Buildable Solutions for Landed Residential Development in Singapore












Building and Construction Authority

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BUILDABLE SOLUTIONS FOR LANDED RESIDENTIAL DEVELOPMENT IN SINGAPORE

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CONTENTS

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Chapter 1 INTRODUCTION

Landed residential developments tend to have the lowest site productivity amongst the different types of developments. In Singapore, these types of developments consistently form a significant proportion of the total number of private residential projects built every year. In the recent years, landed residential projects made up about 80% of the total number of private residential projects awarded per year although landed properties form only about 20% of the total housing supply. This situation will negate measures to improve the overall industry productivity. Hence, it is essential to provide a design solution for small landed residential developments

Landed housing developments comprise terrace houses, semi-detached houses and detached houses. Due to the relatively smaller scale of such developments, designers and developers of such projects have traditionally avoided the use of prefabricated components. This is due to the perception that the use of prefabricated systems will result in inflexible and uninspiring designs, that they are costly and involve unfamiliar construction methods.

A study has been carried out to develop and document a few simple, flexible, innovative and buildable systems suitable for small landed residential developments. The key objectives of the studies were to identify buildable systems that are able to improve site productivity, construction quality, minimize plastering works and minimize wastage due to re-works. These buildable systems are:

- Precast system
- Flat plate system
- Structural steel system
- Light gauge steel frame system

With the use of these buildable systems, especially having some of the components built or cast off-site, wet site works will be reduced, thus leading to improvement in site safety. These buildable systems have proven to be capable of providing significant design flexibility, without significant increase in cost whilst offering early delivery of houses to the homeowners.

Examples of projects constructed using prefabricated systems

81 units of terrace houses & one pair of semi-detached houses at Goldenhill Villas

Designed by S H Lim Architects Pte Ltd and Resources + Planning Design Consultants

Features

- Precast party walls & facade walls
- Precast beams and precast slabs

Benefits

- The use of precast slabs and walls reduces the propping and false work on site

2 storey semi-detached dwelling house with a roof terrace at Seletar Hills Drive

Features

- Structural steel columns, beams with composite steel decking slab
- External precast facade panel with concrete stains

Benefits

- The steel decking for the composite slabs serves as permanent formwork to minimize staging during construction
- Reduce dead load using steel construction leading to a saving on foundation cost

Designed by Look Boon Gee, LOOK Architects

2 storey semi-detached dwelling houses with attic at Tavistock Avenue

Features

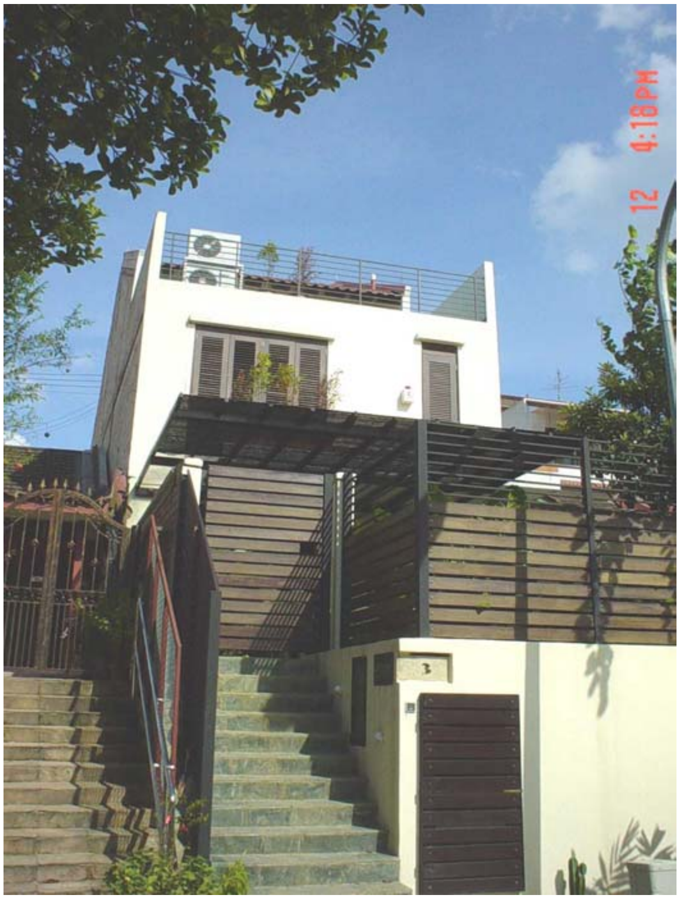
- Structural steel columns, beams, metal deck with concrete topping for slabs
- Structural steel roof

Benefits

- The metal decking for the composite slabs serves as permanent formwork to minimize staging during construction
- Reduce dead load using steel construction

Designed by Look Boon Gee, LOOK Architects

2-storey in-fill terrace with pitch roof at Jalan Batai



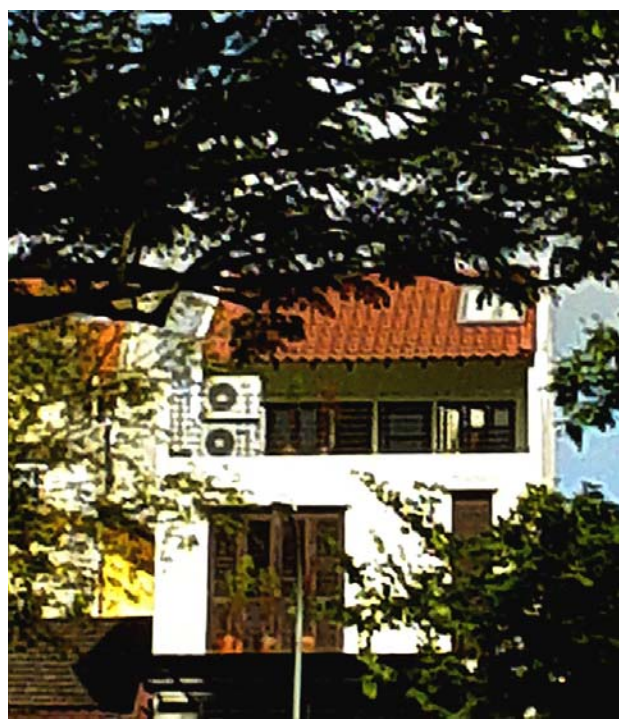
Features

- Structural steel columns, beams with composite steel decking slab
- Structural steel roof

Benefits

- The steel decking for the composite slabs serves as permanent formwork to minimize staging during construction
- Reduce dead load using steel construction

Designed by: Mr Low Cheng Hai, Edmund
Constructed by: Caines Associates



3 storey semi-detached house with pitch roof at Upper Changi Road East

Designed by A-Alliance

Features

- Light gauge steel frame with fibre cement board for walls and slabs

Benefits

- Reduce construction duration with light gauge steel frames
- Reduce dead load on structures
- Simple with installation of services
- Clean and fast architectural finishing work

Examples of completed projects using prefabricated embellishments

3 storey terrace houses at Lorong Chuan

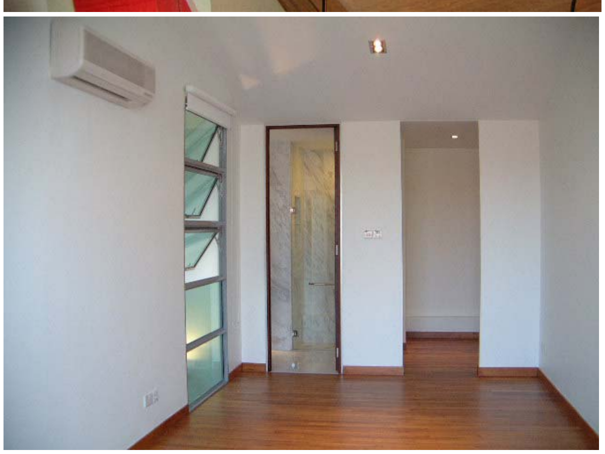
Features

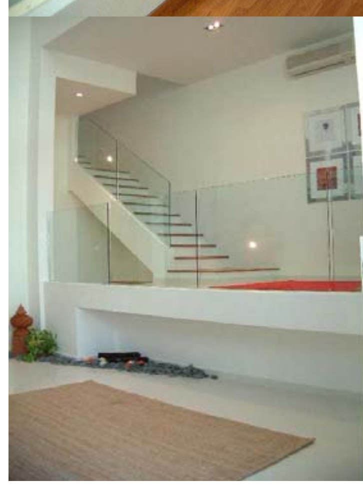
- Modular precast concrete panel for internal and external walls
- Prefabricated metal roofing sheet
- Prefabricated steel frame for car porch
- Prefabricated staircases
- Glass parapet walls

Benefits

- Reduce construction duration with wall installation and roofing
- Reduce dead load on structures

Designed by Pan-Indo Architects International
Constructed by Conint Management Services P L





2 storey detached house with metal roof at Maple Avenue

Designed by WOHA   Photograph by Tim Griffith

Features

- Prefabricated metal louvers as facade walls
- Prefabricated steel staircase
- Metal roof

Benefits

- Reduce construction time for roof & louvers
- Maximisation of space at staircase area

2 storey detached house with flat roof at Berrima Road

Designed by WOHA Photograph by Tim Griffith

Features

- Prefabricated metal roof
- Glass facade with steel stiffeners

Benefits

- Quick to assemble
- Greater accuracy
- Achieve clean edges and lightweight appearance

2 storey detached house with flat roof at Victoria Park Road

Designed by WOHA
Photograph by Tim Griffith & Albert Lim K S

Features

- Steel staircase with prefabricated stair treads
- Prefabricated timber louvers facade
- Glass facade with steel stiffeners
- Glass parapet
- Modular size of columns

Benefits

- Easy installation of staircase
- Repeated details created rhythm and harmony
- Speed of installation for prefabricated timber louvers facade

Designed by HYLA

New erection of a 2 storey bungalow at Bowmont Gardens

Features

- Steel structures with metal roof to single storey living pavilion

Benefits

- Reduce construction time for roof installation
- Lightweight, modern architectural expression

New erection of a 2 storey corner terrace dwelling house at Brockhampton Drive

Features

- Steel structure to verandah
- Metal deck roof with exposed steel members

Benefits

- Slender structures for beams and columns
- Improvement in site productivity for roof installation
- Lightweight sun-shading and screen elements attached to steel structure for sun-shading and privacy

Designed by HYLA

Designed by HYLA

Additions & Alterations to a 2 storey end terrace house at Kee Choe Avenue

Features

- Steel structures with concrete infill to columns

Benefits

- Improvement in site productivity with the use of steel structures
- Exposed steel columns at 1st storey terrace echo traditional 'stilt' houses

Additions & Alternations works to a 2 storey bungalow at Arthur Road

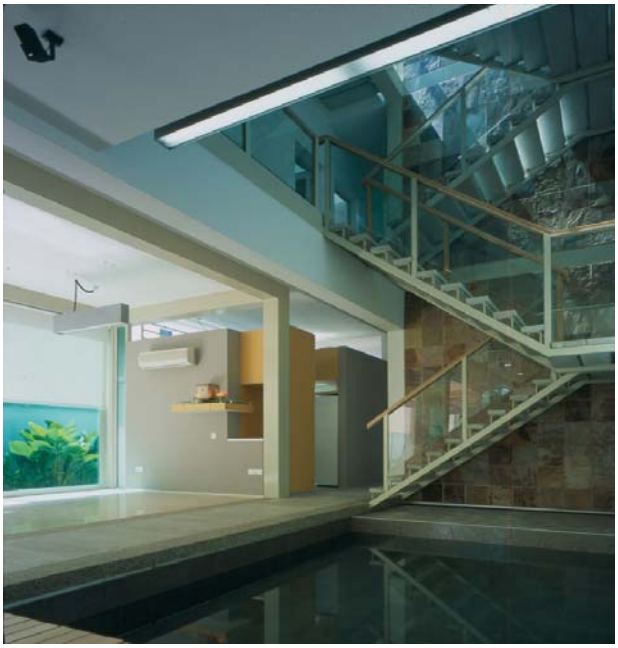
Features

- Steel canopy at front elevation

Benefits

- Easy to install
- Access to light and external sun-shading blinds

Designed by HYLA



Designed by HYLA

New erection of a 2 storey semi-detached dwelling house at Jalan Sedap

Features

- Steel staircase with precast concrete treads
- precast slabs to corridor at 2^{nd} and attic level

Benefits

- Lightweight modern architectural expression
- Fast installation

Chapter 2 SELECTION AND DESIGN OF HOUSES USING BUILDABLE SYSTEMS

2.1 DESIGN CONSIDERATIONS

The design of any project should suit the purpose of use and the building type, i.e. residential development, institutional development etc. For a project involving any prefabricated system, the designer should seek solutions which maximize the beneficial aspects of the system, resulting in optimum buildability and economy.

Often, designers and developers of landed developments avoided the use of prefabricated components due to the perception that it will result in stereotype designs, costly and involved specialised construction methods unknown to most contractors. Hence, the project team has developed a few possibilities on architectural facade treatments using buildable systems. Three different projects were studied. The following pictures show examples of variations in appearance, which can be achieved for residential projects designed for construction using prefabricated components. The different treatments to the precast facade panels results in variation in the elevations whilst using standardized components.

Project 1 - Option A

- Precast facade walls
- Modular dimension for each panel
- Use of aluminium sun breakers
- Use of aluminium cladding as architectural features

Designed by RSP Architects, Planners & Engineers (Pte) Ltd

Designed by RSP Architects, Planners & Engineers (Pte) Ltd

Project 1 - Option B

- Precast facade walls
- Modular dimension for each panel
- Off-form colour concrete or exposed textured surface using reconstructed concrete
- Full height frameless windows using structural sealant
- Precast horizontal shading devices
- Prefabricated glass canopy at the car porch

Project 1 - Option C

- Precast facade walls
- Modular dimension for each panel
- Off-form colour concrete or exposed textured surface using reconstructed concrete
- Use of metal pitched roof
- Use of timber trellis to enhance the elevation

Designed by A-Alliance Architects

Project 2 - Option A

- Timber cladding to dry external walls
- Stone cladding to part of elevation
- Metal roofing for pitch roof

Designed by A-Alliance Architects

Project 2 - Option B

- Paint finished to dry external walls
- Prefabricated metal louvres
- Skylight for car porch
- Flat roof with metal deck

	Project 3 - Option A • Metal cladding to precast walls or dry walls of covered patio • Groove line expressed along the joints of the precast facade walls • Off-formed groove patterns to rear precast wall • Metal cladding to gable end facade wall
 Project 3 - Option B • Metal cladding to rear precast walls or dry walls • Groove lines expressed along the joints of the precast facade walls	 Project 3 - Option C • Stone cladding to precast walls or dry walls of covered patio • Cantilever metal roof to car porch

The following highlights some of the general details that need to be considered with regard to design:

- Simplify architectural façade treatment and special details
- External cladding can be added to wall board facade or precast concrete walls
- Standardize component shapes and sizes where possible to improve economy
- Consider optimal component size and the transportation capability concurrently especially for large precast concrete panels
- Connection details
- Joints details
- Waterproofing details

2.2 SITE CONSIDERATIONS

As with a conventional cast in-situ construction, a prefabricated construction requires site considerations to be taken into account, in particular, the following:

- Ground conditions for heavy vehicular movement
- Access for mobile cranes - commonly 20 tons, 50 tons or 70 tons mobile cranes with telescopic boom
- Manoeuvring space for over-sized vehicles within the vicinity
- Obstruction to other road users - under the current LTA's requirement, a vehicle having a width of more than 3.2m will require police escort
- Storage area for precast concrete components or prefabricated elements
- Risk to overhead infrastructures and neighbouring properties during handling/lifting of the prefabricated elements

Hence, proper planning and good co-ordination is essential for prefabricated construction. Early involvement of precast contractors or steel erectors during design stage will reduce risk and provide a more friendly construction environment for the site and the neighbourhood.

Figure 2.1 Use of 50-tonne crane for hoisting

Figure 2.2 Hoisting of precast facade

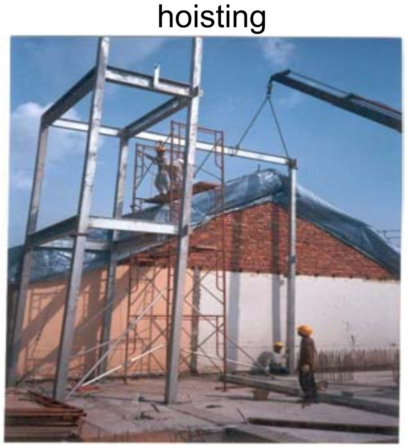


Figure 2.3 Assembly of steel elements in position

Figure 2.4 Use of lorry crane for lifting of steel elements

2.3 COSTING

Construction costs are complex and complicated issues. Although it is a generally accepted fact that the use of repetitive prefabricated components contributes to appreciable cost savings in a high-rise project, it is not clear if such cost advantage applies in a low-rise landed house environment. In the course of investigating the technical feasibility of prefabricated construction for landed houses, one basic and persistent question keeps surfacing – Is prefabricated construction more expensive or cheaper than conventional cast in-situ construction in low-rise houses?

At present, the answer is inconclusive at best. In most cases, we would expect prefabricated construction to cost more than conventional in-situ method. Tender prices from a few recent landed projects, which employ precast construction, seem to indicate a 5-10% cost premium over conventional cast in-situ construction. Because the number of projects involved is limited thus far, this figure should only be taken as a mere indication. However, one contractor who had recently completed a project using structural steel construction, reported that a saving of 5% (of construction cost) was given back to the homeowner.

It is important to note that many factors affect the cost of a project. Apart from direct material costs, factors such as construction time, scale of project, labour components, expected quality, and even external micro economic conditions all affect the overall cost of a project. It is therefore difficult to do a simple direct material cost comparison without also understanding the other affecting factors in the cost analysis.

The cost breakdown for a typical development can be summarised as follows:

	Percentage per house
Land Cost	63%
Construction cost	24%
Other cost	13%

The construction cost may be further broken down into the following:

	Percentage of costing per house
Preliminaries	5 - 10%
Foundation	5 - 10%
Structural works	20 - 30%
Architectural works	40 - 45%
M&E works	10 - 30%
External works	3 - 5%

The project team has reviewed the elemental cost for comparison of precast design with conventional design. The increase in the cost of precast design is found to be minimal as shown below:

**The prices below are indicative only and may differ from time to time and from different contractors and precasters. It is recommended that developers and designers consult precasters and contractors in the actual pricing of the projects.*

**The cost comparison is only on components which were replaced by buildable systems.*

Cost Comparison between Conventional and Buildable Systems for an In-fill Terrace House

Elements	Built-up area (m^2)	Conventional Design ($/$m^2$) [3]	Precast Design ($/$m^2$) [3]	Steel System [2] ($/$m^2$)	Flat plate with Steel Columns [2] ($/$m^2$)
Party wall	280	35 (Brick walls with plastering)	36 (Structural load bearing wall)		
Structure - floor system	280	90	33	73	73.5
External wall	280	10	12.5		
Staircase	280	8	12.5	2.8	2.8
Household shelter	280	11	16.5		
Others					
Waste disposal	280	14.5	9		
Cranage	280	19.6	29		
Grouting	280	0	7.2		

Typical construction cost of residential properties :

Terrace Houses - $1500 - $1700 / m2
Semi-Detached Houses - $1600 - $1900 /m2
Detached Houses - $2100 - $2800 /m2
Source: DLS Handbook Singapore 2002

[1] The above costing does not include other preliminaries such as scaffold and site overheads. The costs for preliminaries generally range from 6% to 10% of the total project cost.

[2] For the layout and elevation of the different systems (Structural Steel system & Flat Plate system) shown above, please refer to the Appendix.

[3] Cost refers to lump sum cost per square metres of the constructed floor area.

Material costs, of which precast components form a significant part of, cannot and should not be evaluated independently of other cost related factors. Otherwise, the comparison would be misleading. For example, by using more expensive precast construction, direct labour costs are reduced. This is a significant consideration in a market like Singapore where labour cost has been and is expected to continue rising. Time saving is another important factor, and this translates directly to lower preliminaries and faster project turnover. On the other hand, the benefits of improved quality are appreciable but difficult to measure. Better quality means lower subsequent defect rectification costs, but its direct cost benefit is not as easily quantifiable.

The following salient points are also important in cost analysis:

1. **Repetition** – Repetition is the primary key to lower costs in precast construction. The more standardised the precast component is, the lower is its basic cost due to reduction in mould costs, set-up etc. Repetition is quite easily achieved in high-rise construction or for a large development of low-rise houses, but comparatively difficult to attain in small-scale and low-rise development. In other words, without some form of standardisation, there simply isn't enough repetition in a small project to attain economy of scale. With this basic premise in mind, this study sought to achieve repetition and economy of scale through industry-wide standardisation across many developments. Repetition of identical / similar components is therefore an achievable goal when one considers the degree of duplication possible in an industry-wide level rather than in a single project level. Precast component's basic cost can thus be brought down even for small developments.

2. **Standardisation** – By recommending standard sizes, similar methods of construction, and consistent, simple precast components, precasters are able to "spread-out" the basic costs of precast moulds / set-ups over many projects. Much effort has been put into standardisation of construction method and components such as precast flooring system, wall panels, staircases, household shelter, etc. The components have been chosen in a format whereby deviations in component dimensions can be achieved relatively simply. From cost point of view, it is generally agreed among precasters that a minor two-dimensional variation in dimensions (in width or length) can be easily accommodated within an existing mould and set-up. A cost difference in this case is negligible. It is the goal that with good degree of standardisation, contractors can order standard precast components from ready-made stock off the shelf or from catalogues.

3. **Creativity** – Creativity is potentially the opposite of standardisation. It is a fact that architects and designers want to be creative and owners almost always expect their developments / houses to be unique and different from others. Fortunately, in the context of landed houses in Singapore, planning guide lines dictate norms and standards that result in an existing level of standardisation. If a house design is truly unique, which may especially apply

to bungalows and large detached houses or houses sited in unusual land configuration, precast construction is probably not a cost-effective solution. On the other hand, for the majority of terrace houses or semi-detached houses, whether in new development, in-fill development or addition & alteration, the general design will typically fall within a certain fixed framework where precast will be a competitive solution. There is sufficient flexibility in the precast system for architects and engineers to still exercise his imagination and creativity.

4. **Risks & Time Factor** – Part of the reason for the current higher costs in precast construction is due to perceived risk factors applied by contractors. A typical small house contractor is not likely to be as familiar with precast construction as compared to larger contractors. Unknown factors contribute to risks and higher costs. It is fair to assume that with gradual and eventual familiarisation with precast construction methodology, the learning costs for contractors and the unknown risk factors will be reduced over time. This would in the long run lead to lower and more realistic costs for precast construction.

5. **Competition** – There are comparatively few precasters in Singapore because the current demands are not high. When precast construction becomes more acceptable and prevalent in the future, more players will enter the market. This will lead to better competition and lower costs for consumers.

Chapter 3 DESIGN CONCEPT FOR PRECAST SYSTEM

3.1 STRUCTURAL CONCEPT

Based on considerations of buildability, economy and standardisation of precast components, the structural concept developed consists of:

- Conventional foundations comprising footings, raft slab or piles and pile caps.
- Cast in-situ first storey, typically reinforced concrete beam and slab system.
- Precast concrete load bearing walls.
- Precast concrete non-load bearing façade panels.
- Precast concrete floor system, either:
  - Precast concrete beams and precast slabs (reinforced concrete or prestressed) with a composite in-situ topping
    or Precast concrete walls with precast concrete slab system

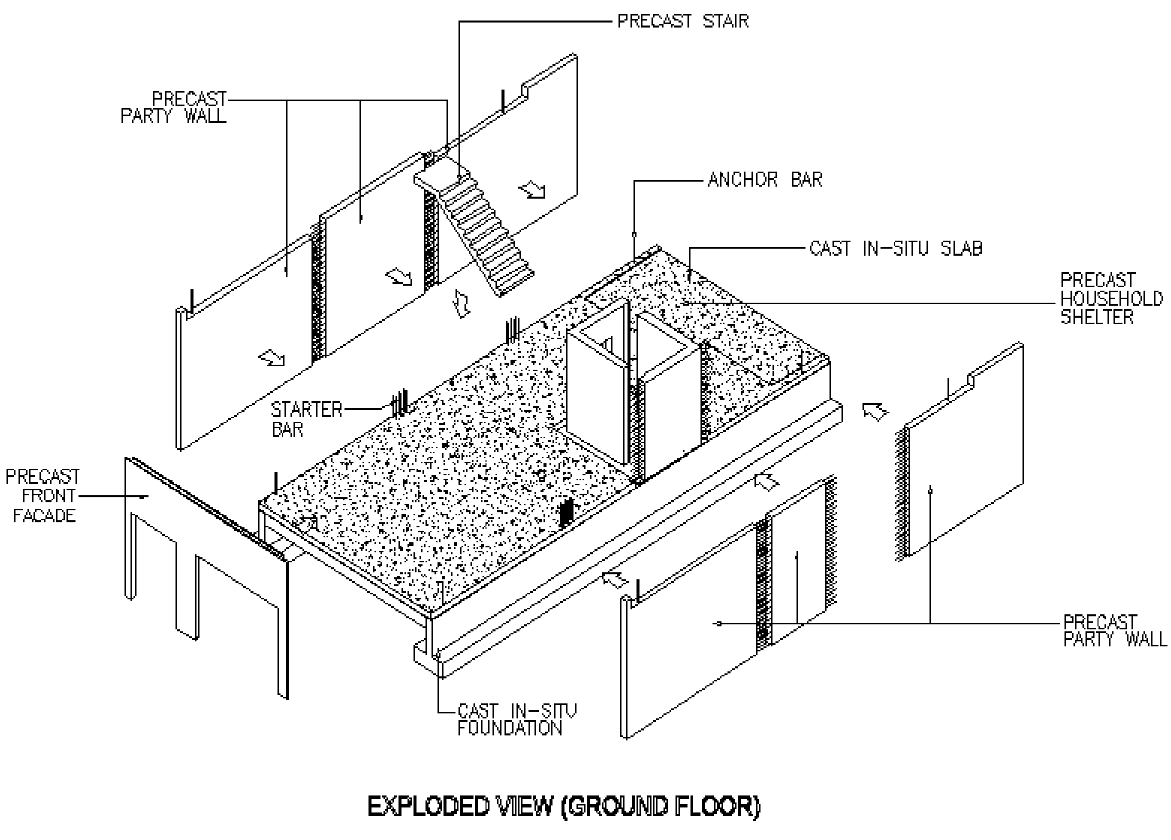


Figure 3.1 Precast prestressed slabs spanning between walls with composite in-situ topping for 1st storey

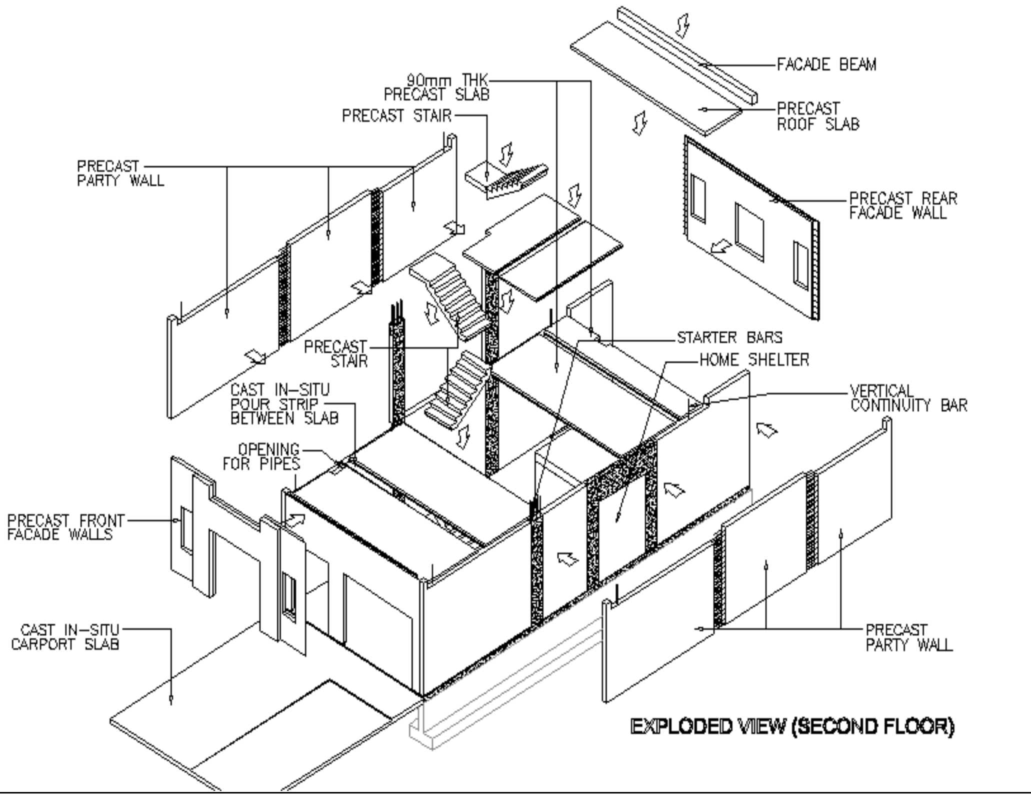


Figure 3.2 Precast prestressed slabs spanning between walls with composite in-situ topping for 2nd storey

