The CONCRETE PANEL HOMES Handbook

A guide to the design and detailing of concrete panel construction for housing.

CEMENT & CONCRETE ASSOCIATION OF AUSTRALIA

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The Cement & Concrete Association of Australia (C&CAA) is a not-for-profit organisation dedicated to promoting the use of cement and concrete in building and construction in Australia.

It is funded by its members who are Australia's leading cement producers.

Our Role
The C&CAA's main function is to support decision-makers in the construction industry by providing information on the latest construction technology.

The C&CAA access a vast amount of information on cement and concrete from around the world. This information is made available via the Association's Internet site or in hard copy form.

The C&CAA also produces and distributes its own publications, aimed at further educating concrete users on innovative applications and technological advances (such as this handbook).

In addition, the C&CAA has a team of qualified staff working directly with architects, building designers, engineers and builders around Australia to help them maximise the benefits of building with concrete.

These team members have experience in a range of engineering and architectural disciplines and concrete applications, including the design and construction of roads and pavements, commercial buildings, medium-density and freestanding housing, and decorative concrete finishes.

The C&CAA plays an important role in representing the cement industry on a range of issues and in a variety of forums - for example, in the development of codes and standards, on environmental matters and in research and development projects.

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HIA

The HIA supports the Cement & Concrete Association of Australia in producing The CONCRETE PANEL HOMES Handbook. HIA recognises the benefits of providing practical and accurate technical information to builders and sub-contractors in the housing industry, and has worked with the Association in releasing this handbook.

Caution
Remember when working with cement, concrete and other cement-based materials or prefabricated products, always follow the manufacturer's instructions, and seek advice from the manufacturer about working safely with these products.

THE CONCRETE PANEL HOMES HANDBOOK

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PREFACE

This handbook is meant to be used as a reference guide for all interested parties who require details about the processes involved in building concrete homes, especially concrete panel homes. It gives both technical and practical information about designing, planning, detailing, constructing, installing and finishing concrete panel homes.

The handbook is meant to be a starting point, though. You will also need the professional advice and services of qualified and experienced professionals, such as consultant engineers, architects, building designers, and panel manufacturers who can provide advice and service to suit the individual requirements of your project.

1 INTRODUCTION

Concrete is one of the most widely-used construction material in the world, especially in commercial and industrial structures, which typically consist of concrete footings, floor slabs, columns, beams and walls. In Australia, the residential building industry has generally been restricted to conventional building methods that typically only use concrete in footings or ground slabs.

This is not the case elsewhere, especially in Europe and the United States, where concrete is commonly used to construct building elements such as footings, floors, walls and even landscaping components.

Interest in building concrete homes is growing in Australia, but designers and builders have been slow to change, tending to stay with more familiar materials and methods. That's understandable: the processes involved in building a concrete home are different from conventional ones, and there hasn't been enough information available on these new processes for builders and designers to feel comfortable using them.

This handbook begins to address that problem by providing you with a single concise reference containing the technical and practical details of building a concrete panel home.

It has been written to support both the less familiar with this form of construction, as well as those concerned with the design, detailing and construction of concrete panel homes.

Chapters 1 through 4 discuss the suitability of building a home with concrete panels, and the possibilities it affords. Chapters 5 through 10 discuss in more detail the issues involved in designing, detailing and constructing a concrete panel home.

1.1 What Is a Concrete Panel Home?

A *concrete home* is, of course, a house built of concrete. Though it may be built entirely of concrete, it is still a concrete home as long as it consists predominantly of concrete.

There are various kinds of concrete homes, but the focus of this handbook is the *Concrete Panel Home* (or "CPH"). The CPH is distinguished from other types of concrete homes by the fact that its external (and sometimes internal) walls are constructed from solid (and/or insulated) concrete panels.

A CPH usually consists of a concrete-based footing system, external concrete panel walls, and slab-on-ground. Suspended floors can either be concrete (in-situ or precast) or conventional timber. Internal walls are normally lightweight conventional studwork, and roofing is standard timber truss.

Australian Standard AS 3850 defines a "concrete panel home" or "concrete panel construction" as "flat concrete panels frequently cast in a horizontal position, (which are) lifted by rotation about one edge until in a vertical or near-vertical position, (and) which may then be lifted into position". These wall panels may be cast either on-site or offsite (under factory conditions).

2 SUITABILITY OF CONCRETE PANEL CONSTRUCTION

2.1 Assessing Suitability

Before planning to use concrete panel construction in any building project, the first task must be to assess the suitability of this type of construction, and whether there are any advantages or inconveniences compared to other building systems.

Most house designs are suited to concrete panel construction. Houses that have an orthogonal floor plan are ideal, as they provide a degree of regularity and repetition–grid plan, spans, panel sizes, and so on. This kind of standardisation and repetition in the design of the house means more efficient and economical construction.

Irregular floor plans are often also suited to concrete panel construction, though costs may be greater than with regular floor plans.

In all cases, costs can be kept to a minimum if the floor plan and wall layouts are made as regular as possible *from the start*.

2.2 Advantages and Limitations

2.2.1 Appearance and Finishes

Concrete comes in more than just "grey and flat" these days. The panels that make up a concrete panel home can have a wide range of quality finishes applied to them, either while they're being manufactured or after they've been erected.

The ability to alter the shapes of the panels, or the layouts of the walls, gives the designer of a concrete panel home a great deal of freedom. Also, the choice of colours and textures for the wall panels, and the possibility of using them in combinations, means the designer is afforded a considerable range of expression.

2.2.2 Physical Properties

Some of the value-added benefits of concrete panel construction are provided by the properties of concrete itself:

- **Thermally Insulating** – Concrete absorbs and releases heat slowly, so it tends to remain cool in the day and warm at night. This can lead to substantial savings in heating and cooling costs.
- **Acoustically Insulating** – Concrete is solid and rigid, so noise does not move easily through the walls and floors of a concrete panel home.
- **Structurally Strong** – Concrete is naturally strong, so concrete wall panels can easily be designed to support vertical loads (such as suspended floors, roofs, stairs, balconies, and so on). That means fewer support frames are necessary in the building's framework. Concrete wall panels can also be designed to withstand lateral loads, and so they can be used as retaining walls or in basement walls. They can even be designed to withstand expected loads from cyclones and earthquakes. The solid walls can also provide a high level of security from vandalism or "break-ins".
- **Fire-Resistant** – The Building Code of Australia (BCA) may require certain areas of a home to be "fire rated". Concrete wall panels can easily be designed to meet these requirements without the need for any of the additional fireproofing and insulating materials that would be necessary in lightweight building systems.
- **Termite-Resistant** – Concrete is resistant to termite attack, termites do not "eat" concrete. If designed and detailed properly, concrete can do an excellent job of preventing termites from entering a home.

2.2.3 Building Services

Concrete panel construction leads to certain advantages in the installation of building services, but there are also some concerns that need to be addressed.

A major advantage with concrete wall panels is that the various building services can easily be catered for by casting holes, recesses and various fixings into the panels.

A major difference, though, between concrete panel construction and other building methods is that *everything that needs to be cast into or blocked out of the panels must be planned ahead of time*. Architects, designers and builders must be ready to define their requirements in time for the panel detailer to prepare the panel drawings. That means the final study of the building's services must be completed much earlier than usual. (This is usually an advantage, though, as it means fewer surprises later.)

2.2.4 Speed of Construction

Speed of construction is an important consideration in most house-building, and in this area concrete panel construction excels. The speed is achieved by fast erection and manufacture of the walling elements.

Precast concrete elements, like wall panels and suspended floors, can be produced away from the building site somewhere else (either in a manufacturing plant, or on-site but away from the actual construction area), to allow footing work to be completed at the same time as the panels are being made.

The building goes up more quickly, so areas of it become available to tradespeople sooner, who can do their work as other areas are being prepared for them. In the end, the home can be completed weeks earlier than with other construction methods.

2.2.5 Reduction in Site Congestion and a Cleaner Site

As the wall panels are produced away from the building site and moved into position only as required, there are fewer tradespeople on the site. Reduced site congestion means reduced amounts of materials and waste, so the site stays cleaner than with other building methods.

In many situations the building site will only require a minimal number of workers on site to prepare the site (ie. casting footings, slab-on-ground, etc) for the installation of the concrete wall panels (and other structural components such as suspended floors, roof trusses, etc). It maybe mistaken that there may not be much happening on site, and then suddenly when the erection of the concrete wall panels commences, that the whole house structure is standing on site within a few days.

2.2.6 Tolerances

As with most other building materials, building with prefabricated concrete wall panels means that allowance must be made for tolerances between the specified and actual sizes of the components (and therefore of the final "as-built" building).

Concrete wall panels are usually manufactured within relatively tight tolerances, but designers should ensure they are being realistic about what tolerances are possible. It is essential to consider this issue from the start, and to discuss tolerances with the panel manufacturer as early as possible.

2.2.7 Transport and Site Erection

Transport is usually a consideration only when the concrete wall panels are manufactured away from the actual building site, in a factory. In that case, they are usually transported to the site on trucks or semi-trailers.

Concrete wall panels are usually erected using a mobile crane. The concrete wall panels are lifted from the transport trailers or casting bed and moved directly into their final positions.

Just how efficient this process is, though, will depend on how accessible the site is to the crane. The crane must position itself between where the panels are and where they need to go. The better the access the crane has to this point, the smaller the crane that will be required, and the more cost-effective the process will be.

Accessibility of the site and the size of the crane could limit the maximum weight of the panels.

3 GENERAL DESIGN CONSIDERATIONS

Homes should be designed to maximise aesthetic and functional areas of the home. Consultation with an architect or building designer will ensure that a good building design is behind your concrete panel home; this handbook does not replace the expert advice of such professionals.

But there are several design issues you should consider ahead of time. This chapter discusses those issues.

3.1 Planning

The most crucial part of constructing a successful and economical concrete panel home is the initial planning. It should begin as early as possible, and should address issues such as (but not limited to):

- The teamwork between the client, builder, designers, engineers and panel manufacturers.
- The type of concrete panel walling that is most suitable for the house design and the site conditions.
- The panel layout and design, and related construction issues.
- The detailing of joints, services, and so on.
- The installation of the wall panels.

The main consideration is always to keep things as simple as possible.

For a more detailed discussion of these issues, refer to Chapter 10, "Construction".

3.2 Energy Efficiency

A concrete home is cooler in summer (reducing the need for expensive air-conditioning) and warmer in winter (reducing the need for heating). The insulating properties of concrete, together with the principles of *Passive Solar Design*, offer the designer a unique opportunity to deliver a comfortable home, day and night, using a natural material.

Floors, walls, windows and roofing can serve together as a passive solar energy system designed to enhance the thermal properties of the solid materials of concrete. The fabric of the building can be used to collect, store, release and distribute solar energy to heat or cool the rooms. Solid walls and floors in particular help condition the internal environment.

3.2.1 Flooring

A concrete slab-on-ground exploits the thermal storage capacity of the solid walls by linking them with the earth's near-constant temperature. As a result, the whole structure reacts slowly to outside temperature fluctuations, helping it stay cool in summer and warm in winter. In cold climates, ducted heating elements can be embedded directly in the slab. Meanwhile, the slab itself can be finished as a polished concrete floor, or in any of a number of other decorative ways.

In very cold climates, the edge of the slab can be insulated to protect it from large temperature fluctuations. A low earth berm can even be built against the external walls (up to window sill height) for added insulation, using the walling as a simple retaining system. (The insulating properties of this kind of semi-underground construction are well appreciated in climates more severe than Australia's.)

Concrete suspended flooring may provide many of the same benefits over lightweight options by virtue of its substantial thermal storage capacity. Many precast concrete suspended flooring systems are structurally stronger, have better fire-ratings, provide a better barrier to noise, and can offer speed of construction.

3.2.2 Walling

Though the substantial thermal mass of solid concrete walls means they store heat well and transfer it slowly, their insulating ability is fairly poor. Some form of insulation, particularly in colder climates, is is strongly recommended to ensure that the benefits of the walls' thermal mass are realised.

Ideally, the insulation should be placed on the outside of the building and the thermal mass retained on the inside. Insulated concrete panels (or 'sandwich panels') offer a solution; they consist of a polystyrene core 'sandwiched' between two concrete panels and bound together with non-metallic ties during casting. Construction with these panels is no more difficult than with standard solid concrete panels, but offers significantly better insulation, both thermal and acoustic. (Concrete sandwich panels are described in more detail in Chapter 5, "Walling".)

Consider using concrete panels for internal walling (where practical), as constructing internal walls of concrete can add substantially to the thermal mass (and therefore the energy-efficiency) of the entire building.

3.2.3 Roofing

For all concrete panel homes, it's most important that the roof be fully insulated so as to optimise the climate in the home while minimising energy use. Double-sided reflective foil is particularly useful for this purpose.

3.2.4 Passive Solar Design Basics

Buildings designed to use solar energy should be planned with their rooms oriented to capture the sun. In temperate climates, buildings that are longest along the east/west axis are more efficient for winter heating and summer cooling, because they have maximum exposure to the north, but minimum exposure to morning and afternoon sun. Of course, buildings of all shapes can be designed so that the windows (and even the shapes of the buildings) exploit sunlight and shade effectively. Putting rooflight or clerestory windows into buildings of two or more storeys is an example of such a strategy.

Once the location, orientation and shape of the building is decided, the interior spaces are the next to be organised. Living spaces (the ones most occupied) should be placed on the north face of the building. Least-occupied spaces, such as garages and storage rooms, should be located along the southern wall to act as a buffer between the living spaces and cooler southern side of the house. Rooms which can benefit from morning sunlight (such as bedrooms, bathrooms and kitchens) should be along the east wall.

Windows provide light and ventilation, but also act as solar energy collectors for the home. The windows for each wall, though, need different treatments:

- Along the north wall, which gets most sun, maximise the amount of glazing, and ensure that the sunlight shines through the windows onto as much exposed concrete as possible.
- The south wall receives little useful solar exposure in temperate Australia, so include only those windows that will be needed for cross-ventilation in the summer.
- Along the east wall, include only a few windows to admit the morning sun.
- To close out the oppressive heat of the late afternoon sun, put no windows in the west wall-or, if you must include them, make them as small as possible. Making them narrow (or even slot-like) will help, as will recessing them so that they provide their own shading.

Doors should also be located carefully, as front and rear doors in small structures such as houses can admit (or release) a great deal of heat. Airflow between the door and its frame should be minimised; recessing the doors, or protecting them from prevailing winds, will help. A protective and insulating vestibule offers another solution.

These are only a few of the improvements in energy-efficiency that can easily be built into a concrete panel home if a little consideration is given to them early in the design.

3.3 Benefits of Two or More Storeys

Concrete panel homes offer significant cost to floor space ratio improvements as the house structure moves from one storey to two or more storeys. All the walls are load-bearing walls, capable to carry suspended floors simply and inexpensive. Concrete floors are commonly preferred by the commercial sector for their cost-efficiency, strength, and serviceability, and can bring these same benefits to housing.

A home with two or more storeys is not just more cost-efficient, though. The extra floor area affords the designer much more freedom in developing the internal spaces. A variety of different floor levels can be created with little trouble, because of the load-bearing capacity of the concrete walls. High-ceilinged rooms, for example, can include multi-level loft spaces to accommodate additional living areas. As concrete floors are typically half the thickness of timber floors, building height can be reduced, lowering the cost of the walls-or enabling you to put the savings into increased floor area.

Prestressed concrete flooring excels at carrying heavy loads over long spans, so the floor can carry the load from stairs, third storeys, roof support columns, and even spa baths, without the need for supporting walls and columns. Such features as cantilevered balconies are easy to include in the design.

Prestressed concrete floors are an ideal substrate for slate, stone or timber finishes, as concrete floors are not subject to the movement and vibration that affects other types of floors. No special treatment is required for wet areas or under fireplaces. The floors can be coloured, topped and even polished for different decorative effects.

3.4 Repeatability and Modularisation

A concrete panel home that incorporates *repeatability* in the design of its panels will be much more cost-effective to build than one that doesn't. This is not to say that all panels should be identical, but that designing them with consistent and repeatable elements (such as height and width, size of window openings, spacing of joints, and so on) will lead to considerable cost savings. If these repeatable elements are used creatively, they can help unify the design of the house, or even become a feature of it.

Often the savings that are gained from panel repeatability for the majority of the house will deliver freedom to include one or two unique feature panels within the structure.

For the same reasons, the possibility of *modularising* areas should be explored. Modular rooms or spaces can be used to link other spaces or to expand areas. A modular design also makes it simpler to add onto the house later if the need arises.

3.5 Site Analysis

Before building a concrete panel home (or any other type of home), you should have the building site analysed to determine what must be done to prepare the site for the construction.

Preparation should not begin until the site has been analysed with respect to:

- Access requirements.
- Slope (or fall) of the site.
- Earthwork and site drainage .

These analyses should be performed by experienced and qualified personnel (such as the builder, designers, panel manufacturers, erectors, and so on).

3.5.1 Access

Construction processes that typically cause higher site congestion (and therefore greater access problems) are:

- Earthworks.
- Concrete placements (footings, floor slabs, on-site panel casting).
- Cranage and erection of panels.
- Roof installation.
- Services fitouts and finishing trades.

It is important to plan each of these processes so as to make full and efficient use of the site, particularly when two or more of the processes are occurring at the same time.

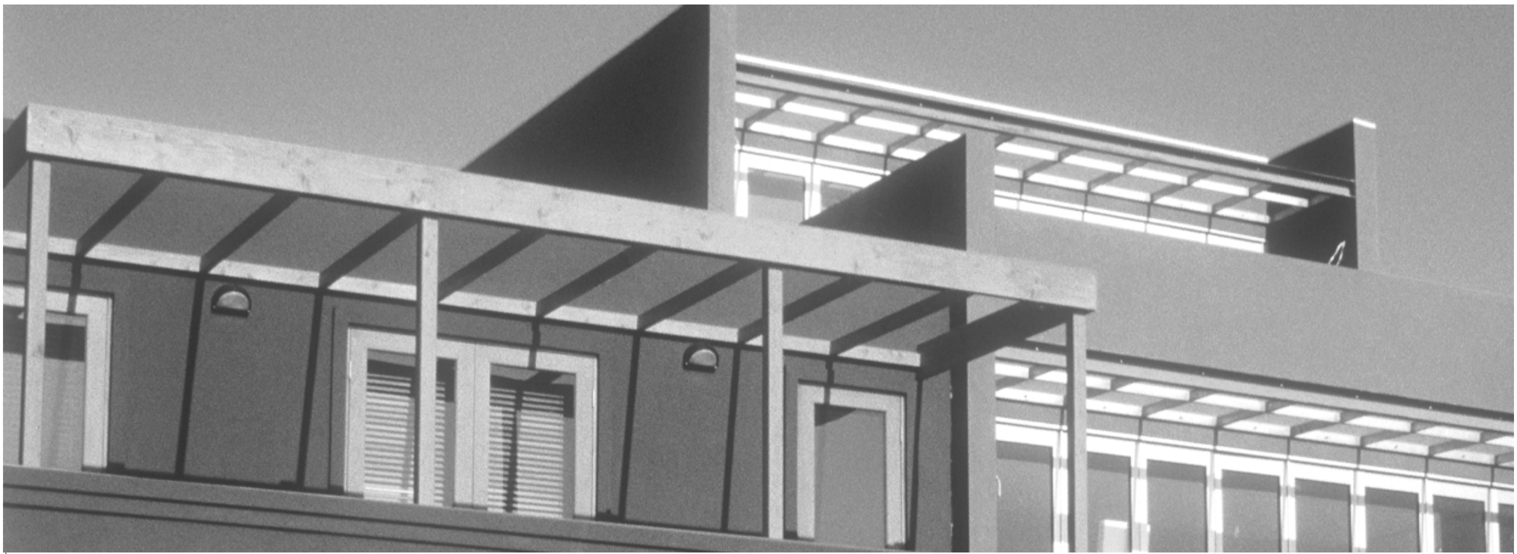
Keep in mind that it may not be necessary for the whole site to be accessible all the time.

3.5.1.1 Access for Heavy Equipment and Vehicles

The main access concerns will normally occur during concrete placement and panel erection processes. This will normally be due to performance schedules being tight at the same time that heavy equipment and vehicles are required, so this is where the main problems with access usually occur.

If on-site space is inadequate, it may be possible to use adjacent space, such as roads, footpaths, or properties, but permission to do this must be sought from the relevant authority (local councils, police, or other traffic authority) or the owner of the property. If the work might disrupt traffic or close roads, early application for traffic disruption permits may be required. In any event, advance notice of traffic disruption is not only good practice but good public relations. Every effort should be made to minimise the inconvenience to the public.

These issues are discussed further in Chapter 10, "Construction".



3.5.2 Slope

Most housing allotments have a certain amount of slope or fall running through them, and so require some earthwork to level the site. Sometimes, it's possible to level (or cut away) the entire site-but the steeper the site's fall, the more economical it becomes to cut away only a portion of the site, and use the debris to fill the remainder.

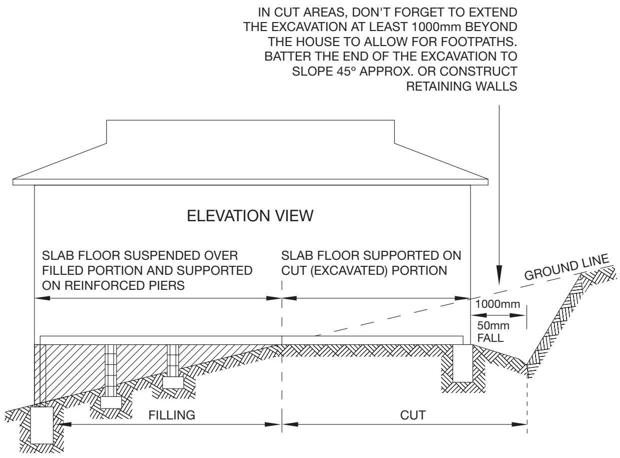


Figure 3.1 Slab-On-Ground (Cut and Fill Site)

3.5.3 Earthworks and Site Drainage

As with any housing project, before any earthworks or construction can begin, the site must be cleared and cleaned of surface vegetation, roots, rubbish and topsoil. (This material is not usually suitable for under-house fill and should be removed from the site.) Only then should the house plan be sited on the allotment.

All large trees and shrubs should be removed, including their taproots. (It is particularly important that all roots be removed, as they can provide a home for termites later.)

All earthworks should be constructed in accordance with the requirements detailed in the appropriate geotechnical reports or surveys. If cut-and-fill is required to level the area, make sure that the batters provide for adequate site drainage.

3.6 Lifting and Erection of Wall Panels

There are two main methods of lifting concrete wall panels: *Edge Lifting* and *Face Lifting*. Very large panels require face-lifting (in which the panel hangs up to 10 degrees off vertical), but edge lifting is usually the preferred method for smaller wall panels. The advantage of edge lifting is that it allows the panel to hang vertically, enabling it to be easily manoeuvred and lowered into place. With edge-lifting, too, the lifting inserts on the panel reveals can be concealed between adjoining panels, within the joint, roof cavity, or capping.

With either method, it will take between 15 and 45 minutes to lift and position each panel, depending on the size of the panels and the difficulty of access.

3.7 Cost Advantages

Using concrete panel walling to build residential housing can greatly increase cost-effectiveness by:

- Maximising the speed of construction.
- Minimising the on-site work.
- Affording the designer freedom and flexibility.
- Enabling the designer to put the strength, durability and insulating properties of concrete to good use.

For a more detailed discussion of the issues discussed in this chapter, refer to Chapter 10, "Construction".

4 STRUCTURAL SHELL

A concrete panel home is not only as comfortable as other types of homes, it's stronger and more solid. Each of its components- the footings, the ground floor slab, the concrete panel walls, the suspended floors, and the roof framework-work together to support and brace each other, forming a solid structural shell.

4.1 Structural Components

4.1.1 Footings

For concrete panel homes, the footings are critical to the long-term performance of the structural shell. The footings support the ground floor slab, as well as the wall panels, which in turn support other floors and the roof, so the footings are responsible for distributing the entire load of the structure onto the surrounding foundations.

Footings can consist of waffle rafts to isolated pads, or continuous strip footings, with the latter two being particularly common. The footing type, though, should be determined by the consultant engineer, after careful consideration of the surrounding soil, the foundation conditions, and the topography of the site.

A variety of designs for footing systems can be found in Section 3 of the Australian Standard, AS 2870 – Residential Slabs and Footings – Construction. Whichever footing system is chosen, it is essential that it be designed and constructed in accordance with AS 2870 and/or AS 3600 – Concrete Structures, and that it satisfy the requirements set out by the Building Code of Australia (BCA).

Further information and details can be found in the C&CAA publication, *"Residential Floors"*.

4.1.2 Ground Slab

The usual ground floor slab for a concrete panel home is a slab-on-ground that will complement the structural, thermal and acoustic properties of the concrete walls. Concrete floor slabs are now very common in Australian homes.

Choosing a concrete floor slab (slab-on-ground) has some major advantages:

- Concrete floors are economical, and can be designed and constructed in a number of ways. All the necessary information for their design and construction on most sites is covered by AS 2870.
- Concrete floors are strong and durable. They are a solid platform upon which the rest of the house can be built safely (and quickly, especially when the wall panels are cast on-site). Accurate construction of a concrete slab-on-ground is essential, not only for proper support of the wall panels, but for the manufacture of them as well (as they can be cast on the floor slab).
- Concrete floors are quiet: their rigidity and solidity limits transmission of sound through the floor.
- Concrete floors are energy-efficient, because of their thermal mass. The temperature of the ground underneath a concrete slab remains almost constant through the year, day and night, which means smaller heating and cooling bills.

A concrete slab-on-ground combined with a suitable footing system will provide a stable support for the building above it, so that if moisture variation in the soil causes the ground under footings to move, the effects will be minimal.

As with the footings, the ground slab must satisfy the requirements of the BCA and relevant Australian Standards, AS 2780 and/or AS 3600.

Further information and details can be found in the C&CAA publication, *"Residential Floors"*.

4.1.3 Walling – Load Bearing / Non-Load Bearing

One of the greatest advantages that concrete panel walling has over many other walling systems is its ability to be load bearing. A single-leaf concrete panel wall can be designed to support suspended floors, stairs, balconies, roofs, and so forth, reducing the need for other supporting framework to do the job. The costs of these additional materials is saved, and the reduction in the number of required columns and beams will provide larger clear spans of living spaces in the home.

The load-bearing capacity of concrete also means that upper stories need not be constructed of lightweight materials. Stronger, solid concrete suspended floors can be borne by concrete panel walls. Concrete stairs and balconies can be included in upper storeys, loads that lightweight walling systems could not accommodate.

No matter the type of panels you use, you should design to exploit their load-bearing capacity to the fullest. Consult with a panel design engineer to discover how best to do this for the home you are building.

4.1.4 Suspended Floors

Suspended floors can be supported directly on the concrete walls, as long as the wall panels have been designed to accommodate the load. The walls can support lightweight timber-framed suspended floors, or stronger, more solid concrete suspended floors, such as:

- In-situ concrete floors (conventional reinforcement, prestressed, and post-tensioned).
- Precast concrete floors (permanent formwork, autoclaved aerated concrete panels, and hollowcore panels).

Suspended concrete floors have advantages over lightweight floor systems in that they provide:

- Wider clear spans from wall to wall, requiring fewer columns and wall supports, and creating larger living spaces under the floor.
- Solid, more rigid floors, reducing 'bounce' and 'flex', and giving the floors better thermal and acoustic properties.
- Higher load-bearing capacities for supporting solid walls on upper storeys, enabling people on those floors to benefit from the thermal and acoustic properties of concrete.
- A stronger structure overall, as the suspended floor structurally ties the house together and stabilises it, providing a diaphragm action within the whole house structure.

Your consultant engineer can determine the most appropriate floor system for your individual design.

Further information on suspended concrete floors can be found in the C&CAA publication *"Guide to Suspended Concrete Floors for Houses"*.

Details on typical support connections can be found in Chapter 6, "Connections".

4.1.5 Stairs and Balconies

Stairs and balconies can easily be supported by concrete floors or walls. Stairs and balconies can be made from lightweight materials (such as timber or steel), but they can be made of concrete as well. Your consultant engineer can design a concrete stair or balcony to maintain the structural adequacy of the structural shell with the inclusion of such concrete stair and balcony units.

There are two methods for constructing concrete stairs and balconies:

In-situ Concrete – Traditional formwork moulds are set and conventionally reinforced, and the concrete is poured. Various shapes and sizes can be created. Stairs can be straight and square, or in a tight spiral. Balconies can be rectangular or curved. The floor or wall panels usually contain cast-in ferrules to act as couplers to starter bars into the stair or balcony.

Precast Concrete – A precast concrete stair or balcony is manufactured off-site (in a factory) and then transported to the site when required for installation. The process for designing, detailing, manufacturing and installing a precast stair or balcony is similar to that for a cast off-site concrete wall panel. As with an in-situ concrete stair or balcony, various shapes and sizes are possible. Connections between the stair or balcony can consist of support angles that bolt into cast-in ferrules in the wall panel, or in the stair or balcony. Starter bars can be cast into stair or balcony, as well as into the concrete floor slab. Precast stairs can have core holes at the upper and lower edges, so that dowel bars can be used to place the stair and once grouted into position they can then be used for access to upper levels during construction.

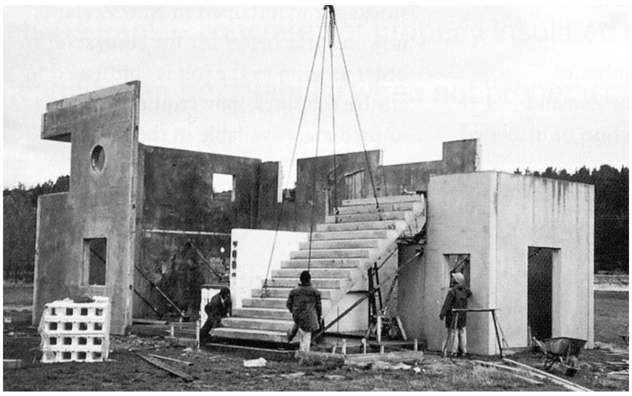


Figure 4.1 Installation of a Flight of Precast Concrete Stairs. (Image supplied by Mikael Carlstrom, Composite Systems Pty Ltd.)

4.1.6 Roof Frame

Like other types of houses, concrete panel homes can accommodate standard roof construction. In most situations, prefabricated roof trusses can be used to minimise costs.

Construction and installation of the roof framework is basically the same as in conventional double brick or masonry housing, where the roof framework is directly supported by the external walls. However, there are some differences in the connections, in that the roof trusses can be bolted directly to the tops of the wall panels with cast-in ferrules, reducing installation times. (You will need to plan the truss positions ahead of time to ensure that the ferrules are cast into the right places in the right panels.)

Alternatively, it may be possible to use mechanical drill-in anchors later on. This method involves much less planning and effort-but the use of it **must be approved** by your consultant engineer ahead of time, as in some instances this may not be suitable due to minimum edge distances and pull out capacities of the anchors.

Discuss these issues with your builder, panel supplier, roof supplier and consultant engineer to determine the most appropriate method.

Details on typical panel-to-roof connections can be found in Chapter 6, “Connections”.

4.2 Types of Concrete Panel Structures

Concrete panel homes can be single-storey or multi-storey. Either type can be fully detached or semi-detached (with common party walls).

