The use of European Standards for Temporary Works design

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Synopsis

Historically, the majority of temporary works in the UK have been designed to British Standards using permissible stress methods. The harmonization of European structural design codes has led to the withdrawal of many of these documents and a change to a limit state approach. Although there is a great deal of published guidance for the Permanent Works Designer, very little is available for the application of European Standards to Temporary Works. In order to assist all interested parties, and foster a common approach, this guidance note provides a comprehensive background to the subject and makes general recommendations on the application of European Standards to Temporary Works.

The Temporary Works sector is currently in a state of transition and unless specified by the contract a designer is free to choose a suitable method of design.

General

The Temporary Works Forum gratefully acknowledges the contribution made by members of the working party in the preparation of this guidance.

Readers should note that the documents referenced in this guidance note are subject to revision from time to time and should therefore ensure that they are in possession of the latest version.

1 Introduction

1.1 Foreword

This document has been written by the Temporary Works Forum (TWf) in response to the limited information available regarding the application of European Standards (ENs) to Temporary Works.

It is intended to foster a common approach and act as starting point for further industry wide discussion.

The majority of the European structural design standards and all of the Eurocodes are aimed at the design of Permanent Works. Because of the differences between Temporary Works and Permanent Works the straight application of the European Standards to the design of Temporary Works may not be appropriate and could lead to unacceptably low factors of safety. The Temporary Works Designer (TWD) must consider these differences and apply the ENs appropriately.

In comparison to Permanent Works, Temporary Works:

- tend to have a greater proportion of variable actions;
- can have greater uncertainty of loads;
- in many forms (and in all forms of falsework), the maximum variable action is expected every time; in permanent works, the maximum variable action can be expected to occur only exceptionally over a long design life;
- tend to have less redundancy and lower residual stiffness;
- frequently have more, and greater, initial imperfections, such as lack of fit, eccentricities, corrosion and damage from previous use;
- have a shorter time allocated for design and procurement;
- tend to be removed after use, often requiring de-stressing prior to removal; and
- tend to have limited site investigation available which must be considered when selecting soil parameters.

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1.2 Scope

The purpose of this document is to provide general guidance to the Temporary Works Designer, and others such as Clients, CDM-Cs and Contractors on the application of ENs to Temporary Works.

1.3 Background

1.3.1 European Standards

European harmonization of structural design codes for construction was initiated by the European Commission in 1975 and by 2010 was substantially complete, with design codes covering most aspects of Permanent Works and some aspects of Temporary Works.

The core advice for all structural design, including Temporary Works, is contained within the 'Eurocode suite' (BS EN 1990 to 1999). These documents are supplemented by product standards, design guidance for particular applications and execution standards. All European Standards are given the designation EN, the Eurocodes suite being a part of them.

It is the responsibility of the National Standard Bodies (e.g. the BSI in the UK) to implement the ENs. They must contain, without alteration, the full text of the EN and its annexes as published by CEN (European Committee for Standardization). This can be preceded by a National Title Page and Foreword, and followed by a National Annex, which may be a separate document. All ENs use limit state principles and, as they are published, any conflicting national standards are obliged to be withdrawn.

Eurocodes provide the basis for all Temporary Works design but may be modified by specific guidance given in product standards.

There are several issues which affect the application of the ENs to Temporary Works:

i. There are only a few ENs which specifically relate to Temporary Works and these only cover a few types of Temporary Works. The designer therefore has to extract or extrapolate relevant information from a range of different standards.

ii. Because of the way some of the Temporary Works standards have been drafted it is difficult to interpret what the requirements are, which standards should be referred to and how the Eurocode suite should be used.

iii. There is little published guidance, or Non Contradictory Complementary Information (NCCI), available for the TWD.

iv. The ENs emphasise performance requirements and a numeric approach, and place great reliance on statistical methods. The original British Standards were more akin to design guides and led the designer through the requirements. A lot of the good practical design advice given in the 'established' British Standards is not available in the European Standards and has to be found elsewhere.

v. The application of limit state principles to the design of Temporary Works has to date been very limited, with the vast majority of schemes being designed using permissible stress methods.

1.3.2 European Standards for Temporary Works

The only substantive European Standards specific to Temporary Works are contained in BS EN 12810 to 12813. These consider falsework and tied access scaffolding. They are not stand-alone but explain how the Eurocodes should be applied, and modified, to suit particular applications. So, for example, all the information required for strut or beam capacity is contained within the Eurocodes while the European Standards for Temporary Works give advice on partial factors. The introduction in BS EN 12812: 2008, *Falsework. Performance requirements and general design*, states clearly, "The information on structural design is supplementary to the relevant Structural Eurocodes".

A similar approach is taken in other ENs relevant to products, such as EN 13377: 2002, *Prefabricated timber formwork beams. Requirements, classification and assessment* and BS EN 13331: 2002, *Trench Lining Systems Part 1: Product Specifications and Part 2: Assessment by calculation or test.*

Although the modifications are strictly only applicable to the named applications several of the standards are titled "Temporary Works Equipment". This implies that the general recommendations and modifications given in BS EN 12810 to 12813, and other Temporary Works Standards, are applicable across a wider range of Temporary Works applications.

As the introduction to BS EN 12812: 2008 makes no distinction between proprietary and bespoke equipment it could be argued that the recommendations and modifications apply to both. However, as the main modification is to the partial material factor it is possible to argue that the modifications only apply to Temporary Works equipment that is re-used. This is something that the industry needs to come to a consensus on. Caution will dictate that the modifications are applied, unless it can be demonstrated that the boundary conditions are as expected for permanent works.