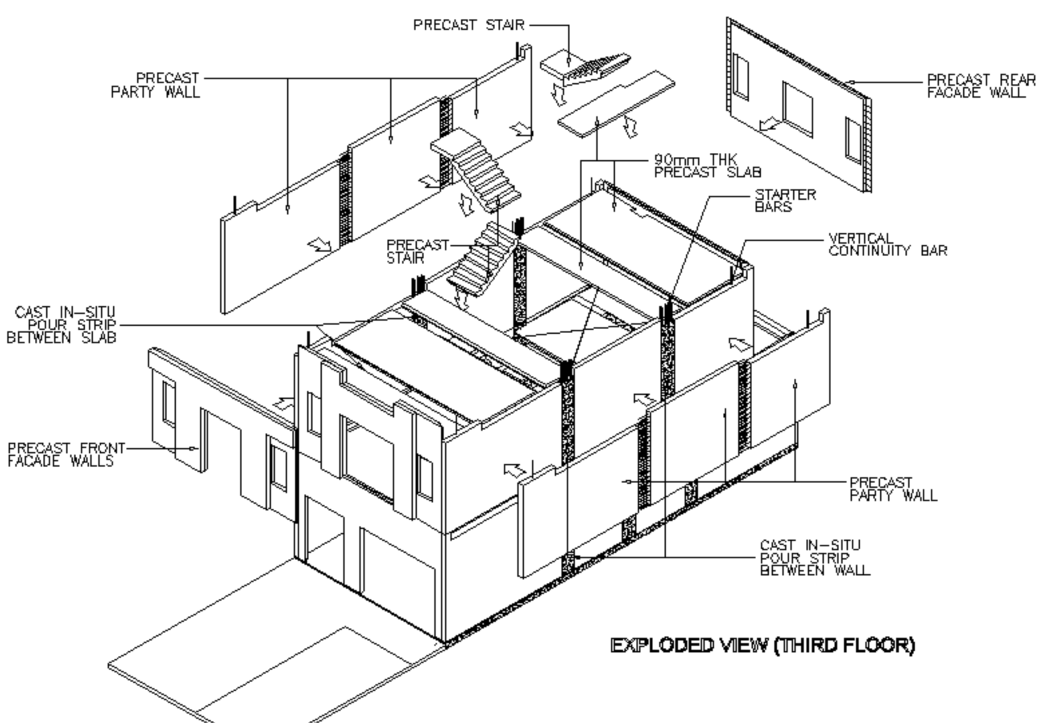


Figure 3.3 Precast prestressed slabs spanning between walls with composite in-situ topping for 3rd storey

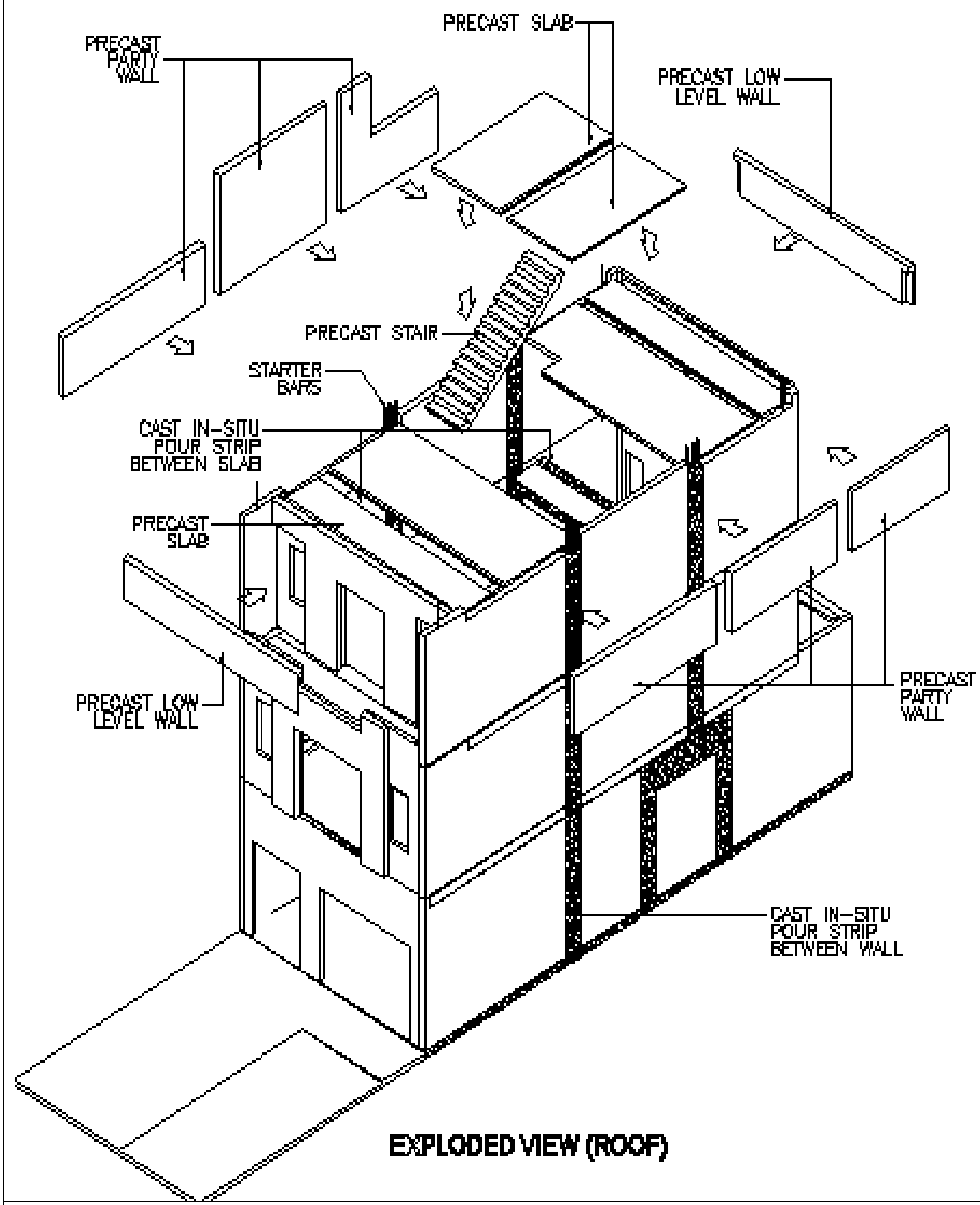


Figure 3.4 Precast prestressed slabs spanning between walls with composite in-situ topping for roof

3.2 FOUNDATIONS

The foundation loads for the precast structural system will be similar to those for conventional design. However, the arrangement of the foundations below the load bearing walls will be different to those normally adopted for a column and beam structural system. The desirable arrangement should provide a relatively uniform support along the length of the wall and minimize the eccentricity effects due to any possible misalignment of the walls relative to the foundations.

In the case of a footing foundation system, the recommended solution is a continuous strip footing below the load bearing walls, as shown in Figure 3.5.

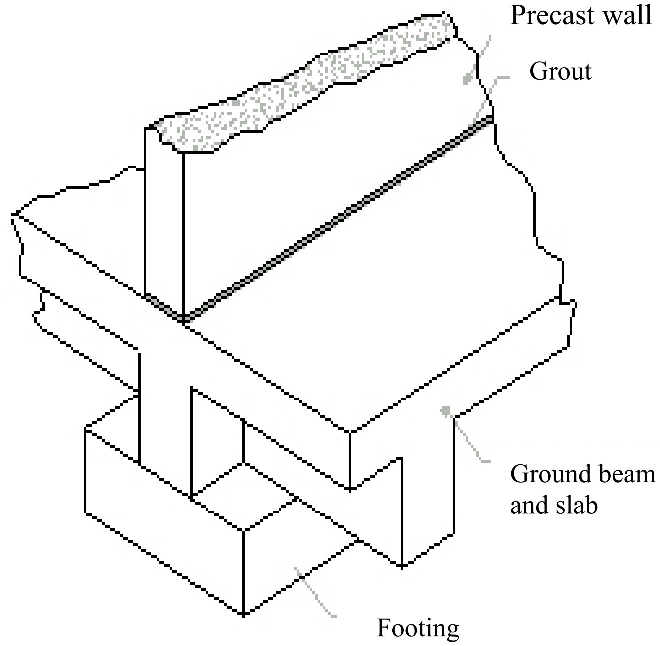


Figure 3.5 Footing below precast load bearing walls

Similarly, a raft foundation system, as shown in Figure 3.6, will provide a uniform support to the load bearing walls and excellent resistance to eccentricity effects.

For a piled foundation, uniform support along the full length of the wall can be provided by adopting piles at closer spacing with a first storey capping beam. This solution is unlikely to be economical. The recommended approach is shown in Figure 3.7, which is based on the following structural concept:

- Within the precast concrete wall, zones are designated as load bearing and non-load bearing.
- Piles are located below the load bearing zones only.
- The first storey beam is used to disperse the pile support along the wall, but is not designed as a capping beam.
- The piles are preferably provided in groups of two or more, located on each side of the wall centerline. If single piles are necessary, first storey beams are required in the transverse direction to accommodate any possible eccentricity effects.

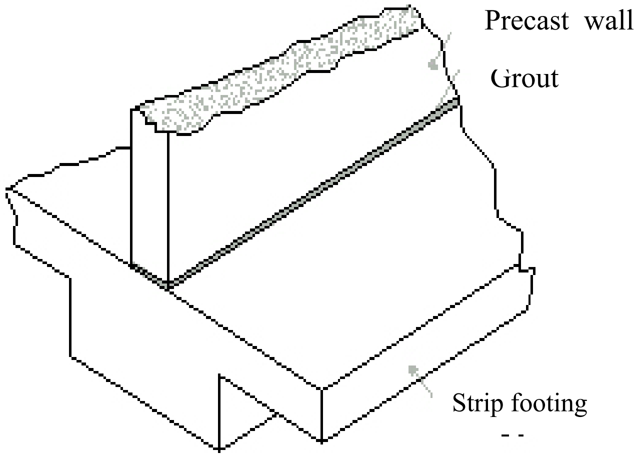


Figure 3.6 Precast load bearing wall on strip footing or raft foundation

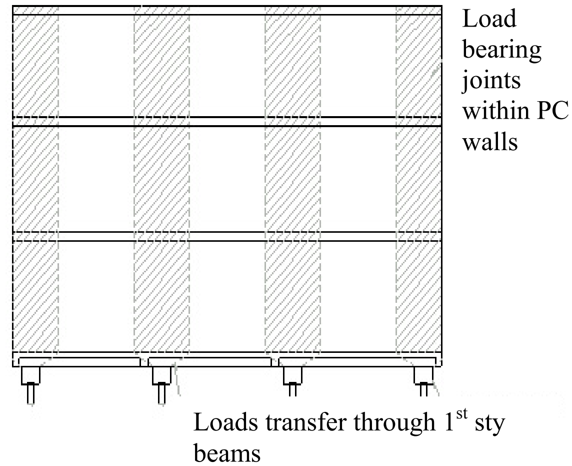


Figure 3.7 Precast load bearing wall on piled foundation

3.3 GROUND BEAMS AND SLAB

Whilst it is possible to adopt precast construction at first storey, it is considered unlikely that this will be cost effective or provide significant buildability advantages over conventional beam and slab for first storey construction. This is based on the considerations that the formwork cost for construction on grade is negligible, and the extent of in-ground services will, in general, be substantial.

Adopting conventional construction for the first storey has the additional advantage of providing more lead time for the production of the precast components. However, it is also possible and sometimes advantageous to use a precast system for the ground beams and slab.

3.4 PRECAST LOAD BEARING WALLS

Precast load bearing walls provide an economical solution when compared to the conventional column/ beam/ infill wall system. The primary advantages are speed of construction and elimination of wet trades.

To minimise the requirement to lap vertical bars, the walls are recommended to be designed as plain concrete members in accordance with CP65 3.9.4.

In adopting the wall thickness, structural adequacy is not the sole consideration. Other factors to be considered include:

- Connection details for supported beams and slabs.
- Sound transmission and fire rating.
- Joint details at panel-to-panel connections.
- Possible future embedded services, which could reduce the concrete area available.

Based on typical layouts and building configurations, a thickness of 180mm is recommended for the precast panels used for party walls.

3.4 a In-fill Terrace Units

In the case of in-fill terrace units, it is unlikely to be acceptable to provide a new full wall panel system, since usable area will be sacrificed. In these types of projects, the wall panel is recommended to be modified as shown in Figure 3.8. For this type of arrangement, it is likely that design as a plain concrete member will not be possible and lapping of some vertical bars would be required. A thickness of 180mm is recommended for these panels, to enable consistency and hence economy of the precast production.

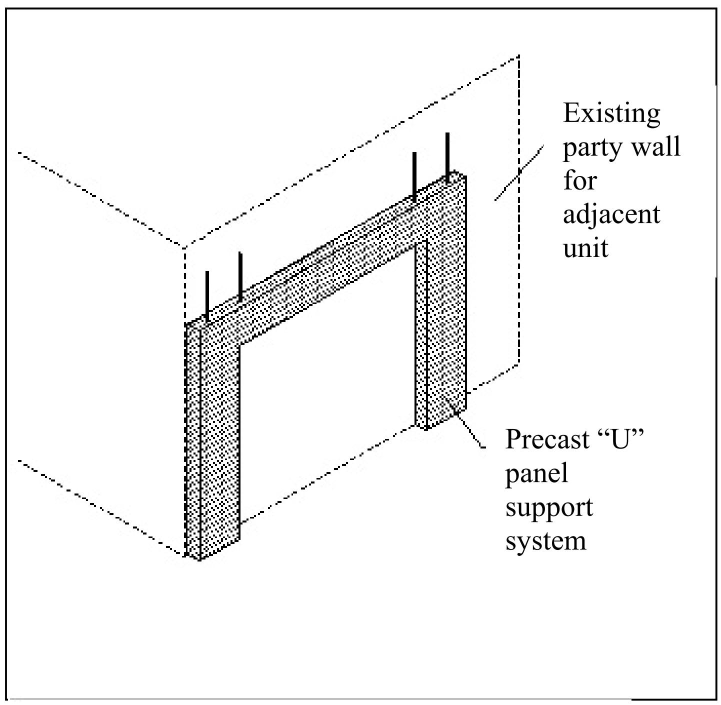


Figure 3.8 Precast load bearing wall for in-fill unit

3.4 b Corner Terrace and Semi-Detached Houses

For corner terrace and semi-detached units, the external side wall is required to be load bearing. In this case, the panel design will be influenced by factors such as:

- The extent of openings required for windows and doors.
- Available load paths for transmission of vertical loads.
- Horizontal joint details, which due to waterproofing considerations are likely to lead to eccentric load transfer.
- Connection details for supported beams and slabs.
- Joint details at panel to panel connections.

In some cases, plain concrete design may be applicable. However, it may usually be necessary to adopt reinforced concrete design with continuity of vertical bars in these load bearing walls. For these walls, the recommended thickness is 150mm.

3.5 PRECAST NON-LOAD BEARING FAÇADE PANELS

Typically, the wall panels for the front and rear elevations are non-load bearing façade elements. Support of these panels is achieved by any of the following methods:

- The façade panel is connected to main load bearing walls and is designed to carry its own weight between supports.
- The façade panel is connected to the floor slab or beam, which is then designed to provide support to the wall.

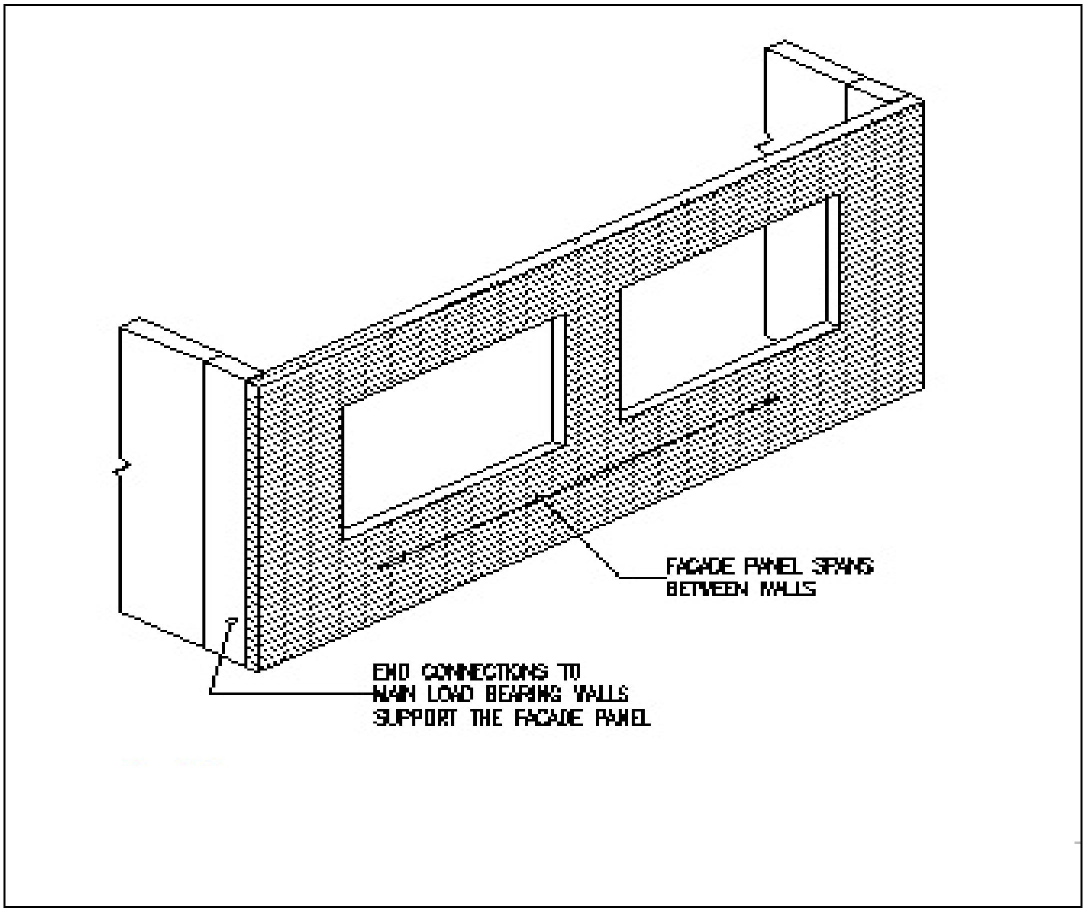


Figure 3.9 Facade panel supported by load bearing external walls

These panels will typically be designed for vertical loads due to self weight and an allowance for floor loads, if applicable, in addition to horizontal loads due to external wind pressures. A typical panel thickness of 120mm is proposed on the basis of strength considerations and to accommodate window fixings and profiles around the window perimeter.

Façade panels will often require three-dimensional architectural features, such as hoods, sills and ledges. In cases where there is a reasonable degree of repetition, customised moulds can be produced, enabling these features to be economically incorporated into the panels. As an alternative, when repetition is limited, it will be most economical to cast the façade panel flat and subsequently add the features, manufactured separately using materials such as precast concrete, GRC, Aluminium or steel.

3.5 a Location of Joints

The location of joints between external wall panels should be selected based on careful consideration of the following factors:

- Structural Considerations

  External wall panels may be load bearing (e.g. side walls of corner terrace, semi-detached or detached) or non load bearing (e.g. front and rear façade panels). In selecting panel joint locations, it is important to consider the panel stability (i.e. ability to resist horizontal loads such as wind pressure or loads specified in the Building Regulations Fourth Schedule).

- Aesthetics

  Whilst in general, panel joints are not highly visible, locations should be selected which minimise any potential impact on the external façade aesthetics. In general, vertical joints should align for the full height of the building and would preferably be located symmetrically with respect to adjacent features.

- Panel Weight

  The weight of panels will dictate the crane capacity required for installation of the wall panels. Apart from the disadvantage of higher cost, larger capacity cranes may not be able to access the site. For typical conditions, a weight limitation of approximately 4 tonnes is considered likely to be applicable. In general, the panel size should be maximized, leading to increased speed of construction and reduced number of panel joints to be treated.

- Transport Limitations

  For transportation purposes, it is necessary to limit one of the panel dimensions to 3.6m. In general, panel heights will be less than 3.6m and panel length is based on weight or other considerations. When the required panel height exceeds 3.6m, the length of panel will be reduced to 3.6m or less. Early planning for site access must be undertaken, particularly when houses are built along Category 5 road.

- Internal Crack Control

  To minimise the risk of cracks appearing at the internal face of wall panel joints, the following considerations are relevant:

  - If possible, locate panel joints at internal wall intersections, inside service ducts or wardrobes and at other non-visible locations.
  - Avoid panel joints towards midspan of floors, where beam or slab deflections could lead to joint opening.
  - Avoid long continuous runs of panels, where accumulated shrinkage could result in joint cracking.

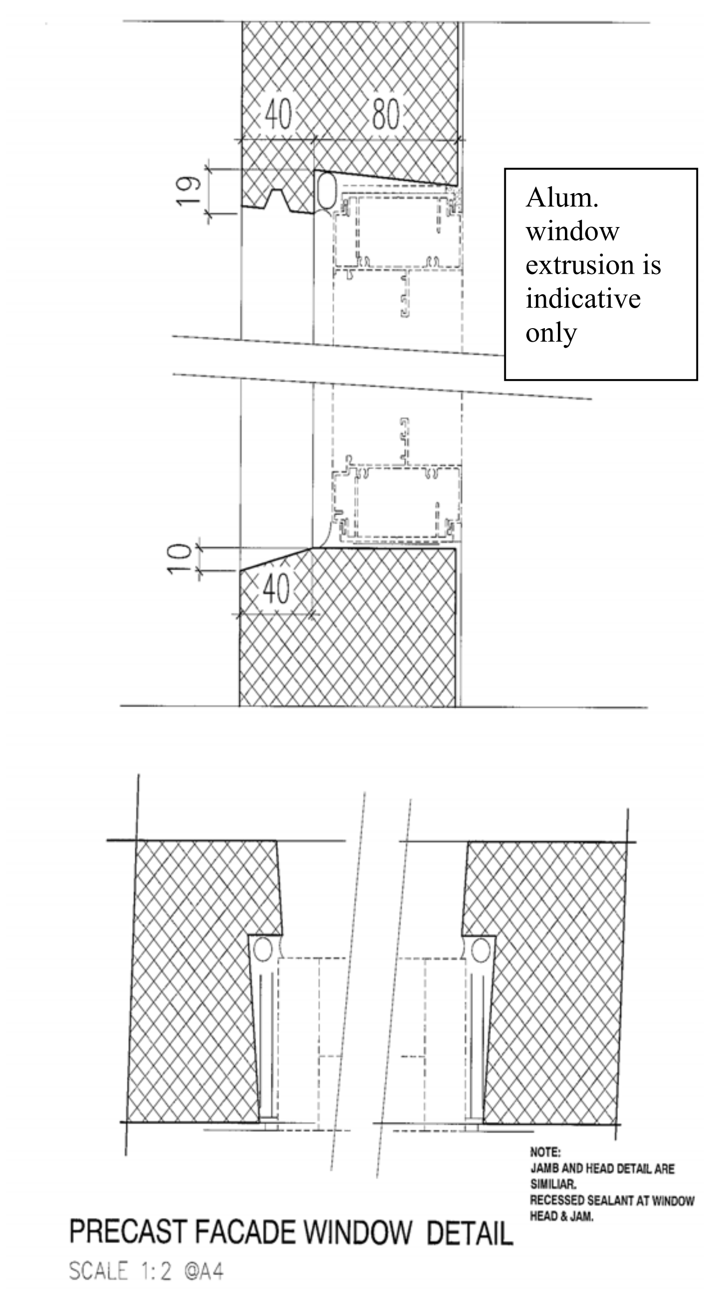
3.5 b Treatment for window openings

An effort has been made to develop a standardised approach for the precast panel profile at window openings. The proposed detail is considered suitable for precasting and can be applied for the majority of projects.

Refer to Figure 3.10 and Figure 3.11 for the proposed precast panel profile at window openings.

The profile has been developed in consideration of the following:

- A drip was provided to the top and the side to discourage the ingress of water.
- The protrusion at the head and jambs is provided for waterproofing and allows the window frame to be fixed from inside the building; this results in some savings as scaffolding would not be necessary.
- The protrusion allows sufficient space to apply grouting at the joint for water tightness.
- The protrusion protects any sealant from direct exposure to the sun.



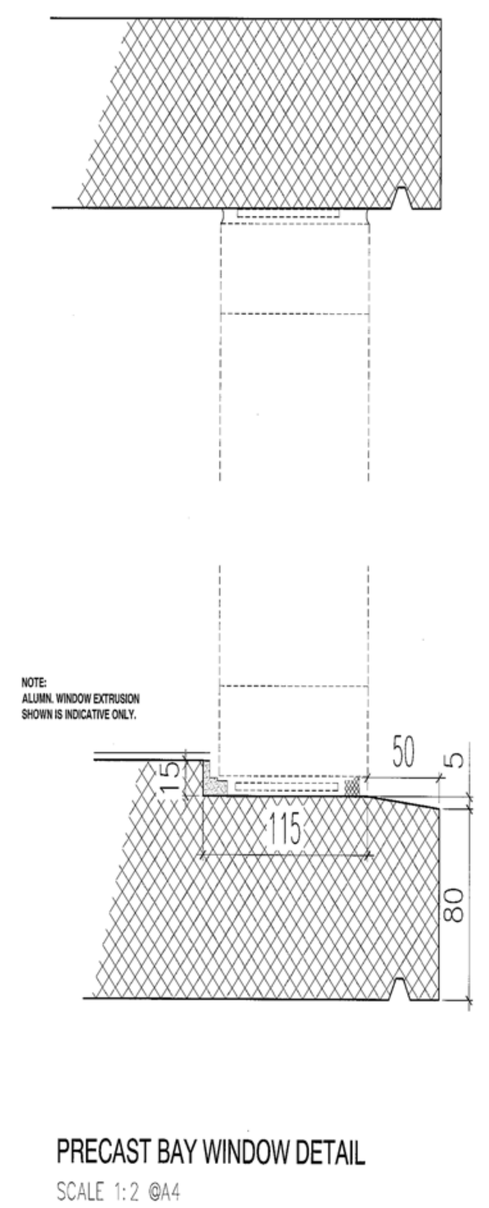


Figure 3.11 Opening for Window at precast facade wall

Figure 3.10 Opening for Bay window

3.6 PRECAST FLOOR SYSTEM

Two alternate floor systems have been developed for the proposed precast system.

In both systems, an in-situ structural topping is adopted, based on the following considerations:

- Precast slabs are less thickness and thus reduced weight.
- Different composite slab thickness can be achieved, as required by structural considerations, by varying the topping thickness but keeping the precast thickness constant.
- The topping concrete and reinforcement provide a simple means of tying the floor and wall components together.
- Services are simply provided at site within the topping concrete.

Services within the bathroom and toilet floors are generally of significant diameter and required to be laid to fall. In these areas, it is likely that a minimum topping thickness of 85mm would be necessary to incorporate these services. Assuming that the slab soffit is flat, to limit the total slab thickness for the floor adjacent to the bathroom, it is encouraged to limit to only one drop of 50mm at the wet areas. For shower areas, it is recommended to have kerb instead of a second drop to avoid thickening the slab at non-drop area.

3.6 a Floor System Alternate 1 - Prestressed Plank and Half-Slab Floor System

This precast floor system (refer to Figure 3.12), comprises prestressed planks spanning between load-bearing walls. Where voids, stairs and other features prevent the slabs from spanning between walls, slabs spanning perpendicularly are provided, supported by the adjacent planks.

The merits of this system are as follows:

- Floor beams are eliminated, resulting in simpler components and reduced services co-ordination problems.
- Stepping of building line at front and rear are easily accommodated.
- Full height window and other facade features can be designed
- Can accommodate irregular layouts, with less requirement for false ceilings

In this system, the following factors need to be considered:

- At roof level, any significant RC gutters will prevent slabs from spanning between walls.
- For some floor layouts, alignment of stair openings and voids can prevent slabs from spanning between walls.
- The volume of concrete for this system is likely to be 0 ~ 20% higher than conventional RC beam and slab.

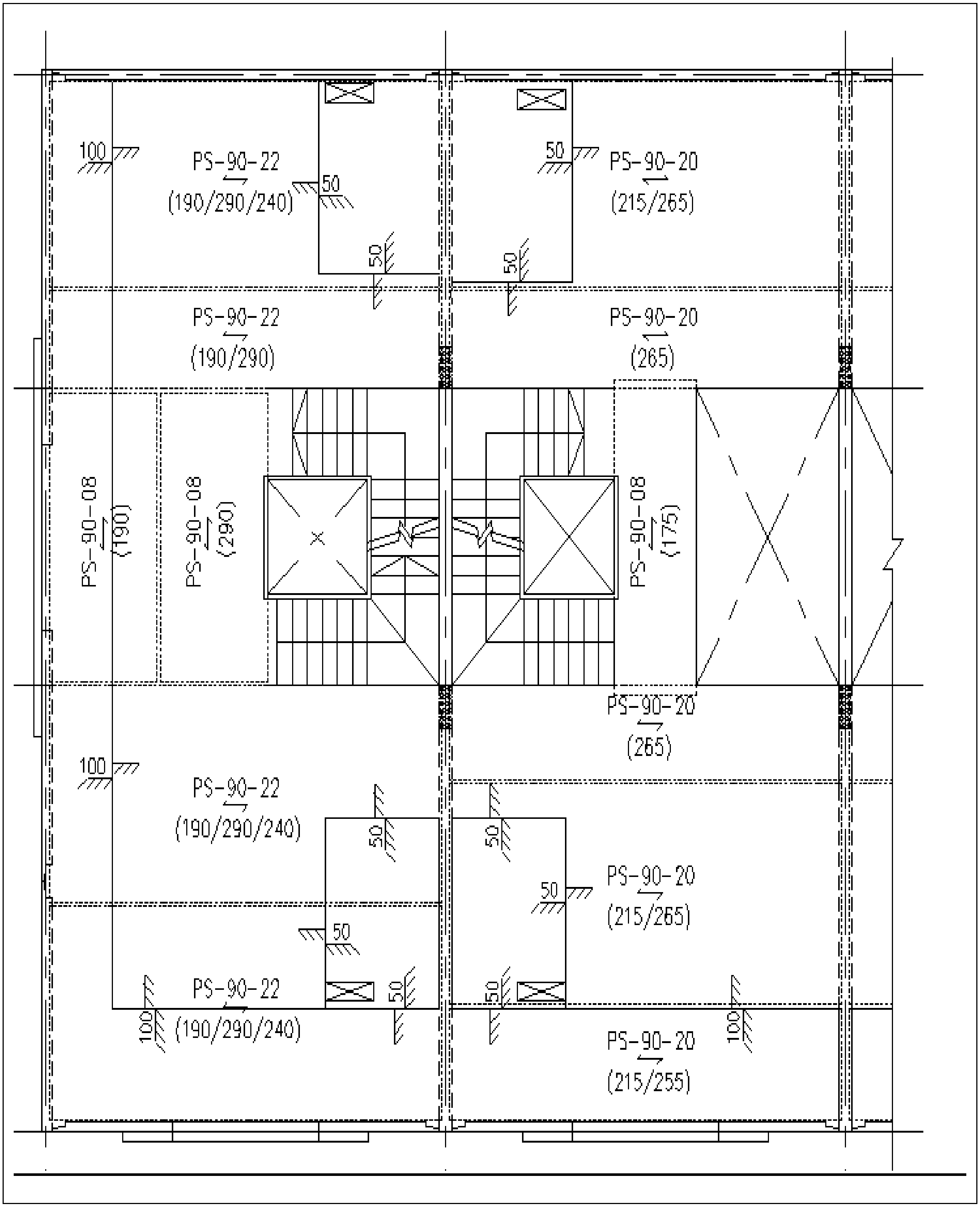


Figure 3.12 Typical floor layout for precast walls with precast slab

3.6 b Floor System Alternate 2 - Precast beams and precast slabs

This precast floor system (refer to Figure 3.13) comprises RC half-beams spanning between load bearing walls and half-slabs spanning between beams.