4.2.1 Single-Storey Structures

A single-storey concrete panel home typically consists of:

- A **concrete footing system** consisting of a ‘strip’ or ‘pad’ footing. The footing system provides a solid, level foundation for the rest of the house. The pad footing system is usually the most economical, especially if the site has a steep fall running through it. Pad footings are normally located at the ends of the wall panels.
- **Concrete wall panels**, which are supported on the footings and provide the structural framework for the rest of the house. The wall panels are usually designed to run from floor to roof, and are braced against each other (or against the roof framing) so as to resist lateral wind loads. The bottoms of the wall panels are usually fixed either to the footings or to the ground slab, depending on the design. The tops of the panels are usually attached to each other with steel plates or brackets to form a rigid wall framework and provide “diaphragm action” with the whole house structure.
- A **ground floor system** of the type used in any single-brick veneer or full brick home. For level sites, or ones with a small slope, the ground floor system can be ideally a concrete slab-on-ground that is poured after the installation of the wall panels. The floor can be tied back to the wall panels with dowel bars, and can then serve as a termite barrier. Alternatively, the floor slab can be poured integrally with the footings before to the wall panels are installed. If a suspended ground floor is required (whether concrete or timber), it can be accommodated, and the edge of the floor can then be restrained back to the concrete wall panels.
- A **roofing system**, typically consisting of standard timber roof trusses. The roof trusses are usually fixed directly to the tops of the wall panels, as the panels have the capacity to carry the roof loads directly down the walls to the footings. The roofing frame can also be designed to further restrain the top of the wall panels.

4.2.2 Multi-Storey Structures

A multi-storey concrete panel home (which, in the context of this handbook will typically mean a home with two or three storeys) is configured in the same way as a single-storey home, but with the addition of suspended floors (and with the possibility of wall panels that bear on top of other wall panels).

- **Suspended floors** are typically also of concrete (precast or in-situ), but they can be of timber. The floor is supported by the wall panels, and either bears directly on them, or (more often) is supported on a timber ring beam or steel shelf angle fixed to the inside face of the external panels. The suspended floor is usually installed after the ground floor wall panels.

5 WALLING

Various concrete panel walling systems can be used to build a concrete home. This handbook discusses the two most common ones:

- Cast Off-site Concrete Panel Walling (commonly referred to as precast wall panels).
- Cast On-site Concrete Panel Walling (commonly referred to as tilt-up wall panels).

It also discusses a common variant of the two:

- Concrete Sandwich Panel Walling (which can be manufactured either on- or off-site).

5.1 Cast Off-Site Concrete Panel Walling

Cast off-site concrete panel walling is a form of construction that is quick and affords the benefits of solid concrete walls at a competitive price.

In this method, the solid concrete panels are cast in moulds on a level surface (usually a smooth steel base) in quality-controlled factories away from the building site. The panels are then left to cure to the appropriate level of strength. Once cured, they are stripped from the moulds, lifted into storage areas, and transported to the site only when they're needed.

The concrete panels are installed with a mobile crane, which lifts the panels from the transport trailers directly into their final positions. The panels can be temporarily braced until a sufficient number are installed to form a self-supporting braced structure.

Panel thicknesses usually range from 150 mm to 250 mm.

5.2 Cast On-Site Concrete Panel Walling

Cast on-site concrete panel walling is also a quick and cost-effective method of construction. In this method, the solid concrete panels are cast within the formwork on a suitable level surface at the building site (often another panel). After curing, the moulds are removed, and a mobile crane is used to lift, tilt and move the panels directly into their final positions. The panels can be temporarily braced until a sufficient number are installed to form a self-supporting braced structure.

Panel thicknesses usually range from 150 mm to 250 mm.

Though this method involves more site congestion than cast off-site walling, it also requires less equipment and expertise. Because the panels are always at or near ground level, traditional techniques for finishing pavement work can be used. It requires only simple formwork, the panel reinforcement can be basic. Panels can be cast on top of one another ("stack-cast") to economise on space, and to use panel surfaces as casting beds for other panels.

5.3 Concrete Sandwich Panel Walling

Concrete sandwich panel walling is a variation of on-site and off-site cast concrete panel walling. In this method, an insulation layer is "sandwiched" between two layers of concrete veneer. Concrete sandwich panel walling has all the advantages of on- and off-site cast walling, but is even more thermally efficient as it combines a high level of thermal insulation capacity with high thermal mass of the concrete.

Panels generally range from 180 mm to 280 mm in thickness.

Concrete sandwich panels are manufactured and installed in the much same way as on- and off-site cast concrete wall panels, with a few differences:

- The panels are cast in two stages, not one:
  - The off-form or external face of the panel is cast first, then the insulation board is installed onto the off-form concrete layer. (The actual insulation material may vary depending on the particular proprietary sandwich panel system being used.)
  - A second concrete layer is then cast on top of the insulation board to enclose it and finish off the panel.
- The internal layer of concrete is load-bearing and provides the structural capacity of the panel, while the external layer is not load bearing.

There are proprietary sandwich panel systems available in Australia.

As with all concrete walling systems, an optimum result will depend on thorough planning and practical design. Don't hesitate to consult with architects, designers, engineers and recognised concrete panel manufacturers, who can advise you on the particular needs of your project.

5.4 Internal Walling

5.4.1 Studwork Walling

Studwork walls are a typical internal walling system in concrete panel homes, and can be constructed out of either steel or timber framing. These walls must be designed according to the Timber Framing Manual (for timber stud walls) or the specifications of the steel-stud manufacturer (for steel framed walls), as well as in accordance with the Building Code of Australia. Studwork walls can be either constructed on site, or prefabricated in a factory. Construction methods are the same as for brick-veneer or other clad homes.

Concrete nails or masonry anchors can be used to connect studwork walls to concrete panel walls and to the floor slab. Shear walls must be anchored with "hold-down masonry anchors", as detailed in the relevant codes.

Internal stud walls have a number of advantages:

- They can be constructed using standard trades.
- They are easy to pass services through.
- They can be altered later (if necessary) with less effort.
- They are fast and cost-effective to build.
- Their lightweight components make installing them easier.

5.4.2 Concrete Block Masonry Walling

Concrete blocks can be used to construct internal walls, whether they be shear walls, non load-bearing, or structural. These walls must be designed and constructed according to the CMAA Masonry Design Manual, as well as the Building Code of Australia. For masonry wall to concrete panel wall connection details, it is common to use brick ties (as per the manufacturer's and the code's specifications). The use of concrete blocks for internal walls offers the following advantages:

- More solid construction
- Lower maintenance
- Quieter rooms

5.4.3 Concrete Panel Walling

Using concrete panels for internal walls has a number of advantages over other building materials:

- Faster construction
- More solid construction
- Lower maintenance
- Quieter rooms

For details on fixing internal walls to base footings, refer to Figures 6.5 & 6.6. For details on connecting internal wall panels to external walls, refer to Figures 6.9, 6.10 & 6.11.

5.5 Service Detailing

There are two groups of services to take into account when planning a concrete panel home: plumbing, electrical/ communications and air-conditioning/HVAC.The reticulation of the services can become difficult if insufficient consideration and planning is not undertaken during the early stages of planning.

In conventional lightweight walling systems, services can be treated almost as an afterthought, as they are usually installed in the wall cavities of the timber stud-work frames. Large openings for air-conditioning ducts can simply be cut out of a wall once it's up. Bricks can be 'punched-out' to accommodate an air-conditioning unit. These methods are possible because the wall structure is non-load bearing, and not a solid shell as in concrete panel homes.

Services can be accommodated in a concrete panel home, but they must be planned for from the early stages.

5.5.1 Plumbing, Electrical and Communication Services

Services should be planned in the early stages of the design, before the concrete panels are cast. Plumbing, electrical and communication services can be hidden within the wall without taking up much space.

If possible, plan the positions of these services when you plan and detail the concrete wall panels, so that blockouts and recesses can be formed into them as they are cast. Polystyrene blocks can be used to recess the face of the panels, or to create openings or conduits can be cast in the panel for the services to pass through. This method is relatively cost-effective, and will result in a level finish on the face of the panel onto which the internal wall-lining material can be directly fixed or battened onto the panel.

Often, though, it's impractical to plan and detail the plumbing services to such a degree so early. In that case:

- You can decide to fix the services directly onto the face of the panels, which requires little planning until installation itself. This method is similar to what is usually done with a masonry or brick wall. Pipes can be concealed in the cavity formed by a battened fixed internal wall lining. This cavity can be insulated to make the installation more energy-efficient.
- As long as only a few services are required in a particular panel, you can chase out the face of the panel and install the services in the cavity, leaving the surface flush. This method can be expensive and time-consuming, and should only be used if there is no other option. Typically, a diamond-impregnated saw blade is used to make cuts along the recess area, leaving thin blades of concrete to be chiselled out (though it can be very difficult to chase out a panel near its edges or internal corners, because of the difficulty of getting a saw cutter into those areas). Such chasing should not exceed 30 mm in depth and width. Discuss any plans for chasing out recesses with your designer or consultant engineer, to ensure that they do not compromise cover and exposure criteria.
- You can accommodate electrical or communications wiring behind the skirting boards or doorway architraves. (This may require larger sections, so that a recess can be provided behind the skirting board or architrave to contain the services, with switches and outlets fixed directly onto them). This results in the wall panels not requiring any additional work performed on them.

5.5.1.1 Australian Standard AS 3600

Australian Standard AS 3600 (Sections 5.11 and 5.12) describes recesses and chases for services within a wall, and their effect on the fire-resistance periods for structural adequacy, integrity and insulation.

5.5.2 Air Conditioning / HVAC

Ducted heating and cooling can be placed either internally (in the ceiling or roof space) or externally (adjacent to the wall panel). Large openings in the panels may be required for the ducting. It is best to decide the locations of the duct openings before the panels are manufactured, so that the openings can be cast into the panels. Although you can saw-cut or core drill openings through the panels later.

If you do decide to drill openings later, you can use a diamond-impregnated core bit to create core holes with diameters of up to 300 mm. Although any cutting or coring will normally be relatively expensive.

Make sure the designer or consultant engineer approves your plans before you cut or core any panel.

5.6 Opening Details (Windows and Door Openings)

Openings for windows and doors in concrete panel walls can be simply detailed to accommodate either timber or aluminium frames. The edge detail around the panel opening is similar to that used with cavity brick or block walls. It is often easier to install window and door frames into concrete wall panels than into other conventional walling systems, because the panels provide a uniform, solid structure onto which to fasten the frame.

Once the openings are detailed to provide the required edge profiles for the heads, jambs and sills, the frames are made to measure, either from the panel shop drawings or from on-site measurements of each of the openings. Alternatively, standard prefabricated window and door frames can be specified, and the panel openings sized to accommodate these frames. There is a wide variety of prefabricated window and door frames to choose from; your supplier can help you make an appropriate choice.

The remainder of this section discusses the usual processes involved in detailing the surrounds of openings meant for aluminium or timber-framed windows and doors. (Individual frame types and their particular installation processes should be discussed with the frame supplier and installer).

5.6.1 General Considerations for Openings

Detailing window or door openings begins with determining their size and location. It's best if an opening is located entirely within a single wall panel; otherwise, small differential movements between panels can later cause weatherproofing problems in nearby joints. Keeping the openings within single panels also enables the openings to be made with greater accuracy.

Whether you plan on using aluminium or timber frames, the principles for detailing openings in the wall panels (including the reveal profiles for the sills, jambs and headers) are essentially the same.

5.6.1.1 Opening Sizing

In determining size of the opening, take all of the following into consideration:

- The *size* of the external window frame.
  The *manufacturing tolerance* in producing the opening in the wall panel.
- The *method and type of installation*, which will determine the amount of clearance that needs to be added to the overall opening to enable the frame to be installed. Prefabricated frames are cheaper, but require greater clearances in the opening to enable installation. Made-to-fit frames provide a better fit, but require on-site measurements of the opening before the frame can be made. This is initially more expensive, but results in a better-fitting windows and doors, and therefore fewer problems with prefabricated frames not fitting openings.
- Whether *cast off-site panels will be used*, in which case it may be possible to install the frames into the wall panels while they are in storage in the factory, thereby reducing on-site construction time. Some types of door frames, such as press-metal frames, can actually serve as formwork as they're cast into the panel, saving the time and expense in fitting them afterwards. To do this, though, you will have to decide on the final locations of the openings from the start, as it will hardly be possible to move them later.

5.6.1.2 Reveal Profiles

Considerations for reveal profiles of the window and door openings:

- The void former or type of formwork used to block out the opening in the panel. The type of material and its level of finish will directly determine the finish of the opening's reveal surface. If the reveal surface of the opening is to be left as off-form, or coated only with a flat (low build) paint, imperfections on the reveal surface will be visible unless the forms are of good-quality ply or steel. Joints along the void former or formwork should be in line, not stepped. Ideally, the joints should be sealed to keep the concrete from leaking. If the reveal is to be finished with a high build coating, though, or lined with a material like tile or timber, it may be sufficient to use formwork with a rougher surface, and/or polystyrene void formers to block out openings. This will reduce costs, especially for openings that aren't repeated elsewhere.
- It is recommended that all surfaces of the reveals (except the sill) are perpendicular to the main surface of the panel, so that the opening can be formed easily, and so that there will be a square surface to attach the frame to. The sill profile should have a fall toward the external face of the panel to allow rain to drain away. Take care to design the formwork so that it can be stripped from the panel without damaging either the panel or the form. That usually means that the formwork must be collapsible (that is, able to be stripped from the panel in sections). Void-formers made of cheap materials (such as polystyrene) are dispensable; they can simply be destroyed during stripping if need be.
- Rebates can also be cast into the reveals of the openings. It is recommended that a *"drip groove"* be cast into the head of the window or door opening to catch rain water running back into the opening. A drip groove can easily be formed by a prefabricated timber or plastic fillet strip. The drip groove should be 10 to 15 mm deep, and should extend along the full length of the head reveal. Ideally, the groove should be located halfway between the external edge of the reveal and the external face of the frame, but at a minimum distance of 30 mm from the external edge of the reveal. Ideally the frame should be set back as far as possible from the external face of the panel so as to maximise protection from the weather.
- Always finish off the external and internal edges of the reveals with either a *"pencil-round"* detail (preferred for ease and simplicity) or a chamfer (bevel) detail. A square sharp edge is more likely to be chipped or damaged, and is therefore not recommended.

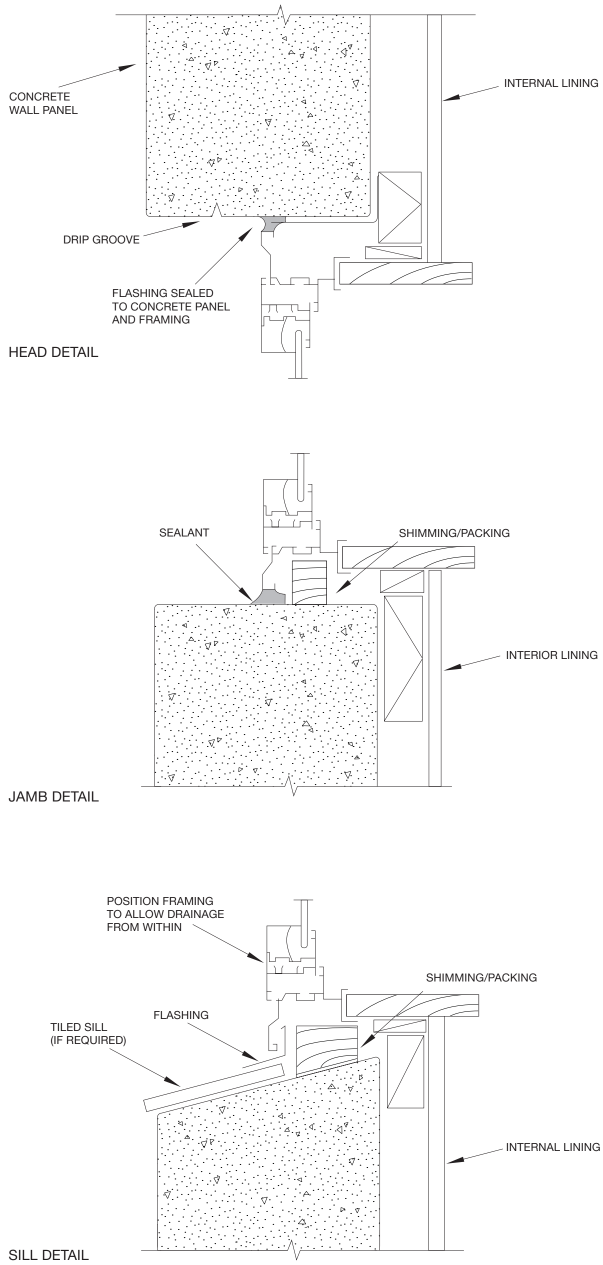
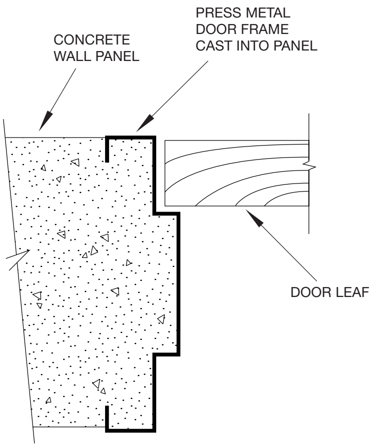


Figure 5.1 Typical Window Header, Jamb and Sill Details. (Based on Aluminium Window Details from C&CANZ, Residential Concrete Detailing and Specification Guide.)

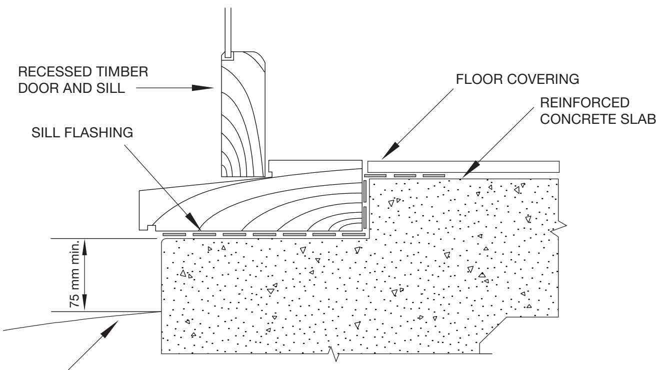
Installing a window or door frame into a concrete panel is similar to installing one into a brick or block-work wall. The frame is inserted into the opening and shimmed to level, then fastened directly to the concrete panel reveals. Proprietary flashing, seals and trims are installed and fastened onto the frame or panel reveals to complete the window or door arrangement. (Actual installation procedures vary, depending on the particular window supplier and installer.)

Avoid details that require frame-fixing inserts to be cast into the reveals of the panel opening. Cast-in fixings complicate the manufacture of the panel and raise the cost, and they are difficult to position accurately. Instead, whenever possible use connection details that require fixings to be drilled into the panel after it has been cast.

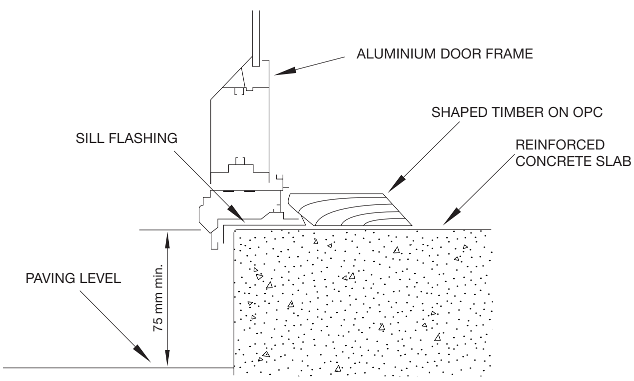


JAMB/HEADER DETAIL

(ALTERNATIVELY, TIMBER TRIMMING CAN BE USED IN LIEU OF PRESS-METAL FRAME).



SILL DETAIL



SILL DETAIL

Figure 5.2 Typical Door Header, Jamb and Sill Details. (Sill Details are based on Aluminium and Timber Door Sill Details from C&CANZ, Residential Concrete Detailing and Specification Guide.)

6 CONNECTIONS

The concrete wall panels that make up a concrete panel home must be stabilised and supported so that they can carry vertical loads and resist lateral loads. This stability and support is usually provided by the panel connections, and their associated fixings to other panels and to external supporting members (such as footings, ground slabs, or framing/bracing supports).

Connection types and their detailing should be chosen with economy in mind, but must be appropriate for its role in stabilising and supporting the concrete wall panels.

6.1 Design Considerations

Connections can be fixed by grouting dowels in core holes in the panels, bolted connection systems, welded connection systems, or a combination of these.

Welded connections systems are simpler to implement and have cleaner lines, but care must be taken to avoid locking up the joints and preventing further movement. Bolted systems are less likely to cause this problem, but are usually more complicated to implement, as tolerances must be allowed for when placing connection plates, brackets, bolt holes, and so on. They generally also occupy more space than welded connections.

The design and detailing of connections for a concrete panel home should ensure a good level of buildability, load capacity and ductility. When designing connections, take into account:

- In-service loads (such as dead, live, or wind loads).
- Construction loads (such as lifting or bracing loads).
- Thermal gradients (such as expansion and contraction of the panel, and the degree of bowing).
- Fire performance.
- Earthquake requirements.
- Complexity of the connection (Keeping the fixing as simple as possible will reduce costs.).

More than one level of fixing is normally required to stabilise a panel. Typically, a panel requires two load-bearing connections at the base, and two lateral restraining connections at the top-but these requirements may vary, depending on the panel's design, shape and size.

The dimensions of the panels, and of the structure itself, shall vary within a specified tolerance, so connections should be designed with this in mind. Connections should also allow the panel to flex or move in response to temperature fluctuations and applied loads.

Permanent steel connections, especially those that are exposed to the external environment, should be protected against corrosion. Any protective coating should be applied over the entire fixing, including those parts that are cast into the concrete. Examples of such coatings are:

- Hot-dipped galvanising.
- Priming and painting with an appropriate corrosion-protective paint system.
- Encasing the components in concrete to an appropriate cover.

Fixings may also require protection against fire. Whenever a wall panel must be fire-rated in accordance with the BCA, the supporting fixings of that panel must also be fire-rated to that level. This requirement is usually met by encasing the fixings in the panel. As per AS 3600, *a minimum cover of 20 mm is required to provide 60 minutes of fire resistance* (the normal fire resistance period for a class-1 residential home).

6.2 Types of Fixings

There are three main types of fixings used in concrete panel homes:

- Dowel and direct-bearing fixings
- Bolted fixings
- Welded fixings

6.2.1 Dowel and Direct Bearing Fixings

In these fixings, steel dowels restrain and stabilise the panel, which bears directly onto a footing, ground slab, or lower wall panel (if the fixing is on an upper storey).

This type of fixing is used at the base of a wall panel to quickly position it before final alignment and grouting. The panel initially bears on dense, compressible packers or shims (usually of dense plastic) to the correct levels. (Steel packers or shims should not be used, as they do not provide suitable compression capabilities, and may lead to future corrosion problems.) There should be only two bearing pads per panel, located at a minimum of 300 mm from either end of the panel. These pads will carry the panel's dead and live vertical loads until the bottom edge of the panel is grouted up (or "dry-packed") to provide uniform distribution of the loads down to the footings, ground slab or lower panels. (Refer to Figures 6.2, 6.4, 6.6, and 6.8 for details.)

6.2.2 Bolted Fixings

Bolted fixings usually consist of cast-in ferrule inserts in the panels, and steel fixing brackets or plates that can be bolted to the ferrules (or threaded dowel bars that can be attached to them). These fixings, depending on their particular design, can provide a panel with both lateral restraint and load-bearing (shear) capacity. They are usually the most flexible, easiest to install, and least costly of the three types of connections, but installing them effectively and efficiently requires good detailing. The main concern with this type of connection is accommodating tolerances for misalignment of the insert in the panel, the panel itself and the supporting structure. The overall encroachment of the connection (fixing plate, bracket, bolt head, etc into the living space may also be a concern. This can be resolved by recessing the fixing into the panel. (Refer to Figures 6.3, 6.4, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.16, 6.17, and 6.18 for details.)

6.2.3 Welded Fixings

Welded fixings consist of cast-in steel weld plates that are welded directly to other steel weld plates or brackets. While welded fixings are perhaps the simplest to install, they are usually the most costly, because of:

- The large cast-in weld plates, which have to be purpose-made.
- The need for a qualified and experienced welder on-site during panel installation.
- The extra installation time needed to weld the fixing plate or bracket in place.

This type of fixing should only be used when no other type is suitable. (Refer to Figure 6.15 for details.) They rely on the weld taking all the load and ensuring a quality weld has been produced on-site may be difficult to guarantee.

Mechanical fixings, such as drill-in mechanical expansion anchors, should not be used to support or stabilise panels unless they have been approved by the design or consultant engineer for the project.

A selection of proven connections for various standard situations are described in the following sections and should be used as a guide to assist with individual design and detailing of connections.

6.3 Panel to Footing / Slab-On-Ground Connections

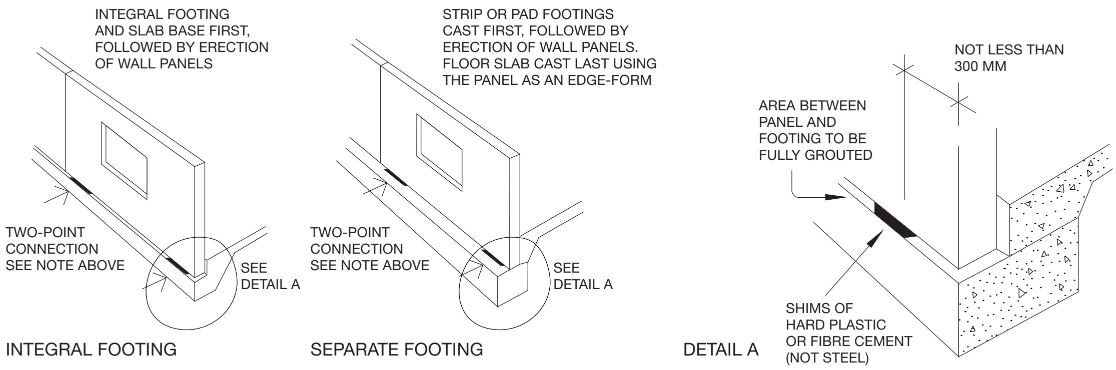


Figure 6.1 Principles of Base Connections

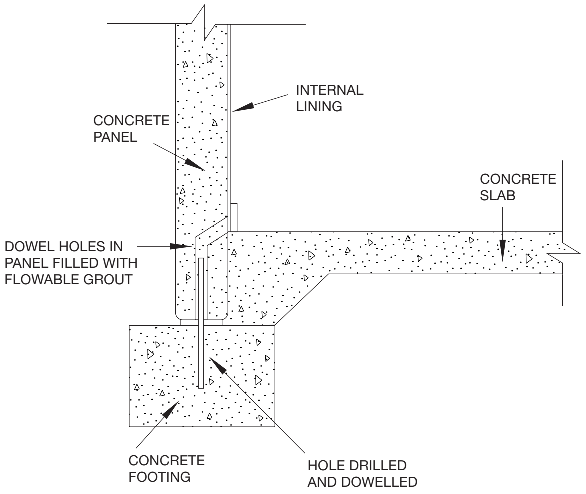


Figure 6.2 External Load Bearing Base Connection. (Laterally restrained by grouted dowel, preferred option)

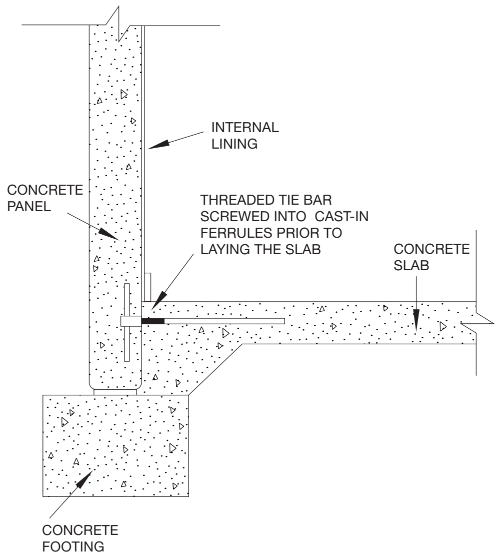


Figure 6.3 External Load Bearing Base Connection. (Laterally restrained by cast-in ferrule and threaded dowel into ground slab)

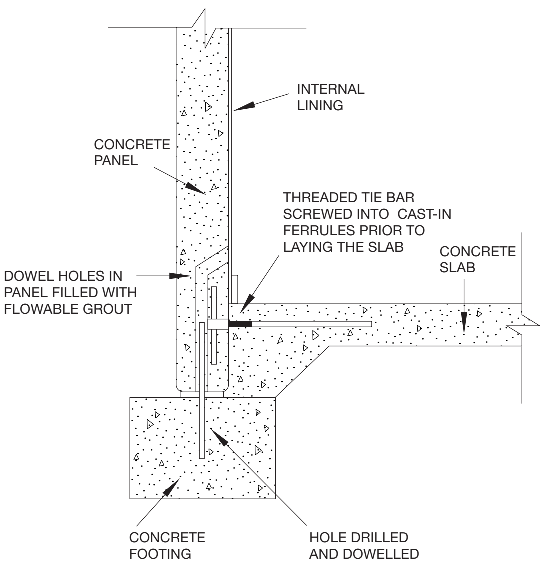


Figure 6.4 External Load Bearing Base Connection. (Laterally restrained by cast-in ferrule + threaded dowel into ground slab, grouted dowel into footing.)

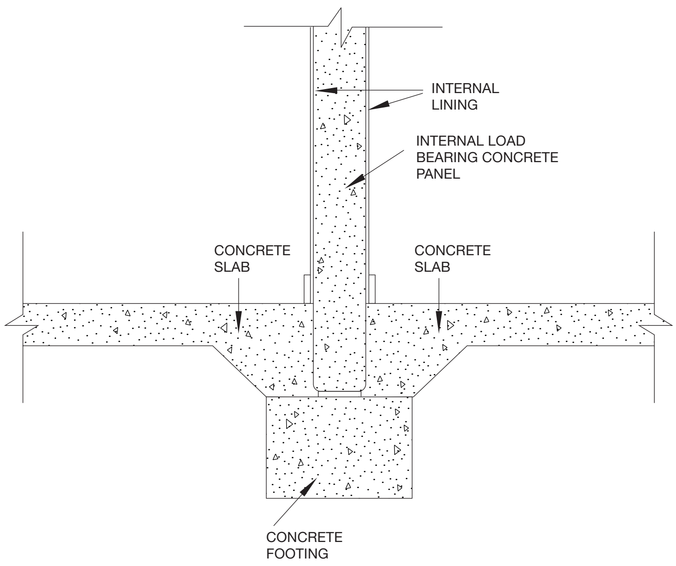


Figure 6.5 Internal Load Bearing Base Connection. (Laterally restrained by floor slabs cast after installation of wall panel)

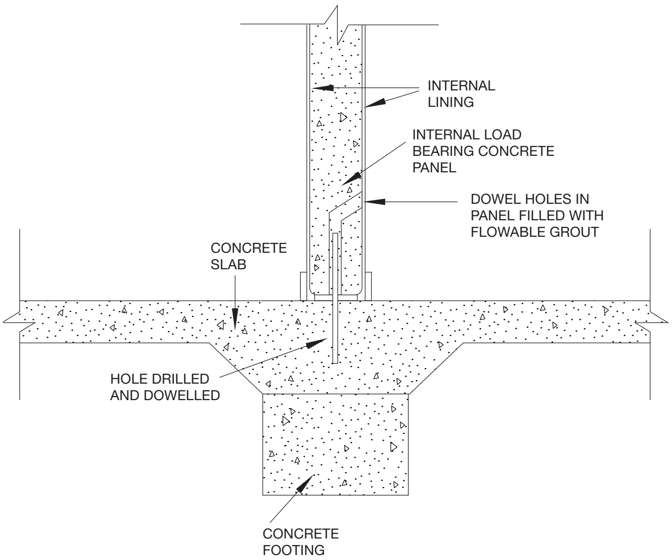


Figure 6.6 Internal Load Bearing Base Connection. (Laterally restrained by grouted dowel)

6.4 Panel to Panel Connections

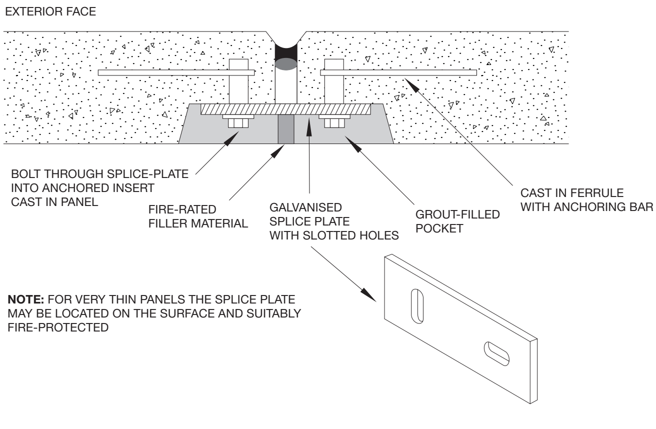


Figure 6.7 Plan View – Panel to Panel Top Restraint Connection, Without Lateral Continuity. (Bolted splice plate to cast-in ferrules). From CIA, Recommended Practice – Precast Concrete Facade Connections.

