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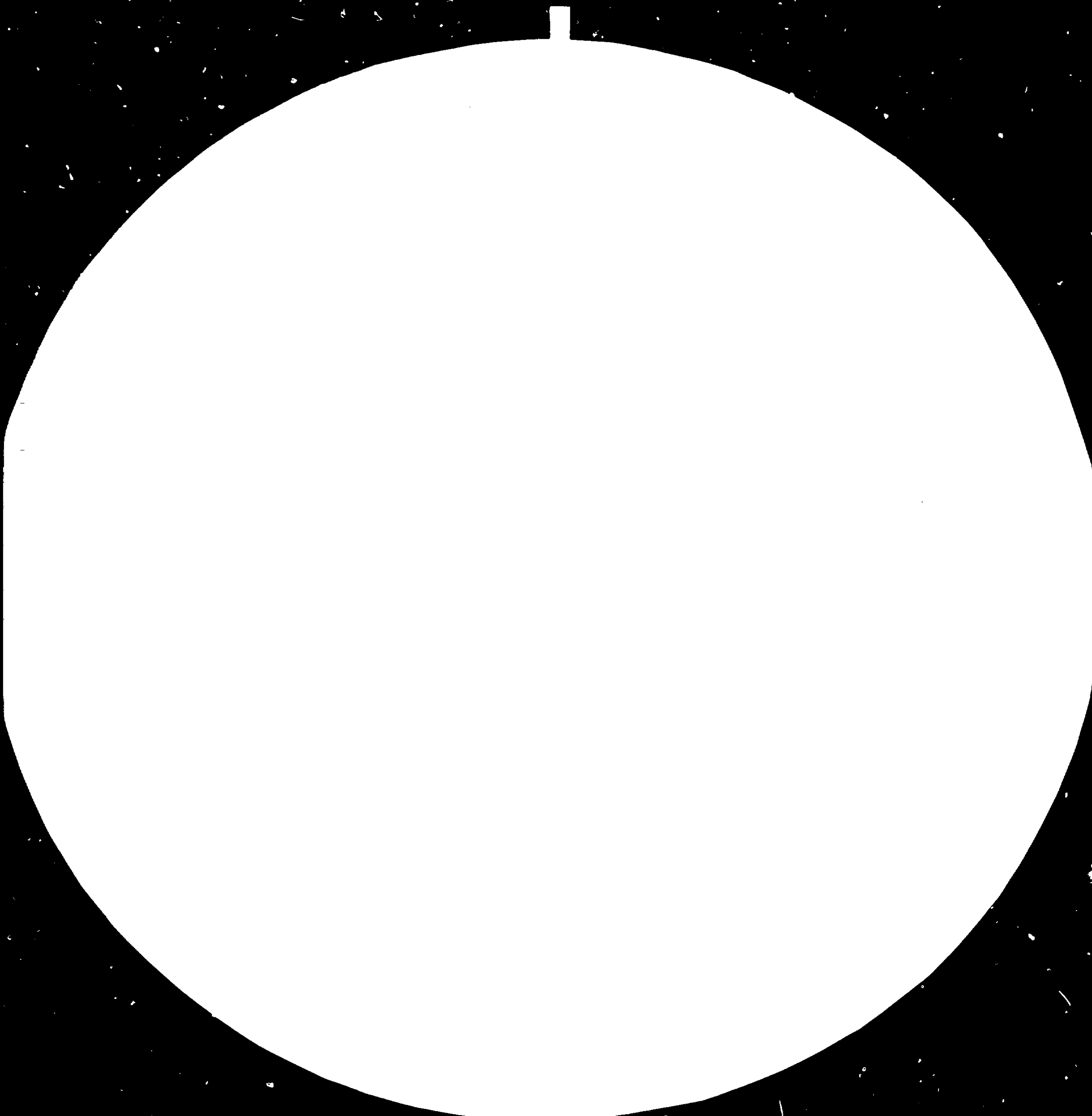

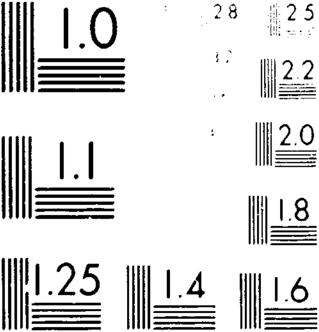
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ON-SITE PRECAST TILT-UP CONSTRUCTION*

by

B. Potter**

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Contents/ Foreword

Tilt-up is an established method of construction which is used on a wide variety of projects both in Australia and overseas, particularly in the USA where its use has recently proliferated.

Use of the term tilt-up is sometimes restricted to concrete elements, eg wall panels, cast on a horizontal surface and requiring only to be tilted into their final location. However, in this manual the term is used in the more common, wider sense to cover also elements cast horizontally, tilted to the vertical and then moved to their final location.

The method can be used for the construction of a wide range of building elements. Planar elements, ie columns, beams and plane frames requiring only simple edge formwork, are the easiest to build and erect. However, since interest centres mainly around tilt-up walls, this manual is confined to consideration of walls only.

As with any precast method of building, the best results using tilt-up are gained when there is close collaboration from the outset between all members of the design and construction team. This manual therefore covers all stages of tilt-up construction from planning through to finishing. It is hoped that this overall picture of tilt-up construction will result in fuller and better use of the method.

2 Applications

In the best uses of the tilt-up method all the attributes of concrete wall panels are used. Initially they were often used simply as cladding panels, continuously supported on strip footings. Today most tilt-up panels are loadbearing, probably spanning between pad footings, and meet fire resistance and acoustic requirements, see Figure 1.

The method has been used in Australia mostly for warehouses, industrial buildings and shopping centres, a trend which is likely to continue, although it will be increasingly used in a wider range of building types, including low-rise office buildings if Australian practice echoes American developments.

In many early tilt-up industrial developments the associated office accommodation (the 'front' of the building) was carried out in a more prestigious form of construction. Newly developed detailing and finishing approaches have made tilt-up walls suitable for use throughout the project, giving the benefits of uniformity without uniform appearance.

It is improved appearance which has largely been responsible for increasing the range of applications for the tilt-up method (see 'Tilt-up was never like this' published by the Cement & Concrete Association of Australia).

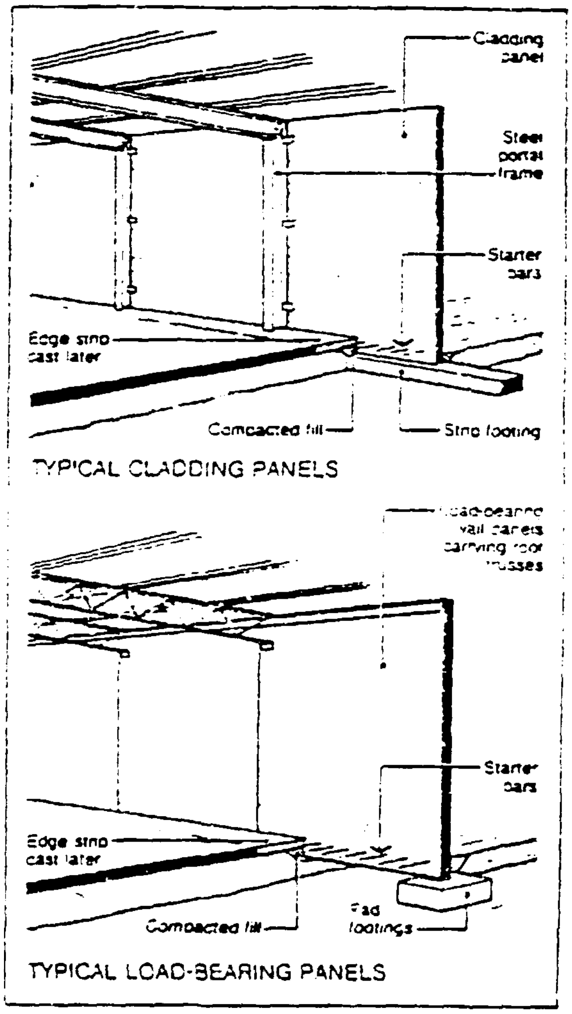


Figure 1

3 Planning for Tilt-up

The planning phase of a tilt-up project is one of the most crucial for its success. During this phase the entire design and construction procedure for the building should be worked out. Time spent in thorough planning can be repaid in full by a problem-free construction period. At the planning stage the various alternatives for each aspect of the project can be calmly evaluated; once construction is underway proper evaluation may not be possible since expediency could be the overriding consideration.

A model of the building (and the site) can be very useful during this phase. It can be helpful in such things as: choice of locations for storage of materials and casting of panels; determining crane movements; establishing the erection sequence. Such a model can later be used to train the construction personnel.

Two aspects of planning for tilt-up are worthy of particular mention: Firstly, the need for the continuous involvement of every member of the design/construction team; secondly, the need to design the building specifically for the method.

The co-operation of the whole team is necessary if the advantages and versatility of tilt-up are to be fully exploited and if cost benefits are to be maximised. It should begin at the planning stage and continue through to the completion of the project.

It is important that each member of the team is aware of the constraints of the method and of the broad implications of any planning decision. Compromise will often be necessary; the participation of all members of the team in all decision making is therefore required if the best solution is to be found.

Once found, change should be avoided since, in planning for tilt-up, decisions tend to be even more interdependent than with other forms of construction. Reversing one decision may start a chain reaction which could necessitate the reconsideration of all subsequent decisions.

The benefits of the tilt-up method can be optimised only when the building is designed for tilt-up. Adapting a design based on the use of a different form of construction will rarely be satisfactory. It will usually result in the tilt-up panels serving only as cladding, size being dictated by grids and frame spacings selected to suit other considerations.

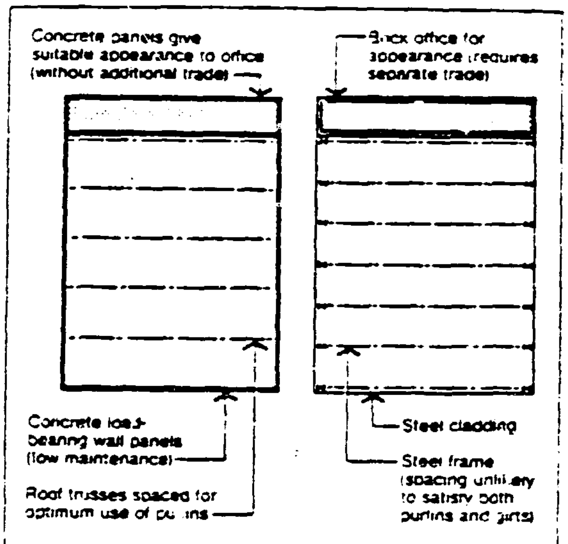
For maximum economy it is most important in designing for tilt-up to (insofar as they are compatible):

1 Make the panels as large as can be handled.

2 Standardise the panels as far as possible.

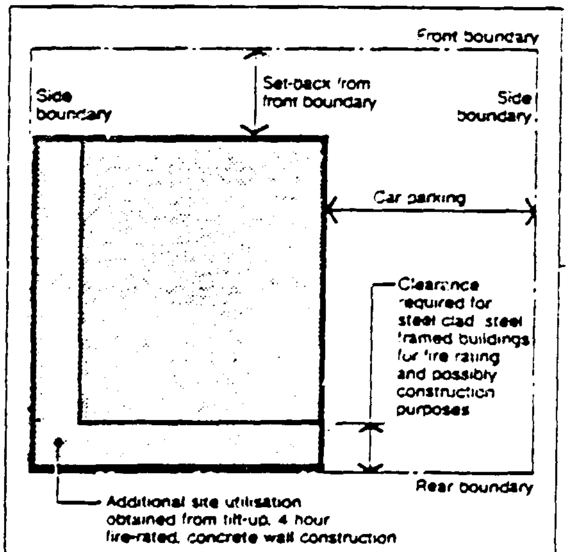
3 Make use of as many of the panel's attributes as possible (structural, acoustic, thermal, fire resistance, etc.).

