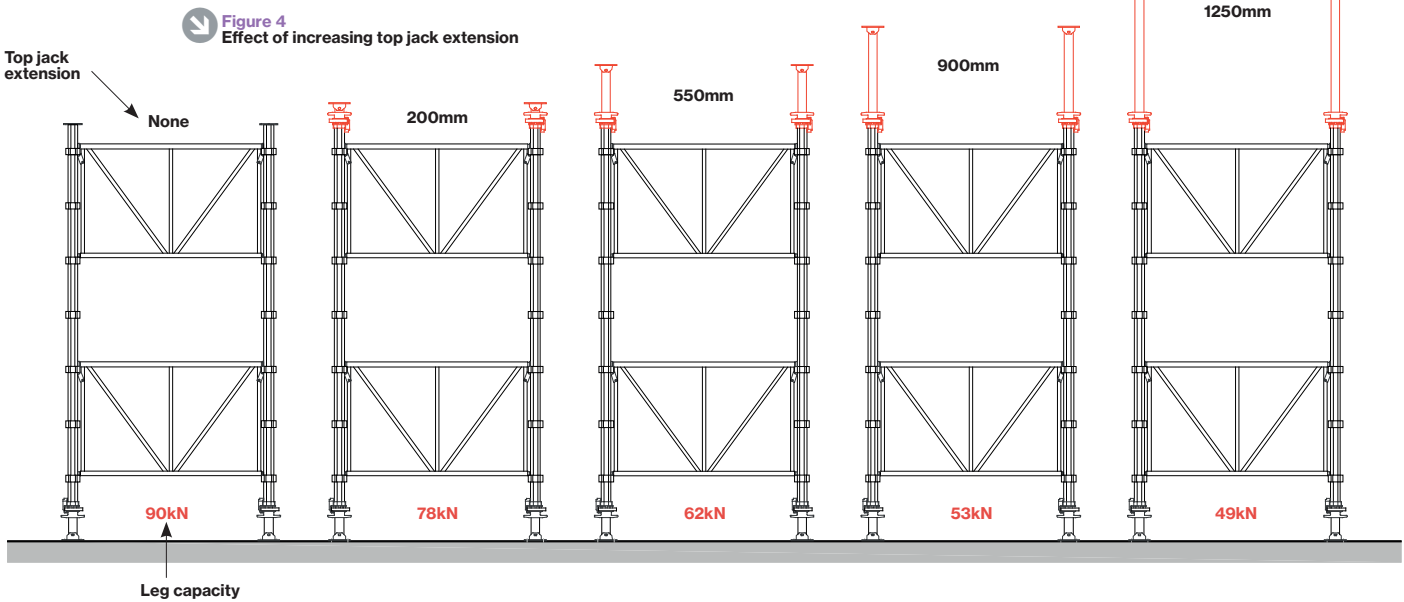
as top restrained and dialogue is required to confirm that the permanent works is able to accommodate the stability forces. Depending on the system, removal of the top restraint will reduce the capacity significantly or precipitate an immediate collapse.

The temporary works designer should provide any required stability reactions as part of their design output and the permanent works designer should then confirm that the permanent works can safely resist them. Communication and coordination between the parties can be an issue and the responsibility for ensuring that it is adequately completed lies with the Temporary Works Coordinator (TWC).

Temporary works designers commonly assume that all permanent works can resist the stability forces. If they cannot, it would be good practice for the permanent works designer to record it as a residual risk.

Difference between fully and partially braced falsework

In a fully braced tower, each leg is considered as an individual strut restrained at regular intervals by lacing and bracing. The legs are designed using simple strut theory and the lacing and bracing checked to ensure that it provides adequate nodal restraint. Depending on the rigidity of the ledger connection,



the effective length may be taken as $1.0L$ or less, where L is the distance between ledgers (Figure 2a). Whether the structure is freestanding or fixed at the head has a significant impact on the effective length of unbraced jacks. The effective length being $2.0M$ for the former and $1.0M$ for the latter. It will also have an effect on the effective length of the top standard lift (Figure 3).