This system is similar to conventional RC design in terms of structural support.

However, other factors to be considered for the precast beam and slab floor system are:

- Beam penetrations will often be required for M&E services. These will require significant co-ordination and are technically difficult for the half beam system.
- Beam connections to supporting walls are preferably via wall pockets. The pockets can become deep when floor levels between adjacent units vary significantly.

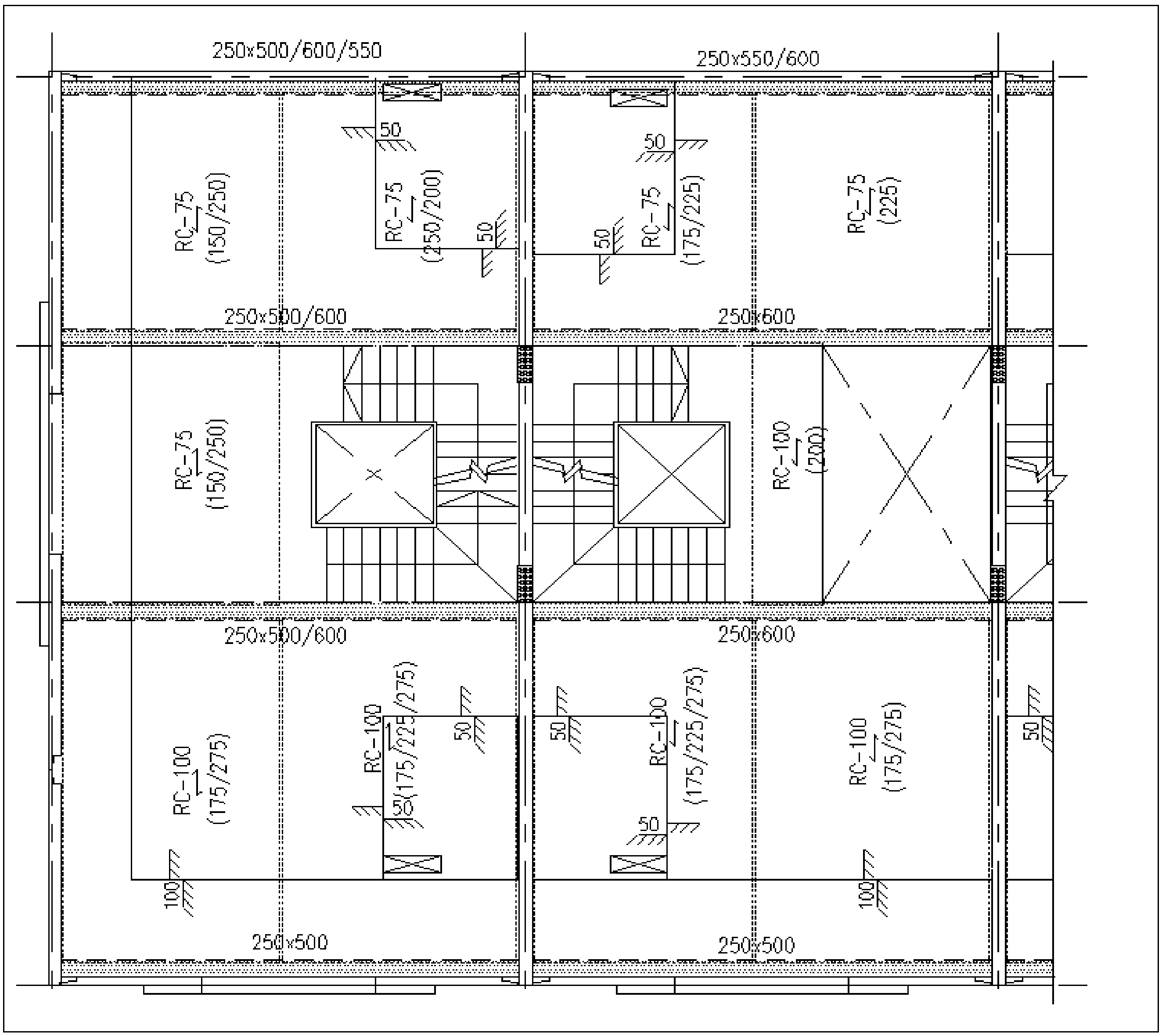


Figure 3.13 Typical floor layout for precast walls with precast beams and precast slab

3.7 Connection details

3.7 a Treatment of joints for load bearing party walls

Recommended jointing details as shown in Figure 3.14 (Detail 1)

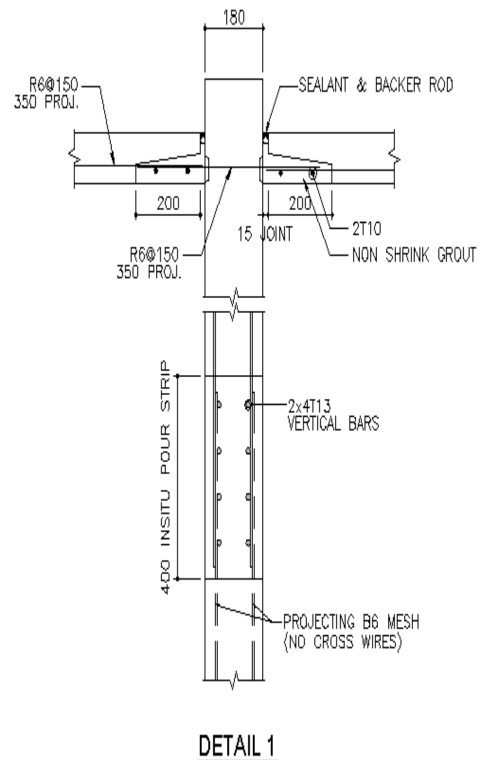


Figure 3.14 Joints at party wall and connection between party walls and facade walls

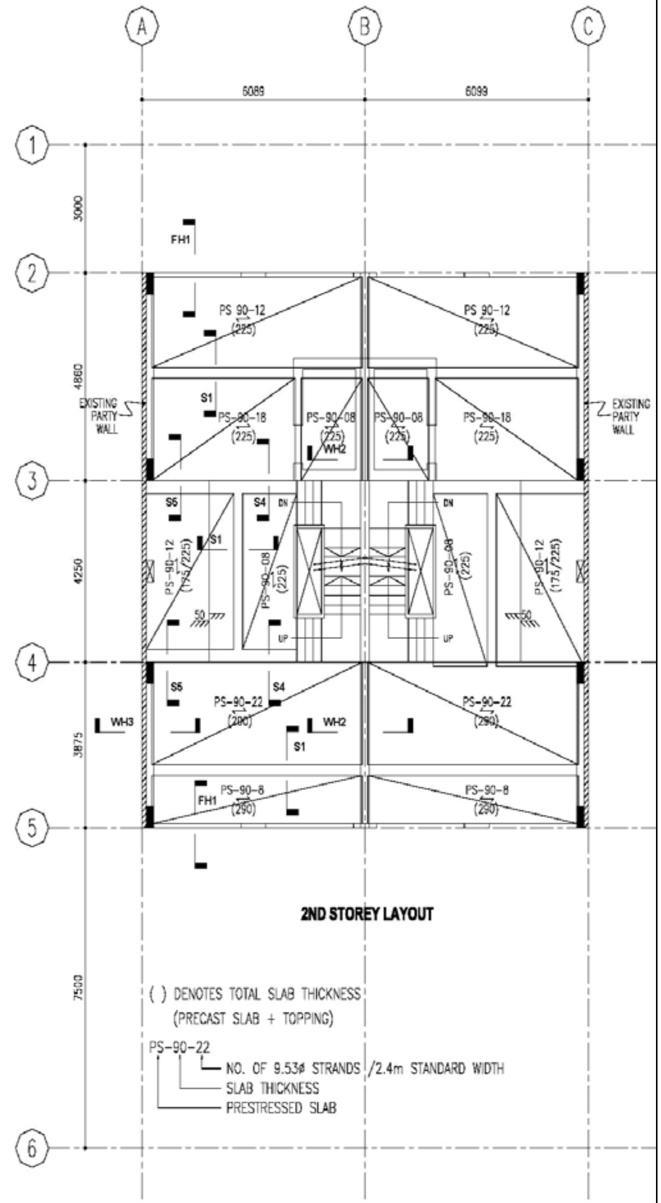


Figure 3.15 Layout plan for precast wall with prestressed precast planks (with section marking)

3.7 b Treatment of Joint for non-load bearing facade panels

- For vertical joints, a wet pour of grout / 9mm aggregate mix is provided as a waterproofing backup and to assist with crack control on the internal face.
- An important consideration with the proposed details is continuity of sealant.
- Options are given for façade to party wall, depending on whether party wall is exposed or hidden. Selection of the appropriate detail will depend on considerations of layout, appearance and whether the adjoining units are staggered horizontally.
- Recommended jointing details as shown in Figure 3.16 to Figure 3.22.

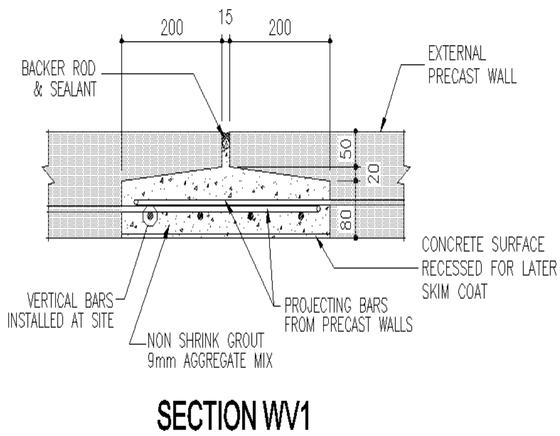


Figure 3.16 Plan of connection for long panel of facade walls or end walls

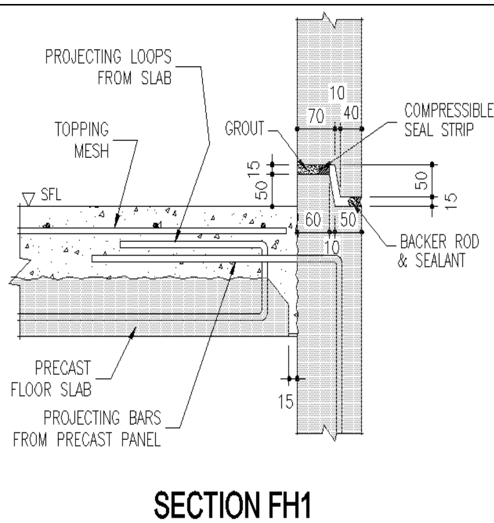


Figure 3.17 Section of water-stop detailing for wall-slab system

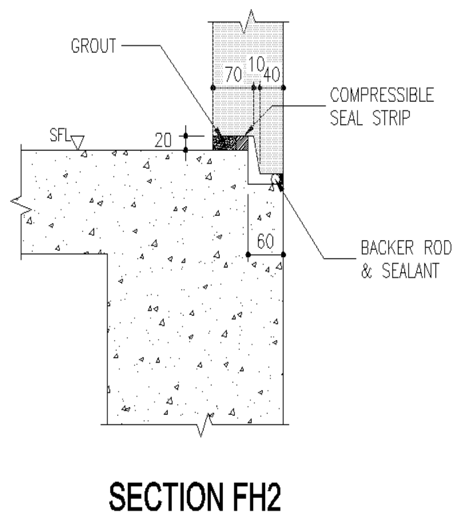


Figure 3.18 Section of water-stop detailing for beam-slab system

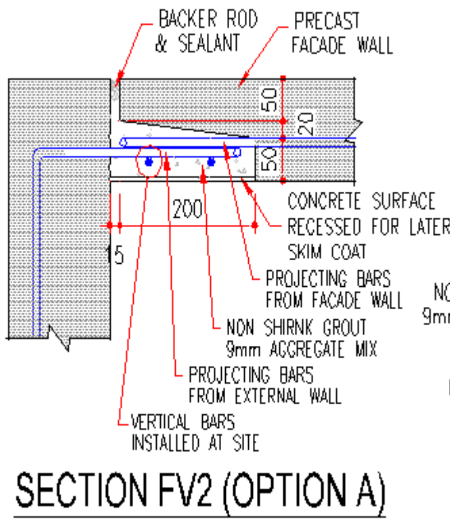


Figure 3.19 Option A - Plan of connection between end wall and facade wall

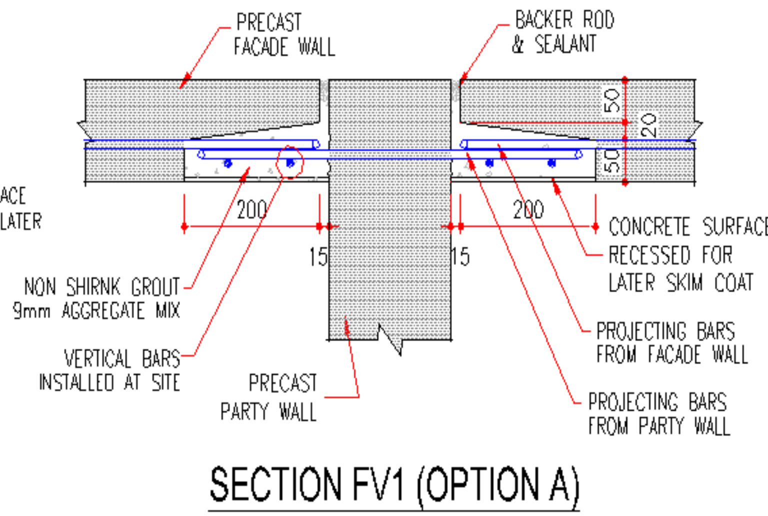


Figure 3.20 Option A - Plan of connection between party wall and facade wall

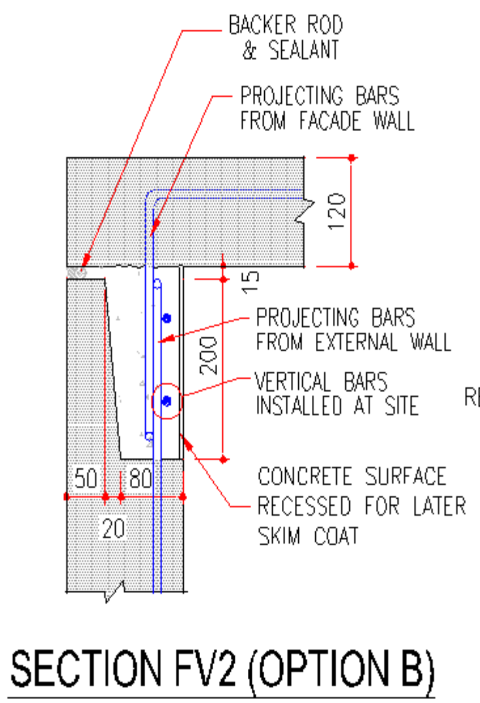


Figure 3.21 Option B - Plan of connection between end wall and facade wall

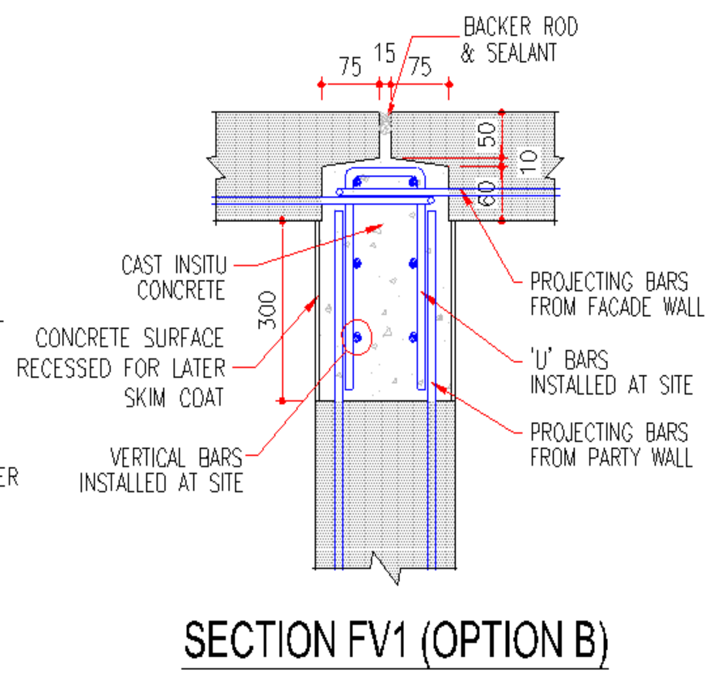


Figure 3.22 Option B - Plan of connection between party wall and facade wall

3.7 c Connection details for floor planks

Recommendations on connection are shown below:

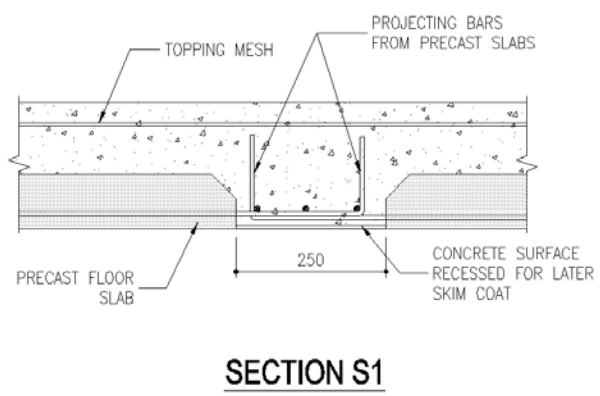


Figure 3.23 Section of pour strip for precast slab

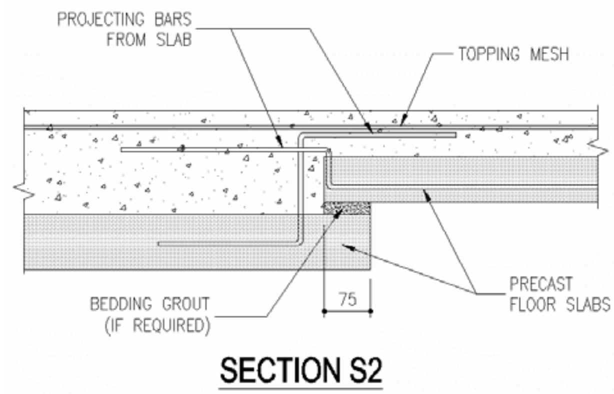


Figure 3.24 Section of slab with change in slab thickness

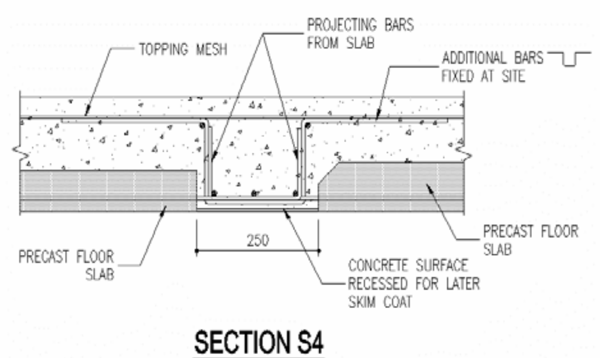


Figure 3.25 Section of pour strip with additional bars for slab support

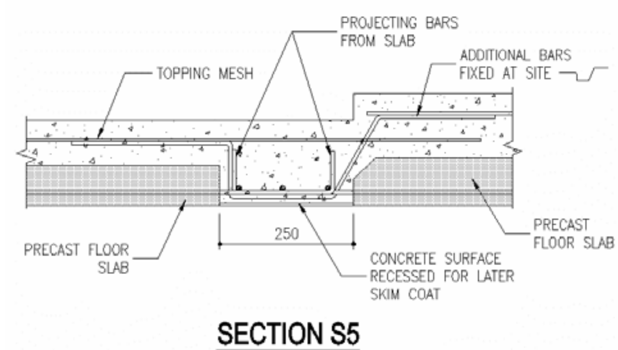


Figure 3.26 Section of pour strip with top drops for slabs

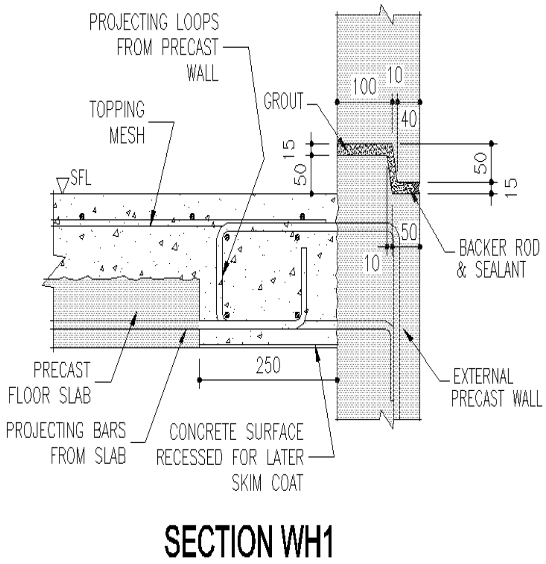
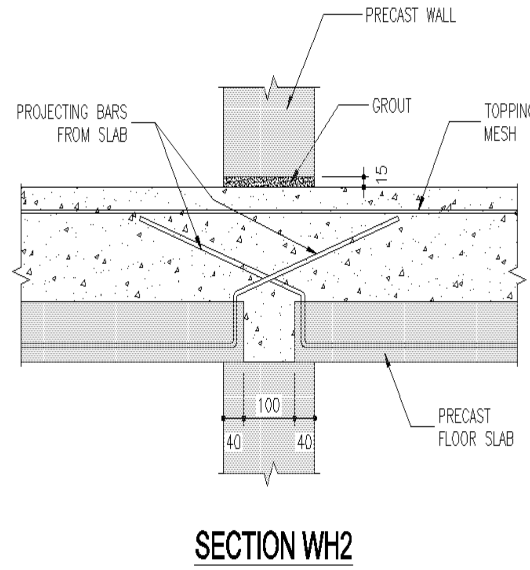
	

Figure 3.27 Section of slab details to facade walls	Figure 3.28 Section of slab details to party walls

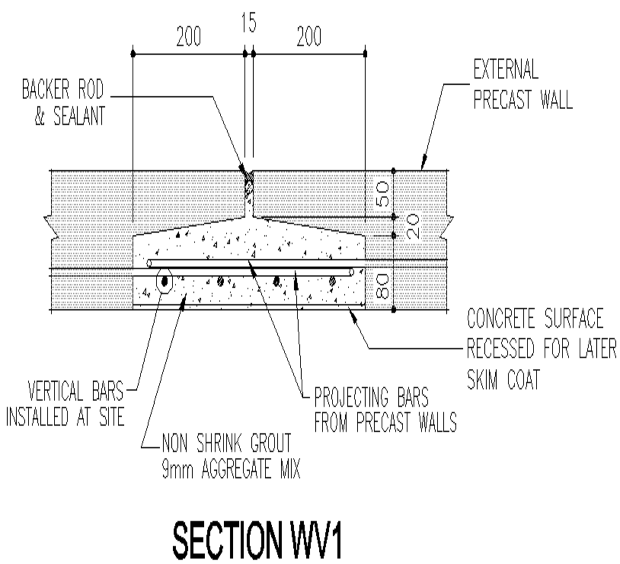



Figure 3.29 Section of slab details to pour strip of party walls	

3.8 M&E SERVICES

In conventional in-situ construction, M&E services are embedded in the cast-in-situ slab/wall/columns or brick walls. The planning and routing of these M&E services are usually left to the various sub-contractors working quite independently of each other on site. However, co-ordination between the different trades can be lacking and unsatisfactory. This frequently results in situations where M&E services are missed out, wrongly placed or cannot be placed because of inadequate space provisions. As M&E installations can often affect concreting works which are on the critical construction path, project delays and additional costs can occur.

Conversely, in a precast construction environment, it is necessary to pre-plan and pre-determine almost all M&E services inside individual precast panels beforehand. This requirement poses a basic change in standard working practice and it can be overwhelming to contractors not accustomed to it or not having enough resources. However, such pre-planning can prevent M&E mistakes, improve quality, reduce delays and reduce costs.

3.8 a Option 1 - Services in Topping

In this option, the horizontal services need to be embedded either in the slab topping or the precast plank itself and the vertical element is embedded in the precast wall. Co-ordination work is quite extensive, as all M&E services inside individual precast panels or planks need to be pre-planned and pre-determined beforehand. In particular, the interface between the horizontal and vertical element needs to be co-ordinated to ensure that they coincide exactly.

Another consideration is that precast panels are usually thinner than conventional brick and plastered walls. Hence, it is important to ensure that all services are accommodated without affecting the structural integrity of the panel.

In view of the above-mentioned considerations, the following section is a guideline for the proper incorporation of M&E services in a precast project.

<u>**Technical Details**</u>

A. Electrical Services

- Provide connection ring for ceiling light points at precast plank. Connection of junction boxes and conduits to be embedded in the slab topping on site with 200mm by 200mm pockets for connection to vertical element.
- Provide cast-in conduit/KO boxes in precast wall panel for switches/wall light, with 200mm by 100mm pockets at top/bottom for switches/wall light points for connection to horizontal element.

- Horizontal conduits for power/SCV/telephone to be embedded in slab topping with pockets provided for connection to vertical element.
- Provide appropriate size groove of 40mm depth at precast wall panel for installation of vertical conduits and KO boxes.
- All pockets and grooves to be patched back with structural grout after completion of installation and connection.

B. Plumbing and Sanitary Services

- Provide 75mm width by 40mm depth groove for concealed hot & cold water piping in precast wall panel.
- Provide 75mm width by 50mm depth groove for concealed basin/sink waste vertical pipes in precast wall panel.
- Minimum topping of 90mm is required for concealing the horizontal waste pipes in the topping with a 250mm by 300mm box-out for the floor trap and 150mm by 150mm box-out for floor waste at the bathroom precast plank.
- Horizontal waste pipes to be embedded within the topping together with the floor trap and floor waste and cast together.
- All pockets and grooves at wall panel to be patched back with structural grout after completion of installation and connection.

C. ACMV Services

- Provide cast-in condensed drain pipes with insulation in the precast wall panel with 150Wx300Hx75D mm groove at bottom and 150Wx500Hx75D mm groove at top for connection and refrigerant pipes at fan coil location.
- Provide individual condensate pipes dropper to ground floor for connection to drain or floor trap at ground floor.
- Provide 75Wx25D mm groove at precast plank between fan coil unit and condensate pipes dropper for horizontal condensed pipes to ensure good gradients.
- Horizontal condensed pipes to be embedded within the topping with 200mm by 150mm pocket for connection to vertical element.
- All pockets and grooves at wall panel to be patched back with structural grout after completion of installation and connection

D. M&E Co-ordination Work

Pre-planning of all M&E services in the precast plank and wall is critical in ensuring that the horizontal and vertical elements can be joined easily and the installation works can be carried out smoothly. The following provides a guideline for the co-ordination of M&E services in a precast development.

- All M&E services routing and installation procedure must be confirmed before commencement of precast operations.

- All precast panels need to be confirmed and individually named to ensure that the location of each panel can be determined correctly during launching.
- Precast Geometry Drawing must be produced by the precaster (including layout plans) and issued to the M&E contractor for him to incorporate the M&E services into the precast panels before commencing precast production.
- Main contractor to incorporate individual services into a combined services geometry drawing for construction.