A check list of all the factors which should be borne in mind when planning for tilt-up is provided on the inside back cover of this publication.



PLANNING CONSIDERATIONS

Figure 2



PLANNING CONSIDERATIONS

Figure 3

4 Structural Design

4.1 General

The same structural principles apply to the design of tilt-up panels as to normal insitu concrete construction. It is necessary, in their design, to satisfy a number of independent criteria. Wall panels must be designed for not only the loadings and conditions to be experienced in the final structure, but also for construction loads during erection, and when temporarily braced. Account may need to be taken of the volumetric effects of shrinkage and temperature. Also, as an integral part of the design, the serviceability criteria, eg durability and fire resistance, for the panels need to be established. These latter considerations frequently control the design.

Throughout the design phase there should be a conscious striving for 'buildability'. A check of the design details should be carried out to ensure that they are practicable. For example, the sizing of elements should allow easy placement of reinforcement and yet maintain required covers with profiled surface finishes. The designer must also anticipate the construction practices and allow for realistic tolerances. See page 21.

4.2 Preliminary Considerations

Before embarking on detailed structural design certain broad questions need to be answered:

Firstly, the type of concrete, eg reinforced concrete or prestressed concrete, needs to be chosen. Reinforced concrete will usually be favoured because the constituent materials and construction skills are readily available. Nevertheless, consideration should be given to other types.

Table 1 lists some of the broad advantages and disadvantages of the more common types of concrete. Of central importance in the selection of the type is the availability of suitable subcontractors. For any given project other specific factors may control the choice. The table is offered only as a starting point for a more detailed evaluation.

Information given in the manual is provided for normal weight reinforced concrete. Some of this data will be directly applicable to other types of concrete. If adapted for this purpose then the designer must satisfy himself as to the validity of the data.

Secondly, consideration must be given to the implications of particular details for the total design, joint and connection details, for example. The SAA Earthquake Code (AS 2121) stipulates that in certain risk zones the connection details adopted between units determine whether or not the building is classed as 'ductile' or 'non-ductile', which in turn will determine the magnitude of the design lateral force. Similarly, connection details will determine whether volumetric changes need to be considered over the total length of the building or not.

4.3 Construction Loadings

Two situations are usually considered in design:

Lifting. Probably the most severe loading experienced by the panel will be that to which it is subjected during lifting. Not only will the loads be severe but at the time they are applied the concrete will not normally have reached its full strength. The design loading must allow for the self weight of the panel, the 'suction'

Type of Concrete	Advantages	Disadvantages
Reinforced (normal weight)	Materials and labour readily available. No special skills required.	Panels reasonably heavy. Dimensional limitations imposed by lifting considerations and lifting stresses. Thin panels liable to warp.
Reinforced (lightweight)	Lower density permits the use of smaller cranes or larger panels. Better insulation and fire resistance.	Lightweight aggregate available only in certain areas. Strength, especially tensile splitting strength, needs to be specified and controlled. Thin panels liable to warp.
Prestressed	Permits lighter panels and longer spans. Can be used to control deflection of thin elements.	Requires the introduction of special skills. Elastic movements and creep deflection need to be taken into account in addition to normal design considerations.
Fibre reinforced (steel fibres)	Permits thinner panels and longer spans. Reduces the amount of conventional reinforcement required. Gives high abrasion resistance.	Restricted availability. Higher cost. Requires more control.

Table 1. Comparison of Types of Concrete for Tilt-up

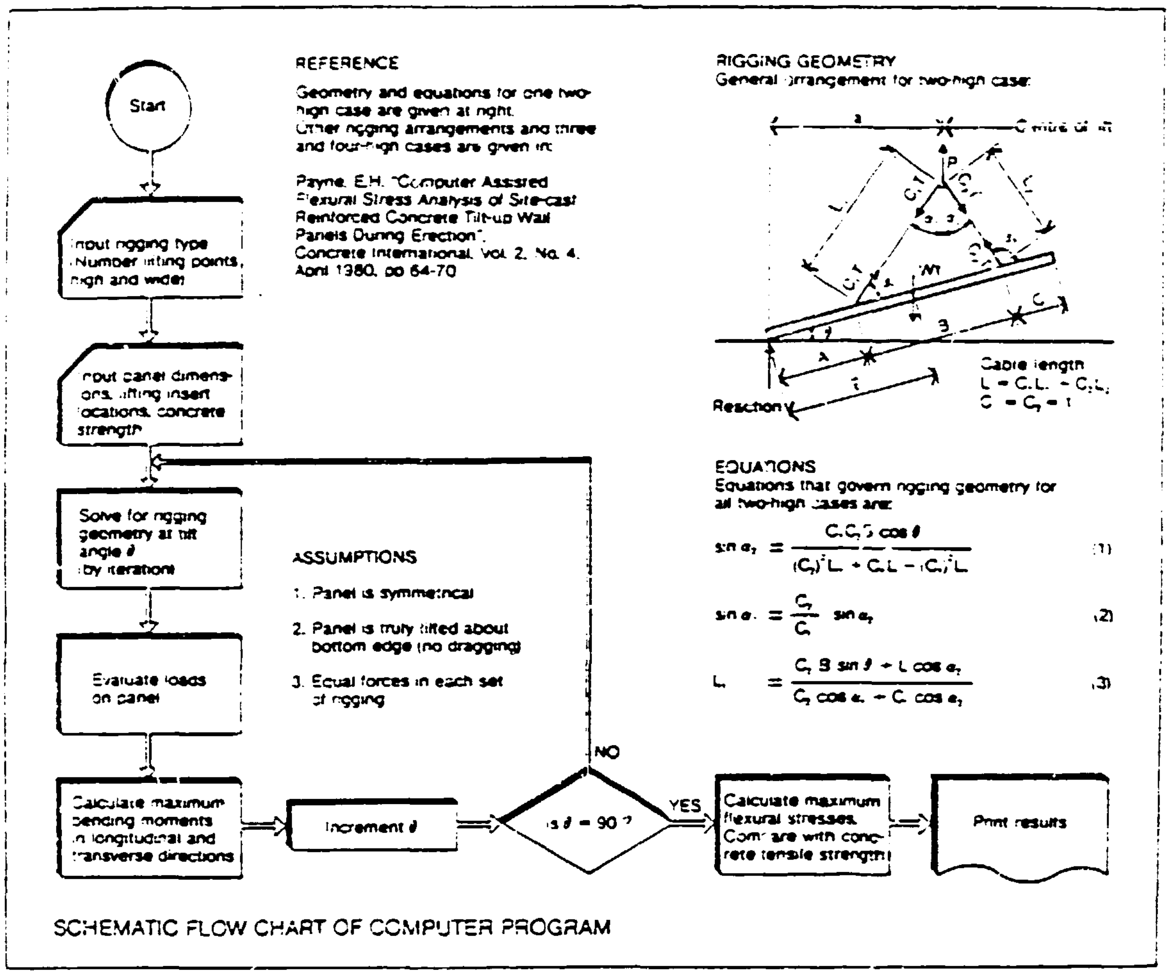


Figure 4

between the panel and the casting surface, and the dynamic impact type loading which will occur when the panel is separated from the casting surface. The effect of these forces must be considered firstly on the panel and secondly on the lifting inserts. See page 10.

It is undesirable for any cracking to occur in the panel during the lifting operation. To restrict the possibility of this occuring the following design approach is recommended:

1 Calculate self weight of panel.

2 Calculate 'W' = 1.4 x self weight.

3 Using this value of 'W', calculate vertical and horizontal bending moments. (The analysis for lifting stresses is statistically determinate but should take into account the change in lifting cable geometry as the panel is tilted from horizontal to vertical, see Figure 4.)

4 Check that bending stresses induced in the concrete do not exceed f_r where $f_r = 0.413 \sqrt{F'_c}$ and F'_c = characteristic compressive strength of concrete at time of lifting, see Table 2.

F'_c at time of lifting MPa	$f_r = 0.413 \sqrt{F'_c}$ MPa
5	0.92
10	1.31
15	1.60
20	1.85
25	2.07
30	2.26
35	2.44
40	2.61

Table 2. Allowable tensile bending stress during lifting.

In the vertical direction the bending moments are assumed uniform over the full width of the panel and calculations are based on a typical metre width. Transverse bending moments are carried on 'notional beams' through the lifting points. The assumed width of these beams is shown in Figure 5.

For estimating purposes the maximum width and height of rectangular panels for given lifting configurations and panel thickness are given in Table 3.

	Lifting Configuration.	Panel Thickness (mm)				
		100	120	140	165	190
Max. height (mm)	edge lift	3170	3440	3660	4110	4420
	1 row	5150	5620	6100	6710	7320
	2 rows	6680	7370	8080	8530	9140
	3 rows	7590	8380	9140	9750	10 360
	4 rows	—	—	10 180	11 060	11 390
Max. width (mm)	2 columns	5760	6220	6710	7320	7920
	3 columns	8500	9200	9910	10 820	11 580
	4 columns	9270	10 030	10 820	11 980	12 650

Table 3. Panel size limitation chart (for 14 MPa concrete at time of lift).

Odd shaped, elongated panels, or those with large or multiple openings can be strengthened for the lifting condition by the addition of strongbacks, see Figure 6. Grooving, profiling, texturing, or any mechanical treatment of the surface will reduce the net section available for structural design and the cover to the reinforcement. The thickness of the panel must be increased to compensate for this.