It is a recommendation of this document that the summary of requirements for Temporary

Works given in Section 1.3.6 forms the basis of all Temporary Works designs to the ENs. In some instances the TWD may choose not to fully apply this advice but it is expected that this will only be the case in a small minority of situations.

The ENs emphasise performance requirements and a numeric approach and rely on the designer using supplementary sources of information such as text books and design guides.

For a full listing of ENs, and other published information currently applicable to Temporary Works, see Section 1.6.

1.3.3 BS 5975: Code of practice for temporary works procedures and the permissible stress design of falsework

BS 5975 was first published in 1982 under the title *Code of practice for falsework.* It contained procedures and design advice and drew together a lot of technical information and practical advice into a single document. It complements *Falsework, Report of the Joint Committee* (The Concrete Society and The Institution of Structural Engineers. Technical Report TRCS 4, July 1971). Shortly after starting work on BS 5975 a major falsework collapse occurred resulting in the 'Bragg Report' (1975), and BS 5975 was informed by its recommendations, the two most well-known of which are:

- That, for stability, the design must consider a minimum horizontal destabilizing force equivalent to 3% of the total vertical load (This was reduced in BS 5975 to 2.5%).
- A suitably qualified Temporary Works Co-ordinator should be appointed to ensure that procedures are followed and relevant designs/checks have been carried out.

The final Bragg Report was published in 1976 during a period of high construction activity that was also marked by a number of bridge collapses during construction. Since the publication of BS 5975, and its adoption throughout the industry, there have been no falsework or excavation failures in the UK on the scale of the failures of the 1960s and 1970s.

Minor changes were made to BS 5975 in 1996. In 2008 a major update was carried out to reflect changes made over the preceding 25 years. The principle changes in the 2008 revision are:

- Emphasis on the importance of the procedures and their application to all Temporary Works and not just Falsework; in this regard:
  - the name of the standard was changed to '*Code of practice for temporary works procedures and the permissible stress design of falsework*';
  - the text was substantially re-ordered to bring all the procedures into a single section (Section 2);
  - the title of Temporary Works Co-ordinator (TWC) was reinstated, having being changed from the original Bragg recommendation to Falsework Co-ordinator;
  - a new role of Designated Individual was instigated to take overarching responsibility for all TWCs within an organisation.
- The sections on materials were reviewed and, in particular, the values for timber, scaffold tube and scaffold fittings were updated to give comparable results to the relevant ENs.
- The loading section was updated to use the same values as the ENs. The calculation of dynamic wind pressure was changed to that given in EN 1991-1-4.
- The design section was updated to include advice on head fixity and partially braced structures; both of which had become more relevant since the standard was first drafted.

1.3.4 Relationship between BS 5975 and EN 12812

Unlike the majority of other 'established' British Standards, BS 5975 has not been withdrawn and exists in parallel with BS EN 12812. This relationship is emphasised by the Forewords in each standard referring to the other. The reasons for them existing in parallel are:

- EN 12812 defines two classes of falsework, A and B; Class A has no design rules and is defined as small simple construction, "which follows established good practice which may be deemed to satisfy the design requirements". As BS 5975 provides established good practice it was decided to retain it, with the recommendation that, in the UK, Class A falsework be designed to BS 5975.
- EN 12812 does not provide any procedural control, an area that Bragg highlighted as being critical for the safe execution of falsework and which forms a central part of BS 5975.
- BS 5975's principal use of permissible stress design is not seen to directly conflict with that of EN 12812 which uses a limit state approach.

Although for falsework BS 5975 has been retained in parallel with BS EN 12812, BS 5973: 1993, for tied tube-and-fitting access scaffolds, was withdrawn on publication of BS EN 12811-1.

Unless specified by the contract, for the design of falsework in the UK, designers are currently free to choose either a limit state approach as set out in BS EN 12812 or the permissible state approach in BS 5975. There is a danger that if only ENs are specified in contracts the procedural control will inadvertently be left out. Regardless of the design approach adopted, the procedural controls given in BS 5975 should be used.

1.3.5 Definitions of Temporary Works and Falsework

BS 5975: 2008 has the following definitions:

3.16 Falsework

temporary structure used to support a permanent structure while it is not self-supporting

3.40 Temporary Works

parts of the works that allow or enable construction of, protect, support or provide access to, the permanent works and which might or might not remain in place at the completion of the works

NOTE Examples of temporary works are structures, supports, back-propping, earthworks and accesses.

The introduction to BS EN 12812: 2008 states:

Most falsework is used:

a) to carry the loads due to freshly poured concrete for permanent structures until these structures have reached a sufficient load bearing capacity;

b) to absorb the loads from structural members, plant and equipment which arise during the erection, maintenance, alteration or removal of buildings or other structures;

c) additionally, to provide support for the temporary storage of building materials, structural members and equipment.

The definition of Falsework can be applied equally to a cofferdam or facade retention as the more conventional applications of vertical support. However, the majority of the design advice in BS 5975 and BS EN 12812 applies most directly to the support of concrete and building materials. This does not mean that BS 5975 and BS EN 12812 should not be applied to other forms but that the designer must decide which aspects of the design advice is relevant.

