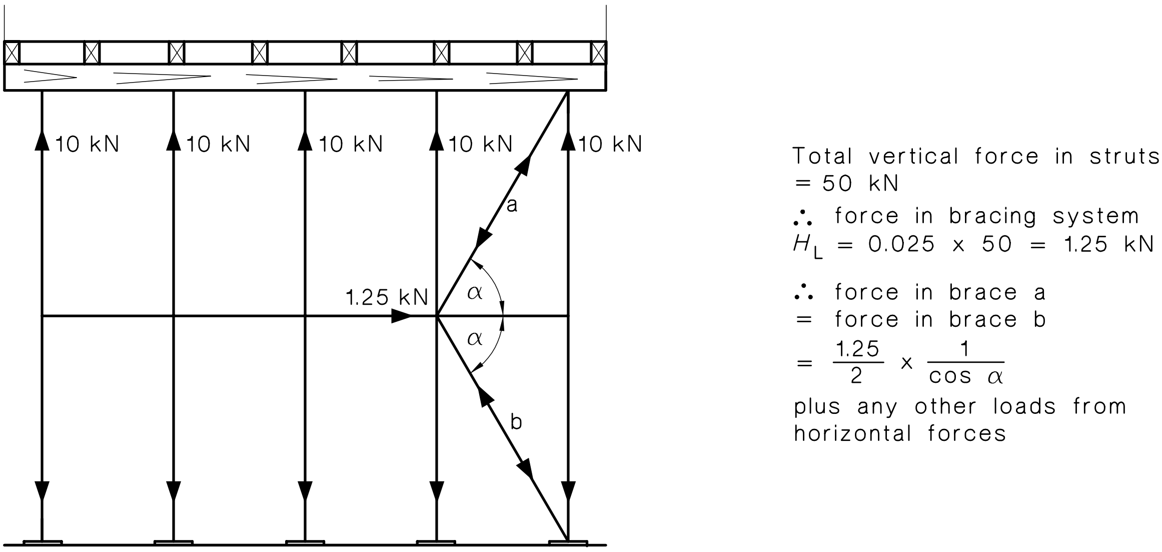

FIGURE C4.4.10 BUCKLING RESTRAINT

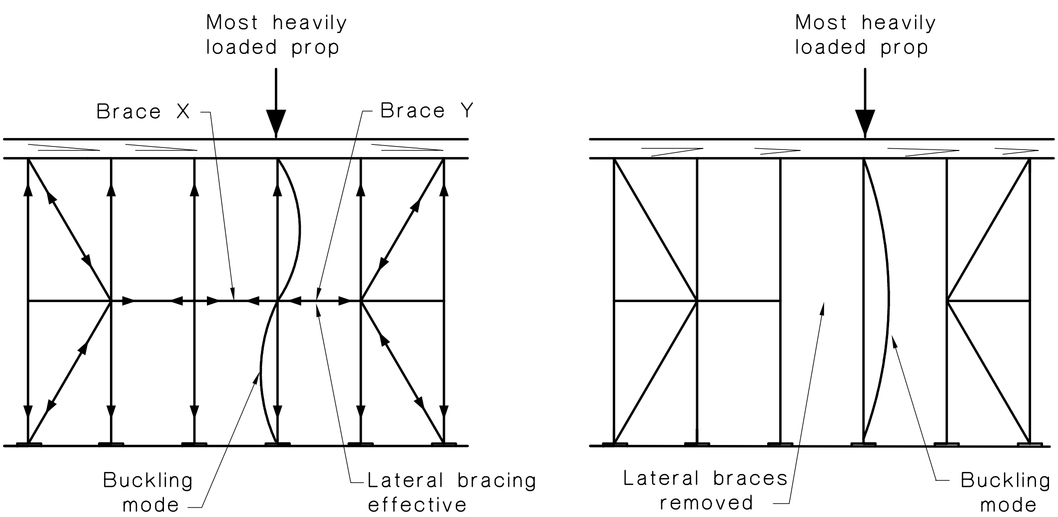

FIGURE C4.4.11 MODIFICATION OF BUCKLING MODES BY BRACING

C4.5 ANALYSIS AND DESIGN

C4.5.2 Theoretical analysis

At present most material structural design Standards relevant to formwork design are written in the permissible stress format. With time this will change and more and more Standards will be written in limit state format. This Standard has been written with the intention of enabling the formwork designer to use either format. In some cases it may be necessary to design one component of a formwork assembly using limit state procedures, and another component using permissible stress procedures.