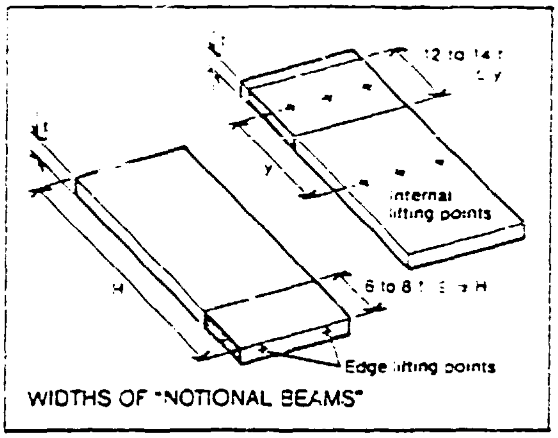


Figure 5

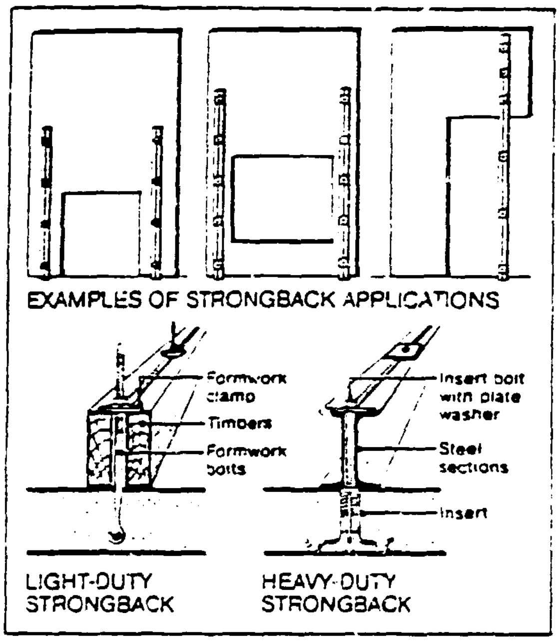


Figure 6

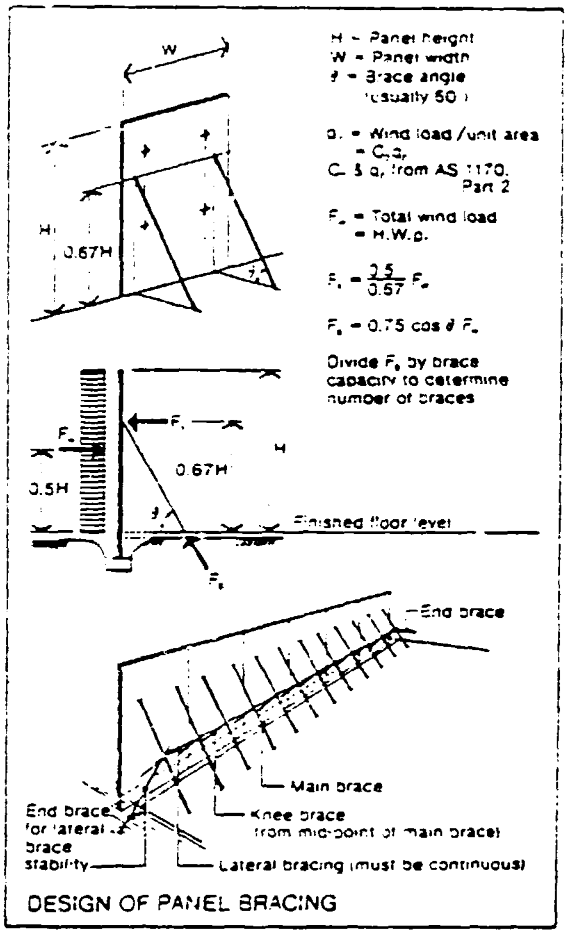


Figure 7

Bracing. It is unusual for the loading on the panel during the temporary bracing condition to control its design. However, the loading needs to be determined so that the bracing can be designed and the stability of the panel ensured.

Braces are usually fixed to the face of the panel. Loads are calculated as indicated in Figure 7. Note that the braces themselves may require bracing, in both directions, to prevent buckling.

4.4 Erected Situation

The design loadings for the erected situation will depend on the building type, how the element is used, the support and fixings adopted and other conditions. It is not feasible to provide detailed design advice covering the many and varied situations. However, some broad comment is made on the following general aspects:

Transverse loadings. It is important that the walls provide a sufficient resisting mechanism for the applied lateral loads, especially where they are being used as loadbearing elements. The roof can function as a diaphragm to carry the lateral load applied on one set of walls to those at right angles. The latter can act as shear walls to resist the applied loads, see Figure 8.

The panels in this wall resist the loading as illustrated in Figure 9, the connections and fixings between the units and between the units and the footings must be designed to carry the induced forces.

Since rules for the design of shear walls are not given in the SAA Concrete Structures Code, AS 1480, it is suggested that designers follow the provisions in the American Concrete Institute Code, ACI 318.

Vertical loads. Wall panels can be used to carry roofs, intermediate floor loads and light gantries. This can be done, for example, by providing a corbel on the face of the panel, see Figure 10.

Loadbearing walls should be designed as columns and not by the empirical rules given in Section 20 of AS 1480. The influence of point loads should be limited to a maximum of the load length plus 12 times the panel thickness. The effect of bending moments induced by the eccentricity of vertical loads and by the applied lateral loading also need to be considered in the design.

It is often desirable to support the panel on isolated footings. This can be done by assuming that the footing reaction spreads into the panel at some angle* or by using a reduction factor.**

Volumetric movements. Except where panels are rigidly fixed together to form a long wall, concrete shrinkage will not have a marked effect on the design. Long walls should be broken up into suitable lengths by the introduction of shrinkage joints and by providing connections at the corners which will permit some movement to take place, see Figure 11.

*G. Weiler and N.O. Nathan. Design of Tilt-up Wall Panels. Concrete International, Vol. 2 No. 4, April 1980, pp 48-51

**K.M. Kripanarayanan. In-place loads and Tilt-up Bearing Walls — a Design Approach. Concrete International, Vol. 2 No. 4, April 1980, pp 43-47

4.5 Floor Loadings

If the floor slab is to double as the construction platform then it must be designed for the imposed loadings. Crane loads when lifting concrete wall panels will be large and may control the design. Design procedures for the floor are outside the scope of this manual. However, the need to provide a compacted sub-base and basecourse under the slab and to provide for shear transfer at the floor joints must be emphasised.

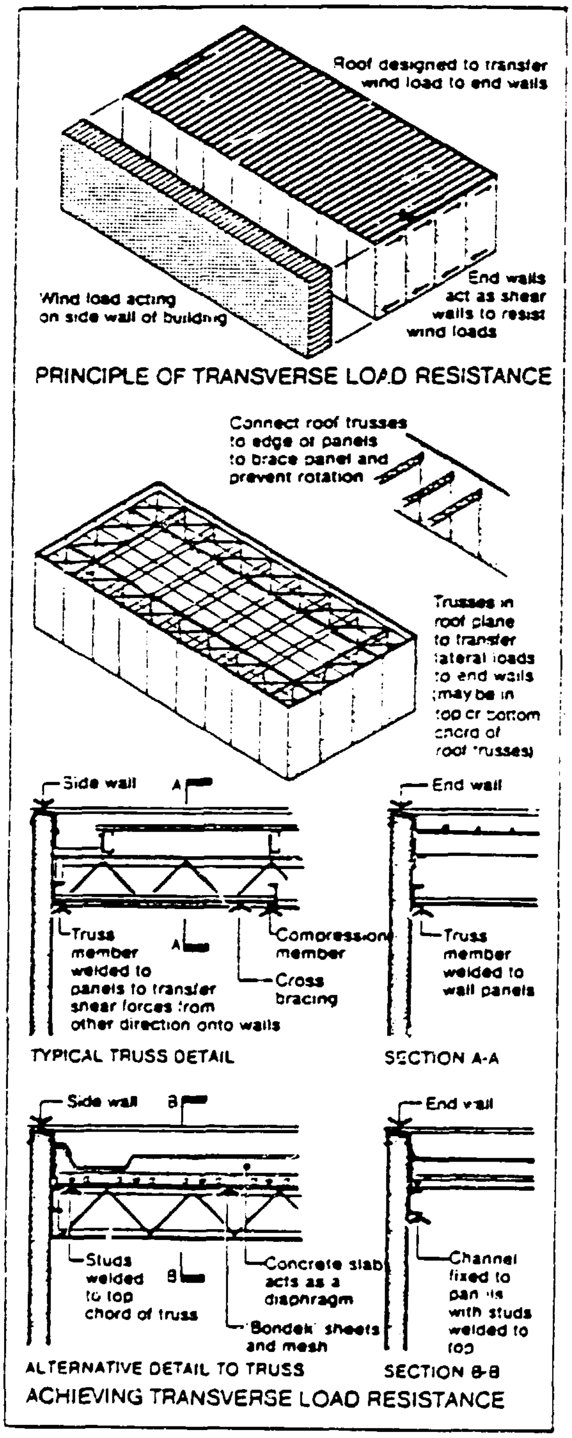


Figure 8

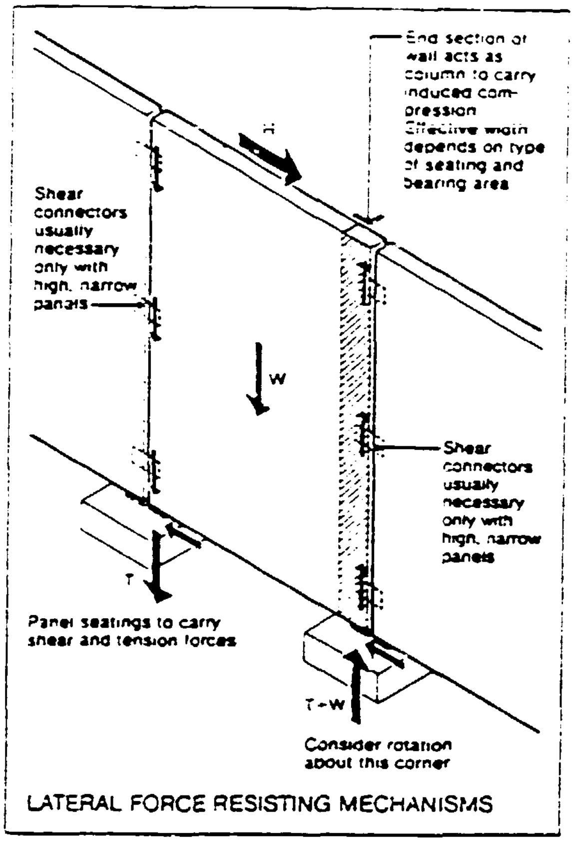


Figure 9

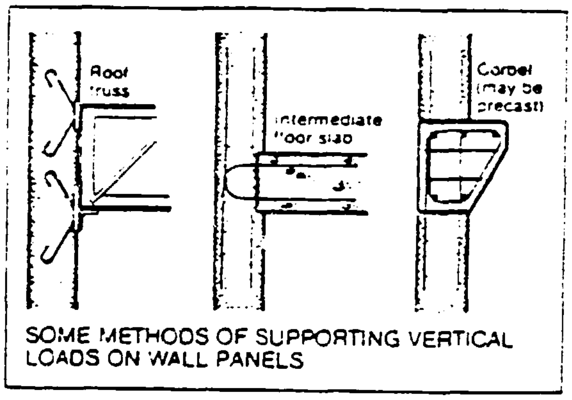


Figure 10

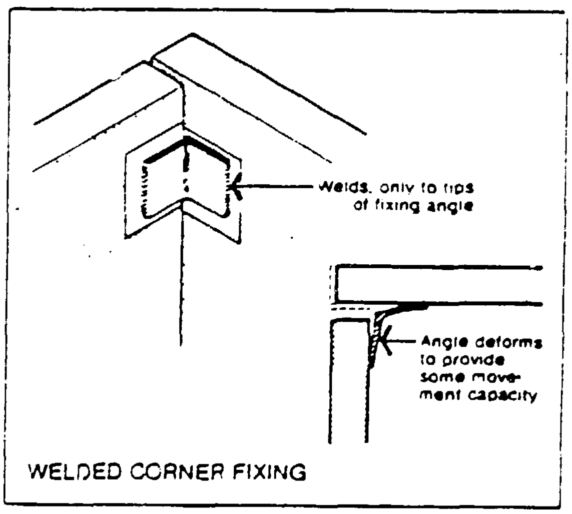


Figure 11

4.6 Durability and Fire Resistance.

Durability as a design criterion is frequently overlooked, as concrete when well made from sound ingredients is inherently a durable material. A number of specific requirements for durability are given in AS 1480, eg water/cement ratio, crack width limitations and cover. These can profoundly influence the design strength of concrete and the thickness of tilt-up panels. Durability considerations should therefore be part and parcel of the structural design and not be relegated to a final gesture of merely checking certain details for compliance.

Fire resistance ratings for various concrete elements are given in both AS 1480 and AS 1481. Those for walls are summarised in Table 4. Note that the Uniform Building Regulations in Victoria prescribe fire resistance ratings for various sized members which differ from those in the Standards.

