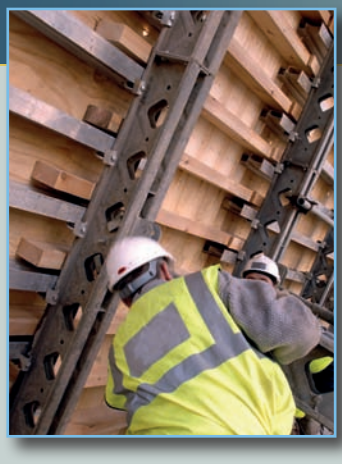
3rd Edition





Formwork

A guide to good practice

Report of a Concrete Society Working Party

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Formwork

A guide to good practice

3rd Edition 2012

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Definitions and abbreviations

The following definitions are used in this guide, They are generally in accordance with BS 5975 ***Code of Practice for temporary works procedures and the permissible stress design of Falsework*** and with BS 6100 ***Building and Civil Engineering. Vocabulary*** (Ref. 20):

Adjustable telescopic steel prop: Prop comprised of two tubes which are telescopically displaceable within each other.

Backpropping: Propping installed at levels below the slab that supports the falsework in order to distribute the load on the uppermost slab to suitable supports, such as lower slabs or the foundations.

Beam: Structural member for carrying loads between or beyond points of support, usually narrow in relation to its length and horizontal or nearly so.

Bearer: Spanning member, usually horizontal, used to transfer load to supports, commonly timber, aluminium or steel.

Bow: Curvature of the length or width of a component expressed as a deviation from a straight line connecting the extremities.

Camber: The intentional upward curvature of a beam or form, either formed initially to compensate for subsequent deflection under load, or produced as a permanent effect for aesthetic reasons.

Characteristic strength: Strength at which members tested would fail, normally associated with a confidence limit that 95% would fail above the value stated.

Component: A part of the formwork system used and identifiable as a distinct unit.

Deviation: The difference between an actual size or position and a specified size or position.

Face contact: The material in direct contact with the poured concrete acting as the material containment shape. It will normally produce a mirror image on the concrete finish.

Factor of safety: The ratio of failure load to the maximum working load.

Falsework: Any temporary structure used to support a permanent structure while it is not self-supporting.

Formwork: A structure, usually temporary, but in some cases wholly or partly permanent, used to contain poured concrete to mould it to the required dimensions and support it until it is able to support itself. Note: It consists primarily of the face contact material and the bearers that directly support the face contact material.

Grade stress: Stress that can be safely sustained by timber of a particular strength class, or species and grade.

Kentledge: Material placed on a structure to provide stability by the action of its dead weight.

Permissible deviation: The specified limit(s) of deviation.

Permissible stress: The stress that can be sustained safely by a structural material under stress for the particular condition of service or loading.

Primary: Principal bearing member transferring load to the falsework.

Repropping: A system used during construction operations in which the original supports to a member being cast are removed and replaced in a planned sequence.

Soffit: Underside surface of a concrete member, slab etc.

Soldier: The stiff vertical member of wall formwork that transmits the force from the pressure of the concrete to suitable restraints, generally tie rods.

Strength class: A classification of timber based on particular values of grade stress.

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.

Tolerance: The difference between the limits within which a size or position should lie. Tolerance is an absolute value without sign but the dimension or axis to which it applies has to be stated.

Top restraint: Method by which stability of falsework is provided by surrounding permanent works or specifically designed temporary works.

Waling: Spanning member used in wall formwork, usually horizontal, used to transfer lateral load from the face contact material to suitable supports, commonly in timber, aluminium or steel.

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The following abbreviations are used in this guide:

ABS	acrylonitrile butadiene styrene
ACoP	Approved Code of Practice
APA	American Plywood Association – now the Engineered Wood Association
BCA	British Cement Association
BRE	Building Research Establishment
BS	British Standard document prefix
BSI	British Standards Institution
CARES	The UK Certification Authority for Reinforcing Steels
Cat.	Category
C&CA	Cement and Concrete Association (renamed British Cement Association in 1988, now Mineral Products Association)
CDM	Construction (Design and Management) Regulations
CESWI	Civil Engineers Specification for the Water Industry
CEM	cement
CEN	Comité Européen de Normalisation (European Committee for Standardisation)
CIRIA	Construction Industry Research and Information Association
CITB	Construction Skills (formerly Construction Industry Training Board)
COFI	Council of Forest Industries Canada (renamed CanPly)
CONSTRUCT	The Concrete Structures Group
COSHH	Control of Substances Hazardous to Health Regulations
CP	Code of Practice
CPCS	Contractors Plant Certification Scheme
CPF	controlled permeability formwork
CS	The Concrete Society
Defra	Department for Environment, Food and Rural Affairs
ECBP	European Concrete Building Project
EEMUA	Engineering Equipment and Material Users Association
EN	Norme Europeenne (European Standard prefix)
ENV	Europaische Vornorm (European Prestandard prefix)
EPS	expanded polystyrene
EU	European Union (formerly EC)
FSC	Forest Stewardship Council
ft	feet
ggbs	ground granulated blastfurnace slag
G1S	good one side
GRC	glassfibre reinforced concrete
GRCA	Glassfibre Reinforced Concrete Association
GRP	glassfibre reinforced plastic
HA	Highways Agency
HAVS	hand–arm vibration syndrome
HD	Harmonisation Document
HDO	heavy-duty overlay (of wood-based panel products)
HSE	Health and Safety Executive
HSWA	Health and Safety at Work etc. Act
HT	high tensile
lb	pound
ICF	Insulated concrete formwork
LHPBFC	low-heat Portland blastfurnace cement
LOLER	Lifting Operations and Lifting Equipment Regulations
MAC	Manual Handling Assessment Chart
MDO	medium-duty overlay (of wood-based panel products)
MEWP	mobile elevated work platform
MHSW	Management of Health and Safety at Work Regulations
MPa	Megapascal
MS	Mild steel
NA	National Annex
NASC	National Access and Scaffolding Confederation
NBS	National Building Specification
NGCS	National Structural Concrete Specification
NGRDL	National Grading Rules for Dimension Lumber (Canada)
NLGA	National Lumber Grading Association (Canada)
NVQ	National Vocational Qualifications
OPC	Portland cement, known as CEM 1 (formerly called ordinary Portland cement)
OSB	oriented strand board
PAR	planed all round
PBFC	Portland blastfurnace cement

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perp.	perpendicular
PUWER	Provision and Use of Work Equipment Regulations
PVC	polyvinyl chloride
PWD	permanent works designer
QCF	Qualifications Credit Framework
RC	reinforced concrete
Ref.	reference
RHPC	rapid-hardening Portland cement
SC	strength class (now referred to as Cxx)
SCC	Self compacting concrete
SCI	Steel Construction Institute
SHW	Specification for Highway Works
SRPC	sulfate-resisting Portland cement
SWL	safe working load
TE	tempered
TMCB	temperature matched curing bath
TRADA	Timber Research and Development Association
TSO	The Stationery Office (formerly HMSO)
TWC	temporary works coordinator
TWD	temporary works designer
TWS	temporary works supervisor
UK	United Kingdom
UKWFBS	United Kingdom Water Fittings Byelaws Scheme
VERA	vegetable extract release agent
VOC	volatile organic compounds
WAH	Work at Height Regulations
WBP	weather- and boil-proof
WPPF	Wood Panel Products Federation
WRc	Water Research Centre
WSA	Water Services Association
yd	yard

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Summary

This Guide and the companion Worked Examples document have been prepared to promote good practice in the design, specification, construction and safe use of formwork for both in-situ and precast concrete. It contains information for the economic and safe design of wall and column formwork used in both building and civil engineering construction. When used for the design of soffit formwork the guide is intended to be read in conjunction with BS 5975 *Code of practice for temporary works procedures and the permisible stress design of falsework*. The guide assumes that formwork will be designed by persons with the relevant design and practical experience. The guide gives information for the building design team, the CDM (Construction (Design and Management) Regulations) coordinator, the Temporary Works Coordinator, for the contractor as well as for the subcontractor and supplier.



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A guide to good practice

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Worked Examples

The seven worked examples of formwork design and backpropping referred to in this 3rd edition are contained in the companion publication; *Formwork – a guide to good practice: Worked Examples*.

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Example 4 Bridge deck soffit formwork with void formers
Example 5 Backpropping Calculations 205mm slab One set formwork, Two sets backprops
Example 6 Backpropping Calculations 175mm slab One set formwork, Two sets backprops
Example 7 Backpropping Calculations 175mm slab Two sets formwork

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Section one

General

1.1 Introduction

Concrete Society Technical Report No. 13 Formwork (Ref. 1)

The first edition of the Joint Report of The Concrete Society and the Institution of Structural Engineers, *Formwork – a guide to good practice,* first published in August 1986, was prepared by The Concrete Society. The joint report had reviewed the Concrete Society Technical Report No. 13 *Formwork* published in 1977 (Ref. 1). The convener of the working party invited assistance from experts in the industry including contractors, architects, consulting engineers, the Health and Safety Executive, specialist suppliers and trade associations. In addition, comment was sought by correspondence following publication of an open letter in the magazine ***CONCRETE*** in September/October 1993 Volume 27 Number 5.

Since publication of the 1995 Second Edition Guide (Ref. 2) many of the reference documents have been revised or superseded, there have been notable advancements and innovations in formwork, further research has taken place and the formwork industry has continued to develop, with subcontractors and proprietary equipment suppliers taking a more prominent role. Building on the success of previous editions, this third edition of the Guide has been updated and revised, taking these changes into account. The revision was prepared by a Concrete Society working party invited from industry. The convener of the working party invited assistance from experts in the industry including contractors, consulting engineers, specialist suppliers and trade associations. In addition, comment was sought by correspondence.

In September 2008 the European Standards Committee CEN/TC 53 for Temporary Works Equipment ruled not to continue work on preparation of a European Standard on Vertical Formwork. Although a working group had prepared a draft performance requirements, general design and assessment document (pEN 15113-1) in May 2006, no activity or interest, with the exception of Italy, was expressed, so the CEN committee by a majority stopped the project, thus leaving individual countries to develop national standards. This Guide thus takes on more importance as the official UK authoritative guidance on formwork.

BS 5975 Code of Practice for temporary works procedures and the permissible stress design of falsework (Ref. 3)

BS 5975 *Code of practice for falsework* was first published in 1982 and extensively updated and renamed from 2008 as *Code of practice for temporary works procedures and the permissible stress design of falsework* (Ref. 3). It will be referred to in this Guide as BS 5975 *Code of practice for falsework.* In 2011 the method of calculating the wind force in Europe was included in Amendment No. 1 to BS 5975 and this Guide was informed by the change. It was desirable that the guide be written as a complementary document to that code. The code only covers the support of soffit formwork, so for wall formwork the guide would need to be self-sufficient. The format selected was similar to BS 5975 with separate sections on materials, loadings and design. One of the principal changes in the 2008 revision of the code was bringing together all of the procedural information into one section and to reiterate the importance of a named person to coordinate all aspects of temporary works. This role, which in previous revisions had been called Falsework Coordinator, was renamed Temporary Works Coordinator (TWC) to reflect the wider scope that was encompassed by the revised code. Formwork is part of temporary works and everyone involved in its procurement, design and use should make themselves aware of the relevant procedural sections in the code.

BS 5268 Structural use of timber Part 2: Code of practice for permissible stress design, materials and workmanship (Ref. 4). CIRIA Report C511 Controlled permeability formwork (Ref. 5), CIRIA Report C558 Permanent formwork in construction (Ref. 6), BS 6399-2 Wind Loads (Ref. 7), Concrete Society Checklists for Formwork (Ref. 9) and for falsework (Ref. 10)

The strength classes for timber, changes to exposure conditions and revised wood-based sheet material properties appeared in BS 5268 Part 2 (Ref. 4) in 2007, and revised trade association and suppliers' properties have been published since 1995. The effect of open-meshed products on the pressure of concrete has been further researched and published; the publication of CIRIA C511 *Controlled permeability formwork* (Ref. 5) has been shown to have an advantage on the long-term durability of concrete structures. The publication of CIRIA C558 on *Permanent formwork in construction* (Ref. 6) gave the industry guidance and informs both permanent and temporary works designers. Methods of determining wind forces have changed three times, initially with the application of BS 6399 Part 2 (Ref. 7) and then with BS EN 1991-1-4:2005 *Eurocode 1. Actions on structures. General actions. Wind loads* which superseded BS 6399 Part 2 on 1 April 2010. An amendment to BS EN 1991-1-4:2005+A1:2010 (Ref. 8) was effective from January 2011. This has affected the method of determining the overturning forces on wall formwork. The Concrete Society has also published checklists for supervisors for formwork and falsework (Ref. 9 and 10).

CS140 Guide to flat slab formwork (Ref. 11)

The European Concrete Building Project (ECPB) completed in 2000 and carried out at the Building Research Establishment (BRE), Cardington was a seven-storey in-situ flat slab commercial building. Extensive monitoring and research carried out on this structure has introduced faster and safer methods of construction. Implications for formwork and backpropping of multi-storey buildings were published in Concrete Society CS140 *Guide to flat slab formwork and falsework.*(Ref. 11). This Guide and BS 5975 (Ref. 3) have been informed by the research.

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The methods of control on site have changed, with few main contractors actually carrying out their own formwork, the majority employing subcontractors. In addition there has been a continued shift in design capability, with the majority of formwork design now carried out by proprietary equipment suppliers. This has led to significant changes in the lines of responsibility, management, liability, and design of all temporary works, including formwork. With this longer supply chain it is important that controls are in place to ensure the adequacy of the work carried out. BS 5975 (Ref. 3) addresses this and now incorporates detailed procedural controls and introduces categories of design checks for all temporary works. Design checks for formwork are introduced in Section 5.1.2 of this Guide.

Many contractors used to have separate temporary works design offices, employing and training experienced temporary works designers (TWDs), but this has changed as more schemes/designs are completed by proprietary suppliers. The emphasis on contractors' TW offices has shifted from initial design to checking, although the principal contractor retains the legal responsibility for the design and operation of the temporary works. This has had a detrimental effect on career progression in temporary works, with very few new opportunities for TWDs to obtain overall experience, apart from working and training in specific systems with proprietary suppliers. See the recommendations in Section 8.

Construction techniques have changed, with more emphasis on reusable system formwork than on the more traditional formwork of timber and plywood. This revision includes new sections on proprietary panel formwork, on handling soffit formwork tables with hoists, on the use of mobile elevating work platforms (MEWPs) for access to formwork, and on the special areas of climbing and jump forms, for example as used on lift shafts.

Eurocodes, EC2 Concrete (Ref. 12)
EC3 Steel (Ref. 13)
EC5 Timber (Ref. 14)

The use of limit state in design is increasing, with the publication of Eurocodes for concrete (EC2 Ref. 12), steel (EC3 Ref. 13), and timber (EC5 Ref. 14) solely in limit state terms. The majority of site engineers have only been taught this method at college/university. As there is a low turnover of personnel involved in temporary works design, both within suppliers and contractors, there is still some reluctance to change old habits of permissible stress – particularly because operatives remain 'thinking' only in safe load terms. Both formwork and falsework will change to limit state after a few years, but with both methods operating in parallel until experience and confidence have been gained in limit state. The republication of both BS 5975 in 2008 and BS 5268 Part 2 in 2002 in permissible stress terms, together with the opinion of the users and experts consulted, has led The Concrete Society to publish this edition generally in permissible stress terminology. One exception is timber, where modification factors affect the design stresses used; hence safe working loads for timbers and wood-based sheet materials are updated in Section 3.4. Appendix E has been added giving the user values of characteristic strength for timber to EC5 (Ref. 14 and 15) and other materials.