Before determining the loads, as set out in Clause 4.4, the formwork designer should decide whether the design will be carried out using limit state procedures or permissible stress procedures, or both.

The loads are combined to produce the most severe load combination for each component of the formwork assembly, so that the component can be designed in accordance with Clause 4.5.6 and the appropriate material design Standard.

At present, load factors for limit state design and combined stress-reduction factors for permissible stress design, are set out in the material design Standard, but the special considerations for load combinations which are necessary for the design of formwork are not. For this reason it has been necessary to include load combinations in this Standard.

For proprietary items, loads on that component may be combined in accordance with this Clause, and the worst load combination checked against the nominated capacity of the component determined by test. Naturally, if a limit state load combination is used, this is checked against the limit state capacity nominated. If a permissible stress combination is used (possibly reduced by a combined stress-reduction factor), this is checked against the permissible stress capacity nominated.

C4.5.3 Testing

Refer to Appendix CA for commentary. Most formwork designers do not need to use this method of design. For this reason, testing has been separated from the body of Section 4.

C4.5.4 Limit state design procedures

C4.5.4.1 *Load combinations for limit state approach*

The load combination equations (see Table 4.5.1) are intended to set out as clearly as possible most load combinations which will be encountered in formwork design. While it is impossible to cover every possibility (just as it is impossible to foresee every load which could be applied), the equations are intended to simplify the task of combining loads. In preparing the equations, approximately 70 load combinations were originally considered. Most of these were subsequently rejected for one or more of the following reasons:

(a) The combination would clearly not be the most adverse combination, e.g. for Stage III, $0.8G + 0.8G_c + 1.5\ X_w$, which has to be less than the given combination No. 2.

(b) The likelihood of simultaneous occurrence of the shorter duration loads was considered too remote, e.g. horizontal impact (I) in combination with wind (W_u).

It is important to note that all loads other than gravity loads can have a value of zero as well as a maximum design value, and that many loads such as wind, water loads, and horizontal impact can act in many different directions. Wind load acting from the north, say, may produce the maximum compression force in a strut when combined with dead and live loads. When the wind load acts from the south, it may produce a maximum tensile force in the same member when applied in combination with the weight for formwork (G) alone.

A1 Ongoing research shows that although the limit states load combinations given in AS 3610—1995 are satisfactory for form face and secondary members, often they are unsatisfactory for the design of primary members, namely, formwork shores, possible formwork ties and the beams they directly support.

In Amendment 1 to AS 3610, Table 4.51 includes global load factors for primary members to produce designs that achieve a target reliability index in a manner consistent with current international practice. The global load factors take into account the disparity between the predicted and actual load effects in primary members. The global load factor has been set at either 1.0 or 1.3. These load factors are shown in column 13 of Table 4.5.1. Note 8 to the

A1 Table states 'For formwork members other than primary members the global load factor shall be taken as 1.0'.

Note that AS 3610, Amendment No. 1 includes a new Clause 1.5.2, which gives a definition for 'Primary members'.

'Not applicable'

C4.5.4.2 *Stability limit states*

No factor of safety need be applied to the load combination determined in accordance with this Clause to satisfy the requirements of stability. The load factors set out in Table 4.5.1, when applied to the loads, serve the same purpose.

C4.5.4.3 *Strength limit states*

Having determined the loads in accordance with Clause 4.4 and combined them in accordance with Clause 4.5.4.1, the most adverse combined and factored load is S^*. ϕ and R_u are determined from the appropriate material structural design Standard or from Appendix A where testing is carried out.

C4.5.4.4 *Stiffness limit state*

Deflection of formwork should be carefully considered, since the formwork will determine the profile of the finished concrete.

Since deflections in the contact surface of the formwork reflect directly in finished surfaces under varying light conditions, forms for architectural concrete must be designed carefully to minimize deflections. Deflections may govern design rather than bending (flexural stress) or horizontal shear. Deflections of sheathing, studs, and wales should be designed so that the finished surface meets the architectural specifications. Timber forms bow with re-use, and hence more bulging will be reflected in the formed surface after several uses. This effect should be considered when designing timber forms.

Vibration in formwork will not normally need to be checked for more conventional formwork assemblies. However, in certain unusual cases, vibration could become a design criterion. In particular, in cantilever or especially slender formwork assemblies, vibration may need to be investigated.