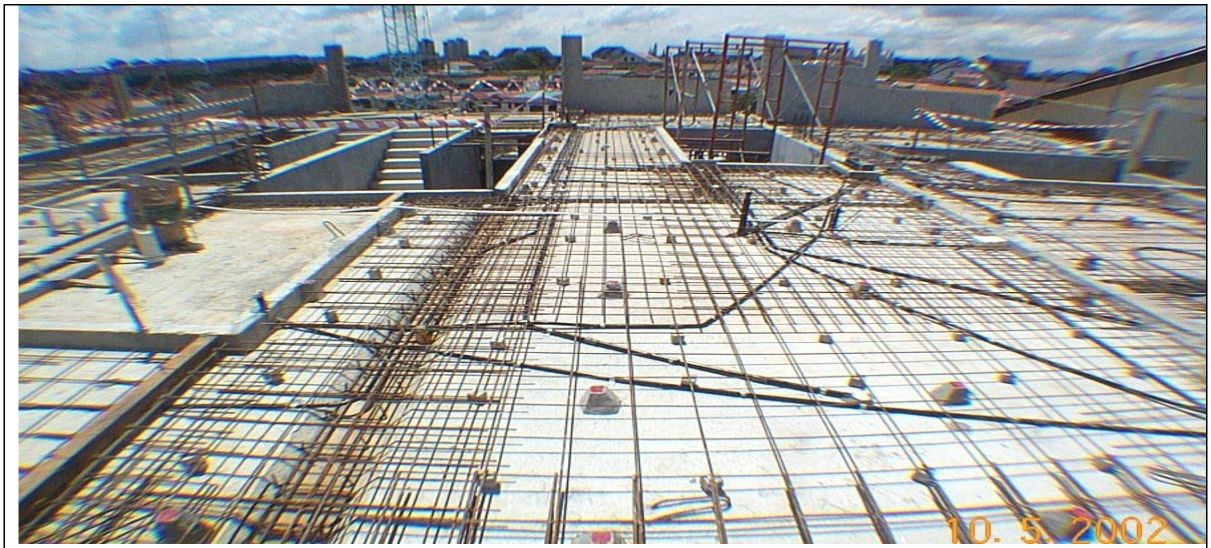


Figure 3.29 Option 1 - Services laid within the cast in-situ topping over the PC slab

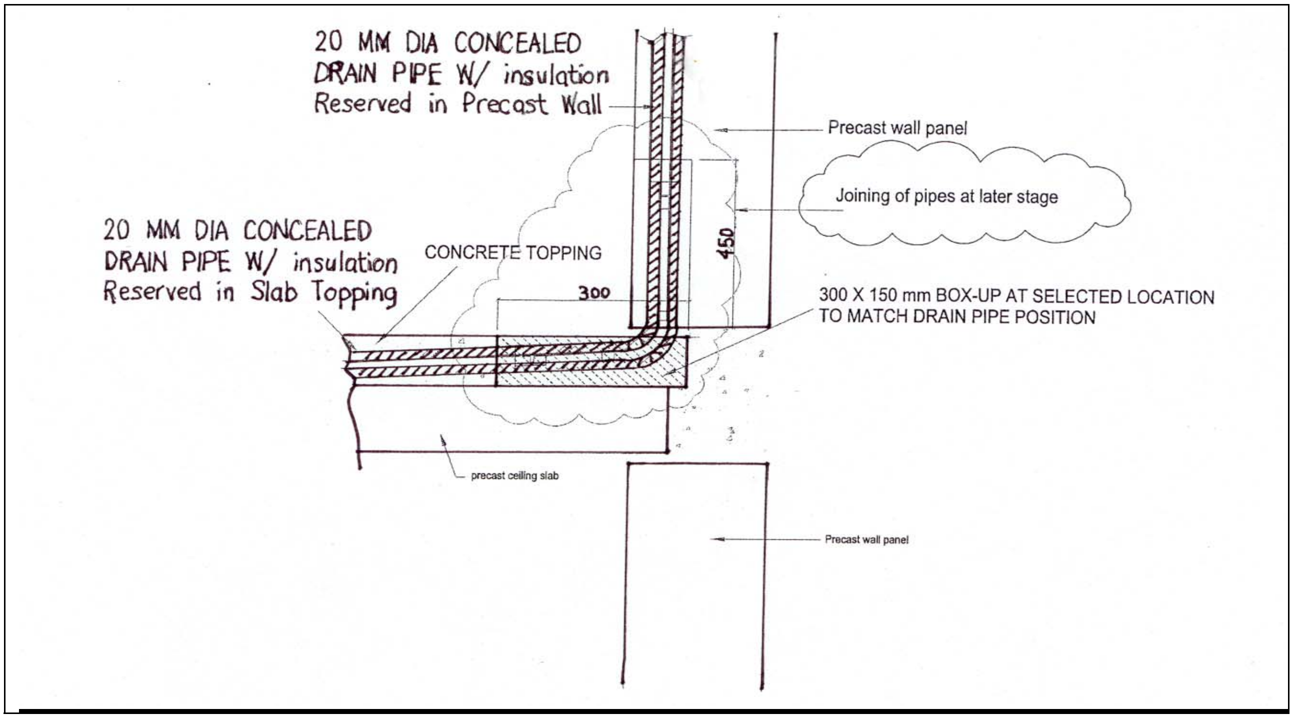


Figure 3.30 Option 1 - Proper co-ordination at interface between horizontal vertical element

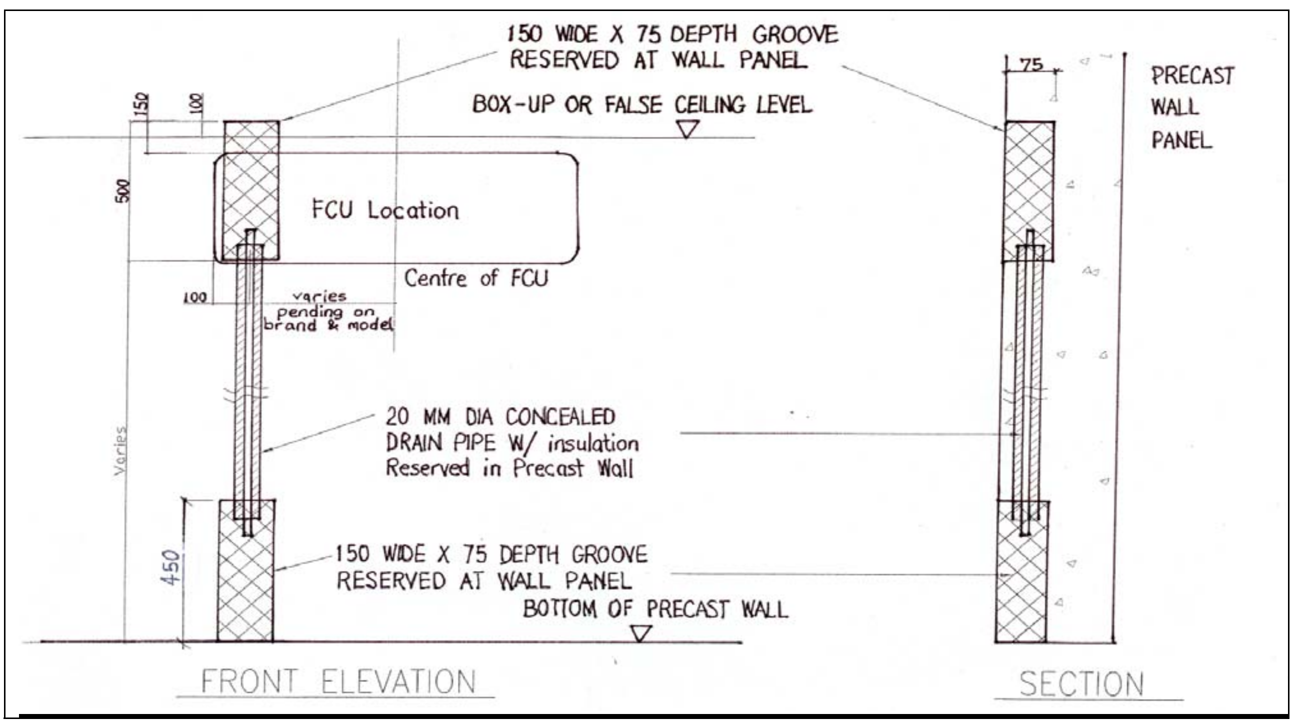


Figure 3.31 Option 1 - Typical elevation and section

3.8 b Option 2 – External Tray

Instead of embedding all M&E services within the precast panels, this option makes use of an external tray / ring system. There are a number of additional advantages to this system (in comparison to the previous option). Whilst good planning is still essential, the option here reduces the extent and degree of pre-planning required. It will no longer be necessary to plan and ensure that M&E services are properly accommodated within the panels to prevent any adverse impact on structural integrity. Instead, there will be additional flexibilities for changes or additions of M&E services.

Technical Details

All M&E services are housed together in an external tray which is mounted on the wall / ceiling surface. Architectural treatment such as a false ceiling or a bulkhead would be used to conceal these services. A typical bulkhead is shown in the attached drawings. In a worse case scenario, a bulkhead of up to 400mm would be needed. This would generally not be an issue as the clear floor height of a typical landed house would be in excess of 3 metres.

Vertical lines generally would have to be pre-planned and concealed in walls. These are facilitated by the use of “pockets” or wider grooves left in the precast panels for connection, such as power points, electrical wirings or pipings for fan-coil unit. The positions of these connecting pockets would have to be pre-determined. Fortunately, in a typical landed housing environment, the positions of these elements are easy to determine and plan for. The pockets would be grouted with appropriate material after the M&E connections have been made on site. The slightly larger size pockets / grooves will cater for site tolerance and ease of connection.

Horizontal lines are installed on top of the precast floor slab at site. These services would be concealed in the concrete topping layer later.

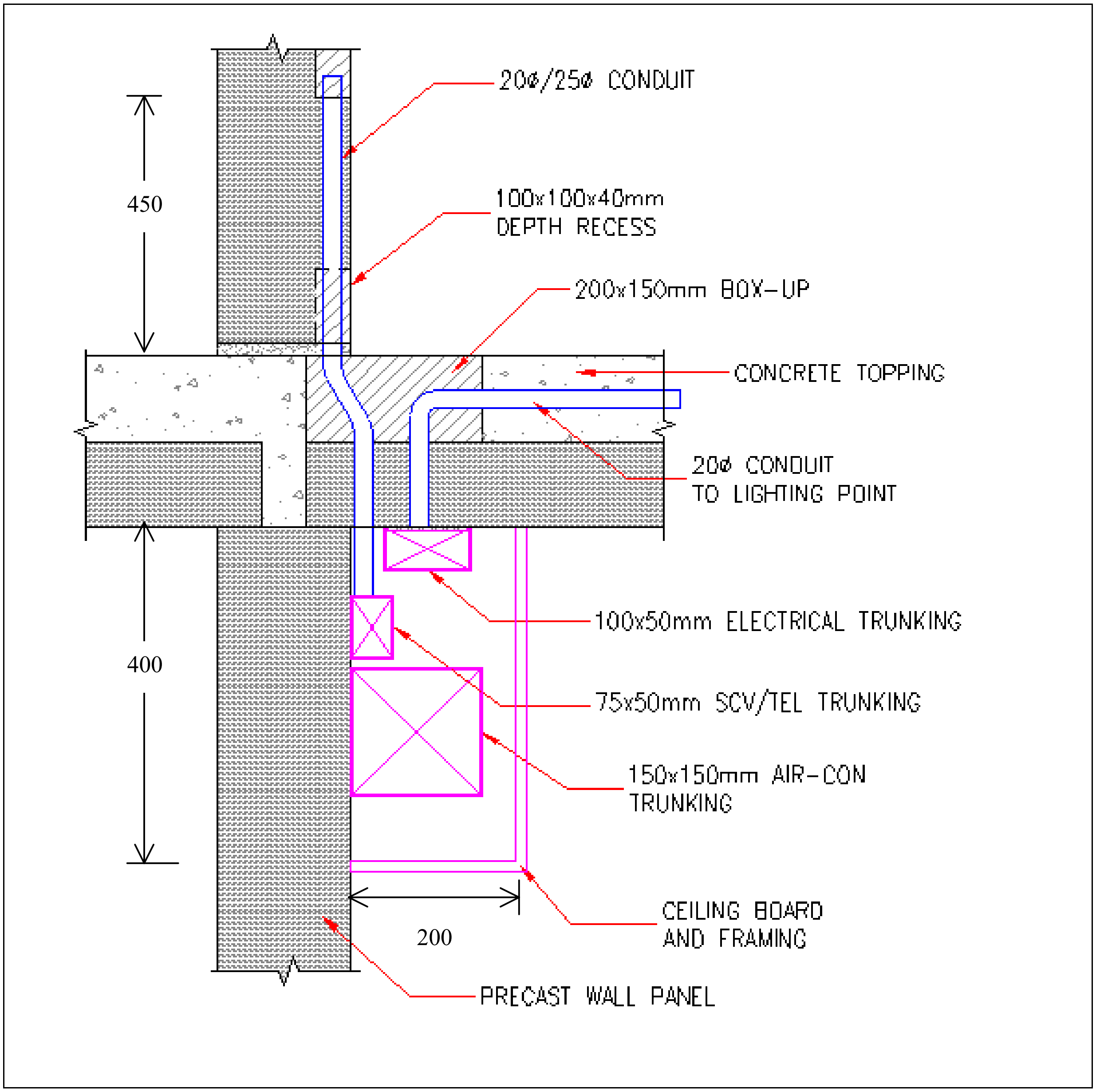


Figure 3.32 Option 2 - Using external tray

Chapter 4 CONSTRUCTION METHOD FOR PRECAST SYSTEM

The main factor that contributes to the success of a precast building project is ‘integration’ of all building professionals. Professionals stated here include architects, engineers, clients, contractors and sub-contractors. The involvement of all players at an early stage is critical to a precast project.

The fundamental mindset of all professionals has to be changed to achieve “Total Building Performance”. Conventionally, consultants are more concerned with meeting clients’ needs, regulatory requirements, design soundness and functionality while clients are more concerned with cost and the end product. Contractors, on the other hand, are more concerned with the building process.

Very often, contractors are tasked to convert a traditional cast in-situ (Architectural and Structural) design to a precast design. The design development will involve modification to the consultants’ design intent. As such, it is not uncommon for the contractor to face strong resistance from the consultant team. This is to be predicted as any player tends to be defensive if his ‘professional’ views are being challenged.

Today, the fragmentation approach towards design and construction among the professionals within a project is evident in most projects. A shift in paradigm is crucial to achieve success in any project. This section attempts to provide a guide for the construction of a precast project. The reader should refine the contents by consultation with professionals and precasters.

4.1 CONSTRUCTION CONSIDERATIONS

The contractor should consider the following:

- All safety issues on site when handling precast elements, especially so when working within a tight site
- The lifting capacity of the crane used
- The working boom-radius of the crane
- The suitability of construction materials for the purpose of use, i.e. sealant, grouting, shim plate, propping etc
- Co-ordination with the precaster and specialist supplier to achieve the best performance and working method - precaster often provide relevant technical requirements to the contractor during the design development phase to avoid discrepancy

Figure 4.1 Precast walls are propped before casting of joints – proper planning is required for perfect alignment

Figure 4.2 The pour strip between 2 pieces of precast walls are cast

Figure 4.3 Precast planks are installed in place

Figure 4.4 Preparation for casting of landing slab to precast staircase

Figure 4.5 Preparation of welded mesh and services for cast in-situ topping

Figure 4.6 Concreting to topping

4.2 SEQUENCE OF WORK

A Quick Check

- Ensure the correct panel before hoisting
- Ensure the crane lifting capacity before hoisting the panel
- Ensure the desired crane's working radius
- Ensure the anchorage for the propping does not damage cast-in building services
- Ensure the desired Reduced Level (R.L.) of panel-base by adjusting the shim plate. Shim plate to be at an interval of 500mm c/c
- Ensure the desired verticality/position is achieved
- Estimated time to install a typical precast element is 1/2 to 3/4 hour

Construction Requirements

- **Elements of control**

  Alignment, Verticality and Levels

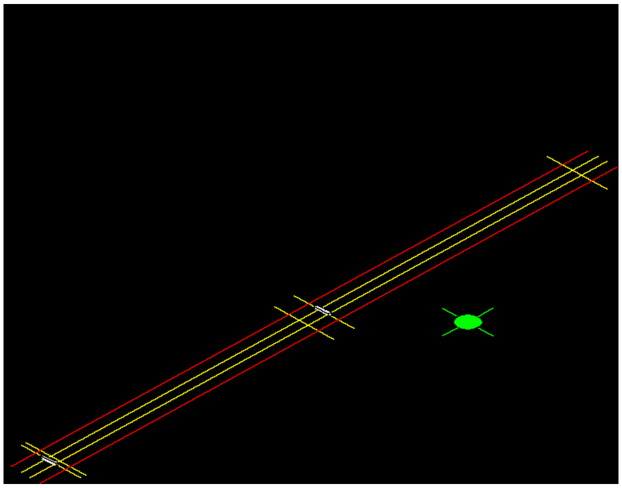
- **Tolerance level**

1. For Wall
    - Vertical deviation +2 mm, -2 mm
    - Horizontal deviation 0 mm

2. For Beam & Slab
    - Departure from intended horizontal position, +2 mm or –2 mm
    - Departure from intended vertical position, +2 mm or – 2 mm

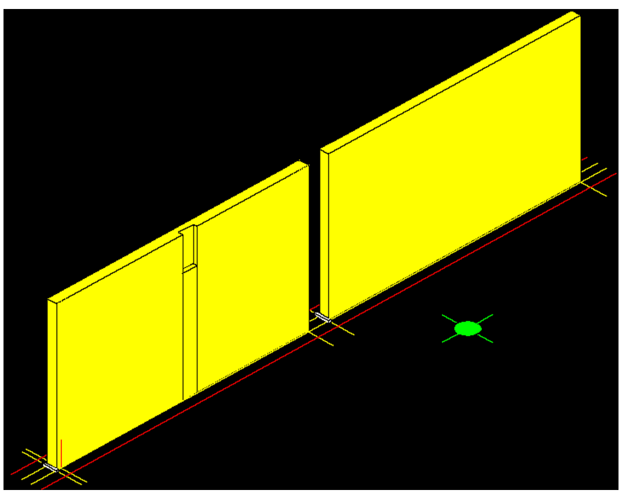
The diagrams below illustrated the sequence of installation for the precast beam-slab system:

The Procedure



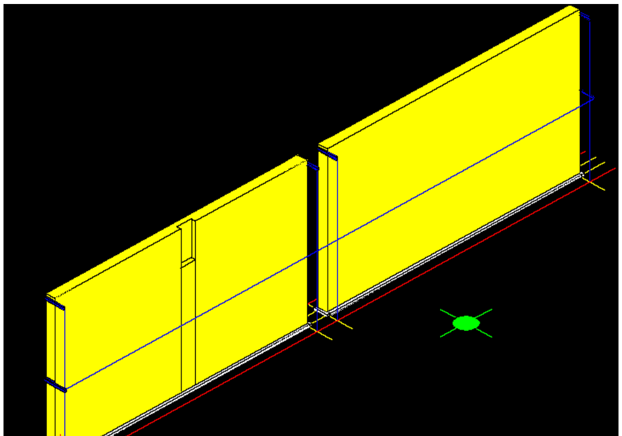
- Setting Out

1. Surveyor to set cross reference.
2. Transfer grid and mark wall position on slab.
3. Mark 100mm offset line from rear building edge.
4. Offset wall position by 200 mm.
5. Secure 2x2 timber to the floor at wall edge to guide wall.



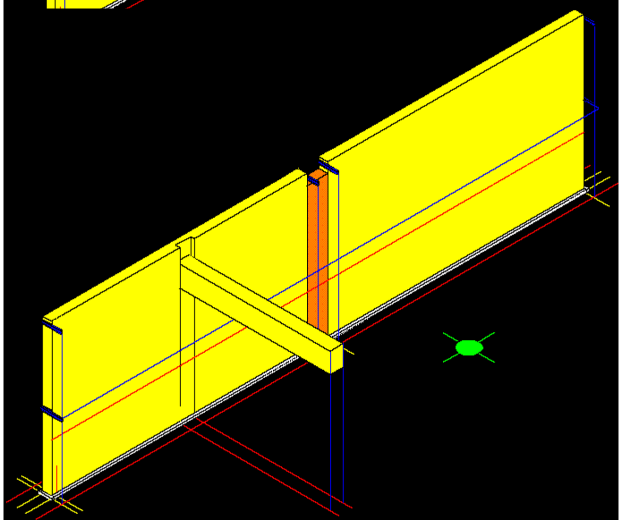
- Wall Positioning

1. The first wall in place has to be the partition wall at the rear.
2. Mark a line parallel to and 100mm from the external edge of the wall.
3. Place shim plate @~500 c/c on the floor and level to wall soffit. Shim plate may also be placed on Non-shrink mortar bed and allow to set.
4. Adjust position of the dowel bar.



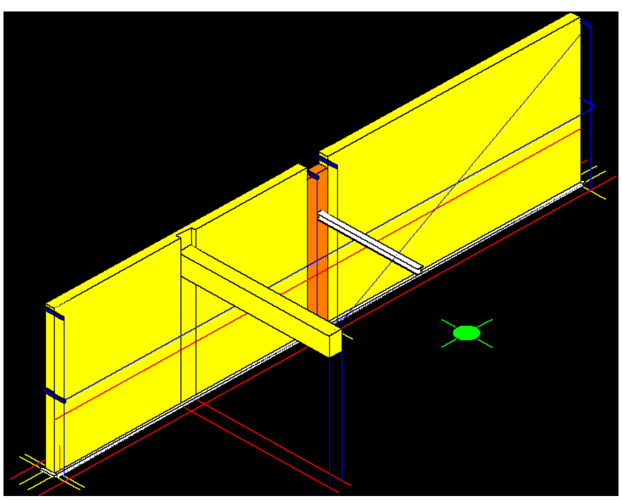
- Wall Adjustment

1. Position adjacent walls and plumb wall corners at 200 mm offset
2. Adjust verticality until within +2 or –2 mm
3. Ensure the four faces of every walls are adjusted
4. Position string 250 mm from face of walls
5. Walls within the same line are to be adjusted within same tolerance
6. Ensure air-pocket is fully grouted.



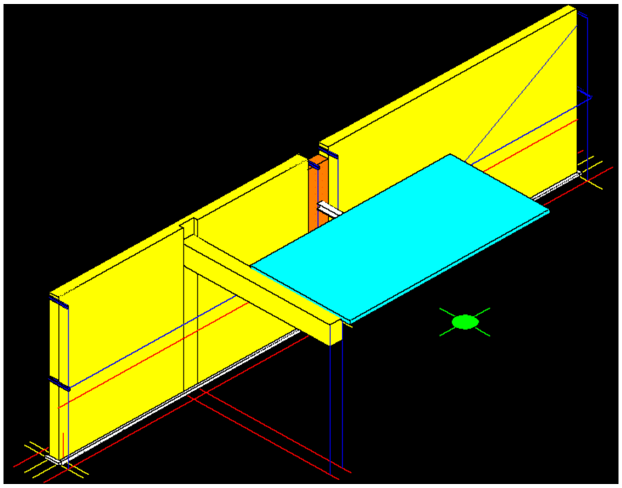
- Beam Setting Out

1. Cast wall joint.
2. Mark 1 m reference line.
3. Confirm pocket level. Position shim plate to correct beam soffit level if required.
4. Mark position of beam on floor.
5. Hoist beam in place and check top level.
6. Plumb beam to verify position on floor below.
7. Ensure beam verticality with a spirit level.
8. Wedge beam against pocket and grout the gap between the beam and the wall.



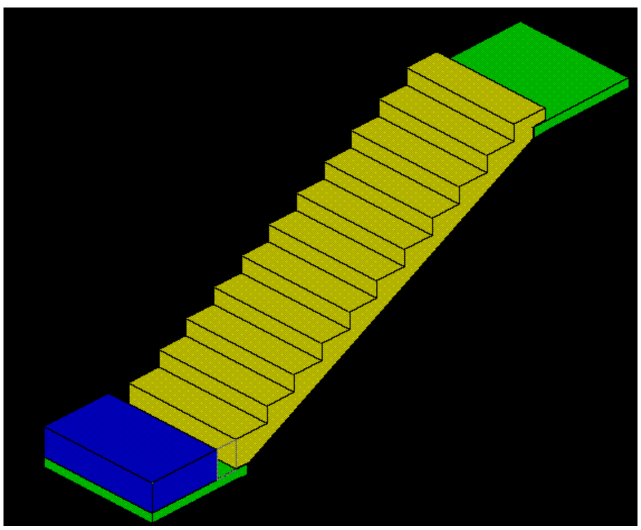
- Slab Setting Out I

1. Position the slab temporary supports and adjust the slab soffit level approximately.
2. Raise the height of the supports about 5 mm above slab soffit level.



- Slab Setting Out II

1. Hoist slab in place on top of beam and support.
2. Verify level of every plank soffit at four corners and center.
3. Adjust level of temporary support accordingly.



- Staircase

1. Position landing or slab and verify soffit level at four corners.
2. Adjust level to within tolerance.
3. Position shim plates at staircase support location to correct level.
4. Verify level difference between pegs on top and below.
5. Hoist staircase in place.
6. 10mm gap between precast plank and staircase

Precaution

1. Specify items which cannot be compromised
   - Zero tolerance on partition walls.
   - Dividing boundary line between units.
   - External building lines.
   - Staircase dimension.
   - HS internal dimensions.

2. Alignment Priority
   - Alignment of grooves.
   - Uniformity of grooves.
   - Horizontality of architectural treatment ie. Brick Tile

Post Installation

1. Verify alignment and verticality of every wall.
2. Verify cast slab level at 1m grid.
3. Report deviation and rectify if required.

4.3 CONSTRAINTS AND SOLUTIONS

4.3a Access

CONSTRAINTS	SOLUTIONS
❖ Small road in front of site may not allow crane and delivery trailers up to 3.5m wide to park.	❖ Use smaller crane and trailers to deliver and install small components.
❖ Crane and trailer are unable to negotiate small turning radius at junctions of small roads.	❖ Study the locality and look for available space for turning. Have one worker direct traffic while crane and trailer is turning.
❖ Diversion of existing services such as lamp-posts, fire hydrants and overhead electrical cables may be necessary.	❖ Diversion must be done before installation of precast components begins.
❖ Existing trees and shrubs in front of site require National Parks Board approval before they can be removed and later reinstated.	❖ The consultants must write in to National Parks Board for approval much earlier before construction begins.

4.3b Crane Capacity and Reach

CONSTRAINTS	SOLUTIONS
❖ Lifting capacity of small crane not enough to lift heavy and far components.	❖ Hire bigger crane with longer boom to lift heavy and far components. Alternatively, plan the sequence such that the crane can park nearer to the heavier components.

4.3c Coordination

CONSTRAINTS	SOLUTIONS
❖ Wrong components delivered to site.	❖ Provide clear labels on components and drawings to avoid confusion.
❖ Wrong sequence of delivery (such as planks arrive first before the beams on the same day)	❖ Person ordering must maintain good communication with person delivering.

4.3d Installation

CONSTRAINTS	SOLUTIONS
❖ Lifting over neighbour's roof may cause anxiety over safety and damage to existing properties.	❖ Crane and trailer can be parked strategically to avoid such lifting. Crane operator can make use of boom angle to keep lifting within site boundary.
❖ Starter bars do not match with grouting holes or clashing of bars at connections between beams and columns.	❖ Equipment and workers to crank or bend the starter bars will be provided on site.

4.3e Handling

CONSTRAINTS	SOLUTIONS
❖ Damage such as cracks and corners chipped-off occurred due to knocking during handling.	❖ If damage is minor, cracked components can be repaired using approved epoxy resin. Non-shrink grout can be used for chipped-off corners.

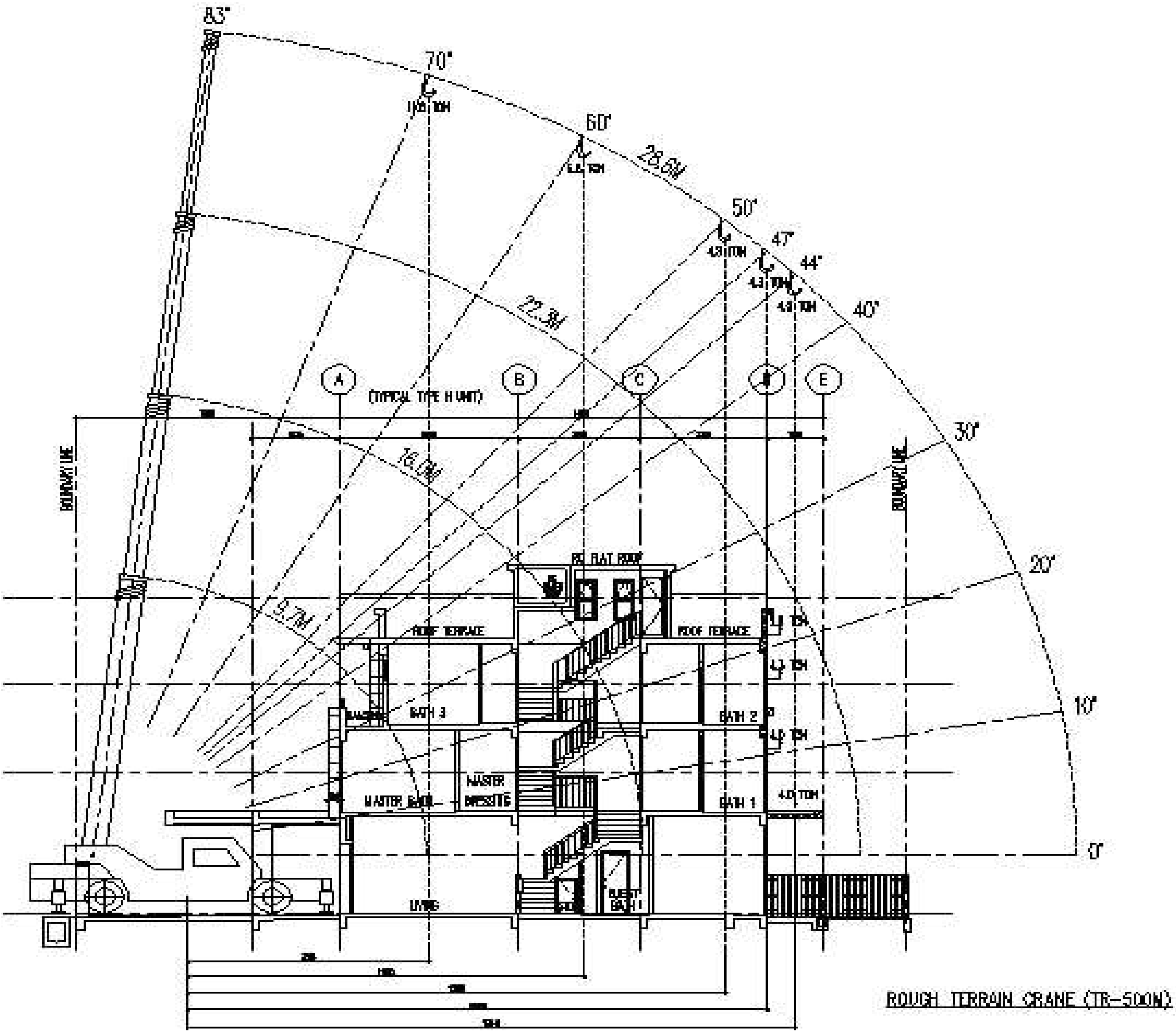


Figure 4.7 Optimisation of crane usage (50 tonne crane) and weight of components

Chapter 5 DESIGN CONCEPT FOR FLAT PLATE SYSTEM

5.1 STEEL/ CONCRETE COLUMN WITH FLAT PLATE SYSTEM

With increasing demand for flexibility in interior layout, the use of flat plate for landed houses is gaining much popularity amongst architects. The main and unique feature of this system is that it provides a way for the architect to achieve the concept of high and completely flat ceiling with no beam protrusion.