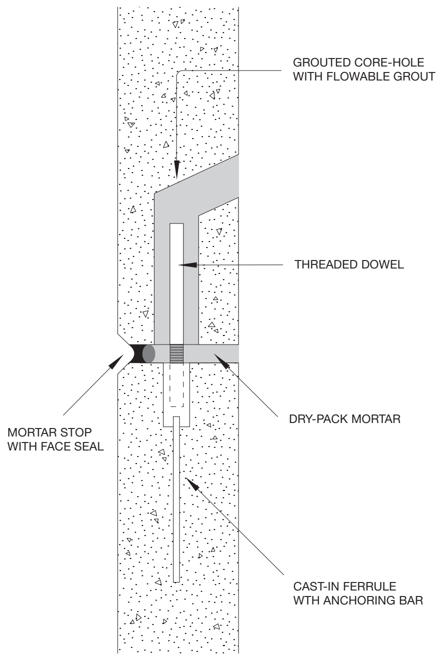


Figure 6.8 Section View – Panel to Panel Top Lateral Restraint Connection. (Cast-in ferrule and threaded dowel, grouted into top panel)

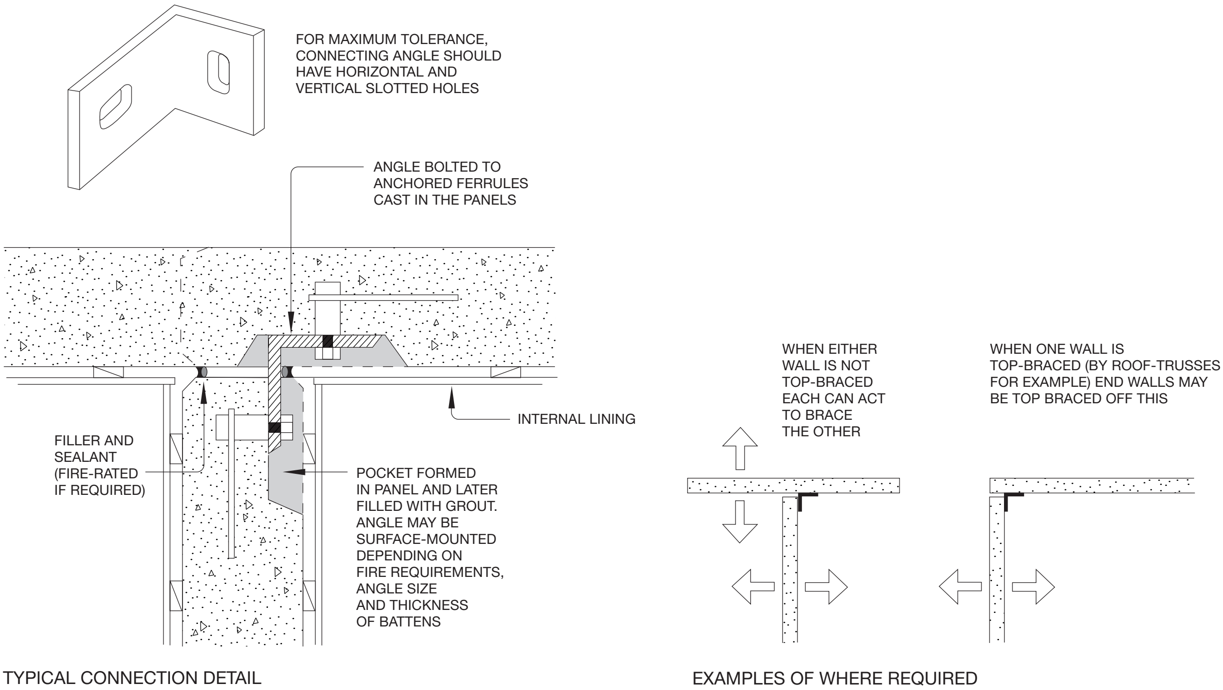


Figure 6.9 Plan View – Panel to Panel Top Corner Restraint. (Recessed angle bracket, bolted to cast-in ferrules to internal back face of panels)

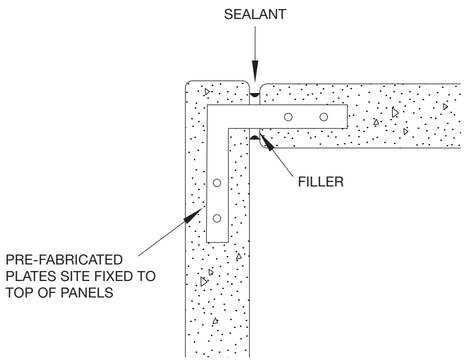


Figure 6.10 Plan View – Panel to Panel Top Corner, L-Plate Restraint. (Plate bolted to cast-in ferrules to top reveal faces of panels)

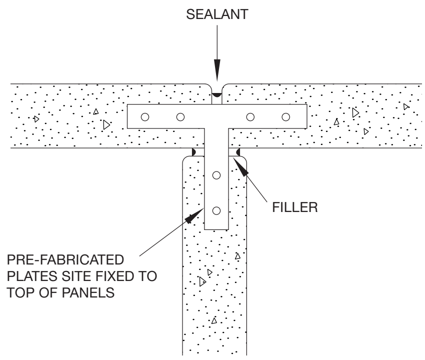


Figure 6.11 Plan View – Panel to Panel Top Corner T-Plate Restraint. (Plate bolted to cast-in ferrules to top reveal faces of panels)

6.5 Panel to Suspended Floor Connections

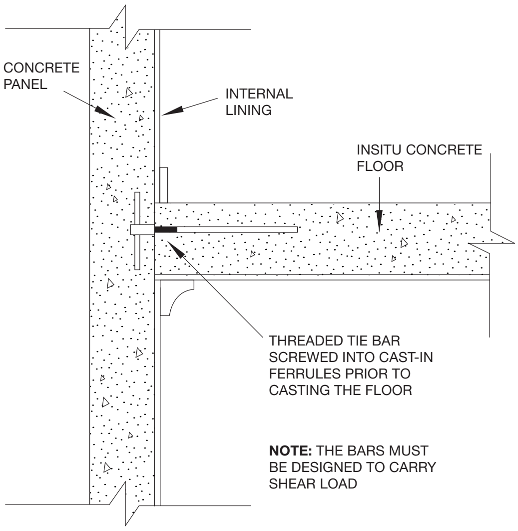


Figure 6.12 Panel to Suspended In-situ Concrete Floor Connection. (In-situ floor is supported by wall panel via cast-in ferrule and threaded tie bar)

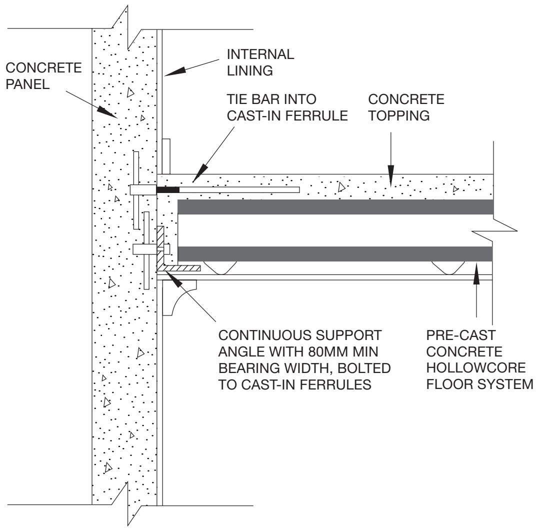


Figure 6.13 Panel to Suspended Precast Concrete Floor Connection. (Precast Hollowcore floor supported by shelf angle fixed to wall panel via cast-in ferrules)

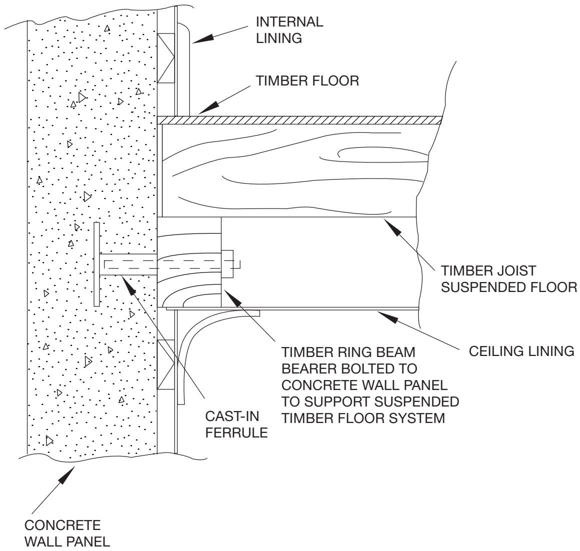


Figure 6.14 Panel to Suspended Timber-Framed Floor Connection. (Timber floor supported by wall panel via timber ring beam)

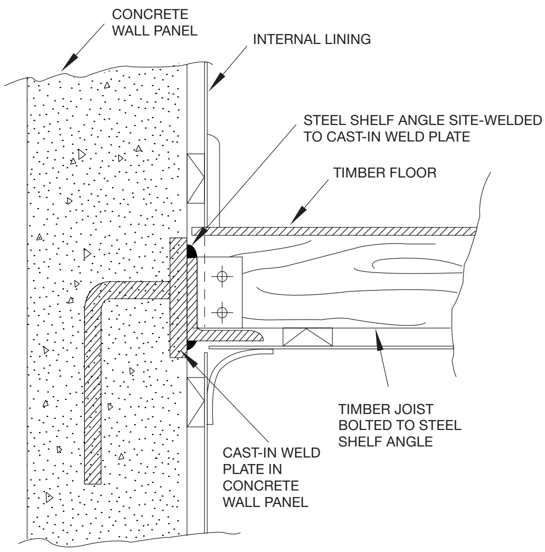
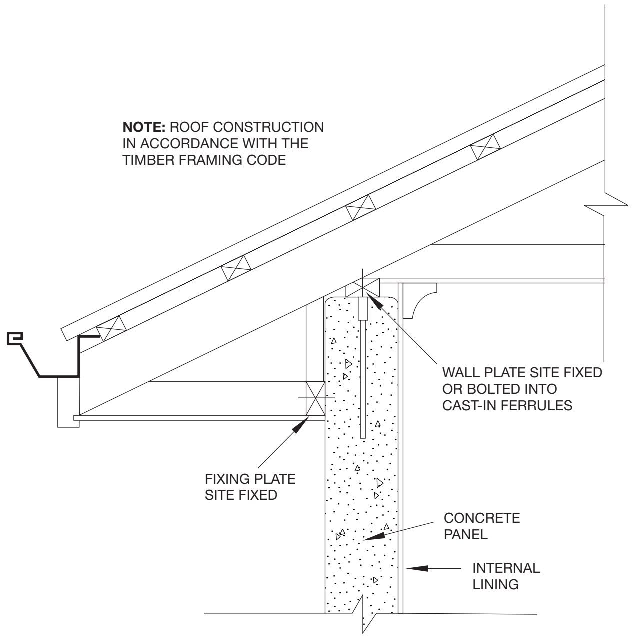


Figure 6.15 Panel to Suspended Timber Framed Floor Connection. (Timber floor supported by wall panel via shelf angle welded to cast-in weld plates in panel. Alternative option is to use cast-in ferrules to bolt shelf angle to panel)

6.6 Panel to Roof Connections



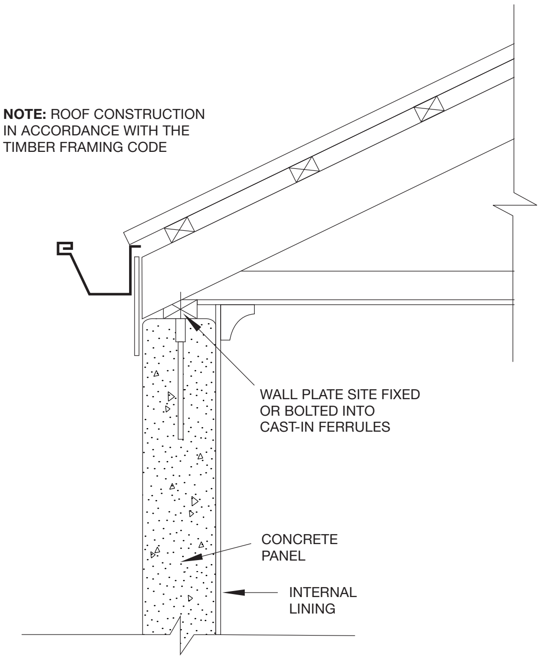


Figure 6.16 Panel to Roof Eave Connection – Extended Eave. (Roof framing is supported by top of wall panel via bolting into cast-in ferrules)

Figure 6.17 Panel to Roof Connection. (Roof framing is supported by top of wall panel via bolting into cast-in ferrules)

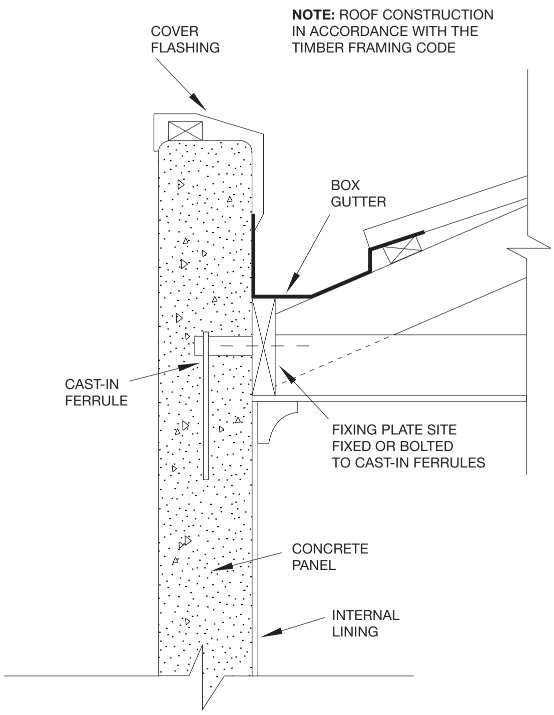


Figure 6.18 Panel to Parapet Roof Connection. (Roof framing is supported by wall panel via bolting into cast-in ferrules)

7 PANEL JOINTING

The joints between adjoining panels have an effect on the cost, performance, and aesthetics of the final structure have always been an inherent issue with concrete panel walling systems.

Panel joints divide the wall into manageable panel units for manufacture, transport and installation. They provide a means for accommodating differential and temperature movements between the panels. They can also be designed to take up any clearance, construction or installation tolerances.

7.1 General Joint Design Considerations

The joints are usually the least weatherproof and fireproof parts of the wall panel system. Take particular care to ensure that they are compatible with the structural design, the erection procedures, and the fixing details. Bad joint arrangements cannot be easily fixed by good joint detailing.

The number of joints should be kept to a minimum. If a small panel appearance is desired, this can be achieved by using *"dummy joints"* (or grooves) in the panel surface to mimic extra joints. Chamfers at the edges of the panels reduce the possibility of damage to the edge, but as they soften the line of the panel edge, they will provide greater tolerances in masking misalignment in the panel joints.

The external corners of the building need special care. Mitred joints (which occur exactly at the corner) are hard to produce, require smaller tolerances, create a weaker panel edge susceptible to damage, and will be visible on the finished house. An oversail corner joint is recommended, where the reveal of one of the panels is entirely exposed; the joint can then be set into the side of the house structure to make it less visible, or it can be hidden behind a downpipe.

Wherever possible, highly-visible midspan joints along a straight wall should be avoided; it's better to restrict joints to the corners of the structure where they are less noticeable. If there must be a joint in a straight flat wall, it can be hidden by introducing a "step" in the wall (though this will change the layout of the floor plan). Another option is to hide the joint with a false downpipe.

Single-Storey Houses Panels are usually only one level high (that is, they run from footing-level to roof-level). Their lengths should be maximised to reduce the number of vertical joints between panels.

Multi-Storey Houses Panels should extend from corner to corner in length, and from floor-to-floor in height. If there is an external balustrade in the same plan as the external wall, then the height of the wall panel should extend from the lower floor level to the top of the balustrade to minimise the number of horizontal joints and the number of panels.

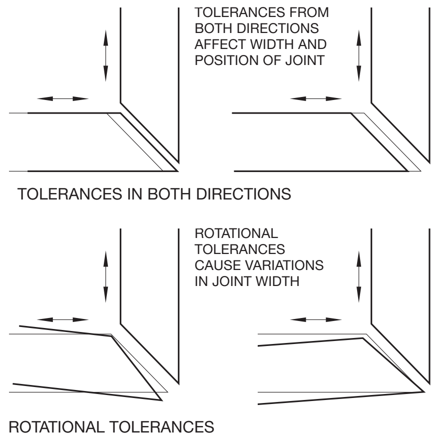


Figure 7.1 Problems of Mitre Joints

Joints between wall panels must be weathertight. The type of sealant will play a large part on the joint's performance over its lifetime. Sealant types and their appropriate uses are discussed in the section, 8.8.2 "Weatherproofing Joints".

Cap flashing should always be used over the top of the panels.

7.2 Joint Types

7.2.1 Face-Sealed Joints (Recommended)

This is usually the most suitable jointing method for concrete panel housing, as it is both the simplest and the most cost-effective. It requires only that there be a simple, clean, square-edge profile between the two adjoining panels that is smooth and dense. The sealant must be capable of adhering to the faces of the joint, and of accommodating normal movement between the panels without splitting or coming loose. The joint should be 15 to 20 mm wide and include a suitably-sized polyethylene backing rod behind the sealant, to contain it and to give it a back profile.

To improve weatherproofing, an optional internal air seal can be created by installing another face-sealed joint, with backing rod and sealant, on the other side of the joint.

The quality of the joint and its durability are directly related to the quality of the sealant and its installation.

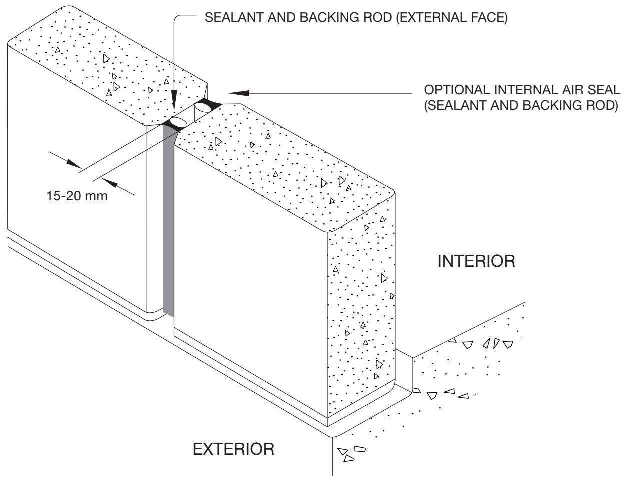


Figure 7.2 Typical Face-Sealed Joint

7.2.2 Open-Drained Joints

Open-drained joints contain two barriers: a backing rod and sealant at the back of the joint, and a main weatherproofing seal (consisting of a loose neoprene baffle installed into a vertical groove in the joint profile) on the external face of the joint.

This jointing method provides for a very good weathertight seal, and is the usual method of detailing joints in the façades of high-rise buildings. The method is not usually suitable for concrete panel homes, because the joint profiles are complicated and expensive to produce and install.

7.2.3 Gasket Joints

In this type of joint, an optional air seal is placed at the back of the panel joint, and a neoprene gasket is installed into a vertical groove in the joint profile. This type of joint is similar to the open-drained joint, but is usually used in low-rise buildings in locations where positive pressure can deform or compress the gasket over the lifetime of the joint. Panel and joint tolerances, as well as any surface defects, must be taken into account to ensure that the joint performs sufficiently.

7.2.4 Compression-Seal Joints

This type of joint is formed by attaching an impregnated foam seal to one of the panels, and placing the adjacent panel hard up against it. The panel edge profile is usually 'tongue and groove' to make the joint more weatherproof.

The effectiveness of this type of jointing detail will depend on the accuracy with which the panels are made, and the extent to which the seal can be compressed. The method is usually used in low-rise industrial buildings, where complete weathertightness is not essential.

7.3 Joint Widths

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

Joint widths for concrete wall panels are usually from 15 mm to 20 mm wide. To determine a suitable joint width, take all of the following into consideration:

- The manufacturing and erection tolerances. (Refer to Section 10.10, "Tolerances for Construction", for further information.)
- The anticipated movement of the panels relative to each other (due to shrinkage, or to changes in temperature and humidity).
- The ability of the sealant to accommodate movement in the joint.
- The possibility of hiding joints so as to allow joint tolerances to be relaxed.
- The cost of sealant (the wider the joint, the greater the amount of sealant required.)

For most face-sealed joints, the width of the joint should be twice the depth of sealant (not including the backing rod) to enable the joint to have a suitable sealant movement capacity.

Allowances must also be made for manufacture and erection tolerances, though, which will further increase this value. (Refer to Section 10.10, "Tolerances for Construction", for further information).

7.4 Fireproofing Joints

Panel joints can be fireproofed simply by using a fire-rated sealant instead of a normal non-fire rated sealant. (Fire-rated sealants can be used throughout the structure, but it is recommended to be used only in areas that require a fire-rating, as they are generally more expensive than non-fire rated sealants.)

Fire-rated sealants are installed into panel joints in the same way as other sealants, and (depending on the type of sealant) can provide up to four hours of fire resistance. However, the BCA only requires a fire-rating in certain circumstances and for a certain period of time (as described in section 8.6, "Fire Resistance Performance").

Fire-rated sealants should be supplied and installed by experienced applicators in accordance with the manufacturer's instructions.
A sealant-specific Fire Test Certificate certifying that particular sealant's fire-rating should also be attained wherever possible.

7.5 Concrete Sandwich Panel Corner Jointing

In joints between concrete sandwich panels, there should be no link between the leaves of concrete on either side of the central insulation board. A link will create a "thermal bridge" between the leaves, which reduces the thermal efficiency and can lead to cracking at the ends of the sandwich panel.

To complete a corner detail without exposing the insulation board at the end of the panel:

- Return the insulation board around the corner to the rear face of the panel. (This may be difficult to form and further consultation is recommended with the panel supplier or manufacturer.)
- Extend the insulation board to the end of the panel, and hide the joint with a corner moulding.

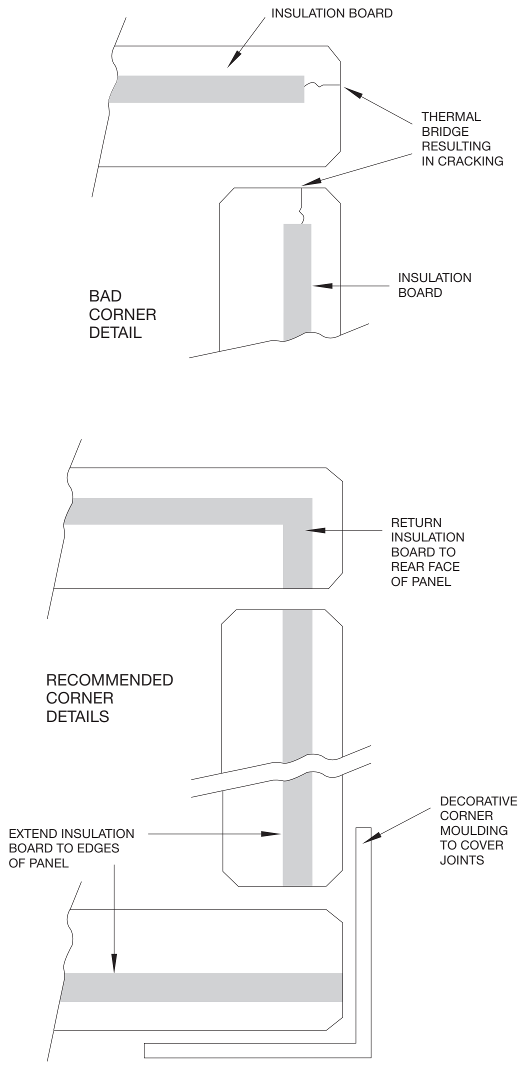


Figure 7.3 Concrete Sandwich Panel Corner Jointing Details

8 PERFORMANCE DETAILS

This chapter discusses the main performance properties of concrete panel walling construction.

8.1 Solid Construction

The main difference between concrete panel construction and conventional lightweight building systems is that concrete panel construction is a form of *"solid construction"*. Solid construction can be defined as a structure that is dense in mass and is solid through its cross section). Solid construction produces structures with certain advantages over those produced by other methods, that shall be discussed in the following sections.

8.2 Structural Performance (Construction, Dead, Wind and Seismic Loads)

One of the benefits of solid construction using concrete panel walling systems is its ability to withstand the various load conditions that a house can be expected to experience during its lifetime.

Each concrete panel is a structural component designed to withstand the loads experienced during manufacture, transportation and installation, as well as any applied loads during the lifetime of the home. Panels are designed to be connected to each other and to other building elements (such as concrete footings, floor slabs and roofs) in such a way that they form a strong, rigid structure.

8.2.1 Structural Design

The same structural principles apply to the design of concrete panel construction as to normal in-situ concrete construction. It is necessary that the design satisfy a number of criteria. Wall panels must be designed to handle not only expected in-service load conditions, but also loads during its handling and erection.

Designing for in-service loads is covered in the BCA's requirements (as discussed below).

Designing for loads incurred during lifting, handling and erection is just as critical, and in most cases will dictate the design of the panels.

8.2.2 The BCA and Relevant Australian Standards

As defined by the BCA, all Class 1 and 10 buildings must be designed, manufactured and constructed:

- To resist loads determined in accordance with Australian Standards:
  - AS 1170.1 – Dead and Live Loads and Load Combinations.
  - AS 1170.2 – Wind Loads. (or AS 4055 – Wind Loads for Housing.)
  - AS 1170.3 – Snow Loads.
  - AS 1170.4 – Earthquake Loads*

  * Most homes do not need to be designed to withstand earthquakes, as the design for the applied wind loads are usually sufficient to cover earthquake loads. Though it should be stressed that earthquake loads should be at least considered prior to dismissal.
- In accordance with the appropriate structural concrete design code:
  - AS 3600 – Concrete Structures

  as well as any other relevant design codes, such as:

Footings:	AS 2870 – Residential Slabs and Footings.
Piling:	AS 2159 – Piling – Design and Information.
Masonry:	AS 3700 – SAA Masonry Code.
Composite Concrete & Steel:	AS 2327.1 – Composite Construction in Steel and Concrete.
Steel Construction:	AS 4600 – Cold Formed Steel Structures. AS 3623 – Domestic Metal Framing. AS 4100 – Steel Structures.
Aluminium Construction:	AS/NZS 1664 – Aluminium Structures, Part 1 – Limit State Design. AS/NZS 1664 – Aluminium Structures, Part 2 – Allowable Stress Design.
Timber Construction:	AS 1720.1 – Timber Structures.
Glazing:	AS 1288 – Glass in Buildings – Selection and Installation. AS 2047 – Window in Buildings – Selection and Installation.

8.2.3 Tilt-Up and Precast Concrete Codes

In addition to meeting the above requirements to comply with the BCA, concrete panel walling systems should be designed in accordance with Australian Standard AS 3850, "Tilt-Up Concrete and Precast Concrete Elements for Use in Building".

This standard deals specifically with the design, casting, and erection of concrete wall panels. This standard should be read in conjunction with AS 3600.

8.2.4 Construction Loads

Perhaps the most severe loading experienced by a panel is that to which it is subjected when it is stripped from its mould. The design must ensure that the panel can support its own weight, that it can withstand the suction created as it is lifted from the mould, and that it bears during handling. It's important to take into account the effects of these forces both on the panel and on the lifting inserts.

As the lifting loads occur early in the life of the panel, the concrete strength at the time of stripping should be specified by the design engineer. This strength requirement may govern the grade of concrete mix. The panel thickness and lifting arrangement should be determined by limiting the extreme fibre tensile stress so that the section remains "uncracked" during erection. According to Australian Standard AS 3850, this tensile stress should be limited to $0.413\sqrt{f_{cm}}$ (MPa), where f_{cm} is the mean compressive strength of the panel at the time of lifting.

Panels produced on-site will need only to be stripped and erected, while panels that are produced off-site will require transport from the factory to site. Panels cast on-site tend to be larger, while the size of panels cast off-site is usually determined by the maximum 'head height' of the transport trailer, which in turn depends on the applicable state regulations and the types of trailers available. Panels up to 15 m high and 10 m wide can be lifted, but the best size for the panels depends on whether they're cast on- or off-site. For panels cast on-site, the optimum weight is 20 to 25 tonnes; for panels cast off-site, the optimum weight is 10 to 12 tonnes, as most transport trailers can carry from 20 to 24 tonnes (or two panels) per load.

Odd-shaped or elongated panels, or ones with large or multiple openings, can be strengthened for lifting by adding 'strongbacks' as required. The designer should indicate when and where this is necessary. Refer to Section, 10.8.5 "Strongbacks" for more information.

Grooving, profiling, texturing, or any other mechanical treatment of the panel surface reduces the net cross section area of the panel and the cover to the reinforcement. The design should take this fact into account.

8.2.5 Erection Loads

AS 3600 and AS 3850 contain the general design requirements that must be satisfied, but bracing loads should also be taken into consideration.

Loads incurred during temporary bracing seldom govern panel design, but these loads must be checked to ensure that the bracing and inserts are adequate and that the panels will remain stable while braced.

Braces are usually fixed to the panel, and come in a variety of forms to suit different loads and panel sizes. Loads due to wind and out-of-plumb forces must be catered for. The braces themselves may need bracing if they are long, to prevent them from buckling. A minimum of two braces per panel should be used to prevent the panel twisting (except if the panel, or brace is designed to provide restraint against twisting).

8.2.6 In-Service Loads

Transverse Loads It is important that the walls provide sufficient resistance to lateral loads, especially if the walls are load-bearing. The roof can be designed to transfer the lateral loads on the walls. Walls that are perpendicular to others can act as shear walls to resist the load imposed by the first set. The panels, and their connections to footings and to other panels, must be designed to carry these induced loads.

