Guide to Tilt-up Design and Construction

Cement Concrete & Aggregates Australia
Concrete Institute of Australia

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CIA Z10

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The mission of the Concrete Institute is to promote and develop excellence in concrete technology, application, design and construction throughout Australia.

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- Increase membership to ensure representation and support from all segments of the concrete and construction industry.

- Facilitate communications and encourage participation for all members through technical meetings, seminars and publications and, in particular, through the quarterly magazine Concrete in Australia.

- Raise the profile of the Institute, and increase public awareness and definition of its place in the construction industry through a clearly identified image.

- Provide industry representation on behalf of the membership through the promotion of good concrete construction and to establish and maintain relations with appropriate local, national and international bodies.

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Preface

Reflecting the relative infancy of the tilt-up method of construction, earlier publications on the subject by Cement Concrete & Aggregates Australia (formerly Cement & Concrete Association of Australia) were partly promotional and partly devoted to the engineering design aspects of the technique. The building industry has subsequently become familiar with tilt-up construction and its benefits, while designers have adopted various approaches to the specific engineering issues the method raises. Furthermore – in response to a small number of failures and their consequences that highlighted the need for appropriate consideration of safety matters – various States have introduced recommended practices for tilt-up construction¹, while an Australian Standard (AS 3850²) has also been published.

A new approach has therefore been adopted for this Guide. Whilst it replaces the Tilt-up Construction Notes³ and the Concrete Institute of Australia’s Recommended Practice⁴, it has a different emphasis. The target audience is engineering designers – although some information on finishes and the range of building types for which tilt-up is suitable is included. (Note that this Guide is generally aimed at single-storey structures though some of the principles and details will apply to the use of the method in multi-storey buildings. However, these buildings will require consideration of a number of issues not covered by this Guide). An ‘issues-based’ approach has been adopted and the Guide therefore, seeks to comment only on matters that are peculiar to the design of tilt-up construction. In suggesting an overall design approach and then discussing specific issues it will alert designers to those issues that may be significant for their particular project. It does not purport to be a comprehensive manual covering all aspects of design and construction.

While construction issues will affect the design of tilt-up panels, this Guide is not aimed at construction personnel. Certain construction issues are discussed but advice provided in the various documents referred to above is not repeated.

At the time of writing, AS 3600⁵ was being revised and it was deemed prudent for this Guide to anticipate the adoption of the revised provisions in the Public Review draft of that Standard, even though they have not yet been adopted. Significant amendments are listed in the Public Review draft for the design of walls, including design for fire resistance.
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Guide to Tilt-up Design and Construction • O5
1.1 General

Tilt-up is a form of construction ideally suited to the rapid realisation of a wide range of buildings for industrial, commercial, residential and community use. It provides the benefits of solid concrete-walled buildings quickly and economically.

There has been some confusion in the terminology used for ‘tilt-up’, eg it has been referred to as ‘tilt-slab construction’. In this Guide the definition given in AS 3850 is adopted, ie ‘Tilt-up panel—an essentially flat concrete panel; cast in a horizontal position, usually on-site; initially lifted by rotation about one edge until in a vertical or near-vertical position; transported and lifted into position if necessary; and then stabilized by bracing members until incorporated into the final structure.’

This definition covers panels cast on-site and those cast off-site; clearly identifies the salient features of tilt-up; and some of the necessary design considerations, eg design for lifting and design for the braced condition.

The system requires: a suitable casting bed (the slab-on-ground floor of the building is often used); simple edge formwork and basic reinforcement; suitable cranes and lifting inserts; and fixings. As the concrete placement is simply accomplished at or near ground level, traditional finishing techniques for pavement work can be employed. When the panels are cast on site, they are often cast one on top of the other (stack cast) to limit the space needed and to facilitate construction access.

When the concrete has gained adequate strength, a mobile crane is used to lift and move the panels into position. They are then temporarily braced until all connections are made to incorporate them into the structure. All operations are usually completed from ground level.

Panel size can be varied, with the maximum size being limited by the capacity of the lifting equipment to be used or, for panels cast off-site, by transport limitations on their size and weight. An endless variety of shapes can be formed to incorporate windows, door openings or architectural features. A wide range of surface finishes is also available to quickly and efficiently provide the desired appearance for the external facade of the building.

The economic benefits of tilt-up construction are not achieved at the expense of quality, durability, performance or appearance. Tilt-up requires thorough planning but results in very quick erection of solid-walled buildings, using readily available materials, tradesmen and equipment.

This Guide is aimed at single-storey structures though some of the principles and details will apply to the use of the method in multi-storey buildings. However, these buildings will require consideration of a number of issues not covered herein.

This publication is not intended to provide a complete design and construction manual; professional advice from architects and engineers should be obtained on all tilt-up projects. Tilt-up equipment suppliers can also provide valuable advice regarding fabrication, lifting and finishing of panels.

1.2 Fully exploiting tilt-up

Thorough planning is important to the success of a tilt-up project. The following are recommended:

- All members of the design/construction team should be involved in the planning process.
- Consultation should begin at the planning phase, especially with the lifting contractor as trouble-free lifting is vital to the success of the project.
- Each member of the team should be aware of the constraints inherent in the method and of the broad implications of any planning decision.
- Consideration should be given to building-in as much flexibility as possible to the proposed construction and erection sequence so that unforeseen changes (eg necessitated by changed owner requirements or availability of specific equipment) during construction can be easily accommodated.

As tilt-up panels are a form of precast construction, the general principles to achieve maximum economy and efficiently exploit precast construction are applicable. These include:

- The building should be designed specifically for this form of construction; adapting design prepared for another form of construction will usually result in inefficient use of the method.
- As far as possible, the panels should be standardised, including reinforcement, fixings and inserts.
- As many as possible of the panel’s attributes should be utilised (structural, acoustic, thermal, etc.).
fire resistance, etc). Thus, in general, loadbearing panels offer a more economical solution than do cladding panels.

In addition, if designers are to fully exploit the advantages the method offers in the design, construction and erection, consideration should be given to:

- optimising the panel size by balancing the maximum lifting capacity of available equipment against the benefits of speed and mobility on site, eg the number of set-ups for the crane – in general, panels should be as large as possible as this minimises the number of panels to be lifted and joints to be sealed;
- casting in as much as possible, eg window and door frames, rebates to delineate finishes, etc.
- planning the casting layout and brace-fixing positions so as to facilitate speedy erection and limit the number of crane set-ups or double handling of panels.

1.3 Avoiding the pitfalls

The interaction between construction and design and the overlapping nature of many construction activities and design considerations make it important to clearly delineate the responsibility for each facet of design and area of construction. For example: the project design engineer will have the responsibility for the structural design of the panels in the completed building and the connections of the panel to the final structure; the erection design engineer may have the responsibility for the design of the panel during lifting and erection, and for the lifting and bracing inserts, etc. All parties need to be clear about their respective tasks and to communicate with each other to ensure the final design incorporates their respective requirements and that no necessary design consideration has been overlooked. These aspects are further discussed in Appendix A Safety.

Throughout the design phase there should be a conscious striving for ‘buildability’ – a term used to refer to the ease with which construction operations can be carried out on site. Factors such as the position the operator has to adopt to carry out the operation, the work space available, and the precision required in terms of location of the elements and the operation itself all affect ‘buildability’. A review of the design details should be carried out to ensure that they are practicable. The project design engineer should provide for realistic tolerances that reflect the precision that can be achieved in the site operations, eg in locating the panels while suspended from the crane. Fixing and joint details, etc should be kept as simple as possible and be robust, ie they should be able to accommodate the tolerances required and not be damaged by normal tilt-up work practices; they should also be easy to construct on site so that the design intention is achieved and the task can be completed quickly.

1.4 Definitions

The following definitions are consistent with those in Industry Standard: Precast and Tilt-up Concrete for Buildings.

**builder** – The company or person responsible for the construction of the completed building and who has control of the building site. (The builder may also be the client or a company or person responsible to the client.)

**building designer** – The project architect or project designer responsible for the design of the building. (The building designer will usually be responsible to the client.)

**client** – The owner of the building or the company or person responsible for developing the building.

**erector** – The company or person responsible for erecting the tilt-up or precast concrete elements. (The erector may be responsible either to the builder, precaster, or client.)

**erection design engineer** – The engineer responsible for the design for the erection of the precast elements of the building. (The erection design engineer should be a person qualified for membership of the Institution of Engineers Australia, be a registered building practitioner and be competent to practice in the structural engineering field. The erection design engineer will usually be responsible to the builder, the precaster or the shop detailer, or may also be the project design engineer.)

**panel contractor** – The company or person responsible for manufacturing the tilt-up or precast concrete elements. (The panel contractor will usually be sub-contracting to, and be responsible to, the builder. The panel contractor may sometimes be
referred to as the precast concrete manufacturer or tilt-up manufacturer.)

**project design engineer** – The engineer responsible for the engineering design of the building. (The project design engineer should be a person qualified for membership of the Institution of Engineers Australia, be a registered building practitioner and be competent to practice in the structural engineering field. The project design engineer will usually be responsible to the client.)
2.1 General
For any project the design should take into account all the particular requirements for the specific building. There are nevertheless, some design issues for which general advice can be provided and which provide the framework within which specific design is carried out.

2.2 Loadbearing versus cladding panels
In single-storey buildings, using the wall panels as loadbearing elements generally reduces the overall cost due to a reduction in the amount of structural framing required. Although more roof bracing is required, eliminating the columns provides greater savings. Also, in terms of scheduling, panels can be cast and erected before steelwork is required to be delivered to the site in the case of industrial buildings; this allows more time for fabrication of the steelwork. When the panels are used solely as cladding, the steelwork is usually on the critical path for the project.

2.3 Building layout
2.3.1 Rafter spacing and panel joint spacing
In single-storey buildings, the rafter spacing will usually determine the joint layout for the panels, eg panel joints coinciding with rafter locations, see Figure 1. Rafter spacing should be chosen to optimise the design of the roof, purlins, roof sheeting, etc. The cost of panels is relatively insensitive to moderate dimensional changes whereas closer-than-optimum rafter spacing can incur a considerable cost penalty. End spans will frequently be shorter than internal rafter spacing.

2.3.2 Door and window openings
The panel-joint layout should be considered in conjunction with the position of door and window openings. The panel width flanking an opening and the panel depth over an opening must provide sufficient structural strength to carry the loads to which the panel will be subjected, particularly during lifting and erection, see Section 2.4.2.

2.3.3 Construction at or near a site boundary
If walls are located at or near a site boundary, the design of footings will be affected. Also, if adjacent buildings are on the boundary, consideration needs to be given to matters such as the erection process, base-joint details, sealing of wall joints and flashing between buildings, as the work must be completed with access only from the project-site side.