Some projects have reported an improvement in the construction speed and cost savings from using this system which requires only simple formwork. The use of flat plate appeals to designers particularly because design flexibility is possible through shifting of walls without the need for columns to be properly aligned. The services can be installed within or below the slab and there are flexibilities in relocating vertical small penetrations. The soffit is often flat and high ceiling height can be achieved.

The columns used in this system are either cast in-situ concrete columns or circular steel hollow sections. When the columns used are steel hollow sections with concrete in-fill, the desired finish with exposed steel can be easily achieved.

Flat plate system with circular steel column

5.2 CONNECTION AND DETAILING

The main consideration for steel column connection to flat plate is to ensure that the base plate for the steel columns are cast into the concrete flat plate. Hence the positioning and alignment of the base plates are of utmost importance.

If concrete in-fill and column bars are required within the steel hollow section, the starter bars for the columns have to be placed and fixed in position prior to casting of concrete flat plate (see figure 5.5 for base plate connection).

In the concrete column with flat plate design, the connection is more simplified without the need for base plate connection. In this case, reinforcement bars should be properly detailed between the columns and slabs. Punching shear checks are critical and vertical shear reinforcement should be detailed accordingly.

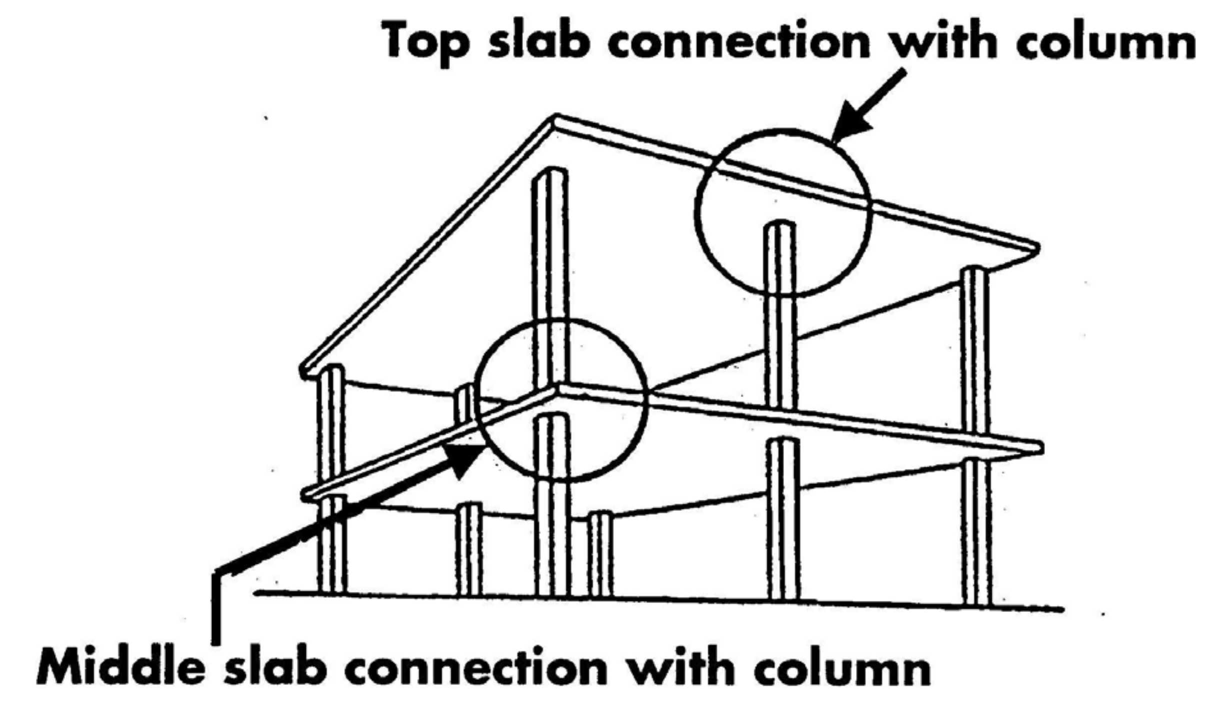


Figure 5.1 Critical connection between slab and columns

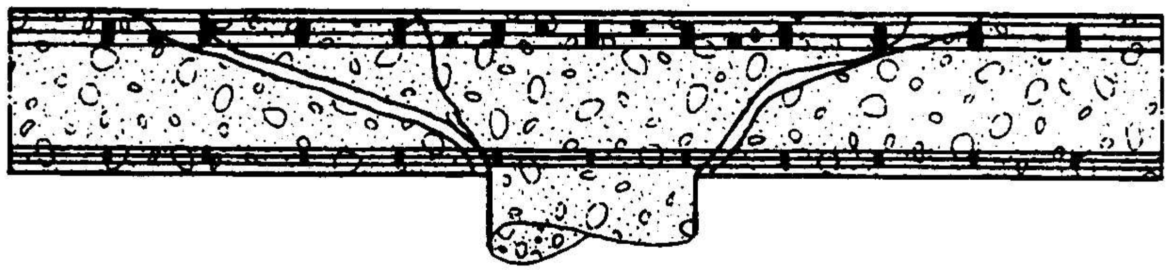


Figure 5.2 Typical shear failure near column. Proper detailing of shear reinforcement must be provided

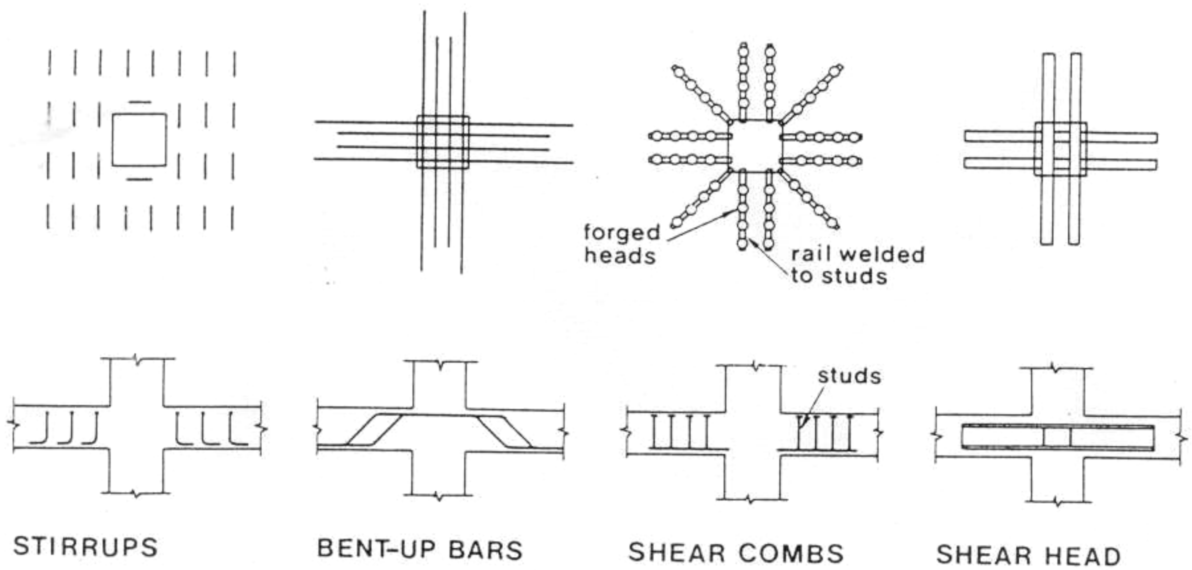


Figure 5.3 Examples of shear reinforcement

Alternatively, designers may introduce hidden beam within slab along column strip to cater for the shear stresses near column location.

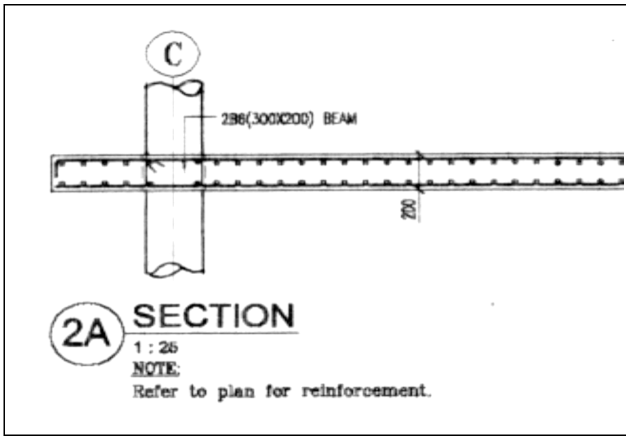


Figure 5.4 Hidden beam within column strip

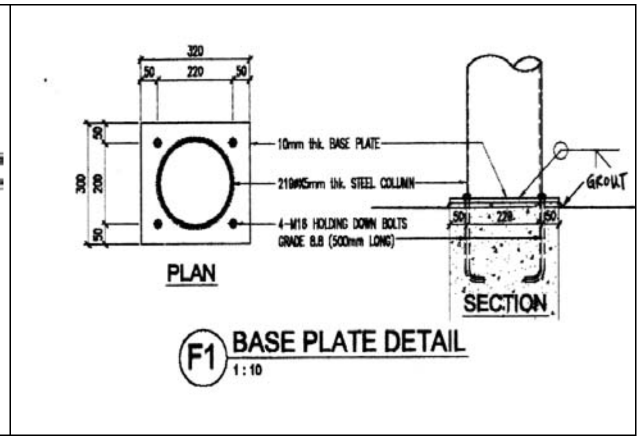


Figure 5.5 Base plate details for column

Figure 5.6 Semi-detached houses using flat plate with steel column (near completion)
Designed by: IP:LI Architects

Chapter 6 CONSTRUCTION METHOD FOR FLAT PLATE SYSTEM

6.1 GENERAL CONSIDERATIONS

The following are the key factors to be considered before adopting the use of the concrete flat plate with steel/concrete column system:

- Architectural layout should be well planned to fully enhance the main area where high flat ceiling with neatly arranged steel/concrete columns are required in the design

- Spacing of columns

- Punching shear checks at column areas

- Long term deflection of the flat plate

- Early planning of routing for M&E services, opening for voids and location of staircase

With the use of flat plate system, no complicated formwork is needed for beams. The formwork for slab can be recycled with repetition in floor layout. The use of prefabricated reinforcement for slab is recommended to achieve higher productivity on site.

6.2 CONSTRUCTION ON SITE

Figure 6.1 Construction of circular steel hollow section with cast in-situ flat plate


Figure 6.2 Flat ceiling with ease in formwork installation


Figure 6.3 Services through slab with provision for opening

Flat plate system with circular columns

Flat plate system with circular columns

Chapter 7 DESIGN CONCEPT FOR STRUCTURAL STEEL SYSTEM

7.1 STRUCTURAL STEEL SYSTEM

- Steel column/ beam/ metal deck

The building vertical design loads comprise of the dead weight of the structure and the live loads. The secondary steel universal beams are spaced to support the composite slab such that during casting, no additional props are required. The main steel beams support the secondary beams and transfer load to the columns. The composite slab with its welded mesh form horizontal ties. The composite slab laterally restrains the beams.

Columns can be in the form of steel hollow section columns with concrete in-fill or steel H-sections with fireproofed box-up to provide for a half-hour fire rating resistance.

All exposed steel members are to be painted with approved coating e.g. zinc chromate primer prior to two coats of enamel paint.

17 Tavistock Ave
Designed by LOOK Architects

7.2 CONNECTION AND DETAILING

Joints can be designed as pin supports. Bolted connections can be considered for easier installation on site. All structural steel members, plates, bolts and nuts used should be hot-dipped galvanised.

For connections to varies structural elements, the following are recommended:

Column to Foundation

The base connections should be designed as pin joints. Bolts can be cast together with the stump. Base plates are to be bolted and leveled with non-shrink grout. Steel columns are to be lowered and welded to base plate.

Column to column

Splice connection between steel columns can be butt welded with splice plates.

Beam to column and beam to beam

Bolt connections for column-to-beams and beam-to-beam connection will allow for ease of installation.

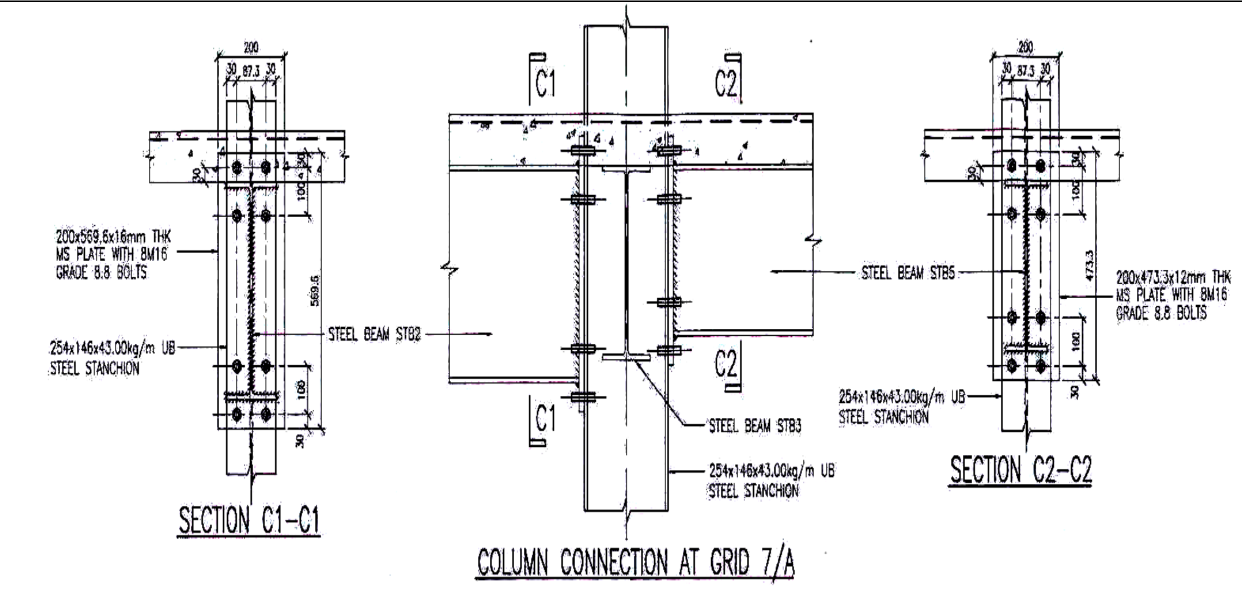


Figure 7.1 Connection details 1 (details and sizes shown are indicative only)

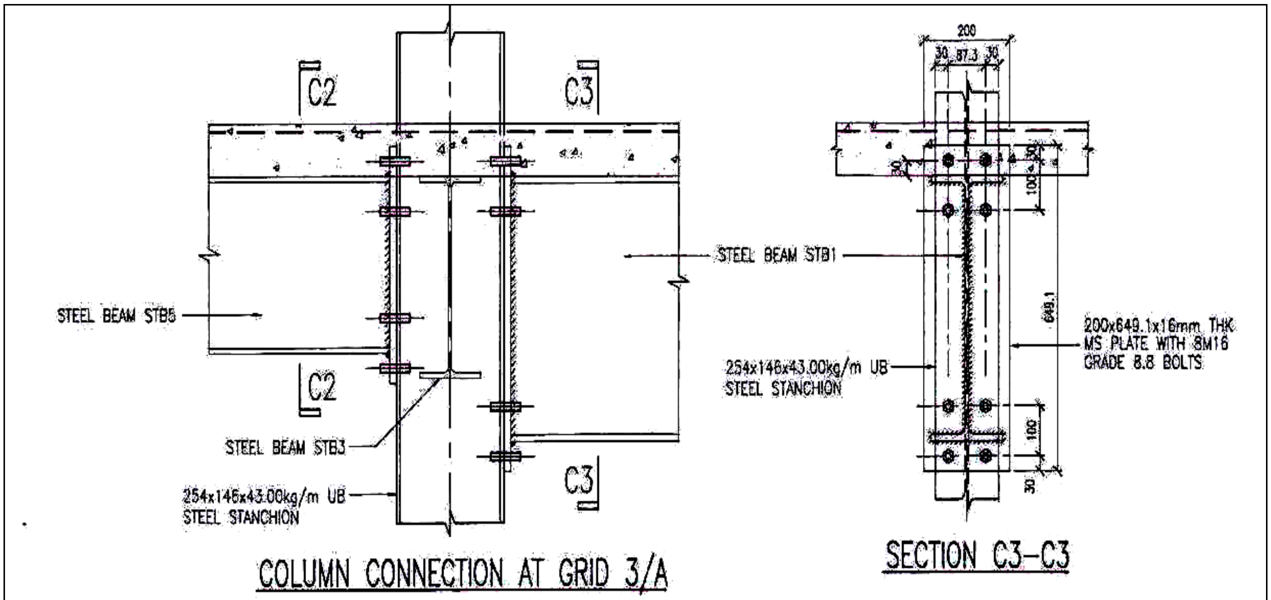


Figure 7.2 Connection details 2 (details and sizes shown are indicative only)

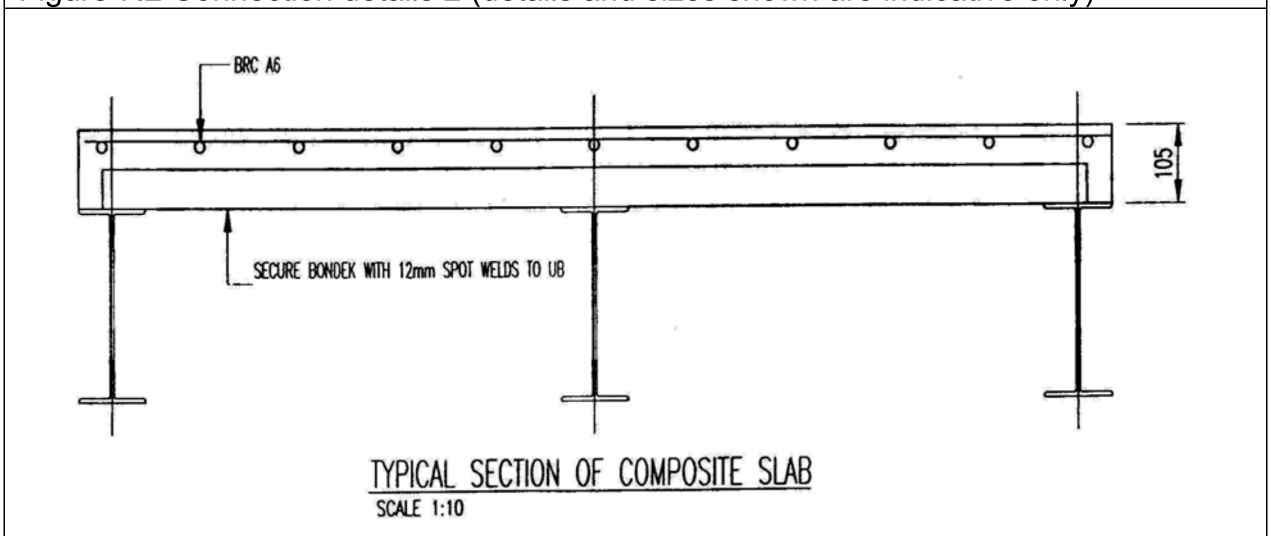


Figure 7.3 Typical section of composite slab (details and sizes shown are indicative only)

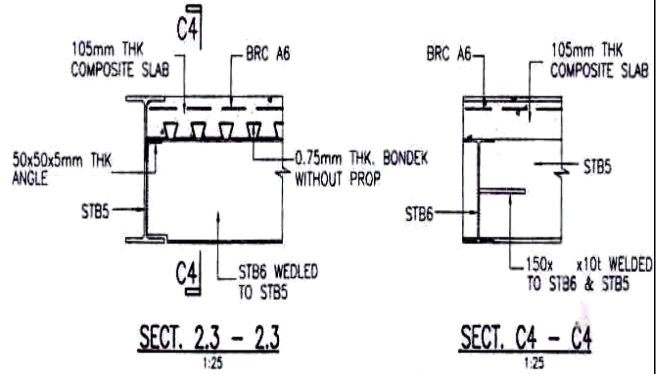


Figure 7.4 Slab details (details and sizes shown are indicative only)

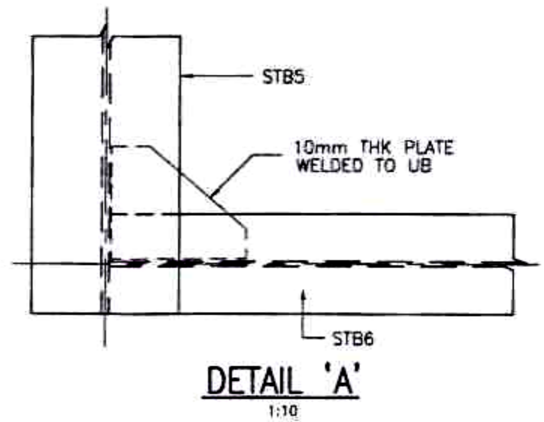
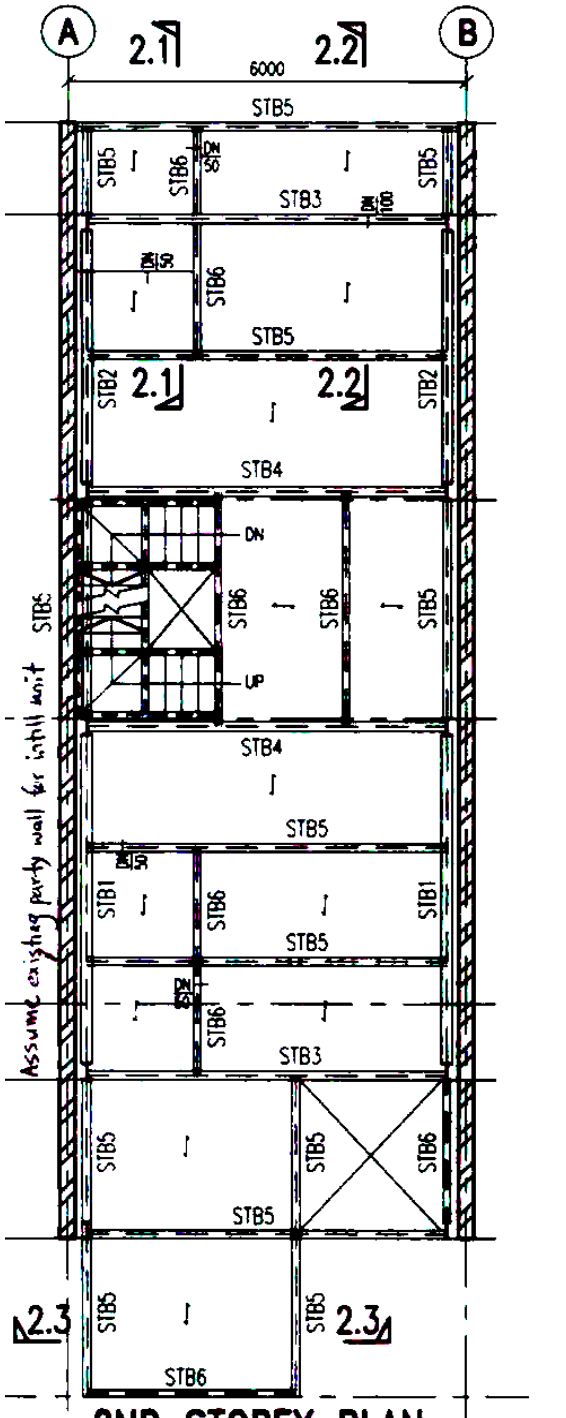


Figure 7.5 Details for cantilever joint (details and sizes shown are indicative only)



2ND STOREY PLAN

1. STB1 - 533x165x74.41kg/m UB STEEL BEAM
2. STB2 & STB4 - 457x152x52.09kg/m UB STEEL BEAM
3. STB3 - 406x140x46.13kg/m UB STEEL BEAM
4. STB5 - 356x127x39kg/m UB STEEL BEAM
5. STB6 - 254x102x17.86kg/m UB STEEL BEAM
7. DESIGN LIVE LOAD, L.L - 1.5KN/m².
8.

GRID REF.	STANCHION SIZE
A/3, B/3, A/7 & B/7	254x146x31.25kg/m UB
A/5, B/5, A/6 & B/6	254x146x43.00kg/m UB

Figure 7.6 Layout plan of a typical in-fill unit (details and sizes shown are indicative only)

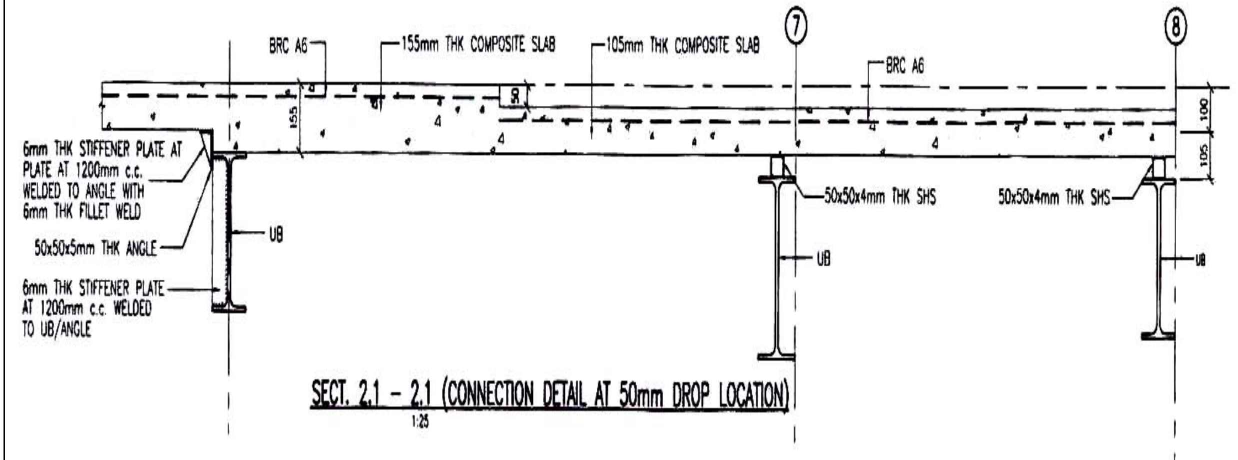


Figure 7.7 Connection details for 50mm drop in slab (details and sizes shown are indicative only)

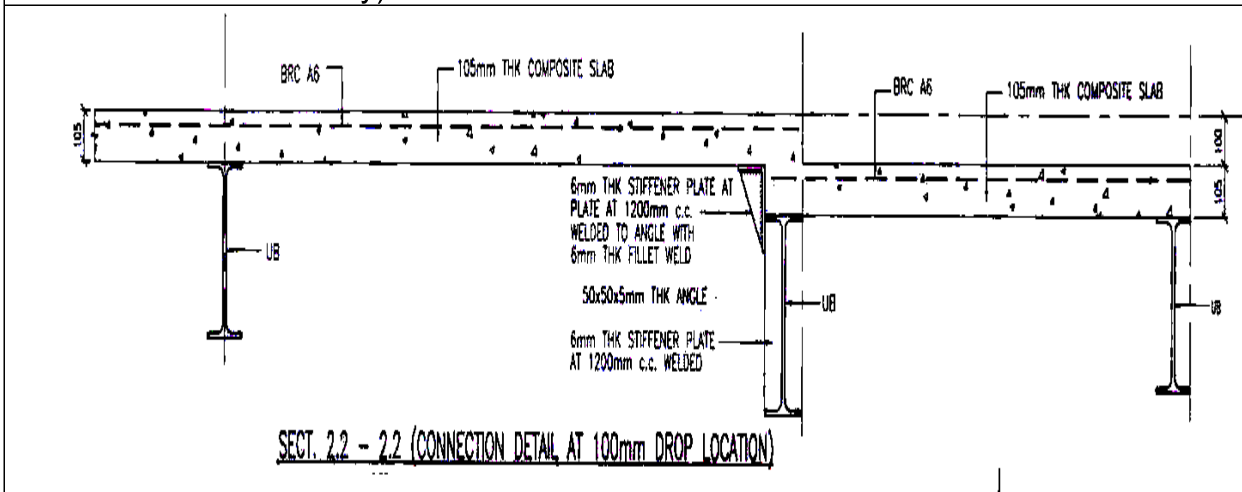


Figure 7.8 Connection details for 100mm drop in slab (details and sizes shown are indicative only)

Treatment of M&E services

A common practice of incorporating M&E services within the floor of steel-framed building is to form openings in the webs of I-section beams. These openings can be a significant proportion of the beam depth. Web stiffeners are often added to consider the local buckling and moment-shear transfer across the opening as it is subjected to high combined stresses from axial force from global bending and local moments.