1.3.6 Summary of Requirements given in Temporary Works Standards

The following table summarizes the requirements given in BS ENs 12810 to 12813:

Design Approach:	Limit state
Actions:	Should be taken from the Eurocodes, BS EN 12811-1 and BS EN 12812. Only the self-weight of the equipment is taken as a permanent (dead) action; all others are taken as variable (live) actions. An additional horizontal load equal to 1% of the vertical load as well as any effects caused by imperfections should be applied.
Load combinations:	Simplified loading combinations, compared with the Eurocodes, are suggested. All the combination factors are 1.0 and there is no use of leading and other variable actions. Note: Load combinations factors are used to combine variable loads that may not occur concurrently and are distinct from partial load factors that are always applied.
Partial factors:	Partial load factors of 1.35 on permanent and 1.5 on variable loads are applied. A partial material factor of 1.1 is specified for steel and aluminium. BS EN 12812 also introduces an additional partial material factor of 1.15 for Class B2 falsework designs. BS EN 12811-1 does not differentiate between permanent and variable loads and uses a single value or 1.5.
Imperfections:	The influence of imperfections such as: eccentricities, angular imperfections at joints, bow and sway have to be taken into account.
Calculation of internal forces:	The calculation of internal forces should take second order (p-delta) analysis into account where appropriate.
Equilibrium:	Static equilibrium including: global sliding, overturning and uplift use partial load factors of 0.9 on stabilizing loads and 1.5 on destabilizing loads

1.3.7 Factors of Safety

Generally, BS 5975 is based on a global factor of safety of 1.65 on yield and 2.0 on failure. Internal forces are calculated using first order analysis with the minimum horizontal load acting as an amplification factor. This approach has been used for over 30 years and has proved successful.

BS EN 12812 uses a partial load factor γ_f of 1.35 for self-weight for the falsework and 1.5 for all other applied actions. All supported concrete (be it wet or hardened) is taken as the latter. This is not the same as Permanent Works design where the 'structure' supported is regarded as self-weight. Internal forces are calculated using second order analysis. A partial material factor γ_m of 1.1 for steel and aluminium is used. For a typical falsework, the majority of the internal forces will be generated by the applied actions. This gives an overall factor of safety of approximately 1.5 x 1.1 = 1.65, which equates to BS 5975.

Whereas BS EN 12812 and BS EN 12811-1 use a partial material factor for steel and aluminium of 1.1 the Eurocodes use a value of 1.0. The Eurocodes also suggest that the supported concrete can be taken as a permanent action with a partial load factor of 1.35. If a design is carried out purely to the Eurocodes there would be a reduction in the overall factor of safety compared to the Temporary Works standards. There is no assurance that this provides an adequate margin against failure.

1.4 Considerations common to all Temporary Works

1.4.1 Procedures

Good management procedures are essential for the safe assembly, use and removal of all Temporary Works and their adoption was a key recommendation of the Bragg Report.

An important element of BS 5975 is that it contains, in Part 2, established management procedures. These do not appear in the ENs, albeit the BS EN 12812 does require certain core ideas to be implemented, such as briefing, coordination and checking.

1.4.2 Contract stipulations

It is important that if the Client specifically wishes Temporary Works to be designed to the European Standards that this is specified in the contract with the main Contractor, and then repeated in all relevant sub-contracts. In doing so the Client should be aware of the strategic issues highlighted in this document. As emphasised earlier, the inclusion of Section 2 of BS 5975: 2008+A1: 2011 (dealing with the management of Temporary Works) is required, even if the design itself is to be to European Standards.

Similarly, in the absence of a requirement by the engaging party, it is prudent for the engaged party to state how it intends to design Temporary Works so that there is no misunderstanding after appointment.

1.4.3 Risk management

In all cases, any designer should apply the principles of risk management, as required by safety legislation, but also as a good business principle. For example, by considering:

- differences between Temporary Works and Permanent Works;
- the appropriateness of the proposed design code;
- familiarity of the designers to EN design methods;
- the necessary checks and reviews;
- data provision and communication;
- task management;
- competency of those involved;
- interface management; and
- site specific hazards.

The adoption of ERIC[1] is a useful way of doing this.

1.4.4 Data provision

A significant proportion of Temporary Works comes in the form of a 'proprietary product', e.g. formwork panels, props, access stairs, falsework. This may be used in isolation, independent of any other piece of equipment, or as an integral part of a larger whole (and contributed to by other parties). In both cases, it is essential that its capacity, and any usage restrictions, are known with confidence.

The law imposes requirements on data provision in a number of ways:

- Section 6 of the Health and Safety at Work etc. Act (HASWA) places duties on those who supply articles, e.g. proprietary Temporary Works equipment, to ensure it is accompanied by adequate information for its safe use.
- The Provision and Use of Work Equipment Regulations (PUWER) and the Lifting Operations and Lifting Equipment Regulations (LOLER), if relevant to a particular case, place similar obligations on suppliers.

[1]Eliminate, Reduce, Inform and Control (See: http://www.cskills.org/uploads/CDM_Designers4web_07_tcm17-4643.pdf).

It is clearly essential that any load quoted by a supplier (or required capacity quoted by a contractor) is unambiguously stated. The consequences of confusion between Serviceability (working) loads (SLS), and Ultimate (failure) loads (ULS), in the units adopted, or in the use of alternative terms, are obvious.

In addition to knowing the SLS or ULS it is necessary to know how it is derived. For example, where proprietary products are quoted with a Working Load, it will be necessary to understand how this relates to the ultimate capacity and, where tested, the test conditions.

The user has a parallel responsibility (under section 2 and 3 of HASWA and the Regulations). Hence, if the equipment lacks the necessary data, the users must satisfy themselves as to its fitness, either by insisting on its provision or by their own determination.