2.4 Panel size
2.4.1 Panel weight
While the erector has to confirm that the panels can be lifted with available cranes (using appropriate crane charts and final lifting locations), Table 1 provides a guide for panel weights that can be lifted by cranes of various lifting capacities. The weight of the panels can be based on a concrete density for reinforced panels of 2400 kg/m$^3$. (The erection design engineer may need to use a more sophisticated approach to calculating panel weights and the determination of the centre of gravity of the panel.)

Table 1 Crane capacity and panel weight

<table>
<thead>
<tr>
<th>Crane capacity (t)</th>
<th>Panel weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical (t)</td>
<td>Heavy$^1$ (t)</td>
</tr>
<tr>
<td>50 (hydraulic)</td>
<td>10–15</td>
</tr>
<tr>
<td>70</td>
<td>12–18</td>
</tr>
<tr>
<td>120–140</td>
<td>18–25</td>
</tr>
<tr>
<td>200</td>
<td>10–28</td>
</tr>
</tbody>
</table>

$^1$ ‘Heavy’ refers to panels that may be lifted and erected close to the crane set-up position. It is unlikely that all panels will be ‘heavy’ and thus a few ‘heavy’ panels may be able to be accommodated by planning the casting positions and crane set-up positions for those panels to be close to each other.
For panels cast off-site, government regulations will control the maximum weight, size, hours and possibly route of panel to the site; these vary from State to State. In broad terms, the weight will be limited to approximately 20 tonnes and the maximum width will be in a range of 4.0–4.5 m, assuming a step-down trailer is used. For units over approximately 12 m long which cannot be carried on a normal articulated vehicle a special permit will be required.

2.4.2 Panels with openings

The following rules-of-thumb provide a starting point in determining the minimum dimensions for legs, mullions and spandrels. Typically, 600 mm is a comfortable minimum width for legs and mullions, while 900 mm is a comfortable minimum depth for spandrels, see Figure 2. In some cases, the leg and mullion width will need to be larger, see Figure 3.

In some cases, e.g. if the panel would be structurally satisfactory without the mullion, a narrower mullion or leg width may be satisfactory, see Figure 4. Apart from the structural capacity of the element it should be noted that thin, slender elements are more vulnerable to damage during transport and erection than solid, more-robust units. Any reduction of the recommended minimum dimensions should therefore be made with caution.

2.4.3 Strongbacks

Concrete panels that incorporate large or awkward openings and/or are of an irregular shape will probably require the use of strongbacks during lifting, Figure 5. These usually consist of steel beams rigidly fixed to the panel to provide additional stiffness to resist forces during the lifting operation. The erection design engineer should advise on the correct engineering details for these particular situations.
2.4.4 Crane capacity

As noted above, the lifting capacity of the crane (height, reach and load capacity) available for use on the project may well dictate the maximum size of panel. The crane’s capacity will also influence the number of set-up positions needed for lifting all the panels. Because moving a crane and setting it up in a new position takes considerable time, the extra cost of a larger crane may be justified since it could result in a shorter overall erection time.

Where panels are transported to site, they will often need to be rotated through 90° so that they hang vertically. The crane will need to have sufficient capacity to be able to carry the panel on each of the two cables to accomplish this rotation. Furthermore, the rotation has to be accomplished without fouling existing construction, panels or bracing.

2.5 Casting and bracing locations

2.5.1 Casting areas

Several factors influence where the panels are cast:

- Can the floor slab be used as a casting bed? If it can, the surface tolerances, joint details and locations, and surface finish will need to be compatible with the surface finish specified for the panels. (The effect of fixings for edge formwork for the panels and the sealing of joints on the final floor finish also need to be considered.)

- Access to the casting positions to enable the panels to be cast easily.

- Most tilt-up panels are cast with the external face down, but some surface finishes dictate face-up casting. This and the erection procedures to be adopted will influence the decision to either cast panels singly over a large area or stack cast them (one on top of the other).

- When stack casting is adopted, the casting order should reflect the erection sequence so as to avoid double handling of panels, ie the panel required first should be cast last. However, smaller panels and panels with openings should be cast at the top of stacks to obviate the need for formwork that would be required if a larger panel is cast over a smaller one and/or one with openings. (Not only is this costly but the change in surface texture will read on the surface of the upper panel.) Stacks should be sited to minimise the number of crane set-ups.

- If the site area is restricted then consideration should be given to using panels cast off-site. In this case transportation limits may restrict panel size and weight.

- The crane positions for erection of the panels and fixing positions for the feet of braces will also affect the casting positions Figures 6 and 7.

2.5.2 Crane position

The position of the crane on site should be planned to maximise its capabilities and minimise erection time. Locations that give clear access to the greatest number of panels should be selected.

If possible, the crane should always be positioned so the rigging and braces are visible by the crane operator. ‘Blind’ lifting, where the rigging is on the side opposite the crane, should be avoided because the crane operator will be unable to visually check the rigging during lifting. Furthermore, if failure should occur, the panel will fall towards the crane.

‘Blind’ lifting is sometimes unavoidable, such as when placing the final closure panel in a building. Unless there is a sufficiently wide opening, the crane must at this point be located outside the building to prevent walling itself in.

When lifting the panels, it is important that the rigging be in full view of the crane operator and that the braces can be attached to the panels before lifting.
commences. If panels are cast outside the building, the crane should therefore be located inside the building. Care should be taken to ensure that the braces do not foul the rigging. Temporary braces can also be quickly attached to the brace-insert points in the floor after the panel is set in place.

Working from inside the building provides the crane with a firm surface (called the erection platform) on which to operate.

*Note: The floor must be designed to carry the point loads from the crane, including its outriggers.*

2.5.3 Brace positions

Generally, the braces are fixed to the floor using load-controlled inserts. If panels are to be braced outside the building it may be necessary to cast external ‘dead men’ in appropriate locations.

Floor slabs should be not less than 150 mm thick to provide sufficient depth and capacity for drilled-in inserts used to anchor the braces. The capacity in both the horizontal and vertical directions should be checked. Standardising the slab thickness throughout the project to provide sufficient depth for inserts may add marginally to the floor cost but save on overall project cost because of the flexibility provided at the erection stage.

2.6 Durability

AS 3600 sets out provisions for concrete quality (minimum characteristic compressive strength) and cover to reinforcement for a wide range of exposure conditions. In general terms, these will not greatly influence the design of tilt-up panels but they must be complied with and may dictate a concrete quality higher than that required to meet other criteria.

Using data extracted from the Tables in AS 3600, Table 2 sets out the concrete strength grades and minimum cover to reinforcing steel for tilt-up panels to meet durability requirements. (Note that grooving, profiling, texturing, or any mechanical treatment of the surface will reduce the cover to the reinforcement and account must be taken of this in the design.)

It will be noted that a concrete strength grade of less than 32 may be used in some exposure conditions, but lifting requirements would generally dictate strength grade 32 or above in nearly all tilt-up applications.
2.7 Design for fire resistance

The Building Code of Australia (BCA) sets out the requirements for the fire resistance of buildings. The requirements of the BCA may be met either by following a deemed-to-comply approach or by using an ‘alternative solution’. Generally, the design of a tilt-up building will follow the deemed-to-comply approach. Using this approach, the required Fire-Resistance Level (FRL) for various building elements is determined from the type of construction, the class of building (occupancy), the height in storeys, and the proximity to the fire source. The FRL lists the Fire-Resistance Periods (FRPs) for structural adequacy, integrity and insulation in that order. For concrete members the FRPs are determined using Tables and Charts given in Section 5 of AS 3600. The effect of grooving, profiling, texturing, or any mechanical treatment of the surface will reduce the net section available and the cover to the reinforcement and the effect of these for fire design should be considered using the rules given in AS 3600.

The BCA also sets out requirements aimed at controlling the behaviour of buildings subject to fire. It contains specific requirements for buildings not more than two storeys high having concrete external walls that could collapse as complete panels. In almost all of these buildings, although the wall is required to have a specified FRL, it is supported by a structure that is not required to have a FRL. Thus when the building is subject to an internal fire, the building will

### Table 2 Concrete grade and cover to reinforcement for various exposure conditions

<table>
<thead>
<tr>
<th>Exposure condition of either surface¹</th>
<th>Concrete strength grade</th>
<th>Minimum cover to reinforcement² (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior environments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fully enclosed within a residential building</td>
<td>20⁺</td>
<td>20</td>
</tr>
<tr>
<td>Fully enclosed within a non-residential building</td>
<td>25⁺</td>
<td>30</td>
</tr>
<tr>
<td>In an industrial building and subject to repeated wetting and drying</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>Above ground and exterior environments² and:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In non-industrial and arid climatic zone</td>
<td>20⁺</td>
<td>20</td>
</tr>
<tr>
<td>In non-industrial and temperate climatic zone</td>
<td>25⁺</td>
<td>30</td>
</tr>
<tr>
<td>In non-industrial and tropical climatic zone</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>In near coastal zone</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>In coastal zone</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Maritime structures (salt water)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In spray zone</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>In tidal/splash zone</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>In contact with ground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In non-aggressive soils</td>
<td>25⁺</td>
<td>30</td>
</tr>
<tr>
<td>In aggressive soils</td>
<td>See AS 3600⁴</td>
<td>See AS 3600⁴</td>
</tr>
</tbody>
</table>

* Lifting requirements generally dictate strength grades 32 or more.

¹ Exposure conditions other than those specified in this Table may necessitate additional requirements and/or protection for both concrete and reinforcement. Reference should be made to AS 3600.

² An exterior wall can have both exterior and interior exposure. The higher concrete grade should be used and the cover to the reinforcement adjusted according to the exposure of the particular surface.

³ Protective surface coatings may be taken into consideration with regard to the depth of cover to be provided. However, the performance of such coatings should be established before a reduction of cover below the figures in the Table is contemplated (see AS 3600 Clause 4.3.1 Note 1).

⁴ AS 3600 provides guidance for some aggressive soil situations, eg sulfate soils.
collapse; the requirements are designed to minimise the likelihood of the panels falling outwards. Most buildings constructed using tilt-up panels will have to comply with these requirements, i.e. connection details have to be such that the panels during and after a fire will either remain standing or tend to collapse inwards. To comply with these provisions, the BCA specifies deemed-to-satisfy requirements that the connections at the top of the panel must be able to resist an ultimate load of a multiplier times the ultimate bending moment capacity at the base or the overturning moment induced by a specified outward deflection of the panel. The multiplier depends on the type of insert. Considering the height of a typical panel, the loads to be resisted by the top connections are not large to satisfy this requirement – even if a tied connection detail providing some moment resistance is provided at the base of the panel, e.g. as in pour-strip detail, see Section 4.4 and Figures 30 and 31.

Wall panels in this type of building have to achieve the FRP for ‘insulation’, e.g. possess the thickness given in the appropriate table. In addition, joints between the panels must not adversely affect the behaviour of the wall and must also satisfy the appropriate FRP for insulation.