The openings in the webs and stiffeners are to allow for during fabrication of steel beams in factory, as these elements are to be hot-dipped galvanized. They require early planning of M&E services in the preliminary design stage.

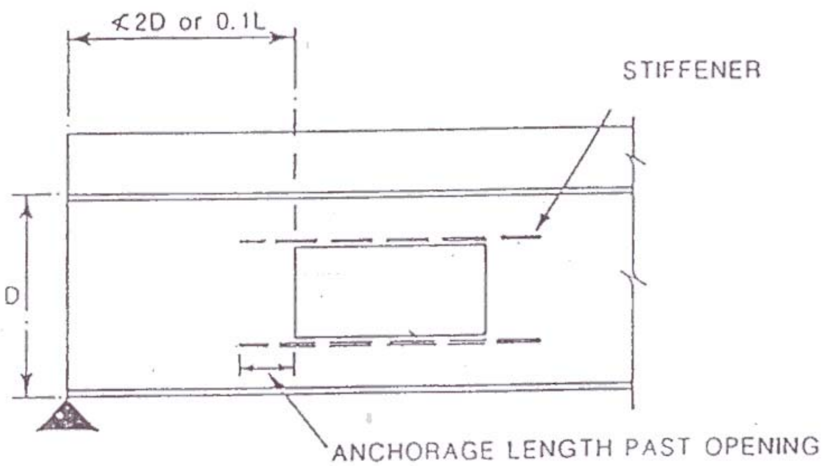


Figure 1 – Position of Web Openings

Figure 7.9 Position of web opening for services

Alternatively, castellated beams may be considered if beam depth is not a constraint. The beams are formed by profile cutting and welding to produce a 50% deeper section. The M&E servcies can penetrate through the web openings. Its usage is often in long span of 6m or more and subjected to light loads as it may not withstand high shear loads unless the castellation is filled in with plate.

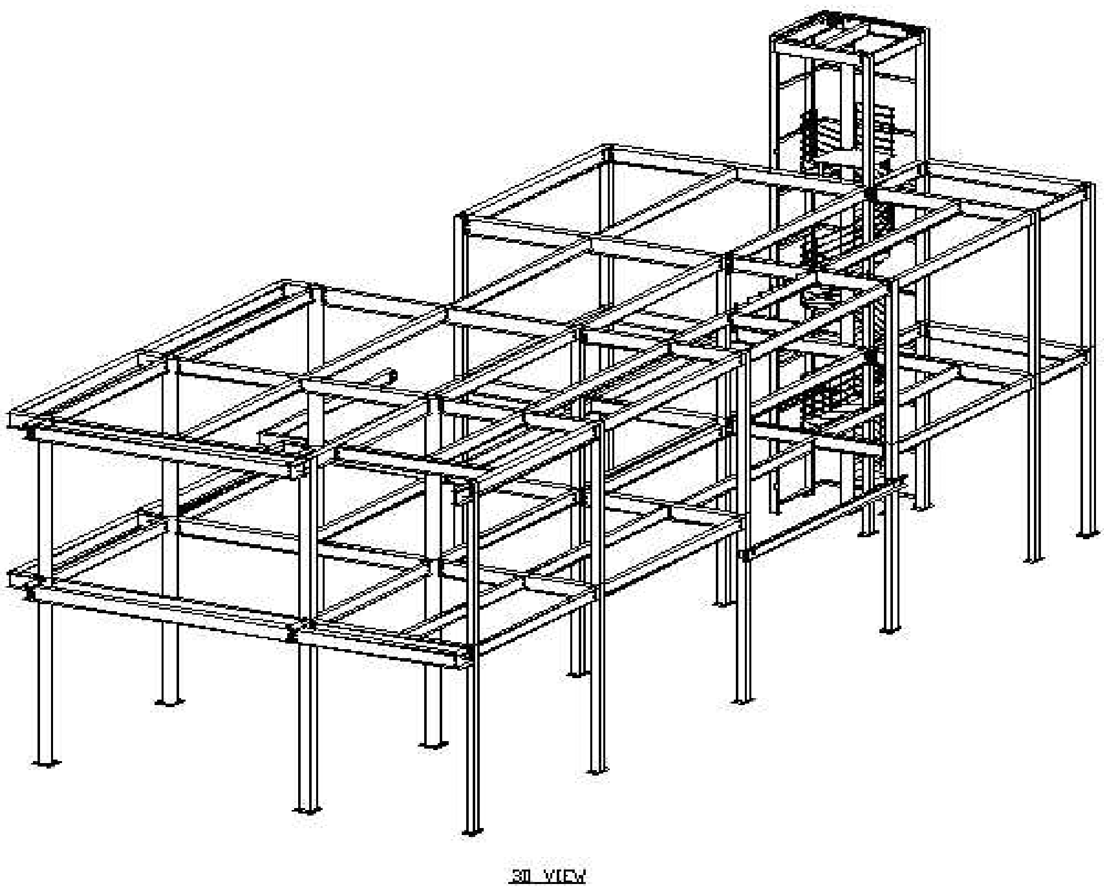


Figure 7.10 3-D graphic presentation of steel frame

Chapter 8 CONSTRUCTION METHOD FOR STRUCTURAL STEEL SYSTEM

8.1 GENERAL CONSIDERATIONS

The priority during the construction is to minimise on-site construction and provide extensive prefabrication. Proper planning during design stage is required, with consideration of column and beam spacing for the following:

- Unpropped metal deck during concreting
- Hoisting of precast facade panel for external walls
- Ensure the steel member sizes are easy to hoist, manage and install on site

Other site constraints such as accessibility and limitations of hoisting equipment need to be considered. These constraints may subsequently affect the sequence of construction for the development.

8.2 SEQUENCE OF INSTALLATION

Figure 8.1 Erection of steel column and beams - Temporary bracing was required to ensure verticality of steel columns when bolt connections from beams to columns were tightened.

Figure 8.2 Bolted connection for column to beam with laying of metal decking for second storey and roof

Figure 8.3
Installation of precast facade walls to beams

Figure 8.4 Fastening of connection

Chapter 9 STRUCTURAL CONCEPT FOR LIGHT GAUGE STEEL FRAME SYSTEM

9.1 BACKGROUND

Steel is widely used in the construction of multi-storey buildings. However, steel construction is seldom used and is traditionally considered uneconomical for landed properties. In many parts of the world, timber or structural brickwork is preferred whereas in Singapore, reinforced concrete construction is usually preferred for landed properties.

Over the years, various improved systems have been developed for use in landed properties. An economical light gauge steel frame system is increasingly being used in America, Europe, Australia and New Zealand. This light gauge steel frame is developed through a cold-formed process without the use of heat. This process enables steel manufacturers to produce light-weight but high tensile steel sheets. The sheet surface is coated with a zinc alloy that completely covers the steel surface and seals it from the corrosive action of its environment. This results in buildings that are more solid, rigid, stronger, durable and easier to build.

As such, the light gauge steel frame system is an attractive alternative for use in landed properties. This is particularly in view of concerns on the depletion of timber resources and low productivities associated with reinforced concrete construction.

Completed house at Upper Changi Road East

9.2 WHY USE LIGHT GAUGE STEEL FRAMING SYSTEM

Benefits

Buildability: The use of pre-fabricated and pre-assembled steel components reduces site works, reduces material waste and improves quality.

Speed: This system requires a shorter construction period compared to that for a conventional system.

Strong but Lightweight: Steel has one of the highest strength-to-weight ratios of any construction material. This results in savings in the foundation required and the lightness also makes for easier on-site handling.

Safety: Steel's inherent strength and non-combustible qualities enable light steel frame houses to resist such devastating events as fires, earthquakes, and hurricanes. Homes can be designed to meet the highest seismic and wind load specifications in any part of the country.

Quality: A better quality finished house that is durable and low in maintenance.

Easy to Remodel: Remodeling can be easily accomplished. Non-load bearing walls can be readily relocated, removed or altered.

Design Flexibility: Because of its strength, steel can span longer lengths, offering larger open spaces and increased design flexibility without requiring intermediate columns or load bearing walls.

Recyclable: All steel products are recyclable.

9.3 STEEL FRAMING LANGUAGE

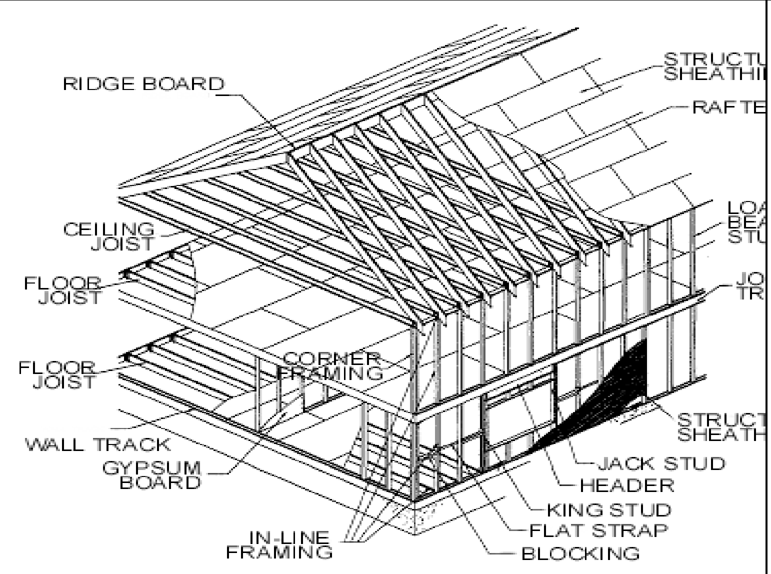


Figure 9.1 Steel Framed Building

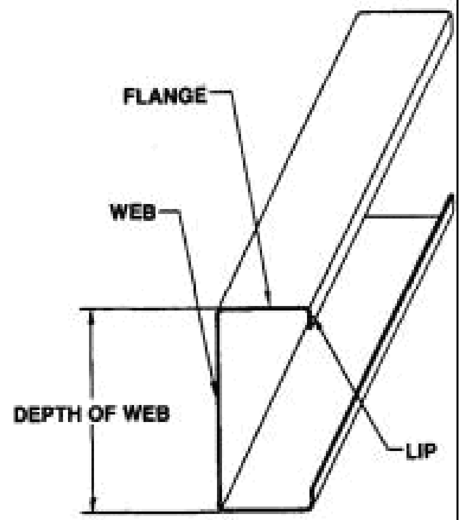


Figure 9.2 Components of a C shaped cold–formed steel member

Bottom Plate: A plate that contains the bottom end of a wall stud. The top plate has a web and flanges, but no lips.

Ceiling Joist: A horizontal structural framing member that supports a ceiling and/or attic loads (See Figure 9.1).

C-section: Used for structural framing members such as studs, joists, beams, girders, and rafters. The name comes from the member’s “C’ shaped cross-sectional configuration consisting of a web, flange and lip. C-section web depth and flange width measurements use outside dimensions (See Figure 9.2).

Clip Angle: An L-shaped short piece of metal (normally with a 90 degree bend) typically used for connections.

Cold-forming: A process where light-gauge steel members are manufactured without the use of heat.

Flange: The part of a C-section or track that is perpendicular to the web (See Figure 9.2).

Flat Strap: Sheet steel cut to a specified width without any bends, typically used for bracing and other flat applications (See Figure 9.1).

Floor Joist: A horizontal structural framing member that supports floor loads (See Figure 9.1).

Galvanized Steel: Steel that has a zinc protective coating for resistance against corrosion. The level of coated protection is measured by the weight of the galvanized coating applied to the surface area of the steel (e.g. G-40 or G-60).

Gauge: A unit of measurement traditionally used to describe the nominal thickness of steel. The lower the gauge, the greater the thickness.

Header: A horizontal built-up structural framing member used over wall or roof openings to carry loads across the opening (See Figure 9.1).

In-Line Framing: Frame systems where all vertical and horizontal load carrying members are aligned (See Figure 9.1).

Jack Stud: A vertical structural member that does not span the full height of the wall and supports vertical loads and/or transfers lateral loads. Jack studs are used to support headers (See Figure 9.1).

King Stud: A vertical structural member that spans the full height of the wall and supports vertical loads and lateral loads. Usually located at both ends of a header adjacent to the jack studs to resist lateral loads (See Figure 9.1).

Lip: The part of a C-section that extends from the flange at the open end. The lip increases the strength characteristics of the member and acts as a stiffener to the flange (See Figure 9.2).

Load Bearing Wall: A wall that carries vertical loads from above or lateral loads resulting from wind. These loads may act separately or in combination. Both internal and external walls may be load bearing.

Material Thickness: The base metal thickness excluding any protective coatings. Thickness is expressed in mils (traditionally expressed in gauge).

Mil: A unit of measurement typically used in measuring the thickness of thin elements. One mil equals 1/1000 of an inch.

Multiple Span: The span made by a continuous member having intermediate supports.

Non-Load Bearing Wall: Walls which do not support any loads.

Punch-out: A hole in the web of a steel framing member allowing for the installation of plumbing, electrical, and other trade installation.

Rafter: A structural framing member (sloped) that supports roof loads (See Figure 9.1).

Shearwall: A wall assembly capable of resisting lateral forces to prevent racking from wind or seismic loads acting parallel to the plane of the wall.

Single Span: The span made by one continuous structural member without any intermediate supports.

Span: The clear horizontal distance between bearing supports.

Structural Sheathing: The covering (e.g. steel sheets) used directly over structural members (e.g. studs or joists) to distribute loads, brace walls, and strengthen the assembly (See Figure 9.1) .

Stud: Vertical structural element of a wall assembly that supports vertical loads and/or transfers lateral loads (See Figure 9.1).

Top Plate: A plate used to carry truss loads from the roof to the studs, where the studs are not located directly under the truss load points. The top plate has a web and flanges but no lips.

Track: Used for applications such as top and bottom plate for walls and band joists for flooring systems. The track has a web and flanges, but no lips. Track web depth measurements are taken to the inside of the flanges (See Figure 9.2).

Web: The part of a C-section or track that connects the two flanges (See Figure 9.2)

Web Stiffener: Additional material that is attached to the web to strengthen the member against web crippling. Also called bearing stiffener.

Yield Strength: A characteristic of the basic strength of the steel material. It is the highest unit stress that the material can endure before permanent deformation occurs.

9.4 STEEL FRAMING DESIGN

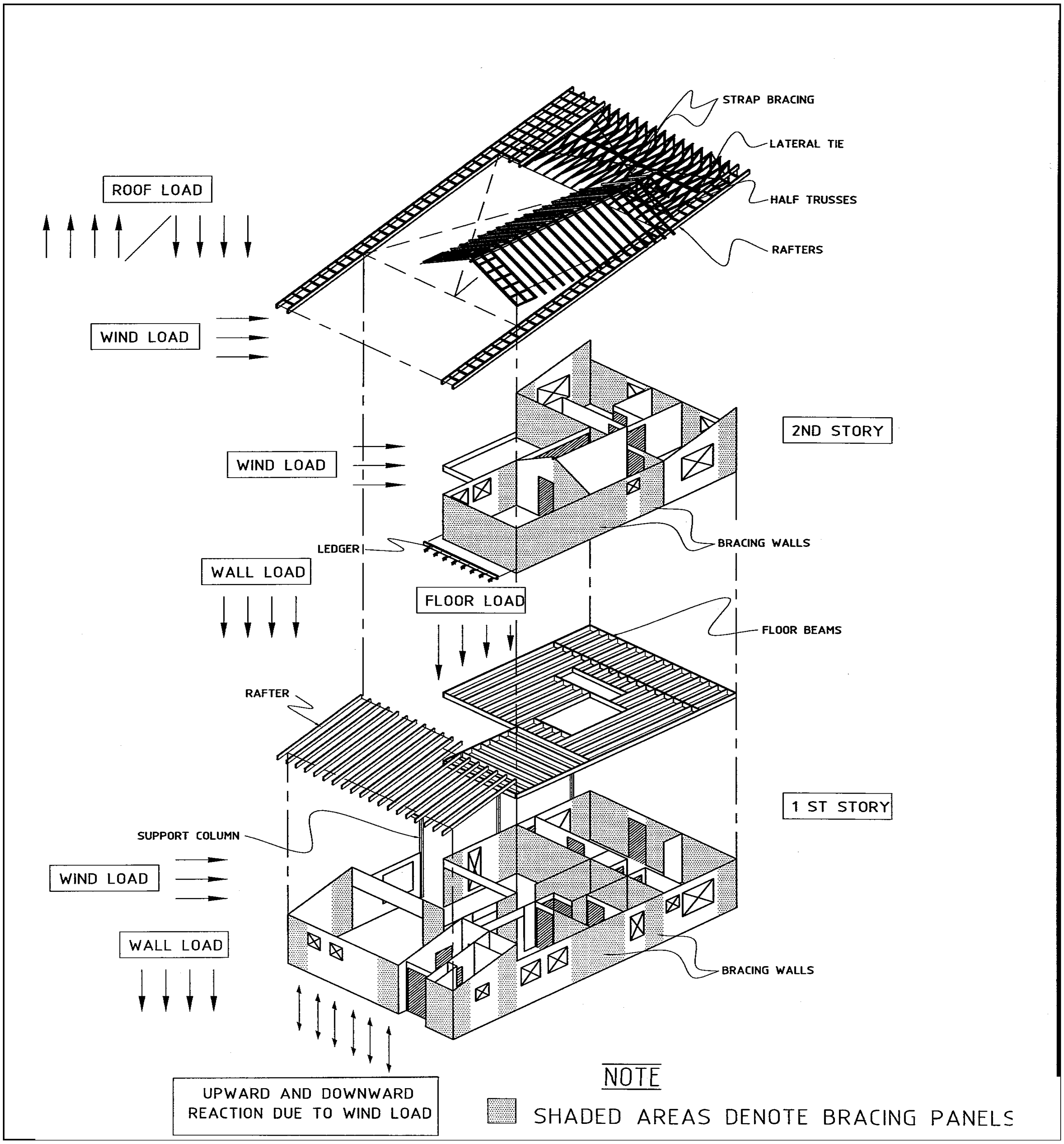


Figure 9.3 Loading Path Diagram
Details recommended by BHP Steel Lysaght

In a steel framed house, the loading path of the house structure is used to determine the design requirement (See Figure 9.3). The roof loads, wind loads, wall loads and floor loads will be transferred all the way down to the ground floor.

A steel framed house would normally be built on a reinforced concrete ground floor slab. The ground floor wall panels would then be fastened and held down to the ground floor slab. The second storey floor bearers would then sit on the top of load bearing walls. These bearers would connect and carry the floor joists. The floor joists would in turn carry the floor boards and the wall panels above. The roof trusses would then sit on the wall panels to carry the roof system and roof loads.

The sizes and spacing of the structural members would depend on the design loads. Generally, BHP Steel Lysaght recommends the following:

- Lysaght C75 and Lysaght C100 sections would be used as the wall studs.
- As for the floor joists, they can be chosen from a range of sections ranging from Lysaght C100 to Lysaght C250 sections depending on design loads and floor configuration.

Connections for steel framing can consist of self-drilling screws, bolts and anchors. Welding is usually not required and mechanical fasteners would suffice in most cases.

9.5 WALL SYSTEM

9.5a Load Bearing Walls

A load bearing wall is one which carries vertical loads from the construction above or lateral loads resulting from the wind. These loads may act separately or in combination. Both internal and external walls may be load bearing.

BHP Steel Lysaght recommends the following for the load bearing walls:

- All load bearing studs shall be minimum Lysaght C75 G550 cold formed section.

- A structural top plate is used to carry truss loads from the roof to the studs, where the studs are not located directly under the truss load points. Top plates shall be Lysaght G550 cold formed section (Structural plate). The top plate shall be secured transversely at a maximum of 1800mm centres by incoming trusses or rafters with approved wall support brackets.

- The bottom plate shall be minimum G550 cold-formed section. The bottom plate must be fully supported under every load-bearing stud. This is critical with studs beside openings, or studs carrying major loads for the roof, ceiling or upper floor construction. The support can be provided by a floor joist, blocking piece or concrete slab located directly under the stud.

- Lintels are needed for openings greater than 1200mm of load bearing walls. Lintels under sheet metal roofs are principally designed for uplift from wind loading on the roof structure while lintels under tile roofs are designed principally to support downward loads from the roof trusses.

- Noggings in the form of a notched plate may be used in load bearing walls to provide lateral restraint to the wall studs.

- Bracing is needed in certain walls to provide racking resistance against wind load. It could be in the form of bracing straps or bracing sheets depending on the requirement.

- The studs, joists and trusses must be properly aligned in order to transfer the loads to the member below.

9.5b Non-Load Bearing Walls

Internal walls which do not support truss loads are considered non-load bearing.

BHP Steel Lysaght recommends the following for non-load bearing walls:

- Studs for internal non-load bearing walls shall be minimum Lysaght G550 C75 cold formed section.

- Top plate should be minimum G550 cold formed section and shall be fixed to trusses at 1800 mm maximum centres to provide lateral stability for the wall. The connection shall not transmit vertical loads to the wall.

- The bottom plate shall be minimum G550 cold formed section

- Angle lintels are not required for openings in non-load bearing wall frames.

- Noggings is generally not needed for internal non-load bearing walls.

9.5c Wall details and connections

Steel framing is fastened to the floor structure through the bottom plate after all panels have been correctly aligned and plumbed. For concrete floor slabs the frame is fixed in place by using masonry anchors, which are generally hammer-driven nails, expanding shell anchors or chemical anchors. Exact recommendations for the type and frequency of anchors would be available from steel suppliers or the engineer. The wall panels are usually connected together by mechanical fasteners such as self-drilling screws.

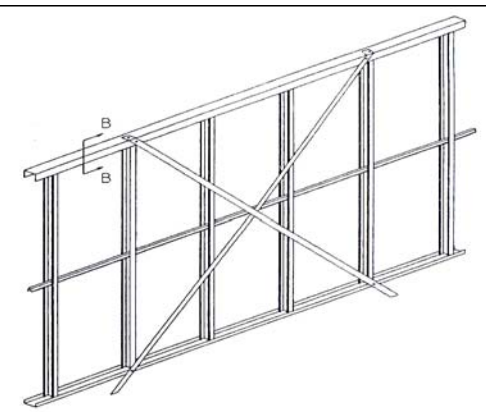




Figure 9.4 Load Bearing Wall Details & Installation

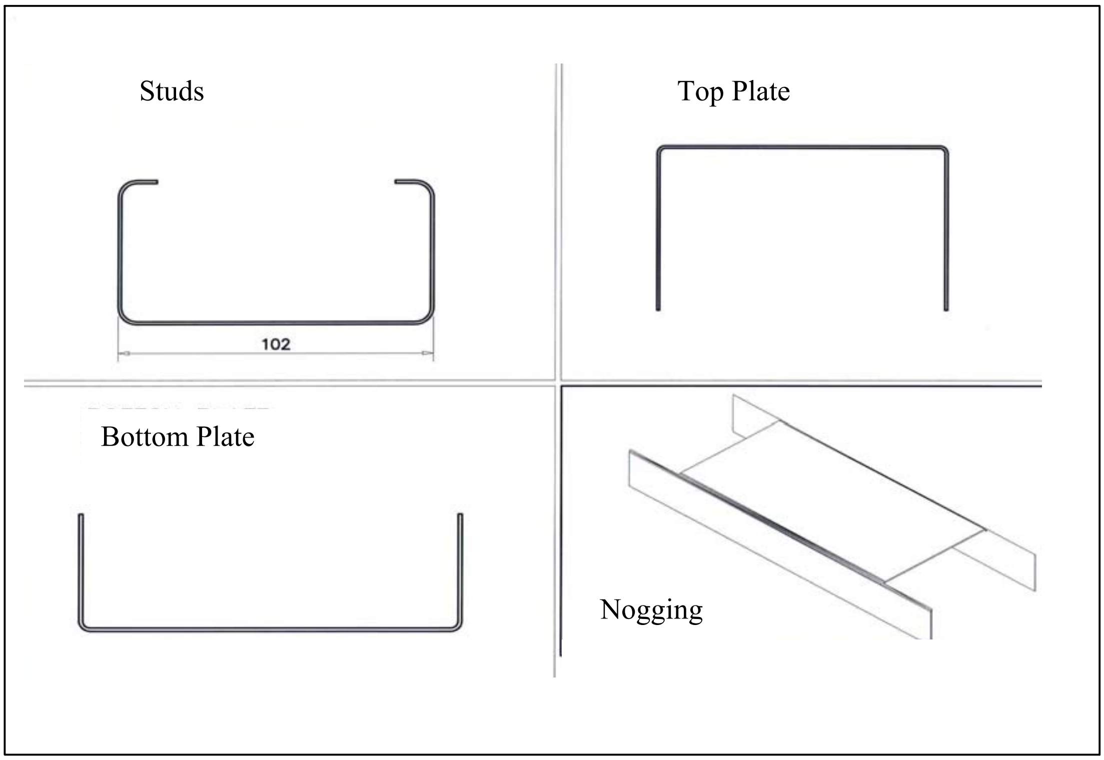


Figure 9.5 Studs, Plates & Nogging Sections
Details recommended by BHP Steel Lysaght

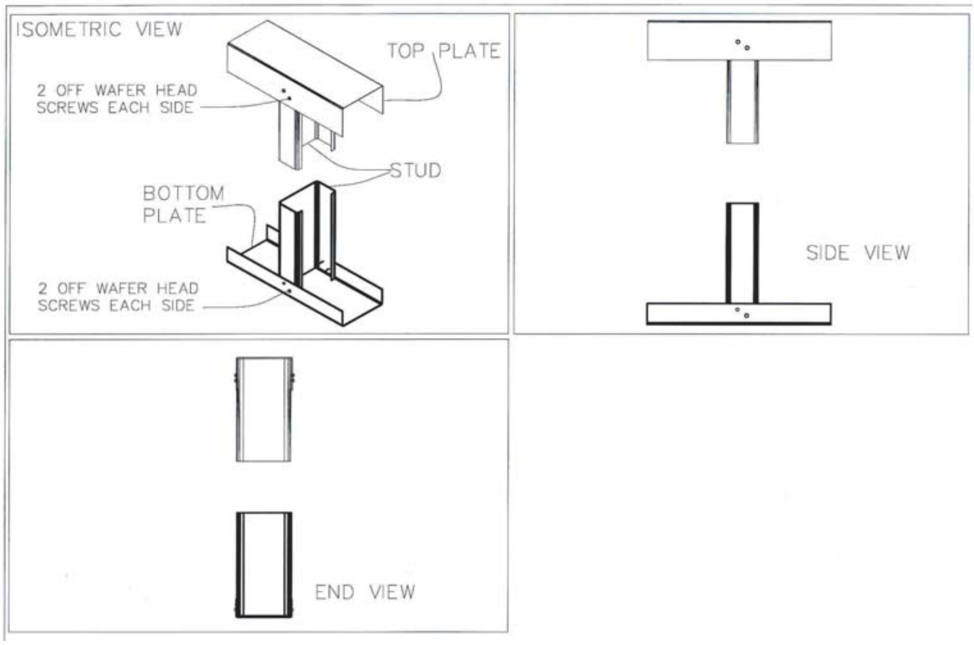


Figure 9.6 Stud to Plate Connection
Details recommended by BHP Steel Lysaght

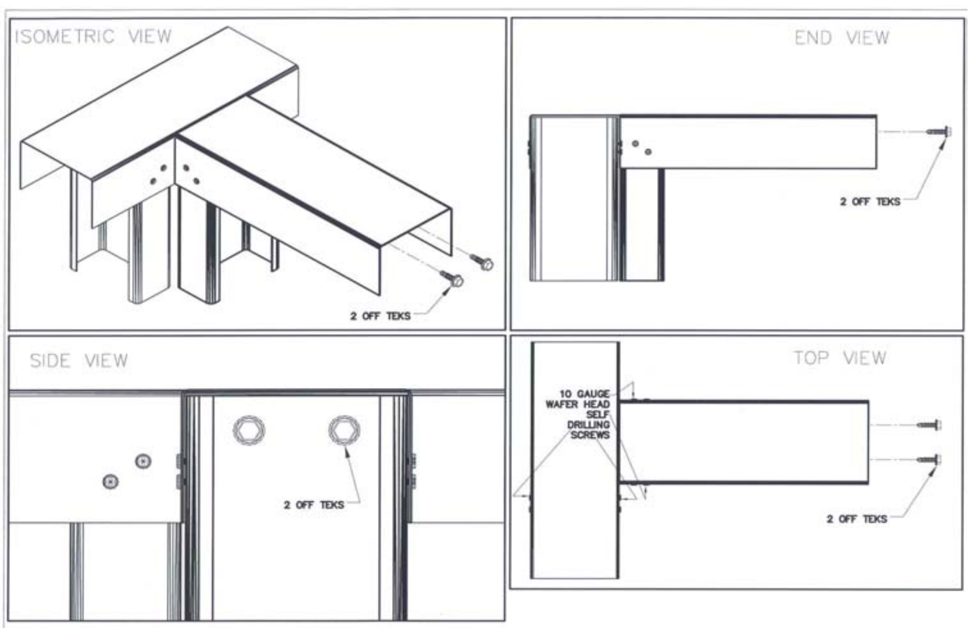


Figure 9.7 Internal to External Wall Connection
Details recommended by BHP Steel Lysaght

9.5d Wall Openings

External Door and Window Frames

The same door and window frames used in timber-framed construction are also used in steel-framed construction. If aluminium window frames are fitted into timber, they can be installed by fastening through the jamb studs into the back of the reveal after positioning. If it is not possible to secret-fix the frame, as may be the case with a window or door head, self-drilling screws of appropriate length can be driven through the frame and packing into the steel framing. The same type of screws may also be used to fasten aluminium window frames direct to steel frame openings.