Vertical Loads Most downward vertical loads are due to the weight of the structure, its contents and its occupants, while most upward vertical loads are caused by the wind. (AS 1170, Parts 1 to 4, quantifies these loads, and the combinations in which they occur.)

Downward vertical loads are usually carried down through the walls to the footings. Wall panels must be designed to carry the loads imposed by the roof and any intermediate floors. The usual method is to include corbels or cast-in connection ferrules on the faces of the panels to be fixed back to the roof or suspended floor.

Upward vertical loads due to the wind should be carefully assessed and catered for. Both roof and walls may need to be physically tied to the footings, especially in parts of Australia where cyclones occur. (Refer to Section 8.1.8, "Cyclonic Loads", for more information.)

Volumetric Movements Panels in a long wall should not be fixed together rigidly, or shrinkage and thermal movement will invariably lead to cracking. Long walls should contain movement joints and/or connections to permit natural movement.

8.2.7 Seismic Loads

Recent seismic occurrences have brought about formal requirements to be addressed in the BCA for residential homes. Solid construction, such as concrete panel construction, can easily be designed to withstand these loads.

Not all residential structures require specific seismic design, though, as long as certain criteria are met.

To cater for seismic loads as required by the BCA, the design must comply with Australian Standard AS 1170.4 – Minimum Design Loads on Structures, Part 4: Earthquakes Loads. To meet the Standard's requirements, the following must be determined:

- The structure classification
- The acceleration coefficient
- The site factor
- The earthquake design category

8.2.8 Cyclonic Loads

In northern Australia, where cyclones occur, there are obvious advantages to using solid concrete panel walling rather than conventional lightweight building materials: greater protection from destructive winds and wind-driven projectiles.

Concrete panel homes can be specifically designed to withstand the loads imposed by cyclonic winds in accordance with the Australian Standards as listed in Section 8.2.2. The loads on wall panels can be accommodated with:

- Additional reinforcement,
- A thicker panel, or
- Additional bracing with cross panels to shorten panel spans.

Cyclonic loads on panel connections can be accommodated by either:

- Increasing the number of connections to the panel, or
- Increasing the capacity (that is, size) of the connections.

Because cyclones impose a large upward vertical load, wall panels should be tied to the footings, and the roof structure should be tied to the wall panels, as in the BCA's requirements for reinforced masonry (BCA, Part 3.3.2).

Panel-to-footing tensile connections The base of a wall panel can be tied to the footing (or ground floor slab, if it is appropriately reinforced back to the footing) by means of cast-in ferrules in the rear face of the panel (near the base). The ferrules can be fixed with a threaded dowel cast back into the ground floor slab (as shown in Figures 6.3 and 6.4), or they can be bolted to angle brackets which are in turn bolted to the top of the footing.

Panel-to-roof connections As shown in the BCA, Part 3.3, Figure 3.3.2.7(a) (for masonry), ferrules can be cast into the tops of the panels to enable them to be bolted to a capping plate over the roof truss. Alternatively, a bracket can be fixed to the sides of the roof truss and then bolted to the ferrules in the panels (as shown in Figures 6.16 and 6.17).

Consultation with a design or consultant engineer is required to ensure that the design properly caters for cyclonic loads.

8.3 Acoustic Performance

Solid walling systems, such as concrete panel walling, are good acoustic insulators. There are many systems that can achieve ratings of 50 dB and higher, enabling them to meet the most stringent requirements.

Below are summarised the main acoustic requirements for walls (and floors) in residential buildings, as well as the main ways that solid construction methods can meet those requirements easily and cost-effectively.

8.3.1 Transmission of Sound

Noise (unwanted sound) is of two types: *airborne noise* (such as speech or music), and *impact noise* (such as footsteps, or the sound of furniture being moved). Both cause building elements to vibrate. The air on the other side of the element picks up these vibrations, and it is these secondary vibrations that are heard as "noise".

Airborne Noise Airborne noise consists of sound transmitted through the air. It can not travel through walls and floors, but it can make them vibrate, causing noise on the other side.

Impact Noise Impact noise consists of sound transmitted directly through a wall or floor by physical contact with it. Impact vibrations tend to make the whole element (and elements in contact with it) vibrate, causing noise in the same way as airborne sounds.

The more mass a wall (or floor) contains, the harder it is for a sound or impact to make it vibrate, so the less noise is heard on the other side. Solid construction, such as concrete panel walling, performs well in this way: its mass is a good acoustic insulator.

With low-mass walling systems that combine mass of the wall lining and some insulation in the cavity wall, rely on the effective jointing of numerous layers of composite materials to block every gap and filling every cavity; something as small as a power point or an unfilled joint can significantly affect the amount of noise the wall transmits. With solid construction, though, most of these problems are solved from the start.

8.3.2 Measurement of Sound

Decibel (dB) The loudness of a sound is expressed in decibels (dB). One dB is the softest sound detectable by the average human ear.

Weighted Sound Reduction Index (R_w) All building elements (walls, floors and ceilings, doors, windows, and so on) mask a given amount of airborne sound. The R_w rating of a building element is a measure of this quality, and is equal to the number of decibels of sound that the element is capable of blocking. An R_w rating of 45 means that the element reduces the level of sound passing through it by 45 dB.

8.3.3 Building Code of Australia

Requirements For medium density housing containing adjacent sole-occupancy units, the BCA specifies a required level of acoustic insulation that the separating walls (and floors) must provide. (The requirements below are from the BCA's 1996 standard, including Amendment 4 of January 1999).

The BCA requires a minimum R_w rating of 45 for the following walls:

- A wall separating sole-occupancy units.
- A wall between a sole-occupancy unit and a plant room, lift shaft, stairway, public corridor, hallway or the like.
- A wall separating any habitable room (other than a kitchen) from a soil or waste pipe serving more than one unit. (For a kitchen, an R_w rating of 30 applies instead.)

The R_w rating is increased to 50, and a requirement for insulation from impact sound is added, for walls separating a bathroom, sanitary compartment, laundry or kitchen in one unit from a habitable room (other then a kitchen) in an adjoining one.

Table 8.1 Recommended Design Sound Levels for Inner-Suburban Private Houses (extracted from AS 2107, Table 1)

	Recommended Design Sound Levels dB(A)	
Activity	Satisfactory	Maximum
Recreation areas	35	40
Sleeping areas	30	35
Work areas	35	40

According to the BCA, a sound of 70 dB–about the same as the noise from a busy street or the sound of a loud argument–will be clearly audible through a wall with an R_w rating of 45, but it will be heard at 25 dB, which is below the AS 2107 limit given in Table 8.1.

Solid construction can cost-effectively perform well above the minimum R_w 45 rating required by the BCA. In other words, concrete homes are consistently quieter.

8.3.4 Industry Response

A house with a high R_w rating offers a quieter environment, which makes the house more desirable, more valuable, and more saleable. There are far fewer complaints about noise in neighbourhoods with high R_w ratings. For these (and other) reasons, some local councils in Australia are already requiring higher R_w ratings than the BCA.

In response, many new (and cost-effective) methods have been developed to meet these more stringent requirements. Single-element walls and floors of solid construction (such as a 150-mm-thick concrete wall panel) can now have R_w ratings as high as 55.

8.3.5 Quality Issues

With concrete panel construction, requirements for mass can be met just by making the wall or floor thick enough.

Gaps around edges, and at the tops and ends of walls, must be properly grouted or sealed with an acoustic sealant.

If chasing of party walls is required, the rebate should be completely filled to maintain the mass of the wall and prevent air gaps.

In short, only a few precautions need to be taken to ensure that concrete walling systems perform well acoustically. Materials are consistent, so success relies less on workmanship than it does in lightweight walling systems.

8.3.6 Concrete Panel Walls with R_w 45 and R_w 50 Ratings

The factors that most influence the R_w rating of a particular building element are:

- Its mass,
- The acoustic absorbency of its surfaces, and
- How it abuts or is connected to adjoining building elements.

Of these factors, mass is the most important, and solid construction provides it.

The BCA deems the following to have an R_w rating of 45:

- Solid precast concrete panel 100 mm thick without joints.
- In-situ concrete 125 mm thick with a density not less that 2200 kg/m³, or 100 mm thick with a density not less that 2500 kg/m³.

If an R_w rating of 50 is required with impact reduction, the BCA does offer some deem to comply solutions for concrete. For impact-sound insulation, the usual solution is to install one of the standard acoustic impact systems available from most lining-board manufacturers. These low-cost and easy-to-install systems consist of standard wall-lining boards (a soft layer to absorb the impact) mounted on furring channels. The furring channels are fixed to the wall with standard clips incorporating some form of resilient rubber mounting to further reduce the vibration transmitted to the wall. These linings are usually installed only on the impact side of the wall. (See Figure 8.1 for typical details.)

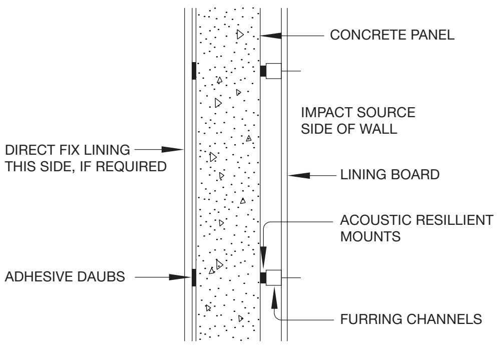


Figure 8.1 Cross-Section of Acoustic Wall System

This type of insulation is required only for rooms specified by the BCA. (Refer to section 8.3.3, "Building Code of Australia".)

For further information, refer to C&CAA's publication, *"Acoustic Benefits of Solid Construction"*.

8.4 Thermal Performance

A recent research project by the Cement and Concrete Association of Australia (C&CAA) and the Concrete Masonry Association of Australia (CMAA), carried out at the CSIRO, assesses various combinations of wall and floor construction to determine how thermal mass and insulation affect their energy-efficiency. Following are points to consider.

8.4.1 Definitions

Thermal mass: A material's ability to store thermal energy.
Thermal capacitance ("C-value"): The amount of heat required to raise the temperature of a unit area of a material of a particular thickness by 1ºC. It is calculated as the product of the material's density, thickness, and specific heat, and is expressed in J/m²K or kJ/m²K.
Specific heat: The amount of heat required to raise one kilogram of a material by 1ºC, expressed in J/kgK.
Thermal resistance ("R-value"): A material's ability to insulate, expressed in m²K/W. The higher the R-value of a material, the more resistant it is to heat loss in winter and heat gain in summer.

8.4.2 For Cooling the Building

For cooling the building, the findings were as follows:

- Solid walls, such as concrete panel walls, require no insulation. They outperform lightweight walls, even when the latter are insulated.
- Insulation has little effect on the energy-efficiency of the walling systems tested.
- Internal solid partition walls perform best. They should not be insulated, so that their thermal mass can be exploited.

8.4.3 For Heating the Building

For heating the building, the findings were as follows:

Without insulation in the walls:

- Solid single-leaf concrete walling systems require only plasterboard on battens to perform as well as cavity construction (which outperforms all other wall types).

With insulation in the walls:

- AAC (Aerated Autoclaved Concrete) outperforms all other wall types, with the others coming equal second.
- Concrete walls require only foil-backed board on battens to provide effective insulation equivalent to that of other walling systems.

8.4.4 How Does Thermal Mass Work?

Figure 8.2 shows how the mass of a concrete panel reduces the heat flowing through it. Its ability to store thermal energy offsets the peak temperature by approximately six hours, an offset called "thermal lag". A thermal lag of six hours means the maximum indoor temperature will not occur until six hours after the maximum outdoor temperature has been reached (usually between noon and 2 pm). The result is that the indoor temperature reaches its maximum in the early evening, when the air outside is usually cooler.

In other words, thermal mass tends to 'iron out' the effects of outside temperatures, reducing the maximum and minimum temperatures inside and making the living environment more comfortable. Thermal mass is the reason that typically buildings of solid construction feel cooler in the summer and warmer in the winter.

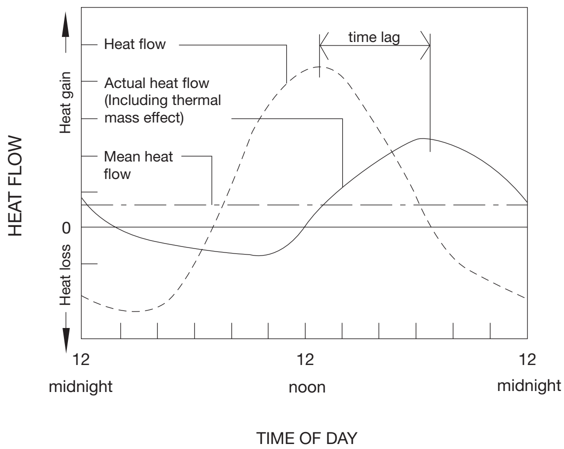


Figure 8.2 Typical Heat Flow through a Concrete Panel (say 200 mm thick)

8.4.5 R-value and C-value

Designers use two main criteria when evaluating the thermal efficiency of building products: the *R-value* and (to a lesser extent) the *thermal mass*.

Table 8.2 lists R-values, as well as C-values (thermal capacitances), for various building materials and thicknesses.

Table 8.2 R-Values and C-Values for Building Materials

Material	Building System	Thickness (mm)	Density (kg/m³)	R-Value (m²K/W)	C-Value Thermal Capacitance (kJ/m²K)
Concrete	Solid Wall	150	2300	0.26	300
Concrete	Solid Wall	100	2300	0.23	200
Clay Masonry	Brick Veneer	110	1600	0.18*	163*
Timber and Weatherboard	Clad Frame	12	500	0.47	12
Glass	Curtain Wall	6	2500	0.16	1

* As measured by the CSIRO.

As can be seen, high-density walling materials like concrete do not fare well when assessed purely on the basis of their R-values. But R-values do not take into account thermal mass; C-values do, and on the basis of C-values, concrete significantly outperforms lighter-weight materials under cooling conditions.

8.4.6 Research Findings

Figure 8.3 & 8.4 display typical results for an apartment building in a cooler climate (Melbourne), and Figures 8.4 & 8.5 display the results in a warmer climate (Brisbane).

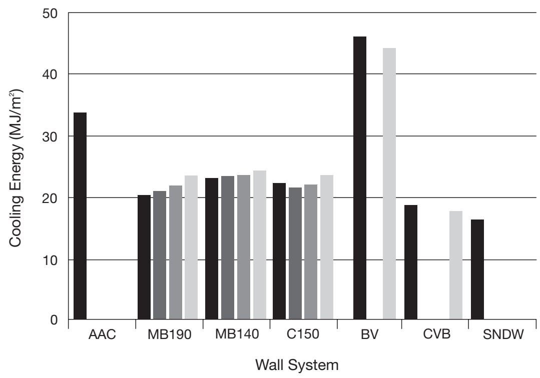


Figure 8.3 Annual Cooling Energy Requirements, Centre Apartment, Melbourne

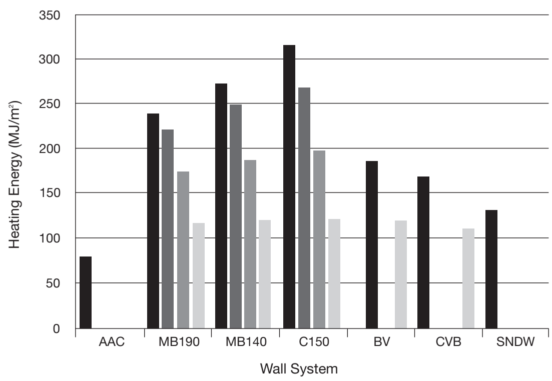


Figure 8.4 Annual Heating Energy Requirements, Centre Apartment, Melbourne

Legend:

External Wall Types

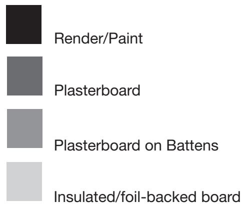
- 200 mm AAC (AAC)
- 140 mm and 190 mm concrete masonry block (MB140/MB190)
- 150 mm solid concrete (C150)
- Cavity brick construction (CVB)
- Brick veneer (BV)
- Sandwich panel (concrete + polystyrene)
- (SNDW – apartments/commercial)

Interior Finishes to Walls

- Paint
- 10 mm render
- Plasterboard direct fixed to wall
- Plasterboard on battens
- Plasterboard on studs (BV only)

Insulation Alternatives

- AAC wall
- Foil backed board (for MB and C150)
- Cavity insulation of 1.0 m²K/W (for CVB only)
- Reflective foil over studs (for BV only)



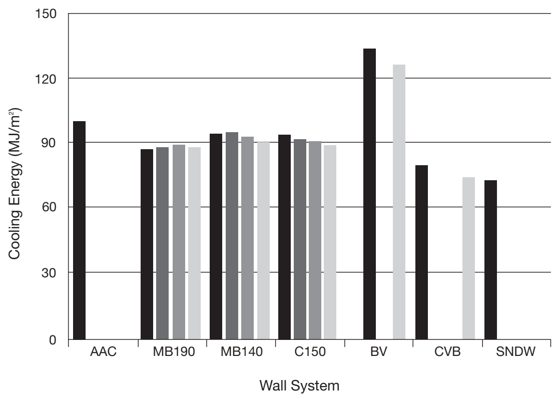


Figure 8.5 Annual Cooling Energy Requirement, Centre Apartment, Brisbane

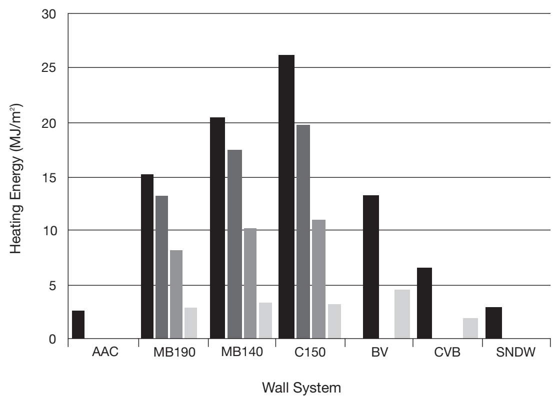


Figure 8.6 Annual Heating Energy Requirement, Centre Apartment, Brisbane

Each of these results is discussed below, followed by some specific comments about apartment buildings.

8.4.7 For Cooling

- In warmer climates where cooling is the predominant requirement (as shown in Figures 8.3 and 8.5), insulated and uninsulated external walls performed alike, meaning that the cooling energy required is independent of the R-value of the wall type. Specifying a minimum R-value for walls in these climates therefore has little impact on the energy-efficiency of the building.
- Solid partition walls perform best internally, and should not be insulated so their thermal mass can be exploited.

8.4.8 For Heating

- In cooler climates where heating is the predominant requirement (as shown in Figures 8.4 and 8.6), all wall types perform relatively alike once the walls are insulated, with the location of the insulation making little difference.
- Solid (uninsulated) cavity construction outperforms all other wall types in homes, regardless of climate or insulation. (For commercial buildings, though, all wall types tend to perform alike).
- External concrete and concrete masonry walls, when finished internally with plasterboard on battens, perform about as well as uninsulated cavity construction.

8.4.9 Apartments: Specific comments

- Corner apartments require about twice as much heating energy as centre apartments, because of their greater area of exposed wall. They require only slightly more cooling energy, though, because of their thermal mass.
- Brick veneer and other lightweight construction types are poorer than all other wall types at keeping a building cool, mainly because they are only capable of supporting lightweight suspended floors that have a low thermal mass.

8.4.10 Conclusions

- The thermal mass of solid construction means that buildings with solid walls require no insulation for cooling, and outperform the lighter-weight walling alternatives tested.
- For heating, insulation improves energy-efficiency-but once the insulation is added, all the walling systems perform about the same.
- A solid concrete wall with foil-backed board on battens performs about the same as walling systems with much higher R-values (such as AAC and insulated cavity construction).
- A thinner concrete wall, with plasterboard on battens, performs about the same as cavity construction.

For further information, refer to C&CAA publication *"Thermal Benefits of Solid Construction"*.

8.5. Condensation Performance

Air contains moisture in the form of water vapour. The higher the air temperature, the greater the amount of water vapour the air can contain; the lower the temperature, the less water vapour it can hold.

The main cause of condensation is a change in the temperature or the moisture content of the air. Such changes can occur naturally, or as a result of residential activities (such as cooking) or industrial processes.

With the right combination of temperature, humidity and ventilation, condensation problems can arise in any building. Persistent conditions can result in dampness and mildew. No type of construction is immune, and the problem can occur in any climate.

8.5.1 Types of Condensation

There are two types of condensation that cause problems in buildings:

Surface condensation occurs on the surface of a building element. When air comes in contact with any surface (such as a window pane or wall) cooler than the *dew-point* (ie. the temperature at which saturation occurs and any excess moisture in the form of water vapour condenses) the air is cooled below the dew-point as well, and deposits its moisture on the surface. Alternatively, increasing the moisture content of the air beyond its saturation point (such as happens in a bathroom during a shower) causes the excess moisture to condense on any available surface. (Note the implication: warm rooms still can be subject to a condensation risk.)

Internal or interstitial condensation occurs inside a building element. Water vapour passes with the air through any building element. If the temperature of the element falls below the dew-point, the excess moisture in the air within the element will deposit its moisture there. When the temperature rises, the water becomes vapour again, and continues to move through the element.

Strategies to avoid condensation include:

- Installing a vapour barrier on the warmest side of the wall to reduce the amount of moisture that can enter the element, and
- Designing the element so that the temperature inside it does not fall below the dew-point.

8.5.2 Consequences of Condensation

If persistent, surface condensation on walls or roofs can damage furnishings and fittings and cause mildew. Internal condensation takes longer to show, but is potentially more damaging, as it can cause the fabric of the building itself to deteriorate. When condensation is worst, it can almost appear to be 'raining' inside the building. Walls and roofs become mouldy, and the subsequent deterioration in air quality can cause health problems.

8.5.3 Performance of Condensation Assemblies

The following points are worth noting:

- Highly effective vapour barriers like aluminium foil sheeting completely block the movement of water vapour, virtually eliminating any vapour pressure gradient. As a result, pressures and dew-point temperatures are almost identical on both sides of the barrier.
- The effectiveness of polythene sheeting as a vapour barrier depends on its thickness, but even at 200 microns (0.2 mm) it is far less effective than aluminium foil.
- Insulation does not usually form a barrier to the movement of water vapour with a high vapour pressure gradient.

8.5.4 Designing for Climate

Appropriate methods of preventing condensation vary, depending on the area's climate.

In hot humid climates, if no air conditioning is used, the internal temperature and vapour pressure will be similar to external conditions. As long as doors and windows can be opened, vapour pressure can be controlled, and condensation can occur only if the RH is near 100%.

If air conditioning is used, though, there is often a difference in temperature of 10-15ºC between the inside and the outside, and therefore a difference in relative humidity of 50-60%. (For example, 35% RH at 35ºC becomes 65% RH at 22ºC, if the moisture in the air remains constant.) With additional moisture generated inside the building, the RH can rise to 85% or more.

Fortunately, the dehumidifying effect of air conditioning units will reduce this considerably. Condensation within the walls is unlikely unless the internal temperature falls or the RH increases, thereby raising the dew-point temperature.

For houses in hot humid climates, you should:

- Install a vapour barrier on the warm (exterior) side of the wall to reduce interstitial condensation as the RH approaches 100%.
- Avoid "thermal bridges" (connections between cool surfaces and the exterior), which cause condensation on the outside of the wall.
- Avoid over-cooling the interior, which can bring the internal temperature below the dew-point and cause surface or interstitial condensation.
- Avoid low-permeability wall coverings or coatings on the interior, as moisture can accumulate behind the covering or coating.

In cool climates, the difference in temperature between the inside and outside can be as high as 20-25ºC, leading to an internal RH as much as 40-50% lower than the outside one. With solid construction, the temperature of the concrete elements can fall below the dew-point, especially if insulation is used on the internal surfaces (as it prevents the panels from being heated from the inside). The risk increases as the relative humidity of the outside air increases.

For houses in cool climates, you should:

- Reduce the amount of moisture generated in the building to minimise the vapour pressure and dew-point.
- Install a vapour barrier on the warm side of the wall to prevent water vapour from reaching the cool surfaces. With a vapour barrier installed, no condensation will occur as long as the temperature at the barrier remains above the dew-point.
- Use external insulation to heat the wall elements more efficiently. Maintaining the temperature of the wall above the dew-point prevents condensation, however the building is often not heated sufficiently.
- Use natural and/or mechanical ventilation to expel moisture or water vapour.
- If you cannot remove the risk of severe condensation, make sure cavities are drained to prevent damage to the finishes.

8.5.5. Designing to Avoid Condensation

The easiest way to avoid condensation is simply to prevent moist air from coming into contact with cold surfaces. Doing this may mean controlling a number of factors that can cause condensation. As designers have little control over the use of the building, it's wise to include a few backup strategies for minimising condensation in case it occurs.

These are the main strategies for minimising condensation, in order of importance:

1. Provide good ventilation to reduce or control the RH and internal vapour pressures (and thereby the dew-point temperature gradients).
2. Provide enough heating to increase the temperature of the solid wall. (This can be difficult in buildings that are not always occupied, or that are heated for only short periods in the evenings.) Heating should be throughout the building, not just in the living areas.
3. Install insulation (in conjunction with heating) to prevent heat loss through the walls and floor.
4. Reduce the amount of moisture generated in the building, or remove it at the source, to help control the RH and vapour pressure.
5. Prevent moisture from moving to colder areas of the building.
6. Avoid thermal bridges.
7. Install vapour barriers on internal walls in cold climates, so that condensation will occur only if the temperature of the wall falls below the internal dew-point.
8. Coat the outside surface with a permeable layer to allow water to evaporate rather than accumulate in the wall.

8.5.6 Types of Vapour Barriers

Vapour barriers come in many forms, depending on where they're to be used. The following types are available:

- Polyethylene sheets
- Reflective foil membranes (such as aluminium foil)
- Foil-backed plasterboards
- Impermeable rigid insulation
- Part membranes with low permeability
- Specialised external coatings

8.5.7 Ventilation

The function of ventilation in buildings is to:

- Improve indoor air quality.
- Reduce indoor moisture content.
- Keep the indoor climate comfortable.
- Cool the building structure.

Internally-generated humidity can reduce air quality and lead to condensation. Ventilation can help address this problem, but is effective only if external conditions are better than interior ones. If ventilation is to reduce humidity in a room, the level of humidity must be higher inside than outside.

The types of ventilation that can be used are as follows:

Trickle Ventilation: Permanent ventilation can be provided for spaces with consistently high humidity to keep air moving through and to discourage hot humid air from remaining in the space. Fixed grilles in bathroom windows are a good example of this technique.

Cross-ventilation: Openings in a façade can be linked to increase the airflow through the space and move hot humid air out of the building. The ventilation rate should be such that the entire volume of air is replaced 0.5 to 1.5 times per hour.

Cavity Ventilation: Ventilators can be planted in wall surfaces to enable air movement in cavities. This technique can remove high levels of humidity in cavities.

Mechanical Ventilation: Fan-assisted ventilation can be used to expel hot humid air by:

- Bringing in external air to replace the moist air, or
- Expelling the moist air by extraction.

The first option (intake fans) is appropriate if external air is needed to cool the interior, or if a great deal of moisture is being generated by processes inside the building.

The second option (exhaust fans) is best for small areas with localised moisture problems, such as bathrooms and kitchens. The fans can be connected to hygrometers and thermostats to reduce the risk of condensation. Always run the humid exhaust to the outside, not into an interior cavity or space (especially exhaust from clothes driers). You will also need to ensure that an equivalent amount of air can enter the building somewhere, to replace what's expelled.

8.5.8 Summary

Condensation in solid construction can be avoided by understanding the processes that cause it, and designing a strategy to cater for the causes. The solution may be a composite one, involving a combination (for instance) of insulation, vapour barriers and dry lining. The positioning of vapour barriers is particularly important, as the proper locations for them depends on the area's climate and on the type of environmental control used in the building.

8.6 Fire Resistance Performance

All solid concrete panel walling systems have high fire resistance levels (FRL)–that is, they can withstand the effects of fire and remain structurally sound for a relatively long period of time.

The Building Code of Australia (BCA) sets out the required FRL for various building elements. This requirement depends on the type of construction, the purpose of the building, the height in storeys, and proximity to the fire source.

8.6.1 For Residential Buildings

For both Class 1a and 10a residential buildings, the fire resistance performance of the walls will determine its ability to provide fire separation of the fire source from:

- the external surrounding of the building containing the fire source.
- the building containing the fire source from the adjoining or neighbouring buildings.

The FRL gives the Fire-Resistance Periods (FRP) for structural adequacy, integrity, and insulation, respectively in minutes. Solid concrete panel walling can easily be designed to achieve FRL requirements, because concrete is a naturally good fire barrier.

Section 5 - Design for Fire Resistance of AS 3600 – Concrete Structures provides methods for determining the various FRPs for concrete walls. Concrete panel systems must comply with these requirements. To achieve the required FRPs, certain criteria must be met, as defined in AS 3600:

- Structural insulation: Effective concrete wall thickness of 80mm will achieve 60 minutes and a solid 150 mm thick panel will achieve 180 minutes.
- Structural integrity: Must comply to the same level of FRP as structural insulation.
- Structural adequacy: Must comply to the same level of FRP as structural insulation, as long as AS 3600, clause 5.7.4 is satisfied.

The joints between the panels must also satisfy the appropriate FRPs. Sealant manufacturers can provide data on the performance of proprietary sealants. This topic is discussed in more depth in the section on Chapter 7, "Panel Jointing".).

8.7 Termite Resistance

Standard concrete with a minimum strength of 20 MPa is regarded as termite resistant-that is, termites cannot "eat" their way through it-so termites are certainly less likely to attack concrete panel homes than they are brick veneer or standard timber-framed homes (which is one of the advantages of concrete panel walling). But termites can still enter through openings in the walls or floor (such as cracks and joints).

Termites live in most areas of Australia, so the risk of infestation must be assessed and managed. The BCA and Australian Standard AS 3660.1 require that a termite risk assessment be performed and (if required) a management system be employed. The intention of a termite management system is to ensure that termites will not enter a dwelling by a concealed route. Termite barriers will not stop termite activity from occurring on site.

This section discusses those requirements, and how they apply to concrete panel walling (and floor slab edges).

8.7.1 The BCA

According to the BCA, installing a termite risk management system* means doing both of the following:

- Installing a termite barrier or combination of barrier systems in accordance with AS 3660.1. (Refer to the more detailed information below on concrete slabs-on-ground and suspended slabs) or termite resistant materials.
- Providing a durable notice, permanently fixed to the dwelling in a prominent location (such as the meter box), that states:
  - The method of protection,
  - The date the system was installed,
  - The life expectancy of the chemical barrier (if one is used), as displayed on a National Registration Authority label, and
  - The installer's or manufacturer's recommendations as to the scope and frequency of future inspections for termite activity.

*Variations and additional measures may be required for building in Queensland and/or the Northern Territory. Refer to the BCA, Part 3.1.3 for detailed information.

Concrete Slab-on-Ground A concrete slab-on-ground is the recommended ground floor system for a concrete panel home. The slab can support the wall panels on a rebated edge, or else the slab edge can be supported from the backs of the wall panels. If the former is true, then the slab can be used as part of a termite barrier system – but only if all the following are complied with as well:

- The slab must be designed and constructed to comply with AS 2870, and
  - For monolithic slabs, the penetrations and perimeter must be protected in accordance with the BCA requirements.
  - For non-monolithic slabs, the penetrations, control joints and perimeter must be protected in accordance with the BCA requirements.
- For slabs not constructed in accordance with AS 2870, the entire area beneath the slab and the perimeter must be protected in accordance with the BCA requirements.
- If the edge of a slab-on-ground is used as a perimeter barrier, then:
  - The edge of slab must be left exposed, and must be a minimum of 75 mm inspection zone (either on the horizontal or vertical face of a slab edge).
  - The face of the exposed edge must not be rough, honeycombed, or rippled, or contain any other imperfections that could conceal termite activity.
  - It is not permitted to fix tiles to the exposed surface, or to render it.