### 2.8 Robustness (progressive collapse)

Design for robustness is covered by Section 6 of AS 1170.0. Because tilt-up construction is a form of precast construction, and therefore prone to progressive collapse, consideration of robustness is an essential aspect of design; redundancy should be incorporated into the system that provides stability. For instance, the failure of a single bracing member due to an event such as a fire, accident or abuse, should not lead to collapse of the whole building. Consideration may therefore be given to providing two sets of cross bracing to give an alternative load path, Figure 8.

The use of the purlins as part of the roof-bracing system needs to be carefully evaluated. Significant deflections and secondary moments (particularly if bracing members are located in different planes) may be induced and the resulting structural behaviour be unacceptable. Also, they are prone to early failure in a fire.

### 2.9 Other

#### 2.9.1 Appearance

It is now accepted that tilt-up concrete buildings no longer need be drab grey industrial boxes. Neither is it thought that their use is to be restricted to industrial buildings.

Grooving and chamfering are common approaches used to visually break up large areas of wall, while surface coatings are available in a range of colours and textures to eliminate the monotony of large expanses of grey concrete. The panel shape and size, together with unusual openings and truncations, should also be considered at the design stage to create buildings with visual interest.

The following photographs illustrate the variety of buildings for which the technique has been used and also give some idea of the range of surface finish and textures which are available.

Some advice on matters to be considered when specifying various finishes and surface textures is given in Appendix B Treatments.

The important points are:

- Ensure that the casting bed is free from physical blemishes which will be reflected in the panel surface.
- Use grooving to break up large areas. This provides visual interest and enables textured coating applications to work continuously in smaller defined areas with breaks in the application process.
- Select surface finishes that are appropriate for the visual effect required. Areas which will be subject to close scrutiny may justify more elaborate textures.
• Ensure that the curing compound and bond breaker will not interfere with the surface-coating application.
• Follow the recommendations of the coating manufacturer with regard to surface preparation and the method of application.
• Conduct trials to ensure that the coating produces the desired effect on the concrete surfaces produced on-site. Produce a test panel if necessary.

2.9.2 Services
Careful pre-planning of all services is necessary to avoid costly delays to the construction programme. Fixing the position of all service locations early in the building design is necessary with tilt-up construction to enable the required ducts and conduits to be cast into the panels.

Although casting service conduits in a panel is relatively simple, connecting the service lines at floor or footings can be difficult and future maintenance awkward. Bringing electrical and plumbing lines down from the top of panels to the outlets can minimise these problems.

Alternatively, services can be located in internal framed partition walls or in the void between the concrete panel and an internal battened lining.

2.9.3 Joint detailing
Joint detailing has a major impact on the cost, appearance and performance of a tilt-up building; its importance 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 number of joints is generally best kept to a minimum. If a small-panel appearance is desired, then this can be achieved by the use of false joints (grooves) in the panel surface. Chamfers at the edges of panels are desirable to reduce the vulnerability to damage during handling.

Corners of tilt-up buildings require special consideration. Where it is acceptable to show a panel edge on one facade, oversail joints are preferred. Mitred joints allow a uniform surface treatment of both walls, but are liable to damage and impose greater restrictions on erection tolerances.

Joints between wall panels will usually need to be weathertight. Face-sealed joints are generally preferred between panels as they require a simple edge profile that is not prone to damage and can be easily inspected. Open-drained joints are sometimes used although they require complex edge formwork, produce an edge profile that may be prone to damage, and the installation of baffles can be difficult. Flashing details at the top of the wall and at the roof junction need to be matched to the adopted joint-detail. In all situations, the use of a cap flashing is recommended.

Joints must be able to accommodate rotation and the variations in width resulting from construction tolerances and erection practices. They must also allow the panels to move relative to each other as the environment changes, eg changes in temperature or humidity.

It is recommended that joint widths be in the range 15 to 25 mm. Generally, erection tolerances are absorbed in the joint; the joint width should thus be sufficient to permit this. In some cases, with a limited number of panels erection tolerances may also be absorbed at corners and openings Figure 9.

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

In the choice of joint type and details, consideration should be given to the implications of the future replacement of sealants as these do not have an unlimited life.
2.9.4 Sealants

Sealant manufacturers will provide guidance and data on the appropriate sealant type and joint details, including suitable sealants for fire-resistant joints. Sealants should be bonded only on the two side faces of the joint. Backup rods which do not bond to the sealant are available to control the depth and profile of the sealant Figure 10. Limiting the depth of the sealant limits the strain developed in it by movement of the joint Figure 11.

2.9.5 Tolerances

It is of utmost importance that the specified panel and joint tolerances are realistic; once established they should be maintained. Depending on their size, joints may be used to absorb these variations either progressively at each joint or collectively at one location, e.g. oversail corner or full-height doorway.

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 tolerances of the insitu work.

Joint tolerances are important for the performance of the joint sealants (most of which have movement capabilities of around ±25%) and are critical for weatherproofing.

The tolerances of the panels can have a marked effect on all aspects of the construction. Suggested tolerances are given in Table 3. Tighter tolerances will be expensive to achieve.

**Table 3 Recommended tolerances on as-cast panels (Table 3.11(A) of AS 3850)**

<table>
<thead>
<tr>
<th>Panel height (m)</th>
<th>Linear width</th>
<th>Height</th>
<th>Thickness</th>
<th>Angular squareness¹</th>
<th>Profile² twist³</th>
<th>Warp⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>+0, –6</td>
<td>±3</td>
<td>±3</td>
<td>±4</td>
<td>±3</td>
<td>±3</td>
</tr>
<tr>
<td>≥3 &lt;6</td>
<td>+0, –6</td>
<td>±6</td>
<td>±3</td>
<td>±5</td>
<td>±3</td>
<td>±3</td>
</tr>
<tr>
<td>≥6 &lt;10</td>
<td>+0, –6</td>
<td>±6</td>
<td>±3</td>
<td>±6</td>
<td>±3</td>
<td>±3</td>
</tr>
<tr>
<td>≥10</td>
<td>+0, –6</td>
<td>±6</td>
<td>±3</td>
<td>±8</td>
<td>±3</td>
<td>±3</td>
</tr>
</tbody>
</table>

¹ Expressed in terms of the distance by which a shorter side of the tilt-up panel deviates from a straight line perpendicular to the longer side and passing through the corner of the panel.

² In addition to the values for twist and warp as shown, AS 3850 also includes tolerance on the straightness of edges and flatness of surfaces of ±length/1000. This value applies to all panel heights.

³ Per metre width in 3-m length.

⁴ Per metre width.
3.1 General
The need for insulation, both acoustic and thermal and the avoidance of potential condensation problems can be overcome by appropriate detailing when using tilt-up panels.

3.2 Acoustic
More noise enters buildings through openings (windows, doors and the like) than through the walls themselves. When sound waves strike a building surface they are reflected, absorbed and transmitted. Solid walling systems such as concrete tilt-up panels provide good acoustic insulation, particularly at the sort of low frequencies that cause many of the complaints in residential buildings.

Solid panels have to comply with the requirements for acoustic performance specified in the BCA. Concrete panels can economically provide acoustic performance well in excess of the 50 dB required by the BCA. Composite systems incorporating linings and applied finishes can be used to achieve higher ratings specified by the BCA for situations such as party walls in residential buildings. Reference should also be made to the Precast Concrete Handbook.

3.3 Thermal
Tilt-up concrete wall panels can be insulated by a variety of methods, e.g. attaching insulation to the face of the panel or including a layer of insulation within the panel thickness. Depending on the level of insulation required, foil-backed or polystyrene-foam-backed plasterboard can be fixed to battens on the face of the concrete panel. It is more efficient thermally to fix the insulation to the exterior face of the panels. However, for practical reasons, e.g. to provide a cavity for the installation of services, it is commonly fixed to the interior face Figure 12.

If a higher level of insulation is required, the tilt-up panels may be battened internally and insulation material installed prior to the application of the plasterboard.

Tilt-up panels that are not insulated or otherwise treated will provide some degree of thermal protection as a result of the high thermal mass of the panels. Thermal mass is the ability of the material to absorb and store heat (also known as the specific heat of the material). The thermal mass of the material will enable heat to be stored in the panel rather than being immediately transferred into the building. This delay in heat transfer is known as the thermal time lag; used correctly, it can benefit the energy efficiency of the building by providing an apparent increase in resistance to heat flow into the building.

The thermal mass of the concrete panels is additional to the ‘R’ value commonly used to determine the performance of insulation products and the ability of those materials to resist heat transfer.

Proprietary systems are also available that incorporate polystyrene foam layers within the concrete panel to produce sandwich panels. These panels consist of two concrete layers, preferably a thin external skin and a thick internal skin, encasing a foam insulating layer. This uses the benefits of thermal mass of the concrete and high ‘R’ value of the foam to increase overall thermal performance.

3.4 Condensation
Condensation can occur in any building if the environmental and internal conditions are conducive. Water vapour is always present in the air to some degree, the warmer the air the more water vapour it can hold. Washing machines, dryers, boiling water, hot showers and people breathing all increase the amount of water vapour in the air.

![Figure 12](image-url)
Condensation forms when warm air, high in water vapour, comes into contact with a cold surface, causing a rapid drop in temperature. The cooler air can no longer hold the same quantity of water vapour – which then condenses on the cold surface.

Understanding of the condensation process and utilising an appropriate design strategy can avoid condensation problems.

The position of vapour barriers is also important, especially where composite walling construction is used. The general rule is to place the vapour barrier on the warm side of the construction and thus minimise the flow of water vapour through the element.

An effective way to reduce the risk of condensation in tilt-up construction is to effectively insulate the internal surface of the panels. This can be achieved in a variety of ways, some of which are discussed above under thermal insulation. The amount of insulation necessary will depend on the environmental conditions and the intended use of the building.

In addition to insulation, the key to avoiding condensation problems is to provide adequate heating and/or ventilation throughout the building.

Full details on how to design for condensation can be found in Condensation—Design strategies.10
4.1 General

The same structural principles apply to the design of 'tilt-up' buildings as to normal insitu concrete construction. Tilt-up panels may be used either as cladding panels or loadbearing panels, i.e. to form part of the building structure Figure 13. In either case, the design has 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 the construction loadings during erection and when temporarily braced. Normally, the overall building system is chosen, the panel dimensions determined and the structural design of the building carried out. The individual panels are then designed for lifting and handling. Finally, the design for the braced condition (i.e. of braces and fixings) until the panels are incorporated into the final structure, is carried out.

When the panels form part of the building structure, carrying the vertical and lateral loading, the walls must provide a sufficient force-resisting mechanism to carry the applied lateral actions (loads) Figure 14. Generally, the roof is designed to function as a diaphragm to carry the lateral actions applied on one set of walls to those at right angles. The latter act as shear walls to resist the applied actions Figure 15. A suspended floor may also act as a diaphragm.