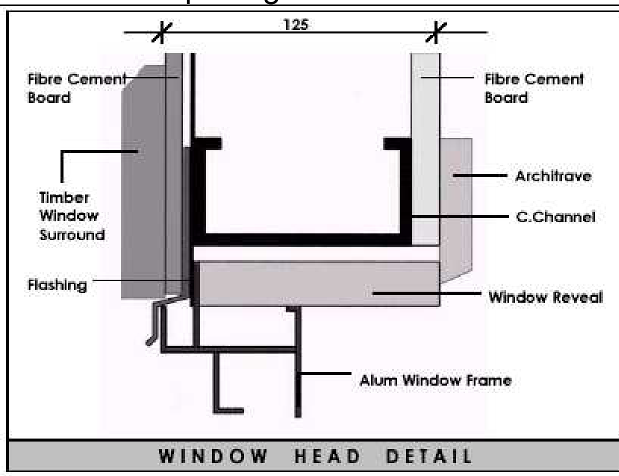


Figure 9.8 Window head details

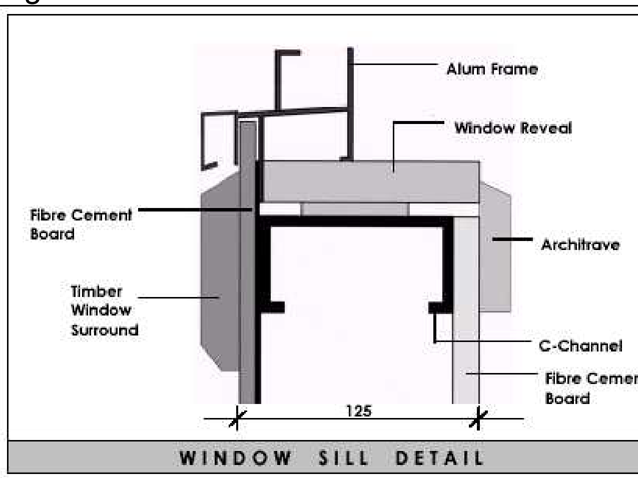


Figure 9.9 Window sill details

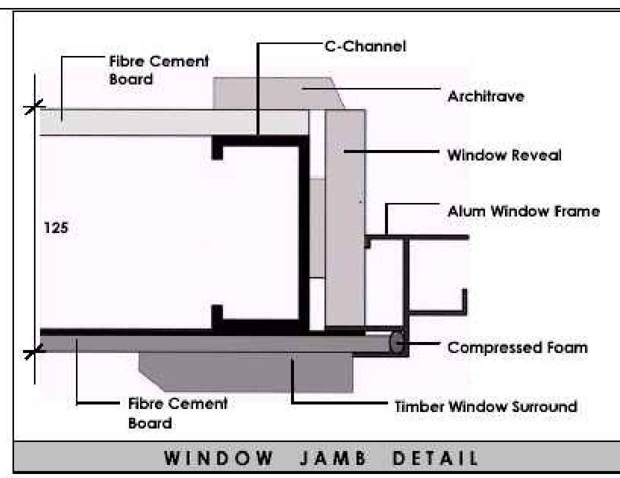


Figure 9.10 Window jamb details

Internal Door Frames

Timber door frames in internal walls can be secret-fixed through the back of jamb studs with screws or nails. Alternatively the frame may be fastened through the jamb into the studs with self-drilling screws.

9.5e Wall Cladding & Partitions

If required in the external walls, reflective foil sarking may be attached to the external flange of the steel studs with self-drilling screws fitted with 25mm flat fibre washers. Alternatively wafer head screws may be used. Wire brick ties which simply clip on to steel studs are available for brick veneer construction. For single wall construction, fibre cement sheeting can be fixed to steel frames with self-drilling, self-embedding head screws. Timber weatherboards can be fastened to steel studs with extended point countersunk head self-drilling screws. Steel sheet cladding is also fixed with self-drilling screws.

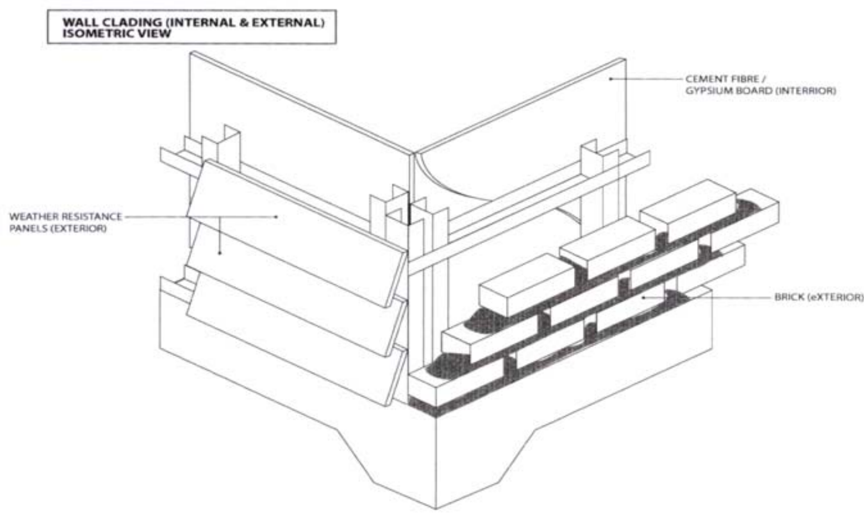


Figure 9.11 Internal & External Wall cladding

9.6 FLOORING SYSTEM

The flooring system can be made up of C-sections as joists connected to C-section bearers. The floor joists can be designed from a range of C-section sizes depending on loading parameters.

Lattice Beam Flooring (see Figure 9.14) gives a stronger and stiffer base for the floor-board to be fitted onto. This will eliminate squeaky sounds made when floor-boards are not properly fastened onto the beams. It also gives better sound insulation between the ground and upper floor. This flooring can be used on platform support or where the ground is split-leveled.

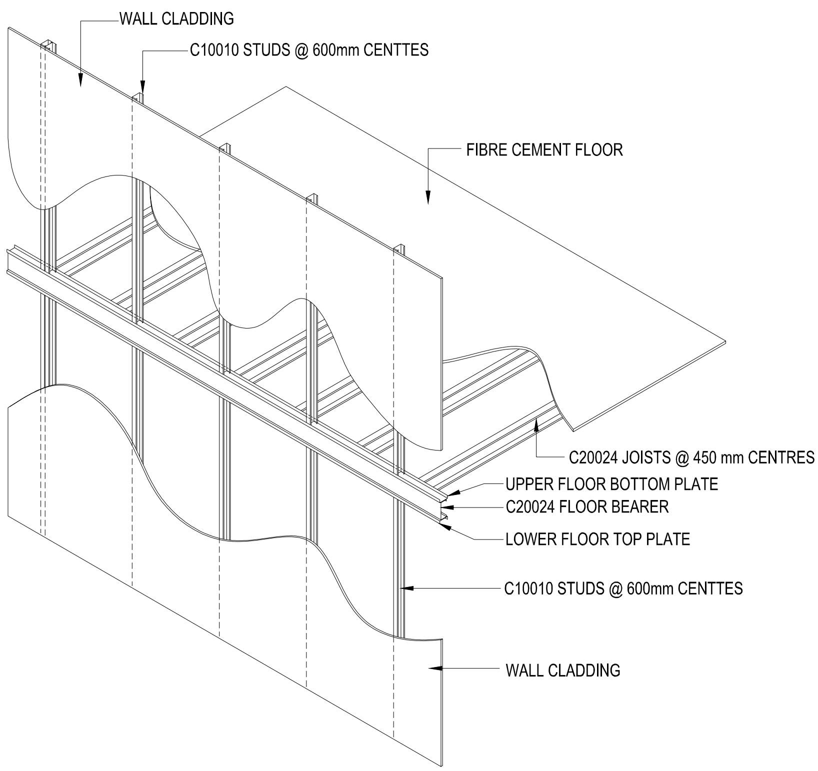


Figure 9.12 Steel frame wall & flooring using C-sections

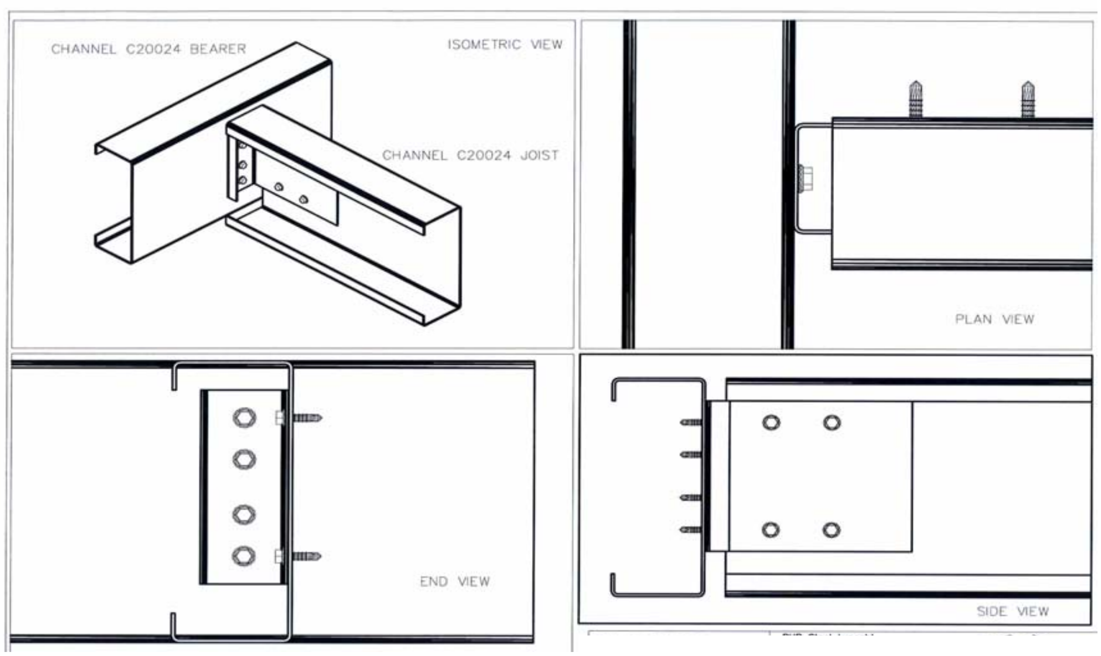


Figure 9.13 Joist to C-Section Bearer Connection for Flooring
Details recommended by BHP Steel Lysaght

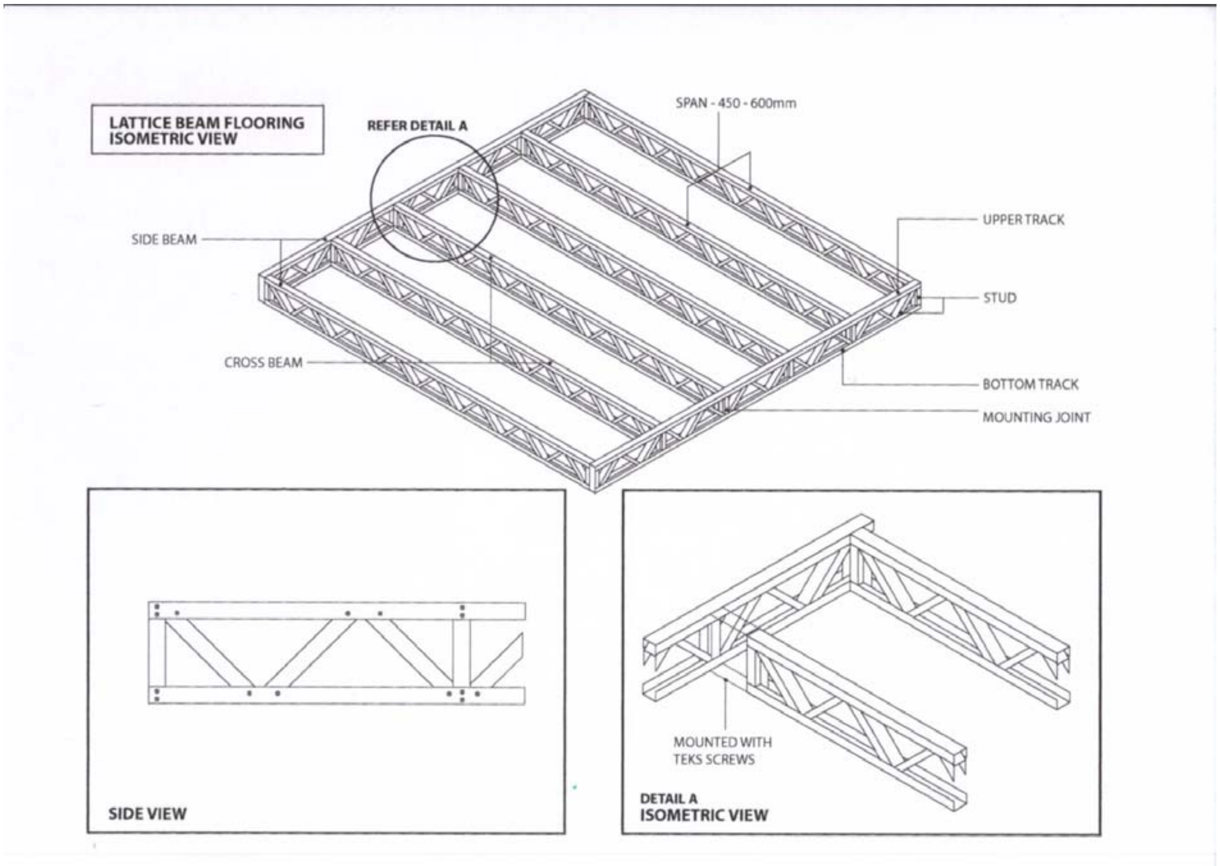


Figure 9.14 Lattice Beam Flooring
Details recommended by QWik Built-Tech International Pte Ltd

The following shows some suggested details of floor finishes on the floor board:

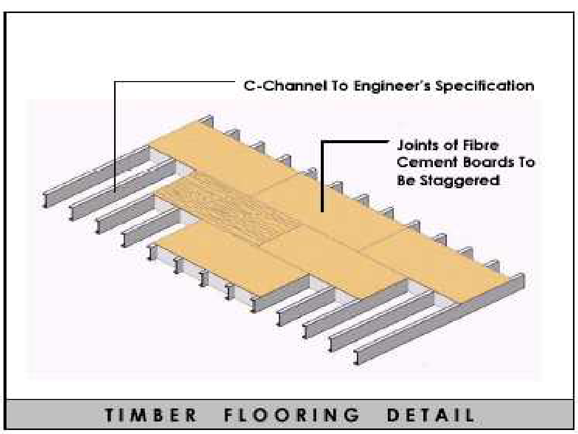
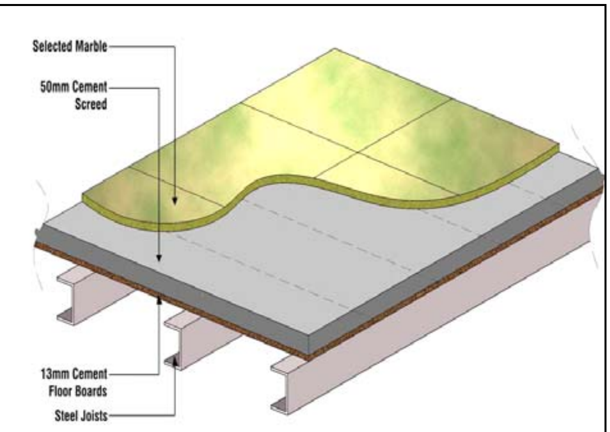
	

Figure 9.15 Floor finishes with timber flooring	Figure 9.16 Alternative floor finishes with granite flooring

9.7 ROOF SYSTEM

The roof structure is generally a steel truss system which can be designed for metal sheets or tiles. This is a roof truss system which typically consists of C75 and C100 sections as the chord and web members of the truss. The steel roof framing system can suit all types of roof design – hip, gable, dutch dable, steel roof sheeting or tile and would be screwed directly onto the wall frame.

When using tiles, wooden-styled roof trusses are used with purlins running across them for the tiles to be fitted.

Figure 9.17 Roof Truss

9.8 M & E Services

Pre-punched service holes in the web of the steel frame allows electrical, gas and plumbing services to be installed within the wall framing system. Plastic grommets and silicone seals are used to fasten and protect wiring and pipes from corrosion and damage arising from vibrations.

	
Pre-punched holes for services	Services can be suspended from steel frames
	
Plug and Socket Points	Water Piping

Figure 9.18 Pre-punched service holes for M & E Services

Chapter 10 CONSTRUCTION METHOD FOR LIGHT GAUGE STEEL FRAME SYSTEM

10.1 STEEL WALL FRAMING - Erection

Prefabricated steel wall framing can be used with all types of floor construction. Although framing varies in detail between manufacturers, the general principles are the same for all systems. Steel wall framing is erected in the same sequence as pre-fabricated timber, ensuring squareness and vertical alignment of individual frames.

Figure 10.1 Construction of lightgauge steel frame

The general procedure is as follows:

1) The wall layout is marked on the floor using straight lines.

2) Squareness is checked by accurately measuring diagonals in large areas of the house first, then individual rooms.

3) Internal wall frames are stacked inside the boundaries and external walls around the foundations, with the first frame on top.

4) External frames are placed around the perimeter with their bottom plates adjacent to their final positions.

5) Starting at any convenient external corner stand and plumb a wall frame panel in its exact position.

6) Stand and plumb the adjoining frame to make a self-supporting corner.

7) Clamp the frames together and check again that both frames are in their exact locations and standing vertical.

8) Connect the frames using the manufacturers recommended method - generally nails, screws or rivets.

9) Proceed with the erection of the frames around the house, standing internal and external frames as they occur.

10) Provide adequate temporary bracing during wall frame erection. The line of top plates in a run of walling should be checked with a string.

Figure 10.2 Installation of floor joist and wall studs

10.2 STEEL WALL FRAMING - Anchoring

Steel framing must be firmly anchored to the foundation or floor structure. Wherever possible, the walls should be anchored as soon as possible after they have been plumbed and aligned.

There are two forces you must account for when attaching walls to the foundation or floor slab. These forces are shear and uplift. The Prescriptive Method for residential cold-formed steel framing provides details, sizes and types of anchoring.

The Prescriptive Method provides several details for anchoring steel-framed houses. Figure 10.3a in the Prescriptive Method depicts a steel frame floor system anchored to a wood sill on top of a concrete foundation. The wood sill is tied to the foundation with anchor bolts, similar to wood construction. The rim joist of the steel floor system is fastened to the wood sill with a steel plate. Figure 10.3b of the Prescriptive Method shows a detail of a steel floor system attached directly to the concrete foundation using clip angles and anchor bolts.

Figure 10.4 shows the wall to foundation connection. J-bolts are commonly used in such connections. A piece of stud is used as a washer when bolting the walls to the foundation.

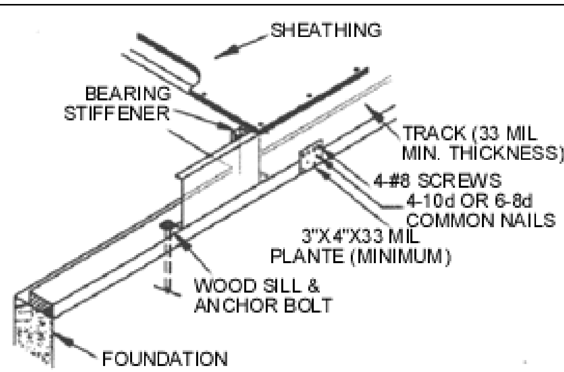


Figure 10.3a: Floor to Wood Sill Connection

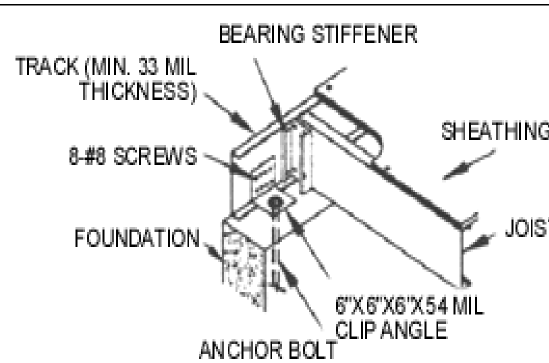


Figure 10.3b: Floor to Foundation Connection

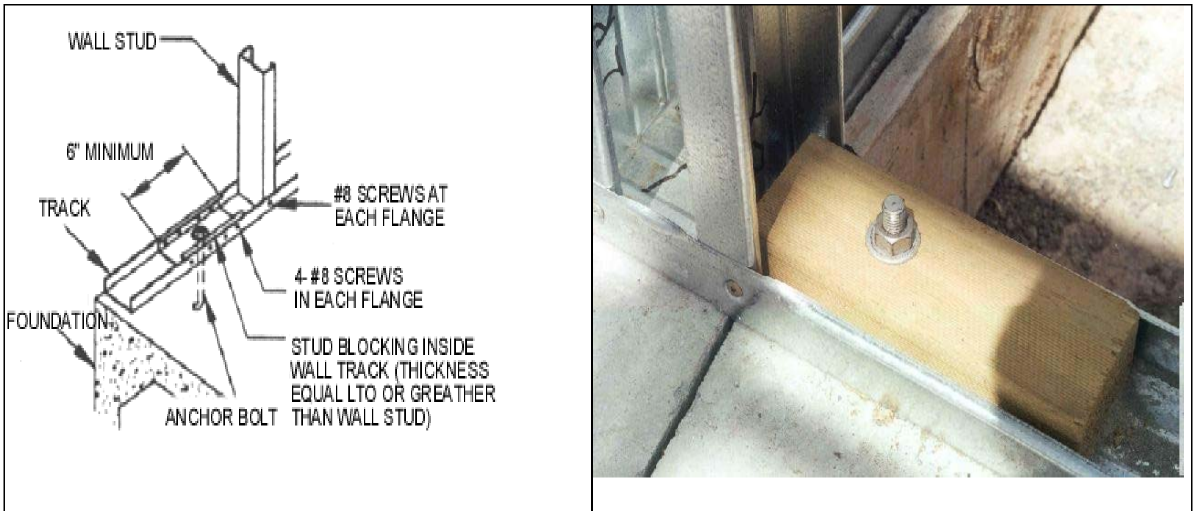


Figure 10.4: Wall to foundation connection

The load bearing walls of a steel-framed house must be braced to protect the wall from shear forces and prevent the walls from racking. Shear bracing keeps a house from leaning or falling over. There are two ways of applying shear wall bracing on a steel-framed house; either **structural sheathing or X-bracing**.

Structural Sheathing

Zinc-coated metal sheet ie; 0.8mm thickness is adequate to keep the wall from racking as long as there are not excessive openings in the wall or excessive lateral loads.

In order for structural sheathing to be effective, it should be installed with the long dimension parallel to the stud framing (vertical orientation).

- The metal sheet may be attached to the wall while panelizing or after the wall is plumb and level.
- Make sure that the sheathing is fastened tightly to the steel frame.
- Draw the metal sheet up tight against the wall with No. 8 self-drilling screws.
- Finish attaching the metal sheet with screws or pneumatic pins. (See Figure 10.5 of the Prescriptive Method, Structural Sheathing Fastening Pattern, shown here.)

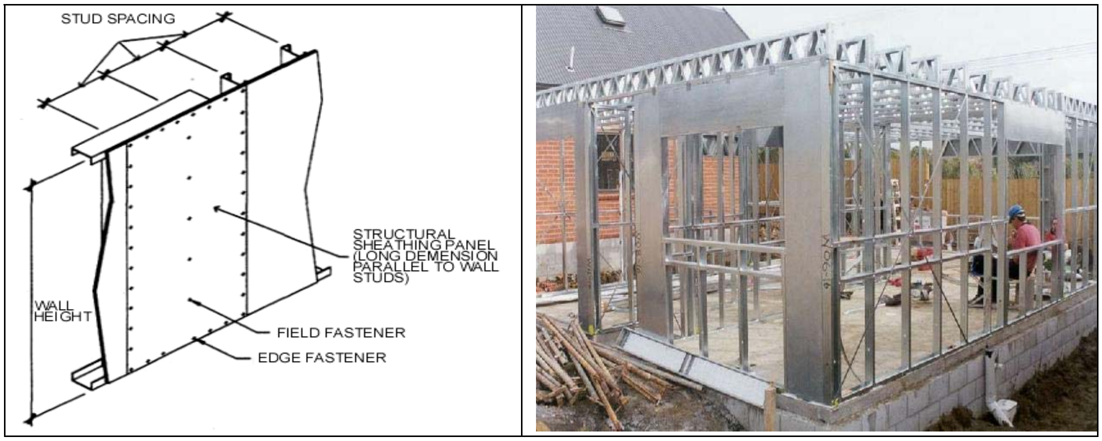


Figure 10.5 Structural Sheathing Fastening Pattern

X-Bracing

X-bracing is another way to obtain shear strength when structural sheathing is not used. X-braces are diagonal steel straps attached to the walls with screws. They are most commonly used with stucco walls or in termite-prone areas. The following must be taken note when using X-bracing:

- An engineer must design X-bracing
- Installation of the straps should be inspected to ensure the correct number of fasteners is used.

It is recommended to either cut and tack the strap to the wall during panelization or install the strap after the wall is in place. X-bracing can be installed after the walls have been raised, plumbed, aligned and attached to the foundation or floor deck.

10.3 ROOR FRAMING

The roof frame can be screwed directly onto the wall frame. Truss spacing can be at 600mm centres for sheet and tile roofs or 1200mm centres for sheet roofs only. The manufacturer's instructions on type, placement and number of fixings should be followed at all times.

10.4 EXTERNAL DOOR AND WINDOW FRAMES

The same door and window frames used in timber-framed construction are also used in steel-framed construction. If aluminium window frames are fitted into timber they can be installed by fastening through the jamb studs into the back of the reveal after positioning. If it is not possible to secret-fix the frame, as may be the case with a window or door head, "countersunk head" self-drilling screws of appropriate length can be driven through the frame and packing into the steel framing. The same type of screws may also be used to fasten aluminium window frames direct to steel frame openings.

10.5 INTERNAL DOOR FRAMES

Timber door frames in internal walls can be secret-fixed through the back of jamb studs with screws or nails. Alternatively the frame may be fastened through the jamb into the studs with "countersunk head" self-drilling screws.

10.6 EXTERNAL WALL CLADDING

If required in the external walls reflective foil sarking may be attached to the external flange of the steel studs with self-drilling screws fitted with 25mm flat fibre washers. Alternatively wafer head screws may be used. Wire brick ties which simply clip on to steel studs are available for brick veneer construction. For single wall construction fibre cement sheeting can be fixed to steel frames with self-drilling, self-embedding head screws. Timber weatherboards can be fastened to steel studs with extended point countersunk head self-drilling screws. Steel sheet cladding is also fixed with self-drilling screws.

10.7 INTERNAL WALL LINING

To fix plasterboard wall linings in a steel-framed house, self-drilling screws are used instead of plasterboard nails. The same adhesives are used on a steel frame.

With a correctly set screw gun bugle, head screws can be tightened to finish slightly below the surface of the plasterboard without damaging the paper facing.

Figure 10.6 Installation of boards

In wet areas, water resistant lining board is fixed with self-drilling self-embedding head screws. Flashing and tiling are done in the usual manner. Pre-finished wall linings may be glued to steel studs with a wallboard adhesive and braced in place until bonded.

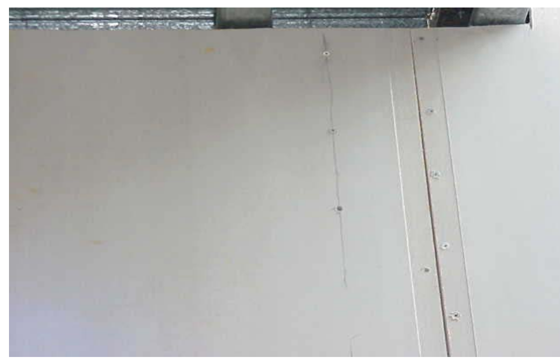


Figure 10.7 Plasterboard is screwed into position to complete the wall installation

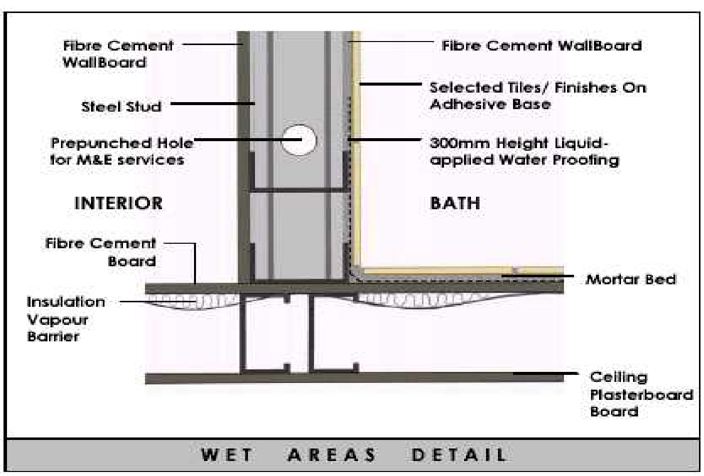


Figure 10.8 Detailing for wet areas

Chapter 11 PREFABRICATED COMPONENTS

11.1 PRECAST HOUSEHOLD SHELTER

The installation of the household shelter (HS) is often in the critical path of construction works and often affects the progress of concurrent works on site. Hence, the use of precast household shelters in place of the current in-situ design will likely reduce the construction period.

A precast HS system, comprising L-shaped wall panels, has been developed. This precast system is more buildable and will be of better quality in comparison with those systems currently available. At the same time, the production costs of these new precast HS systems are comparable to those for in-situ shelters. This precast HS system will also eliminate the need for propping works on site. These potential savings in time and costs will make the precast shelters more attractive than conventional design.

- Attached diagrams show the proposed precast 'L' panel arrangement and the two standardised basic shelter dimensions.
- The 'L' panels are stable during installation, subject to the base conditions.
- RC stumps are provided at the base of the panels to support the panel weight before casting the shelter base slab.
- The 'L' panels reduce the amount of in-situ casting required for walls.