Timber characteristic strength - Appendix E

Permissible stress v. limit state

Although steelwork can be designed in limit state terms using BS EN 1993-1-1:2005 (Ref. 13), the appropriate partial safety factors for temporary works have not been agreed within the industry. Other changes have been the introduction of improved proprietary formwork systems and the increasing use of permanent formwork to reduce the labour content of formwork in use. Many of the systems are described in detail within the guide as their nature and operation are often not fully appreciated. New materials and ideas are given fuller consideration in the document than conventional materials and equipment.

A principal recommendation of the first Concrete Society Technical Report No. 13 *Formwork* published in 1977 (Ref. 1) was that design guides and textbooks to assist the education of personnel at all levels in the industry should be commissioned. It was considered that this had not been achieved in sufficient detail and that The Concrete Society should provide the necessary guidance and authoritative text for the industry. This guide has been written to promote good practice and give detailed guidance to both the newcomer and the regular user of formwork. Several sections contain more detail than will normally be necessary for the experienced reader, in particular Section 5 on design, but the result represents a significant contribution to the industry by identifying the problems and forces associated with formwork and providing for their solution. The worked examples, published separately, will allow the reader to follow the design philosophy of the guide. Section 1.6, on economics, is included to familiarise the inexperienced with the essential factors involved in the design of formwork which affects the final economics of both the temporary and permanent works.

Worked examples – See separate booklet
Section 1.6, on economics

The very practical nature of formwork, its attention to detail and the experience of the persons engaged in its design, based on their own knowledge and judgement, recommend that exhaustive and complex mathematics are rarely justified, and for this reason the guide is deliberately written in an easily understood format. The use of the tabulated typical loading cases in Appendix B will, with engineering judgement, provide safe and economic formwork designs for the majority of applications.

Typical loading cases in Appendix B

A separate section in the guide on computers and their application was not considered necessary as they analyse the mathematical problem and not the design problem. Whenever a computer is used in formwork design the relevance of the answer should always be related to the accuracy and assumptions of the initial input. For example, in a wall form design, the assessment of design concrete pressure will require judgement based on several factors; changing any one factor by a small amount may cause a disproportionate change in the pressure and change the answer, whether calculated by computer, or otherwise. The elasticity of the formwork system will also influence the final outcome on the site.

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thus rendering an exhaustive analysis unrealistic. As proprietary suppliers often use more sophisticated methods of computer design and analysis to that available to end users of formwork equipment, the ability to carry out independent checks becomes more difficult, and often is simply not possible. The assumptions made by suppliers in their analysis programs may not be available to end users, and careful verification of output is required. The supplier's responsibilities under 'sales of goods' legislation and HSWA (Health and Safety at Work etc. Act 1974) legislation is discussed further in Section 2 and Section 5.1.1. This increases the importance of simple design checks and rules of thumb listed in this Guide. Checking of formwork designs is discussed Section 5.1.2.

Research Recommendations are listed in Section 8

Further research and investigation is still needed in some areas and recommendations are listed in Section 8.

A mass of 100 kilograms (kg) exerts a vertical force of one kilonewton (kN)

In this guide the approximation is made that 100 kilograms (kg) exert a vertical force of 1 kilonewton (kN).

The diagrams in the guide are indicative of formwork systems and the concrete pressure diagrams are shown acting in the ''wrong direction'. This method of indicating the pressure is used throughout the guide and is standard practice in the industry.

1.2 Sustainability

The construction industry is a very large consumer of materials, and it operates on a growing scale. At the same time, concerns about the effects on the Earth's environment have been emerging and these concerns are now at the top of the agenda of issues faced by the construction industry.

Ecologists and environmentalists have proposed various criteria (such as carbon footprinting) for evaluating the impact of materials and energy use. The concept of sustainability has gained increased publicity in recent years. Formwork is no exception, and designers need to assess the impact of using certain materials, consider procurement from sustainable sources and minimise the environmental impact when disposing of temporary works materials. The economic implications, however, are outside the scope of this Guide.

The choice of formwork system to be employed will also impact upon sustainability during the construction phase of a project using concrete. The BRE booklet *Formwork for modern, efficient concrete construction* (Ref. 17) lists the sustainability features associated with the modern formwork systems currently available.

Formwork for concrete construction has traditionally been associated with waste from used formwork.

Use of resources and waste generation in the construction phase are key factors in sustainability.

These can be improved by:

- minimising material used by design and good housekeeping
- reuse of materials
- specifying materials with a high recycled content
- avoiding and reducing waste
- recovering wastes by recycling into new applications.

All of these actions can minimise carbon emissions and wider life-cycle environmental impacts and are likely to be cost-neutral or cost-saving.

The issue by the Department for Environment, Food and Rural Affairs (Defra) of the *Non-statutory guidance for site waste management plans* required on all construction projects over £300,000 from April 2008 are intended to reduce the amount of waste generated by construction (see www.defra.gov.uk). This legislation also helps identify costs which should help drive the sustainable use of resources on site. Where timber is used in formwork, it is recommended that, wherever possible, only material which is certified under the Forest Stewardship Council (FSC) scheme (see www.fsc-uk.org) should be used. This helps to ensure that timber is sourced from FSC certified forests which are managed sustainably. Within the scheme there is a Chain of Custody which tracks the timber through the supply chain to the end consumer.

Where formwork release agents are used, care should be taken to ensure any potentially significant contamination is avoided.

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1.3 Scope

BS 5975 Code of Practice for temporary works procedures and the permissible stress design of falsework (Ref. 3)

This guide covers good practice in the design, construction and safe use of formwork employed in in-situ and precast concrete work. The guide is complementary to BS 5975 *Code of Practice for temporary works procedures and the permissible stress design of falsework* (Ref. 3) and is intended primarily for use by the TWD and by those involved in supplying, constructing and supervising the work. It should be noted that this guide has been written in permissible stress terms and structural properties shown are recommended working values and, with the exception of timber in Appendix E, are NOT characteristic values. Additional information is provided to assist the permanent works designer (PWD) to take appropriate account of formwork in designing and specifying the permanent works.

1.4 References

The full titles of standards, publications and articles referred to in the guide are given in Section 9. The number of the reference is included in brackets in the text. In Section 2.3 and Section 5.9 several British Standards have been listed for information only and these are not referenced in Section 9. BS 5975 (Ref. 3) is considered to be a complementary document and is not always referenced in the text.

Advertisements at back of Guide provide further information on specialist suppliers

A useful trade index of proprietary equipment suppliers is given in the Concrete Society *Industry source book* published annually (Ref. 18). In addition, advertisements at the back of this Guide provide further information on specialist suppliers.

Readers of the guide wanting an insight into the day-to-day supervision and control of concrete on site including materials, production, placing and use of simple formwork are referred to the Concrete Society book *Concrete practice – guidance on the practical aspects of concreting* (Ref. 19).

Names and addresses of relevant organisations are not listed in this guide because internet search engines are readily available to provide up-to-date information. The relevant abbreviations of organisations are given in *Definitions and abbreviations*. The definitions used in this guide are generally in accordance with BS 5975 *Code of Practice for temporary works procedures and the permissible stress design of falsework* and with BS 6100 *Building and Civil Engineering. Vocabulary* (Ref. 20)

1.5 Economics of formwork and falsework

1.5.1 General

See Table 1

The cost of formwork and its associated falsework is a significant element of the total cost of constructing any concrete structure. In a typical in-situ reinforced concrete building the formwork and falsework may amount to between 35% and 40% of the total cost of the frame (see Table 1). In other types of construction (e.g. in-situ concrete bridges) the proportion may rise to between 40% and 55%; in a particular bridge structure the proportion was 65%, increasing significantly when working over water, to as much as 95% of the cost of the concrete structure.

From Table 1 it can be seen that where reasonable reuse of formwork materials is possible, the cost of labour and plant has the greatest influence on the unit price. It follows that efforts to reduce the cost of making, fixing and striking formwork are likely to yield greater savings than merely seeking the use of cheaper formwork materials. (See also Section 6.1 and Figure 103.) A useful review of construction techniques to maximise speed and economy is contained in the Building Research Establishment (BRE) publication BR 495 *Formwork for modern, efficient concrete construction* (Ref. 17). One way of eliminating striking of formwork is to use permanent formwork (see Section 3.9), with more detailed guidance given in CIRIA C558 *Permanent formwork in construction* (Ref. 6).

BR 495 Formwork for modern, efficient concrete construction (Ref. 17), C558 Permanent Formwork in Construction (Ref. 6)

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Table 1. Typical construction costs for a reinforced concrete frame.

Item	Material cost: %	Labour and plant cost: %	Percentage of total cost of structure: %
Concrete	15	8	23
Reinforcement	14	6	20
Formwork and falsework	9	30	39
Sundries	12	6	18
Total	50	50	100

Note: *The example assumes several uses of the formwork. See also Figure 103.*

1.5.2 Influence of the permanent works designer (PWD)

Table 1

The permanent works designer (PWD) should be aware of the interrelationships between the costs of concrete, reinforcement, formwork and other items. Some typical costs are shown in Table 1; however, the repetitive use of formwork will reduce the unit costs. Often a small increase in the size of a concrete member will make the placing and satisfactory compaction of the concrete easier and more assured whilst adding little to the overall cost. Thus the PWD's selection of member sizes and arrangements should take into account the effects of these on the formwork and other construction activities.

PWD to ensure design can take loading from temporary works (Ref. 21)

PWD check overall design and sufficient space (Ref. 22)

The PWD has a statutory requirement under the Construction (Design and Management) (CDM) Regulations to ensure that the design of the permanent works can support any loadings from the temporary works. See Clause 104 of the CDM ACoP (Ref. 21). In addition, Clause 2.6.8 of *CDM 2007 – Industry guidance for designers* (Ref. 22) requires the PWD to check that the overall design takes full account of any temporary works, and has allowed sufficient space, and adequate ground support, to construct the structure.

Other factors which can have an adverse influence on formwork costs are:

- variations in column centres
- variations in slab soffits
- variations in wall heights
- variations in beam sizes
- curved/radiused walls and soffits
- inclined walls and sloping soffits
- steps and staggers in walls and slabs
- box-outs
- inserts, particularly in walls
- corbels
- special joints
- special grades of tolerances for line, level and plane
- inappropriate as-cast finishes
- restrictions on the use, type and position of ties
- restrictions on sequence and timing of construction
- specification of specific materials that can affect sustainability and disposal.

The PWD should have regard for these factors in his design concept and attempt to dissuade other members of the design team from requiring them, unless they are fully appraised of the costs involved.

1.5.3 Influence of the temporary works designer (TWD)

See also Sections 2.2 and 5.1.1

The shape of the formwork follows from the requirements of the permanent works drawings and specification. However, within these parameters the temporary works designer (TWD) must make a number of decisions which affect the initial cost of the formwork, the cost of its use on site, and the indirect costs associated with other construction activities. The objective is to produce a functional temporary works design. There can be several parties involved in the formwork design and the responsibilities and methods involved to obtain a design are discussed in Sections 2.2 and 5.1.1. For example the design services of an equipment supplier will have a duty for design of their products, but not for the design of the whole temporary works – for this reason the TWD will most likely be from a contractor, subcontractor or contracted specialist design organisation. A well-engineered formwork and falsework scheme can have an effect on quality and cost well beyond the benefits accruing directly to the concrete work. For economy and good results formwork should be kept simple.

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See also Section 2.9 and Appendix A

Many of the factors affecting cost will be decided during the preparation of the temporary works design brief (see also Section 2.9 and Appendix A). The construction management will call for certain features as a consequence of site or programme restraints.

These may include:
- time of construction (season) and the need for insulation or solar protection
- mix design and concrete grade together with rate of placing concrete (maximum and optimum)
- crane capacity (weight and height)
- key dates for all or parts of the structure
- limitations imposed by phased construction
- site restrictions
- availability of key labour
- limitations on working hours, noise etc.
- availability of existing formwork/falsework equipment (plant holding etc.)
- use of materials that can affect sustainability and disposal.

Clause 8.4, BS5975, (Ref. 3)

The information in the design brief listed above, including those listed in Clause 8.4 of BS 5975, (Ref. 3) may not be sufficient for the design to commence. The TWD has an important role in assessing the adequacy of the design brief and adding further request items based on the TWD's experience and knowledge.

It will then be necessary to consider the concept of the temporary works design to conform with the brief and to consider the cost implications of the choices available.

These may include:
- position of construction joints
- few large pours or many small pours
- inexpensive face material with few uses versus more expensive material with more uses; alternatively, allow for refacing and/or repairs (see Figure132)
- clear span or multiple support
- ease of stripping and refixing (cycle time)
- the need for backpropping and repropping
- purchase or hire of support materials.

At the contract stage, the TWD may also consider proposing modifications to the design of the permanent works to permit the use of his preferred methods of construction and available equipment. Such modifications could only be undertaken after the full implications have been assessed and evaluated, and would need the approval of the PWD. When assessing the possible benefits the TWD should allow for the additional time (and costs) which may be expended when seeking such approval and during redesign.

1.5.4 Influence of the temporary works coordinator (TWC)

The role of temporary works coordinator (TWC) is defined in BS 5975 *Code of Practice for Falsework* (Ref. 3). The code gives recommendations for the requirement (see Foreword), appointment (see Clauses 6.3.1.1, 6.3.2.2, and 7.1), independence (Clause 7.2.4), responsibilities (Clauses 6.3.1.3, 6.4.3 and 7.2) and role (Clause 7.2.5) of the TWC.

The TWC plays an important role in coordinating the activities of all those involved in the provision of temporary works including formwork. As this expanding team of people involved in the procurement, design, supply and use of formwork will represent a large increase, probably involving several different separate organisations, it is vital that the TWC role is effectively carried out.

The main activities of the TWC, as given in BS 5975, are:
- to coordinate all temporary works activities;
- to ensure that the various responsibilities have been allocated and accepted;
- to ensure that a design brief is prepared with full consultation, is adequate, and is in accordance with the actual situation on site;
- to ensure that any residual risks, identified at the design stage, assumed methods of construction or loading constraints identified by the designer of the permanent works are included in the design brief;
- to ensure that a satisfactory temporary works design is carried out;
- to ensure that an adequate design check is carried out;
- where appropriate, to ensure that the design is made available to other interested parties, e.g. the CDM coordinator or the designer of the permanent works;

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- to register or record the drawings, calculations and other relevant documents relating to the final design;
- to ensure that those responsible for on-site supervision receive full details of the design, including any limitations and guidance notes associated with it and prepare a specific method statement;
- to ensure that checks are made at appropriate stages;
- to ensure that any proposed changes in materials or construction are checked against the original design and appropriate action taken;
- to ensure that any agreed changes, or corrections of faults, are correctly carried out on site;
- to ensure that during use of the temporary works all appropriate maintenance is carried out;
- after a final check, to issue formal permission to load/bring into use if this check proves satisfactory;
- when it has been confirmed that the permanent structure has attained adequate strength, to issue formal permission to dismantle the temporary works and specify any relevant sequence;
- to ensure that the temporary works is dismantled in accordance with a defined procedure.