Termite barrier systems are designed so that if termites are present, they will be forced into visible areas where they can be seen during regular inspections. Inspection areas such as exposed edges of slabs-on-ground should always be kept clean and free of debris. Attachments such as downpipes should be located so as to permit visual inspection. A clearance of not less than 40 mm between fittings and the edge of the slab is usually adequate.

Cracking in concrete slabs constructed to AS 2870 is common, but the widths of the cracks are controlled by adequate steel reinforcement in the concrete. The appearance of cracks does not necessarily indicate a failure of the termite barrier system; many cracks do not penetrate the full thickness of the slab depth, while those that do are rarely wide enough for termites.

Suspended Floors In general, suspended floors are not used as the ground floor system in concrete panel homes, as they are more complicated to construct and connect than slabs-on-ground (and are therefore not as cost-effective). If they are used, though, the area beneath the suspended floor must be protected in accordance with Clause 3.1.3.4 of the BCA.

8.7.2 Australian Standard AS 3660.1 – Termite Management, New Building Work

Australian Standards AS 3660.1 gives the various methods and materials that can be used to provide a termite barrier system. The main ones are discussed in the following sections:

- Concrete Slab-on-Ground
- Sheet Materials
- Woven Stainless Steel Mesh
- Graded Stone Particles
- Chemical Soil Barriers

8.7.3 Concrete Slab-on-Ground

Most concrete panel homes have a concrete slab-on-ground. If the slab is to be used as a termite barrier, then all the following must be complied with:

- The slab must be designed and constructed in accordance with AS 2870 and/or AS 3600 so that it includes enough reinforcement to control shrinkage and minimise the widths of cracks in the concrete.
- All vertical constructions, saw cuts, cold joints and penetrations in the slab must be protected with a termite barrier, either a stainless steel mesh, a chemical, or a barrier of graded stone particles. It is easiest and cheapest to have the slab designed and built so that there are no construction joints. When the slab construction incorporates a joint in accordance with AS 2870 (as shown in Figure 8.7c), the slab is deemed to be monolithic, and the joint needs no further protection as long as suitable reinforcement has been used to tie the footing to the slab-on-ground.
- If the outside edge of a slab-on-ground is used as part of a termite barrier, the requirements are essentially the same as for the BCA. The surface should not be rough, and the exposed edge must be a minimum of 75 mm above the final ground level (that is, the level after landscaping and paving). This face must not be rendered, tiled, paved, clad or concealed.

As long as these points are complied with, there is no need for any additional protection against termites. This scheme is the recommended one for most concrete wall panel homes, as it is the most efficient and economical.

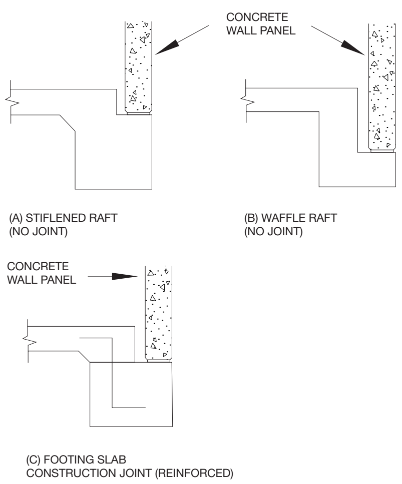


Figure 8.7 Examples of Footing Systems Requiring No Joint Treatment

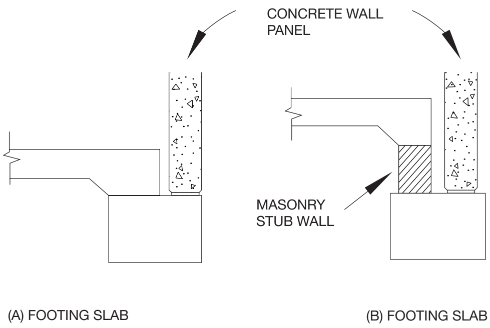


Figure 8.8 Examples of Footing Systems Requiring Joint Treatment

Concrete walling systems are usually not used for suspended ground slabs, but if they are, the slab must be designed and constructed in accordance with AS 3600. Joints and penetrations that cannot be seen must be protected with termite barriers such as stainless steel mesh, chemicals, or graded stone particles.

8.7.4 Sheet Materials

Sheeting materials refers to cappings over masonry walls, piers, posts, and so on. They are not usually appropriate for concrete panel homes.

8.7.5 Woven Stainless Steel Mesh

If woven stainless-steel mesh is to be used as part of a termite barrier system, then the mesh must meet the following standards:

- The mesh must be made of woven wire of a fine loom with a minimum diameter of 0.18 mm.
- The wire must be stainless steel (grade 304 or 316).
- The aperture of the mesh must be no larger than 0.66 mm x 0.45 mm (except in areas where *Heterotermes Vagus* (a very small species of termite) is prevalent, where an aperture of 0.40 mm x 0.40 mm is required).

Dissimilar metals must not be used in contact with the stainless steel mesh, or they could cause electrolytic corrosion of the mesh.

The parging material (grout) used to hold the mesh to the slab or wall consists of a dry mixture of Type GP Portland cement, a water-dispersed co-polymer, and aggregate that has been sieved so it will pass through the mesh. The hardened grout must be termite-resistant, and have a bond strength of at least 1 kN after 28 days. It must maintain this strength after 60 freeze-thaw cycles in saline solutions.

If the mesh must be lapped at joints, the joint should be constructed by folding 10-15 mm of the adjoining edges of the mesh two and a half times. If parging material is to be used to form the lap joint, the parging area must be a minimum of 35 mm wide along the full length of the joint.

The use of woven stainless steel mesh in concrete panel housing should be measured and it is recommended that the manufacturer's advise be sort.

8.7.6 Graded Stone Particles (GSP)

If graded stone particles (GSP) are to be used as part of a termite barrier system, they must meet the following standards:

- The stone particles must consist of crushed igneous or metamorphic stone.
- The stone must originate from a sound source (as described by AS 1141.22), and have a wet/dry strength that varies by less than 35%.
- The stone must have a specific gravity of at least 2.52.
- The particles must have a grading and shape that will deter termites.
- The stone particles must be handled and stored in such a way that they will not be contaminated by soil or organic matter.

Seals and/or capping systems, when used with GSP systems, must be continuous, and able to withstand any exposure or wear and tear they will be subjected to. The capping must always be in physical contact with the GSP, so as not to provide concealed entry points for termites. The capping or seal can consist of concrete, bituminous material, acrylics or plastics. If the capping or seal is wider than the GSP beneath it, vertical termite shielding should be cast into the capping or seal. The shielding should penetrate a minimum of 75 mm into the GSP to maintain a continuous interface.

Installation There is one acceptable method for installing an external perimeter GSP barrier for external walls: to place it in a perimeter trench adjoining the building's footings or slab-on-ground. The barrier must extend from the external ground level to no less than 100 mm below this level, and be compacted. It should be a minimum of 100 mm wide as well, and have a seal or capping.

The vertical face of the concrete slab or footing must be smooth; honeycombing, ripples, folds, or uneven surfaces must be made smooth before the GSP is installed so that there will be complete contact with the surface of the concrete.

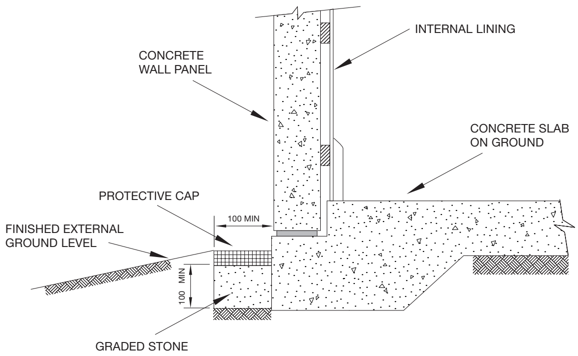


Figure 8.9 Typical Detail for Graded Stone External Perimeter Barrier at Slab-On-Ground

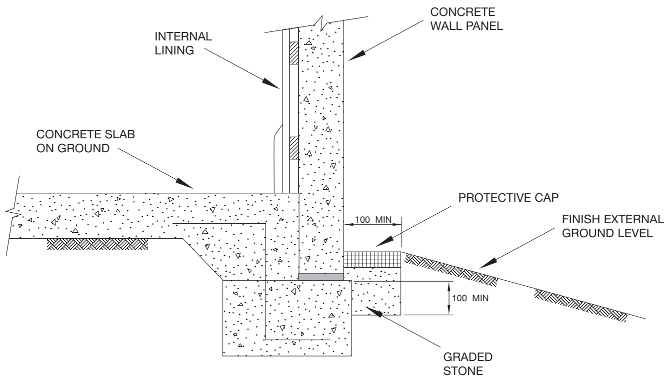
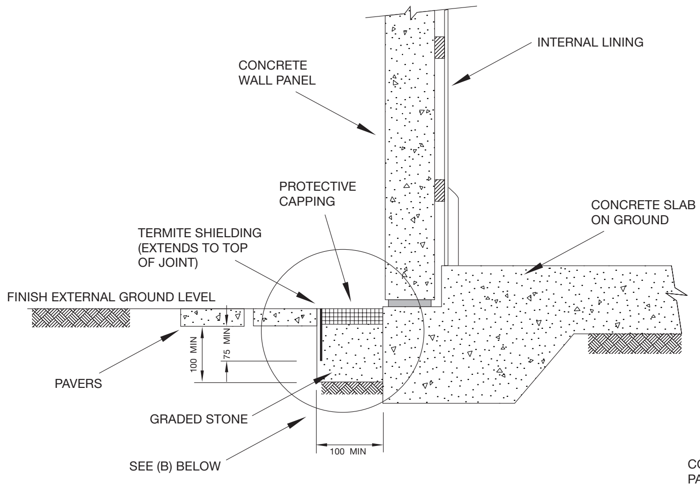


Figure 8.10 Typical Detail for Graded Stone External Perimeter Barrier at Slab with Separate Strip Footings



a) External Paving

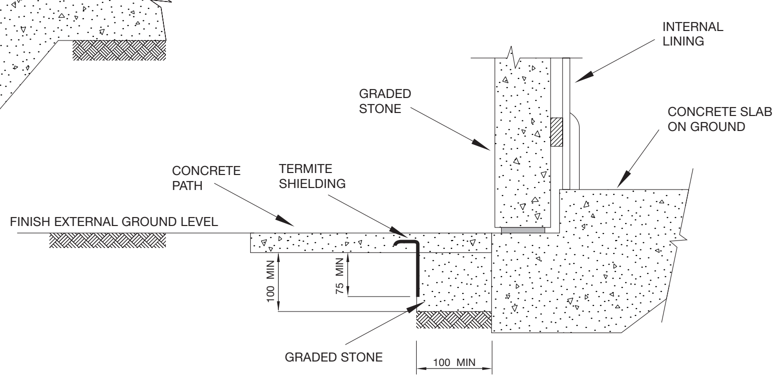


Figure 8.11 Typical Detail for External Trench Perimeter Graded Stone Barrier

b) Concrete Path

8.7.7 Chemical Soil Barriers

Chemical soil barriers are installed while the building is under construction. For effectiveness, it is essential that the whole system be installed at one time, while the entire subfloor area is accessible. The chemicals used in the system must be registered by the NRA and applied in accordance with the instructions on their labels.

Areas where chemical barriers *cannot* be installed are:

- Near drains of any kind.
- Directly on impervious surfaces (such as concrete, timber, rocks, masonry, and so on), though they can be used on cracks, faults, joints and the soil in contact with their perimeter.
- On the surfaces inside cavity walls.

Before the application of chemical mixtures into the soil, the soil must be prepared to enable the chemical to penetrate to a sufficient depth:

- Contaminants should be removed, such as building debris, timber, formwork and other waste.
- In clayey soils and on sloping sites, the chemical penetrates more slowly, and the likelihood of runoff is greater. The surface of these sites should therefore be scarified along the contours to form furrows with a minimum depth of 50 mm to 80 mm. Alternatively, a 50 mm layer of sand on the ground will help retain the chemical.
- In sandy or porous soils, where the soil is dry or loose, the ground should be moistened with water immediately before treatment.

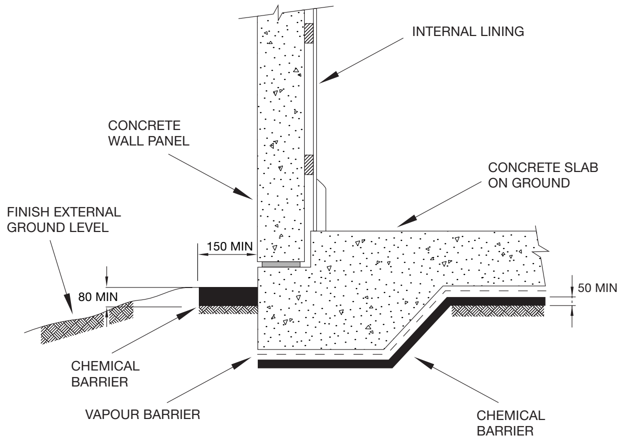
Installation/Soil Application The application of the chemical treatment must be in accordance with the manufacturer's instructions. It should be applied by hand or by a reticulation system. Soil-sampling protocols and testing methods should be in accordance with AS 3660.1 – Appendix E.

External perimeter barriers (for protecting the perimeter of a slab-on-ground) can consists of:

- A barrier not less than 150 mm wide and 80 mm deep that extends not less than 50 mm below the lowest point at which the construction could permit termites to enter.
- A barrier not less than 150 mm wide that extends not less than 50 mm below the top of footing.

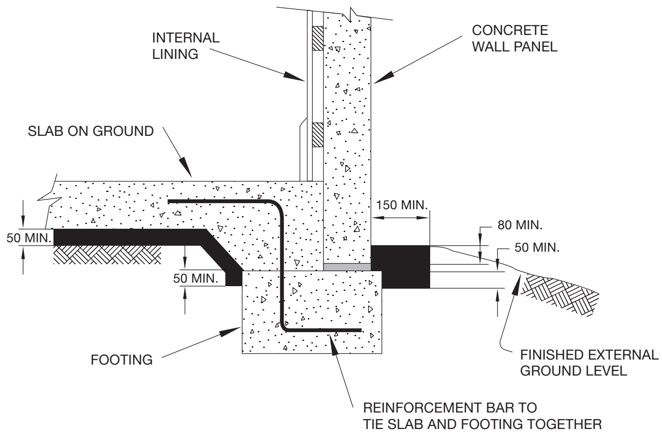
The treatment must not be performed just before or after heavy rain unless the barrier is physically protected as the rain may cause leaching and run off of the chemicals from the soil.

The acceptable way to place a chemical soil barrier is shown in the following figures.



NOTES:
1. Perimeter chemical barrier is not required if there is 75 mm min. of slab edge exposed.
2. Barrier systems will not be effective where the nest is established inside the building and has no contact with the soil.

Figure 8.12 Typical Detail for Chemical Under-Slab Barrier and Perimeter Barrier – Slab-On-Ground



NOTES:
1. Chemical to penetrate below top of footing as indicated.
2. Where required, a stepdown from the top of the slab to external weephole is to be provided.
3. Barrier systems will not be effective where the nest is established inside the building and has no contact with the soil.

Figure 8.13 Typical Detail for Chemical Under-Slab and Perimeter Barrier – Footing Slab

8.7.8 Conclusion

To provide an efficient and cost-effective termite barrier system for a concrete wall panel home:

- Design and construct the slab-on-ground in accordance with AS 2780 or AS 3600. The perimeter slab edges should be finished smooth, and should sit at least 75 mm above the final ground level.
- Concrete wall panels should bear onto a rebate of (say) 40 mm on the top edge of the slab, so that no part of the concrete wall panels is below the 75 mm inspection zone formed by the vertical face of the concrete slab-on-ground perimeter edge.
- Minimise the number of joints and penetrations in the slab, as these will be the only areas that will require additional protection (such as woven stainless steel mesh, a chemical barrier, or graded stone particles).

The combination of the three points will provide a suitable termite barrier scheme for a concrete panel home. However, the above scenario is for a simple case and only one of many possible solutions. Each individual housing situation must be examined thoroughly to derive the best solution to suit each case.

8.8 Weatherproofing

Concrete panel homes are usually more weather-tight than most other types of homes simply because of the building materials and the construction method. Concrete panels are denser (and therefore more impermeable) than conventional masonry, timber and cladding. The concrete used to produce wall panels has a compressive strength of 32 to 40 MPa. The solid construction of a concrete panel home means there are fewer entry points for water and wind ingress.

The issue of weather-tightness should not be taken lightly, though. Making a concrete panel home suitably weather-tight still requires good planning, design and construction methods.

Water can penetrate through concrete wall panels in two ways:

- Through the concrete itself (though this is rare), or
- Through the joints between panels and other panels, the footings, or the roof.

8.8.1 Water Permeability in Concrete

The watertightness of concrete is its level of impermeability to water under ambient (normal) pressure. (The term “waterproof” cannot strictly be applied to concrete, as it is a porous material and can therefore be penetrated by water under high enough pressure.)

To increase the watertightness of concrete:

- Keep the water-to-cement ratio as low as reasonably possible, while maintaining satisfactory workability, good compaction and adequate hydration. Blended cements can help make the concrete more impermeable. Silica fume can reduce the size of the pores in the cement paste.
- Use chemical admixtures, such as:
  - *Water-reducing admixtures* to increase the workability of concrete and reduce the water-cement ratio.
  - *Superplasticisers* (high-range water reducers) to allow a more flowable concrete with a low water-cement ratio and to promote efficient compaction of the concrete.
  - *Air-entraining agents* to increase the durability of concrete where freeze thaw environments are encountered.
  - *Permeability-reducing admixtures* (waterproofing agents) that minimise moisture uptake by the concrete surface under normal environmental conditions.
- Add acrylic copolymer latex to a suitable concrete mix to produce a polymer-modified concrete that is highly resistant to penetration by water and chloride ions.

Crack Control One of the easiest ways for water to penetrate a concrete wall is through cracks that have formed in the panel. Cracking can occur because of a variety of reasons:

- *Flexural cracks* are caused by excessive loads. (Widths of up to 0.3 – 0.4 mm may be acceptable in dry areas that are protected from the weather.)
- *Plastic shrinkage cracking* is caused by the surface drying too rapidly during the first two to four hours after mixing. This type of cracking can often occur through the full thickness of the panel, allowing water to penetrate. Strong winds, high temperatures and low humidity are likely to cause this kind of cracking. To minimise plastic shrinkage cracking, protect the surface of the concrete by spraying it with a layer of aliphatic alcohol after the final screeding, by applying a curing membrane or sheeting after the concrete sets, or by wetting the formwork.
- *Shrinkage cracking* is caused by drying and by temperature changes that cause the concrete to contract, and can extend through the thickness of the wall panel. As the wall panel systems discussed in this handbook are cast flat similar to a concrete floor slab and then erected into vertical position, minimum reinforcement requirement for crack control must be addressed. AS 3600 provides such minimum requirements to satisfy this.

Surface Treatments It is also possible to treat the surface of a concrete panel with a sealant or to cover it with a membrane to improve its watertightness. Mainly, though, these treatments are used on below-ground concrete panels (such as those in basements). Most concrete panel homes will not need a surface treatment any more complicated than a coat of paint or render, as concrete panels are already sufficiently watertight under normal environmental conditions.

- *Waterproofing membranes.* Available types of membranes include:
  - Cement-based render (with or without chemical admixtures to make the concrete more water-repellent)
  - Resin-based render (for resistance to chemicals)
  - Continuous vapour-proof membranes (such as in-situ membranes of rubber, asphalt or plastic, or liquid membranes applied by roller-coating)
- *Concrete impregnation sealants* can be used to make concrete watertight. These include:
  - *Silicates* (usually sodium silicate) reacts with the calcium ions in the concrete to form a calcium-silicate gel. The material is sprayed or brushed into the surface of the concrete, and penetrates dense, well hydrated concrete to a depth of 5mm. The reaction hardens the surface, but in dry conditions the gel can eventually dry out completely, allowing water to enter through the spaces it occupied. There are products available for inhibiting the dehydration of silicates in dry conditions.
  - *Silanes and siloxanes* are low-viscosity liquid sealants that are applied to the surface of the finished concrete. They create a barrier to moisture by covering the pore surfaces with hydrocarbon chains that repel water.
  - *Crystalline sealers* block water by causing crystals to grow inside the pores and seal them. Temperature fluctuations after application of the sealer can cause uneven crystal growth, so these sealers are best suited to interior or below-ground applications where the temperature will remain fairly constant.

- *Surface coatings* protect the concrete with a relatively thick surface film. They usually consist of a polymer binder, as well as pigments and fillers. Polymers used in these coatings include chlorinated rubber, epoxies, polyurethanes and acrylics.
  - *Chlorinated rubber* coatings resist moisture well and are flexible, but resist UV poorly and tend to collect dirt.
  - *Epoxies* are tough and resist water very well, but resist UV poorly and are not very flexible. They also do not allow water vapour to escape freely from the concrete.
  - *Polyurethane* paints can be formulated to produce flexible waterproof coatings with good UV resistance. Water vapour does not pass through them easily, though, so they cannot be used on damp concrete.
  - *Acrylic* and *methacrylate* coatings can be pigmented, are good at resisting water, carbon dioxide and UV, and do not collect dirt. Most of these polymers are not very flexible, but some flexible acrylic formulations are available.

8.8.2 Weatherproofing Jointing

All joints in a concrete panel home must be sealed properly to prevent water and wind from entering the structure. This section discusses available weatherproofing materials that can be used in these joints. (For further information on joints and their detailing, refer to Chapter 7, “Panel Jointing”.)

In selecting the sealant material, take into account the width of the joints, the depth of the sealant, and the anticipated movement between the panels.

The most commonly-used sealant types are *silicones* and *polyurethanes*, as they have the best properties for coping with both external conditions and movement between panels.

- *Silicones* (organopolysiloxane with a curing agent). Advantages include a transparent finish, excellent resistance to UV and high temperatures, ease of application, and excellent adhesion to the parent material. Disadvantages include a low tensile strength and resistance to abrasion, non-paintability, an inability to bond to themselves, and the uneven quality of the products currently on the market. Silicones are most suitable for expansion joints.
- *Polyurethanes* (reaction products of isocyanates and polyols). Advantages include a fast curing time, ease of application, a wide choice of products, and a wide range of uses. Disadvantages include sensitivity to moisture, moderate UV resistance, and low temperature resistance. These are the most commonly-used type of sealant for concrete panel construction and expansion joints.

Paintability The chemical composition of the sealant, and of its solvents and curing agents, will determine its paintability and the types of paint that can be used on it. As a general rule, an elastic sealant should not be painted over, as the paint is not as elastic as the sealant and may crack over time.

9 CONCRETE SURFACE FINISHES

One of the reasons that concrete wall panelling is becoming more accepted across all sectors of the building industry is that it no longer has to appear flat and grey. A wide variety of both external and internal finishes are available for the concrete panel home.

External finishes can include chamfers, grooving, and rebates, as well as various surface coatings and textures that can be used to create an individual design for each home. These finishes can be continued internally, or more conventional wall finishes (such as battens and plasterboard) can be used instead.

9.1 General Design Considerations

Simplicity of finish should be the primary objective.

The concrete mix design should be appropriate for the quality of surface finish required. It should be cohesive and rich enough to reproduce any fine textures that have been specified. To ensure a uniform colour on concrete surfaces, it is necessary to maintain a consistent supply of cement, aggregate and sand. Good mix design, including controlling of the water-cement ratio and minimum cement content, will also help maintain colour consistency. (Note it is these considerations, rather than structural ones, which may determine the specification of the concrete.)

Simple surface treatments are:

- Rebating and grooving
- Surface coatings
- Cement-based renders

Other more complex treatments can also be used, such as:

- Formliners
- Oxide colouring
- Exposed aggregate

To ensure that a particular surface treatment or combination of treatments meets with the specified requirements, it may be necessary to construct one or more test panels prior to the casting and treatment of all the panels.

9.1.1 Casting Surface

In most cases, the casting surface will have a direct bearing of the finish quality of the panel, as any imperfections on the casting surface will be reflected on the panel surface. Care should be taken that its finish is uniform over the casting area, and that its flatness is controlled.

For cast on-site panels, to reduce the risk of a joint on the casting bed being reflected in the panel, restrict the location of contraction and construction joints in the area of the casting. If this is not possible, the joints should be filled with plaster (which can be removed after casting) and the surface smoothed over to match the texture of the surrounding floor. Any surface penetrations should be filled and inspected for smoothness before pouring.

9.1.2 Surface Flatness

Surface flatness affects the final appearance of concrete wall panels. In large unbroken walls, for example, strong glancing light can accentuate any unevenness in the panel surface.

Texturing purposely provides relief from large expanses of flatness by creating shadows. The greater the depth of texturing, the less noticeable will be the shadows created by glancing light.

Surface coatings can diffuse light over the surface. The less gloss the coating, and the greater the degree of texturing, the more the effect is enhanced. Textured coatings are usually more costly than traditional paint systems, so the final selection of finish may need to balance desired degree of texturing against cost.

9.2 Surface Finishes Under Australian Standards

Australian Standard AS 3610, Formwork for Concrete, covers only off-form surfaces and does not apply to unformed or subsequently-treated surfaces (including pigment-coloured concrete). It would be inappropriate, for instance, to specify AS 3610 as the standard for an exposed aggregate finish that is both unformed and surface treated.

Australian Standard AS 3600, Concrete Structures, makes mention of a S-Class concrete that can be used to specify colour concrete applications, as well as any other non-standard concrete mixes.

9.2.1 Applied Low-Build Finishes

For applied low-build finishes, such as paint, the concrete panel should comply with good concreting practices. AS 3610 may require treatment of air holes or other minor imperfections in the surface of the panel before application of the surface coating. Unless otherwise agreed, this treatment is usually the client's responsibility.

9.2.2 Surface Classes from AS 3610

Class 1 This is the highest standard with the most rigorous specification of off-form surface finish available. It should be used only for "very special features of buildings of a monumental nature" that can be cast in a single pour. **A Class 1 off-form surface finish is not suitable for concrete wall panels, and should never be specified in domestic construction.**

Class 2 This class is specified for most high-quality architectural concrete finishes. The resulting finish should be uniform in quality and texture over large areas. It is intended to to have a superior appearance when viewed at close quarters. This is the highest level that should be specified for concrete wall panels (though it may still be too high a level for what is required for most houses). Producing this level of finish may cost more than producing a Class 3 finish.

Class 3 This class of finish has a good appearance when viewed at close quarters. For concrete wall panels meant for a home, this level of finish is usually the most suitable and cost-effective one. This level of off-form surface finish should usually be the lowest one specified for concrete wall panels.

Classes 4 and 5 These classes of finish are for concrete elements whose appearance is not important, such as those that will be concealed from view. These finishes can be specified for visible surfaces that will later be surface-coated-but as Class 4 and 5 finishes can be quite rough, you will need to ensure that the surface doesn't end up too rough to take the surface coating.

9.2.3 Prototype and Sample Panels

As the current Australian Standards do not specifically cover coloured or textured concrete, it is prudent to include prototype or sample panels in any specification agreement.

The principle purpose of prototype or sample panels is to define what is achievable and satisfactory for a particular project. Defining the colour and texture range over a panel or panels for a whole project is difficult and at times can be very subjective to all parties involved. The provision for sample or prototype panels that have been approved by all parties and thus become the controls for an acceptable range of variation will provide assistance and guidance to defining both satisfactory surface colour and texture which subsequent production panels can be matched.

It is recommended that these panels are produced at full size and ideally they would be the first few panels produced. Small sample panels (that can range from 150 x 150 mm tiles to 1 x 1 metre panels) will only provide a guide to the overall visual effect of a surface finish and it will be difficult to compare a small sample panel over a full size wall panel. A full size panel may fall within the range of the sample panels when compared in isolated areas over the whole wall panel, but an overall visual effect may be patchy when examining the wall as a whole.

The construction of the prototype or sample panels should replicate the conditions and materials that will exist during panel production, including:

- Consistency of mix, water/cement ratio, and dosage rate of oxide pigments.
- Type of formwork and its absorption rates.
- Types and application of release agents and curing compounds
- Methods and rates of curing.
- Methods of panel storage.

The constructed prototype or sample panel should be stored near the panels that will be compared against it, but in a place where it will not be damaged during the duration of the project. Panels should be compared to each other when they are standing side by side in the same light, and the comparison should be made from a few metres away. Panels should be inspected while they are dry, as minor imperfections, colour variations, and even "hairline" cracks may be masked when the surface of the panel is wet.

9.3 Rebating and Grooving

One of the cheapest and easiest ways of making a flat panel visually interesting is to include grooves or rebates into the surface of the panel. Timber, steel, polystyrene or polyethylene strips can be used to form the grooves, chamfers or rebates. Such blockouts can be spot-fixed to the casting bed or formwork with contact adhesive or anchors, and should have stripping tapers on their vertical faces for easy removal.

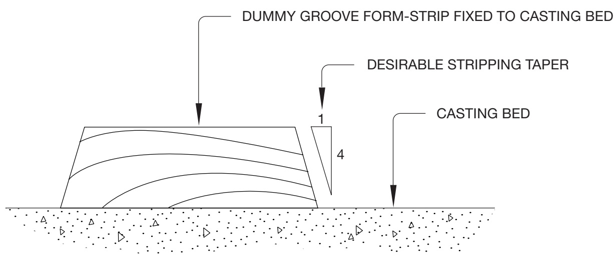


Figure 9.1 Typical Groove Formers

The depth of any groove or rebate will reduce the structural section of the panel, so this must be considered in the design of the panel. Grooves and rebates should never be more than 20 mm deep; 10 mm is usually sufficient to achieve the desired effect.

9.4 Applied Surface Coatings

Surface coatings are the easiest way to improve the appearance of a smooth flat concrete panel. Coatings help mask minor imperfections and colour variations in the concrete surface and can also be used to give an identity to the building.

Table 9.1 Surface Coating Treatments

Coating	Type	Coating Thickness	Method of Application	Colour Range
Paint	100% acrylic, matt or flat	Up to 50 microns (2 coats)	Brush, roller or spray	Extensive
Paint	100% acrylic, gloss	Up to 50 microns (2 coats)	Brush, roller or spray	Extensive
Paint	Chlorinated rubber, satin	Up to 50 microns (2 coats)	Brush, broom or roller	Extensive
Low texture coating	Acrylic base with texture building filler	250-500 microns	Spray, roller or trowel	Extensive – some products may require over-coating
High texture coating including small exposed aggregate	Acrylic base with texture building filler, one or two part system	500 microns to 4 mm	Spray, roller or trowel (experienced applicator recommended)	Extensive – can be over-coated to produce matt or gloss finishes
High texture coating including large exposed aggregate	Acrylic based system	Up to 25 mm aggregate size	Specialised applicator required	Aggregate as selected

The surface preparation, the required class of concrete finish, and the extent to which imperfections can be masked will all depend on the product chosen. The manufacturer's recommendations for application rates and methods should always be followed.