In more conventional formwork assemblies, effective control of the resonant vibration of the assembly will usually be achieved by increasing stiffness, with a minimum increase in mass. However, a case where increase in mass may be effective to overcome resonance would be a casting yard in a precast factory.

NOTE: In order to minimize vibration, a suggested design criterion would be that the natural frequency of the assembly or any of its components lies outside the range of 0.5 to 2.0 times the forcing frequency of any vibrating equipment or cyclic loads likely to cause vibration.

External vibration of forms may cause fatigue problems with bolted or welded connections, particularly where the forms are to be re-used. Otherwise, fatigue is generally not a problem with formwork.

As vibration of the whole form assembly occurs in precasting techniques, special attention should be paid to form detailing and foundations. Elsewhere many forms have external vibrators fitted. These vibrators have various energy dissipation levels and can have frequencies of up to 15 000 cycles per minute.

External vibrators are frequently used on forms for large precast segments for bridge construction or tunnel forms. In these cases particular care is needed to prevent form damage and fatigue at welds.

C4.5.5 Permissible stress design procedure (See also Paragraph C4.5.4.)

C4.5.5.1 *Load combinations for permissible stress approach*

The load combination equations (see Table 4.5.2) are intended to set out as clearly as possible most load combinations which will be encountered in formwork design. Whilst it is impossible to cover every possibility (just as it is impossible to foresee every load which could be applied), the equations are intended to simplify the task of combining loads. In preparing the equations, approximately 70 load combinations were originally considered. Most of these load combinations were subsequently rejected for one of the following reasons:

(a) The combination would clearly not be the most adverse combination, e.g. for Stage III, $0.8G + 0.8G_c + 1.4\ X_w$, which has to be less than the given combination No. 2.

(b) The likelihood of simultaneous occurrence of the shorter duration loads was considered too remote, e.g. horizontal impact (I) in combination with wind (W_u).

When using the equations in Table 4.5.2 in conjunction with AS 1720, the combined stress-reduction factor of Column 13 is not used. Rather, the duration of the shortest duration load, in any combination, is used to determine factor $K1$ from AS 1720.

Example A timber prop supports a formwork deck to carry a 600 mm deep concrete slab. The grid spacing for the props is 2 m by 1.2 m.

Under Stage II loading the compressive loads in a prop due to each load source are as follows:

Formwork dead load (G) = 0.9 kN

Concrete dead load (G_c) = 36 kN

Distributed live load (Q_{uv}) = 2.4 kN or concentrated live load (Q_c) = 5.1 kN

Combinations to be considered, in compliance with Clause 2.5.1.1 of AS 1720, are as follows:

Case	Combination	Total load kN	Shortest duration load in combination (see Table 4.5.3)	For combination K_1	Total load K_1
(a)	G (alone)	0.9	5 months	1.4	0.64
(b)	$G + G_c$	36.9	5 months	1.4	26.36
(c)	$G + G_c + Q_{uv}$	39.3	5 days	1.65	23.82
(d)	$G + G_c + Q_c$	42.0	5 minutes	1.75	24.0

Assuming all factors affecting strength (other than duration of load) are equal, the equivalent long duration load for any combination may be calculated as the sum of the loads in the combination, divided by the value of K_1 corresponding to the shortest duration load in that combination. The combination with the largest equivalent long duration load will be the critical combination. In the example, Case (b) is therefore the critical one.

It is important to note that all loads other than gravity loads can have a value of zero, as well as a maximum design value, and that many loads such as wind, water loads, and horizontal impact can act in many different directions. Wind load acting from the north, say, may produce the maximum compression force in a strut when combined with dead and live loads. When the wind loads act from the south, it may produce a maximum tensile force in the same member when applied in combination with the weight for formwork (G) alone.

A1 In Amendment No. 1 to AS 3610, Table 4.5.2 at Equation 7 shows that the combined reduction factor for use with steel or aluminium has been changed from 0.75 to 1.0. Thus Equation 7 increases by 33% the load on steel and aluminium components subject to the combined actions of the self-weight of the formwork, the self-weight of concrete and an allowance for mounding and will bring this Equation into line with the equivalent limit state equation.

'Not applicable'

C4.5.5.3 *Strength*

Having determined the loads in accordance with Clause 4.4 and combined them in accordance with Clause 4.5.5.1, the most adverse combined and factored load is F_{ps}.

C4.5.5.4 *Stiffness*

For commentary, see C4.5.4.4.

NOTE: Examples of design for stiffness may be found in the Plywood Association of Australia manual.