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Section 2

Preamble to design

2.1 General

Formwork Designers' brief. Section 2.9 and Appendix A

Whenever carrying out a formwork design, whether simple or complex, the temporary works designer (TWD) will require to have access to certain detailed information prior to commencing the design. Often, within an organisation, the procedure for collating this information is formalised. This section of the guide details the collation of that information, commencing with the relationships between the various parties to the design, and then outlines the statutory requirements for safety. The comprehensive requirements for the formwork are covered by the formwork specification, the finishes, the tolerances and the permissible deflections of the formwork. Finally, all the information is assembled into the design brief before design proper is started. It is part of the responsibilities of the temporary works coordinator (TWC) to ensure that this process is carried out adequately. See Section 1.6.4.

Responsibility for achieving the specified result always remains with the contractor. Any approval that the permanent works designer (PWD) may give to formwork proposals does not reduce this responsibility.

2.2 Parties to the design

Roles and responsibilities of temporary and permanent works designers Table 21, BS 5975 (Ref. 3)

A satisfactory standard of construction requires the cooperation of all the parties concerned in the design. The principal parties usually involved are the permanent works designer (PWD), the contractor, the temporary works designer (TWD), the subcontractors, and the supplier of specialist or proprietary equipment. The TWD will most likely be from a contractor, subcontractor or contracted specialist design organisation. The TWD may utilise the services of the proprietary equipment supplier's staff whilst retaining overall duty for design of the whole temporary works. Although the PWD has an important influence on the formwork and falsework through drawings and specifications (see Section 1.6.2), the PWD will rarely have any direct involvement in the design process for the temporary works, which will normally only involve the contractor, subcontractor, TWD and equipment supplier. More information on the relationship, roles and responsibilities of the parties to the design is given in Table 21 of BS 5975 (Ref. 3.)

In design-and-build contracts the principal contractor accepts a proportion of the risk associated with the project and will usually carry out his own quality assurance of the formwork design. Although the parties to the formwork design may not be as clearly defined as under 'conventional' contract, there will still be separate responsibilities taken for the permanent and the temporary works designs. In effect, the PWD is employed by the contractor.

2.2.1 Permanent works designer (PWD)

The PWD should:

(a) Have due regard to the Construction (Design and Management) Regulations (Ref. 23) and the Health and Safety Executive's (HSE's) *Managing Health and Safety in Construction. Approved Code of Practice* (Ref. 21) concerning risks to health and safety, both those within the PWD's sphere of influence and those outside it, so far as is reasonably practical. This includes passing on information on any foreseen hazards and risks to the construction. The Regulations also require a CDM co-ordinator to be appointed with duties to reduce risks, such as in the use of formwork. See also Section 2.3.

(b) Have due regard to ensuring that the permanent works is buildable allowing for a safe system of work, and that it can support any loadings from temporary works.

(c) Ensure that there is sufficient space for the temporary works.

(d) Have due regard to economy, sustainability and feasibility of formwork in preparing the design for the structure, by rationalising dimensions and simplifying outlines to allow reuse and to reduce complexity of forms,

(e) Describe adequately the required outlines and finishes by means of drawings and specification clauses, if necessary, amplified by other suitable means, such as reference to sample panels.

(f) Make available samples of any special surface finish or member to illustrate what is required and indicate where its uses can be seen.

(g) Specify any limits which have to be placed on formwork removal, propping and support of the completed structure.

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(h) For beams, slabs and cantilevers, make available the design working load and grade of concrete specified for assessment of striking criteria. In multi-storey construction, the method of assessment of concrete strength at early age should be included.

(i) Specify any limits on size of pours, position of construction joints and any special sequences of construction required by the design.

(j) State for what work, if any, the contractor will be required to submit details of the formwork for comment before fabrication is commenced.

(k) Describe, for approval before work is begun, any trial panels or members which the contractor is required to construct.

(l) When considering specifying proprietary equipment, such as waffle or trough moulds or sculptured forms, in order to produce a particular result, be satisfied that the result can be achieved from the equipment in question – for example, by consulting the proprietary supplier or examining examples of finished work.

2.2.2 Contractor

The contractor undertaking the work should:

(a) Examine the specification, drawings, sample panels etc. at tender stage, to ensure that prices are properly formulated.

(b) Raise with the PWD, during tender stage, any point in the contract documents which is considered insufficiently clear to price properly.

(c) Draw to the attention of the PWD any items which require clarification.

(d) State clearly any alternatives to specified methods which may be used. Quoted rates for the work should be for methods as specified, but rates may also be given for alternatives offered.

(e) Design and construct formwork to the appropriate standard to achieve the specified results and to ensure the safety of all parties concerned.

(f) Ensure adequate quality of materials, workmanship and supervision to achieve the specified requirements.

(g) When specified by the PWD, provide details of formwork for comment and/or approval before commencing fabrication.

(h) Construct trial panels or members if specified, and obtain the approval of the PWD before proceeding further with the work.

(i) Ensure that all proprietary formwork specified complies with the description on which the design of the concrete work has been based.

(j) Provide any formwork subcontractor with full information from the documents and details of the work to be carried out.

See Section 5.1.1

(k) Ensure that the terms of appointment of any formwork subcontractor and/or proprietary supplier are clearly set out and agreed, and that the subcontractor and/or proprietary supplier adequately discharge all responsibilities entrusted to them (see Section 5.1.1).

2.2.3 Temporary works designer (TWD)

The temporary works designer (TWD) should:

(a) Comply with the Construction (Design and Management) Regulations (Ref. 23) with regard to risks to health and safety, both those within the TWD's sphere of influence and those outside it, so far as is reasonably practical. This includes passing on information on residual risks to those carrying out the work.

(b) Have adequate procedures to ensure that all designs produced are safe.

(c) Carefully study the design brief, and clarify with the TWC prior to commencing the design any items that are unclear. If appropriate, discuss and agree alternative options with the TWC to ensure that the most appropriate solution is designed.

(d) Design formwork and falsework to the appropriate standard to achieve the results specified in the design brief.

(e) Ensure that the design is buildable, allowing for a safe system of work at all stages of use.

(f) Have due regard to economy by standardising formwork panels, and by making the equipment efficient to assemble and use/reuse.

(g) Describe the design adequately, typically by drawings/sketches and, if appropriate, user manuals.

(h) Perform a designer's risk assessment.

(i) Prepare a designer's outline method statement if relevant.

(j) If required, perform a design check.

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2.2.4 Subcontractor

It is common for contractors to employ specialist subcontractors to carry out formwork operations. These subcontractors are almost always of the contractor's own choice. Having appointed a subcontractor, the main contractor should supervise the design and erection in such a way that operations are carried out in a safe manner and that the specified result is achieved. Only when there are very special requirements for formwork, perhaps involving special decorative finishes or important structural elements, are specialist subcontractors nominated by the PWD in the main contract.

The range and scope of the subcontractor's work can vary considerably depending on the nature of the job in question, the contractor's requirements and the subcontractor's capabilities. It is neither possible nor desirable to make detailed recommendations in this regard.
Proprietary systems of formwork are increasingly owned and used by subcontractors, but with designs provided by third-party designers. The control of the design interface takes on significant importance. See BS 5975 (Ref. 3).

When a subcontractor is appointed, the contractor's contractual and statutory responsibilities for quality and safety of work respectively cannot be delegated to them, though at the same time the subcontractor has duties regarding the safety legislation in force at the time. In the same way, when appointing the proprietary suppliers as designer, the subcontractor retains the duties regarding the safety legislation in force at the time. (See also Sections 2.3 and 5.1.1.)

See also Sections 2.3 and 5.1.1

2.2.5 Supplier of specialist or proprietary equipment

See also Section 3.3

Suppliers of formwork equipment, whether as manufacturer, agent or importer, have specific duties under the Health and Safety at Work etc. Act 1974 (Ref. 24) to ensure that their products are properly designed for safe use, and that sufficient information is available. See also Section 3.3 for the type of information likely to be supplied. As this duty applies to all designers, including those designing formwork, a more detailed explanation is given in Section 2.3 of this Guide.

Items excluded from the design to be covered by others

Most suppliers will provide a service to relate the use of their products to specific jobs – often as a 'free' service. The design element will generally be limited to equipment supplied by them and may exclude site timber details, foundation/fixing details, stability conditions and items supplied by others. All exclusions should be clearly stated on the drawings and must then be reviewed by the TWC and the TWD, and subsequently addressed by the contractor or subcontractor. Often during the tender process the supplier will produce drawings intended for pricing purposes only and not for the erection of equipment. It is important that all such drawings are upgraded to working/construction status prior to the equipment being used. Because the supplier's designer will usually be remote from the site, it is essential that the drawings produced are carefully reviewed by the construction team to ensure that:

- the current structural drawings have been used
- the design complies with the design brief
- the layout of equipment satisfies the requirements
- the assumed loadings are appropriate
- reactions can be adequately resisted
- the arrangement is buildable to the method statement
- any residual risks highlighted in the design can be addressed
- any items that have been excluded from the design are adequately covered by others.

Interpretation of suppliers' drawings

Particular care is needed in the interpretation of suppliers' design drawings as the style or content may be unfamiliar to the operatives. The industry concerns over interpretation of such drawings was highlighted in 2001 in the HSE Report 394/2001 *Investigation into aspects of falsework* (Ref. 25). This highlights the importance of adequate temporary works procedures and design checks (see Section 5.1. and BS 5975). (Ref. 3) Where the contractor or subcontractor intends to make use of such a service a comprehensive design brief should be provided. (See Section 2.9 and Appendix A.) Regardless of method of design and procurement of the formwork and falsework, the responsibilities for the overall design remain a duty of the principal contractor (under the CDM Regulations).

See Section 2.9 and Appendix A

2.3 Safety legislation

CDM – Construction (Design and Management) Regulations (Ref. 23)

There are a large number of separate pieces of legislation that are relevant to the formwork contractor. The introduction in 1995 of the Construction (Design and Management) Regulations (Ref. 23) imposes significant duties on the designers (PWD and TWD) which will only be properly dealt with if the designer understands the duties imposed on the contractor.

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Also refer to the Designers Guide (Ref. 22) HSWA (Ref. 23) and HSE Guide (Ref. 26)

Previously, the principal Acts dealing with safety on construction sites were the Factories Act 1961 and the Health and Safety at Work etc. Act (HSWA) 1974 (Ref. 24). The HSE Guide covers the HSWA (Ref. 26).

The HSWA has carried over into statute law the common law concept of a 'duty of care' and covers most work situations in respect of safety and health, not only for employers and employees but also for the self-employed, persons in control of premises and members of the public affected by the work activities.

Employers now have a statutory duty to ensure that their employees are given adequate information, training and supervision, and further, that they are provided with a safe and healthy place of work.

All designers and suppliers of formwork equipment should particularly note section 6 of the HSWA which states that it shall be their duty:

(a) to ensure, so far as is reasonably practicable, that the article is so designed and constructed that it will be safe and without risks to health at all times when it is being set, used, cleaned or maintained by a person at work';

(b) to carry out or arrange for the carrying out of such testing and examination as may be necessary for the performance of the duty imposed on him by the preceding paragraph;

(c) 'to take such steps as are necessary to secure that persons ("the customer") supplied by the person ("the ostensible supplier") with the article are provided with adequate information about the use for which the article is designed or has been tested and about any conditions necessary to ensure that it will be safe and without risks to health at all such times as mentioned in the paragraph above and when it is being dismantled or disposed of; and

(d) to take such steps as are necessary to secure, so far as is reasonably practicable, that persons so supplied are provided with all such revisions of information provided to them by virtue of the preceding paragraph as are necessary by reason of its becoming known that anything gives rise to serious risk to health and safety.

The scope of and detail in the safety legislation has been considerably widened by a series of regulations enacted under both the principal Acts.

2.3.1 Regulations enacted under the Factories Act 1961

Those under the Factories Act include the:

- Work at Height Regulations 2005 as amended by the Work at Height (Amendment) Regulations 2007 (Ref. 27)
  - This describes the requirements for a suitable work platform and means of access including their widths and side protection.
- Lifting Operations and Lifting Equipment Regulations 1998 (Ref. 28)
  - This covers the requirements for mechanical lifting including the use of chains and slings etc. and their testing and inspection. The HSE Guidance Note L113 covers the LOLER Approved Code of Practice (Ref. 29).

2.3.2 Regulations enacted under the Health and Safety at Work etc. Act 1974

Those under the Health and Safety at Work etc. Act 1974 include the:

HSE Guidance note L5 on COSSH approved codes of practice (Ref. 30)

- *Control of Substances Hazardous to Health Regulations 2002*
  - This regulation, widely referred to as COSHH, sets out the requirements for the handling and control of any substance that might be a risk to health. The HSE Guidance Note L5 covers the COSHH approved codes of practice (Ref. 30).
- *Noise at Work Regulations 2005*
  - This sets out the noise limits to which persons should be subjected.
- *Control of Vibration at Work Regulations 2005*
  - This gives requirements that govern exposure to vibration and assists with preventing the occurrence of *hand–arm vibration syndrome* (HAVS; known more commonly as '*vibration white finger*').

Good practice in industrial health and safety management requires that worker vibration exposure is assessed in terms of acceleration amplitude and duration. Using a tool that vibrates slightly for a long time can be as damaging as using a heavily vibrating tool for a short time. The duration of use of the tool is measured as trigger time, the period when the worker actually has their finger on the trigger to make the tool run, and is typically quoted in hours per day.

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The HSWA also enables the Health and Safety Inspectorate to take action by issuing notices:

- **Improvement Notices** give any person who contravenes the law a specified period for the contravention to be remedied and the defective item or system brought up to standard.
- **Prohibition Notices** can become effective immediately or state a time after which the activity will be prohibited unless the required steps are taken.

The penalties and possible imprisonment for infringement of regulations was extended in early 2009 by the Health and Safety Offences Regulations 2008, giving clearer guidance to courts.

In addition, regulations have also been prepared under HSWA to enact a series of EU Safety Directives.

These include the:

HSE Guidance Note L21 Management of Health and Safety at Work (Ref. 31)

- *Management of Health and Safety at Work Regulations 1999*
  - This important piece of legislation introduces the concept of risk assessment which should be undertaken by those who have control of the work or whose job influences how the work is done. Refer to HSE Guidance Note L21 (Ref. 31).

HSE Guidance Note L22 on provision and use of work equipment regulations (Ref. 32)

- *Provision and Use of Work Equipment Regulations 1998*
  - This requires that equipment should be so arranged and designed that it can be easily controlled by the operative. Refer to HSE Guidance Note L22 (Ref. 32).

HSE Guidance Note L25 on personal protective equipment at work regulations (Ref. 33)

- *Personal Protective Equipment at Work Regulations* 1992 (as amended)
  - This sets out the requirements for the hard hats and other protective equipment to be worn by persons on site. Refer to HSE Guidance Note L25 (Ref. 33).