In general, panels should not be rigidly fixed together to form a long wall since concrete shrinkage and normal thermal movements will invariably lead to cracking. Long walls should be broken up by the introduction of movement joints and/or by the use of connections that will permit some movement to take place, e.g. by bolted connections with slotted holes, see the Precast Concrete Handbook. Because in-service and erection are two independent design cases, the erection design may or may not be carried out by the project design engineer. Erection design may be carried out as part of the preparation...
of the panel shop drawings or by the supplier of lifting hardware as part of the design service for the lifting operation. It is therefore important for the project design engineer to have an understanding of what is involved in the erection design procedure to ensure that the most economical panel size and panel layout are used. Further, parties need to be clear about their area of responsibility. Each should provide the other parties appropriate documentation and ensure that the building contractor is provided with complete documentation for the panels, bracing and the complete structure (see Appendix A Safety Matters).

The effect of grooving, profiling, texturing, or any mechanical treatment of the surface will reduce the net section available and this depth should be used for structural design and the cover to the reinforcement.

The overall thickness of the panel should be used when determining the weight of the panel.

The structural design issues are discussed in the following order: the design of the building; design of panels for erection and handling; and design for bracing and stability.

Current Australian standards and building codes have adopted ISO nomenclature when referring to forces and loads and this is followed in the Guide though the more-familiar alternatives are also shown in brackets.

4.2 Design of panels in final structure

4.2.1 Design method

At the time of preparation of this document a major revision of AS 3600 was underway. The 2001 version allowed walls with an effective height-to-thickness ratio not exceeding 50 and axial loads not exceeding $0.03f'_{cA_g}$ to be designed as flexural members, and the P-Δ effect of lateral deflections arising from face loading on the walls and the eccentricity of the applied axial loading to be ignored. These effects are frequently large and should be considered in the design of tilt-up panels. Major changes have been proposed for Section 11 Design of walls in the revision to address these shortcomings; the new rules which require that the P-Δ effect be taken into account have been adopted in this Guide.

Alternative design procedures are available but that shown in this Guide is one widely used in the USA. The method is given in ACI 31811 though it was originally developed by the Structural Engineers Association of Southern California and is also included in the Uniform Building Code (UBC). It is discussed below with advice on calculating the various factors required in design and on other factors that should be considered.

4.2.2 ACI Method

ACI 318 Clause 14.8 Alternative design for slender walls provides a method that takes into account the deflection of the wall and the induced P-Δ effect. An equation is given to calculate the deflection of the panel, thus the P-Δ effect can be calculated.

By-and-large the load factors and ø factors in ACI 318 are very similar to those used in AS/NZS 1170.0 and AS 3600; the equations given there can thus be used without alteration except for changing the units.
The method assumes that the wall is designed as a simply-supported, axially-loaded member subject to an out-of-plane uniform lateral load, with maximum moments and deflection at midspan. The cross-section is assumed to be uniform over the height, while the reinforcement ratio is not to exceed 0.6 of the ratio at the balanced condition. The requirement for minimum reinforcement to be provided to develop the modulus of rupture must be complied with. Concentrated gravity loads are assumed to be distributed over a width as discussed in Section 4.2.3. The vertical stress at the mid-height is not to exceed 0.06 $f'_c$.

The design strength at the mid-height cross-section is to be:

$$\phi M_r \geq M_{ua} + P_u \Delta_u$$

where:

$$\Delta_u = 5M_{ul}^2/[0.75 \cdot 48E_c I_{cr}]$$

and $M_{ul}$ is calculated by iteration of deflections, or from

$$M_{ul} = M_{wu}/[1 - (5P_{ul} l_c^2)/[0.75 \cdot 48E_c I_{cr}]]$$

where:

$$I_{cr} = nA_{se}(d-c)^2 + (l_w c^3)/3$$

and

$$A_{se} = (P_u + A_{sf} f_{sy})/f_{sy}$$

In addition the maximum deflection, $\Delta_s$, due to service loads including P-\Delta effects is not to exceed $l/150$.

$$\Delta_s = [(5M)l_c^2]/[48E_c I_e]$$

and

$$M = M_{wu}/[1 - (5P_{ul} l_c^2)/48E_c I_{cr}]$$

4.2.3 Actions (loads) and combinations of actions

The design actions (loads) that need to be considered are shown in Figure 16 and are described below.

**Self-weight of panel** Since the critical design section usually occurs at or above mid-height of the panel, it is necessary to include the self-weight of the panel above this section as an axial load.

**Applied axial actions** These are usually the sum of permanent actions (dead load) and imposed actions (live load) from roof and/or floor structures supported by the panels. Where these actions occur as isolated concentrated actions they can be distributed over a length of panel as described under *Concentrated actions (loads)* below.

**Lateral actions** The controlling case is usually from wind action although in some areas seismic actions may be significant. The magnitude of these actions should be calculated in accordance with the requirements of AS/NZS 1170.212 and AS 1170.413 as appropriate.

Considering wind actions first; following AS/NZS 1170.2 in general for roof slopes $\leq 10^\circ$ the external forces on the roof will be upwards. For roof slopes $>10^\circ$ the forces may be upwards or downwards. The internal pressure due to wind is dependant on the ratio of the area of the dominant opening to the total area of open area in all the roof and wall surfaces. For industrial-type buildings where the dominant openings tend to be in one wall this will mean that the internal pressure will be positive and add to the suction pressure on the roof and leeward wall.

Considering earthquake forces; note that although the magnitude of the earthquake actions may not govern the design, the detailing requirements given in AS 1170.4 will still have to be complied with. Advice on the detailing of connections to provide appropriate behaviour under an earthquake is discussed in Section 4.6.

Where a panel acts as a retaining wall, earth pressure can apply lateral loading and this should be taken into consideration.

**Combinations of actions** The combinations of actions to be examined in design should be in accordance with Section 4 of AS/NZS 1170.0; each combination should be investigated separately.
The load combinations to be considered include:

1.2G + 1.5Q (1)

1.2G + Wu + y_c Q (2) wind forces in same direction as G

0.9G + Wu (3) wind forces in opposite direction to G

For industrial-type buildings load combinations (1) and (3) will tend to be the controlling ones. However, designers must calculate the wind loads for all wind directions on the building they are designing and determine the controlling cases.

On multi-level buildings where panels support suspended floor slabs, and therefore have high axial loads at large eccentricities, the permanent and imposed actions plus the lateral load combination generally will control the design.

In most cases, the maximum moment will occur very near mid-height of the panel – although on multi-storey panels it may be necessary to plot the bending moment diagram to establish the location of the critical section.

**Concentrated actions (loads)** For design purposes, roof or floor loads that occur as concentrated reactions on the panels can be distributed over a length of panel at the critical design height.

The length is calculated on the assumption that the reaction spreads into the panel at 60° to the horizontal plane Figure 17. However, this should not exceed the spacing of the concentrated loads nor extend beyond the edge of the wall.

**Isolated footings** Where panels are supported on isolated footings it is necessary to allow for the effect of the concentrated reaction. This is treated in a similar manner to a concentrated load at the top of the panel Figure 18.

**In-plane forces** In-plane forces in panels generally result from lateral forces being transferred through bracing diaphragms to panels that act as shear walls. In these cases it is rare for the shear stress in the panel to be critical. The critical factor is usually stability of the inclined compression strut in the panel; this should be checked for buckling under the induced axial forces Figure 19.

The compression strut can be checked for strength and stability against buckling using strut-and-tie theory as set out in ACI 318 – 2003.

Panels with large openings and subjected to large in-plane forces should be regarded as frames within the wall plane and analysed accordingly.

Overturning and sliding of the panels due to in-plane forces should be checked and, where necessary, ties provided to the footing or floor slab.

4.2.4 Initial out-of-straightness and creep Random initial out-of-straightness caused by variations in shrinkage or by casting on uneven surfaces should be allowed for by adding a nominal deflection at mid-height when calculating load eccentricities. A value of 20 mm is usually appropriate.
Since deflections due to permanent actions (dead load) even on slender panels are usually quite small, long-term deflections caused by creep are not normally considered.

Where high permanent actions (dead loads) do occur (eg in multi-level buildings), the panel is usually not slender and deflections are therefore also small. If this is not the case, creep deflection should be taken into account.

4.2.5 Slenderness and effective height

The slenderness of a panel is the ratio of the effective height to section thickness; AS 3600 limits this to a value of 50. Adopting this value is a reasonable assumption for preliminary design.

The effective height of a wall panel depends on the support conditions at the top and bottom of the panel and the degree of fixity they provide to the panel. Depending on the support conditions, other factors such as section thickness, reinforcement configuration, and loading condition may also influence the degree of fixity. However, unless the panel is specifically designed and detailed so that rotation is prevented at the supports it is recommended that all panels be considered as pinned at top and bottom and the effective height taken as equal to the height between the supports. The height of panel (distance between points of supports) for a given panel thickness given in Table 4 is based on this assumption.

Situations where rotation is prevented (at least partially) include where the panel is supported at ground floor level in such a way that some degree of base fixity is provided, eg with the panel acting as a propped cantilever and connected so that end rotation at the floor level is partially restrained. The result is a reduced mid-height moment and a reduced effective height.

Analysing this case taking the P-Δ effect into account is difficult; the effective height can be obtained only by complex computer iteration. An alternative approach is to use an effective height factor, k, in accordance with the requirements for column design as given in AS 3600 Section 10 to modify the height of the panel. Because the result is sensitive to small deflections of the supports or displacement of the footings that can lead to significant secondary moments being introduced it is best to be somewhat conservative. A ‘k value’ of less than 1.0 should therefore be adopted only with caution.

For multi-storey panels that support suspended floor slabs the effective height factors can be obtained by a rational frame analysis. The effective height can be taken as the distance between points of inflection and the capacity of the panel checked for both positive and negative moments. In these situations, because of the unknowns discussed above, the positive span moment should never be taken as less than the negative end moment.

Lateral deflection at the top of the panel due to flexibility of the bracing diaphragm has no influence on effective height unless there is fixity at either the top or bottom of the panel. If fixity is assumed and the bracing diaphragm allows appreciable deflection, consideration should be given to making an appropriate adjustment to the effective height of the panel.

Table 4 Maximum height of panels for given thickness (based on H/t = 50)

<table>
<thead>
<tr>
<th>Panel thickness t (mm)</th>
<th>Height of panel H (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100*</td>
<td>5.0</td>
</tr>
<tr>
<td>125*</td>
<td>6.25</td>
</tr>
<tr>
<td>150</td>
<td>7.5</td>
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<tr>
<td>175</td>
<td>8.75</td>
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<tr>
<td>200</td>
<td>10.0</td>
</tr>
<tr>
<td>225</td>
<td>11.25</td>
</tr>
<tr>
<td>250</td>
<td>12.5</td>
</tr>
</tbody>
</table>

* These panels may require strongbacks for lifting
4.2.6 Panels with openings

Where window or door openings occur within a panel, the imposed axial and lateral loads plus the self-weight of the entire panel must be carried on the section each side of the opening Figure 20.

An accurate analysis of this condition is possible only by use of finite-element methods or yield-line theory to establish applied bending moments.

For most situations, an approximate analysis based on hand calculations combined with the use of reinforced concrete design charts will give results that are sufficiently accurate. This method involves dividing the panel into vertical and horizontal strips and checking each strip for the applied actions (loads).