Fire Resistance Rating (h)	Thickness of Wall (mm)		Minimum Cover (mm)
	Normal weight concrete	Lightweight concrete[1]	
1½	100	80	25
2	125	100	25
3	150	120	25
4	175	140	25

Table 4. Fire Resistance Ratings (AS 1480)[2,3]

Notes

1. Lightweight concrete, design density between 1250 and 2000 kg/m^3 and made with specified aggregates. See AS 1480, Appendix B, Rule B3.2.
2. These regulations are currently under review.
3. Walls are not covered in AS 1481.

5 Detailing

5.1 Reinforcement

A single layer of reinforcement placed at the mid-depth of the section will usually suffice. Two layers of reinforcement may be necessary if the panel thickness is greater than 200 mm or to increase the shear capacity around the lifting inserts.

Placing a single layer off-centre to resist the bending moments during lifting is not recommended, nor is draping the reinforcement since it is is difficult to maintain the desired draped profile. Furthermore, the panel may warp due to the non-uniform restraint of concrete shrinkage. Improved durability is also provided when the reinforcement is placed centrally.

Either mesh or bar reinforcement may be used. Bars provide greater flexibility in adjusting cross-sectional areas, especially in irregularly shaped panels. On the other hand mesh costs less to place and fix.

The control of temperature and shrinkage cracking in tilt-up panels may require a higher percentage of reinforcement than is specified in AS 1480. Recommended minimum areas are given in Table 5.

Specified yield stress of reinforcement	Ratio of area of reinforcement to gross area of concrete
MPa	
450	0.0045
410	0.0050
230	0.0085

Table 5. Minimum Areas of Reinforcement when Shrinkage and Creep are Major Design Considerations.

Extra reinforcement is required both at edges and around openings in a panel to control shrinkage stresses and possible cracking. American practice is to use a single 20 mm bar in these locations, whereas here two smaller bars have been favoured. Diagonal bars across re-entrant corners are more easily located when single edge bars are provided, see Figure 12.

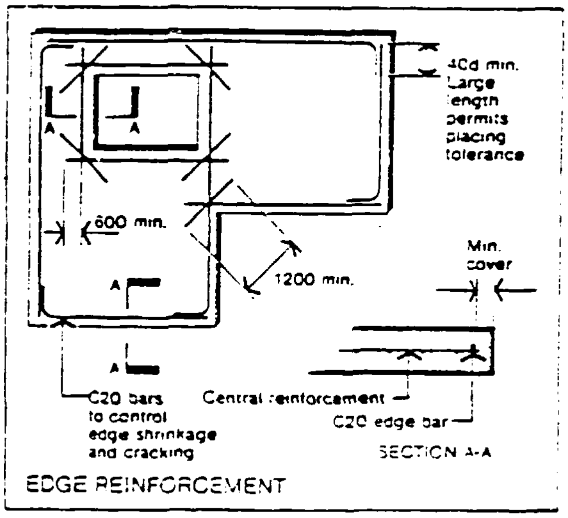


Figure 12

5.2 Lifting and Other Inserts

The use of proprietary lifting inserts specially designed for lifting and carrying panels is recommended. Each manufacturer will normally supply test data giving the capacity of the insert under various types of loads. However, as there are no standard test procedures to determine design capacity, designers should translate these test results into design values with caution.

Inserts and fixings must satisfy the requirements of AS 1480, Rule 24.2.2(d): 'Each lifting device shall be designed for a working load not less than 1.65 times the maximum calculated static load at that point and an ultimate load not less than 4 times the maximum static load'. Note that the lifting loads previously determined for the panel (Section 4.3) are factored to include an allowance for impact and should not be used to satisfy the above rule. On the other hand some allowance should be made for suction, say 0.5kPa.

The critical loading condition for the insert may occur when the panel is either horizontal or tilted at some angle. The loading on the insert being either direct tension, shear or a combination of the two, see Figure 13. Note that failure may occur in either the steel bolt or in the concrete anchorage, both should be checked.

The capacity of other types of proprietary inserts, eg expansion anchors and explosive fasteners, should also be obtained from the manufacturer. Drilled-in inserts, expansion anchors and other similar types of fixing may be used for the temporary braces to the floor.

5.3 Fixings

General criteria to be considered when specifying fixings for tilt-up panels are:

1 For stability the panels will normally require more than one level of fixings.

2 Panels should be supported on seatings in direct bearing, see page 11.

3 Unless the wall is continuously supported along its length by a grouted seating, its weight should be carried at one level by two (no more no less) seatings.

4 Fixings should be designed to accommodate the permitted dimensional inaccuracies of both panels and structure.

5 Fixings should allow the panel to flex under thermal gradient.

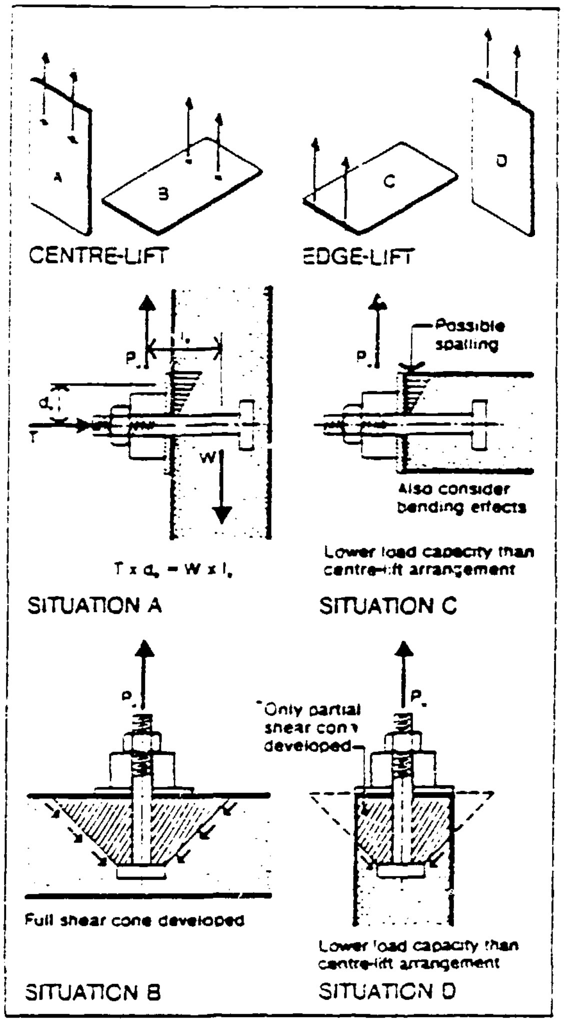


Figure 13

The use of welded fixings is the simplest way to accommodate fabrication and erection tolerances. Bolted fixings may, however, be used and are required as temporary fixings in certain situations. Typical fixings for various situations are illustrated in Figure 14.

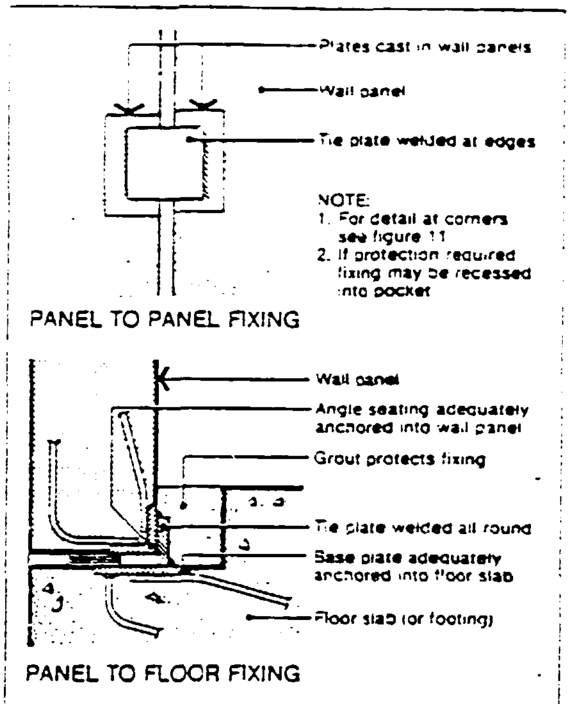
The failure mechanism of fixings should be in tension or bending of the steel. Failures of the weld or by pullout of the concrete should be avoided. Bearing failure by crushing of the concrete may be permissible. However, the effect of bearing crushing on the subsequent performance of that and adjacent fixings should be checked.

Permanent fixings, especially those exposed to the external environment, should be protected against corrosion. This can be achieved by using stainless steel or by protective coatings, eg epoxy or rustproof paint. Any protective coating should be applied over the entire fixing, including those parts to be cast into the concrete.

Fixings may also have to be protected against fire if heat will adversely affect their performance. In general, this can be achieved by recessing the parts and filling the pocket with concrete or mortar, or covering the steel parts with mesh-reinforced concrete. Note in particular the requirements of AS 1480, Rule 24.12.

5.4 Seatings

Various types of seatings are illustrated in Figure 15. Design for vertical loads on these connections is based on the bearing strength of the various materials, eg concrete and steel. In the horizontal direction friction will normally be available to help resist the applied loads. Footings should be detailed to provide an easily accessible area to land wall panels and complete seatings.



1. ROOF TO PANEL	See figures 1, 3 and 10
2. FLOOR TO PANEL	See figures 1, 9 and 15
3. PANEL TO PANEL	See figures 9 and 11
4. INTERMEDIATE FLOOR TO PANEL	See figure 10

OTHER TYPES OF FIXINGS

Figure 14

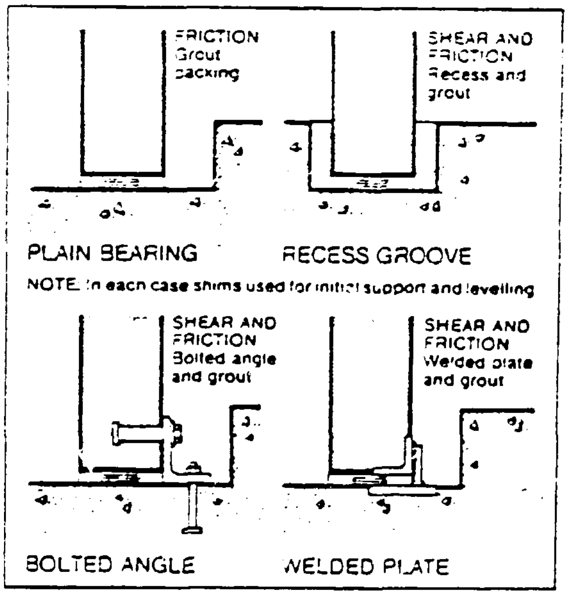


Figure 15

Unless they are designed to carry the final loading, steel shim pads used for erection purposes and left in place after the base of the wall is grouted may cause spalling due to the disparity of the moduli of elasticity. The use of plastic shim pads is therefore preferable.

5.5 Joints

The importance of joint detailing in respect of the cost, appearance and performance of a tilt-up building cannot be over-emphasised. Joint details must be compatible with the structural design assumptions, the erection procedures, the fixing details and the construction tolerances. The aspects of joint design which must be considered are:

Appearance. The number of joints should be kept to a minimum. If the appearance of smaller panels is desired then this can be achieved by the use of false joints (grooves) in the panel surface.

It is usually desirable to express the joints, not to try to hide them. The use of a recess or a dark band of paint on either side will help mask any variation in the width of a joint. It will also minimise the effects of any variable weathering at the joint line. In certain circumstances, eg with heavily ribbed panels, it may be possible to conceal the joints in the overall texture of the wall.