HSE Guidance Note L23 on manual handling (Ref. 34)

- *Manual Handling Operations Regulations* 1992 (as amended)
  - This limits the weight of the loads that are lifted manually. Refer to HSE Guidance Note L23 (Ref. 34).

The most important regulation to implement the EU Temporary and Mobile Works Sites Directive is the:

CDM Construction (Design and Management) Regulations (Ref. 23). Refer also to the Approved code of practice, and HSE Guidance note L144 (Ref. 21), and HSE Guidance for Designers (*.pdf only) Ref. 22)

- *Construction (Design and Management) Regulations* 2007 (Ref. 23).
  - This regulation, commonly referred to as the CDM Regs, came into force on 6 April 2007. These regulations highlight the duties of the CLIENT and the DESIGNER (i.e. PWD and TWD) in controlling risks to health and safety, both to those within their sphere of influence and those outside it so far as is reasonably practicable. The regulations also introduce the concept of the CDM Coordinator and the principal contractor. The CDM Coordinator is required to ensure cooperation between the TWD and the PWD and is able to require alterations to the design if it is necessary to reduce the risks to health and safety.The regulations have both an Approved Code of Practice (refer to HSE Guidance Note L144 (Ref. 21) and HSE Industry Guidance for Designers (Ref. 22).

Particular safety considerations are outlined below.

The Work at Height Regulations (2005) (Ref. 27), Section 7.6.2

- The provisions of adequate access and working platforms are covered by the Work at Height Regulations (2005) (Ref. 27). This is an important consideration in formwork design. Section 7.6.2 gives detailed guidance on access and working platforms.

Section 5.9

- The mechanical handling of formwork on site is covered by the Lifting Operations and Lifting Equipment Regulations 1998 (Ref. 28). Although not strictly formwork, it is a critical operation on site. Section 5.9 of this guide gives references and design information for formwork when mechanised handling is involved.

COSSH Approved codes of practice (Ref. 30)
HSE Guidance Notes on labels for chemicals are L131 (Ref. 35)
Working with substances hazardous to Health (Ref. 36)

- The increasing use of chemicals on site can cause hazards. The Control of Substances Hazardous to Health Regulations 2002 (known as COSHH) give the requirements for the handling and control of these chemicals on site (Ref. 30). All such materials should be clearly marked. Useful guidance to the labelling of such products is provided in the HSE Guidance Note L131 (Ref. 35). A useful publication for site use is the HSE publication *Working with substances hazardous to health* (Ref. 36). In enclosed environments in particular, toxic fumes can be dangerous. Users of such substances should be made aware of the applications and limitations of each chemical.

Section 5.3.7

- Particular care is necessary in striking soffit and beam forms. Guidance on suitable striking procedures is given in Section 5.3.7.

CSG/005 A Guide to the Safe Use of Formwork and Falsework (Ref. 37)

SG4:10 Preventing falls in Scaffolding (Ref. 38)

The formwork designer and the site personnel should all be aware of the detailed requirements for safety in the assembly, handling and striking of formwork. Useful guidance on safe use is contained in the following books: CONSTRUCT CSG/005 *A guide to the safe use of formwork and falsework* (Ref. 37); NASC SG4: 10. *Preventing falls in scaffolding* (Ref. 38); and NASC pocket booklet User Guide to SG4: You. *Preventing falls in scaffolding* (Ref. 39). Some general items for consideration are given in Section 7.6.

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2.4 Formwork specification

2.4.1 General

A properly conceived and appropriate specification is of paramount importance to all parties involved in the construction process. Unnecessarily exacting specifications which may be difficult to achieve should be avoided.

Specification for Highway Works (Ref. 40), CESWI (Ref. 41), National Building Specification (Ref. 42), BS EN 13670 (Ref. 43), NSCS (Ref. 44)

The three main UK specifying authorities for the majority of concrete construction are the Highways Agency (Ref. 40), the water industry (CESWI) (Ref. 41) and National Building Specification Ltd (Ref. 42). BS EN 1992-1-1:2004: *Eurocode 2. Design of concrete structures. General rules and rules for buildings* (Ref. 12) gives the rules for design but does not specify the surface finishes. The surface finishes are introduced in BS EN 13670 *Execution of concrete structures* (Ref. 43), which have been incorporated into the *National Structural Concrete Specification for Building Construction* (NSCS) fourth edition (Ref. 44).

See Section 8.1, Item 2.

Section 2.5

There are differences between the specifications and it is a recommendation of this Guide that more standardisation of specifications is needed (see Section 8.1, item 2). The contractor should, wherever possible, be given the option of proposing alternative means of achieving the outline or surface finish required. Section 2.5 details the classes and likely materials for achieving different concrete surface finishes.

2.4.2 Specification by method or performance

A performance specification is a description of a desired end result, whereas a method specification is a description of how the specifier requires that a result is to be achieved.
Clause 8.8 of BS EN 13670 (Ref. 43) states that requirements, if any, for the finish of formed or unformed surfaces shall be given in the execution specification.

Specifications should be written in performance terms as far as possible, so enabling the contractor to optimise his procedures and use equipment and expertise available to him. The contractor should be given all necessary liberty in the manner of the execution of the work because he carries contractual liability for its production. In addition, performance specifications have the advantage of avoiding disputes that arise when the contractor's implementation of a method specification fails to achieve the required result. If the specifier cannot anticipate the end result of his performance specification then the specifier should call for trials.

See Section 2.8, Sample and trial panels

There may be instances when the nature of the work demands a method statement. Method statements tend to be needed where special surface finishes are required, but may be avoided by providing sample panels or photographs or citing sections of nearby finished work. It is always advisable to allow the contractor to propose alternative methods.

The main difficulty in the use of performance specifications is that the PWD will be aware at tender stage of the required end product but may not be aware of the method the successful contractor will adopt. This can be overcome by specifying that the contractor advises the PWD of the proposed methods prior to commencement of formwork construction, in order that the latter has the opportunity of commenting on the procedure in the light of the requirements for the finished result.

TR52 Plain Formed Finishes (Ref.45)
CONSTRUCT Sample Panels
Section 2.5.2 and Figure 5

Specification by performance places a greater workload on site supervisory staff. In particular, advice by the PWD's representative that the formwork will not produce the required result, will not necessarily be accepted by the contractor. Insistence that procedures be modified may result in a variation to the contract, changes in responsibility and increased costs. The introduction of sample panels in various locations in the UK for the basic NSCS finishes shown in Figure 5, and certain Highways Agency finishes, together with quality photographs such as in TR52 *Plain formed concrete finishes* (Ref. 45), can give PWDs and contractors a visual record of the likely appearance of a specified concrete surface using local materials, and workmanship.

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2.5 Finishes

2.5.1 General

The prime purpose of formwork is to form and contain the concrete. Frequently, formwork materials which perform this function adequately cannot be relied upon to give a satisfactory finish.

If there is a particular concern about the finish, texture, pattern or appearance of the hardened concrete the requirements should be accurately specified since such finishes are more costly to produce. A set of useful reference documents is given in the *Visual Concrete* series published by The Concrete Society (Ref. 46). The fundamental aspects of visual concrete are discussed in *Visual Concrete – Planning and assessment*. Blemish-free concrete finishes of uniform colour and texture are very difficult if not impossible to produce consistently. This is discussed in *Visual Concrete – Control of blemishes*. A useful visual guide to the variety of finishes available is the Qi Training DVD *Finishes in concrete* (Ref. 47) and The Concrete Society's Technical Report *Plain formed concrete finishes* (Ref. 45).

Visual concrete series (Ref. 46)

Among the basic considerations for exposed concrete finishes are durability, appearance and weathering. Generally speaking an 'open' textured finish may have a better resistance to weathering than a smooth 'closed' finish. The subject of design for weathering, including the effect of rain washing dirt down the structure, is very important and deserves separate detailed consideration. See also *Visual Concrete – Weathering, stains and efflorescence* (Ref. 46).

Visual Concrete Series (Ref. 46)

Assess quality for viewing for: close quarters at 1m , external buildings at 3m, civil engineering in general 6m (Ref. 46)

The importance of the appearance of a concrete finish is relative to the observer. There is no point in specifying a high-quality finish unless it is really required. The appearance of concrete should relate to its environment and its proximity to those who will be living with it.

Rendering – a practical handbook (Ref. 48)

Thus before specifying a finish these aspects should be considered and assessed, and specified accordingly. Certain situations will require the addition of paints or renders to the concrete surface as discussed in *Rendering – a practical handbook* (Ref. 48).

Whilst the difficulties of producing finishes of uniform colour and texture cannot be overemphasised, the chances of success can be improved by considering the following factors:

- The right concrete mix.
- Consistency of the concrete and its materials.
- Use of a constant rate of placing,
- Uniformity of compaction.
- Uniformity of face contact material,
- Avoiding the direct flow of concrete against the form face by the use of a baffle, raised as concreting proceeds. Similarly, there should never be a surcharge of more than 150 mm above the compacted concrete and placing should be in a steady stream so that vibrators consolidate from the bottom upwards.

See Section 5.7

- Walls and columns should have a minimum of joints and preferably be in one lift. See Section 5.7.

See Section 3.10

- The correct choice of formwork pretreatment and release agent. See Section 3.10.

See Section 2.8

- Trial panels, if required, should be made using similar materials, formwork and placing techniques to those planned for the permanent works. See Section 2.8.
- It is difficult to reproduce complicated features on vertical faces since they tend to trap air bubbles, encourage plastic cracking and local honeycombing. Features should be designed to be predominantly vertical, such as ribbing, and permit easy runoff of water and dirt. Horizontal or sloping features will often weather badly.

See Sections 2.5.10 and 3.7.8

- Sloping inward faces, and top forms, can be improved using controlled permeability formwork (CPF) fabrics to almost eliminate blowholes. See Sections 2.5.10 and 3.7.8.
- The period between completion of concreting and stripping the formwork should be constant for all panels of a wall where minimising variations in colour. This is of particular importance for impervious face materials.

2.5.2 Classes of finish

Finishes should be specified so as to provide the appropriate desired finish. Whilst the quality and complexity of the formwork will vary, all formwork must satisfy the requirements for structural integrity, safe handling, grout-tightness, watertightness and compliance with the safety regulations.

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Table 2. Approximate comparison of the major UK specifications for concrete finishes.

Specification for Highway Works	CESWI*	National Building Specification	BS EN 13670 and NSCS (4th edition)	See Section	Comments and typical applications
F1	Rough finish	Basic finish	Basic finish	2.5.3	Foundations, unseen
F2		Plain smooth	Ordinary finish	2.5.4	Back of retaining walls, car park beams/ columns
F4	Fair finish	Fine smooth finish	Plain finish	2.5.6	Visible surface, bridge abutments, ties allowed
F3 (see Note 1)				2.5.5	Visible surfaces but NO ties. Parapet edges etc.
F5				2.5.7	Precast items, embedment of metal parts allowed
–	Fair worked finish	–	–	2.5.8	Aqueous liquid-retaining faces
Special finishes		Rough board finish Ribbed finish Proprietary liner Abrasive blasting Finish for tooling	Special finish	2.5.9 and 2..5.10	Functional or aesthetic finishes including enhanced durability

**CESWI: Civil Engineering Specification for the Water Industry (Ref. 41).*

Notes to Table 2:

(1) Note the sequence of the Specification for Highway Works classification is in consideration of difficulty in achievement.

(2) The table is intended for general guidance. Varying interpretations and additional clauses may change the specification on specific contracts.

(3) The NSCS finish Type A, B etc. was discontinued with publication of the 4th edition.

SHW, Volume 1, Structural Concrete, Cl 1708 (Ref. 40) CESWI Cl 4.22 (Ref. 41) NBS for Section E20 Cl 610 to 710 (Ref. 42) NSCS (Ref. 44) BS EN 13670 Execution of concrete structures (Ref. 43)

Typical classes of finish for formed surfaces are specified in the *Specification for Highway Works, Volume 1, Structural Concrete*, Clause 1708 (Ref. 40), the *Civil Engineering Specification for the Water Industry* (CESWI) Clause 4.22 (Ref. 41), National Building Specification *Formed finishes* for in-situ concrete Section E20 Clauses 610 to 710 (Ref. 42), the *National Structural Concrete Specification* edition 4 (Ref. 44), and BS EN 13670 *Execution of concrete structures* (Ref. 43). The specifications are similar in many respects.

Table 2 makes an approximate comparison of the terminology used to describe the finish in these specifications. The exact division between the finishes is subjective and is shown diagrammatically only; individual contract specifications may vary.

Reference Panels in UK for ordinary and plain finish Figure 6 http://www.construct.org.uk/surfacefinishes.html

Reference Panels in UK for SHW Class F2 and F4 http://www.construct.org.uk/surfacefinishes.html

The terms Type A, B and C finishes, previously referred to in both BS 8110 (Ref. 186)and the earlier versions of the *National Structural Concrete Specification* edition 3, have been replaced by the terms 'ordinary', 'plain' and 'special' as per the European description of finishes in BS EN 13670 (Ref. 43). The term 'basic finish' is unchanged. The *National Structural Concrete Specification* (Ref. 44) has been updated to suit. The pairs of reference panels that have typical Type A and Type B finishes have been renamed as 'ordinary' and 'plain'. These panels are located at several sites around the UK and may be inspected to help gauge the appearance of the standard quality expected for these finishes (see Figure 6). To assist visitors in their assessment of the panels on display, detailed notes for guidance are available at each site. The locations can be found at; www.construct.org.uk/surfacefinishes.html. Panels with typical finishes Classes F2 and F4 as specified in the *Specification for Highway Works* can also be found at some of these locations.

TR52 Plain Formed Finishes (Ref. 46)

Another useful reference is The Concrete Society publication TR52 *Plain formed concrete finishes* (Ref. 45) which contains details of 22 examples of 'plain formed concrete finishes' on actual concrete structures, with colour-matched photographs taken under controlled conditions. The finishes illustrated all met their specifications, so they provide a benchmark to the quality of work being achieved. Details of the specification, concrete mix and formwork are given for each example. The main specifications in current use and the assessment of surface quality are also considered in the report.

"a smooth surface"

Care should be taken with specifications that include words and phrases that are not fully defined; often these can lead to different interpretations by the parties involved on site. For example, what is 'a smooth surface'? The *Specification for Highway Works* for Classes F3, F4 and F5 states 'The resulting finish shall be smooth ...' and the CESWI specification for fair finish states 'forms designed to produce a hard smooth surface'. The manufacturing tolerance on the thickness of most wood based sheet materials is

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0.5 mm giving a possible 1 mm lip at joints (see Section 3.3.2.5). This can increase to 1.5 mm if moisture contents of adjacent sheets are considered. Even when using proprietary special items the tolerance on the thickness of materials at joints will still be 0.5 mm. Consider the connection between formwork items that are bolted together: using standard 2 mm clearance holes for bolts gives a possibility of maximum misalignment of 4 mm, which in practice would be controlled and limited. These are known as induced deviations (see Section 2.6.1) which need to be considered, but all will introduce a surface deviation not precisely smooth.

In contrast, the NBS specification also uses 'smooth' but defines the limits: for a plain smooth surface it states 'abrupt irregularities to be not greater than 5 mm' and for the fine smooth finish it limits the abrupt irregularities to 3 mm. The NBS also gives guidance on gradual irregularities expressed as a permissible deviation from a 1 m straight edge. (Note: this is not the deflection limit – see Section 2.7.)