In order to restrict the possibility of local buckling at the edge of the opening, the effective height used in this check should be based on the full-panel height and not the opening height.

For narrow openings it is usually necessary to increase only the loads acting on the legs by the ratio of the total width to the leg width.

For wide openings it may be necessary to provide a thickened section (stiffening rib) at each vertical edge and a horizontal header beam at the top (and bottom) of the opening.

Where the ratio of leg width to panel thickness is less than three \((b/t_v<3)\) and loads are high, consideration should be given to designing the leg as a column in accordance with the requirements of AS 3600 Section 10.

4.2.7 Panels with stiffening ribs

Stiffening ribs or integral columns may be necessary to provide additional stiffness or strength where isolated concentrated loads occur – most commonly at roof- or floor-beam bearing points or at either side of large door or window openings.

The design of stiffening ribs or integral columns can be treated in several ways. If the concentrated load is small it may be sufficient to thicken the panel immediately below the point at which the load is applied and to design this section to carry the applied actions, eg as a wall using design methods given herein. Alternatively, the thickened section of panel can be designed as a column in accordance with AS 3600 Section 10. In this case, if compression is the controlling factor, confining ties will be required to contain the compression reinforcement. It is therefore usually more economical to increase the width or depth of the stiffening rib to ensure that bending is the controlling factor so that only flexural reinforcement is required.

Since shear stresses are usually relatively low it is seldom necessary to provide shear reinforcement.

4.3 Footings/piers

Number of piers

If panels are supported on piers, then there are two cases for the arrangement of the piers. Either two small piers are provided per panel (Case 1) or one larger pier is used to support two panels (Case 2), Figure 21.

The following points should be considered when deciding which alternative to use:

- Case 1 requires more drilling than Case 2, although the Case 1 pier sizes may be substantially smaller than those required for Case 2.
- Cracking at the bottom corners of panels, due to misplaced reinforcement, Figure 22, is less likely with Case 1 because piers and the bearing pads can be located away from the corners of the panels.
- If skin friction on piers is significant then Case 1 can require less concrete.
- If obstructions are encountered when drilling piers, then for Case 1 the piers can generally be moved sideways because there is more tolerance in pier locations.
If piers are shallow, the advantages of using two piers would generally make Case 1 the preferred option.

Regarding Case 2, some of the issues to consider are:
- The minimum diameter of the pier or pier cap should be at least 750 mm in order to accommodate the specified edge clearances to bearing pads nominated in AS 3850 Figures 23 and 27.
- At a corner, Figure 24, the bearing pads which transfer the loads onto the pier should be equally spaced about the centreline of the pier so that adverse moments are not introduced into the pier. Note that it will not always be possible to avoid introducing a moment into the pier; in this case the pier must be designed accordingly.

Piers at boundaries. At boundaries, the piers supporting panels will require pier caps because the bearing pads usually cannot be satisfactorily located on the piers, Figure 25. If the adjoining building has already been constructed, the proximity of the piers...
to the boundary (especially for smaller piers) may be determined by the drilling mandrel, Figure 26. Typically, a pier with a minimum diameter of 750 mm is required along boundaries to achieve the necessary edge distances.

In cases where the pier cannot carry the moment induced by the eccentricity of the panel load, a tie beam may be required.

**Provision of pier or pile caps** If pier/pile caps are required, consideration should be given to the minimum dimensions required to allow for construction tolerances and minimum edge distances given by AS 3850. The cost of increasing the dimensions of the pile cap to make it a 'comfortable' size is small, Figure 27.

With both panels resting on the pile cap, the load on the pile is balanced. During erection however, an eccentric load and moment is induced in the cap whilst only one panel is resting on it. Starter bars, which connect the pier or pile and the capping member, will normally carry the induced moments while the panels are being erected. Note that with the use of timber piles, no starter bars are available and a solution in this case is to extend the cap to encase the top of the piles to allow some moment transfer to take place, Figure 28.

With the use of screw-in steel piles, consideration of the unbalanced condition during erection and possible moments from eccentricity at the boundary will require special consideration.

### 4.4 Floor slab

**Design considerations** The floor slab design must take into account construction loads, eg cranes, concrete trucks, the strength of the concrete in the slab at the time these loads are applied, and the thickness needed for drilled-in inserts. Generally, the strength of the floor will require that packing (grillage) is used under the feet of the cranes to develop sufficient area to preclude a punching shear failure in the floor slab.

**Plan of ground floor slab** Frequently, the ground floor slab is used as a casting bed for wall panels. Where this is the case, the location of the casting positions needs to take into account the location of floor joints and other details. The slab plan, Figure 29, should indicate not only the joint types and locations, but also the construction details adjacent to the
panels to allow the completion of the floor slab once the panels have been erected, Figure 30.

The pour strip as indicated in Figure 30 gives the panel some additional stability and is a means of building in some redundancy into the structure, i.e., in case one of the bracing members fails. However, panels have to comply with the requirements of the BCA relating to the performance of external panels in fire, (see Clause 2.6 above).

If a pour strip is not incorporated into the slab plan, Figure 31, the layout of floor joints should ensure that they coincide with panel joints at the perimeter. This prevents locking of the panels at their base and allows free shrinkage and thermal movement of the panels and floor.

Figure 32 indicates the support of internal wall panels supported on the slab.
4.5 Roof Bracing

**Typical layout** Each bay must be braced in order to transfer the lateral loads on the walls to the supporting cross walls Figure 33.

**Bracing design** The traditional model for wind truss analysis involves applying the lateral loads as forces at the truss nodal points and calculating the reactions to be resisted by the shear walls at the ends of the roof truss Figure 34. In this type of analysis, the tension and compression loads in the chord members are generally largest at the centre of the truss.

To reduce the load in the chord member adjacent to the panels (and perpendicular to the wind direction), an alternative model which uses the shear capacity of the panels perpendicular to the wind direction can be used Figure 35. In this model the loads induced in the top chord of the truss are resisted by the shear capacity of the individual panels. The chord is fixed to each panel at the centre of the panel; the chord/strut or tie can generally be reduced to a single angle section.

Note: As the panel joints are typically located at rafter centres (or nodal points), the angle member along the panel will normally have slotted holes at the ends of the panel to allow for long-term shrinkage of the panels. The horizontal loads are therefore not transferred from the steelwork at the ends of the panels, but carried by one or two rigid connections at the centre of the panel Figure 36. Rigid connections include welding the angle to a cast-in plate, Figure 37, bolting to the panel through a non-slotted hole in the angle or using a plate washer welded to the angle over a slotted hole in the angle (to allow for construction tolerances).

**Lateral support** For large panels, the joints between panels are generally located at rafter centres so that the roof framing (or portal frames when the panels are used as cladding only) laterally supports both panels, Figure 38.

For smaller panels, an intermediate strut can be provided to laterally support the panels at the intermediate joint location Figures 39 and 40.
4.6 Connections, fixings and inserts

4.6.1 General

The detailing of connections and fixings for the project should be carefully considered to ensure buildability, load capacity and ductility. Design considerations include:

- thermal gradient – effect of bowing;
- expansion/shrinkage of materials;
- fire performance; and
- earthquake requirements.

Permanent connections, especially those exposed to the external environment, should be protected against corrosion. Any protective coating should be applied over the entire fixing, including those parts to be cast into the concrete. Fixings may have to be protected against fire if heat will adversely affect their performance.
The design of connections, fixings and inserts is covered in the *Precast Concrete Handbook*. In designing connections and fixings the following general principles should be observed:

- The panel should be supported at one level by two (no more, no less) seatings in direct bearing.
- For stability, panels may require more than one level of fixings.
- Connections should be designed to accommodate the permitted dimensional tolerances of both the panel and structure.
- Connections should allow the panel to flex and/or move under environmental conditions. Care must be taken with welded connections to avoid locking the joints up and thus preventing movement. However, bolted connections will generally permit such movement to occur.

Site welding of connections is time consuming and expensive. Welded connections that require the member being attached to be supported by a crane while welding is carried out should be avoided: Connections at the upper levels of the panel will require a ‘cherry picker’ or similar for access.

A selection of tried connections for various situations is shown in Figures 41–53. As well as the recommended detail for panel-to-rafter connection Figure 49 comment is offered on two non-recommended details Figures 50 and 51.

### 4.6.2 Inserts

**Types and varieties of insert** From a tilt-up perspective, inserts are usually primarily referred to in terms of their function, eg ‘lifting inserts’, ‘bracing inserts’ and ‘fixing inserts’. Suppliers however, tend to refer to inserts in terms of their manufactured variety (the mechanism through which they achieve anchorage), viz:

- cast-in inserts
- load-controlled expansion anchors
- deformation-controlled expansion anchors
- drop-in anchors
- spring-set bolts
- self-drilling anchors
- chemical anchors.
Figure 44  Panel to suspended precast floor

Concrete topping to precast units if required
Threaded tie-bars screwed into ferrules cast in wall panel if topping used
Precast concrete floor units

Bearing pad (70-mm wide typical)
Continuous-angle seat, site-welded to plates cast in wall panel or bolted to inserts cast in panel

Figure 45  Panel to panel T-junction (recess version)

Filler (fire-rated if required)
Pocket formed in panel and later filled with grout. Angle may be surface-mounted depending on fire requirements.

Figure 46  Panel to panel T-junction (top fixing version)

T-connector plate with elongated holes, bolted to ferrules cast in top edge of wall panels

Figure 47  Panel to panel at exterior corner

Sealant and backing rod
Angle bolted to cast-in inserts

For maximum tolerance, connecting angle should have horizontal and vertical slotted holes

Figure 48  Panel to roof truss

Roof truss with angle seat
Purlin seat
Member of horizontal wind-load truss welded or bolted to panels (roof truss seat uses similar connection)
Member of horizontal wind-load truss welded or bolted to panels to transfer lateral loads to end walls

Figure 49  Rafter to panel connection at joint

Sealant and backing rod
Filler (fire-rated if required)
AS 3850 and the various State regulations, eg *Industry Standard: Precast and tilt-up buildings* place restrictions on where and when the various manufactured variety of insert can be used. Deformation-controlled expansion anchors (conventional, single-wedge, cone-type expansion anchors) are not permitted for either temporary or final fixing of tilt-up panels because they do not adequately resist tensile and shear dynamic loads.

**General** Failure of fixings may occur in either the steel, bolt or weld or in the concrete anchorage; the design should cover both. Fixings that are cast-in or drilled into the concrete can fail due to concrete failure, insert failure or through slippage. Concrete failure occurs when the concrete ruptures and the insert pulls out, usually without warning. Inserts should be manufactured from material that will provide a degree of ductility so that there is some evidence of distress prior to failure. Slippage occurs when an anchorage slips progressively in the hole in which it has been set, and is specific to expansion anchors.

In general, inserts in the panel and, where possible, elsewhere should be specified as ‘cast-in inserts’ or ‘purpose-made fixings’ that are cast in. The position of all inserts should be determined and shown in the shop drawings.