9.4.1 Parent Surface Preparation and Surface Coatings

Before using surface coatings, it is very important to remove all traces of bond breaker, release agent, or curing compound, because if they are not compatible with the coating, the coating may not adhere. Most bond breakers and curing compounds will break down when exposed to ultraviolet light, but this may take some time; meanwhile, some traces may remain even after high pressure or hydrochloric acid washes. The simplest method of checking for residual traces of these compounds is to splash an area of the panel with water. The water should be immediately absorbed, and darken the concrete, and not bead on the surface. If a slippery, shiny or oily film forms, then there is still residual compound on the panel.

The environment that the coating will be exposed to should be taken into account, and the manufacturer's advice sought. The coatings should be carried under flashings and parapets, to prevent raw edges where water can penetrate. The surface should be carefully prepared as required for the selected coating, paying particular attention to cleaning, patching and filling. All loose surface contaminants should be removed.

The moisture level and temperature of the concrete at the time of application should also be taken into consideration. The surface of the panel must have a moisture content of no more than 5% when the surface coating is applied; excess moisture in the panel may prevent the coating from adhering. The panels should be left for a minimum of 28 days to cure, and then their moisture content should be checked. Moisture meters can be used to measure the moisture level of a panel, but a simpler method is to attaching a one-metre-square sheet of impermeable thick plastic onto the panel surface, sealing it around all its edges, and leaving it for 24 hours. If after this time there is visible moisture on the inside of the plastic, then the panel's moisture content is still too high to apply the coating.

Any concrete surface that is meant to receive a "low-build" paint coating and then be seen at close quarters should have a skim coat specified under the paint system.

Table 9.1 briefly summarises the most commonly-used surface coatings. This information is meant to be used as a guide, and should be supplemented with your manufacturer's recommendations.

9.4.2 Renders

Cement-based renders can be used to coat the surfaces of concrete wall panels to create a decorative coloured and textured finish. Renders are becoming more popular, as they are very good at giving the panel a naturally-coloured and textured surface that is cost-effective to produce and easy to maintain.

A cement-based render is usually made up of the following materials:

- *Cement* – General purpose grey cement is normally used, but if a light-coloured finish is required, an off-white cement can be used instead.
- *Lime* – Hydrated lime is added to the mix to give the render a creamier, more workable consistency. It also helps to minimise cracking.
- *Sand* – The sand should be a good quality one. A coarsely graded sand is suitable for the undercoats, while a finer-graded sand should be used for the finishing coat.
- *Water* – The water should be clean and free from impurities. Mains water or drinkable water is usually suitable.
- *Pigments* – A variety of colours are available (as discussed later in this chapter) that can be added to the render. They should not exceed 5% of the weight of cement in the mix, and they must be thoroughly mixed with the other materials before the water is added. It is a good idea to produce a sample of the coloured render and allow it to dry before starting the job, to ensure that the colour is correct.

Renders can be either individually mixed or purchased in pre-mixed bags. If they are individually mixed, the proportions of the mix will vary depending on the type of background surface and the type of exposure it will receive.

Table 9.2 Render Mixes

Mix (cement : lime : sand)	Exposure conditions	Application
1 : ¼ : 3	Internal	Single coat, undercoat work (2 part)
1 : ¼ : 5	Internal	Finish-coat work (2 part)
1 : ¼ : 4½	External	Strong mix for strong background surfaces
1 : 1 : 6	External	Moderate strength mix for porous and weaker background surfaces
1 : 2 : 8	External	Final coat for weak background surfaces in shelter conditions

Parent Surface Preparation The surface should be clean, and free of release agents, bond breakers, loose materials, and so on. Purpose-made bonding agents, applied in accordance with manufacturer's instructions, can improve adhesion. After initial preparation, the parent surface should be dampened and allowed to dry immediately before rendering.

Table 9.3 Parent Surface Preparation

Parent surface	Building material	Treatment
Smooth, strong	High-strength concrete	Scabble surface and apply dash coat *
Strong, porous	Standard concrete	Rake joints and apply dash coat *
Weak, porous	Lightweight concrete, render undercoat	Dampen surface

* Dash coats are used to provide a high-strength bond between the parent surface and render coat. Dash coats contain one part cement to one or two parts sand. The coat is flicked and splattered over the parent surface to produce a rough finish to 'key' with the render coat.

Number of Coats One or two coats are usually required for most concrete panels. A minimum of three days should be allowed between coats. Undercoats are usually applied by trowel to a thickness of 10 to 15 mm, and when firm should be raked or scratched to provide a key for the next coat. The final coat should be no more than 10 mm thick.

Decorative Textured Finishes A variety of decorative textured finishes can be produced on the final coat with different finishing techniques. The application of these finishes can be difficult, so a competent tradesperson should do the job. Some of the finishes that can be created include:

- *Trowelled Finish* – Created by skimming the final coat with a wood float to produce a dense surface that can appear either smooth or notched in texture.
- *Bagged* – Created by rubbing damp hessian into the final coat.
- *Sponged* – Created by mopping or sponging the unhardened surface with a damp sponge. (Excess water from the sponge should not be allowed to run down the wall.)
- *Roughcast* – The final coat is thrown or flicked onto the wall with no additional rework.

Control Joints Cement-based renders can crack as a result of shrinkage or movement in the parent material. To minimise cracking, control joints should be placed to coincide with all joints in the parent material and with all locations where movement is likely to occur.

Curing All render coats (undercoats, dash coats, and final coats) should be kept damp for the first three days, or until the next coat is applied. Render should not be allowed to dry out quickly. Don't render in direct sunlight or in exposed windy areas, as these conditions will dry out the render too quickly and reduce its strength. Fresh render should be protected for the first three days after application. If plastic sheeting is used for protection, ensure that the sheeting does not touch the render, as this may lead to discolouration. Internal render should not require any additional protection, as long as the building itself provides enough.

9.5 Integral Colouring and Texturing Concrete

Another way of colouring or texturing a concrete panel is to colour or texture the concrete itself. Specific types of cement, aggregates and pigments can be used to give the panel a particular colour or texture. Formliners or stamps can create patterns on the surface of the panel. Colours and textures can be used in combination to create further variations.

The main constituents of concrete – the cement and the aggregates – play a large part in determining the final colour and texture of the concrete. The colour can, if necessary, be modified further with mineral oxides.

Cement Cement is produced in grey, off-white, and white, and the colour you choose will have a direct effect on the colour of the surface finish. Shades vary from manufacturer to manufacturer, so all the cement should come from one source to ensure a consistent colour. White and off-white cements are more consistent in colour–but are also more expensive.

Aggregates In exposed aggregate finishes, the aggregates will influence the colour. The colour of the sand or fine aggregate will tend to dominate in lightly-exposed aggregate finishes (like abrasive blasting, acid etching, or surface set retarders), while the colour of the coarse aggregates will dominate in more heavily-exposed finishes (such as water washing, heavy abrasive blasting, or honing and polishing).

Mineral Oxide Pigments Mineral oxides occur naturally in soil and rock, but they are also made synthetically. Synthetic oxides are more widely-used because they are purer, more uniform, and better colouring agents. They are suitable for concrete because of their chemical inertness: they do not react with the alkalies in cement, and they resist fading under exposure to weather and UV light.

Unlike dyes, which colour by staining, mineral oxides are insoluble in water and colour the concrete by masking the cement matrix. They come in either powder or liquid, and are available in a wide range of colours.

9.5.1 Colouring

Integral Colouring Integrally coloured (or "colour-through") concrete is concrete whose entire mass is coloured. If used in the correct proportions, the colouring oxides do not have a significant effect on the strength of concrete. The amount of oxide required is usually no more than 5% of the weight of the cement, and must be thoroughly mixed into the concrete mix to ensure consistency of colour.

Coloured Topping Slabs A monolithic topping is a layer of concrete that is placed on top a structural panel while the concrete is still plastic, allowing the two to bond as they set and harden together into a single (or "monolithic") element. This process reduces costs, as only the topping is coloured. The concrete topping usually consists of a 10 mm aggregate mix in a layer from 25 to 40 mm thick.

Dry Shake Toppings These toppings are created by hand-broadcasting a coloured dry-shake mixture over the surface of the panel, following the evaporation of the bleed water. The surface is floated (ideally by hand, though this may not be practical for large areas). If a power float is used, care must be taken not to work the coloured mixture into the surface of the panel–but even then, up to three coats may be required to produce a uniform finish. The coloured dry-shake toppings can be supplied pre-bagged; they contain mineral oxides, cement, sand, and a surface hardener to strengthen the coloured surface.

9.5.2 Off-form Texturing and Stamping

Off-form finishes are produced by casting concrete against a mould, formliner, or form-face, which imparts its texture or pattern to the surface of the concrete. The most common example of this technique is the standard smooth off-form finish. Off-form finishes are usually created on the lower face of the panel (the side on the casting bed).

Stamping is a method of imprinting the concrete surface by pressing a stamping-mould or tool into it. Metal dies or rollers with textured rubber mats can be used to replicate stonework. This kind of texturing is carried out on the upper (trowelled) face of the panel.

If you plan to use these types of finishes, keep the following points in mind:

- Textured or replicated surface finishes can hide imperfections in the concrete surfaces.
- Good formliner materials include polystyrene, rigid plastics, fibreglass, polyurethane rubber, silicone rubber, steel plates and timber battens.
- The choice of formliner material should take into account the complexity of the formliner, the required surface texture, and the number of times the liner is to be reused. Undercut surfaces should be formed with flexible liners, such as polyurethane or silicone rubber, so they can be stripped without damaging the panel.
- Joints created by abutting liners must be sealed well, as leakage can cause discrepancies in both the texture and the colour of the rest of the panel.
- High temperatures can degrade the liner material. Prolonged exposure to direct sunlight can also damage formliners.
- Formliners should be cleaned thoroughly and coated with a compatible release agent before they're reused.

9.5.3 Exposed Aggregate Finishes

Exposed aggregate finishes by definition reveal the aggregates (sand and stones) near the surface of the panel, which are otherwise hidden by a thin layer of cement paste (matrix). This can be produced by various techniques that result in different depths of exposure and texture. Techniques include abrasive blasting, acid etching, bush hammering, water washing, honing and polishing.

The type of aggregate used will affect both the density of exposure and the colour of the final finish. Coarse aggregates are available in a wide range of colours, including white, black, green quartz, dark grey basalt, brown and red gravels. Sands are also available in a range of colours. The cement matrix can also be coloured, using mineral oxide pigments that either complement or contrast with the aggregate.

Grading As defined by Australian Standard AS 2758.1 – Aggregates and Rock for Engineering Purposes – Concrete Aggregates, a coarse aggregate has a nominal size of not less than 5 mm, and a fine aggregate is smaller than 5 mm.

Abrasive Blasting Also called sandblasting or grit-blasting, this technique involves blasting the surface of the panel with sand, boiler slag or carborundum to remove a specified amount of the surface. It produces a cost-effective finish with good weathering characteristics.

There are four grades of abrasion:

- *Brush Blasting* – A light surface texture, similar to sandpaper, that does not reveal the coarse aggregates. The dominating colour is from the cement paste. This type of abrasion can be performed after the panel is seven days old.
- *Light Blasting* – Exposes the fine aggregates (sand). The dominating colour is from the sand, while the colour of the cement paste and coarse aggregates are secondary. This type of abrasion can be performed when the panel is between 7 and 45 days old.
- *Medium Blasting* – Exposes the coarse aggregates so that they project approximately 3 to 6 mm proud of the surface. The coarse aggregates should be hard enough not to be eroded during the blasting. This type of abrasion should be performed before the panels are 7 days old, and the use of a chemical retarder is recommended.
- *Heavy Blasting* – Results in the coarse aggregates projecting by up to a third of their diameters from the surface. To achieve uniformity, a higher-than-usual proportion of coarse aggregates is usually required in the mix. The colour is dominated by the coarse aggregates. This type of abrasion should be performed within 24 hours after casting, before the concrete has reached full hardness. The use of a chemical retarder is recommended.

Key points to consider for abrasive blasting:

- An experienced operator is necessary if the finish is to be uniform.
- The concrete must be placed and compacted well, as sand blasting will reveal any air pockets or uneven compaction.
- All panels must be abrasive-blasted at the same age, so that the finish will be uniform.
- After sand blasting, a light acid wash should be used to clean the surface.

Acid Etching In this method, a diluted acid is applied to the concrete panel to remove the surface and expose the underlying aggregates. The resulting textures usually resembles fine sandpaper (though deeper etches are possible if it's necessary to expose the coarse aggregate).

Key points to consider for acid-etching:

- An experienced applicator should always be used.
- The concrete must be high-density, well-compacted, free from cracks, and of sufficient thickness above the reinforcement.
- The panel should be inclined during etching to prevent the acid from pooling and etching some areas more than others.
- After etching, the surface must be thoroughly washed with water to remove residual acid.

Water Washing This technique is performed on the panel once it has stiffened, but while it is still plastic. The top surface of the panel is sprayed with water to wash away the cement paste and exposing the coarse aggregates underneath, so that they project from the surface by up to a third of their diameters. The exposed aggregates are non-absorbent, so this finish is good at resisting staining from air-borne grime, and is therefore low-maintenance.

Key points to consider for water washing:

- Aggregates should be 10-14 mm in diameter. Dense stones (such as river gravels, crushed granites, and rounded or cubic quartz) are the most suitable types.
- A gap-graded mix (a mix with just one size of aggregate) produces a more uniform surface than one with different sizes of aggregate.
- Stock piling specified aggregates will help maintain colour consistency.
- The cement matrix can be coloured with mineral oxides that either complement or contrast with the aggregates.

- Panels are usually cast face up so that they can be washed while the concrete is still plastic. If the panels are cast face down, then a surface set retarder is used, and the panels are washed immediately after they have been stripped.
- If the panels are cast face down, you can lay split rock, cobbles or thin brick tiles onto the casting bed after it has been lined with surface set retarder (but before pouring). After the panel is stripped, the surface of the concrete can be washed away, exposing the rock, cobbles or tiles.

Honing and Polishing Honed or polished concrete is produced by grinding the surface to expose the underlying aggregates. The resulting finish can range from a dull honed finish to a high-lustre polished finish. The type of aggregate determines the possible level of polish. Most commercial quartzites, limestone and basalt can be honed, but not highly polished. Granites (of various colours), quartz and river gravels composed primarily of quartz can be highly polished. Keep in mind that this technique is usually much more expensive than any of the others.

Key points to consider for honing and polishing:

- A gap-graded mix (a mix with just one size of aggregate) produces a more uniform surface than one with different sizes of aggregate.
- Some aggregates contain silica, which will react with the alkalies in the cement. This reaction produces an alkali-silica gel that swells with moisture and causes the concrete to crack. Common aggregates of this type that should be avoided are chert, chalcedony, common opal, acidic or vitreous volcanic stone (such as obsidian), and mica.
- Other aggregates (such as ironstone) can contain enough iron content to produce a rusty stain when exposed to the atmosphere, and should be avoided.
- Aggregates should be stock piled to better maintain colour consistency. It is a good idea to produce test samples or prototypes of the specified finish for inspection to maintain quality.
- The cement paste can also be coloured using mineral oxides. (For details, refer to Section 9.5.1, "Colouring".)
- Small, awkward areas, such as reveals and internal corners, can be polished using small hand tools.
- Care should be taken when polishing the edges or corners of the panel, as they are vulnerable to chipping. A chamfer or bevel should be provided along these edges if possible.

9.6 Decorative Exterior Façade Mouldings

Decorative exterior façade mouldings can be used to add interest to the exterior of a concrete panel home. A large range of these products is available for improving the appearance of a plain, flat wall:

- Window mouldings (heads, sills, and reveals)
- Door mouldings
- Stringer, keystone and quoin profiles
- Parapet profiles
- Corbel mouldings
- Arch mouldings

The particular product range and profiles will vary with the supplier, but these products are usually made of a lightweight core material reinforced with a hard coating of resin and/or cementicious material. They are typically mechanically fixed to the concrete panels, and their joints are sealed. The assembly can then be painted, or a coating applied to match the rest of the wall.

Preparation of the panel surface and installation of the mouldings or profiles should be in accordance with the supplier's instructions to ensure a long-lasting façade detail.

Lightweight column façades can also be used to clad supporting timber or steel columns. These column façades can be installed on both load-and non-load-bearing columns. Again, installation should be in accordance with the supplier's instructions to ensure a long-lasting façade.

Figure 9.2 Decorative External Façade Mouldings: Window Mouldings. Image supplied by www.unitex.com.au.

Figure 9.3 Decorative External Façade Mouldings. Image supplied by www.unitex.com.au.

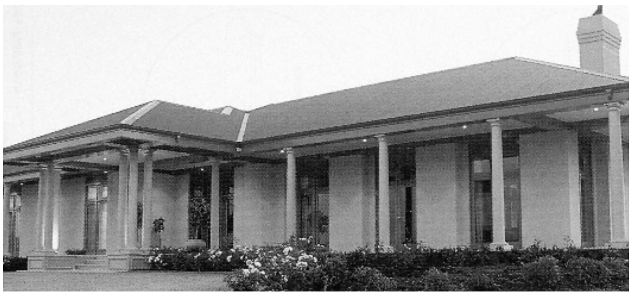


Figure 9.4 Decorative External Façade Mouldings: Column Mouldings. Image supplied by www.unitex.com.au.

10 CONSTRUCTION

This section discusses the issues concerning the construction stage for concrete panel walling.

Further details on concrete panel walling can be found in C&CAA publications: Tilt-Up Construction Notes; and AS 3850.

10.1 Planning / Programming

For all concrete panel walling types, planning is crucial to success. During this stage the entire design and construction process for the structure should be carefully planned. Time spent thoroughly planning will be regained many times over by a more productive and efficient construction stage. The various alternatives for each aspect of the project should be evaluated in the planning stage, as once construction is underway, proper evaluation may no longer be possible due to time constraints.

The walling system should be planned first, as each system raises its own set of design and construction issues. Determining whether you will use a cast off-site system or a cast on-site system will determine the set-out of the site, and the date that construction can begin. Panels that are cast off-site, freeing up site space, but requiring transport of the panels to the site. While, panels that are cast on-site, do away with the need for transport, but requiring site space for the casting beds.

Carefully assess the size of the workforce necessary to complete the project in the required time. This will depend (amongst other things) on the level of experience the workforce has with the walling system you've chosen. The learning period need not be long if there is a high level of standardisation in the panels, but allowance for learning time should be included in the overall time for the project.

Other important considerations in the planning of all concrete panel homes include:

Teamwork Planning should involve discussions between the main players in the building of the home: the Client (owner), the Builder, the Designers (Architect or Building Designer and Structural Engineer), the Panel Manufacturer and the Panel Erector. Cooperation should continue through to the completion of the project so as to ensure that the advantages of the panel system are fully exploited and that cost benefits are maximised.

It is important that each member of the team be aware of the limitations of the chosen panel system. Compromise may be necessary, so to achieve the best solution, all members should participate in all decision making. The casting and erection sequences are of particular importance, as are any changes that may occur during construction. Changes during construction should be made only after careful evaluation, since many will affect subsequent operations.

Design The structure must be designed specifically for the chosen panel system, so as to maximise the benefits of the system. For greatest cost-effectiveness:

- **Keep it simple**. Simple designs are most cost-effective.
- Optimise the panel size by balancing the maximum lifting capacity of the equipment against the benefits of on-site speed and mobility (as well as transport limitations, if the cast off-site panel system is being used).
- Standardise the panels as far as possible.
- Ensure that, if possible, the wall panels are loadbearing. Try to use the wall panel's load-bearing capacity so as to minimise the need for other structural elements.
- Make use of as many of the panels' attributes as possible (structural, acoustic, thermal, fire resistance, and so on. All are discussed in more detail in this handbook.)

There are two phases to the design: (1) structural design for in-service conditions, usually carried out by the structural consultant engineer, and (2) design for the conditions experienced during the handling, transportation and erection of the panels, carried out by either the structural consultant engineer or a design engineer employed by the panel manufacturer.

The design phase is discussed in more detail in Chapter 3, "General Design Considerations" and Chapter 8, section 8.2 – "Structural Performance (Construction, Dead, Wind and Seismic Loads)".

Layout The panel layout should be planned so as to facilitate quick erection and avoid unnecessary crane set-ups or double-handling of panels. When planning the layout, take all of the following into consideration:

- Location(s) for crane set-ups.
- Start of erection, and sequence of panel erection.
- Size and orientation of panels.
- Size and working radius of crane appropriate for the particular panels' weights. (For face-lifted panels, the true working radius of the crane should be assessed by adding a minimum of 1.5 m to the final panel position radius. This amount may need to be increased for taller panels.)
- Any overhead obstructions (like overhead power lines, or trees) that may restrict the crane's working radius.
- The site layout should allow for all-weather access to minimise any down-time in erection of panels after wet weather.
- The structural capacity of the site (footings, suspended slabs, and so on) to carry the concentrated loads of the crane and/or transport trailer while they are carrying panels.

For Cast On-Site Panels:

- If panels are to be cast on the ground floor slab, confirm the constructed dimensions, and level and finish the slab, before constructing the panels.
- Most panel types are cast with the external face down, but some surfaces need face-up casting.
- Location(s) for casting, and the sequence of panel casting, should be planned so that so that both ready-mix concrete mixers and erection cranes will have easy access.
- The option to 'stack-cast' panels (one on top of another) will provide extra casting space on site, if the type of surface finish allows for it. If this option is adopted, give careful consideration to the casting order and erection sequence so as to minimise double-handling of panels.

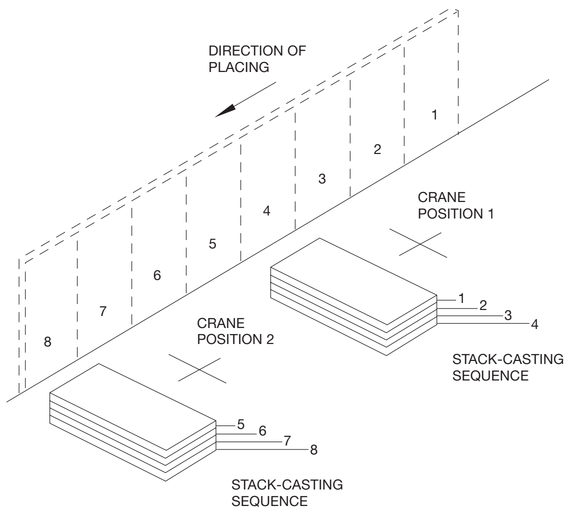


Figure 10.1 Stack-Casting Sequence

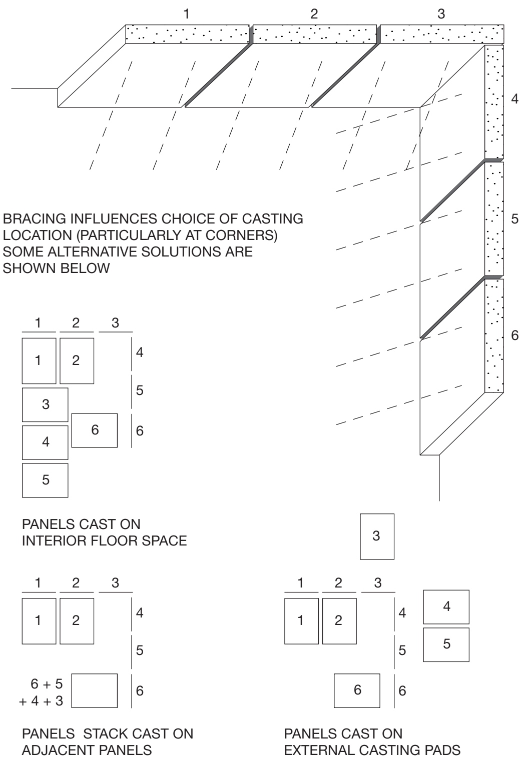


Figure 10.2 Influence of Bracing on Casting Layout

For Cast Off-Site Panels:

- Determine size and type of transportation required to bring the panels to the site.
- Plan the loading sequence and delivery sequence of panels so as to minimise double-handling of panels on-site.

Structural and Shop Drawings For effective concrete panel walling construction there must be good structural engineer's drawings of the structure's design (including the panel walling system design), as well as shop drawings of the individual panels, the layout elevations, and the connection details.

Structural drawings should be produced in accordance with Australian Standards AS 3850 and AS 3600, and contain sufficient information for detailed shop drawings to be prepared. Structural drawings should include at least:

- The project location.
- Elevations clearly indicating the structural framing and panel layout.
- The structural dimensions.
- Reinforcement for in-service loads.
- Framing connection locations and details.
- Panel supporting details (such as footing/pad).
- Design criteria affecting construction, including lifting inserts, bracing and strongback locations (if applicable).
- The fixing connections and reinforcement specifications.

Shop drawings of individual panels should include all information from the structural drawings relevant to the concrete panel walling system, and contain sufficient information to produce the individual panels. The drawings of the panels should include at least:

- The project location.
- The panel's dimensions, centre of gravity, weight, and concrete volume.
- The location of all reinforcing steel, cast-in inserts (connection, lifting and bracing), and embedded items (fixing plates, service conduits, blockouts, window or door frames).
- Edge details and panel sections.
- Architectural features and their locations (including panel surface finishes, grooves, and rebates).
- The reference number of the panel, and its location in the building plan, as well as references to the layout and elevation drawings (which should include enough information to erect the panel).

For further information on what must be included in shop drawings, refer to AS 3850.

Shop drawings should be approved by the builder, the structural engineer and architect prior to commencing panel manufacture.

10.1.1 Typical Cast On-Site Wall Panel Construction Programme

There are a variety of possible construction programmes for building with cast on-site panels that will depend on the on-site lead times, site preparation and restrictions, panel sizes/shapes, and numbers off. However, a typical programme could consist of the following steps:

- Structure is planned and designed, and walls are modularised into panels to suit the structure and construction restrictions.
- Site is levelled and any termite management systems installed.
- Foundations are dug and cast.
- Ground floor sub-base material is rolled, vapour barrier laid, and floor slab edge forms installed and accurately levelled.
- Floor slab is poured and finished by a power float.
- Once the slab has gained sufficient strength, panels are constructed on top, with either single layer or ‘stack-cast’ edge forms. Appropriate release agents or bond breakers are applied on formwork.
- Panel reinforcement and cast-in inserts are placed accurately within the moulds. Panels are concreted, finished and cured.
- After a curing period of up to seven days, panels are ready to be stripped. Braces and lifting devices are attached, and panels are gradually lifted and tilted up into an upright position. Flexure stresses during lifting reach a maximum when the panels reach an angle of approximately 30 degrees.
- Panels are then moved into position, and braces are fixed to the slab or bracing footings to temporarily restrain the panels until they are fully fixed and braced to the structure. The braces can be used to adjust the panels into their final position. Panels must not be detached from the lifting gear until they are securely braced.
- If required, suspended floors can be installed once a sufficient number of panels have been erected to support the floor.
- Roof framing can be added after all the main structural components of the house are installed.
- Servicing and fit-out work can commence within the building once it can be locked. Meanwhile, external finishing work can proceed, such as sealing of panel joints, painting, or application of other external surfaces.

10.1.2 Typical Cast Off-Site Wall Panel Construction Programme

A typical programme for cast off-site construction is similar to one for cast on-site, with a few obvious differences:

- While on-site work is being performed, the manufacture of the panels can be occurring off-site in a casting factory, and the panels can stored off-site until required. Panels are produced in steel moulds to give them a higher level of off-form finish, and are stripped after only one or two days due to the use of higher early strength concrete and/or accelerated curing methods (such as steam curing).
- Once the footing or floor slab is constructed to support the panels, the wall panels can be transported to the site in erection sequence.
- Panels are then lifted directly from the trailer into position with a mobile crane. The programme is then the same as for cast on-site panels.

10.1.3 Sequencing Roof Installation

Roof installation is usually the last of the major construction processes, and occurs only after all wall panels have been erected. Ideally, the same erection crane is used for installing both the wall panels and the roof framework, to avoid access problems and to reduce costs.

10.2 Excavation and Earthworks

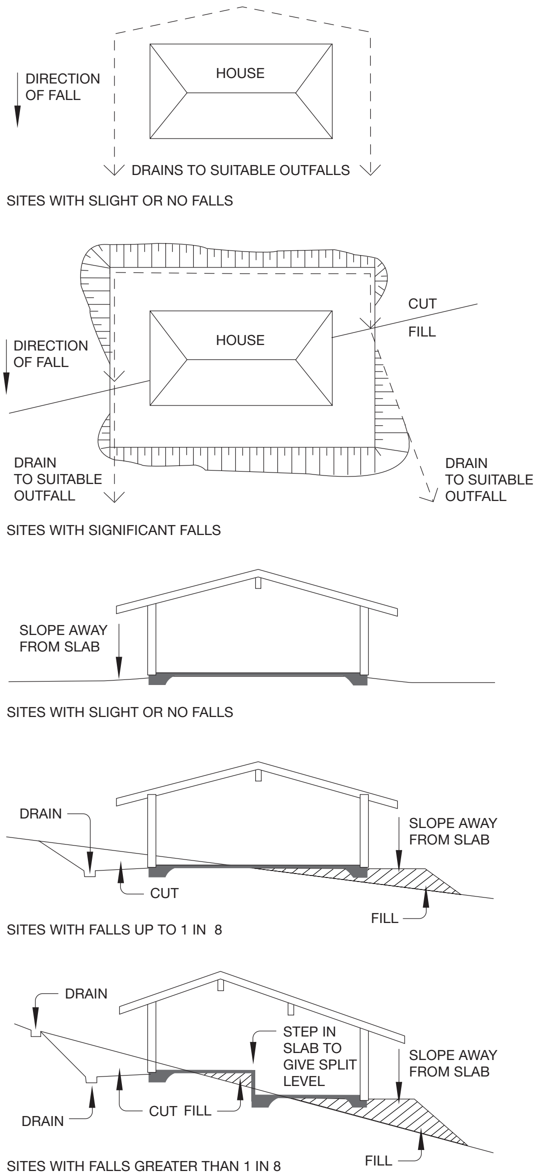


Figure 10.3 Typical Surface-Water Drainage Arrangements

Bulk excavations are best carried out by suitable earthmoving machinery. If imported fill is to be used, it is important to determine the type and makeup of the fill, and the most suitable compaction method. Various traditional compaction methods include:

- A rolling layered fill using bulk excavation machinery.
- A controlled fill using a fully-articulated or towed vibratory drum roller and/or a sheep’s foot vibratory drum roller or vibrating plate.

In some cases, local authorities may require a *Sediment Control Plan*. This is a document indicating the measures to be taken to control soil and silt run-off from the building site.

For further details regarding the BCA requirements on earthworks and site drainage, refer to the BCA, Volume 2 – Class 1 and 10 Buildings, Housing Provisions, Parts 3.1.1 and 3.1.2. Further information on slab-on-ground construction can be found in this handbook in Chapter 4, “Structural Shell”, and in the C&CAA publication, *“Residential Floors”*.

10.3 Formwork

An especially important process in concrete panel walling systems is the setting-up of the formwork or mould work that will determine the shape the panel.

The formwork must be in accordance with Australian Standards AS 3610, Formwork. Formwork often simply frames the perimeter of the panel-but the extent and sophistication of the formwork and formlining will depend on the amount of modelling and texturing required on the external surface. The choice of materials for the formwork, and the accuracy of its construction, play a vital part in ensuring that the erection process goes smoothly and efficiently.

The possibility of re-using formwork should be considered during design. Timber formwork is versatile, and cheaper than steel, but steel forms can be re-used more often, and may therefore end up being better value.

Currently, timber is most often used for cast on-site panel systems, while steel is preferred for cast off-site panels systems. If timber formwork is to be used, it should be sealed, and the timber should be of suitable quality to enable the forms to be reused.