Assess quality for viewing for: close quarters at 1m , external buildings at 3m, civil engineering in general 6m (Ref. 46)

Specifications that imply that the formwork face should impart NO blemishes on the concrete are also unrealistic in practice. The reader is referred to *Visual Concrete – Control of blemishes* (Ref. 46) which suggests that all civil engineering structures should be viewed from 6 m or greater when assessing the quality of surface, reducing to 3 m on buildings and 1 m on surfaces that can be seen from close quarters. One way of controlling the blemishes is to give tolerances on colour variations and also limit the permissible blowhole size. This is stated on certain finishes in the NBS specification.

Whilst the *Specification for Highway Works* is primarily intended for bridge structures, it is often used in other classes of work directly or by reference.

2.5.3 Class Fl, basic or rough/board form finish

This class of formwork is the least costly of the classes. It is normally used where appearance is of minimal or no importance, e.g. backs of retaining walls and abutments, foundations, inside faces of voided structures, areas to be subsequently clad, rendered or plastered – in fact, any non-exposed concrete. An example is shown in Figure 1.

Figure 1

Whilst appearance is of minimal or no importance, the formwork should still be structurally adequate, grout-tight and watertight, be safe for handling and comply with the safety regulations. However, the class does not permit the use of second-hand face contact materials of mixed type and irregular pattern, which may have had many uses and been repaired. Allowance may have to be made for reduction of strength of second-hand materials, particularly plywood.



Figure 1. Example of a basic/Fl finish to a wall to be subsequently clad.

2.5.4 Class F2, ordinary finish

This class is more costly than Class F1/basic/rough and is confined to exposed areas not normally or easily visible, e.g. inward-facing beam sides, the insides of box beams, deck soffits between beams, walls and undersides of ceiling slabs in plant rooms, inside ducts or lift shafts. It is recommended that plywood-faced or proprietary panel forms be used for this class (see Section 3.2.2). Sound, used forms will probably suffice; however, care will be required to prevent grout loss at joints. Some repairs to the formwork, nail holes, joints or other materials can be accepted.

Panel Systems give F2, 3.2.2

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An example is shown in Figure 2 for the external face of a wall to a large tank achieved using proprietary panels. Other examples of this finish are the walls to a culvert shown in Figure 3, and the underside soffit of a building shown at Figure 28.



Figure 2. Example of ordinary finish on a wall.

See Section 2.5.9

Some clauses of old specifications refer to board forms. The production of consistently good finishes with boards or planks is difficult and expensive and is not recommended for this class. Use of 'sawn board' formwork is covered in Section 2.5.9.

Imperfections and non-uniformity of colour are normally permitted as is the making good of blowholes, fins and discolouration. Making good of small areas of defects such as honeycombing and grout leakage may sometimes be permitted dependent on their position and extent. This finish also applies to areas required to receive an applied render finish.



Figure 3. Example of an ordinary/F2 finish to walls of underpass with an F3 finish to edge of deck.

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2.5.5 Class F3, plain finish without ties

This class of plain finish applies also to the surface known as Class F4 (see Section 2.5.6 below) in the Highways Agency Specification, with the additional requirement of no tie rods as restraint. Designing and using vertical formwork of any significant height without ties is difficult. Pour heights above 2.5 m are particularly difficult without through ties as the size of strongbacks necessary to control deflection makes the forms very expensive, heavy and difficult to handle. Absence of anchorage points at the top of the previous lift makes good grout-free construction joints very unlikely

Figures 3 and 4

Most clients restrict 'no-tie' areas to the edges of bridge decks and parapets, but even these can present a contractor with problems, such as when in-situ sections have to be attached to steel or precast concrete girders. Examples are shown in Figures 3 and 4. CIRIA Report 155 Bridges – design for improved buildability

Limit F3 on bridge edges (Ref. 49)

(Ref. 49) strongly recommends that on bridge edges this Class F3 be limited to small areas, such as the vertical edge face of a parapet form, and not the whole edge elevation. Some specifications permit ties and specify that they shall be evenly spaced, placed in grooves or where their presence can be disguised or hidden. Obviously the use of textured surfaces facilitates this. The required finish may be obtained

See Section 3.9

using permanent formwork – see Section 3.9.



Figure 4. Example of an F3 finish to a bridge parapet edge with special finish to wing wall.

2.5.6 Class F4, plain class finish

Figure 5 and 13

This class (and particularly F4 in the *Specification for Highway Works*) is intended for visible surfaces. Typical areas are the sides of bridge superstructures, piers, abutments and retaining walls, and walls of buildings. Examples are shown in Figures 5 and 13.



Figure 5. Example of an F4 finish to bridge pier with F3 facings.

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Section 2.5.1

Plain, unblemished concrete of uniform colour is extremely difficult to produce with predictable certainty. Many factors affect appearance which are beyond the scope of this guide, but some are given in Section 2.5.1.

The task of producing this class of finish is a formidable one. Only very minor inherent surface blemishes should occur, with no discoloration from release agents. Given certain conditions an inexpensive form may produce results equally acceptable to those obtained from expensive purpose-made forms. However, the use of expensive forms will not guarantee acceptable results if the quality of workmanship is substandard.

Visual concrete - Finishes (Ref. 46) See Sections 3.9 and 3.12

Where a large plain untextured surface is produced there is nothing to draw the eye away from any blemishes which may occur. Thus it is sensible, where appearance is important, to provide significant features, or to make such surfaces patterned or textured using one of the many techniques now available, such as form liners or permanent formwork. See *Visual concrete – Finishes* (Ref. 46) and Sections 3.9 and 3.12.



Figure 6. The NCSC sample panels of ordinary and plain finish.

***Note**: The panels shown are representative of the 'ordinary finish' (former Type A) (seen on the left) and 'plain finish' (former Type B) (seen on the right) achievable in the location of the panels. See also www.construct.org.uk/surfacefinishes.html for locations.*

2.5.7 Class F5, plain finish

This class of finish is intended for precast members and pre-tensioned beams either made on site or supplied by a manufacturer. The requirements of the surface finish are similar to those for Class F4, but tie rods are not allowed. Provision for the embedment of metal parts, such as lifting details or prop fixings for stability during erection, is allowed.

2.5.8 Fair worked finish/special finish

Aqueous structures finish

To provide a concrete surface without blemishes has already been seen to be difficult, but in structures designed to retain aqueous fluids the problems of bacterial and algal growth on the surfaces can be reduced by improving the quality of the surface finish to the concrete. This is particularly relevant on structures designed for potable water (see Figure 7).

The prime consideration is the size of blowholes and the surface quality of the concrete. It is for these reasons that the CESWI specification (Ref. 41) has an additional finish called 'fair worked finish'. This finish is obtained by first producing a fair finish and then where possible filling all surface blemishes with a stated cement paste while the concrete is still green. Further work after curing requires it to be rubbed down, if required, to produce a smooth and even surface. If there are no surface blemishes to fill, then a quality 'fair finish' (similar to class F4 finish) would be adequate, but if this is not achieved 'as struck' then the surface would require further treatment. Contractors and subcontractors should be aware of the practicalities of achieving a fair worked finish when specified.

Select release agent Section 3.10.2

The CESWI specification (Ref.41), has a requirement that the release agent should be carefully chosen (see Section 3.10.2.1).

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Figure 7. Fair worked/special finish to a reservoir wall.

The type of finish on containment vessels/tanks will depend on the member's position in the structure, its exposure, whether it is to receive an applied finish, and the properties of the liquid to be stored. BS EN 1992-3:2006 Eurocode 2 – *Design of concrete structures* – Part 3: *Liquid retaining and containment structures* (Ref.12) makes no recommendations as regards surface finish.

Section 2.5.10 below gives details of one method of enhancing the durability of the surface and reducing blowholes by using a CPF fabric.

The BS EN 13670 (Ref. 43) and the NCSC Specification (Ref. 44) require that a special finish in general construction requires particular care in selection of form face and release agent, together with thorough concrete compaction. Detailed requirements of the finish should be stated in the execution specification, and often, sample panels will be required (see Section 2.8).

2.5.9 Special surface finishes

A special surface finish may be either functional or aesthetic. An example of the former is a finish on a spillway or weir channel, and an example of the latter would include the wide range of surface finishes used for decorative effects, or where special quality is required. An example of a special finish exposed to view for a railway station is shown in Figure 8.

Visual concrete - Finishes (Ref. 46)

A useful guide is *Visual Concrete – Finishes* (Ref. 46).

See Section 3.1.2

See Section 3.7.8

In view of the difficulties experienced in obtaining visually satisfactory smooth finishes, such as the risk of black markings from any impervious shiny surface (see Section 3.1.2), where appearance is important it is advisable to introduce a pattern or controlled degree of roughness to the face of the concrete. The use of CPF materials (see Section 3.7.8) also imparts a texture to the face and some of the methods by which this can be achieved are discussed in this same section.

Figure 4 and 9

Surface roughness can be obtained by the use of textured linings of plywood, rubber or plastic. Rubber linings are made in a large range of patterns and, whilst expensive initially, can have a large number of uses. An example of a plastic liner used on a wing wall is shown in Figure 4, and a liner with the resulting concrete wall finish is shown in Figure 9.

Figures 10 and 11

Glassfibre reinforced plastic (GRP) sheets also give excellent results. High-density polystyrene in proprietary panels is also used to give textured finishes. Examples of the finishes obtained are shown in Figures 10 and 11.

Vertical grooved finishes are an excellent way of breaking up a large surface and they also weather well. The tops of the ribs can be treated in a variety of ways, by bush-hammering, light abrasive blasting, or by controlled hammering off to produce a random roughened effect. An example of vertical grooves with tooling is shown in Figure 12.

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Figure 8. Special finish to station building.



Figure 9. Special finish obtained using a proprietary plastic liner.



Figure 10. Finish obtained using a GRP form liner.



Figure 11. Special finish obtained using polystyrene former to a wing wall.

Tooling and risk of HAVS (White finger)

When using such equipment to produce tooled finishes the risk of *hand–arm vibration syndrome* (HAVS) or '*vibration white finger*' syndrome must be borne in mind. HAVS is a disorder which affects the blood vessels, nerves, muscles and joints of the hands, wrists and arms. You are at risk of HAVS when using any vibrating equipment, for example bush hammers. Employers should ensure that a risk assessment is undertaken in accordance with the Control of Vibration at Work Regulations 2005. Tools are given an Exposure Action Value (EAV – the length of time for which a tool can be used before action needs to be taken to reduce vibration exposure) and an Exposure Limit Value (ELV – the length of time after which a tool may not be used).

Tooling can sometimes be used to improve a plain smooth finish which is discoloured or blemished, but should only be considered as a last resort since it is an expensive remedial method. Tooling will not remedy bad concrete. The cover to the reinforcement is reduced by tooling and the designer (PWD) should make the necessary allowances.

Figures 12 and 13 , Visual concrete - Finishes (Ref. 46)

An example of vertical striations on a bridge pier to Class F4 finish is shown in Figure 13. The formwork to produce this finish is shown in Figure 25. A useful guide is *Visual concrete – Finishes* (Ref. 46).

Sawn board finish see Figure 14 and Section 3.3.2.1

Selection of a face contact material to achieve a specified finish may depend more upon its reuse potential than upon the actual finish required, and due account should be taken of this in the selection. This is particularly so in the case of 'sawn board' formwork, also known as 'board marked finish', where it can be expensive to produce a consistent special finish and maintain the quality. An example is shown in Figure 14. Detailed guidance on the preparation of material and specification for this finish is given in Section 3.3.2.1.

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Figure 12. Finish obtained with vertical grooving.



Figure 13. Example of F4 finish on bridge pier with striations(for formwork see Figure 25).



Figure 14. Finish obtained using rough sawn boards with polyurethane sealer and chemical release agent.

See Figure 15

Foamed polyurethane and polyethylene are also produced in a range of patterns but can normally be used only once. Care is needed during compaction of the concrete to keep vibrators away from these materials. Along with moulded polystyrene they are also used for sculptured concrete, and an example is shown in Figure 15 which combines sculptured precast panels into a large futuristic face – a portion of the mould used to form the chin of the face can also be seen.

The general requirements for special surface finishes are the same as for Class F4, fine/high-quality finish. However, forms for special surface finishes are often larger than for normal work and this may impose particular requirements, such as cranage.

Section 3.12

A number of the more common form liners and face contact materials are listed and considered in Section 3.12.

Tooled finishes will NOT correct poorly placed concrete

A surface roughening of cast concrete to alter the appearance of the as-struck face can be achieved either by chemical methods, such as surface retarders to expose the aggregate, by pressure washing, by chemical etching, or by tooling such as bush-hammering (see previous warning about HAVS), though these are outside the scope of this guide. Further information is contained in *Visual Concrete – Finishes*. A satisfactory tooled finish can however only be achieved from concrete that has been correctly designed, well compacted, cast against uniform formwork, and made to a high standard. Tooled finishes are labour intensive, very expensive and should only be specified when they are required for architectural reasons and can be seen at close range.

A very special surface finish can be achieved using a photographic mould. A black and white picture is represented on a plastic form liner by pixels/dots of retarder. Where light colour is required, the dots of retarder are small, increasing to larger dots of retarder for darker colours. Placing the correct concrete mix against such a sheet will generate areas of varying retardation giving the visual impression of 'photographic concrete'. An example on an in-situ cast retaining wall is shown in Figure 16.

2.5.10 Enhanced durability finishes

The durability of concrete can be an emotive subject, but increasingly the whole-life cost of a structure is being considered when comparisons are made of concrete against other materials. Generally the methods of increasing the durability of concrete are outside the scope of this guide, but the use of CPF as a form liner involves formwork. The durability and quality of concrete when using CPF are covered in CIRIA C511 *Controlled permeability formwork* (Ref. 5) and the Current Practice Sheet 144 (Ref. 50). See Sections 3.7.8 and 3.12.3 for a detailed explanation of the material and its use.