If cast-in inserts have been omitted or incorrectly located, proprietary anchors are available to provide connection points. Chemical anchors, undercut anchors or drill-in anchors are also available to provide acceptable connections, but note the restrictions given above on their use. Care should be taken to ensure an appropriate anchor is selected and that it meets the required load capacity.

**Lifting inserts** Lifting inserts are specially-designed components that are cast into the concrete panel and used when lifting the cured panel. Where lifting inserts are omitted or become unusable, AS 3850 requires that the erection design engineer approve the proposed alternative. Note that the solution will also have to satisfy any limitations imposed by the available lifting gear.

These devices are available in a variety of sizes with different load capacities. Some can be used in both face and edge-lifting situations, while others are suitable for one situation only. A typical lifting insert is shown in Figure 54. Plastic recess formers are located around the actual lifting point with tell-tales for easy location after the concrete has been placed.

**Bracing and fixing inserts** Purpose-made ferrules (threaded inserts) cast into the panel are the recommended way to provide connection points to the completed panel. They are suitable for attaching...
roof beams and the like and are essential for providing connection points for transverse structural bracing. Figure 55 shows a typical cast-in ferrule.

To provide a connection point for temporary braces in the floor, a load-controlled expansion anchor should be used. AS 3850 draws attention to the fact that these anchors must be installed to the nominated torque and should be regularly inspected as they may work loose under windy conditions. If this is not possible, undercut anchors, or chemical anchors may be used. However, chemical anchors must be proof-tested to the working load limit.

4.7 Lifting

General

Probably the most severe loading experienced by the panel will be that to which it is subjected during lifting. The design loading for lifting must allow for self weight of the panel, the ‘suction’ between the panel and the casting surface, and the dynamic loading that will occur when the panel separates from the casting surface and is carried by the crane. The effect of these forces has to be considered on both the panel and the lifting inserts.

Suction and handling forces

Suction and handling forces are specified in AS 3850. For cases not covered in the Standard, reference should be made to the Precast Concrete Handbook. The multipliers given in AS 3850 are summarised in Table 5.

Design

The design for erection of a tilt-up panel is a completely separate design case from that for the in-service condition. The most important difference is in the treatment of flexural stresses. For the in-service condition the panel is designed for factored actions and loads and the concrete is assumed to be cracked. For erection, the design is based on the assumption that the concrete carries the stresses due to the applied loading (including impact) as an uncracked section. At any section where the concrete flexural tension stress exceeds about $0.4\sqrt{f'_{c}}$, reinforcement should be added to carry the entire load.
At the time of lifting, the concrete must have developed sufficient tensile capacity to resist stresses caused by lifting. As panels are typically lifted at an early age (three to seven days after casting), the required concrete strength at the time of lifting will need to be specified and the concrete grade adjusted accordingly.

The analysis for maximum stress during lifting is statically determinate but is complicated by the fact that there is a redistribution of the panel forces and moments as the angle of inclination changes. This is a result of the changing angle of lifting cables as the panel rotates to the vertical.

Design for lifting is usually carried out by computer analysis whereby stresses are checked at incremental increases in angle as the panel is rotated from the horizontal. For panels without openings the critical stresses with two-or-more-high rigging usually occur with the panel at 30°–50° to the horizontal. For panels with one-high rigging, the critical stresses occur with the panel near horizontal. Many insert/tilt-up hardware suppliers use computer programs to determine stresses in panels and forces on inserts induced by the lifting process.

As a guide to allow preliminary selection of panel sizes, Figures 56 and 57 include influence-line diagrams for bending moments during rotation of panels with two-high and four-high rigging systems. These diagrams apply only to rectangular panels without openings. For panels with openings or for large or non-regular panels, a more-rigorous analysis is required to locate lifting inserts.

**Insert location and rigging system** Figure 58 shows some of the more common lifting insert locations and rigging systems. Rigging systems are configured...
with slings running through pulleys so that equal
cable loads are applied at each lifting point. Note
that configurations of three-high and/or three-wide
systems are not recommended due to the complex
rigging required. Unusual panel shapes may, however,
necessitate awkward lifting configurations; most
specialised computer programs will cater for these
situations.

4.8 Temporary bracing

It is unusual for the loading on the panel during the
temporarily braced condition to control its design.
However, the loading needs to be determined so that
the bracing and inserts can be checked for adequacy
and the stability of the panel ensured.

The wind actions on the panel should be determined
from AS/NZS 1170.2 using an appropriate value for
the annual probability of accedence as specified in
AS/NZS 1170.0.

It is recommended that the panel also be designed
for a minimum accidental loading of 1% of the panel
weight acting at the centre of gravity of the panel, or
1.5 kN/m acting at the top of the panel.

The bracing system for each panel should provide
stability against panel twisting. Generally, providing
two braces along the length symmetrically disposed
about the centreline of the panel will achieve this.
However, for tall, slender panels (eg with a height
to length ratio greater than 4, or panels where the
shim points are closer than 1200 mm) consideration
should be given to bracing the panel in two orthogonal
directions.

The design of the braces should be carried out in
accordance with the rules set out in AS 3850.

The design of the fixings is also affected by the
geometry chosen for the braces. The fixings have to
be designed to carry the induced shear parallel to the
plane of the wall or floor as appropriate and tension
perpendicular to the surface. In general, for single-
storey buildings the panel fixings will be located
approximately at 2/3 of the panel height. However,
the fixings have to be located below the level of any
intermediate concrete floors to enable the floors to
be constructed. The vertical tension force in the floor
fixings can be minimised by decreasing the bracing
angle, ie increasing the distance of the fixing point
from the panel. See Appendix D.

Figure 58 Lifting insert locations for common
rigging systems.
5.1 General
Some construction issues that the project design engineer should consider mentioning in the project documentation, eg specification, are set out below. The list is not comprehensive but is provided to draw attention to matters considered important enough to warrant specific mention.

5.2 Compatibility
Compatibility of components used on a tilt-up project is necessary if site delays or failures are to be avoided. Two areas are of major concern are:

- Hardware lifting, bracing and fixing of panels. Mating items, eg lifting clutches and lifting inserts should be sourced from the same supplier. Similarly, braces need to be able to be fastened to the bracing inserts.
- Bond breakers and curing compounds (if they are separate materials). Furthermore, care should be taken to ensure that they will not inhibit the adhesion of any final coating, sealer or covering on either the walls or the floor slab. (If compatibility is not possible, then the concrete surface will need to be mechanically cleaned before the finishes are applied.)

5.3 Concreting
Normal work practices for placing, compacting and curing of concrete should be specified.

- Generally, lifting of panels earlier than 28 days after casting will be desirable. AS 1379 sets out mean 7-day strengths for normal-class concrete. If lifting earlier than 7 days is required, or if higher strengths are required, special-class concrete with the desired properties can be specified. In these cases specific testing of the concrete should be carried out to confirm the strength prior to lifting.
- Early-age strength requirements, eg E3 or E7, can be specified where it is proposed to lift panels at seven days or less after casting.
- Project testing may be required to confirm strength at lifting.
- ‘Component’ reinforcement should be attached to inserts and located in the panels in accordance with the insert manufacturer’s recommendations.
- ‘Structural’, ‘additional’ and ‘component’ reinforcement should be shown on the shop drawings.

5.4 Bond breakers
A liquid curing compound/bond breaking system that can be sprayed on by hand is usually the most successful and economical method for curing and bond breaking.

The standard of the surface finish of the concrete on which panels are to be cast should be sound, dense, smooth and have low absorbency to achieve the best results from the chosen bond breaker.

The application of the bond breaker should be strictly in accordance with the manufacturer’s recommendations.

As rain and heat can adversely affect the performance of some bond breakers, it should be specified that prior to placing the concrete the surface should be inspected to confirm the coating is still functional.

5.5 Rigging
This is a specialist area and the specification should clearly allocate the responsibility to the appropriate party. The rigging configuration will depend on the number and location of lifting inserts and must ensure that all inserts are loaded equally. Where two lifting points are connected by one sling, the sling length will affect the loading on the lifting inserts, eg short slings may overload the lifting inserts because of sideways drag.

Typical terminology of rigging systems and layouts are shown in Figure 59.

5.6 Lifting clutches
The specification should require the use of purpose-made lifting clutches. Quick-release lifting clutches that enable the erector to quickly and safely connect, lift and release the rigging to the panel during erection Figure 60 should be preferred.

It is essential that lifting clutches are compatible with the lifting inserts in both connection and load capacity. The use of matched items from the one manufacturer should be specified.

5.7 Braces
The specification should require that the design of bracing be carried out by suitably qualified personnel and the design be checked by the project design engineer or some other independent authority.
The use of purpose-made and load-rated braces should be permitted. Generally, a minimum of two braces is required for each panel. Wherever possible, they should be attached to the panel prior to lifting, thus eliminating the need for workmen to carry out any work above ground.

5.8 **Levelling pads**
Levelling pads (levelling shims) are a series of shims used to support a tilt-up panel at the correct level during installation. They should be specified to be inert, waterproof and slip-resistant. The total height of the shims should not exceed 40 mm and they should have a minimum width of 100 mm, or equal to the panel thickness if this is less than 100 mm. 

*Note: Some regulations exclude the use of steel shims.*

![Typical rigging systems/layouts](image)

5.9 **Lifting and repair**
The specification should set out the responsibility for the lifting operation. It should also set out the procedure to be followed in the event that a panel becomes stuck, i.e., does not separate at the expected load. The specification should set out the procedure to be followed in the event of damage to a panel. Note that damage may range from minor cosmetic damage, e.g., spalling of edges, to major damage that may necessitate the panel being condemned and removed.

![Typical levelling pad arrangement](image)
from the project, eg significant cracking or spalling that jeopardises the panel’s structural capacity or durability. The specification should address the issues of who will assess the severity of the damage; determine the appropriate repair procedures or rejection of the panel; and approval of the repaired panel for incorporation into the final structure.
O6 References

3 Tilt-up Construction Notes (T50) Cement and Concrete Association of Australia, 1977.
4 Design of Tilt-up Concrete Wall Panels (Z10) Recommended Practice, Concrete Institute of Australia, 1992.
5 AS 3600 Concrete structures Standards Australia, 2001.
6 Precast Concrete Handbook National Precast Concrete Association Australia, 2002.
8 AS/NZ 1170.0 Structural design actions Part 0: General principles Standards Australia, 2002.
11 ACI 318 Building code requirements for reinforced concrete American Concrete Institute, 2004.
13 AS 1170.4 Structural design actions Part 4: Earthquake actions in Australia Standards Australia (to be published).

AS 1170.1 Structural design actions Part 1: Permanent, imposed and other actions, Standards Australia, 2002
Kripanarayanan K M 'In-Place Loads and Tilt-up Bearing Walls – A Design Approach' Concrete International, Vol. 2, No. 4, April 1980, pp 43–47.