The expected data might include:

Aspect required	Data required	Comment
Ultimate capacity Characteristic strength	Whether derived from calculation or test	Sufficient detail to understand the basis of the calculation or test.
Serviceability capacity	Whether derived from calculation or test	Its relationship to ULS.
Accuracy of erection and use		For various conditions of use, such as different extensions and eccentricities, together with details of any necessary bracing or lacing. Any limiting deflection conditions.
Regulation		The Provision and Use of Work Equipment Regulations and the Lifting Operations and Lifting Equipment Regulations require data and actions to ensure safe use.
Whether, in the case of towers, top restraint is assumed or not		This is a vital assumption regarding stability and capacity.
Interaction with other items		Information on how loads are transmitted to other components and to the foundations.
General	The intended uses for the components, how they can be identified and the appropriate dimensions and masses.	
End conditions	Whether it is assumed the ends of relevant components are pinned or fixed.	

1.4.5 Loading

Loadings should be taken from an appropriate EN. BS EN 12811-1 provides access loads for working areas, BS EN 12812 provides loads relevant to falsework and BS EN 1997 should be referred to for geotechnical loadings.

BS EN 1991-1-6, *Actions on structures. General actions. Actions during execution*, provides some additional information. It was not written in conjunction with the Temporary Works suite of ENs and the information does not completely align. For falsework and access scaffolding the requirements of the Temporary Works suite should take precedence.

Wind loading should be calculated to BS EN 1991-1-4, *Actions on structures. General actions – Wind Actions*. BS EN 12812 states that the velocity pressure can be modified to take the period of use into account. This means that the probability and seasonal factors can be used, but should be done so with caution as part of a risk based approach.

The seasonal factor C_{season} should be used only if the Temporary Works are guaranteed to be used during a particular sub-annual period. Due to the nature of general construction work it is normally recommended to use a value of unity.

As the basic wind speed is given for a return period of 50 years, and Temporary Works are erected for much shorter periods than this, the probability factor takes into account the likelihood that a maximum wind will not take place. Stated simply, the designer is taking a gamble that there won't be a 1 in 50 year wind event while the Temporary Works is erected.

Hence, the designer should assess the risks and consequences of failure and only apply the reduction if appropriate. For example, the factor could be applied for a small wall form on an isolated site but not for a form next to a railway line. Its use (or not) should be clearly stated as a significant residual risk. CIRIA Report C579, *Retention of masonry facades - best practice guide*, states that a probability factor of 1.0 should be used for all façade retention.

BS EN 12812: 2004 set the probability factor as 1.0 and then allowed the designer to multiply the dynamic pressure by 0.7. BS EN 12812: 2008 changed this and allowed the velocity pressure to be modified according to EN 1991-1-4 taking the period of use into account; hence the 0.7 factor was removed. BS 5975: 2008 was originally based on the BS EN 12812: 2004 and, when amended in 2011, introduced a recommended probability factor of 0.83 for a minimum two year return period for wind on falsework.

BS EN 1991-1-6 provides a table of suggested return periods (Table 3.1). However, it is suggested for Temporary Works that if the probability is to be taken into account a single reduction be used. The reduction being applied either by using a C_{prob} of 0.83 (two years) or by multiplying the dynamic pressure by 0.7, but not both.

This value of reduction has been used in BS 5975 since it was first published and has proved satisfactory. It has also proved satisfactory for other Temporary Works such as formwork, scaffolding, hoardings, etc. Despite this, however, 0.7 should not be used as a standard factor but considered with caution on a case by case basis.

1.5 Outline Requirements for Temporary Works Design using European Standards

The outline design requirements can broadly be split into 6 groupings:

Group 1 – Falsework, Formwork, Access and Protection

Categories in this group are either specifically covered by the Temporary Works suite, BS EN 12810 to 12813, or are comparable with them and should be designed using the same parameters.

Group 2 – Geotechnical

The design of categories in this group will be heavily based on BS EN 1997: Eurocode 7. *Geotechnical design. Ground considerations*. The designer should take cognisance of the general advice above and select appropriate partial factors depending on the particular situation.

Group 3 – Vehicle and pedestrian bridges, support to trafficked bridges

Group 4 – Underground

Group 5 – Marine

Group 6 – Other

Group 1	Group 2
Falsework Support to wet concrete Propping Clear Span Openings Façade Retention Needling Flying Shores Gantries/cantilever Service Bridges Jacking Structures providing stability during construction or demolition Moving of structures	**Geotechnical** Trench Support Tower Crane bases Pilling/Crane Mats Retaining Walls Slope Stability Foundations Cofferdams Horizontal Propping Shafts Underpinning
	Group 3
	Vehicle and pedestrian Temporary bridges Propping of live road, rail or pedestrian bridges Temporary edge protection
Access Tied Scaffolds Freestanding Scaffolds Gantries	**Group 4**
	Underground Tunnels Shafts Chambers Tunnelling thrust pits
Formwork Vertical (Wall and Column) Soffits Sloping	**Group 5**
	Marine Temporary Works Cofferdams Dolphins Access Jetties Floating Plant
Advancing Falsework/Formwork Formwork Travellers (Horizontal) Climbing Formwork (Vertical) Advancing/Launching Formwork	**Group 6**
	Structural support to cranes Temporary grandstands Push launched bridge structures
Protection Crash Decks Hoardings	

1.5.1 Falsework

Unlike many other forms of Temporary Works there is a specific EN relating to the design of Falsework, BS EN 12812. Because of the way it has been drafted its requirements are not always easily understood. An overview of the basic requirements has been set out in Section 1.3.6.