Comparison of liners, Figure 49

The surface finish achieved using CPF materials will give a slightly textured pattern on the finished concrete, the mirror image of the fabric/material used; the slightly matt appearance of the surface often gives an aesthetically better overall aspect of the concrete. A comparison of some of the finishes obtained is shown in Figure 49. This uniform texture on a surface without irregularities is considered as providing a

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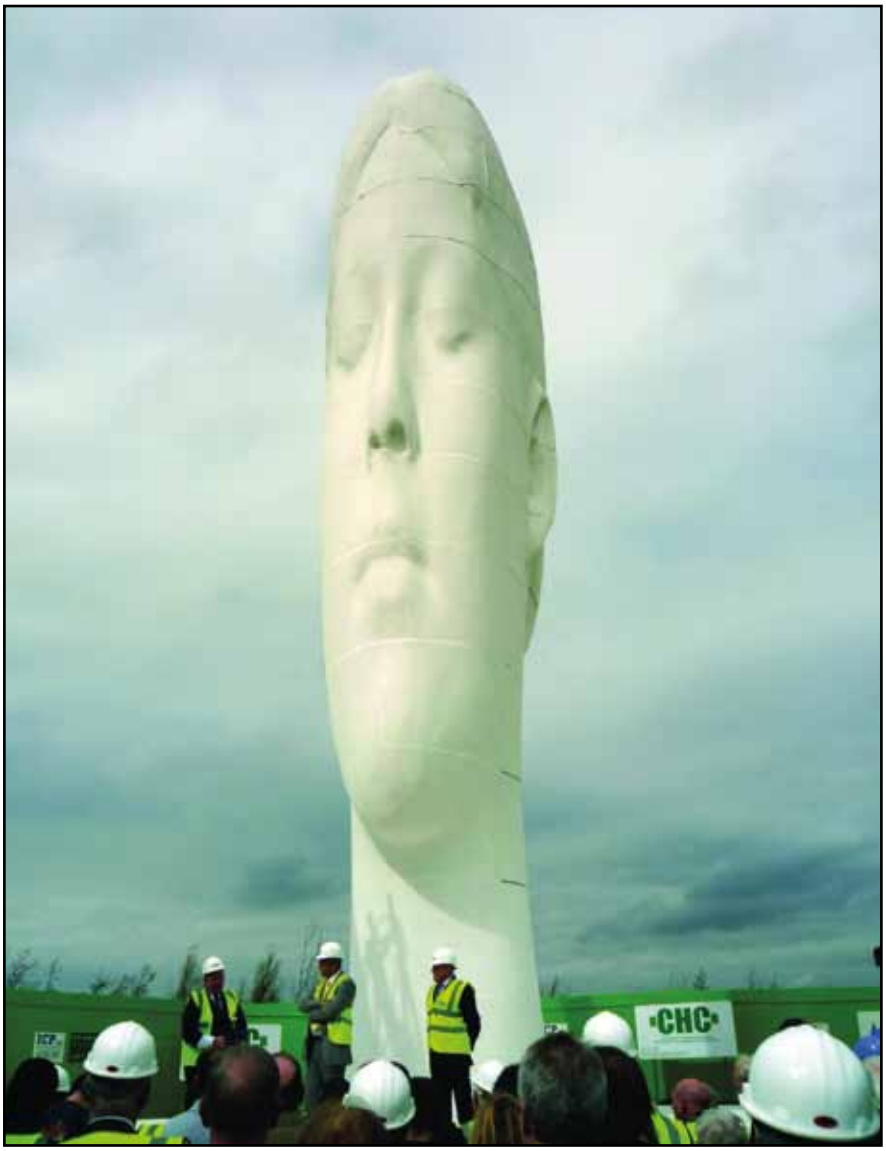


Figure 15a. Finish obtained from precast sculptured panels (Dream).



Figure 15b. Mould used to create the chin section of Dream.



Figure 16a. Finish obtained using 'photographic concrete'.



Figure 16b. Original photograph.

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finish satisfying the requirements of Classes F1 to F5 inclusive (Ref. 40) and the equivalent of a fair worked finish (Ref. 41). Further, because of the significant reduction in blowholes, the surface is more uniform than that achieved using impermeable formwork, particularly relevant on potable water structures, wastewater structures, in splash zones, sea defences and highway structures affected by road de-icing materials.

Controlled Permeability Formwork
See Section 3.12.3

CPF has been shown by tests in laboratories and on site (Ref. 5 and 50) to improve the quality of the concrete in the critical surface zone. These improvements occur on all vertical, inclined and soffit surfaces. The improvements are also of a similar magnitude irrespective of the strength of the mix, the type of cement used, the type of admixture used and also the orientation of the formwork. By reducing chloride ingress, carbonation and water absorption, yet increasing the surface strength and frost resistance for a range of concrete types and blends, CPF gives the PWD the ability to change the concrete properties in the critical area, without having to specify stronger mixes. Tests on 10- to 15-year-old potable and wastewater structures have shown that the in-service degradation of surfaces cast with CPF is significantly reduced compared to surfaces cast against oiled impermeable formwork, thus increasing the period before first maintenance (Refs.51 and 52). Two additional benefits to concrete surfaces of using CPF are (1) the reduction in depth to which graffiti can penetrate, thus making graffiti removal easier, and (2) reduced microbiological growth due to the less porous surfaces not being contaminated by release agent residues, making surfaces easier to clean.

In a major study of a hypothetical building, a detailed cost analysis was based on a 15-year-old, six-storey concrete cast-in-situ framed building (Ref. 53). The hypothetical building was generated by studying faults and repairs on 97 buildings of different ages. The model showed that the use of CPF saved 7.4% on the cost over its life, with an immediate benefit at time of construction of 3.9% by obviating the need to increase the concrete strength for durability.

Enhanced durability finishes obtained using CPF fabrics should not be subjected to further surface treatments, such as bush hammering, wire brushing or etching processes, or wherever the treatments involve removing the physically enhanced concrete surface.

2.6 Tolerances

2.6.1 General

All members of the construction team should be aware of the importance of tolerances and their implications. The aim is to construct a concrete structure which complies with the drawings and specification. Absolute accuracy is impossible, and the level of inaccuracy that can be accepted needs to be considered. The relationship between accuracy and cost is complex, but the smaller the tolerances, the greater will be the cost. Close tolerances should only be specified when the result will make a significant contribution to quality, function, appearance or overall economy.

When specifying the permissible deviation for a member of a structure, that tolerance should be able to be measured and should be within the accuracy range of the measuring equipment. For example, on a member with a permissible deviation of ±5 mm the tolerance is 10 mm; this could be the product of deviations at the base and top of a column. In this example, the base could be +5 mm from the intended position with head –5 mm measured from the same datum, giving a 10 mm departure from vertical. However, this does not mean that the head or base can deviate from the datum +10mm or –10 mm. See also Section 2.6.4. Similarly, on a member of permissible deviation +2 mm, –8 mm, the tolerance is also 10 mm. If it cannot be measured then it is unrealistic to specify it as a target for the site to achieve. The *Guide to accuracy in building* BS 5606 (Ref. 54) records the expected dimensional deviations of buildings from site measurements completed and gives statistical guidance on the accuracy likely to be achieved. This section discusses the likely standards of accuracy in formwork which will, of course, be a contributory factor to the overall accuracy of the structure.

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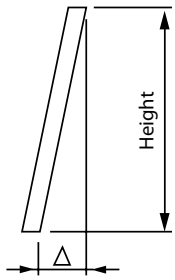


Table 3.Typical deviations for wall, column, beam and soffit formwork.

Concrete component of a structure	Typical formwork deviations		
	Normal work	High quality	Very special
	mm	mm	mm
WALLS			
Verticality up to 2 m	15	10	4
Up to 3 m	20	12	6
Up to 7 m	25	15	8
Up to 10 m	25	20	10
Straightness in 5 m length	10	6	3
COLUMNS			
Verticality up to 3 m	15	10	5
Up to 7 m	20	12	7
Up to 20 m	25	20	10
Cross-section up to 300 mm	± 5	± 3	± 2
300 to 600 mm	± 10	± 5	± 3
600 to 1.5 m	± 15	± 10	± 4
Squareness	10	6	3
BEAMS			
Depth up to 300 mm	± 8	± 3	± 3
Up to 600 mm	± 15	± 8	± 4
Over 600 mm	± 20	± 10	± 5
Variation in datum	± 10	± 10	± 5
Straightness in 5 m length	12	8	3
SOFFITS			
Flatness (on 2.5 m grid)	± 20	± 15	± 9
Variation in datum	± 15	± 10	± 8
Abrupt changes of in-situ surface (e.g. form joints)	6	3	1

Notes to Table 3.

- *The typical deviations stated are for the formwork. These are mostly tighter tolerances than those stated in BS 5606 (Ref. 54) and BS EN 13670 (Ref. 43) which refer to the finished concrete surface.*
- *The table is intended for general guidance. Contract specifications may require different deviations to those shown.*
- *The term 'flatness' is a measure of the variability in level from the average plane, and 'variation in datum' is a measure of the variability in level of the average plane from its intended level.*

The magnitude of the permissible deviation in the formwork, and hence in the resulting concrete surface, will vary with the type, finish and quality of the work. As a guide, Table 3 gives typical deviations for formwork for in-situ concrete components of a structure, classified into normal, high quality and very special formwork applications. The very special category is normally associated with quantity precast operations and the tolerances achieved will require precision moulds often with machined steel plates. Specifiers should be aware of the increased costs when using tight tolerances. See also Section 2.5.2 and the visual limits for assessing the quality of the completed concrete structure.

The three sources of deviations in the finished structure are inherent deviations, induced deviations and errors.

Section 5.1.3.1

Inherent deviations. An example of this is the elastic deflection of formwork under load. See also Section 5.1.3.1 which suggests limits. Inherent deviations can also occur from foundations consolidating during concreting, or if changes in form length take place due to thermal effects. The inherent deviation from elastic deflections need only be considered on the member in which they act, and not cumulatively as the summation of the deviations on all the members. This ensures that the elastic deviations can sensibly be measured, if required, on the surface of the finished concrete.

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Induced deviations arise from inaccuracies in the measuring equipment, such as the error in the actual benchmark used. Laser-based survey equipment is not as accurate as optical instruments and should not be used to achieve small tolerances in formwork. Another induced deviation is the manufacturing tolerance of the components of the formwork. For example, the permitted overall tolerances on the thickness of certain wood-based sheet materials may cause lipping (see Section 3.3.2.5). When specifying straightness the PWD and the TWD should be aware of the straightness tolerance inherent in the materials. For example, the tolerance on straightness of rolled steel sections may be greater than those permitted in the finished concrete structure.

Section 3.3.2.5

Errors arising from inaccurate setting out or misreading of drawings etc.

The following sections discuss the realistic formwork deviations, given in Table 3, that can be specified on site for walls, soffits and columns, which may differ from those stated in the contract specification.

2.6.2 Wall formwork

The final position of a cast-in-situ wall will be affected by several factors: accuracy of the initial setting out; plumbing and starting location of the kicker; means of stabilising the form to resist horizontal forces arising from wind etc. Within the formwork system not only will the face contact material deflect between walings but the walings will also deflect between the soldiers (if fitted). In turn the soldiers will deflect between ties or propping positions. If tie rods are used through double-faced forms then elastic lengthening of the tie rods at working loads will occur. These factors will all contribute to the final position and thickness of the wall.

Specifying a particular spacing of tie rods in a wall will automatically decide the likely order of magnitude of deflections in the formwork. Thus the specification of a maximum deflection value can cause significant increase in cost of the formwork.

The surface finish of the concrete should be considered when selecting the tolerance. For example, a wall used in an apartment formwork system (Section 6.7) may be required to be suitable for direct decoration with minimum surface preparation; this will require tight control for straightness and minimum elastic movement to give an acceptable visual appearance, whereas a tall retaining wall with a patterned form liner will not require such a degree of control. Certainly in the latter case the visual straightness of the wall could not be measured over short lengths and the deviations recommended for normal work would be suitable. In contrast, if precast units are to be incorporated in a structure then improved speed of construction may justify a much stricter control of overall dimensions of the in-situ walls. It is then important to control the maximum area of bearing surfaces and maximum width of joints to be filled.

Section 6.7

2.6.3 Soffit formwork

The final position of an in-situ concrete slab is determined by several factors. The falsework, its location and stiffness, will affect the final soffit level. Not only will the falsework shorten elastically under the applied load of fluid concrete but its own supports and foundations will also be subject to settlement. Combining these with the 'take-up' at the joints of falsework items and the induced deviations in the manufacture of the falsework, causes the soffit formwork to settle overall as load is applied, the normal practice being to set the forms a few millimetres high to allow for the expected take-up – about 3 mm in single-storey building work, and about 5 mm in soffits up to about 5 m high. Allowance for elastic shortening is discussed in Section 5.1.3.1.

Set soffit forms about 3mm to 5mm high

The TWD should be aware that designs with uniform settlement will reduce differential deflections and give more satisfactory solutions. Some guidance on joint take-up and elastic shortening is given in Section 5.1.3.1 and Clause 19.3.1 b) of BS 5975 (Ref. 3)

Section 5.1.3.1 and BS 5975 Clause 43.2 (Ref. 3)

The top surface level of the slab is generally set from screeding rails or set out from the soffit form. The final level, with suitable care, should be correct to a tolerance of ±3 mm in 3 m. However, it should be remembered that on a large slab area the measuring equipment would not realistically set out to ±5 mm over a 50 m length of construction and the final tolerance should be set with this in mind. The introduction of cambers, either as residual cambers or, on long-span members for elastic deflections, will affect the tolerance of the soffit and top of slab levels. See also Section 2.7.

Top slab levels ±3 mm in 3m See also Section 2.7

Attention is drawn to the effect of induced deviations on long lengths of structure when considering the reinforcement detailing. For in-situ slabs up to 30 m long BS 5606 (Ref. 54) recognises a dimensional accuracy of ±35 mm, On a flat slab soffit this presents no problems but on a soffit such as that of a waffle or trough floor the effect of this deviation may cause serious lack of fit of edge reinforcement. This total deviation is generally positive and arises not only from the cumulative tolerances from the moulds but also from manufacturing tolerances in any supporting falsework with its spacing of supports.

BS 5606 Table T2.1 (Ref. 54)

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2.6.4 Column formwork

The control of tolerance in column forms requires consideration in three dimensions.

Firstly, the **plan sizes** depend on the arrangement of restraint of the concrete pressures. The higher pressures at low level can give larger local face deflections. Table 3 gives typical values for the control of dimensions on cross-sections of columns, and also an indication of squareness.

Secondly, the tolerance on the overall **height** of the column should be considered. It is common practice to take the top of the column concrete into the next slab or beam by, say, 10 to 25 mm (to assist when the slab formwork is being fitted around the top of the completed column).

Thirdly, the **verticality** of the column (or alignment in the case of a sloping column) must be controlled – see Table 3. This needs to be considered along two axes mutually at right angles.

The final position of the top relative to the intended position depends also on the accuracy of the starting point at the kicker and, for rectangular columns, the squareness at the top. The tendency for the form to 'wind' or rotate torsionally is more prevalent on tall square columns. Provided the form is robust, is carefully handled between uses, and props are fitted to secure points on the form, then this will not generally be a serious problem.

2.7 Deflection limits and cambers

δ = 1/270 of span
See also Figure 73

The appearance and function of most concrete work is satisfied by limiting the design deflection of **individual** formwork members to 1/270 of the span. This value can be taken as a guide unless stricter requirements prevail in the specification for the finished work.

Economies may be made by the relaxation of this deflection limit where appearance and practical criteria permit.

Effects such as 'quilting' of face material can be greatly exaggerated by lighting effects and by colour changes in the concrete. Where appearance is critical, special consideration should be given by the PWD to the requirements written into the specification.

See Section 5.1.3 Deformations

On slab or beam soffit formwork where the permanent work consists of long spans, say over 8 m, the specifier may require a residual camber to be incorporated. Where the support involves clear span members there will also be an additional precambering required to allow for the elastic deformation of the members under the imposed loads. See also Section 5.1.3. The position of the soffit will depend on the accuracy of the estimates made in predicting the precamber values; differences between estimated loads and those occurring in practice, together with varying load characteristics for the members of the formwork or falsework, will all contribute to the final camber. A useful guide to determining deflections to the actual concrete structures is in Section 8 'Deflection calculations' of The Concrete Centre's *How to design concrete structures using Eurocode 2* (Ref. 55).