C4.5.6 Design information

C4.5.6.2 *Unidentified materials*

Unidentified materials should not be used in the construction of formwork. Many formwork collapses in the past two decades were due mainly to the use of unidentified materials, or the wrong use of proprietary items. If it is not possible to identify the type and grade of any material, it is important that the material be submitted to an appropriate testing authority for evaluation and identification. Failing to do this may mean both the designer and user of formwork taking unnecessary risks, which could lead to litigation. Therefore, in the interests of safety, both the formwork designer and the user should ensure that all materials are identified, before putting them into use. Never under any circumstances should assumptions be made in respect of any material. With timber, the load-carrying capacity is adversely affected by weathering.

C4.5.6.3 *Components*

When using formwork components, it is essential that consideration be given to the following:

(a) *Proprietary items* All documentation issued by manufacturers and suppliers for proprietary items should state the structural capacity of these items in accordance with Paragraph A6. It is a simple matter to convert the working load to limit state terms. This is covered in Paragraph A4.4.4.

(b) *Scaffold tubes and fittings* All documentation issued by manufacturers and suppliers for scaffold tubes and fittings should state the structural capacity of these items in accordance with Paragraph A6.

(c) *Tension members* Care should be taken in assessing the loads in tension members. Should the member be overloaded, a sudden failure can occur, which will then transfer an impact load to adjacent tension members. Progressive collapse can then occur.

 The factor increasing the tension forces on members has been amended from at least 50% in the 1990 edition to at least 20% in the 1995 edition on the basis that the lower value will provide an adequate factor of safety, given the addition to Table 5.3.1 of the line on threaded components.

(d) *Anchors* Anchors and inserts in concrete can exhibit considerable variation in load-carrying capacity when tested in the laboratory. In the field the load capacity can be further reduced by incorrect installation, insufficient edge distance, incorrect spacing or low concrete strength.

C4.6 CONSTRUCTION CONSIDERATIONS

C4.6.1 General

As with all structures, the design should ensure that the form assembly will produce the structure as specified. It should also include adequate provisions for safety. For formwork, it is also essential that the formwork can be dismantled easily, safely and without distress to the permanent structure.

C4.6.2 Footings

The design of the formwork assembly is not complete until it includes design of the base supports.

Usually, formwork is initially supported by a foundation. In multistorey structures, the formwork may subsequently be supported by the permanent structure.

Where poor foundation conditions occur, the design of footings for formwork assemblies is often carried out as a separate exercise, by an engineer experienced in footing design. Nonetheless, the design of the footings is an essential part of the formwork design, and the documentation is incomplete without documentation for the footings.

Footings may consist of nothing more than sole plates on a sound base course, or they may involve extensive piling or some system between these two extremes. Whatever the footing system chosen, it is important that due consideration be given to the support of the base of the formwork.

It is not sufficient to verify that the foundation material has adequate bearing capacity to support the loads without failure. In performing its role of providing support to concrete until it develops adequate strength, formwork must also have adequate stiffness. Settlement of foundation material under formwork can result in premature failure of the permanent structure due to deformation. It can also result in excessive deformation of the permanent structure, resulting in rejection.

Many foundations settle under load. Where settlement is anticipated, that will have a detrimental effect on the permanent structure, and there is no reasonable way of avoiding it, supports should be regularly monitored and adjusted to ensure that movement of the soffit forms is minimized.

Where the formwork is supported by the permanent structure, the project designer should be provided with sufficient information for him or her to ensure that the formwork assembly and the loads imposed upon it do not adversely affect the permanent structure.

C4.6.3 Formwork

There are a number of construction-related considerations enumerated in this Section, and they are mostly self-explanatory. Particular attention should be given to the following:

(a) At a construction joint it is frequently necessary to fix formwork to existing concrete. Where this is done, it will often be necessary to ensure that a grout seal to the concrete face is achieved. The formwork will need to be very rigid, since the fine granular particles in the concrete will readily work their way in between the concrete face and the form, possibly resulting in an unacceptable face step in the finished concrete, or excessive grout leakage. Particularly with sloping wall forms, 'flotation' of the forms may also result if they are not adequately fixed to their base.

(c) Adjustment devices for formwork are essential for erection, alignment and controlled stripping. Such devices need to be prevented from moving or unwinding at other times, especially during placement of the concrete, and when the formwork is subjected to vibration.

(d) In formwork assemblies, joists are often not nailed to the forms. Consequently, especially during Stage I, it is important that joists are of a reasonable width to prevent them from rolling.