Various other reference material is available on tilt-up construction including manufacturers’ literature, conference papers, monographs and the like produced by industry and its associations.

O7 Bibliography
A.1 General
While tilt-up panels are routinely tilted, lifted, handled and braced without incident, the safety of these operations must be taken into account during design. AS 3850 is specifically aimed at this aspect of the process. In many States there are also regulations which must be followed, eg Industry Standard: Precast and tilt-up concrete for buildings. The comments offered herein are meant only to draw attention to major considerations and should not be seen as a comprehensive treatment of safety issues.

The Occupational Health and Safety regulations may assign the responsibility for various actions to particular parties.

A.2 Access
Access to and around the site will influence the safety of construction and erection operations. Access for vehicles and personnel should be such that operations can be carried out safely.

It is advisable for the builder to prepare a site plan in conjunction with the erector/crane operator to check: crane access; crane set-up points; the erection sequence and bracing layout. Where the crane is to operate off the ground floor slab, the suitability of the ground (including the position of any service trenches) to carry cranes should be checked.

A.3 Compatibility
Compatibility of all components used in the tilt-up project will have a direct impact on the safety of operations.

As noted above, hardware for lifting, bracing and fixing of panels should be compatible. Mating items such as lifting clutches and lifting inserts should be sourced from the same supplier.

A.4 Shop drawings
Good shop drawings of the panels are essential for efficient and safe tilt-up construction. The shop details are usually provided by the erection design engineer. Copies of the shop details should be sent to the project design engineer to ensure they reflect the design intent for the completed structure. They should incorporate all the dimensions (including diagonal measurements) and details required for the manufacture of the panel including:

- the location and capacity of lifting anchors;
- the location and capacity of bracing inserts, fixing inserts and/or fixings;
- any cast-in elements such as grouting ducts and steel plates;
- reinforcement details;
- edge and face rebates;
- concrete strength at time of lifting and at 28 days.

A typical shop detail of a panel is shown in Figure A.1.

Panels should be allocated reference numbers for identification purposes and have all details shown.

A.5 Concreting
Normal work practices for placing; compacting and curing of concrete should be employed. The concrete should be placed, compacted, screeded level and finished as quickly as possible.

Where panels are to be lifted earlier than seven days, project testing of the concrete strength on site should be used to confirm that the concrete has achieved the specified strength.

A.6 Bond breakers
A liquid curing compound/bond breaking system that can be sprayed on by hand is usually the most successful and economical method of providing the bond breaker. However, if the bond breaker used is not doubling as a curing compound then the compatibility of the two compounds should be checked.

The application of the bond breaker should be strictly in accordance with the manufacturer’s recommendations.

The application should commence after placement of the formwork but before reinforcement is placed to ensure that all areas, especially corners, receive adequate coverage and that no bond breaker gets onto the reinforcement.

Some bond breakers must be dry and continuous before panels are cast. In these instances, site personnel should be kept off the surface until the compound has hardened.

Immediately prior to concrete placement, the bond breaker film should be visible on the casting surface. This can be checked by sprinkling water on the surface. If the water beads up, the coating is probably intact. If there is any doubt, a second coat should be applied.
Figure A1 Typical shop drawing of panel details.

Note: Typical items such as reinforcement details, insert capacities, ferrule sizes and concrete details may be covered on other drawings or in the documents.
A.7 Inserts
The restrictions placed on the use of various types of inserts given in AS 3850 and the various State regulations must be observed.

The position of all inserts should be accurately located in the panels and the floor and as shown in the shop drawings.

Deformation-controlled expansion anchors (conventional, single-wedge, cone-type expansion anchors) are not permitted for either temporary or final fixing of tilt-up panels because they do not adequately resist tensile and shear dynamic loads.

In the event that the specified inserts have been omitted or incorrectly located, advice should be obtained from the appropriate engineer as to rectification procedures to be followed and for approval to lift the repaired panel.

Where load-controlled expansion anchors are used to fix panel braces to the floor AS 3850 draws attention to the fact that these anchors must be installed to the nominated torque and should be regularly inspected as they may work loose under windy conditions.

A.8 Rigging
Crane rigging should be under the control of a suitably qualified and experienced rigger.

A.9 Lifting clutches
Lifting clutches must be compatible with the lifting inserts in both connection and load capacity. The use of matched items from the one manufacturer is recommended.

A.10 Lifting
During erection, safety is of prime importance. As tilt-up construction involves the handling of large, heavy concrete elements good work practices should prevail at all times.

It is imperative that the lifting sequence is well planned and the site team communicate well, knowing how each sequence of work is to proceed. Among the requirements for site personnel safety during lifting are:

- Panels should not be lifted in high winds.
- Braces should always be of the correct size and capacity and connected properly at each end before the rigging is released.
- Correct size and number of lifting points and correct lifting equipment should always be used (never exceed maximum capacity).
- The crane operator should never leave the crane while the panel is connected.
- ‘Blind’ lifting, where the crane operator cannot see lifting eye attachments, should be avoided if possible.
- Good housekeeping around the site should be maintained at all times.
- Close site supervision and common sense should always be used.

The force required to separate a concrete panel from the casting surface will be greater than that for just lifting the panel – due to suction forces between the two. If water is lying around a panel, lifting should not be attempted as suction forces will be substantially increased. If the panel fails to separate at the specified lifting load then the process should be stopped and advice sought from the appropriate engineer as to remedial measures that may be undertaken.

A.11 Braces
Generally, a minimum of two braces is required for each panel. Wherever possible, they should be attached to the panel prior to lifting, thus eliminating the need for workmen to carry out any work above ground.

Braces must be positioned so that they will not foul the rigging during lifting. (The lifting inserts and bracing connection inserts should be offset and not be in the same vertical line.)

Braces and their fixings should be checked regularly, at least once a week, to confirm the bolts are tight and any ‘locks’ on the braces are still in position. Braces should not be removed until the final connections have been made and the structure is sufficiently complete to carry any loads applied to the panel. Braces should be removed only after receipt of written authorisation from the project design engineer.
A.12  Levelling pads
The most common type of levelling pad is made of high-density polyethylene which is chemically inert, waterproof and will not slip. Some regulations exclude the use of steel shims.

The total height of the shims should not exceed 40 mm and they should have a minimum width of 100 mm, or be equal to the panel thickness if this is less than 100 mm. Levelling pads should be positioned as shown in the drawings.

A.13  Responsibilities
Some of the areas of responsibility for each party in respect of safety are set out below for guidance. Details should, however, be agreed by the parties involved and spelt out in the contract documentation.

- **Project design engineer**
  - Overall building stability
  - Design for fire
  - Design for durability
  - Design of floor/pavement for working loads
  - Panel size/shape/tolerances
  - Fixing insert selection and location
  - Structural reinforcement
  - Concrete specification, including strength and any special requirements
  - Communication of all aspects of design and any special requirements to the builder via drawings and other documentation.

- **Builder**
  - Work method document
  - Access for crane/trucks
  - Preparation of hardstanding/pavements
  - Workshop drawings and casting and erection drawings
  - Insert selection
  - Casting sequence
  - Erection sequence
  - Selection of bond breaker
  - Placing and compaction of concrete
  - Curing of concrete
  - Achievement of specified concrete quality including strength at lifting
  - Bond breaker application
  - Essential forms of communication.

- **Erection design engineer**
  - Design of panels for transport, lifting, erection and bracing
  - Additional and component reinforcement
  - Sling length
  - Lifting and bracing insert selection and location
  - Design of bracing.

- **Erector**
  - Safe working environment/procedures
  - Crane access
  - Crane position
  - Erection procedure
  - Crane/panel weight ratio
  - Strongbacks
  - Rigging gear
  - Correct clutches
  - Concrete strength
  - Fixing bracing.
Appendix B: Surface Treatments for Site-cast Panels

B.1 General
When tilt-up panels are cast on-site, it is difficult to achieve the sophisticated finishes and detailing possible in a precast concrete manufacturing factory. Consistent results can, however, be achieved with the many more-straightforward but visually appealing treatments available, viz:

- Rebating/grooving
- Coatings
- Exposed aggregate/stone veneer.

The surface treatment that is specified will affect the quality of finish required on the concrete itself. Other factors that can influence the appearance of the panels are: the uniformity of absorption of the casting bed; the curing compound; the bond breaker; and their compatibility. To ensure that a particular surface treatment or combination of treatments meets the client’s requirements, the construction of a test panel may be necessary prior to the casting and treatment of all panels.

B.2 Casting surface
Most often, the floor of the proposed building is used as the casting bed. Care should be taken in its finishing to ensure uniformity of the finish and to control the flatness over casting areas. Any obvious imperfections should be patched, while ensuring that the repair matches the texture of the surrounding areas.

To reduce the risk of the joint being reflected in the panel, it is desirable that contraction and construction joints do not occur in casting areas. If this is not possible, the joints should be filled with plaster (to be removed later) and the surface smoothed over to match the texture of the surrounding floor.

If any surface penetrations occur in the floor in the casting areas, the holes should be filled with sand and covered with a 20-mm-thick skin of concrete finished to match the surrounding floor area. This can easily be broken out once casting is completed.

Recommended tolerances for the planeness of the casting bed are set out in Clause 3.11 of AS 3850.

Note: Any imperfections in the casting surface will be reflected in the panel cast on it. The effort spent on inspecting and rectifying any imperfections will be well worthwhile.

B.3 Surface flatness
One of the most important considerations in the final appearance of a tilt-up panel is the flatness of the surface. In large unbroken wall areas, strong light from a source almost in the same plane as the surface of the panel (glancing light) can accentuate the unevenness of the surface.

Whilst tilt-up panels produced on appropriate casting areas can be apparently flat and blemish free, this will not always be the case in unfavourable lighting conditions. A consequence of even slight deviations from true flatness is that glancing light will result in irregular patterning of the surface. On plain walls where there is no deliberate texturing of the surface, these shadows can be quite noticeable. The impact of this can be reduced by appropriate detailing and workmanship and the selection of the surface finish.

The use of texturing provides relief to large expanses by creating shadow lines. The greater the depth of the texturing, the less noticeable will be the shadowing effect of glancing light. This can be achieved by simply brooming the concrete surface before the concrete has hardened.

As far as the use of coatings is concerned, the diffusion of light over the surface (which is the desired effect) will be increased as the gloss level is reduced and the degree of texturing is increased.

Because textured coatings generally are significantly more costly than most traditional paint systems, the final selection of a finish may be a compromise between the degree of texture required and cost.

Obviously, flatness of the panel and the absence of surface blemishes are very much part of the construction process and every care should be taken to minimise variation between adjacent areas and panels.

B.4 Rebating/grooving
The forming of grooves in tilt-up panels at the time of casting is one of the easiest and cheapest methods to provide visual interest to otherwise-flat areas of concrete. The use of vertical grooves of the same dimensions as the joints between panels disguises the individual panels and provides visual interest. If the groove width matches paint-brush or roller width, it is a simple matter to apply a coloured coating in the groove which contrasts with the rest of the panel.
Chamfers at the edges of both the panel and the grooves assist in removal of forms and eliminate sharp corners that are vulnerable to damage, especially during lifting and subsequent construction work. 