A bevel at the edge of the panel is preferable to an arris which is vulnerable to damage.

Corners of tilt-up buildings demand special consideration. Oversail joints are preferred where it is acceptable to show a panel edge on one facade (its prominence will depend on the finish used on the face of the panels). Mitred joints allow a uniform surface treatment of both walls, but they do impose greater restrictions on erection tolerances and are generally not recommended, see 7.3.

Weathertightness and maintenance. Joints between wall panels will usually need to be weathertight.

There are a number of joint types used for butt joints between wall panels, the most common are open drained joints and one stage, face-sealed joints, see Figure 16.

Open drained joints are recommended though face-sealed joints are frequently used on low rise industrial buildings. The advantages and disadvantages of the two types of joint are summarised in Table 6.

At a corner joint the situation is different. The movement of the joint will include some shearing as well as tension and compression so the design criteria will be different.

Flashing details at the top of the wall and roof need to be matched to that adopted for the joints. In all situations the use of a cap flashing is recommended, see Figure 17. Such cappings must be securely fixed to prevent wind uplift.

Joint width and sealants. Joints must be able to accommodate rotation and the variations in width caused by construction and erection practices. They must also allow the panels to move relative to each other as the environment changes, eg changes in temperature or moisture.

For tilt-up construction it is recommended that

1 Joint widths should be in the range 15 - 25 mm.

2 To maintain specified joint widths, erection procedures should allow cumulative fabrication tolerances to be absorbed at corners or openings. See page 21.

The design of the seal for both open drained and single stage joints is complex and involves the consideration of a number of factors, eg expected movement, type of sealant, width to depth ratio of sealant. A full discussion of all factors is outside the scope of this manual, a detailed evaluation can be found in the ACI Guide to Joint Sealants for Concrete Structures. The following general points should be noted:

1 Wide joints lower the strain due to volume movements and are preferred, see Figure 18.

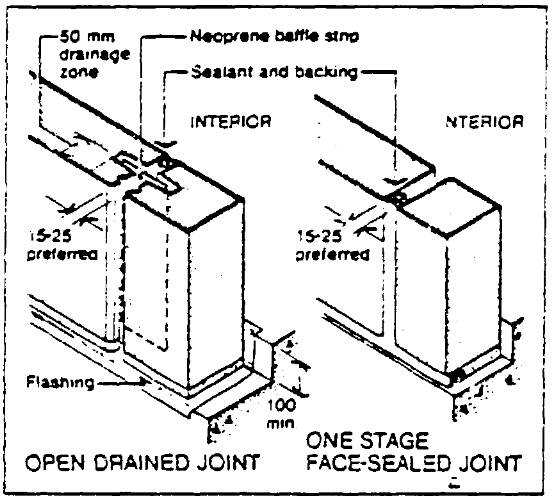


Figure 16

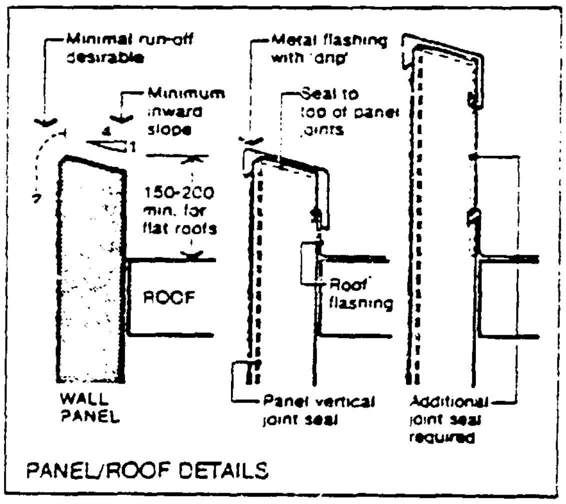


Figure 17

	Advantages	Disadvantages
Open drained joints	Basic sealing mechanism dependent on geometry not on adhesion.	Require complex edge formwork.
		Profiled edge prone to damage.
	Will tolerate larger construction variations and subsequent movements.	Installation of baffle and bottom flashing has to be carried out during erection.
	Installation during wet weather possible.	The drumming of baffle under certain wind conditions may be objectionable.
	Air seal protected from U.V. light and weather.	
One stage, face-sealed joints	Simple edge profile (no grooves necessary)	Effectiveness of seal totally dependent on continued adhesion and performance of sealant.
	Completed joints easy to inspect.	Access necessary to front face of panel after erection
		To ensure good adhesion, condition of concrete surface critical, ie must be clean, smooth, dense, dry.
		Sealant exposed to major deteriorating influences, eg U.V. light and weather.

Table 6. Comparison of open drained and one stage, face-sealed joints

2 Preferred sealant cross section dimension proportions are 2:1 as these also help to limit stresses due to movement, see Figure 18.

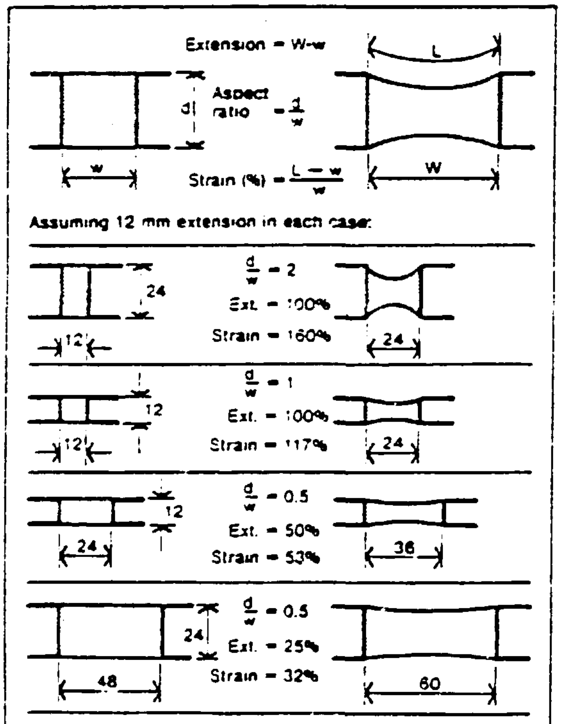
3 Sealants should be bonded only on the two side faces. Backup rods which do not bond to the sealant are available to control the depth and profile of the sealant.

4 The concrete faces at the joint should be dense, smooth, clean and dry to enable a good bond to be made with the sealant. The compatibility of the form release agent and any curing compound with the adhesion of the chosen sealant should be checked.

5 The extension and compression capacities of mastic sealants will be inadequate for most tilt-up structures.

6 The effect of aging and exposure on the sealant must be considered. Most tilt-up buildings are not tall and therefore access to the joints for maintenance or repair may be neither difficult nor costly.

7 The removal of a failed sealant can be difficult and the cleaning of the joint surfaces to permit the installation of a new seal may not be easy. Thus for low maintenance costs a resistant sealant (not the cheapest available), shielded where possible from direct exposure to sunlight and weathering, is desirable.



STRESSES AND STRAINS IN SEALANTS

Figure 18

6 Surface Treatments

A major factor in the acceptance and therefore the increased use of tilt-up in the USA has been improved appearance. A wide range of treatments and finishes which are easy to achieve has been developed.

These developments notwithstanding, the improved appearance very largely stems from the sensitive detailing of panels to break up the monotony of long walls of large uniform panels.

Detailed information on a range of finishes is given in a series of data sheets 'Tilt-up Techniques' being published by the Cement and Concrete Association of Australia. General information is provided herein.

6.1 General Principles

Simplicity of finish should be the primary objective. It is not generally possible to achieve on the site the same degree of control over surface finish that is normal in a precasting factory.

Painting can be used to provide strong visual effects, to mask colour changes and reduce the visual prominence of accidental variations in texture.

Grooves should be used to break up the scale of panels and to separate different finishes or colours. If these grooves are to be painted then they should be wide enough to accept a small size standard roller.

The compatibility of the bond breaker with the desired surface finish should be checked, by test panel if necessary. This should establish any risk of surface staining and the effect on any subsequent paint film to be applied to the surface.

Concrete mix design should take account of the quality of surface finish desired. It should be cohesive and be rich enough to reproduce any fine textures which may have been specified.

To ensure uniform colour on concrete surfaces it will be necessary to maintain a consistent supply of cement, aggregates and sand. Good mix design (including control of water/cement ratio and minimum cement contents), uniformity of formwork absorption and curing conditions are also imperative. (Note that these considerations rather than structural considerations may control the specification of the concrete.)

The use of test panels is strongly recommended. They should be large enough to be representative of the specified technique, approval should be related to the entire panel, not just sections of it.

6.2 Implications of Surface Treatment

Each face of a tilt-up panel can be given a special finish but it is usual to confine special finishes to the external face. The internal face is normally given only a plain, smooth finish.

Finishes are described as being provided 'face-up' or 'face-down', depending on the position (at the time of casting) of the face receiving the finish.

Table 7 provides a list of the types of surface finishes and how they can be achieved on face-up and face-down surfaces. From the comments also included it can be seen that face-down is preferable for most types of finishes. This approach has the further advantages that the panels can be stack cast, and that the lifting inserts are on what becomes the back of the panel, where the subsequent filling will usually be least objectionable.

Type of finish	Face-up (Single casting*)	Face-down (Single or stack casting*)
Rebates and grooves	Hammer form into top surface. (Position and depth difficult to control.)	Fix timber form to base slab. (Position and depth easy to maintain.)
Plain, smooth surfaces	Finish panel with bull float and trowel. (Common paving technique.)	Finish off floor or casting pad. (Reproduces all imperfections of that surface.)
Exposed Aggregate	Water washed. (Special aggregates and patterns difficult to control.)	Sand embedment. (Different aggregates and patterns easy to achieve, independent of concrete mix.)
Fine Textures	Broomed, Combed, Imprinted, Rolled.	Timber forms, Formliners.
Coarse Textures	—	Timber forms, Profiled steel sheeting, Polythene over stones, Formliners.

Table 7. Methods of achieving various types of finish by both face-up and face-down approaches.

*See Table 8.

An early decision on the finishes to be used and, more importantly, whether a face-up or a face-down approach will be adopted is important since it can influence the whole casting procedure — location, sequence, etc.

6.3 Particular surface treatments

Paints/stains. Painting or staining is the easiest way of improving the appearance of smooth finished surfaces. They can also be used on textured surfaces although application becomes more difficult as the coarseness of the texture increases. Painted surfaces have the advantage of masking minor imperfections and colour variations in the base surface but will not conceal major texture variations. Further, they offer the advantage of being easily reinstated after despoiling (accidental or intentional) and are easy to maintain and change to give a new image to a building following a change in tenancy.

The effect of the bond breaker and of the curing process on the adhesion of the paint film needs to be checked. If an incompatible material has been used any bond breaker adhering to the surface can be removed by lightly sandblasting or by grinding. See page 19.

Various paint applications may be used, both high build or thin film are suitable. High build applications can be used to mask unwanted surface texturing. Surface preparation will depend on the paint type, the recommendations of the manufacturer should be followed. Application may be by spray from a 'cherry picker' or by roller, depending on the paint type and desired paint film texture.

Formliners. These are applicable only to cast-down faces but can be used in either stack or floor cast approaches. A wide range of patterns and textures is available overseas and can be imported or fabricated. They can be made of a number of materials: rubber, timber, thermoplastics, and fibreglass-reinforced plastics. Formliners need specialist release agents, these are usually recommended by or available from the manufacturer. Where not supplied by the formliner manufacturer testing will be necessary.