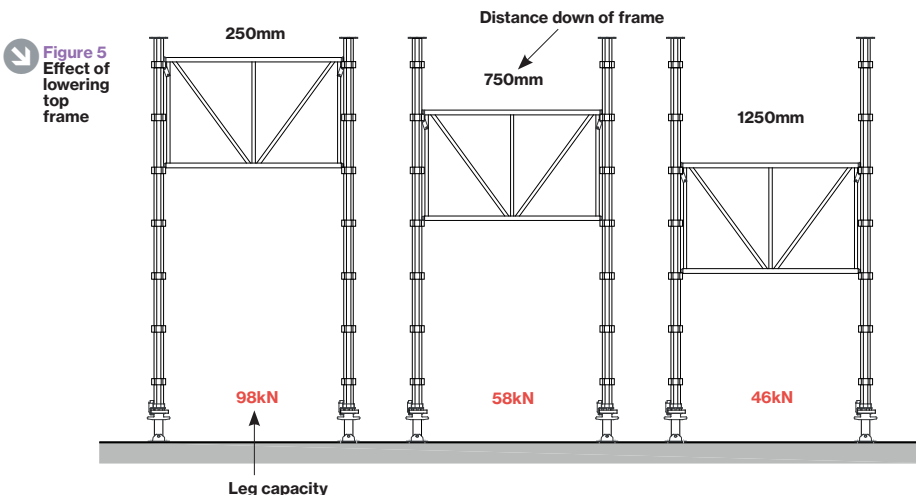
Although, at first glance, partially braced and fully braced towers look similar, their structural behaviour and design methods are completely different. The discontinuity in bracing in a partially braced tower means that there is no nodal restraint and, instead of considering each leg as an individual strut, the pair of legs and bracing frames is considered as a composite battened strut with an effective length based on the full height of the tower (Figure 2b). It cannot be analysed simplistically, but requires a second-order analysis, taking initial bow imperfections and end conditions into account. Because of the complexity of

this, analysis is carried out on standard configurations and then published in the form of charts or tables by the suppliers. The jack extension and number and location of frames can have a significant effect on the capacity of partially braced towers (Figures 4 and 5).

Conclusion

Although the design of falsework uses the same basic design principles as permanent works, the differences between the two mean that falsework should generally be designed with higher factors of safety. If the advice given in BS EN 12812 and PAS 8812 is not taken and a straight Eurocode design is carried out, then ‘there could be a considerable reduction in overall safety compared with what the industry is used to’⁷.

Designers of permanent works should consider the type of falsework that is commonly used and, if the permanent works cannot accept the likely stability forces, include this as a residual risk.



REFERENCES

- ▶ 1) British Standards Institution (2011) *BS 5975:2008+A1:2011 Code of practice for temporary works procedures and the permissible stress design of falsework*, London: BSI
- ▶ 2) British Standards Institution (2011) *BS EN 12812:2008 Falsework. Performance requirements and general design*, London: BSI
- ▶ 3) British Standards Institution (2016) *PAS 8812:2016 Temporary works. Application of European Standards in design. Guide*, London: BSI
- ▶ 4) British Standards Institution (2005) *BS EN 1991-1-6:2005 Eurocode 1. Actions on structures. General actions. Actions during execution*, London: BSI
- ▶ 5) British Standards Institution (2005) *BS EN 1991-1-4:2005+A1:2010 Eurocode 1. Actions on structures. General actions. Wind actions*, London: BSI
- ▶ 6) Health and Safety Executive (1976) *Final Report of the Advisory Committee on Falsework [The Bragg Report]*, London: HMSO
- ▶ 7) Jones A. (2014) ‘Use of European standards for temporary works design: a warning’, *Proc. ICE - Civ. Eng.*, 167 (3), 99

HAVE YOUR SAY

- To comment on this article:
- ▶ email Verulam at tse@istructe.org
 - ▶ tweet @IStructE #TheStructuralEngineer