Residual Cambers

Specifiers should be aware of the increased costs involved when incorporating residual cambers, particularly if a constant slab thickness is also required, as this will necessitate precambering the top of the slab. The value of the specified residual camber should be included in the designer's brief and should be considered with the permitted deviation on the soffit levels. Further, it will require to be within realistic limits of measurement. In general, residual cambers should only be specified where visual appearance is critical. If considered necessary, then a generous tolerance on the camber will contribute more to an acceptable appearance than attempting to produce an unrealistically flat soffit to a tight tolerance. Residual cambers alongside fixed items such as existing walls or steel beams are extremely difficult to achieve and should be avoided.

2.8 Sample and trial panels

Particular requirements of a job may indicate that a sample or trial panel is necessary. Normally these will incorporate significant features in the design of the structure, particularly where high standards of finish are required. The hypothetical sample or trial panel shown in Figure 17 is designed to incorporate a number of features that will affect the appearance of a typical job. Panels must be specifically designed to incorporate those features which affect the appearance of the job in question.

Reference Panels in UK for ordinary and plain and for HA Class F2 and F4

Sample panels or sample sections (not to be confused with trial panels) of the work are those prepared to the PWD's instructions in order to demonstrate to tendering contractors the type of finish required. The size of the samples should be consistent with relevant elements of the proposed works and it is essential to retain the formwork for inspection by tenderers. In making sample panels, due regard

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must be paid to the practicability of obtaining the required finish on the site. On occasions it may be possible to designate a section of nearby finished work as indicative of the standard required. Data on the formwork used should be made available.

The UK already has sample panels erected at several sites around the UK. One location of sample panels is shown in Figure 6. These currently show the National Structural Concrete Specification typical 'ordinary' (formerly Type A) and 'plain' (formerly Type B) surface finishes, and the Specification for Highway Works typical finishes Classes F2 and F4. See Section 2.5.2

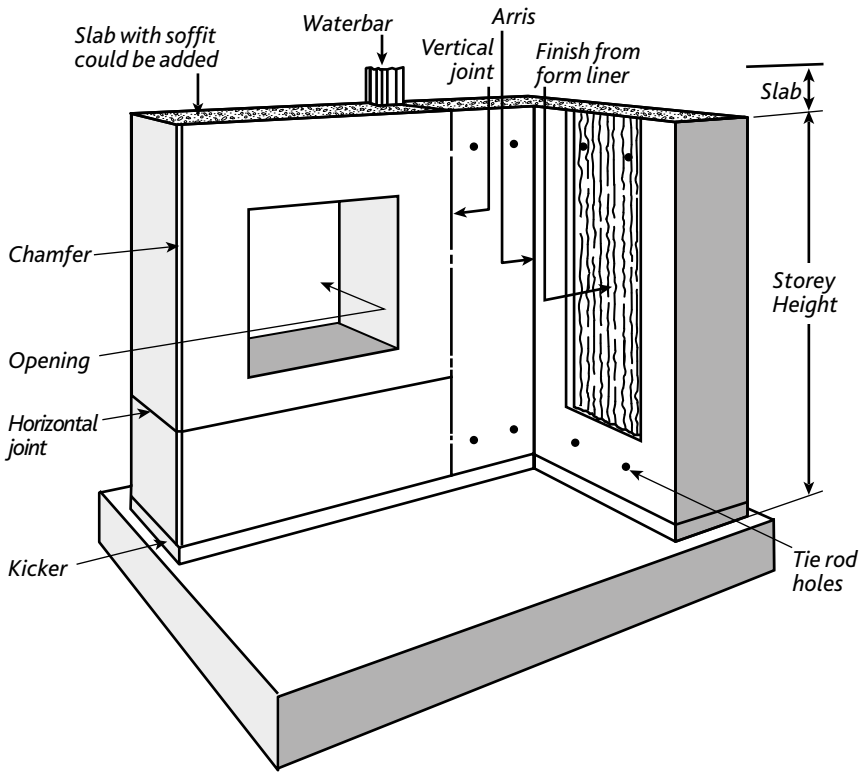


Figure 17. Composite sample or trial panel (hypothetical).

Note: *The hypothetical panel shown does not indicate any reinforcement projecting from the wall. The width of the wall, together with the position and density of reinforcement, may affect the standard of workmanship on the panel and, if considered significant for the appearance of the work, then similar reinforcement to that specified for the permanent works should be included in the panel. Note that some reinforcement may be needed for the stability of the panel.*

Trial panels are those panels or trial sections which are carried out by the contractor, under the contract, in the preliminary stages of the work, as a means of establishing that his proposed method of working will achieve the required results. Such panels, when accepted, may be used as the standard by which the completed work will be judged. There may be advantages in using visually unimportant parts of a structure for trial, for example basement retaining walls, in order that realistic site conditions may be simulated, but where the consequences of an unsatisfactory trial need not lead to demolition.

It should be noted that the finish obtained from the first use of formwork on sample or trial panels may not necessarily be repeated on subsequent casts.

2.9 Formwork designer's brief

2.9.1 General

Design Brief CRITICAL for all formwork. See Appendix A

The formwork designer's brief is the essential information required by the design office for the purpose of preparing a formwork scheme. The lists given in Appendix A are not exhaustive but do include important details for each type of construction and are representative of the type of information required. With the majority of formwork arrangements being carried out using proprietary equipment, often by the suppliers, information is included that is considered necessary when briefing such suppliers. The lists are also intended to be used as aide-memoires.

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It is the responsibility of the temporary works coordinator to ensure that the temporary works designer has all the information required to complete the design. However, information on all factors affecting a design will not necessarily be available at an early stage. Where information is not available and assumptions have to be made, it is important that they are clearly identified, so that they can be reviewed/verified at a later stage and, where necessary, the design can be amended.

2.9.2 Design details required

The following is a checklist of details which the formwork designer (TWD) may be required to convey in the design.

(a) All residual risks arising from the design risk assessment.
(b) Material and surface finish of form face of lining.
(c) Material, size and position of other formwork members, including propping arrangements.
(d) Where specific proprietary products are included in the design, these should be correctly referenced.
(e) Arrangements and dimensions of panels and/or forms.
(f) Description and position of form ties, anchors and spacers.
(g) Method of sealing the form face.
(h) Method of sealing panel joints.
(i) Method of sealing tie holes.
(j) Method of forming and sealing construction joints.
(k) Method of forming features such as ribs or patterned surfaces.
(l) Method of forming holes and openings, indents, drips, chamfers etc.
(m) Method of securing inserts.
(n) Method of striking formwork to ensure that completed work is not damaged or overstressed.
(o) Method of preventing formwork from restraining concrete movement, which could cause cracking.
(p) In the case of prestressed members, method of ensuring that elastic shortening due to tensioning is not restrained by the formwork.
(q) Position of air release holes and/or access doors, if required.
(r) Position and details of clean-out openings.
(s) Procedure to be adopted to ensure that the specified construction sequences are observed – particularly relevant in multi-storey construction.
(t) Method of achieving required falls and cambers.
(u) Types of release agents.
(v) The area required for the formwork and the associated working spaces etc.
(w) Loads assumed in the design.
(x) Loads applied into the permanent works, e.g. fixings, kentledge.
(y) Method of disposal of formwork materials after use.

2.10 Equipment selection

2.10.1 General

The choice of formwork system for the construction of elements of a building can have significant project cost, programme and health and safety implications. It is important that those people involved in either specifying concrete elements or selection of equipment understand the implications of their choices.

Formwork Design Brief Appendix A

In addition to the traditional formwork of plywood and timber, there is a large variety of proprietary formwork equipment available. Each proprietary product will have benefits that suit particular site requirements, and a well-prepared design brief (see Section 2.9 and Appendix A) will assist the supplier in advising on the selection of the most appropriate system. When considering the costs of the formwork it is important to give close consideration to the overall costs; a high proportion of the formwork costs is the labour element in erecting and utilising the equipment – see Section 1.6.1. Modern formwork systems often incorporate features that can offer major labour cost savings compared with more traditional systems.

This section aims to give awareness to specifiers/procurers of the particular questions that should be raised in order to understand the relative hazards and risks associated with various formwork types.

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2.10.2 Permanent design considerations

Table 4 gives an appreciation of the comparative formwork and falsework requirements related to different concrete elements.

(Note: The CDM Regulations, discussed at Section 2.3, require all designers to identify hazards, eliminate hazards if reasonably practicable, adapt the design to reduce the risks from residual hazards and provide information on residual hazards.)

Table 4. Comparative temporary work element requirements.

Type	Effect on formwork and falsework
SLABS Flat slabs	Simpler detailing. Large amount of repetitive use possible with rolling/flying tables or use of soffit panel systems. Usually a faster construction cycle.
Ribbed and waffle slabs	Additional moulds required on top of falsework. Less repetitive use possible. Tables are possible, but a larger striking distance of jacks is required.
Beams and slabs	Less repetitive use is possible. Beams are often different sizes leading to multiple single use details and adding costs of falsework erection and dismantling. Different allowable striking times of beam and slab make early removal problematic.
Post-tensioned slabs	Check effect of back-propping requirements. Access for prestressing jacks required. Falsework may be in place longer to allow phased stressing.
Non-ground-bearing slabs	Back-propping of upper-level slabs needs consideration. If ground slab is too weak to take the back-propping loads then significant falsework costs could be added.
Apartment form structures (cross-wall buildings)	Fast programme. Temperature dependent. Longer lead time due to steel form fabrication. Dimensions are fixed. Late changes are difficult.
WALLS Double-sided with ties	Wall formwork with double sides can be made structurally efficient by using tie rods placed through the wall. The ties restrain the concrete pressure exerted on the forms, and additional stabilisers are only required for alignment and stability. Tied walls require significantly less equipment than tie-less walls. The tie holes require filling, leaving marks on the finished concrete.
Double-sided without ties	Double-sided wall formwork can be made without ties to a higher specification of concrete finish. The equipment required will result in large beams or trusses attached to formwork panels, and significantly increase the formwork cost.
Single-sided without ties	Single-sided walls, such as basement walls cast against piles, require large A-frames and ties to the base slabs to resist the concrete forces. Formwork costs may be significantly reduced if ties (and tie loads) could be used and connected to the piles.
Circular	The PWD should consider if a truly radiused wall is required, or if a series of straight segments (polygonal) will meet user requirements. Truly radiused can add significant costs to the formwork compared with polygonal.
COLUMNS Repetitiveness	The PWD should try to include as many repetitive column sizes as possible, in order to maximise use of column forms and reduce cost. Intricate shaped formwork can be made for feature columns but will add significant cost unless representatively used.
Large columns	Large plan dimensional columns greater than 1 m should have consideration of the possibility of through ties to reduce formwork costs.

Factors to consider when selecting any formwork system include:

(a) safety – safe system of work, including hazard assessment and risk control

(b) potential for preassembly and reuse

(c) assessment of manual handling and mechanical handling

(d) complexity of assembly and competence of site operatives

(e) programme and concreting cycle, striking times, availability of labour and quantity of equipment and lead times

(f) site constraints such as proximity of boundaries, interaction with third parties

(g) site location for delivery, storage, handling

(h) quality of finish required

(i) design of formwork and falsework and coordination of the design.

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BR 495 Formwork for Modern, Efficient Concrete Construction (Ref. 17), CSG/005 A guide to the safe use of formwork and falsework (Ref. 37)

A useful review of construction techniques to maximise speed and economy are contained in the BRE publication BR 495 *Formwork for modern, efficient concrete construction* (Ref. 17) and Concrete Society publication CSG/005 *A guide to the safe use of formwork and falsework* (Ref. 37).

2.10.3 Safe system of work

The concrete/formwork contractor has a duty to apply a safe system of work during assembly, concreting, striking and dismantling, identifying hazards and using appropriate risk controls. The choice of a correct formwork and falsework solution will lead to the development of the safe system of work. Some aspects for consideration are outlined in the following subsections.

2.10.3.1 Hazard assessment

Consideration should be given to significant hazards arising from the following:

- Working at height – avoid if possible, then apply hierarchy (see Section 7.6).
- Access and egress – justify choice of access system (staircase, ladders, platforms, etc.).
- Mechanical movement of loads.
- Manual handling – Manual handling assessment charts (MAC) guidance in HSE document INDG383 (Ref. 56) can be used to score relative risk of weight/frequency/reach of various systems.
- Structural instability – temporary stability requirements of the permanent works.
- Use of small hand tools and equipment.

Wherever reasonably practicable, work at height should be avoided

One of the most hazardous activities is that of working at height, with falls from height alone accounting for 45% of all site fatalities. In accordance with the Work at Height Regulations (Ref. 27), Where this cannot be achieved the regulations define a hierarchy of control measures, which should play a prominent part in the selection of an appropriate formwork and falsework system.

2.10.3.2 Risk control

HSE promotes a structured approach to risk control based on a hierarchical system.

- Prevention is better than protection.
- Passive protection (protecting all personnel and not requiring actions by the individual) is better than active protection (requiring individual action).
- As a last resort care must be taken to mitigate the consequences of any individual risk.

2.10.4 Work on site considerations

2.10.4.1 Assessment of manual handling and mechanical handling

- Potential for preassembly at ground level. Ability to avoid work at height. Ability to reuse assembled equipment and infill requirements.
- Cost benefits of additional set-up time against reduced reuse costs.
- Labour requirements.
- Mechanical handling requirements.
- Manual handling requirements.

2.10.4.2 Potential for preassembly and reuse

- Preassembly
  - On or off site.
  - Consider use of dedicated assembly areas for limiting/avoiding work at height.

2.10.4.3 Complexity of assembly and competence assessment of site team

- Deviation from supplier's assembly instructions.
- Site-specific method statement.
- Complexity of erection and dismantling. Skill levels and training requirements for site operatives.
- Lateral stability of the system itself and the requirement for any additional restraints.

2.10.4.4 Training

- Refer to Appendix 8.2 and The Concrete Society publication CSG/005 Appendix B of *A guide to the safe use of formwork and falsework* (Ref. 37).

2.10.4.5 Programme and concreting cycle, striking times, volume of labour and equipment and lead times

Understand the timescales to shortlist/eliminate formwork and falsework systems for the various structural elements based on:

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- minimum striking times
- equipment volume requirements and availability
- labour requirements
- lead-in time for design, manufacture (specials), delivery, preassembly.

2.10.4.6 Proximity hazards such as boundaries, interaction with third parties

All constraints on activities should be defined to enable systems to be identified and/or eliminated. For example:

- temporary stability of the permanent/temporary structure and any additional propping requirements
- oversailing restrictions on site and over the site boundaries
- noise limitations, duration and times
- dust and other environmental hazards
- third-party contractual restrictions.

2.10.4.7 Site location for delivery, storage, handling

- Safe deliveries
  - Transportation limits, for example shipping by container imposes length and weight restrictions.
  - Width restrictions on road transport with/without police escort can affect size of formwork.
  - Routes and frequency.
  - Offloading hazards: does equipment have to be turned over after delivery?
  - Traffic management.
- Safe storage
  - Can storage be avoided by preassembly and lift directly into place?
  - Consideration of storage: 'face up' or 'face down'?
  - Well-defined storage areas, access, egress, lighting, traffic management.
  - Palletisation/stillages.
- Handling and lifting
  - Is lifting equipment certified/systemised (for the product)/standard/special design? (See Section 5.9.)
  - Weight of units (see Section 4.2) and crane capacity/reach requirements.
  - Placement of slings and attachment of lifting chains (see Section 5.9).
  - Method statement/sequence/training requirements.