The depth of any groove reduces the structural section of the panel and this must be considered in the design of the panel. Grooves are usually less than 20 mm deep.

B.5 Coatings

A surface coating is the easiest way to improve the appearance of a smooth, grey concrete panel. Coatings help mask minor imperfections and colour variation in the concrete surface and can also be used to provide things such as a corporate identity to a building. Colour schemes are easily changed to reflect a new image should a change in tenancy occur.

Recent developments in coatings have produced a wide range of products in an almost endless colour range. Various products ranging from flat, acrylic, thin-film paints to high-build textured coatings are available.

The surface preparation, class of finish to the concrete and extent of imperfections that can be covered will depend on the product chosen. The manufacturer’s recommendations for the application rate and method should be followed. The latter can vary from brush, spray, roller or trowelled applications, depending on the product and desired finish.

A very important consideration in the use of surface coatings is the removal of any traces of the bond breaker or curing compound; if it is not compatible with the coating, a delamination failure of the coating may result. Most bond breaker/curing compounds will break down when exposed to ultra violet light. However, this may take some time, especially on shaded areas of a building. High pressure washing and even hydrochloric acid etching can be ineffective in removing some bond breakers and wet sand blasting may be the only method to ensure a clean surface. The compatibility of the bond breaker or curing compound to the selected coating should always be investigated to ensure adequate surface preparation prior to application.

The simplest method of checking for residual presence of the bond breaker or curing compound is to splash an area of the panel with water. The water should be immediately absorbed and darken the area of concrete and not bead on the surface, if a slippery or shiny film can be detected, then bond breaker is still present. Other identification can be made visually, ie panels of varying colour, footprints in the surfaces, etc.
The environment to which the coating will be exposed should be considered, ie industrial, coastal, etc and the manufacturer’s advice sought. The coating should also be carried under flashings and over parapets, with raw edges where water can penetrate being avoided. Particular attention should be given to the surface preparation required for the selected coating in terms of cleanliness, patching and filling, moisture levels and temperature at the time of application.

Table B.1 provides a brief summary of the most commonly used coating treatments. The information has been compiled from manufacturer’s data but is not exhaustive.

**B.6 Exposed aggregate/stone veneer**

A variety of methods is available for producing an exposed-aggregate finish to tilt-up concrete panels including the use of chemical retarders, sand blasting and sand-embedment casting.

Use of chemical retarders requires care in both the placement and vibration of the concrete and application of the retarder. The retarded surface is most often exposed by the use of a high-pressure water blaster, although care is required to ensure a uniform finish.

Sand blasting is used in the treatment of tilt-up walling to remove the shiny panel surface and provide a fine-textured surface finish. It is done after erection and requires a special concrete mix for a consistent finish. Alternatively, a retarder can be used to provide a deeper exposed-aggregate finish.

To avoid the problems associated with the treatment of the face-up side of a panel (and particularly the presence of lifting inserts), a face-down, sand-bed method of casting can be used. The placing of aggregate or building stone veneer on a sand bed over which the concrete is then placed is an economical method to create an exposed aggregate or stone-look panel. Once erected, the panels have the sand cleaned out by water blasting; in the case of stone veneer, the joints can be mortared to create the final effect.
Appendix C Design Example

Assume rafters at 8 m centres, span 30 m.

Calculate reactions for permanent and imposed loads and the various wind load cases for the different directions of wind. (These calculations not shown).

Rafter reactions for this example:

\[ G = 25.5 \text{ kN} \]
\[ Q = 30.0 \text{ kN} \]
\[ \text{Windward} \ W = 48.0 \text{ kN (upwards)} \]
**WIND LOAD ON WALL**

Windward wall external pressure and negative internal pressure = 1.1 kPa.

Leeward wall external negative pressure and internal pressure = 0.7 kPa.

**DESIGN WIDTH OF PANEL**

Assume that the rafter connects to the panel at the joint between two panels and is shared equally between the two panels.

Assume that the load from the connection is distributed into the panel at a slope of 1:2 (see diagram).

Effective width carrying rafter loads = 2000 mm.

Self weight of panel at midheight = \(\frac{1}{2}\) effective height + parapet \times thickness \times concrete density.

\[= 4.5 \times 0.15 \times 24\]

\[= 16.2 \text{ kN/m}\]

Load combinations (see AS/NZS 1170.0 CI 4.2.2)

\[b = 1.2G + 1.5Q\]

\[d = 1.2G + Wu + \gamma_c Q \text{ (wind in same direction as G)}\]

\[e = 0.9G - Wu \text{ (wind in opposite direction to G)}\]

Consider windward wall (assume rafter load divided equally between adjacent panels).

\[W_u = \frac{48}{2} = 24 \text{ kN}\]

\[G = 0.9 \times 25.5/2 = 11.43 \text{ kN}\]

Rafter reaction = \(-24 + 11.43\) = \(-12.52\) kN (ie upwards)

Assume 150 thick panel
Check panel able to hold roof down.
Assume only 2 m width of panel effective
self weight = 6.0 x 0.15 x 2.4 = 28.8 kN/m
0.9 G = 25.9 kN/m
\[ \text{uplift resisted} \]
Assume Reinforcement = RF818 central (454 mm²/m) \( f_c' = 32 \text{ MPa} \)

Design BM at midheight
\[ M_u = 1.1 \times \frac{72}{8} + 12.52 \times \frac{0.175}{2} = 6.74 + 1.1 = 7.84 \text{ kN.m} \]

Note the BM due to wind on the wall and that due to the upward rafter load at the connection are opposite, and of the same sign.

Using ACI method as in ACI 318 Chapter 14 Clause 14.8 direct calculation.

\[ M_u = M_u / (1 - 5P_u) \sqrt{\frac{0.75 \times 48 \times E_c}{I_{cr}}} \]

Where
\[ I_{cr} = n A_{se} (d - c)^2 + \frac{l_w c^3}{3} \]
\[ n = \frac{E_s}{E_c} = \frac{2 \times 10^5}{2.8 \times 10^4} = 7.14 \]
\[ A_{se} = \frac{P_u + A_{sf} f_{sy}}{f_{sy}} \]

Take
\[ P_u = \text{self weight of panel less share of rafter reaction} = 0.9 \times 16.2 - 12.52 / 2 = 14.58 - 6.26 = 8.32 \text{ kN/m} \]

Assume
\[ A_{se} = 454 \text{ mm}^2 / \text{m} \]
\[ d = \text{distance from extreme compression fibre to centroid of reinforcement} = 150 \text{ mm} \]
\[ c = \text{distance from extreme compression fibre to Neutral Axis} = 75 \text{ mm} \]
Calculate $c/d$:

$$c/d = \sqrt{pn^2} = 2pn - pn$$

$p = \text{reinforcement ratio} = \frac{A_se}{b.d}$

$$= \frac{470.64}{103 \times 75}$$

$$= 0.0063$$

$p_n = 0.0063 \times 7.14 = 0.045$

$$c/d = \sqrt{0.045^2 + 2 \times 0.045 - 0.045}$$

$$= 0.258$$

$$c = 19.4 \text{ mm}$$

$I_{cr} = 7.14 \times 470.64 \times (75 - 19.4)^2 + (1000 \times 19.4^3)/3$

$$= 12.81 \times 10^6 \text{ mm}^4$$

$$M_u = 7.86 \times 10^6 / (1 - \frac{5 \times 8.32 \times 10^3 \times 700^2}{0.75 \times 48 \times 2.8 \times 10^4 \times 12.81 \times 10^6})$$

$$= 7.86 \times 10^6 / (1 - 0.158)$$

$$= 8.33 \text{ kN.m}$$

$A_{st} = 340 \text{ mm}^2 / \text{m} - \text{from Chart 5.2 Reinforced Concrete Design Handbook}$

$<456 \text{ mm}^2 / \text{m}$

$\Rightarrow \text{OK.}$

Note: The design method is conservative by assuming $I_{cr}$ since $M_u < M_{cr}$

$M_{cr} = 0.6 \sqrt{f'c \times BD^2/6} = 0.6 \sqrt{32 \times [103 \times 150^2/6]} = 12.72 \text{ kN.m}$

However, an assumption of $I_{gross}$ on the basis of an un-cracked section would be un-conservative since it would return deflections for $P$ calculations that would be less than normal 'out of straightness deflections' or deflections that commonly occur in panels due to temperature gradients.

When $M_u < M_{cr}$ the designer may therefore choose to use a design method using a less conservative means of calculating the deflection implicit in the ACI method.

However, careful judgement is necessary to ensure the value chosen is not less than deflection resulting from construction inaccuracies and actions other than the application of direct loads.

The possibility of shrinkage cracks dictates that strength design for the ultimate applied moment is based on the assumption of a cracked, reinforced, cross-section, even when $M^* < M_{cr}$. 

Guide to Tilt-up Design and Construction Corrected February 2010
Assume panel 8.8 m high by 8.0 m wide and 150 mm thick

Wind pressure assumed = 1.03 kPa
(Note this ultimate load calculated assuming annual probability of exceedance of 1/100)

Brace panel with two braces along panel.

Calculate horizontal reactions $R_1$ at top of each brace and $R_2$ at shim supports

$$R_1 = W \times A \times 4.4 \times 8.8 \times 4.4/5.8$$
$$= 1.03 \times 4.0 \times 8.8 \times 4.4/5.8$$
$$= 27.5 \text{ kN}$$

$$R_2 = 1.03 \times 4.0 \times 8.8 - 27.5$$
$$= 8.76 \text{ kN}$$

Check shear capacity at shim pads

$$V = 4.0 \times 8.8 \times 0.15 \times 24$$
$$= 126.7 \text{ kN}$$

$$\mu V = R_2$$

$$\mu = 8.76/126.7$$
$$= 0.07 \leq 0.2$$

OK
DESIGN BRACING FIXINGS

At panel, top of the brace

\[ T_1 = 27.5 \times \frac{5600}{4000} \]
\[ = 39.88 \text{ kN} \]

Thus as wind can reverse fixing has to be designed for shear = 39.88, say 40 kN and tension (pull out) = 27.5 kN

Note the tension value, ie R1, is dependant on the height of the fixing up to the panel.
The shear value, ie T1, is affected by the angle of the brace.

At the base of the brace

The fixing here has to be designed for shear = 27.5 kN tension = 40 kN

The shear and tension loads are ultimate values and may need to be adjusted to working loads to be consistent with the manufacturer’s data for fixing anchors. (See AS 3850, Clause 2.2).

The fixing anchor capacity must be checked for tensile capacity, ie the lesser of concrete failure and slip failure, and shear capacity, ie the lesser of steel failure and concrete edge failure. (See the commentary on methods of assessing anchor capacity given in AS 3850).

Note anchor manufacturers generally provide tabulated data on the capacities of their inserts.