From the title of the standard, *Falsework – Performance requirements and general design*, it can be seen that the standard does not give detailed design advice and the designer will be required to get this from elsewhere. In particular, the standard does not give advice on:

- The difference between fixed at the head and freestanding structures;
- Effective lengths;
- Bracing for nodal stability;
- Bracing of beams and trusses; and
- Wind coefficients specific to falsework.

A design to BS EN 12812 will give a comparable result to BS 5975 but the designer will need a thorough understanding of falsework design, as the EN only provides general advice and does not lay out all the checks that are required.

1.5.2 Formwork

In September 2008 the European Standards Committee, CEN/TC 53, for Temporary Works Equipment ruled not to continue work on the preparation of an EN for Vertical Formwork.

In the UK the Concrete Society published, in May 2012, a third edition of, *Formwork – a guide to good practice* ("the Formwork Guide"). This publication was informed by the Eurocodes and is considered the authoritative guidance on all formwork matters in the UK. The Formwork Guide covers the philosophy of design of formwork for walls, columns, and for soffits. Information is presented in permissible stress terms, with information on limit state included in an appendix.

1.5.2.1 Formwork Loads

Concrete pressure should be calculated using CIRIA Report R108, *Concrete pressure on formwork*. Advice on its application to modern concrete types and classifications is given in the Formwork Guide.

Imposed service loads should be taken from the relevant EN as discussed in the loading section above.

1.5.2.2 Properties of Timber and wood-based products

Timber and wood-based products have many different modification factors for varying conditions. Timber stresses can change depending on exposure, duration of load, etc. Timber is often used in Temporary Works, and the design process and common rules for limit state design are covered in BS EN 1995-1-1. Separate ENs give section sizes, stresses, methods of testing, etc. Appendix E to the Formwork Guide gives recommendations for the relevant modification factors, to be applied to basic stresses, for use by the designer in limit state design.

The recommended permissible stresses and moduli of elasticity for formwork timbers are given in the Formwork Guide for various conditions of use. The values, which are based on the characteristic strengths stated in BS EN 1995, are published as grade stresses in BS 5268-2.

The European Standards Committee failed in their attempt to produce a product standard for the various wood-based sheet materials currently available. They have, though, produced a method of testing (see BS EN 789: 2004, *Timber structures. Test methods. Determination of mechanical properties of wood based panels*, to determine the characteristic strengths of plywood) and it is the responsibility of the supplier/importer to provide the relevant properties, using the relevant testing standard. The modification factors for various Plywood and Oriented Strand Board (OSB) are given in BS EN 1995, *Eurocode 5. Design of timber structures. General. Common rules and rules for buildings*.

To assist design to limit state, recommendations on relevant factors are given in Appendix E of the Formwork Guide and, to further assist designers, the Concrete Society obtained approval, from trade associations and from supply organisations, to publish their characteristic values for commonly used wood-based sheet materials. These, also, are given in Appendix E of the Formwork Guide.

The recommended safe structural properties of these materials, based on the characteristic values stated, are given in Appendix D of the Formwork Guide.

Where only the characteristic values of Plywood, Particleboard or OSB are available from the supplier and the designer wishes to use permissible stress design, the Formwork Guide gives numerical factors to enable the formwork designer to establish both the grade stress and the elastic moduli for wall and for general soffit use of the materials.

1.5.2.3 Factors of Safety

The recommendation in the Formwork Guide, for permissible stress design, is that a minimum factor of safety (FoS) of 2.0, against failure, should be used. Deflections at serviceability state should be considered and may control.

There is no guidance in the ENs on appropriate partial factors for use in limit state design for formwork. The use of the global (or combined) safety factor of 1.65 (based on the product of a material factor of 1.1 and load factor of 1.5), might be suitable for steel or aluminium products, but might not suit fabricated components, or plastic or timber products.

When considering static equilibrium (overturning) the Eurocodes state partial safety factors of 0.9 for stabilizing loads and 1.5 for destabilizing loads, giving a combined value of 1.66. This is first stated in BS EN 1990 and repeated in BS EN 12812. This compares with a value of 1.2 given in BS 5975 and the Formwork Guide. Although this reduced value has been used for many years in the UK, in order to comply with the ENs the higher value should be used.

1.5.3 Access Scaffolding

BS EN 12811-1 was published In June 2004 and gives the performance requirements and general design criteria for all UK scaffolds. It replaced the permissible stress code, BS 5973. Further ENs cover prefabricated scaffolds (BS EN 12810), towers (BS EN 1004), edge protection systems (BS EN 13374), components, scaffold tube (BS EN 39) and scaffold fittings (BS EN 74).

BS EN 12811-1 is in limit state terms and uses a partial load factor of 1.5 on all actions and a partial material partial safety factor for steel and aluminium of 1.1. This combined gives a global safety factor of 1.65.

In 2005, the NASC published TG20, *Technical guidance on use of BS EN 12811-1*, and gives safe height tables, working values, etc. for basic tube-and-fitting scaffolds.

The safe working load for scaffold tube in compression, and for scaffold fittings, is calculated in TG20 using the global combined limit state factor of 1.65 on characteristic strength. The safe strut buckling capacities for different effective lengths presented in TG20 are calculated using BS EN 1993, with the 1.65 factor applied. There is little information in the ENs on establishing the effective lengths of members to be used, and industry user guidance such as TG20 and BS 5975 remains a valuable source.