2.10.5 Quality of finish

- Specification requirements. See Section 2.5.
- Panel finishes:
  - Leave an impression of the joint on concrete.
  - Regularity requirements.
  - Can be ply lined for higher-quality finish.

2.10.6 Design coordination

The CDM Regulations (Ref. 23) place a duty on contractors to ensure the competence of suppliers. This should involve checks for quality of systems, competence, experience, procedures, and may include audits of suppliers to confirm competence. See Section 2.2.2.

The role of the temporary works designer (TWD) (see Sections 1.6.3 and 2.2.3) is often carried out by the supplier. Whoever designs the temporary works scheme should be checked for competence, experience and product knowledge. Clarity on the design responsibilities of the various parties involved should be sought and given in the full scope of the supplier's design.

The role of the temporary works coordinator (TWC) (see Section 1.6.4) is crucial in the selection of the suitable and relevant formwork equipment. BS 5975 (Ref. 3) recommends the appointment of a TWC, to ensure the flow of information and site requirements to the temporary works designer. The TWC must also ensure that all other areas of formwork are coordinated and that design work/safe systems are in place.

Suppliers' design service (see Sections 2.2.5 and 3.2.1.3) is usually limited to the equipment supplied; this is discussed in more detail in Section 5.1.1.

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Section 3

Materials and equipment

3.1 General

All materials should, when new, comply with the requirements of the appropriate British Standards. These are being changed to introduce into the UK the European Standards. Most of the new standards are written in limit state terms.

Limit state v permissible stress

Designers should be aware of the differences between the limit state and permissible stress methods of design. Briefly, limit state considers the ultimate condition as the structure fails and a serviceability state (i.e. working) condition by applying different safety factors to the loads and the material. In limit state terms the characteristic strength is normally considered with a confidence limit assuming 95% will fail above a particular value. Permissible stress considers the safe load on the structure by applying a factor of safety to its failure load. It is important to point out that limit state considers the plastic properties of the material, whereas permissible stress considers the elastic properties.

Operatives on site will continue for many years to think in 'safe load' terms, hence the working party have published this edition generally in permissible stress terminology. Both the falsework code BS 5975 (Ref. 3) and the NASC industry guidance for tube and fitting scaffolds TG20:08 (Ref. 187) are both in permissible stress terms.

Safe working properties for timber and wood-based sheet materials are given in Section 3.3, and for adjustable steel props in Section 3.2.9.

To assist designers wishing to use limit state design using timber, the characteristic strengths and relevant modification factors, as necessary, for timber from Eurocode 5 (Ref. 14 and 15) and for adjustable telescopic steel props (Ref. 57) are given in Appendix E .

Although traditional formwork of timber and plywood is still used, there is increasing use of reusable proprietary systems for wall formwork, using crane-handled panel systems, and soffit formwork with aluminium prefabricated components to form tables. There is also a requirement for traditional formwork in the necessary make-up areas, stop ends, around columns etc. Hence this Guide has given priority to sections on proprietary formwork, and included handling soffit formwork tables with hoists, see Section 3.2.15. The updated information on traditional materials of timber and plywood at Section 3.3 follows the proprietary equipment at Section 3.2.

Dispose of materials safely and environmentally

With the exception of permanent formwork (see Section 3.9), the materials and equipment used will be required to be either disposed of at the end of the operation or removed from the site. The subsequent disposal of temporary works materials is an important consideration in formwork. Material should be disposed of safely, and the effect on the environment considered. Materials will have different disposal conditions, for example plastics compared to timber, and recycling may not be possible, therefore the advice of suppliers should be sought. The sustainability and reuse of materials to reduce wastage is discussed in Section 1.2.

3.1.1 Permissible stresses

Permissible stresses in formwork should be selected bearing in mind the properties of the material to be employed, especially its behaviour under short-term loading. The importance of this is illustrated by the fact that the properties of timber allow an increase in working stress above that permitted in the design of permanent structures. In contrast, properties of steel are unaffected by load duration so no increase of permissible stress under load is allowable, although some is permitted under maximum wind loading.

BS 5268 (Ref. 4)

Formwork often involves the use of timber and plywood, and as it is difficult to extract the relevant design stresses from BS 5268 (Ref. 4) which was replaced by European limit state codes in March 2010, detailed recommendations for users are now given in this Guide. For formwork designed using other materials the relevant British Standard and other references are stated, from which the design stresses may be readily obtained. Furthermore, such formwork design is normally carried out by specialists.

Section 3.2.1.3

In addition to the use of basic materials, formwork design involves the application of many different types of proprietary equipment. In preparing the design, the supplier's technical literature should be consulted. Section 3.2.1.3 gives recommendations on the detailed information which should be available

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Where the properties of plywood or wood-based panel products are stated from test data or by suppliers/ importers only in characteristic strength terms, the grade strength and moduli for permissible stress design may be obtained using the formulae given in Tables 12 and 13. See Section 3.3.2.3.

3.1.2 Materials as form facing

The choice of material in face contact with the concrete has a significant effect on the resultant finish. Specification of finish and class of finish are discussed in Sections 2.4 and 2.5 respectively. The main features requiring consideration are the hardness, permeability and surface texture.

Hardness will contribute to long life and consistency of performance.

Permeability has an effect on the resulting colour. Generally, absorbent forms give a dark finish whereas permeable forms give a light finish. The permeability of the face reduces with use as the cement paste fills the pores, hence the quality of finish changes. Where the surface is impermeable and vertical, the air does not escape easily during compaction and blowholes are formed on the concrete face. Recently, materials have been developed to control the permeability – see Section 3.7.8.

Surface textures range from highly glossed, through matt, to deliberately textured. High-gloss or even glass-like surfaces can occur in new forms made of impervious materials and, despite the generally light colour expected, can give rise to blackening of the concrete. See also Section 3.3.2.2, and Section 3.4.1 on steel formwork. It is thought that this effect is caused by the effects of vibration where the smooth surface allows the movement of water and fine particles of sand and cement.

See also Section 3.3.2.2 and 3.4.1 on steel formwork

Highly glossed surfaces which are repeated on the cast face of the concrete frequently show crazing of the concrete and exaggerate the effect of blowholes. The crazing may only be very shallow cracks and the effects will fade as the concrete carbonates, but the gloss imparted to the concrete is reflective and exaggerates the visual effects. As a result there is an unnatural marbled effect.

Highly polished faces of formwork only remain polished for one or two uses before being abraded to a matt texture. Where necessary the gloss can be reduced by 'pre-ageing' or by light abrading before use. A matt surface avoids the worst aspects of the results from glossy forms. Alternatively a deliberately textured surface may produce light and shadow effects which are more noticeable than, and divert attention from, the colour variations and blemishes from other causes.

The concrete pressure developed in a wall will also have an effect on appearance. The pressures at the bottom of a form cause greater effects than at the top. Other pressure variations due to varying rates of rise, changes in day-to-day conditions such as temperature, can also affect the concrete colour produced from porous forms.

Although the effect is not fully understood, the positions of stiffeners on an impermeable form can sometimes be seen repeated on the concrete face. This seems to indicate a secondary effect of pressure and form face deflection, in the migration of water in the concrete during setting.

See also Section 2.5.1

To achieve consistent quality of finish in the concrete it follows that variations in mix, materials etc. should be reduced as much as possible. See also Section 2.5.1. Selection and use of the correct pretreatment and release agent is an essential prerequisite for maintaining quality of finish.

Formliners. See also Section 3.12

Sections 3.3 to 3.8 give the descriptions, illustrations, working stresses etc. for the majority of materials commonly used in formwork. Many are used in applications where they are not in direct contact with the concrete, and Section 3.12 considers the particular characteristics of these materials when used as form liners.

3.2 Proprietary equipment

3.2.1 General

There are many varied items of proprietary formwork equipment available to limit or eliminate the need for site manufacture. This equipment is generally available on hire and, on contracts of short duration, can show appreciable economies, with labour saving and in-built safety being particular benefits. Contractors and subcontractors may also own and maintain a stock of proprietary equipment and look to utilise a variety of equipment purchased from more than one source of supplier. It can be the case that some suppliers are not the original developers and manufacturers of the equipment. Although the different suppliers' items may appear similar and equally suitable for a

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given application, it is necessary to establish their physical properties, and particularly whether the properties are the safe working values or the characteristic values at or near failure. This section deals with the general description and application of the majority of the products available.

3.2.1.1 Safe storage, handling and transportation

A guide to the safe transportation of formwork and falsework equipment (Ref. 58)

Formwork and falsework products, by their very nature, require safe storage, handling and transportation between uses. Often the components themselves are individually packed and require special attention for bundling/handling. The supplier's recommendations should be followed. A useful guide is CONSTRUCT's *A guide to the safe transportation of formwork and falsework equipment* (Ref. 58).

Work equipment - guidance on regulations L22 . (Ref. 32)

All items of equipment for use at work come under the EU Directive and useful guidance is given in HSE document L22 *Safe use of work equipment. Guidance on regulations* (Ref. 32).

Section 2.2.5
Section 5.1.1

Suppliers of equipment have design obligations (see Section 2.2.5) and may also have legal responsibilities – see Section 5.1.1. The extent of these responsibilities depends on the category of design.

The three main categories are:

(a) Design of individual items for general formwork use, e.g. formwork ties, column clamps.
(b) Design of formwork systems which are capable of being adapted to different requirements, including design of the component parts.
(c) Design of formwork assemblies for particular applications using proprietary equipment based on information included in the design brief (see Section 2.9 and Appendix A).

See Section 2.9 and Appendix A

Generally, users of the equipment have little direct influence on design carried out in (a) and (b) but will have close control over design in (c) as this is carried out to their specific requirements for a particular project.

3.2.1.2 Suppliers' guidance

Suppliers have duties to provide information and user guidance about their products. Manufacturers' safety instructions and other relevant operational and assembly documentation should be made available to the temporary works coordinator (TWC) including project drawings, parts lists and any other relevant data, and disseminated to the site operatives as necessary. All operatives working with proprietary systems should be familiar with the content of the relevant instructions and safety information for their particular application. Conditions on site may dictate the need for additional guidance to be created if deviations from the normal procedures will occur.

The documentation provided should address:

- any product-specific tools
- lifting equipment and accessories
- area required for assembly
- weight of system for assessing mechanical lifting requirements
- transport and storage requirements
- maintenance and repairs
- access
- protection against falling objects
- any specific procedures to be followed, particularly for climbing or slip form operations.

Provide user with instructions on individual stages of sequence

Temporary works designers (TWDs) should pass on any information relating to the safe transfer of all load effects into the supporting permanent structure. Stability must be guaranteed at all times and it should be ensured that the permissible imposed loads are not being exceeded. Where climbing or travelling are involved, the user must be provided with clear instructions on individual stages of the sequence.

All operatives working with climbing and slip form systems should be comprehensively trained to ensure competence and be familiar with the content of the relevant manufacturer's instructions and safety information for their specific application. See Sections 6.2 and 6.3.

Specific guidance should be made available by the manufacturer for all working operations, climbing operations and non-operational conditions and in particular during periods of high winds (of particular relevance to climbing formwork and slip forming). If it is expected that design conditions are to be exceeded, then as a minimum the system should be lowered so as not to extend above the height of the completed structure and the formwork locked into the concreting position. However, consideration must be given to any protective sheeting applied (see Section 7.6.3) and also any materials and other equipment which may remain on the platforms.

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3.2.1.3 Technical information

Suppliers' technical information is often intended as an introduction to the product and as a selling aid, and may not contain much technical detail. The formwork designer, however, is likely to need such detail and should ensure that up-to-date information is available. Such technical information should be obtainable from suppliers. Where contractors use their own equipment, it is important that they inform the designer of the exact products proposed for use. It is common that suppliers update and improve products and this may mean the specification of the material and technical data also change. More detailed advice or explanations should be obtained by making contact with the suppliers.

The information listed below will not be required by the formwork designer in every case, but should be available if needed:

(a) Description of basic function of equipment with illustrations.

(b) List of items of equipment available, giving range of sizes, overall dimensions and available spans etc., with manufacturer's part numbers or other references. If items listed are only available on special order, this should be stated.

(c) Instructions for use and maintenance, including any points which require special attention during erection or dismantling, especially where safety is concerned.

(d) Detailed information, as follows:

(i) Self-weight.

(ii) Full dimensions of connections and any special positioning arrangements. If the item relies on an end bearing, the area of that bearing should be given.

(iii) Any permanent camber built into the equipment.

(iv) Details of any special attachments, e.g. access brackets, hand rail standards, plumbing feet.

(v) Locations for tie bolts or support points. If the item is a beam spanning horizontally or vertically then loading tables should be provided which give recommended permissible spans and spacings.

(vi) For panel formwork, the maximum design concrete pressure permitted (kN/m^2).

Suppliers should STATE the safe working strength and/or the characteristic (failure) strength in descriptions

(e) Data relating to strength of equipment. To avoid confusion by the users of such data, the strength data should clearly state whether the values given refer to either the **safe working strength** for use in permissible stress design, or the **characteristic (failure) strength** for use in limit state design. The information may include:

(i) Characteristic (failure) strength for various conditions of use, stating whether the strength is based on the normally accepted 95% confidence limit using a standard deviation, and/or recommended maximum safe working loads (kN) for various conditions of use.

(ii) Section properties, such as moment of resistance (*fZ* in kNm), bending stiffness (*EI* in kNm^2), shear capacity (*qA* in kN), shear rigidity (*GA* in kN) and any bearing limitations stating whether failure or recommended working values.

(iii) The basis on which the ultimate or safe working loads or properties have been determined. If stating the safe working values it is also necessary to state whether the factor of safety given applies to collapse or yield.

(iv) Whether the strengths and properties are based on calculations or tests. This should be clearly stated. When based on calculations the source of the computer programs/formulae should be verifiable, particularly when using unfamiliar formulae. When based on tests, users should be aware that the restraint conditions and assumptions made in the tests may not reflect the actual on-site conditions. Reference should be made to the supplier.

(v) Deflections under working loads (serviceability limit) together with recommended precamber and limiting deflections, if relevant.

Note:

- *This Guide recommends the use of the word 'failure' in the description of this strength to highlight the difference. This is not strictly correct because in limit state terms the phrase 'characteristic strength' is usually the value at which 95% of samples would fail at or above the limit.*
- *In order to avoid confusion it is also a recommendation that the strength data be stated in kN and metre units.*

Wherever possible suppliers may wish to state both values side by side to reduce the risk of misrepresentation.

3.2.2 Formwork panel systems

3.2.2.1 General

Panel systems are quick to assemble and can be easily adjusted to suit different pour lengths, heights and geometries. Thus, the amount of equipment on site can be optimised due to the adaptability of the components. Panels are ideal where short lead times are encountered and where the forms need adjustment to suit different applications on site. Where repetitive reuse is envisaged or where specialist

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