Assumptions relating to effective lengths of struts should usually be conservative, since lateral restraint is often difficult to assess.

(e) In all cases, horizontal forces (see Clauses 4.4.5 and 4.4.6) shall be resisted by bracing designed for that purpose. The bracing in frames may not have been tested for that purpose. See also Clause 4.4.7.

(f) It is frequently the case that additional bracing must be provided, which is not essential in the completed formwork assembly. This bracing is required for erection and dismantling of the formwork. At all times the formwork should be maintained in a safe and stable condition. In assemblies where stability is important, the first bay of formwork to be erected should be braced, as should the last bay to be dismantled.

A formwork designer should consider it wise practice to provide excessive bracing rather than too little. The likelihood for progressive collapse is reduced when the number of 'pathways' for loads is increased. Additional bracing helps to reduce the likelihood of progressive collapse (see also Paragraph C5.4). (See also Refs 18, 19 and BS 5975.)

C4.7 FORMWORK DOCUMENTATION

C4.7.1 General

Until its removal, the formwork carries the construction loading and also provides safe working areas and access ways for construction personnel. It is therefore of significant importance that its engineering design be communicated by adequate documentation.

The extent of the documentation will largely depend on the complexity of the structure, and on the design and details of the formwork. In preparing the documentation, the formwork designer has a right to expect that the construction staff are experienced in the fabrication and erection of formwork.

Regardless of whether the formwork design is carried out by one or several designers, it is essential that the documentation adequately covers the entire design. It may well contain documentation for—

(a) proprietary items which may be designed by testing in accordance with Clause 4.5.3, i.e. the manufacturing information required in Paragraph A6;

(b) items analysed and designed in accordance with Clause 4.5.2; and

(c) footings analysed and designed in accordance with Clause 4.5.2 and the appropriate geotechnical information.

Separate documentation for each of these components is then brought together, to make up the formwork documentation.

Item (e) of this Clause draws attention to the importance of the project designer's influence on the design, detailing and construction of the formwork. The justification for this is the far-reaching effect that the activities of the formwork construction can have on the safety and serviceability of the permanent structure.

Attention is drawn also to Figure C4.7, which gives typical formwork drafting symbols.

C4.7.2 Proprietary items

The minimum data required to be given on an information brochure so that it can be a valid and acceptable part of the formwork documentation is listed in Paragraph A6.

The testing procedures of Appendix A are arranged to give the limit states load for formwork components and assemblies. However, it is the custom at present for the formwork industry to work in terms of 'working loads'. Paragraph CA4.4.4 discusses the method for producing a factor that relates limit state load to working load.