The number of “square” edges should be minimised along the panel, as they are susceptible to damage. Chamfered or bevelled edges are more durable, and can easily be produced with a steel, timber or plastic triangular fillet strip fixed to the edge formwork.

To make vertical formwork easier to remove, it should have a ‘stripping taper’. This is especially important for recesses, rebates or groove formers that are formed off the casting bed, which will be very difficult to remove from the face of the panel without stripping tapers on the vertical side faces of the formers.

Surface Finishes The panel surface finishes are influenced by the formwork surfaces: the concrete panel surface will reflect any imperfections or blemishes in the form it is cast on. Special care is therefore required to control the tolerances and finishes of all surfaces, especially the main faces of the panel.

If temporary bracing for the side forms are located on the casting surface, they should be positioned so that they don’t mark the surface of the panel cast over them. Formwork that is to produce recessed areas in the panel face should be robust enough and be secured well and remain in place as the concrete is placed and compacted. (If a recess-former moves out of position, it’s usually not noticed until the panel is cured and stripped from the mould.

For cast on-site panels:

- If panels are stack-cast (cast one on top of another), additional care needs to be taken with the top-steel floated surface of the panels, as any imperfections (like trowel marks, joint lines, uneven surfaces, or boney areas) will be reflected in the next panel cast on top.
- If openings (for pipes, utilities, and so on) must be left in a floor slab that is to double as a casting slab, then a form ply or a 20 mm coat of concrete on a sand fill can be used to close the opening temporarily. The infill can be knocked out after the panels have been erected.
- Check the tolerances on the floor slab to ensure that it is suitable to be used for the casting of panels.

Edge Formwork Wall panels are usually cast flat, so edge formwork is all that is required. Edge formwork can be made of timber or steel. Supports or bracing may be required to stiffen the side form to keep it straight enough to meet the required tolerances. Leave enough space between the bracing and the side forms of cast panels to avoid clashes with adjacent forms or panels during stripping and lifting.

As with all formwork, great care must be taken with the casting surface at joints, corners and edges of side forms. These areas are susceptible to damage, both to the panel and to the formwork. Special care also needs to be taken to ensure that the formwork is installed within specified tolerances to form a tight seal, and that joints in formwork-to-formwork and formwork-to-casting surfaces are sealed with a non-staining sealant. This initial care will reduce the likelihood of a leak of concrete slurry or mortar, which can lead to honeycombing or discolouration of the panel surface around the leak, and weakening of panel edges.

Blockouts and groove or rebate formers can be made from timber or steel, but plastic and high-density polystyrene can be used instead; these materials can be cheaper and maybe more practical (depending on the sizes, shapes, and number of reuses required).

Bond Breakers “Bond breakers” or “release agents” are coatings that prevent a bond from forming between panel surfaces, or between a panel and its formwork. They are critical to the manufacture of concrete wall panels: if a panel doesn’t separate easily from its casting mould or formwork, it can delay the entire production schedule. The additional force needed to strip a stuck panel can damage both the panel and the formwork.

If panels are stack-cast, or cast on a concrete surface, the bond breaker acts as a water-repellent film that seals the concrete casting surface against the absorption of cement paste, preventing adhesion to the panel above.

In short, the functions of the bond breaker are:

- To enable a clean, complete separation of the panel from the casting surface.
- To minimise the dynamic loading caused by suction at time of separation.
- To function as a curing compound for the casting surface (in the case of panels being stack-cast, or cast on a concrete floor slab).

If the bond-breaker leaves a residue on the panel or the casting surface, it must not discolour it, or affect the adhesion or performance of any subsequent coatings or coverings that the panel is to receive.

Bond breakers are of various types:

- Film-forming bond breakers These form a waterproof coating on the concrete surface. Most also double as a curing compound if applied to the top surface of the concrete immediately after finishing. A second coat must be applied later. Using this type avoids any problems of incompatibility between curing compound and bond breaker. This type of bond breaker is usually used on panels that are cast on concrete surfaces (either on the floor slab or on top of another panel).

- Resin-based film-forming bond breakers These are designed so that the film will oxidise and break down over a period of time, depending on exposure to weather and sunlight. Wax-based compounds do not break down in this way, tending to leave a residue that can interfere with applied finishes, and so are not recommended. Resin-based compounds are generally used for cast on-site panel manufacture.

- Non-film-forming bond breakers These are also known as 'release agents' and can either be reactive or non-reactive. Reactive bond breakers work by combining with the alkalies in the concrete to produce a soapy layer which prevents bonding. Non-reactive bond breakers act as waterproofers. They do not react with the casting surface, but block its pores, repelling fresh cement paste and thus preventing bonding. These compounds usually do not function as curing compounds, and are primarily used in cast off-site panel manufacture where the concrete panels are rarely cast against other concrete surfaces. The release agent should be checked for compatibility with the curing compound and any other applied finishes and joint sealants.

The compound must be applied to the casting surfaces in accordance with the manufacturer's instructions. Keep the following points in mind when using bond breakers and release agents:

- Before application, the surfaces should be free of dirt and foreign materials.
- Application should be in two coats, each application at right angles to the other so that the compound doesn't pond on the casting surface. For best results, application should be uniform and cover the entire surface.
- If the compound is designed to cure the concrete, it should be applied directly to the top surface as soon as it begins to harden, just after finishing the surface.
- The application rate of the compound should never be lower that that recommended by the manufacturer. On porous or high textured surfaces, a higher-than-recommended rate may be required.
- Application should happen before reinforcement is placed to ensure complete coverage of surfaces in corners, rebates, reveals and grooves.
- If there are lengthy delays in the casting due to weather or other circumstances, the coating should be re-examined afterward to ensure that it is still intact, and that the reactive compounds have not broken down (if they are being used). The coating may need to be reapplied. If the surface is excessively wet from rain, then the water should be removed before casting.

Freeing "Captive" Panels If a panel does not readily come free of the casting mould or surface, it's dangerous to try to pull it free with the crane: the sudden release of tension when it does spring free can damage the panel, the formwork, and possibly the crane itself.

If the panel is not too strongly bonded to the casting surface, it can be separated by driving wedges between the panel and casting surface, along the lifting edge of the panel in line with the lifting inserts, while slowly lifting the panel in an effort to peel it off. Wooden wedges are better than steel ones, as they are less likely to damage the panel.

10.4 Steel Reinforcement

The steel reinforcement for all concrete wall panels is designed to resist handling, installation, and in-service loads. It also controls cracking caused by temperatures and shrinkage stresses.

The type of reinforcement must comply with the relevant Australian Standards (AS 1302 for reinforcement bar and AS 1304 for fabric reinforcement).

There are three categories of reinforcement, as defined in AS 3850:

Structural Reinforcement includes reinforcing and prestressing steel that resists in-service loads, and controls cracking from thermal and shrinkage stresses.

Additional Reinforcement is reinforcement for resisting the additional loads created during stripping, handling and erection.

Component Reinforcement is reinforcement associated with cast-in lifting, fixing and bracing inserts, to enable them to attain their design capacities and to ensure that their failure mode is ductile rather than brittle. Structural and additional reinforcement must be shown on shop drawings, but component reinforcement can be specified as part of an insert assembly and therefore does not need to appear in the drawings.

The reinforcement 'cage' is usually in the form of one or two layers of reinforcement. If possible, the reinforcement should consist of fabric or mesh, with supplemental reinforcement bars to achieve the required area of steel in the panel's cross section. (Using fabric or mesh instead of loose reinforcement bars eliminates the time and expense of fixing the loose bars.) Reinforcement can be fabricated in one or two completed pieces and lifted directly into the casting mould, so there are minimal delays. Additional reinforcement bars are provided around the edges and any openings in the panel to strengthen corners and control cracking.

The reinforcement is usually located centrally in the cross section of the panel, but there are cases (such as panels thicker than 180mm, odd-shaped panels, or panels that will bear excessive loads) that require two layers of reinforcement. Sandwich panels need a layer of reinforcement in each leaf of concrete enclosing the insulation board. The reinforcement should always be placed accurately relative to the side forms and casting surface, using bar chairs and/or spacers of the correct size to ensure that the reinforcement has the required cover. If possible, reinforcement should be secured to keep it from moving during the pouring of the concrete. Lapped reinforcement should also be tied to avoid movement.

Finally, the whole panel must be checked to ensure that the all reinforcement is of the correct size and in the right place. Particular attention should be paid to ensuring correct and uniform cover at the corners and along reveals.

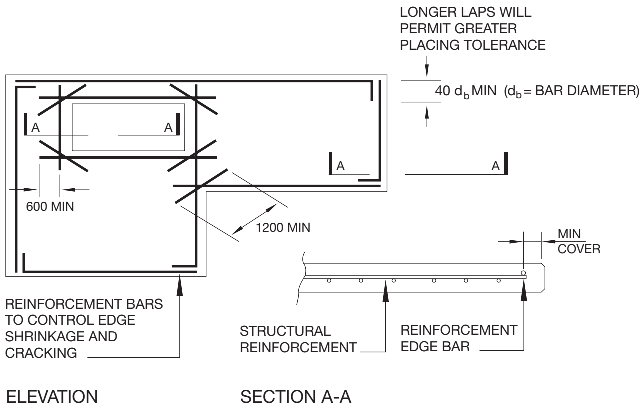


Figure 10.4 Typical Structural Reinforcement

In sandwich panels, the reinforcement for the second concrete leaf (the one poured on top the insulation board) is laid in the same way as for solid panels, except that special chairs are needed to support the reinforcement without punching through the insulation.

10.5 Fitments / Embedments

Besides reinforcement, there are numerous other elements that may need to be cast into the panel, such as:

- Lifting inserts and lifting devices.
- Bracing inserts.
- Connection or fixing inserts, fixing plates, brackets, and so on.
- Insulation board and tie inserts (for concrete insulated sandwich panels).

10.5.1 Lifting Inserts and Devices

Australia has a number of specialist manufacturers and suppliers of proprietary concrete panel lifting systems for safely handling wall panels during stripping, transport and installation. The inserts and associated lifting devices must comply with Australian Standard AS 3850, which details the correct procedures and necessary certification.

Lifting systems are comprised of inserts (specially-designed components cast into the concrete panel) and an associated lifting 'clutch' that can connect to the inserts. Lifting systems are available in a variety of types and sizes to accommodate different kinds of lifting and sizes of loads. (All lifting systems, though, should have a corrosion protective coating such as hot-dipped galvanising.)

There are two types of lifting systems: face-lifting systems and edge-lifting systems. *The inserts for one system cannot simply be used for the other*. In fact, it's extremely important that all components used for lifting be compatible with each other. For this reason, all cast-in inserts and their associated hardware should be obtained from a single manufacturer. If possible, the same size and type of lifting system should be used for the entire project, to reduce the possibility of the wrong size or type of lifting hardware being used on a lifting insert.

Face-Lifting Systems are comprised of a forged steel anchor that is cast into the face of the panel in a specially-formed recess. The head of the anchor can then be connected to the lifting clutch. If the cast-in end consists of an 'eye', a Y12 to Y20 deformed bar (of a length specified by the proprietary system) must be threaded through the eye and lapped behind the panel's main reinforcement. If the cast-in end consists of a 'foot', then no additional reinforcement maybe required. (Other types of anchors are available as well, such as plates with a splayed tail, or with an eye for an additional reinforcement bar.)

For face-lifting systems to be effective, the panel must have a large surface area on the main panel face, so as to facilitate a failure cone large enough to provide a suitable "pull-out" capacity of the anchor. Face lifting systems are available for lifting typically 1.3, 2.5, 5.0 and 10.0 tonnes. A minimum of two anchors are cast into a panel to provide for a controlled and balanced lift.

This type of lifting system is usually the least expensive of the two.

Edge-Lifting Systems are comprised of a forged steel plate anchor with a corrugated edge profile that is cast into the edge of the panel in a specially-formed recess. The head of the anchor can then be connected to the lifting clutch. Edge-lifting anchors are usually longer than face-lifting anchors, and so require additional reinforcement with Y12 to Y20 deformed bars. The bars lap around the anchor to increase the diameter of the failure cone.

Edge lifting systems are available for lifting typically 2.5, 5.0, 10.0 and 20.0 tonnes. A minimum of two lifters are cast into a panel to provide for a controlled and balance lift.

Lifting Inserts When deciding the type and number of cast-in lifting insert to use, and where to put them, all the following should be taken into consideration:

- Method of lifting (face or edge).
- Mass of the panel.
- Size and shape of the panel, taking into account any openings.
- Structural capacity of panel section.
- Concrete strength at the time of lifting.
- Capacity of the lifting insert, taking into account edge effects and embedment depths.

If wall panels will be lifted and tilted about an edge, anchors are cast into the face of the panel, but above its centre of gravity, so that the panel hangs off the vertical. (Panels lifted in this manner should be designed to hang no more than about 10º off the vertical. If this is not possible, consider using a combination of face-lifters and edge-lifters.)

Australian Standard AS 3850 requires that lifting inserts be designed, manufactured and installed such that the Working Load Limit (factor of safety) is at least 2.5 against failure. A minimum dynamic and impact factor of 20% of the dead load of the panel must also be incorporated into the design.

The lifting inserts should be marked (in a place that will remain visible after casting) with the following information, which should be checked both during and after manufacture of the panels:

- The manufacturer's symbol and name.
- The lifting capacity of the insert.
- The insert length.

Lifting Clutches With all types of cast-in lifting inserts, a purpose-made, quick-release lifting clutch is used to enable the erector to quickly and safety connect, lift and release the rigging from the panel during installation.

It is essential that lifting clutches be compatible with the lifting inserts they're connected to, both in type and in lifting capacity. It's recommended that all the items be from the same manufacturer.

The lifting clutches must be designed and manufactured with a safety factor in accordance with Australian Standards.

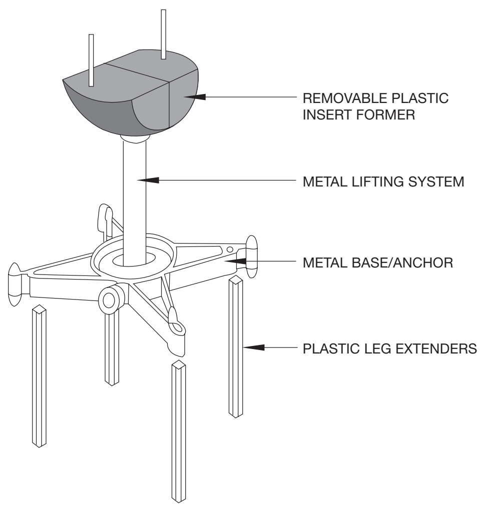


Figure 10.5 Typical Face-Lifting Insert

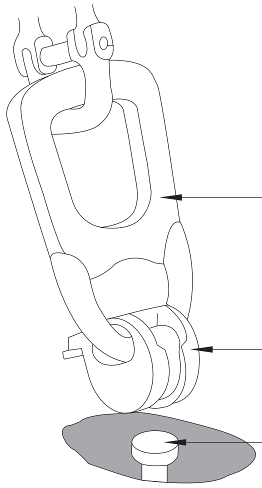
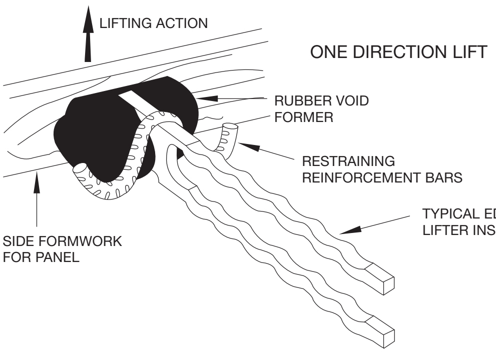


Figure 10.6 Typical Quick-Release Lifting Clutch



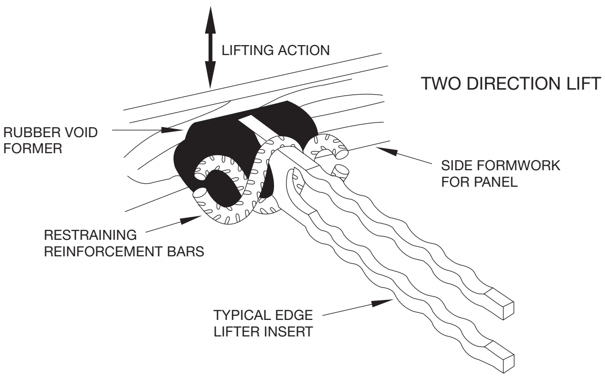


Figure 10.7 Typical Edge Lifting Inserts for One-Direction and Two-Direction Lifts. From Reid Swiftlift Concrete Lifting Systems – Design Manual.

Quick-release lifting clutches, if used properly, offer the following advantages:

- Easy positive connection to the lifting insert.
- Safe operation, as the clutch cannot be released until the tension on the lifting rigging is released.
- Easy installation and release from ground level, once panel is secured in the correct position.
- Proven and documented capacity of the lifting gear.
- Certification by State authorities.

10.5.2 Bracing Inserts and Braces

Bracing inserts are either threaded inserts (like connection and fixing inserts, discussed below), or coil-like sockets similar to the coil threads used in formwork systems.

It can be quite difficult to cast bracing inserts into ground slabs or pad footings because of the difficulties of controlling the accuracy and quality of installation on ground. In this case, another option is to use drill-in fixing anchors once the slab or footings are cast, just before installation of the panels. There are various types of drill-in anchors available, all of which must be installed in accordance with AS 3850 and the manufacturer's recommendations:

Mechanical Anchors are either installed into specially prepared undercuts in the slab, or drilled completely through and locked under the slab.

Chemical Anchors rely entirely on the chemical bond between the resins and the concrete they are drilled into and embedded in. They are very susceptible to variations in operating conditions, so AS 3850 allows them only if each anchor is individually proof-tested. Because of this restriction, and because of the delay as the resin sets, chemical anchors are not widely used.

Expansion Anchors are the most commonly-used type of drill-in anchor for fixing braces in ground slabs and footings. They are comprised of a bolt attached to one or more conical wedges enclosed in an expansion sleeve; the assembly is inserted into a hole drilled in the concrete, and as the bolt is tightened, the wedge is drawn into the sleeve and progressively expands.

Expansion anchors must be tightened to a specified torque to induce a preload in the bolt. This preload must be maintained for the load-controlled anchor to perform adequately: unless it exceeds the specified working-load limit, the bolt will eventually fail by creep pullout.

The use of any of the above anchor types should be approved by the consultant or design engineer for the project, prior to their use.

10.5.3 Connection/Fixing Inserts and Fixing Plates/Brackets

A connection or fixing insert is a ferrule, either purpose-made or a standard proprietary one, that is cast into the panel to enable it to be connected to other structural members, fixing plates, brackets and the like, with the purpose of permanently restraining the panel in its final position. The insert usually consists of an internally-threaded steel bar or tube, a base plate, and an anchor bar.

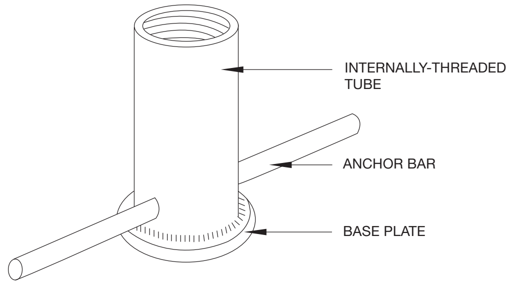


Figure 10.8 Typical Cast-In Ferrule

Inserts should be hot-dipped galvanised, or have some other protective coating, so as to resist corrosion. The positions of all inserts should be determined during the designing and detailing stages and be included on all panel shop drawings. The fixing inserts themselves must comply with AS 1110.

To remain within specified tolerances for connecting adjacent building elements, connection inserts must be placed accurately. Mistakes will mean expensive delays as the fixings are modified.

Weld plates usually have reinforcement bars protruding from the bracket that are cast into the panel. Care must be taken during the detailing of the cast-in component and the surrounding reinforcement so that they don't clash with each other, and so that the component is placed accurately and has the required cover.

10.5.4 Sandwich Panel Insulation (Board and Tie) Inserts

With concrete sandwich wall panels, rigid or semi-rigid insulation boards are normally cast into the panel, however fixing onto the panel after casting (usually after installation on site) is also an option.

The interior leaf of concrete is usually load-bearing, carrying vertical loads down to the footings. The exterior concrete leaf can be designed to carry a proportion of the lateral wind loads, though. Freedom of movement of the inner and outer leaves is important, so as to avoid induced stresses due to creep, shrinkage and temperature.

The ties that are used to connect the two concrete leaves through the insulation boards can be made from:

- Stainless steel
- Composite fibre rods
- Other non-corrodible materials

These ties transfer the lateral loads from the exterior leaf to the interior leaf, while allowing the exterior leaf to move independently in response to temperature changes. The type of tie is usually determined by the proprietary insulation system chosen.

Stainless Steel Ties These ties come in a variety of shapes, such as looped pin ties, round or sleeve connector anchors, or flat plate anchors. The ties or anchors are made from either 304 or 316 grade stainless steel. They connect both inner and outer concrete leaves through the insulation boards to produce an integrated unit that effectively behaves as a monolithic concrete panel. The setout and spacing of the ties and/or connectors will vary depending on the particular design and system used, but the typical spacing for these ties and anchors is at intervals of 1100 to 1200 mm, with an edge distance of 100 mm.

Composite Fibre Connectors The composite fibre connector system is the most commonly-used insulation system and is often the simplest to install. The connectors are usually made from a glass fibre composite material and are extremely resistant to corrosion. They can have up to three times the elasticity and twice the tensile strength of mild steel, and cause minimal heat loss through thermal bridging.

Composite fibre connectors usually come in the form of stubby cylindrical ties that have wedged ends to lock the ties into the concrete. Like stainless steel ties or anchors, they are cast into the bottom leaf of concrete, and the insulation board is laid on top. The spacing of the connectors will vary depending on the proprietary system used, but can range from 400 mm to 1000 mm.

The type of proprietary thermal insulation system you use will determine the type of ties and thickness of the insulation board. It is strongly recommended that you consult with the manufacturer as to the most suitable system for your project, so that you end up with the most efficient design possible.

10.6 Concrete Requirements

Concrete to be used in concrete wall panels should have the appropriate strength, workability and durability.

10.6.1 Strength (High-Early Strength)

The strength of concrete for concrete wall panel projects has to satisfy two design criteria:

- It must enable the panel to function in its final position as part of the complete structure.
- It must enable the panel to resist the forces to which it is subjected during erection and bracing.

The panels frequently experience their greatest stresses during stripping and lifting, when the concrete is still relatively "green" (weak in strength). The concrete must have sufficient tensile strength at time of stripping to resist stresses caused by:

- Its own weight.
- The lifting point configuration.
- Suction forces between the panel and casting surface.
- Dynamic factors (such as lifting speed, sudden movement, and so on).

Correctly determining the panel thickness, lifting point configuration, and concrete strength will enable the designer to ensure that tensile stresses do not exceed allowable limits during the lifting process.

As the panels are stripped at early age, it's important to specify the concrete's strength at time of stripping. (A concrete with a compressive strength of 32 MPa or higher is usually needed to achieve the necessary early strength.)

10.6.2 Workability

Usual good work practices for placing, compacting, finishing and curing concrete should be employed. These processes should be completed as quickly as practically possible.

The most efficient method of compacting concrete is to use a double-beam vibrating screed (if possible) in combination with conventional poker vibrators. The poker vibrators should be used to ensure full compaction at the edges, blockouts, penetrations in the panel and around the lifting and bracing inserts. The vibrating screed supported from the edge formwork will produce a flat, well compacted surface that will require minimal finishing.

Concrete suitable for mechanical compaction and finishing should have a slump of not more than 100 mm. An 80 mm slump is usually be appropriate.

10.6.3 Durability

AS 3600 gives the grades of concrete to be used in various exposure conditions. The Standard also nominates the minimum cover to reinforcement for different exposure conditions. The table below gives these values.

Note that concrete grades less that 32 MPa have be listed for some exposure conditions, but lifting stresses during stripping usually necessitate grade 32 or greater.

Table 10.1 Concrete Grade and Reinforcement Cover for Various Exposure Conditions (extracted from AS 3600, Tables 4.3 and 4.10.3.2)

Exposure condition of either surface[1]	Concrete strength (MPa)	Min. cover to reinforcing steel[3] (mm)
Fully enclosed inside a building:	20	20
Inside a building subjected to repeated wetting and drying:	32	40
Above ground in exterior environments[2] and in...		
• in a non-industrial zone with...		
– an arid climate:	20	20
– a temperate climate:	25	30
– a tropical climate:	32	40
• in an industrial zone:	32	40
• between 1km and 50 km from coastline:	32	40
• up to 1 km from coastline, but not in a tidal or spray zone:	40	45
In contact with ground[4]	25	30

Notes:
[1] Exposure conditions other than those specified in the table may have to meet with additional requirements for protection of both concrete and reinforcing steel.
[2] An exterior wall can have internal and external exposure. Only the higher concrete grade should be used, but reinforcement cover may vary according to the exposure of the particular surface.
[3] Protective surface coatings can be included in the depth of cover, but their performance should be established before reducing cover below the value shown in the table. For details, refer to AS 3600, clause 4.3.1(c), note.
[4] Applies to non-aggressive soils only. Refer to AS 3600 for information on contact with aggressive soils.

10.6.3.1 During Construction

The construction processes necessary to produce a sound and watertight concrete wall panel fall into three main groups: compaction of the concrete; formwork selection and design; and curing techniques.

- *The concrete must be compacted* thoroughly to make it sound and watertight. It should be compacted using immersion vibrators (such as a stick vibrator) or external vibrators attached to the outside of the mould base or formwork to reduce the occurrence of voids and honeycombing in the panel that can lead to water penetration. Prolonged vibration should be avoided, since it can cause segregation and excessive bleeding, thus leading to areas of weak mortar at the surface.
- *Formwork selection and design* can affect the watertightness of the surface of a concrete panel. The formwork should be:
  - Able to produce a smooth, tightly compacted concrete surface finish.
  - Constructed with tight joints for good surface alignment.
  - Sealed to prevent leakage of slurry while the concrete is still plastic.
  - Coated with a surface release agent to enable easy disengagement of the forms from the concrete at time of stripping.
- Using the proper *techniques for curing concrete* enhances the strength and permeability of the concrete surface and reduces the risk of cracking. Concrete wall panels should be cured continuously for at least seven days using normal curing processes (such as moist curing, covering with an impermeable plastic sheeting, or spraying with a liquid membrane curing compound). The curing compound should have a water retention efficiency index of not less than 90% when tested in accordance with AS 3799 – Appendix B.

With all curing methods, it is vital that they be implemented immediately after the finishing operations, before the concrete surface has had a chance to dry out. In hot weather, moist curing should be continued for at least the first 24 hours, after which the concrete should be covered with plastic sheeting or liquid membrane curing compound for a further six days.

10.6.4 Summary

As a rule, the concrete for concrete wall panels should be:

- Normal Class (or Special Class if coloured or other special concrete is used)
- Grade 32
- Slump of 80 mm
- Maximum aggregate size of 20 mm

Higher early-strength grades may be required if the panels must be lifted (or exposed to harsh conditions) soon after casting.

Project testing may be required to confirm early strengths.

10.7 Transportation / Delivery

10.7.1 Loading and Transport

Planning In the planning for the transportation of the wall panels to and around the site, take all of the following into consideration:

- Before the panel design is complete, confirm that all panels will be able to be transported to the site and erected. (It is the responsibility of the panel manufacturer to ensure that the panels are sufficiently strong enough to withstand the stresses of transport and erection.)
- It is the responsibility of the transporter to ensure that all panels are appropriately secured during transport so as to prevent damage or injury. Unusually heavy panels, or panels with unusual shapes and sizes, should be fitted with additional restraints or support frames during transportation.
- Road regulations along the transport route may limit the overall weight, length or height of a loaded transport vehicle. Panels that fall outside these parameters may require additional permits, need special escorts, or be restricted to special haulage times. This will raise the cost.
- The route to the site should be examined, and possible obstacles noted, such as over-head power lines, tramlines, train lines, OD routes (recognised truck routes), roundabouts, over-head bridges, or reverse-cambers in the road.

- The panels should be loaded onto the transport in the reverse of the erection sequence, so that the last panel loaded is the first to be erected. Most transport trailers carry more than one panel per load, so if the panels are of different shapes or sizes, loading them in reverse erection sequence can result in an unbalanced load. Panels should be as evenly distributed as possible along the centreline of the vehicle, and their centres of gravity should be as low as possible.
- The panels should be loaded so that their identification markings are visible during unloading.
- Ensure that the delivery vehicle will have all-weather access to and around the site.
- Determine whether panels will need to be temporarily stored off-site (or on-site). This may be necessary to minimise the number transport loads, but may result in panels being delivered to site before they're needed.
- The lift points on each panel should be checked and clearly marked before loading and unloading, so that they can easily be located during lifting.
- It is most cost-efficient if panels are lifted directly from the transport vehicle into their final positions. Every effort should be made to ensure this happens so as to avoid the cost of double-handling panels.

Support Frames These frames are the main support for the panels, and are usually in an A-frame configuration. They support the panels in an out-of-vertical position (up to 10º off vertical) on the transport trailer, and allow for more than one panel (usually two or three, but more if the panels are small) to be transported at once. The frame must be able to withstand not only the panel weights, but also the induced dynamic loads that will be generated by the panels while the transport vehicle is in motion.

Panel Protection Places where the panel comes in contact with support frames, restraints, and other panels should be protected from damage and staining. Damage can occur during loading, transport and unloading. Staining or marking can be caused by dirty strap restraints, or even by the timber in the hardwood blocks used to support or space the panels (if the blocks get wet). If there is a danger of this, then plastic or non-marking rubber should be placed between the contact surfaces.

Concrete wall panels that are transported horizontally should be stacked so that all panel supports are directly above the panel supports below them, so that the panel loads are transferred directly from one support to another without creating any additional stresses on the panels. For rectangular panels, supports should be placed 1/5 the length of the panel from each end.

Delivery There must be an authorised traffic management plan in place on the site before any panels are delivered. It is usually the responsibility of the builder to create this plan. It may necessitate flagmen, barricades and road closure permits to allow unimpeded access to and around site for both transport vehicles and crane. Drivers of the transport vehicles should be well informed of the travel route, and they should know how to enter the site and where to bring each of the panel loads.

It is the responsibility of the driver to ensure that the load is appropriately secure at all times while it is on the transport vehicle, even during unloading.

10.8 Cranage

10.8.1 Planning

The following issues should all be taken into consideration before choosing a crane or finalising construction plans, erection sequences or panel design:

- On-site and public safety (including written procedures, training and induction schemes, requirement of safety equipment, and emergency procedures).
- Local street access, and when it will have to be restricted for unloading and erection.
- Panel sizes, weights, and on-site locations.
- Panel bracing details.
- Maximum reach of crane from set-up position to final position of erected panels. As a rough guide, crane capacity should be two to three times the maximum panel weight. Consideration should be given for extra reach from any additional lifting rigging required to lift the panels (such as spreader beams or equalising sheaves). For panels that are 'face-lifted', the true working reach of the crane may be up to 1.5 m or more than the final position of the panel, as the panel is not lifted in a true vertical position.
- Any site limitations (such as limited access due to nearby buildings or power lines).
- Capacity of floors or other areas that may need to bear the crane. Crawler mounted cranes impose higher loads than mobile cranes, as they are able to distribute the load onto a greater area.
- Required number of crane set-ups. Dismantling and setting up the crane takes a considerable amount of time, so crane set-ups should be restricted to a minimum. The more panels that can be lifted from a single position, the more efficient the process.
- If a 'dual lift' is planned, the required capacities of the cranes should be carefully assessed. The capacity of either crane should not be less than 70% of the mass of the panel.