Exposed aggregate surfaces. These may be formed on either the face-up or face-down surfaces and are therefore suitable for either floor or stack casting. However, the techniques for forming them in the two approaches are quite different: water washing for face-up surfaces; sand embedment for face-down.

In the USA the face-down sand embedment technique is generally preferred because of its versatility.

7 Construction

7.1 Programme

The dual aspects of construction and programming should be anticipated during the planning and design stages and not regarded as a problem solely for the builder.

As well as considering the physical aspects of how the building is to be constructed, thought must be given to the requirements for labour, time for construction, and the sequence and timing of the construction.

The size of the workforce needed to complete the job in the required time will depend (amongst other things) on the level of experience with tilt-up. The learning period need not be long, particularly if there is a high level of standardisation, but allowance for this must be included.

As much work as possible should be carried out on panels when they are on the ground rather than when they are, or are being, erected. For example, fixings (both temporary and permanent) and preparation for jointing.

7.2 Access

Access to and around, the site greatly influences the construction and erection processes. Two aspects have to be considered: access for construction of the tilt-up panels and access for their erection.

The locations for casting the panels should allow easy access for concrete trucks and the discharge of the concrete, preferably directly from the truck. Figure 19 gives clearances, dimensions and turning radius for a typical 5 m^3 concrete truck. If truck access to the casting areas is not possible then other methods, such as pumping will need to be considered.

All-weather access to the casting locations and for erection will be required if construction is to proceed with the minimum of interruption. For this reason many contractors prefer to work off the floor slab. Alternatively, consideration should be given to providing temporary construction roads around the building area, or the early construction of final road and car parking area bases.

Having checked the requirements for access during construction those for erection need to be examined. The crane frequently operates on the final floor because either the building is to occupy the whole site or it is the only suitable surface for the crane to use for transporting panels. In this case the design load for the floor must take this into account.

It is desirable that crane operation is restricted as little as possible by other construction operations or by the building itself. For example, even with a steel frame building where the tilt-up wall panels are being used only as cladding, the panels should be erected as soon as possible. Depending on the type of column base connections, the panels may be erected and braced before or after the columns. The roof beams can then be erected inside this shell. This is preferable to the crane having to operate in the restricted area between the already erected frames.

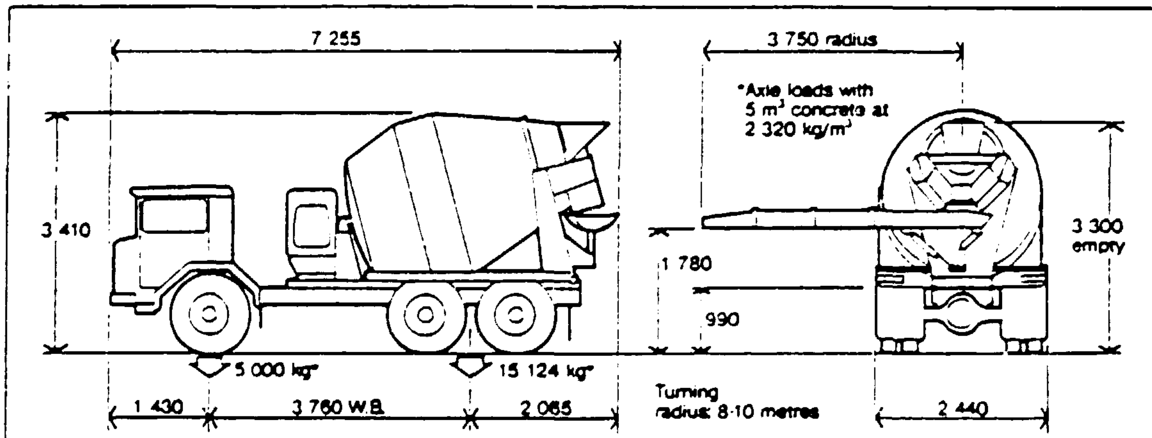
The position of overhead services should be established so that clearances during erection can be checked.

The position of underground services should also be determined and the path of any required connections to them plotted. Operating a mobile crane over or near recently backfilled trenches is always dangerous, when carrying a large, heavy wall panel particularly so.

7.3 Layout and casting method

The choice of surface finish will determine whether the panels are cast face-up or face-down. Erection procedures will influence the decision whether to cast singly over a large area or to stack cast (one on top of the other) and the choice of the casting locations.

The advantages and disadvantages of the two methods are summarised in Table 8.



DIMENSIONAL DATA FOR TYPICAL 5 CUBIC METRE CAPACITY CONCRETE TRUCK

Figure 19

	Advantages	Disadvantages
Single Casting	No separate casting pads required. Simple edge formwork. Full range of surface finishes possible* Simple checking of line-up of adjacent fixings, etc. Easy set-out of patterns in wall and panels. Units close to final position.	Surface finish of floor and location of construction joints must suit required panel finish and dimensions. Floor may require repair after fixings removed. Little reuse of formwork possible. Conflict at corners requires resolution.
Stack Casting	Can proceed independently of floor. Permits greater programming flexibility. Number of reuses of formwork possible.	Requires separate casting pads. Limited range of finishes*. Lifting more difficult and needs to be carefully controlled. Formwork quite sophisticated.

Table 8. Single and Stack Casting

*See Table 7.

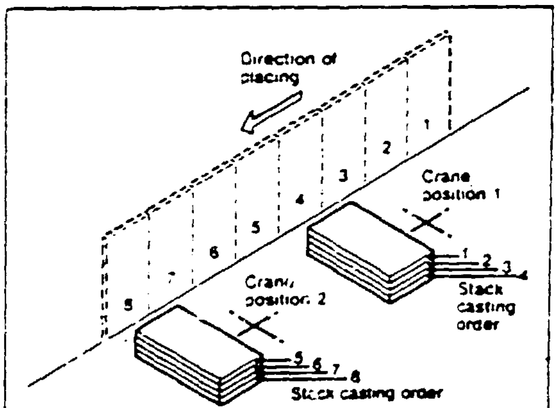
Panels should be cast as close to their final position as possible to avoid double handling and to keep the erection time as short as possible.

When the floor is used as the casting bed then the layout and the erection procedure should be planned to avoid the crane having to move over, or set up on cast panels.

In determining casting locations it is important to remember that, if the crane is to operate from inside the building, it may be necessary to omit one panel, move the crane out, and then erect this panel from the outside.

It should also be noted that casting on the floor probably means that the construction programme is less flexible, eg the construction of tilt-up panels cannot be commenced until that area of the floor is completed.

When stack casting is adopted then the casting order should reflect the erection order to avoid double handling the panels or having to erect one between those already placed, see Figure 20. An exception to this general rule is that smaller units should only be cast on top of larger.



STACK CASTING ORDER

Figure 20

Casting stacks should be sited to allow room for the crane to be set up in positions such that double handling of panels is avoided and the number of set up positions is kept to the minimum.

The number of panels in the stack is controlled by the number which can be erected without double handling, and by the need to limit the height of the stack so as not to make concrete placing and finishing too difficult. If parking areas and access roads are in concrete, they can be used as casting beds.

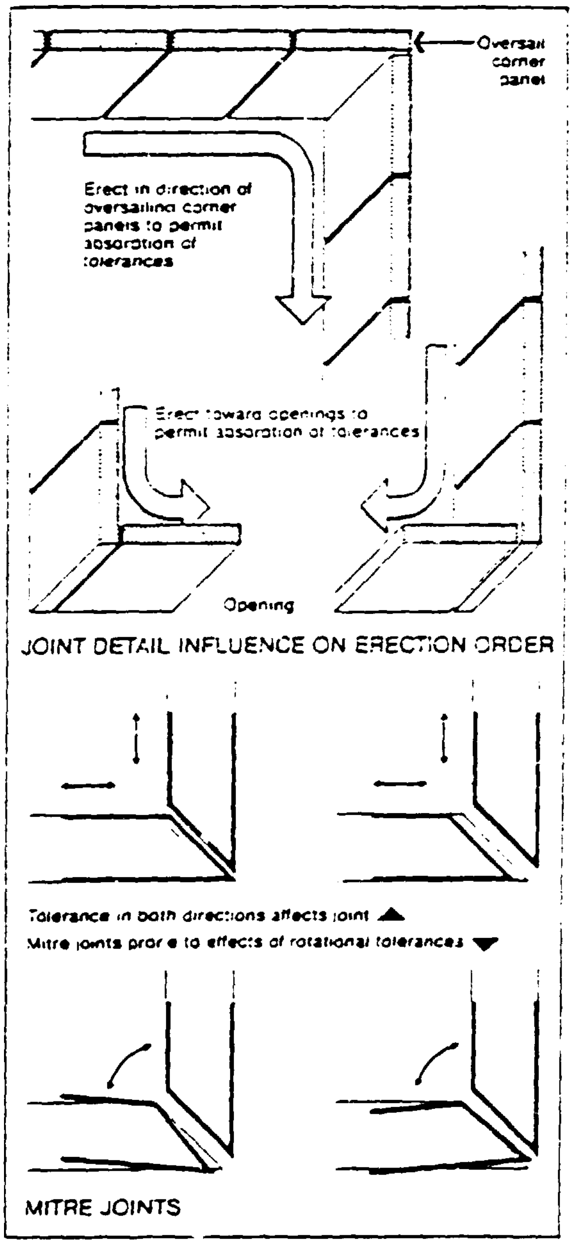
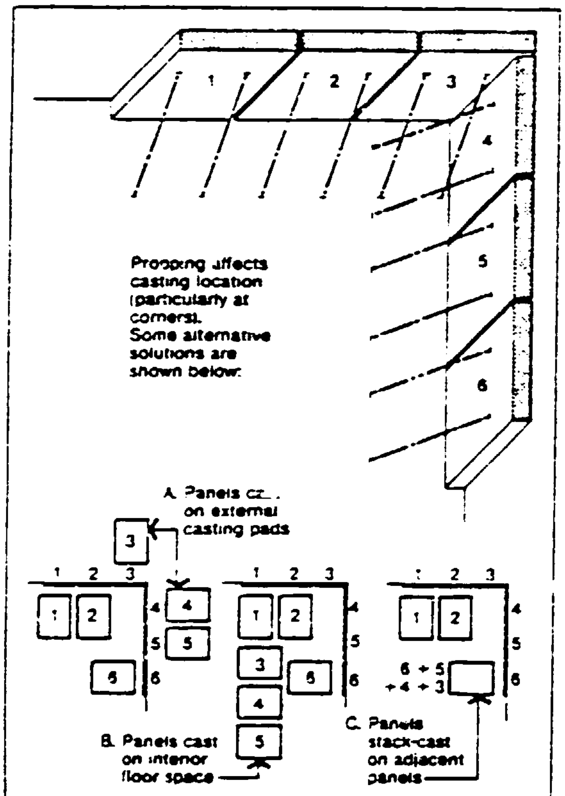


Figure 21

Joint details may also influence layout and erection sequence. If oversail corner joints are adopted then the erection sequence should enable any accumulation of erection tolerances to be absorbed in the oversail. Mitre joints do not impose any restraints on erection sequence. However, they do require more stringent control of erection tolerances and are best avoided, see Figure 21.

After erection the panels will require to be temporarily braced until the final fixings can be made. If the panels are to be cast on the floor slab the braces will restrict the choice of casting locations of corner panels and movement of the crane. Various ways of overcoming this problem are shown in Figure 22. The alternative using external bracing is not generally recommended as it requires the provision of purpose-made 'dead men'. Furthermore, it places fixings on the external (often decorative) panel face.