An example of this factor on a brochure would be—

LIMIT STATE FACTOR = 1.4

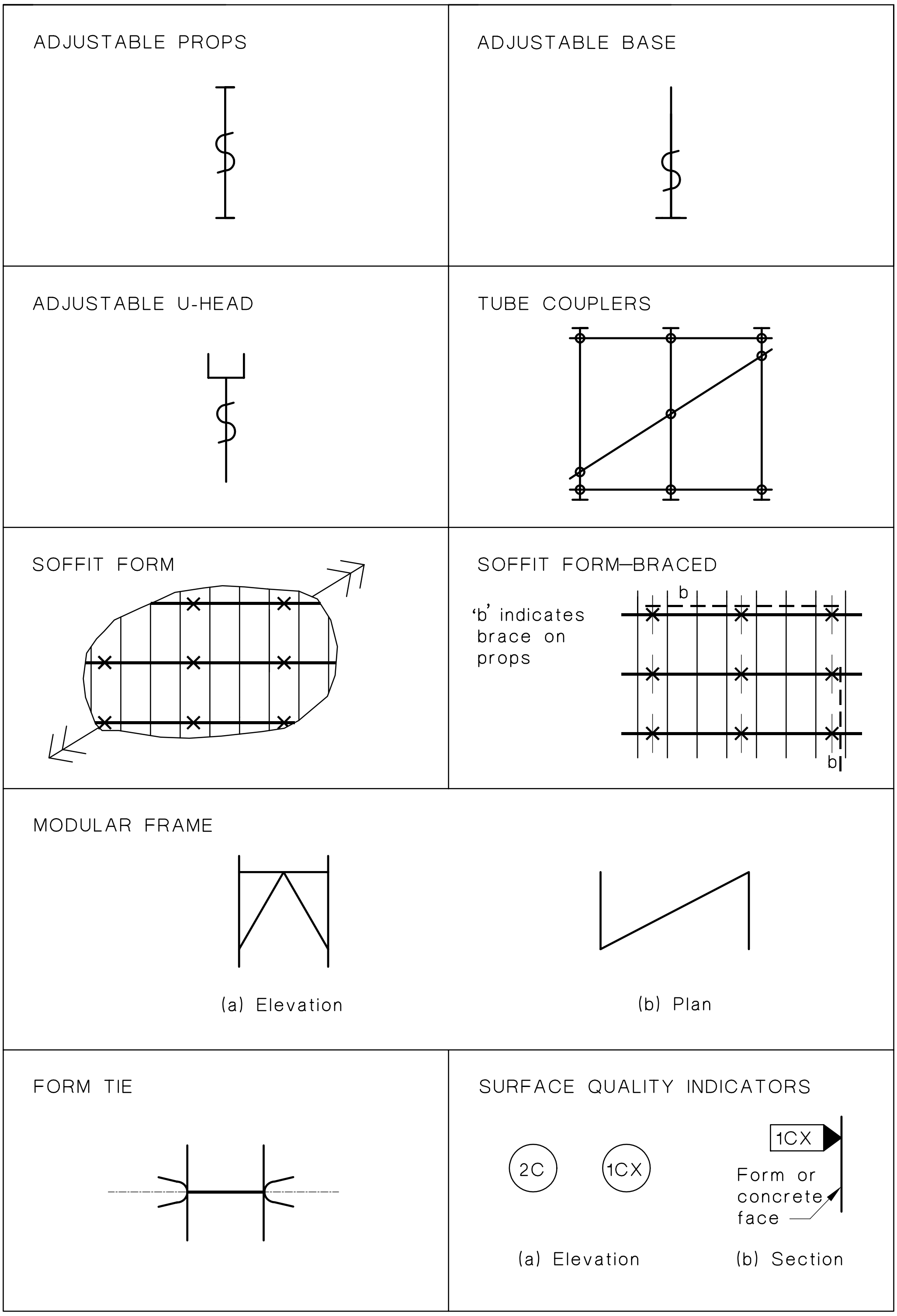

FIGURE C4.7 FORMWORK DRAFTING SYMBOLS

SECTION C5 CONSTRUCTION

C5.1 SCOPE OF SECTION

This Section covers site practices that should be observed in order that the formwork assembly fulfils its intended function. Because of the variation of design requirements that exists from one project to another, this Section can only outline minimum requirements. Any additional features that are required by the project designer and which are applicable to a specific project, should be indicated in the project documentation and repeated in the formwork documentation.

Most of this Section concerns the requirements of in situ concrete, but some of its provisions apply equally to precast concrete and are noted accordingly.

C5.3 GENERAL FORMWORK REQUIREMENTS—IN SITU CONCRETE

C5.3.1 General

The activities of the project designer and the formwork designer are discussed in Sections 2, 3 and 4. It is essential that the formwork documentation contains relevant data from the project documentation. It is normally the responsibility of the formwork contractor to ensure the safe erection of the formwork and compliance with the requirements of the formwork documentation.

It should be noted that this formwork documentation has been prepared in the reasonable expectation that all fabrication and site work will be undertaken by personnel who have sufficient experience to recognize construction problems and obtain advice from the formwork designer or project designer where required. Specific comment on the items listed in Clause 5.3.1 is as follows:

(a) The erection of formwork should be carried out in a manner that allows work to proceed safely, both on or adjacent to the component or assembly.

(b) It is essential that all the relevant documentation has been prepared and is available to ensure the formwork can be erected correctly. Adequate communication between the project and formwork designers and the formwork constructor is essential. Some examples are as follows:

  (i) Details of limitations on stacked materials. This may include nominating areas for the stacked materials. (See Clauses 2.3, 4.7 and Paragraph C4.4.2.4.)

  (ii) Limitations of bracing to the permanent structure. It may be necessary to specify the minimum age of concrete components before bracing can be permitted.

  (iii) Specific loading provisions.

  (iv) Surface finishes.

  (v) Stripping requirements.

(c) Where the formwork assembly might adversely affect the permanent structure, the project designer should be consulted. If insufficient details are provided in the formwork documentation, additional information should be obtained from the formwork designer. Any modifications that are needed to the work method, or sequence to be carried out by the formwork contractor, should be communicated to the project designer and formwork designer.