One anomaly is the consideration of the working wind load, stated in BS EN 12811-1 as the standard wind velocity pressure of 200 N/m^2. For mobile access towers of prefabricated materials, e.g. an aluminium tower, the horizontal design load to simulate wind is reduced to only 100 N/m^2. This is based on the assumption that the mobile access tower can be quickly dismantled or tied to another structure if high winds are forecast. The use of a working wind less than 200 N/m^2 should not be extended to other forms of Temporary Works.

There is also an anomaly when considering temporary edge protection systems. BS EN 13374 introduces three classes of edge protection depending on roof angle and gives different testing requirements. If, though, the edge protection is constructed from tube-and-fitting, the design is more onerous to BS EN 12811-1 which has different load values and, importantly, the introduction of an upward load on the handrail. There is no upward loading requirement on system handrails in BS EN 13374.

Scaffold boards are not considered under BS EN 1995, but BS 2482 gives the recommended working moment of resistance of boards complying to the standard. Based on the minimum ultimate moment of any board tested the minimum factor of safety is about 1.54, but considering the lower fifth-percentile increases this to a minimum 1.8 factor.

1.5.4 Geotechnical Design

The relevant European Standard is BS EN 1997-1: 2004, *Geotechnical Design* (referred to as “Eurocode 7” or EC7). This outlines the engineering principles to be used whilst, giving considerable scope to use a variety of analytical techniques. Clause 2.4.1 states that design should be by calculation and that the calculation model may consist of any of the following:

- An analytical model;
- A semi-empirical model; or
- A numerical model.

BS EN 1997 introduces the limit state design concept to geotechnical design and, in the UK, it is necessary to analyse two load cases referred to as *Design Approach 1 – Combination 1* (DA-1) and *Design Approach 1 – Combination 2* (DA-2). In these load cases, factors are applied to loads and material properties; the factors vary depending on whether the load is permanent (dead load) or variable (live load). The factors also vary depending on whether a load is unfavourable (destabilising) or favourable (stabilising).

BS EN 1997 outlines the engineering principles to be used for design but does not prescribe a particular method. The UK National Annex (NA) to BS EN 1997-1 guides the designer elsewhere for more definitive design guidance (Non-contradictory Complementary Information, NCCI). Several sources of NCCI are listed. However, all of them are, at least partially, in conflict with the principles of BS EN 1997-1: 2004 and the Eurocode takes precedence in these cases.

1.5.4.1 Temporary Foundations

It is imperative that the designer of any Temporary Works supported by the ground understands the principles of geotechnical analysis and the inherent approximations/uncertainties in it so they are able to allocate appropriate factors to the Temporary Works.

Typical examples of temporary foundations are:

- Crane bases;
- Crane outrigger foundations; and
- Foundations to falsework.

  The main differences between temporary foundations and permanent foundations are:

  - Temporary foundations are often constructed on the surface of the ground;
  - Temporary foundations are likely to be subjected to their full design load whereas a permanent foundation might never be subjected to its full design load; and

- The load on a permanent foundation builds up slowly over a period of time. Where the foundation is on clay, this will allow the clay to consolidate and increase in strength from that shown in the site investigation report. This is not usually taken into account in Permanent Works design but gives an additional factor of safety. This benefit is not available to temporary foundations which are likely to be subjected to the full load more or less instantaneously.

Appendix D of BS EN 1997: 2004 has a sample analytical method for bearing resistance calculation which can be used for the basis of calculation. The sample method is not complete (for example it excludes the depth factors), so it is still necessary to use appropriate NCCI.

This process of applying partial factors is relatively straightforward for foundations with only vertical load. However, for foundations with horizontal and vertical load it is not always obvious whether the vertical component of the load is favourable or not and it is necessary to analyse both cases with appropriate partial factors to determine the critical case.

Traditionally in the UK, foundation design has adopted a factor of safety of 2.5 or 3.0 and the resultant allowable bearing pressure is deemed to satisfy settlement criteria. However, BS EN 1997 uses lower partial factors for the verification of bearing capacity but requires the designer to undertake separate calculations for settlement. To comply, both are required.

1.5.4.2 Slope Stability

For permanent slope stability it is rarely appropriate to use the undrained strength of a fine grained soil in the analysis. However, for Temporary Works of short duration the use of undrained strength can greatly enhance the calculated stability of a slope. This needs to be used with caution; fine grained soil does soften with time and a slope that initially appears stable can fail after an indeterminate time.

Once appropriate soil parameters, water levels or pore pressure ratios and surcharges have been selected, analysis of a temporary slope can proceed as for an analysis of a permanent slope. Moderately conservative soil parameters should be selected for Eurocode designs or parameters derived from analytical methods prescribed in EC7 which allows for adequacy of site investigation and complexity of soils, consequence of failure, etc. Previously these variables were considered in BS 6031 by allowing the designer to select an overall FoS between 1.2 and 1.4.

1.5.4.3 Granular Working Platforms

Granular working platforms are currently designed in accordance with BRE Report 470, *Working platforms for tracked plant*, which is not compatible with Eurocodes. The TWf has a Working Group investigating working platforms and aims to produce relevant design guidance which will be the subject of a separate guidance note. BRE Report 470 only considers tracked plant.

1.5.4.4 Retaining structures, cofferdams and trenching

Eurocode 7 refers to CIRIA Report C580, *Embedded retaining walls*, as NCCI. The current version of CIRIA C580 is not compatible with Eurocodes but it is understood (February 2014) that CIRIA have started preparation of a fully-compatible revision.