BRACING INFLUENCE ON CASTING LAYOUT

Figure 22

7.4 Formwork

Formwork for tilt-up construction is at its simplest limited to perimeter framing of the panel. However, the extent and sophistication of the formwork and formlining will depend on the amount of modelling or texturing of the external surface. The choice of materials for formwork and the accuracy of its construction play a vital part in ensuring that the erection process goes smoothly and efficiently.

Casting Surface. When one concrete surface is cast on another it reflects all the imperfections and blemishes of that surface. Special care is thus required to control the tolerances and finish of all surfaces which are to have another cast directly against them. If possible, no construction joints should be included in an area of floor which is to have a panel with a smooth finish cast against it.

When openings must be left in the floor for piping, utilities, or the erection of interior columns at a later date, a 20 mm skin coat of concrete over a sand fill can be used to close the opening temporarily. The skin coat can be knocked out after the panels have been tilted.

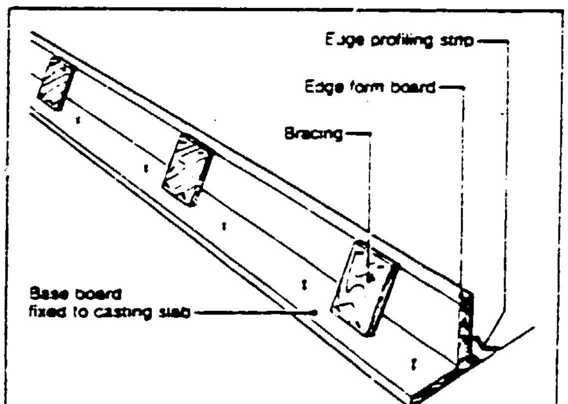
If temporary bracings are to be fixed to the casting surface, fixings which require pre-drilling or casting in should be avoided since they may read on the face of the completed panel. Expansion type fixings, drilled in after the panel has been lifted are prefered.

Casting surface considerations will usually dictate tighter tolerances on construction and surface finish for the whole floor than are required for its subsequent use.

Formwork to provide recessed areas in the panel face should be robust enough to remain plane under the application of concrete and associated construction loadings.

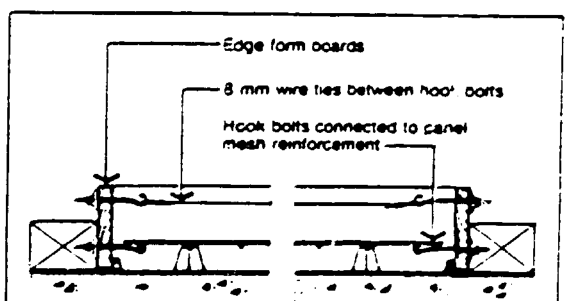
Edge formwork. With planar units edge formwork is all that is required. For floor casting timber formwork robust enough to withstand the rigours of construction is normal. The size of edge formwork members and the spacing of the supports needs to be related to the tolerances of construction. Bulkier or stiffer edge members will require fewer braces or ties. This must be considered in conjunction with the possible need for space between panels required for striping the edge formwork prior to lifting. The forming of any edge profiling, from joint considerations, needs also to be taken into account. 50 mm dressed boards shaped to suit joints and braced as shown in Figure 23 are commonly used.

The forms are generally fastened to the floor using explosive fasteners. These, however, may lead to some spalling of the floor surface. Alternatively drilled fasteners may be used. To avoid damage or the need to repair the floor, the formwork is in some cases not fixed down but sealed round the edge and cross tied through the reinforcement, see Figure 24.



EDGE FORMWORK BRACING

Figure 23



CROSS-TIED EDGE FORM SYSTEM

Figure 24

For stack cast panels more sophisticated edge formwork, eg steel channels, can be justified as there will be a number of reuses, see Figure 25.

As with all formwork great care must be taken at the joints, eg at corners and between the edge forms and casting surface, to form a tight seal to prevent leakage of fines and mortar which could lead to honeycombing, weakened edges and severe discolouration.

Edge forms should be coated with form release agents to permit easy stripping.

Blockouts. Blockouts for major openings can be treated in similar fashion to edge forms. They should be securely fixed to the base slab to avoid displacement during concreting.

Grooves, indents and rebates. Grooves, indents and rebates are most easily formed on the cast down surface as mentioned previously. To ensure correct location it is desirable where possible to continue the grooves to the edges of the panel. Timber strips for forming grooves should be splayed as shown in Figure 26 and sealed to prevent swelling.

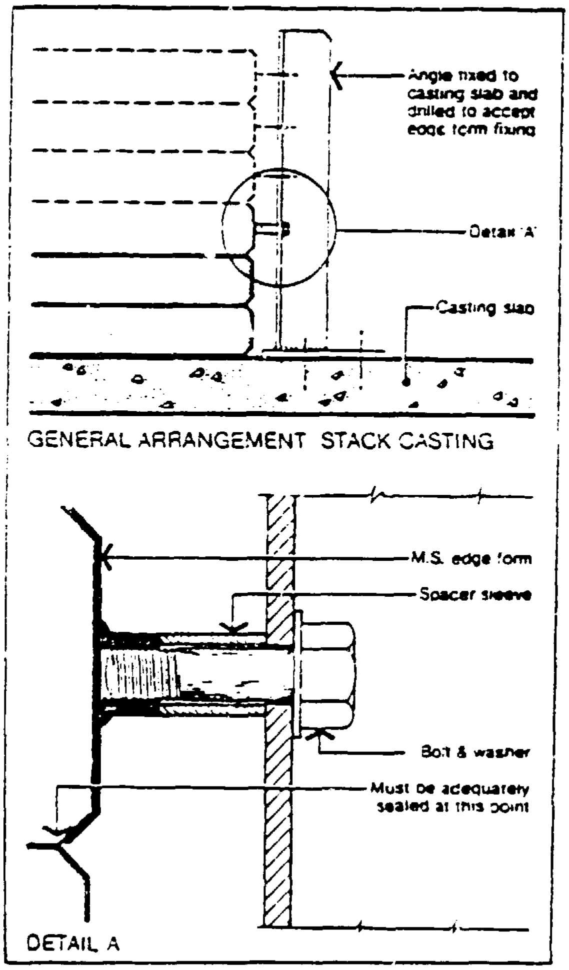


Figure 25

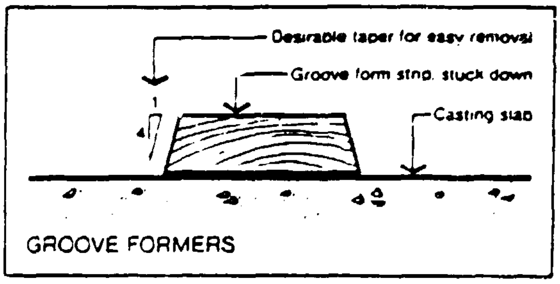


Figure 26

7.5 Bond Breakers

Coatings used to prevent bond between the casting surface, typically concrete, and the panel cast on it are variously known as bond breakers, separation compounds and parting agents. Their performance is probably the single most crucial element in the tilt-up process. The moment of truth for any tilt-up project is at lifting. Will the panel separate or not? A single captive panel can disenchant all associated with the project. Thus the choice and application of the bond breaker is crucial to the success of any project.

The functions of bond breakers are:

1 To permit clean complete separation of the tilt-up panel from the casting surface.

2 To minimise the dynamic loading caused by suction at the time of separation.

3 Generally, to also function as a curing compound for the casting surface.

The residue of the compound on the panel or the casting surface should not discolour or interfere with the adhesion or performance of any applied coatings or coverings or cause discolouration of the concrete.

It is important to stress that release agents used to facilitate the stripping of formwork in insitu concrete construction are not suitable for use as bond breakers for tilt-up construction.

A number of satisfactory bond breakers is, however, available. It is essential that one of these be used.

If the bond breaker is not doubling as a curing compound, then the compatibility of the two must be checked.

When applying particular compounds the manufacturer's recommendations should be followed. However, the following points are offered as a general guide:

1 Apply two coats of the bond breaker each in two applications at right angles to each other.

2 When the first coat is being used for curing it is usually applied immediately after the concrete surface has received its final trowelling and when the moisture has just disappeared from the surface. The second coat is applied after the formwork is in position.

3 Prior to spraying the compound ensure that the surface is clean and free from dirt, debris, sawdust, etc.

4 Apply the compound uniformly. Check particularly the perimeter of the panel adjacent to edge forms. Do not leave puddles on the surface.

5 When applying over fine textured surfaces a heavier application will be required than on smooth trowelled surfaces.

6 If spraying over old concrete, eg dry absorbent surfaces, dampening the surface prior to spraying is recommended, as well as a heavier application, to limit and compensate for absorption.

7 No traffic should be allowed on the coated surface before the coating is dry.

8 Before casting the panel check questionable areas, eg those with light or dull colour, by sprinkling on to the surface a few drops of water which should bead, not be absorbed into it. If necessary recoat the doubtful areas and allow to dry before casting. Reinforcement should be protected from contamination by bond breakers as it will impair bond.

7.6 Separation of Captive Panels

If a panel is not too strongly bonded then it may be separated by driving in steel wedges at the top edge and at insert lines while trying to lift the panel in an effort to slowly peel it off. Care needs to be exercised in the amount of tension applied to the panel otherwise the jolting as the panel springs free may damage either the panel or the crane. This method will probably damage the edges of the panel and the surface against which it was cast. Alternatively, prestressing tendons on a temporary cross head can be used to induce a shear across the interface and thereby break the bond.

Where, however, the problem results from the use of a completely ineffective bond breaker, these methods will not be effective. It is therefore a golden rule to test the proposed compound and casting procedures prior to the commencement of full scale construction.

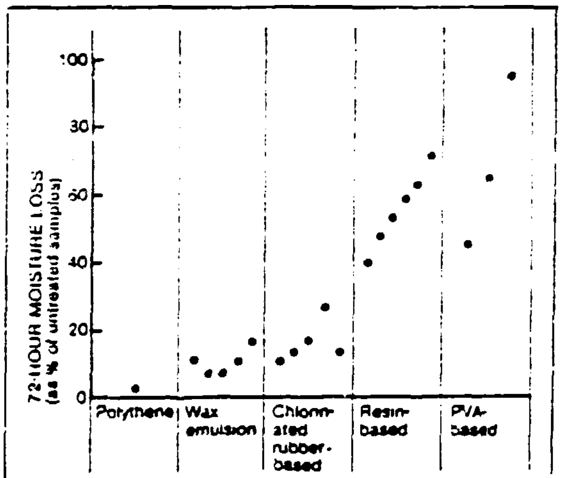
7.7 Placing and Curing

In general, normal practices for placing, compacting and curing should be followed. The concrete should be placed, compacted, levelled and screeded as promptly as possible. Care should be exercised around fixings where steel congestion may prevent easy compaction. No final finishing should be attempted until the bleed water has disappeared from the surface. No driers should be used.

In hot conditions the top surface of the concrete should be protected against rapid drying by shielding the surface from winds, shading from the sun and timing the placement to avoid the worst conditions. Working aliphatic alcohols into the surface will also help control evaporation from the surface and the risk of plastic cracking.

Tilt-up panels should be cured properly to ensure that the full potential concrete strength is developed and that colour control can be maintained.

In Notes on the Science of Building N.S.B. No. 115 the Experimental Building Station published the results of tests on the four main classes of curing compounds and some traditional curing methods, see Figure 27. Note that the lower the moisture loss the better the curing.