10.8.2 Crane Position

The crane should be carefully positioned on-site to make the most of its capabilities and to minimise the erection period. If possible the crane should be always located so that 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, as the crane operator will not be able to check on the rigging during lifting, and if there is a failure, the panel will fall towards the crane. Care should be taken to ensure that bracing doesn't foul the rigging.

10.8.3 Operation near Power Lines

Crane operations near power lines certainly require pre-planning, so that the power will be isolated when the crane is working. Electric Supply Authorities can usually isolate any power line, if given sufficient notice. If power lines are isolated, the Electric Supply Authority's access permit must be obtained and kept by the crane operators during their operations.

If there is no access permit, the power lines must be treated as live. Compliance with individual state's minimum requirements for operations near live power lines must be met.

10.8.4 Rigging

Proper crane rigging is essential for successful wall panel construction. The selection and configuration of the rigging system connecting the concrete panel to the crane should be discussed and approved by the panel manufacturers and erectors. The configuration will depend on the number and location of lifting inserts, and must ensure that all inserts are loaded equally. Care during rigging is crucial for preventing accidents. Typical terminology and layouts for rigging systems are shown in Figure 10.9.

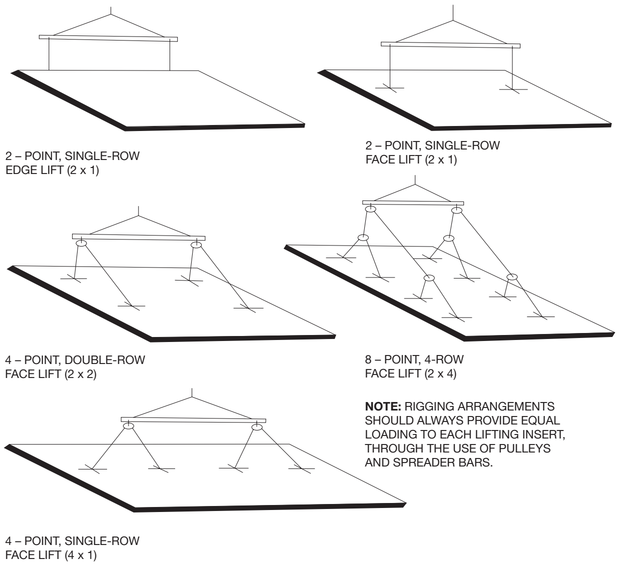


Figure 10.9 Typical Rigging Systems/Layouts

It is important to determine the proper sling length (or chain length) of the rigging for a particular lifting point configuration, especially if two lifters are connected by a single sling. Short slings can overload the lifting inserts because of sideways drag. If the slings are connected to equalising sheaves, spreader or lifting beams can be used to determine the length of slings. Single, double or even four-leg slings are commonly used. (The angle between slings at reeving points should not exceed 120 degrees.) The use of three rows of lifting inserts should be avoided if possible due to the complex rigging configurations required.

Re-useable, “quick-release” lifting devices (lifting clutches) are commonly used to enable the crane to be freed from the panel as soon as the temporary bracing has been fixed, thus speeding up erection.

Temporary bracing must be positioned clear of the lifting inserts and rigging. If possible, braces should be attached to the panel before lifting. The use of purpose-made adjustable braces speeds up the erection process. Final plumbing of the panels can be performed using these braces.

If panels need to be rotated with a tailing lifter (that is, if tall narrow panels need to be transported on their sides and rotated into vertical position), the capacity of the crane winch that is being used to rotate a panel must be approximately 70% of the mass of the panel.

10.8.5 Strongbacks

Concrete wall panels that are odd-shaped or elongated, or have large or awkwardly located openings, can be strengthened for lifting by the addition of strongbacks. Strongbacks can be formed from steel angles, channels, or even timber beams, and are fixed to the back of the panel with either cast-in inserts or temporary fixed mechanical anchors. Strongbacks should be designed by a qualified engineer and be produced and installed in accordance with design details and shop drawings.

If the panels are cast off site, strongbacks should be attached to the panels before they reach the site to avoid the crane sitting idle while this is being done.

The designer of the strongbacks should plan their shapes and sizes carefully, to ensure they do not clash with the roof, suspended floors, support angles, braces or rigging.

The mass of the strongback must be included when assessing the load on the crane. Any changes to the specified strongback system should be re-approved by the designer before being implemented.

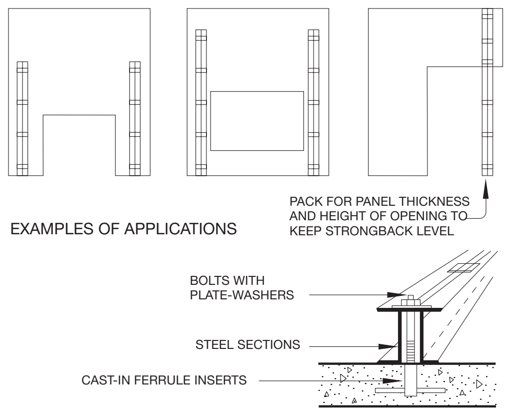


Figure 10.10 Use of Strongbacks to Strengthen Panels During Erection

10.9 Lifting and Erection

Panels must be lifted smoothly at all times. Any sudden movement can damage the panel or even the crane.

Accurate placement of the first few panels is critical for ensuring the straightforward placement of succeeding panels. Extra time should be spent on the first few panels so the erection crew can become familiar with the erection procedure.

Lifting should be carried out so that the panels are rotated about their bottom edges, which shall limit possible damage to the bottom edge. Any damage that does occur to the bottom edge can either be concealed below ground level or easily repaired. Care should be taken to avoid sliding or dragging the panel across the trailer floor, other panels, casting slabs, or the site floor, as this can damage both the panel and the surface it’s on.

Slenderness Effects Buckling and instability can occur during lifting and erection of long slender panels. Lifting inserts should be located to ensure that compression flange buckling (as in a long slender beam) cannot occur, particularly during rotation of long wall panels. The span/thickness ratio of the element between lifting points should be limited to a maximum of 60.

No one should be inside the drop zone when the panel is being lifted, tilted or rotated from the horizontal to the vertical. **At no time should anyone be underneath a panel.**

During strong winds, no attempt should be made to lift or erect a panel if there is a possibility that control of the panel may be lost. It is the responsibility of the erection crew to determine whether conditions are suitable or not.

In no case must there ever be fewer than two connections supporting a panel before the lifting equipment is released.

10.9.1 Levelling Shims / Packers

To meet tolerances in the panel's size and in the footing or foundation levels, levelling shims are usually required. They carry the vertical loads from the panel into the foundations.

The shims must be made out of a durable material and be manufactured to meet the requirements of AS 3850. The most commonly-used materials are compressive fibre sheets or P.V.C. Steel shims should not be used.

Shimming should be limited to a maximum height of 40 mm, and a minimum width of 100 to 300 mm, depending on the size of the panel. Shims should be located a minimum of 300 mm from the ends of the panel (particularly with thinner panels). There should only be two shimmed-up bearing supports per panel. Three or more supports may result in an uneven distribution on each support, and the resulting stresses can crack the panel.

Direct concrete-to-concrete or concrete-to-steel bearing should be avoided, as edge spalling and cracking may occur due to uneven bearing.

The gap between the bottom of the wall panel and the footing should be grouted or dry-packed to distribute the load throughout the footings.

10.9.2 Missing and Unusable Lifting Points

Sometimes, during the installation of the wall panels, a lifting point is incorrectly located, faulty, or even missing. If this happens, the lifting point should be identified, and the panel designer should be contacted so that he or she can establish a suitable solution to the problem.

Such a solution might include:

- Using a temporary fixing plate with undercut anchors.
- Drilling through the panel and attaching lifting plates or through-bolts.
- Placing slings or straps around the panel (if the panel is small enough to allow it).

Whatever the solution, the working load capacity must be calculated using a working load limit (or factor of safety) of greater than 2.5 against failure.

Expansion inserts should not be used as lifting points, as failures are sudden and can occur without any warning.

10.9.3 Bracing

Braces or props are temporary supports that stabilise wall panels while they ae being erected. The braces usually stay in place until the wall panels are connected together to form a self-supporting structure.

All panels should be braced in accordance with the requirements of the structural design. Shop and panel layout drawings should be followed detailing locations and types of braces to be used, as well as any requirements for the brace footings or floor slab. It is especially important that the concrete strength, and the size of footings and floor slab, be large enough to resist the anticipated loads. Refer to the figure below for a typical example of a brace set-up from which the required propping forces can be determined.

The typical setout of braces on a typical small rectangular wall panel is as follows:

- A brace is located approximately one-fifth the width of the panel from each side.
- The cast-in bracing inserts are located two-thirds the height of the panel from the base.
- The braces form an angle of approximately 60º with the ground slab or footing.

As panel shapes and sizes vary, though, each panel's bracing should be individually reviewed and, if necessary, individually designed.

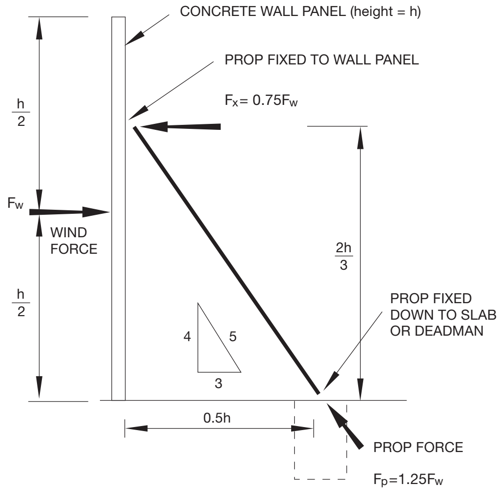


Figure 10.11 Typical Bracing Set-Up

The braces should have a permanent name plate displaying:

- The supplier's or manufacturer's name.
- The model type or designation.
- The maximum safe working loads for minimum and maximum extensions.

Adjustable braces must have stops on the threads so as to prevent over extension.

Wherever possible the bracing should be fixed to the panel before lifting. During lifting the erection crew should adjust the extension of the braces (if necessary) to ensure that the braces do not hang below the base level of the panel. In the case of face-lifted panels, both lifting inserts and bracing inserts should be installed on the same face of the panel so that the crane operator is able to observe both lifters and braces during the lift.

If braces must be attached to the panel after it has been lifted into place, the panel should be hung just past the vertical while the braces are being installed. <u>No personnel should ever work on a panel that is leaning towards them</u> until the panel is secured.

A minimum of two braces should be used to stabilise a wall panel (though this may not be necessary if other fixing brackets or permanent connections are present).

After erection of the panels, the braces and their associated components should be checked at regular intervals to ensure their integrity. If there is a requirement to service the braces, it should be done by the bracing installer or supplier.

Before the bracing is removed, the structure created by the panels must be secure and stable. It is usually the responsibility of the design and/or consultant engineer to ensure that this is so. Braces should be removed only upon written instruction.

10.10 Tolerances for Construction

In all concrete panel construction, suitable construction tolerances must be catered for in the building structure. It is especially important that specified panel and joint tolerances be realistic. Once they are established, they must be assiduously maintained, or finished walls will not be the right length.

Depending on the size of the tolerances, joints can be used to absorb any variations, either progressively at each joint or collectively at one location. If panels are being erected in conjunction with in-situ construction, then the tolerances for the panels should not be used to compensate for construction errors in the in-situ work.

Joint Tolerances Joint tolerances are important for the performance of the joint sealant (most of which have a movement capability of around +25 %), and therefore are critical to weatherproofing. It's best to maintain joints at their specified widths, and to take up any variations at doorways (or oversail corners, if applicable).

Panel Tolerances The panel tolerances can have a marked effect on all aspects of the construction: the tighter the tolerances, the greater the expense required to achieve them. If panels are carefully formed and thoroughly checked before and after manufacture, though, and if their footings are checked as well, then the tolerances listed in the following table are both achievable and cost-effective:

Table 10.2 Recommended Tolerances on As-Cast Panels (Table 3.11(A) of AS 3850)

Panel Height (m)	Tolerances (mm)						
	Linear			Angular	Profile		
	Width	Height	Thickness	Squareness[1]	Twist[2]	Warp[3]	Straightness of Edges and Flatness of Surfaces
<3	+0,-6	±3	±3	±4	±3	±3	± Length / 1000
≥3 <6	+0,-6	±6	±3	±5	±3	±3	± Length / 1000
≥6 <10	+0,-6	±6	±3	±6	±3	±3	± Length / 1000
≥ 10	+0,-6	±6	±3	±8	±3	±3	± Length / 1000

Notes:

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

[2] Per metre width in 3 metre length.

[3] Per metre width.

Table 10.3 Recommended Panel and Erection Tolerances

Type of Tolerance	Item	Details	Tolerance (mm)
Casting	Thickness[4] of panel		±5
	Skew of panel or opening[5]	Per 1.8 m	±3
		Maximum difference	±12
	Openings cast into panel	Size of openings	±6
		Location of openings	±6
	Location/placement of embedded items	Fixing inserts	±5
		Face-lifting inserts	±20
		Edge-lifting inserts – longitudinal	±20
		Edge-lifting inserts – thickness	±5
		Bracing inserts	±50
		Strongback inserts	±5
Erection	Joint width variation[6]	Panels up to 6 m tall	±6
		Each additional 3 m height	±3
	Joint taper[7]	Maximum for entire length	±10
		Panels up to 6 m tall	±6
		Each additional 3 m height	±3
	Panel Location	Deviation from specified final position of panel (but will not reduce specified joint width by more than 33%)	±5

Notes:

[4] The average variation of panel thickness through any horizontal or vertical cross-section of the panel.

[5] The measured difference in length between the two diagonals.

[6] Measured between panels at the exterior face of the panels at the joint.

[7] The measured differences in joint width indicating panel edges are not parallel.

10.11 Quality Assurance / Control

10.11.1 Quality of Workmanship

If the final product is to satisfy all the requirements of the project, all aspects of construction must be a planned and systematically checked. A quality management system will provide the necessary structure, but it will succeed only if individual workers take responsibility for checking the quality of own tasks before handing off their work to someone else. *Quality can be assured only if it is* ***built into*** *the work as it progresses.*

10.11.2 Guiding Principles for Quality

To ensure that the job is done properly, everyone involved must:

Principles	Actions
Know what to do	Have the correct specifications and drawings
Know how to do it	Be properly experienced or trained, know the appropriate procedures and have ready access to any necessary instructions
Be able to do it	Possess the resources, plant and materials required
Know if it is done properly	Check, measure or test items as appropriate
Be able to effect it	Obtain feedback and undertake any corrective action needed
Want to do it	Be properly motivated
Record it	Keep proper records, obtain any certification specified and undertake or participate in audits.

Quality Control means *the techniques and processes for achieving and sustaining a quality of goods or services that will satisfy the specified requirements*.

In other words, quality control is a set of control and monitoring procedures (prescribed by a quality assurance system) for ensuring that the product or service stays within the specified limits.

A functioning and effective total quality management system involves both quality control and quality assurance at every step in the production of concrete panel housing.

10.12 Occupational Health and Safety

The object of the Occupational Health and Safety Act is to prevent harm to employees at work. Under the OH&S Act, employers must provide, "such information, instruction, training and supervision to employees as necessary to enable the employees to perform their work in a manner that is safe and without risk to health". This covers both independent contractors and general employees at the workplace.

It is imperative that a structured system of education and training be maintained in the concrete walling industry to enable identification and management of risks.

10.12.1 Safety Issues

Concrete wall panel construction methods are relatively safe, but the erection phase of construction is the period where there is most scope for accidents. During erection, safety is of prime importance. As concrete panel construction involves the handling of large, heavy concrete panels, good work practices must prevail at all times to maintain a safe working environment.

It is imperative that the lifting sequence be well planned, and that the site team communicate well and know how each sequence of work is to proceed. Among the requirements for keeping the site safe are these:

- Personnel should stand clear of panel edges in case of slew.
- Personnel should never work below or reach under a panel being lifted.
- Panels should not be lifted in high winds.
- Braces should always be of the right size and capacity, and be connected properly at each end before releasing the panel from the crane.
- Always use the right size and number of lifting points and the proper kind of lifting equipment. The maximum capacity of the lifting equipment must never be exceeded.
- The crane operator should never leave the crane while a panel is connected.
- If possible, avoid "blind" lifting, where the crane operator cannot see the lifting attachments.
- The site should be kept as clean, orderly, and free of debris as possible at all times.
- Sites should be closely supervised, and common sense should always be the rule.

The following table lists some of the safety-related responsibilities of each of the main parties.

Party	Safety-Related Responsibilities
Consultant Engineer and/or Panel Design Engineer	• Overall building stability • Panel lift design • Insert selection and location • Bracing design and type • Panel design (including panel size, shape, concrete strength and reinforcement) • Design for fire • Lifting procedures • Load design on floor/pavement (if applicable) • Communication of all aspects to the builder via drawings and other documentation
Panel Manufacturer (Contractor)	• Panel size, shape and construction tolerances • Access for cranes/transporters • Preparation of floor/pavement (if applicable) • Insert selection • Fixings and fittings (including bolts, brackets, strongbacks, etc.) • Bond breakers/release agents, type selection and application • Concrete quality, its compaction, curing • Casting sequence • Erection sequence • Essential forms of communication
Erection Crew	• Safe working environment and procedures • Crane access and positions • Erection sequence and procedures • Rigging gear • Correct lifting gear ('quick-release' clutches, spreader beams, etc.) • Fixing bracing

A site safety meeting before the start of any lifting is strongly recommended, so that safety issues can be discussed. Issues covered should include at least the following:

- Proper on-site attire (hardhats, safety boots, and so on).
- The function and responsibility of each person in the erection crew.
- Any requirements for documentation before on-site work can start (work method statements, insurance documents, erection crew qualification certificates, and so on).
- Emergency and accident procedures (location of first aid kits, emergency contacts, and so on).
- On-site hazards that the erection crew may be exposed to.
- A safety checklist, and an assurance that all parties are aware of and understand each item in the list.

10.12.2 Temporary Access

Temporary access is usually required to the panel during erection, initially to brace it, and finally to fix it into its final position with fixing brackets, plates, dowels, and so on. Access to the panel at ground level is quite simple, but most fixings on the panels are located above ground level, where access is more difficult.

Ladders, platforms, scaffolding, mobile towers or boom-lifts (cherry-pickers) can be used during and after erection, but must comply with the applicable provisions of the Occupational Health and Safety Act.

Ladders should only be used as access for short-duration work (like fixing anchor points). The use of lightweight mobile scaffold towers and alternative working platforms should be considered, especially if they might be useful over the long term. In most cases, these options should prove sufficient for concrete panel homes that are relatively small. But if overhead access becomes difficult due to extreme height or reach, mobile boom-lifts (cherry-pickers) may be suitable (though they are more expensive).

The use of safety harnesses, static lines or anchor points can be a good idea if work is in high or awkward areas.

Safety Harnesses Safety harnesses are used to limit the distance of a fall, and thereby minimise the risk of injury. They provide valuable protection, but are not a substitute for effective prevention. For a safety harness to be effective, it must be securely fastened to a point where the lanyard length will prevent a fall to the ground. The use of an inertia reel adds to the range of movement while still preventing a full fall, though its load limitations must be carefully assessed.

10.12.3 Hazard Management

An effective method for identifying hazards on-site should be implemented to determine whether there are significant hazards that require further action. (A hazard is an “existing, new, or potential situation or event that could jeopardise the safe working environment”.)

In concrete panel construction, risk is always present when handling, transporting and erecting panels. Under no circumstances should personnel ever stand below or work on a panel that is leaning towards them. Although component failure is rare, the consequences are always significant.

An assessment of the risks from hazards must be carried out by the builder in conjunction with the contractor involved in the work. A Job Safety Analysis that lists the hazards and suggests safety procedures should be prepared. At a minimum, this Job Safety Analysis should include:

- An identification of the hazards.
- An assessment of the risks from the hazards identified.
- The control measures required to minimise the risks from the hazards.
- The name of the person responsible for implementing and monitoring the control measures.

If possible, each risk should be reduced by changing the proposed work method, construction procedure, or equipment.

If a hazard cannot be eliminated, control measures must be implemented to isolate it and minimise the risk to workers on site. This may involve the implementation of specific safety training and work instructions, the use of protective equipment, the posting of warning signs, or the fencing off of the hazardous area. Such measures should be discussed with personnel, and evaluated to ensure that they are effective and do not create hazards themselves.

Planning to prevent injury means identifying, assessing, and controlling risk.

10.13 Training / Education On-Site

All workers on a building site, including independent contractors, need to work in a safe environment. Training, including instructions in safety and work practices, are essential for providing such an environment.

The workers must be sufficiently experienced to carry out their tasks safely, or must be supervised by an appropriately experienced person.

Training programs should emphasise occupational health and safety, and provide opportunities for individuals to have their existing skills recognised and to develop new knowledge and skills. Education and training programs should be structured, lead to nationally recognised qualifications, and be delivered by a Registered Training Organisation. Such training should be in addition to, not a replacement for, the required site-specific induction training.

Training and instruction programs should include:

- Instruction in relevant industry standards and codes of practices.
- OH&S training to the industry-competency standard established by the National Building and Construction Industry Training Board, Construction Training Australia.
- First-aid training to the minimum requirements of the Code of Practice, First Aid.
- Supervised practical experience programs relevant to the tasks being performed by the worker. Such training should be part of a program that leads to a national qualification (if applicable).
- Identification of hazards associated with the safe use of plant and equipment on site.
- Correct use of protective clothing and equipment.

10.14 Cost Advantages

There are significant benefits of concrete panel construction that can relate back to cost-effectiveness. This benefit can be realised in several ways:

- Speed of Construction – This is the primary way in which the cost-effectiveness of concrete panel construction is realised. Concrete panel construction is very fast; buildings seem to go up almost overnight. The costs of non-occupancy (such as lost rent) are reduced.

  Cast off-site panel construction is fast because the panels are manufactured off-site while work continues uninterrupted on-site. Cast on-site construction, panels are produced on site, can be poured on a separate casting slab so that work can still continue on the building. Panel sizes are usually larger for cast on-site panels, so there are fewer panels to cast, lift and erect.

  Once foundations and floor slabs are completed, and wall panels have been poured, a typical detached house can be erected within a few days if planned well. (Large, complex homes with suspended floors and multiple levels of wall panels might take as much as two or three weeks.)

- Reduction in On-Site Labour – This is especially true for cast off-site panel construction, as panels are made off-site; a small erection crew are the only personnel required to erect the entire wall system for the house. For cast on-site construction, a small crew of concretors are required to produce the wall panels, together with the same small erection crew. With both construction methods, a relatively small number of on-site personnel are required to construct the house. Costs are saved on materials and labour.

- Design Freedom and Flexibility – A variety of wall panel sizes, shapes and finishes are available to afford the designer a great deal of latitude. (This benefit needs balancing, though, against the cost-effectiveness of repetition and simplicity in the design.)

- Durability and Solid Construction – The durability and solidity of concrete panel construction means a structurally sound and long-lasting home that will retain its value better and longer than homes made with more conventional building methods. Maintenance is greatly reduced, as the materials are longer-lasting.

- Structural Performance and Load-Bearing Capacity – Because concrete wall panels can be load-bearing, they can be designed to support themselves, other panels, suspended floors, roof structures and even balconies, making other structural support (such as columns and beams) unnecessary. Ensure that the wall panel designer takes full advantage of the load-bearing capabilities of the panels. This could reduce the need for other structural support member (ie. columns & beams), reducing costs and increasing clear open areas internally.

10.15 Construction Checklist

Checklist Item	Issues
Safety	• A preliminary safety meeting involving all personnel is essential. • Note on-site hazards such as overhead and underground wires. • Remove all debris and obstacles from the work area. • Inform surrounding neighbours of time of lifting and its local impact. • Strict discipline must be maintained during the lift. Remain alert at all times, and watch out for fellow workers. • The rigging foreman is the only person who should signal the crane operator. • Always stand at a safe distance from the panel while it is being lifted, tilted and erected. • Always keep clear of panel edges during lifting, in case of slews. • Never stand under or place hands under an inclined panel or behind a panel being lifted. • Panels should not be lifted in high winds. • Bracing must be complete (properly fixed) before releasing a panel from the crane. • Keep well clear of any panel being lifted.
Shop Drawings	• Are the shop drawings being used correct, signed off for construction, and are they the current issue? • Shop drawings must be available for each panel, and conform to the requirements of AS 3850, including clear details of reinforcement, type and location of inserts, mass, dimensions, concrete strength, and concrete strength at time of lifting.
Panel Mould	• Ensure that all panel moulds or setouts of the formwork are inspected for correct dimensions, position and type, and are in accordance with panel shop drawings. • Ensure edge details are correct (such as chamfer and bevel details). • Ensure that the mould or formwork has been properly coated with release agents or bond breakers. • All inspections should be performed before the pouring of the panel. Ensure that enough time is available between inspection and pouring so that any modifications or rectifications can be performed to the mould without delaying the pour. Delays will reduce workability times and delay subsequent pours.
Reinforcement	• Ensure that reinforcement bars of the correct size and length are used, and are in accordance with the panel shop drawings. • Check that the cover and location of all reinforcement complies with panel shop drawings.
Inserts and Ferrules	• All inserts should be visually inspected to ensure that the types and strengths are correct and in accordance with panel shop drawings. • Check that shear reinforcement is correctly placed for each insert in accordance with panel shop drawings. This reinforcement is critical to the performance of the insert, and must be correctly positioned. • Only proprietary inserts and ferrules rated for the particular application should be used. (For example, do not use a face-lift insert in lieu of an edge-lift insert.)

Anchors	• Know when chemical anchors can and cannot be used. (Refer to Section 10.5, "Fitments and Embedments" or to AS 3850.) • Only load-controlled (torque-controlled) expansion anchors comply with the standard; other types of expansion anchors should never be used. • Ensure that the anchor has been embedded to the proper depth before loading it.
Concrete Standard	• Ensure that the concrete complies with design requirements and with AS 1379: The Specification and Manufacture of Concrete. If the concrete is being supplied, insist that the concrete supplier provide certification for the concrete. The concrete strength is critical to the performance of the panels, and must be assured. • The concrete supplier's certificate should include a statement that the concrete supplied is compliant with AS 1379, or that the supplier is a member of the APMCA. • Good concrete practice applies to concrete wall paneling. For instance, it is important not to add additional water to the mix; it is important to have proper curing procedures in place; and so on.
Rigging and Lifting	• It is very important that the erection crew, especially the crane operator, be experienced at lifting and erecting concrete panels. Do not choose the crew solely on the basis of cost. • Panels should never be lifted in high winds. • Personnel should keep well clear of panels being lifted. No one should work under a lifted panel. • It is important that any water around the panel be swept away before the panel is lifted, so the water will not create additional suction that will stress the panel.
Temporary and Permanent Fixings	• Panels should not be leaned or braced against other panels unless they have been designed to take the loads. • All panels must be restrained with appropriate fixings as detailed on shop drawings, • The fixings must be attached to the panels in the correct positions. • All roof bracing must be complete. • Grouting of dowels and under panels must be complete. • All permanent fixings should be inspected by the panel designer and/or consultant engineer and signed off before the removal of the temporary bracing or fixings.
Bracing	• The builder should prepare a checklist to ensure that the bracing system is installed correctly, and that maintenance inspections are performed. • Visually verify that brace types are correct, and that anchors are ready for panel erection and are correctly sequenced and installed. • There should be a minimum of two braces per panel unless specified otherwise in the design. • Bent braces must not be used. • Telescopic braces must be used correctly. Proper restraining pins must be used; nothing should be substituted for them. • Bracing corner panels can be a problem if corner panel braces clash with each other. The problem can be prevented if the braces for the first corner panel erected are positioned lower than the braces for subsequent corner panels.

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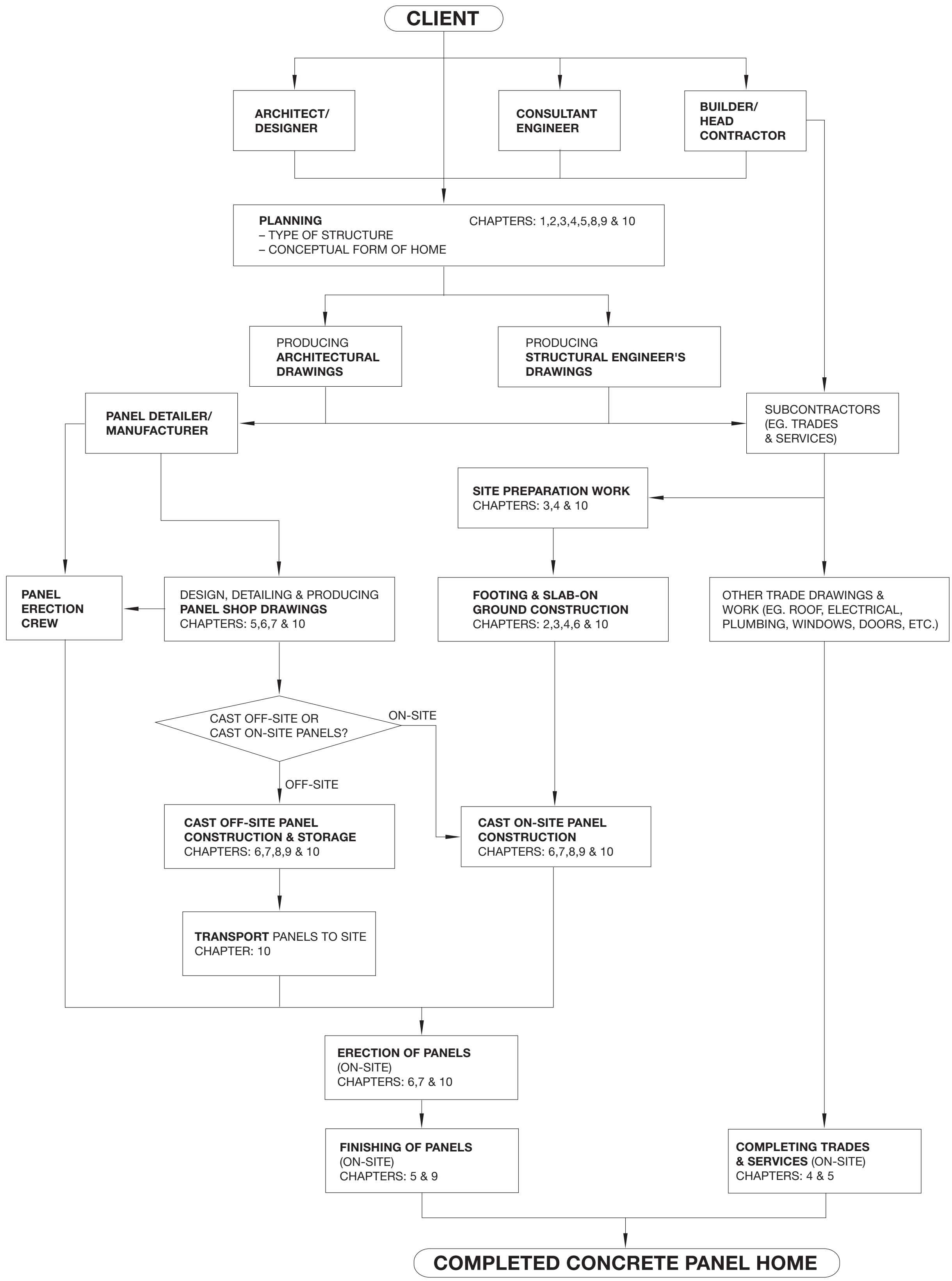
12 APPENDICES

12.1 Process Flowchart



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