In order to determine the capacity of the equipment used for trench support two main standards are available:

- BS EN 13331: 2002, *Trench Lining Systems Part 1: Product Specifications and Part 2: Assessment by calculation or test*.
- BS EN 14653: 2005, *Manually operated hydraulic shoring systems for groundwork support Part 1: Product Specifications and Part 2: Assessment by calculation or test*.

Both of these standards state that if assessment by calculation is used then EN 1993-1-1 should be used together with a partial material factor γ_m of 1.1 for steel and aluminium and a load factor γ_m of at least 1.5. This concurs with the other temporary works ENs. However, it does differ from the factors used in both the main Eurocodes and the earlier limit state BSs.

Proprietary sheet pile design software generally now includes Eurocode compliant designs and considers DA-1 & DA-2.

Although it is possible to calculate pressures on proprietary trench sheet and boxes to the Eurocode, currently supplier only state SWL capacities. Further development from the suppliers is required to state Eurocode compliant capacities.

1.5.5 Tower Crane Foundations

In 2006, CIRIA published C654, *Tower crane stability*. The report provides an understanding of the issues relating to the safe use of tower cranes and also provides specific guidance for designers of Temporary Works involving tower cranes. This is currently being updated.

1.5.5.1 Loading data supplied by tower crane manufacturers/suppliers

Tower cranes produced in the past few year have been designed to the harmonised ENs for tower cranes, BS EN 14439: 2006, which refers to the standards to be used for the design of tower cranes. The Construction Plant-hire Association have published a Tower Crane Technical Information Note, TIN 027, *Tower Crane - Out of Service Wind Speeds*, which provides additional information regarding the wind loading in the UK.

At present, the crane manufacturers supply characteristic (working) foundation loads/ actions with no separation of permanent and variable loads/actions. It is anticipated that, in the future, manufacturers will be able to supply a split in loads.

1.5.5.2 Designing tower crane foundations to Eurocodes

CIRIA C654, Appendix 2, provides examples of foundation design calculations using traditional allowable ground bearing stress design and BS EN 1997-1: 2004.

Since the split in the loads between permanent and variable actions are not currently available, the report gives guidance on the appropriate partial factors to be used for stability, geotechnical capacity and structural design.

It is worth noting that if an element of the foundation, e.g. the pile design, is to be designed by a specialist designer, then the loading data supplied to the designer needs to clearly state if the loads are characteristic or design actions/ loads and for clarity state the design actions/ loads for both Combination 1 and 2 for Design Approach 1.

1.5.6 Temporary Vehicle and Pedestrian bridges

1.5.6.1 Public Highway Bridges

Eurocode 1 refers to variable actions (live loads). These are radically different to the Highways Agency BD37 and the superseded BS 5400.

The effects on shear and bending of main members are significantly different (usually higher) on short and medium span bridges, i.e. up to 30 metres. Concentrated loads and local deck loads are considerably higher.

It is not possible to make general assumptions on a percentage change as differences are highly dependent on span.

Partial Factors on Actions

Self-weight factor (permanent actions):

- Eurocodes: 1.20
  Was 1.05 for steel and 1.15 for concrete

Highway actions:

- Eurocodes: 1.35
  Was 1.50 for HA standard loading and 1.30 for HB special loading

The changes to highway loading present no significant risk providing that the actions are understood. Many of those specifying are currently making fundamental errors such as requesting "HA Loading to Eurocodes" or specifying "Load Models LM1 & LM2" instead of "Load Group 3, 4", etc.

1.5.6.2 Site Access Bridges

The use of public highway loading is unusual for site access bridges as it is usually overly conservative. Single vehicles or a combination of single vehicles is common.

Many clients choose to specify the design of site access bridges to Eurocodes. This does usually lead to confusion.

The Eurocodes allows, "Agree with approving body". Here, the approving body can agree load factors (Ref BS EN 1990 Part 2 (bridges), Appendix. A – notes under table).

Typical examples of risks for site access bridges if adopting Eurocodes:

- Using a load factor 1.35 for a single vehicle. The 1.35 factor is intended for the conservative public highway notional load patterns and not an actual vehicle.
- Impact factors are often much lower for public highway bridges and/or built into the notional highway load. Appropriate impact factors that are commonly applied to site vehicles range from 1.25 up to 1.50 depending on specific circumstances.

Factors of safety equivalent to traditional working stress methods such as 1.7 are recommended.

1.5.6.3 Footbridges

- Loading remains 5 kN/m^2.
- Load factors have gone down (1.50 in BS 5400 down to 1.35 in the Eurocodes).
- Vibration performance: There is little knowledge in industry as yet in how to specify vibration performance, e.g. Clients need to specify a peak acceleration limit.

1.5.7 Propping of Bridges

1.5.7.1 Choice of the use of standards

BS 5975 is a valid option, either by choice or if specified by the Client or other body.

Designing to BS EN 12812 would usually lead to the use of the Eurocode suite due to the size and nature of typical heavy propping schemes, i.e. it would be classified as Class B1.

Clients may choose to specify the Eurocode suite on the basis that:

- They wish to regard the temporary support as an integral part of a permanent structure (as is often the case with the Highways Agency).
- They believe that this approach is required to comply with legislation.