COMPARISON OF CURING COMPOUNDS

Figure 27

As with bond breakers, two further points need to be stressed. Firstly, to be effective the curing compound needs to be properly applied giving uniform and complete coverage to the concrete surface. This application should take place just when the sheen of surface moisture has disappeared but the concrete is still damp.

Secondly, the compatibility of the chosen compound with the bond breaker and its effect on subsequent surface treatments needs to be evaluated, eg wax emulsion will impair the bond of future surface coatings.

7.8 Cranes

The size of crane to be used needs to be considered and the limitations of a small crane (smaller panels, more joints, more set ups, slower erection) balanced against the increased cost of bringing a large crane to the site. Mobile cranes impose high point loads on the ground and the ground must be capable of supporting these loads. This loading should also be considered when designing the floor. Crawler mounted cranes impose lower bearing stresses on the ground and can be useful when erection from outside the building is possible.

The lifting limitations (height, reach and load capacity) of the chosen crane should be carefully examined. As a rough rule of thumb crane capacity should be two to three times the maximum panel weight. Some thought should be given to the extra reach required to enable the lifting rigging to be attached to the panel. On the basis of these limitations the layout of the casting locations and the erection procedures should be determined. Dismantling, moving and setting up in a fresh location takes considerable time and is completely unproductive. Therefore, the more panels which a crane can erect from a given position the more efficient the operation.

Some cranes can lift only when supported on outriggers. Those which can lift without them can also travel with a panel, provided the operating surface is suitable. Operation on the completed floor slab or concrete road pavements is ideal.

All rigging, lifting beams, shackles, etc may be available from the crane supplier, but this should be checked. Ideally, sufficient equipment for three panels is desirable, one set being removed from the erected panel, whilst one set is on the panel being lifted and one is being fixed to the panel about to be lifted. Nevertheless, it is possible to make do with a lesser number though slower progress may result.

Rate of erection will vary with the size of the panels, layout, complexity of bracing, etc. As a guide it is reported that in the USA contractors aim to erect one panel every half hour and frequently manage a 15—20 minutes cycle.

7.9 Rigging and Bracing Hardware

Edge lifting is sometimes preferred as it allows the panel to hang vertically, although fittings have been developed to permit face lifted panels to hang vertically. However, this has been found unnecessary and most erection overseas is done with face lifted panels which hang slightly off vertical.

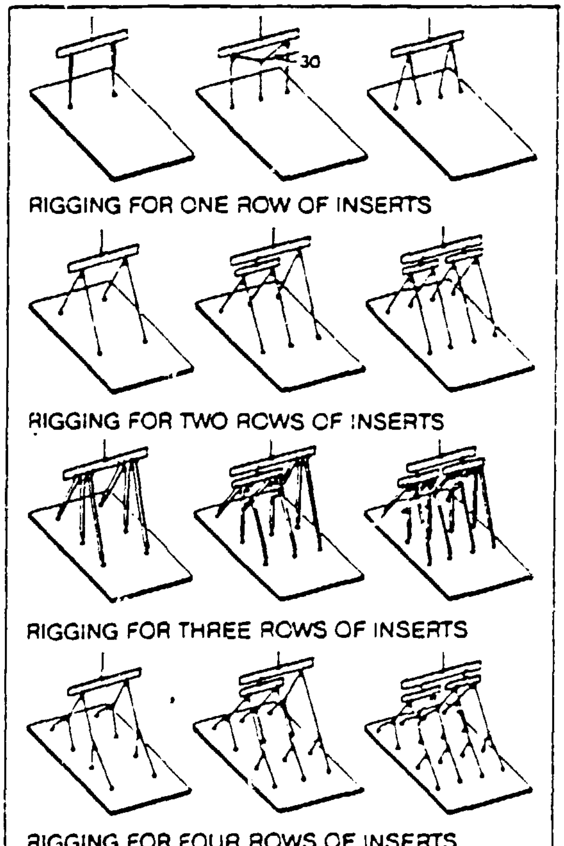


Figure 28

For large panels with multiple lifting points the rigging can be quite complex, see Figure 28.

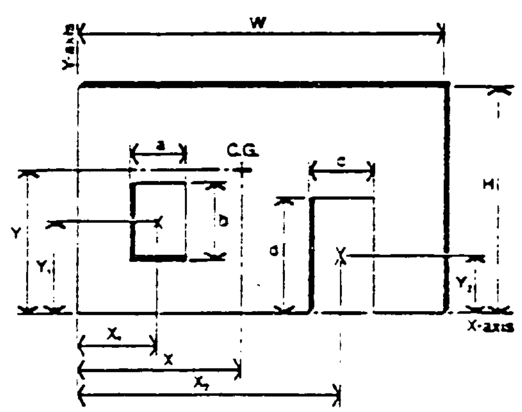
Quick release fittings have been developed overseas to enable the crane to be freed from the panel as soon as the temporary bracing has been fixed. These provide a worthwhile time saving.

Temporary braces must be positioned clear of lifting inserts and rigging. Where possible they should be fixed to the panel before lifting. Purpose made adjustable braces are available in the USA from the major accessory companies. These speed the erection process as final plumbing of a panel can be carried out using these braces.

7.10 Lifting

Where possible the crane should be on the same side of the panel as the bracing so that the driver can see the erection operation.

The lifting inserts must be placed symmetrically about the centre of gravity in the horizontal direction so that the panel will lift level, and above the centre of gravity in the vertical so that the panel will tilt. Centres of gravity for each panel should be calculated as shown in Figure 29, and marked on the drawings.



A. Window opening only:

$$X = \frac{\frac{W^2H}{2} - abX_1}{WH - ab} \qquad Y = \frac{\frac{WH^2}{2} - abY_1}{WH - ab}$$

B. Window plus door opening:

$$X = \frac{\frac{W^2H}{2} - abX_1 - cdX_2}{WH - (ab + cd)} \qquad Y = \frac{\frac{WH^2}{2} - abY_1 - cdY_2}{WH - (ab - cd)}$$

CENTRE OF GRAVITY CO-ORDINATES

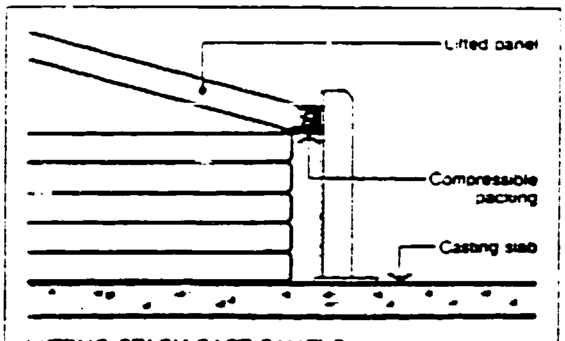
Figure 29

The layout of the lifting holes should also be clearly shown. Very tall panels, or those with thin legs or multiple or large openings may need to be strengthened by strongbacks before lifting.

Lifting should be carried out so that the panel rotates about the bottom edge. Any damage to this edge can be hidden by appropriate joint detailing. Care should be taken to avoid sliding or dragging panels across the finished floor because of the risk of damage. With stack cast panels more care is needed to prevent the panels sliding off the stack and damaging the face of the lower panel. A means of doing this is illustrated in Figure 30.

If, after heavy rain, surface water is lying against a panel, lifting should not be attempted since suction forces will be substantially increased.

The accurate erection of the first few panels is critical. Extra time spent in plumbing these in both directions and establishing the correct line will repay itself in quicker erection of succeeding panels. Extra time should also be allowed on the first panels for the erection team to become familiar with the procedure.



LIFTING STACK-CAST PANELS

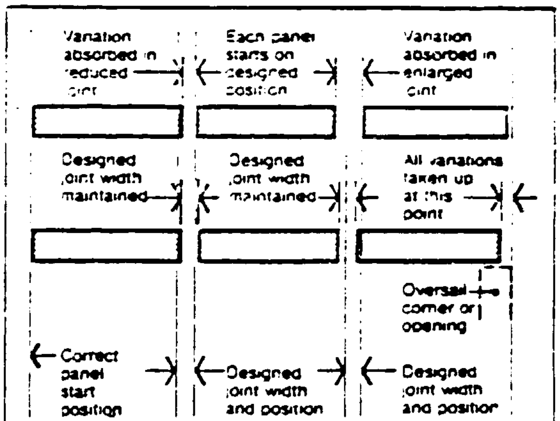
Figure 30

Panels must be moved smoothly at all times to avoid shock loading which may induce cracking or possibly damage the crane.

Final fixings should be completed as soon as practicable after the panels have been temporarily braced. Safety considerations will usually dictate a short interval between the two operations.

7.11 Tolerances

It is of the utmost importance that the specified fabrication and erection tolerances are realistic. Once established they must be maintained. Suggested fabrication tolerances are given in Table 9. In general, fabrication and erection tolerances will lead to a growth in overall wall length. Depending on their magnitude joint details may be used to absorb these variations either progressively at each joint or collectively at one location, eg oversail corner or doorway, see Figure 31.



ABSCRPTION OF TOLERANCES IN JCINTS

Figure 31

Length and Height

Up to 3 m	+0 / −10 mm
3 m to 6 m	+0 / −12 mm
Over 6 m	+0 / −15 mm

Thickness, overall ±5 mm

Straightness (deviation from intended line)

Up to 3 m	±10 mm
3 m to 6 m	±15 mm
6 m to 12 m	±20 mm

Skewness (measured as tolerance in length of diagonal)

Up to 3 m	±10 mm
3 m to 6 m	±15 mm
6 m to 12 m	±20 mm

Table 9. Recommended Fabrication tolerances

if tilt-up panels are being used in conjunction with insitu construction then the tolerances for tilt-up panels should not be used to absorb the construction errors of the insitu work.

7.12 Construction Plans and Checking

Construction Plans. One of the advantages of tilt-up is that it gives the builder direct control over the manufacture of the precast units. For each type of panel it is desirable to have a separate drawing for each of the following:

1 Formwork.

2 Layout of lifting inserts.

3 Reinforcement details.

4 Layout of fixings.

This avoids the misreading of any dimension off a composite plan.

Checking. It is desirable that the builder checks the construction and the progress of any panel at various stages:

1 Initial layout on site, overall dimensions.

2 Layout of lifting inserts, reinforcement and other fittings.

3 The casting surface prior to placing concrete, checking application and state of the bond breaker.

8
Check List

Structural Design

• type of concrete	4.2
• implications of details	4.2
• design for lifting	4.3
• design for bracing	4.3
• design for erected situation	4.4
• diaphragm action of roof	4.4
• shear wall action of panels	4.4
• vertical loads	4.4
• volumetric movement	4.4
• durability	4.5
• design floor slab to take crane loadings	4.5
• fire resistance	4.6

Detailing

• reinforcement	5.1
• lifting inserts	5.2
• fixings	5.3
• seatings	5.4
• joint appearance	5.5
• joint type	5.5
• joint sealant	5.5

Surface Treatment

• texture and colour	6.1
• face-up or face-down	6.2
• painted surfaces	6.3
• formliners	6.3
• exposed aggregates	6.3

Construction

• programming	7.1
• access for fabrication	7.2
• access for erection	7.2
• casting layout	7.3
• single or stack casting	7.3
• erection sequence	7.3
• formwork casting surface	7.4
• edge formwork	7.4
• blockouts	7.4
• grooves, indents and rebates	7.4
• bond breakers	7.5
• placing and curing concrete	7.7
• crane size	7.8
• rigging	7.9
• lifting	7.10
• tolerances	7.11

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