1.5.7.2 Potential risks associated with the use of Eurocodes

There are some areas of risk which require careful consideration. Such as:

- By using the EN suite, it is assumes that BS EN 1090 has been considered in full. This is unlikely to be the case for structures made up of proprietary systems or previously used steelwork. For example:
  - Tolerances of proprietary systems are usually less stringent than EN 1090;
  - Connection details are usually different to a typical permanent design detail, e.g. the use of welded end plates or pins is common;
  - Minor damage to parts is normally accepted (and accounted for in suppliers' data).
- There are numerous situations where the global factor of safety when applying Eurocodes (without reference to EN 12812) could be significantly lower than if applying BS 5975 to the same scheme. For example, a propping system supporting the self-weight only of a bridge deck:
  - Using BS 5975 would result in a minimum global FoS against yield of around 1.65. Whereas using the Eurocodes could result in a minimum global FoS against yield of around 1.35.
- Analysis: Interaction between permanent and temporary supports. Risks are present with temporary heavy propping design at this design interface, for example:
  - The accuracy of data on existing structures is often less reliable than with the design of new structures. Also, the accuracy of the analysis of existing structures is often lower than for new structures.

Such aspects must be taken into consideration in the design process.

1.6 European Standards and Reference Documents Relevant to Temporary Works Design

1.6.1 European Standards

Reference (BS)	Title
EN 39: 2001	Loose steel tubes for tube and coupler scaffolds. Technical delivery conditions
EN 74-1: 2005	Couplers, spigot pins and base plates for use in falsework and scaffolds Couplers for tubes. Requirements and test procedures
EN 74-2: 2008	Couplers, spigot pins and baseplates for use in falsework and scaffolds Special couplers. Requirements and test procedures
EN 74-3: 2007	Couplers, spigot pins and baseplates for use in falsework and scaffolds Plain base plates and spigot pins. Requirements and test procedures
BS EN 789: 2004	Timber structures. Test methods. Determination of mechanical properties of wood based panels
EN 1004: 2004	Mobile access and working towers made of prefabricated elements. Materials, dimensions, design loads, safety and performance requirements
EN 1058: 2009	Wood-based panels. Determination of characteristic 5-percentile values and characteristic mean values
EN 1065: 1999	Adjustable telescopic steel props. Product specifications, design and assessment by calculation and tests
EN 1090-1: 2009+A1: 2011	Execution of steel structures and aluminium structures Requirements for conformity assessment of structural components
EN 1090-2: 2008+A1: 2011	Execution of steel structures and aluminium structures Technical requirements for steel structures
EN 1090-3: 2008	Execution of steel structures and aluminium structures Technical requirements for aluminium structures

1.6.1 European Standards – continued

Reference (BS)	Title
EN 1263-1: 2002	Safety nets Safety requirements, test methods
EN 1263-2: 2002	Safety nets Safety requirements for the positioning limits
EN 1298: 1996	Mobile access and working towers. Rules and guidelines for the preparation of an instruction manual
BS EN 12063: 1999	Execution of special geotechnical work. Sheet pile walls
EN 12369-1: 2001	Wood-based panels. Characteristic values for structural design OSB, particleboards and fireboards
BS EN 12369-2:2011	Wood-based panels. Characteristic values for structural design. Plywood
EN 12810-1: 2003	Facade scaffolds made of prefabricated components. Product specifications
EN 12810-2: 2003	Facade scaffolds made of prefabricated components. Particular methods of structural design
EN 12811-1: 2003	Temporary works equipment. Scaffolds. Performance requirements and general design
EN 12811-2: 2004	Temporary works equipment. Information on materials
EN 12811-3: 2002	Temporary works equipment. Load testing
EN 12811-4: 2013	Temporary works equipment Protection fans for scaffolds. Performance requirements and product design
EN 12812: 2008	Falsework -performance requirements and general design
EN 12813: 2004	Temporary works equipment. Load bearing towers of prefabricated components. Particular methods of structural design
EN 13331-1: 2002	Trench lining systems Product specifications
EN 13331-2: 2002	Trench lining systems Assessment by calculation or test
EN 13374: 2013	Temporary edge protection systems. Product specification. Test methods
EN 13377: 2002	Prefabricated timber formwork beams. Requirements, classification and assessment
EN 14653-1: 2005	Manually operated hydraulic shoring systems for groundwork support Product specifications
EN 14653-2: 2005	Manually operated hydraulic shoring systems for groundwork support Assessment by calculation or test
EN 16031: 2012	Adjustable telescopic aluminium props. Product specifications, design and assessment by calculation and tests

1.6.2 British Standards

Reference	Title
BS 1139: Part 1:	Safety nets Safety requirements, test methods
BS 1139: Part 2: Section 2.1: 1991	Metal Scaffolding. Couplers. Specification for Steel Couplers, Loose Spigots and Baseplates for use in Working Scaffolds and Falsework Made of Steel Tubes
BS 1139: Part 2: Section 2.2: 1991	Metal Scaffolding. Couplers. Specification for Steel and Aluminium Couplers, Fittings and Accessories for use in Tubular Scaffolding
BS 1139: Part 4: 1982	Metal Scaffolding. Specification for Prefabricated Steel Splitheads and Trestles
BS 1139: Part 6: 2005	Metal scaffolding. Specification for prefabricated tower scaffolds outside the scope of EN 1004, but utilizing components from such systems
BS 2482: 2009	Specification for timber scaffold boards
BS 5975: 2008+A1: 2011	Code of practice for temporary works procedures and the permissible stress design of falsework

1.6.3 Other documents

Title
Formwork: A Guide to Good Practice, 2nd Edition. Concrete Society.
SCI Publication P360. Stability of steel beams and columns
TG20:13 Good Practice Guidance for Tube and Fitting Scaffolding, NASC
Hewlett, Jones, Marchand and Bell (2014), Re-visiting Bragg to keep UK's temporary works safe under EuroNorms. Proceedings of the Institution of Civil Engineers – Forensic Engineering 167 (May 2014): 58-68

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