The weight of the 'L' panels is in the order of 5.5 to 6 tonnes. If this presents a problem to the crane lifting capacity, a lighter flat panel weighing 4 tonnes can be adopted. Refer to Figure 11.1, Figure 11.2, Figure 11.3 and Figure 11.4 for different views of the HS shelter.

For both proposals, the base slab and top slab are constructed in-situ.

Proposed precast HS shelter sizes

GFA range	**Minimum internal floor area of HS**	**RECTANGULAR SIZE (m^2)**
GFA ≤ 45 m^2	1.6 m^2	NA
45 < GFA ≤ 75 m^2	2.2 m^2	1.8x1.25 (=2.25)
75 < GFA ≤ 140 m^2	2.8 m^2	2.3x1.25 (=2.88)
GFA > 140 m^2	3.4 m^2	Size 1: 2.0x1.7 (=3.4) Size 2: 2.3x1.5 (=3.45)

Note:

Thickness of 250mm may be adopted depending on the set back distance

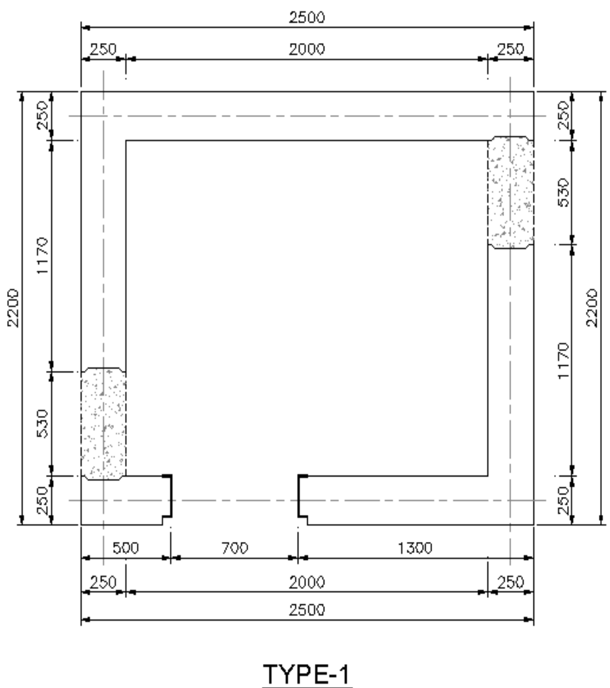


Figure 11.1 Plan showing type 1 (2m x 1.7m) of precast household shelter

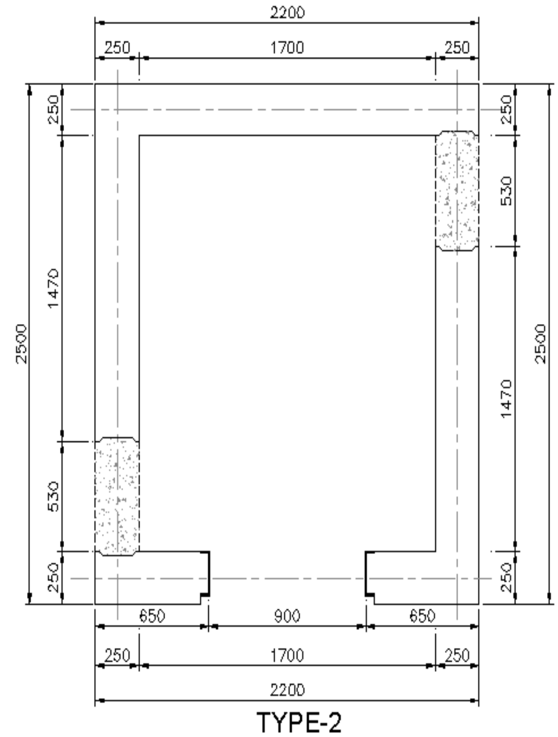


Figure 11.2 Plan showing type 2 of precast household shelter

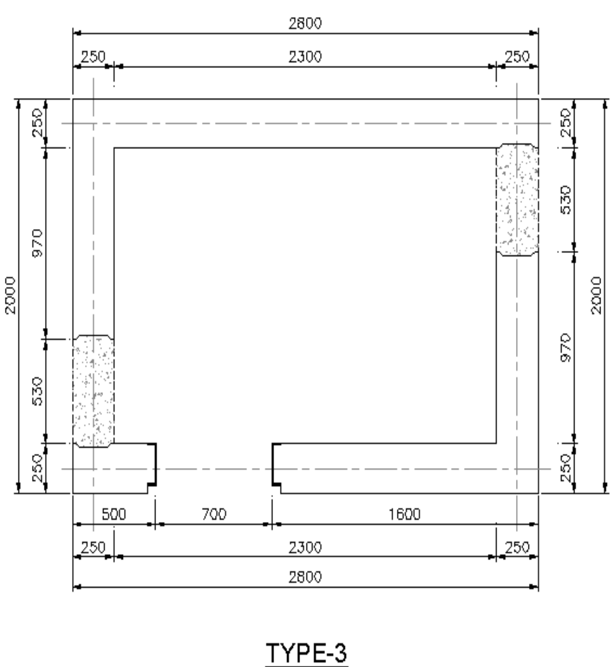


Figure 11.3 Plan showing type 3 of precast household shelter

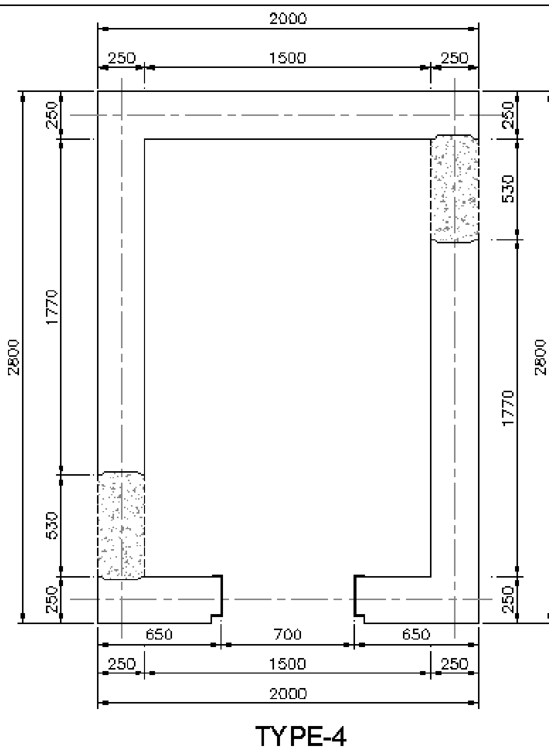
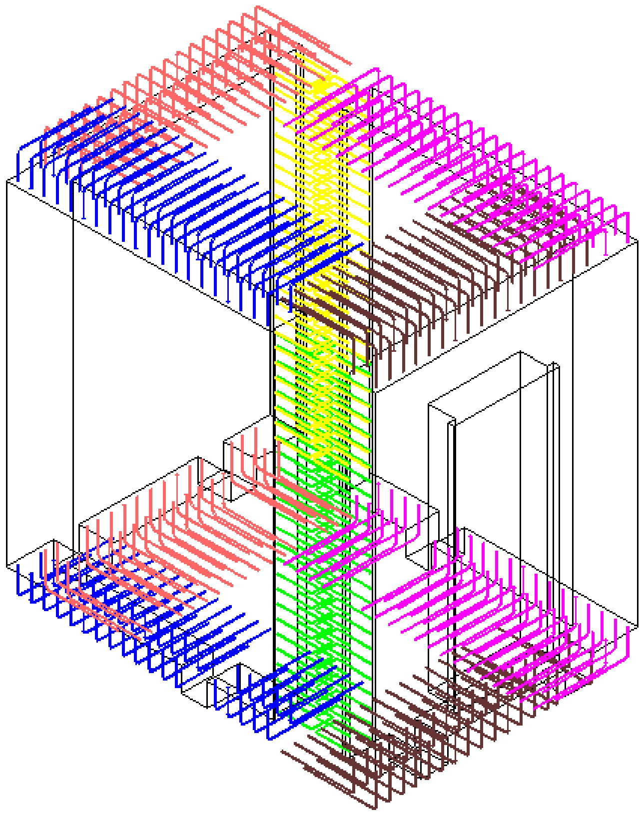
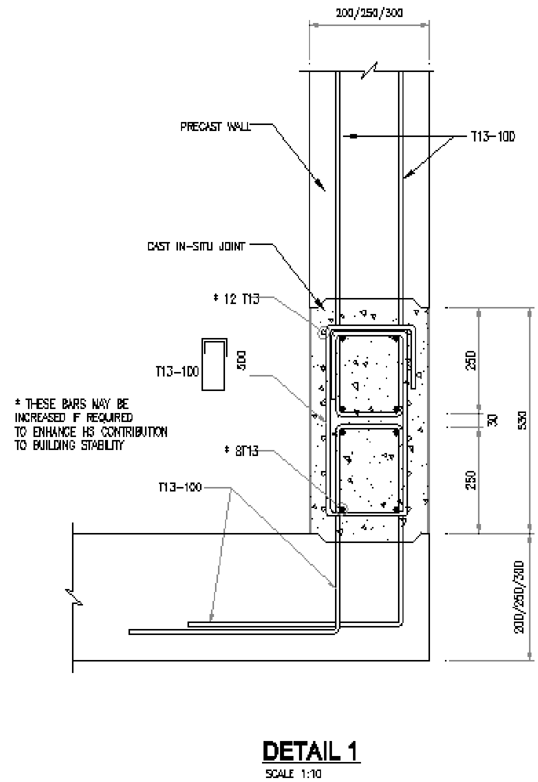


Figure 11.4 Plan showing type 4 of precast household shelter





Recommended joint details
QP to consult BCA on actual application

Figure 11.5 Detail showing precast household shelter

11.2 PRECAST BOUNDARY WALLS

Precast boundary walls are similar to precast wall panels but are typically of smaller sizes. This makes them quite ideal for precasting as the smaller panels mean that the contractor would have fewer problems with handling, transportation and installation on site. At the same time, additional use of such precast components will result in improved site productivity and construction quality.

Joint details

The considerations for proper joint details in the precast boundary panels are similar to those for precast wall panels. The design of the wall joints will include the following considerations:

- water tightness
- installation method
- structural movement
- type of wall finishes
- panel sizes
- weathering
- tolerance

Finishes

The use of precast boundary walls continues to allow a wide range of design flexibility and innovation.

There is a wide range of surface finishes that the architect can use on the precast boundary wall design. The most common techniques used are modeling techniques like sand blasting, acid washing, polishing and honing, hammering and chipping to create the required effects. These finishes can then be treated with appropriate protective coatings to prevent weathering and staining problems.

A wide range of colours for precast boundary wall panel can be derived from aggregates, cement or pigments. Aggregate can provide colour to the final finishes. Cement with different colours can also give the desired colour for the boundary wall panel. Another form of colour finishes are colour and oxide pigments.

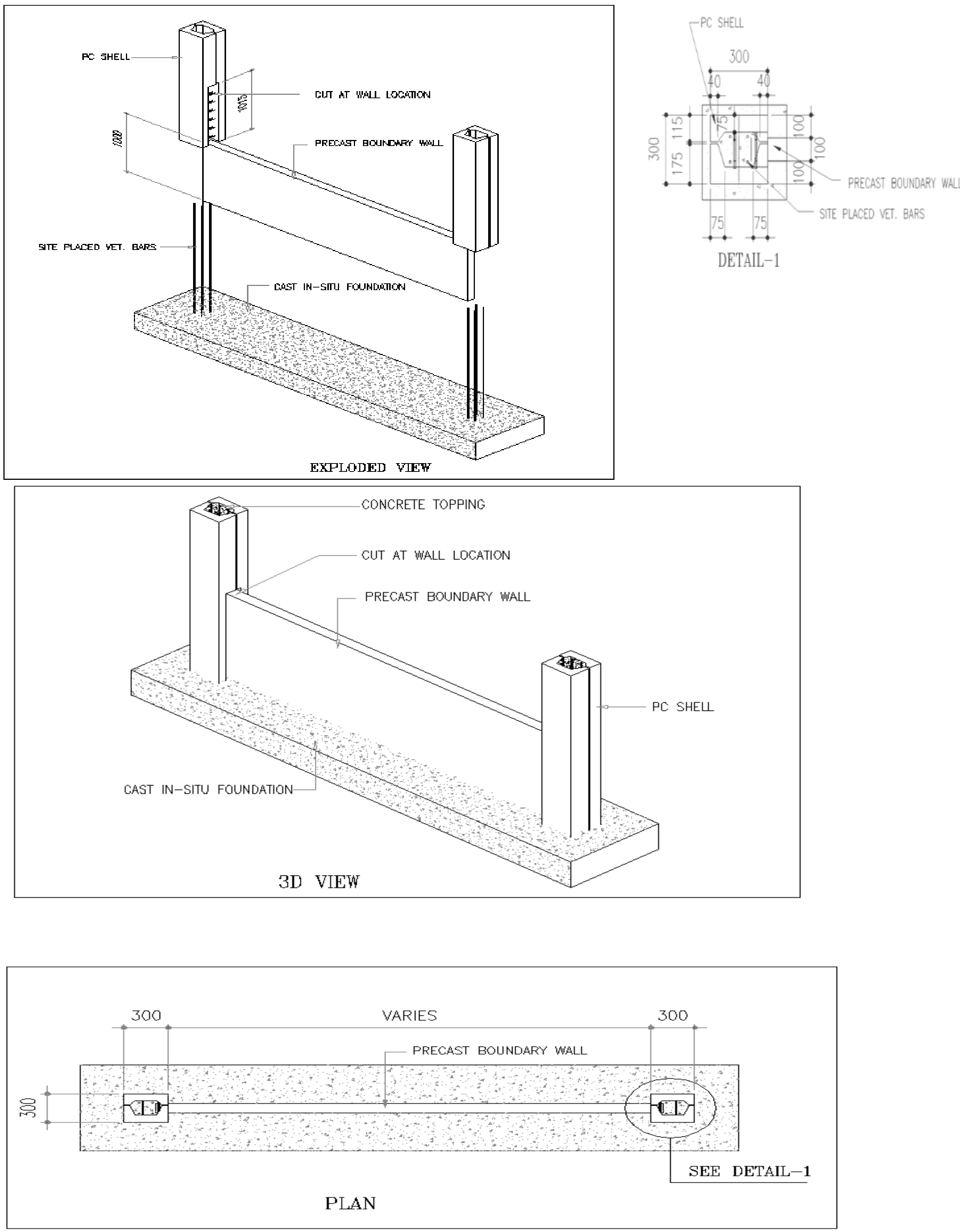


Figure 11.6a Details of the precast concrete boundary wall (type 1)

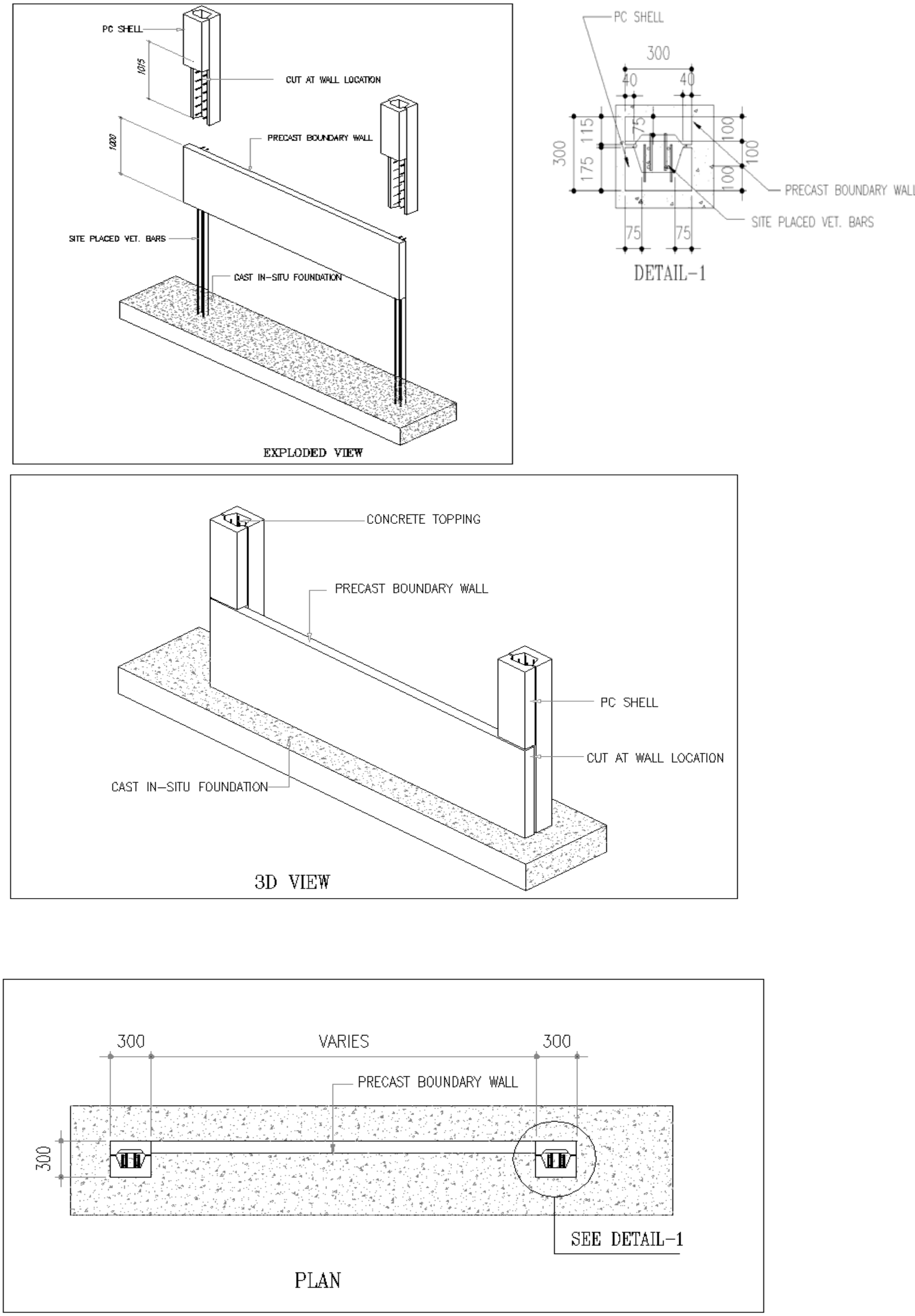


Figure 11.6b Details of the precast boundary walls (type 2)

Figure 11.7 Installation of wall base

Figure 11.8 Precast walls are placed and propped

Figure 11.9 Completed view of the precast boundary panel walls

11.3 PRECAST METER CHAMBER

A precast meter chamber/ compartment can be used. The meter chamber is the housing for the electrical meter, water meter, SCV/ TV board chamber and letterbox. The chamber is also very often the pillar for supporting the entrance gate.

The precast meter chamber is fabricated in two separate components; one is the chamber and the other consists of precast concrete shelves which slot into the precast chamber to separate each of the different services.

The size of the chamber is typically 800 x 800 x 1800 high. This results in a meter chamber that is of manageable size and weight. Hence, this precast component can be transported and installed easily. Moreover, the neat and proper compartmentalization will make it easier to run and install the services between the mains, the chamber and the house.

The finishes to the chamber can be similar to those for precast panels/walls and come in a variety of textures, colours and effects. Figure 11.14a to Figure 11.14c show the details of meter chamber type 1 and Figure 11.15a to Figure 11.15c show the details of meter chamber type 2.

Completed precast meter chamber

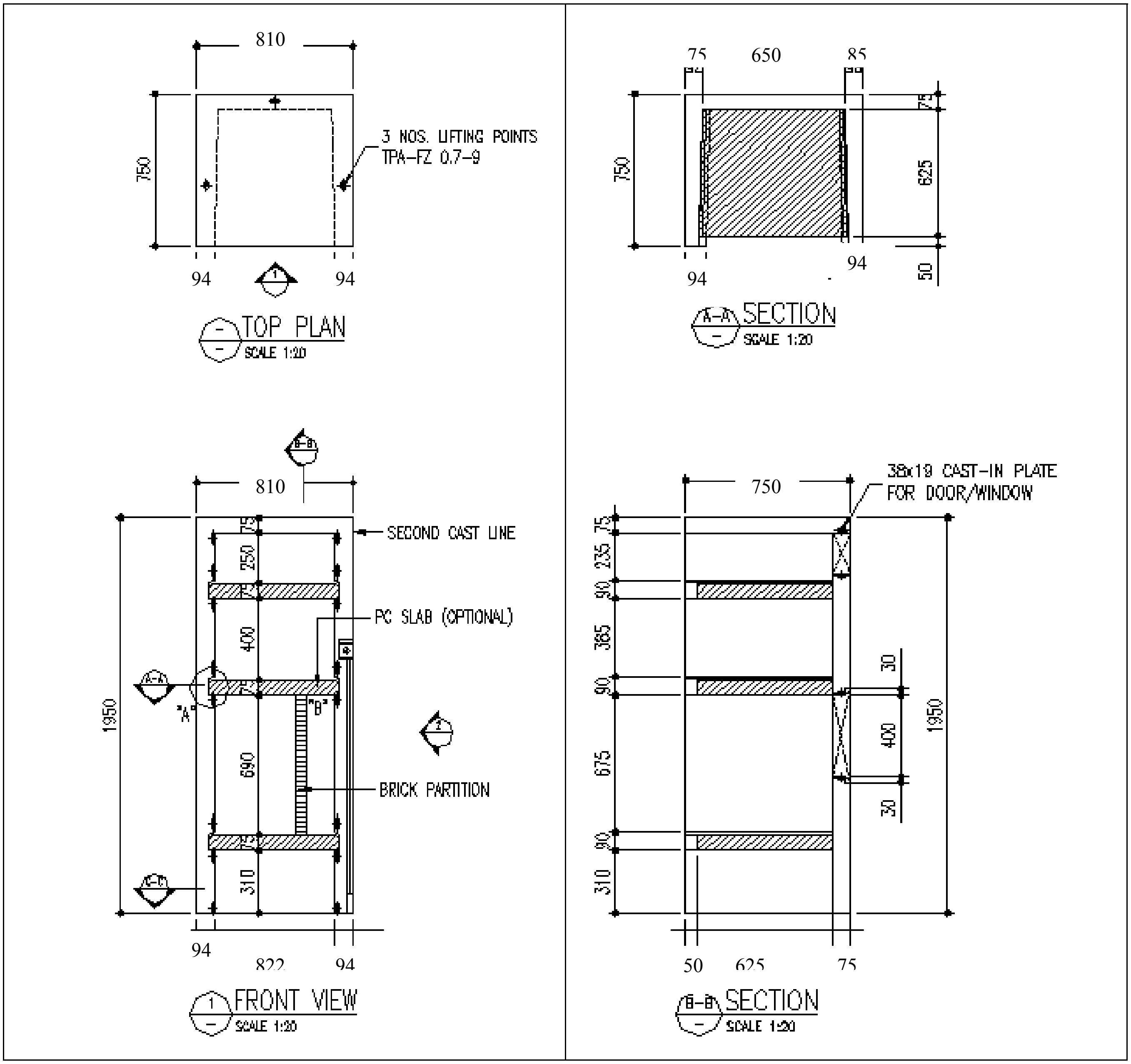


Figure 11.11a Details of meter chamber 1

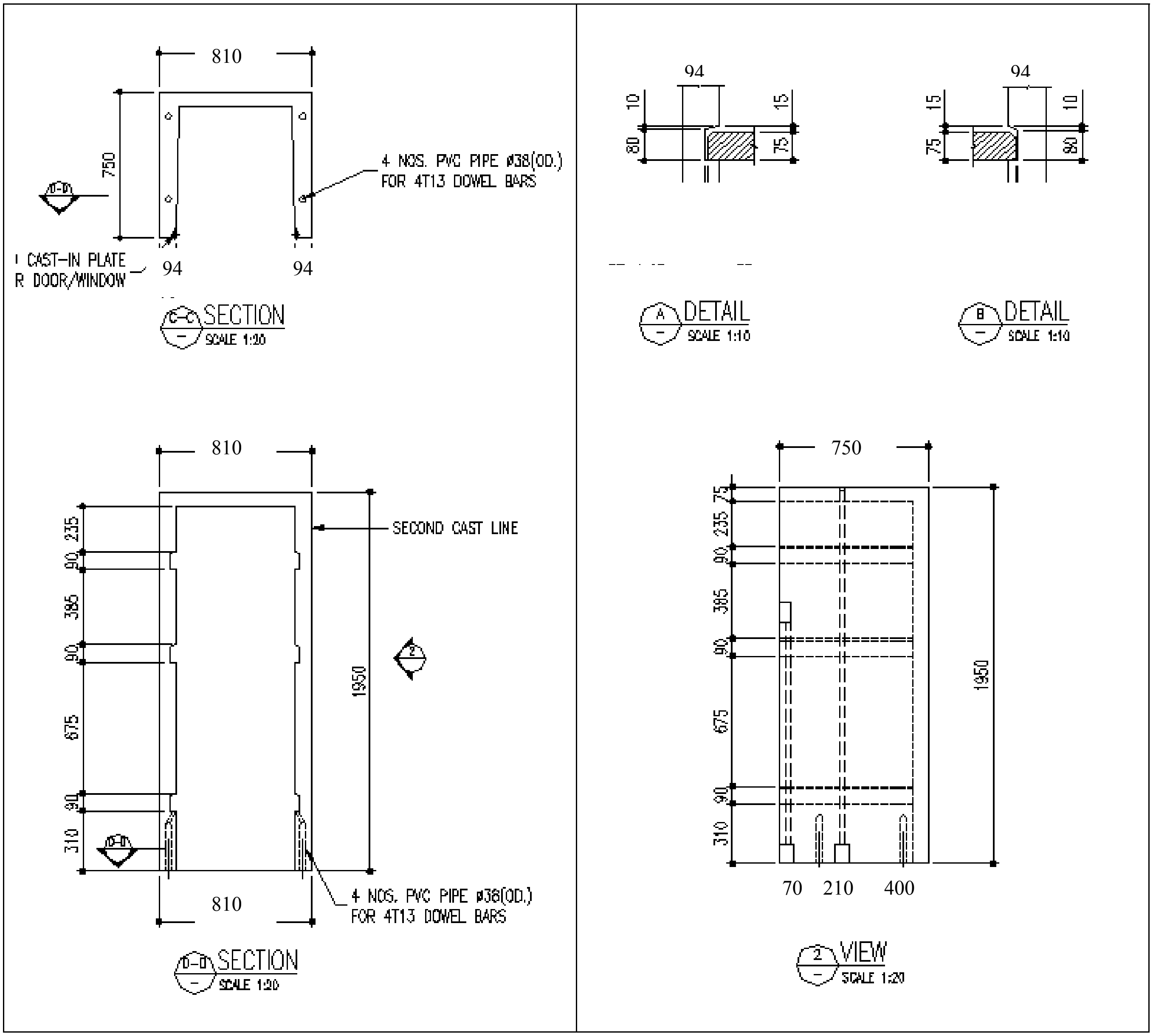
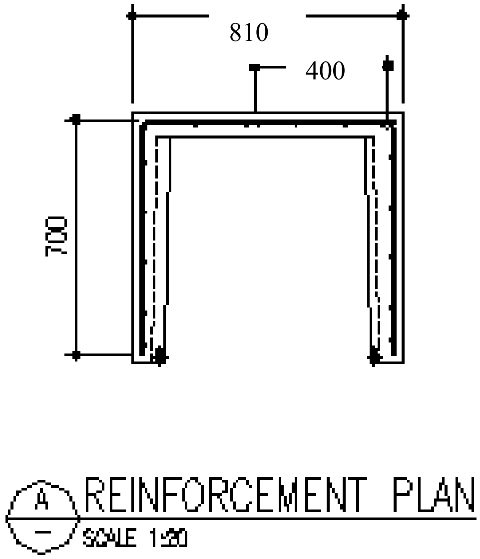


Figure 11.11b Details of meter chamber 1



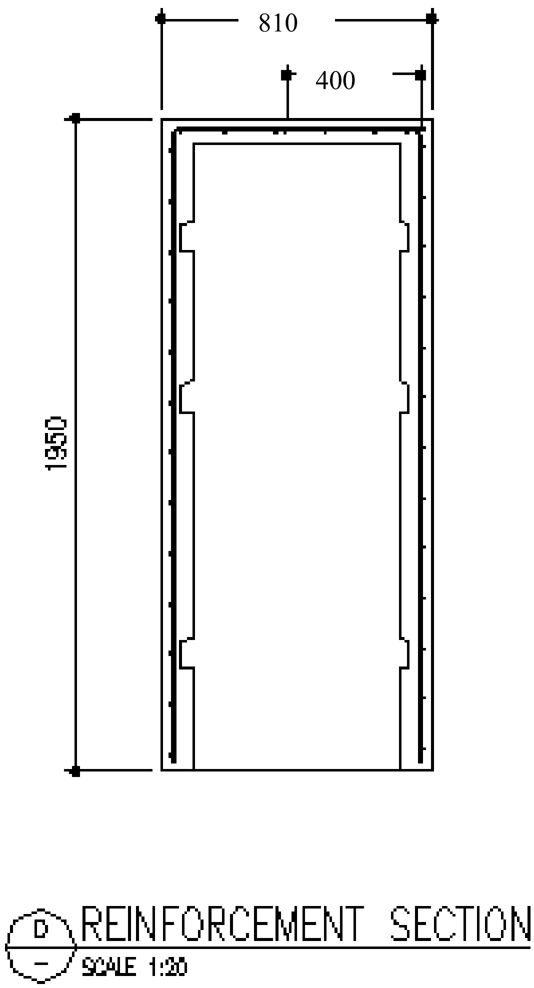


Figure 11.11c Details of meter chamber 1

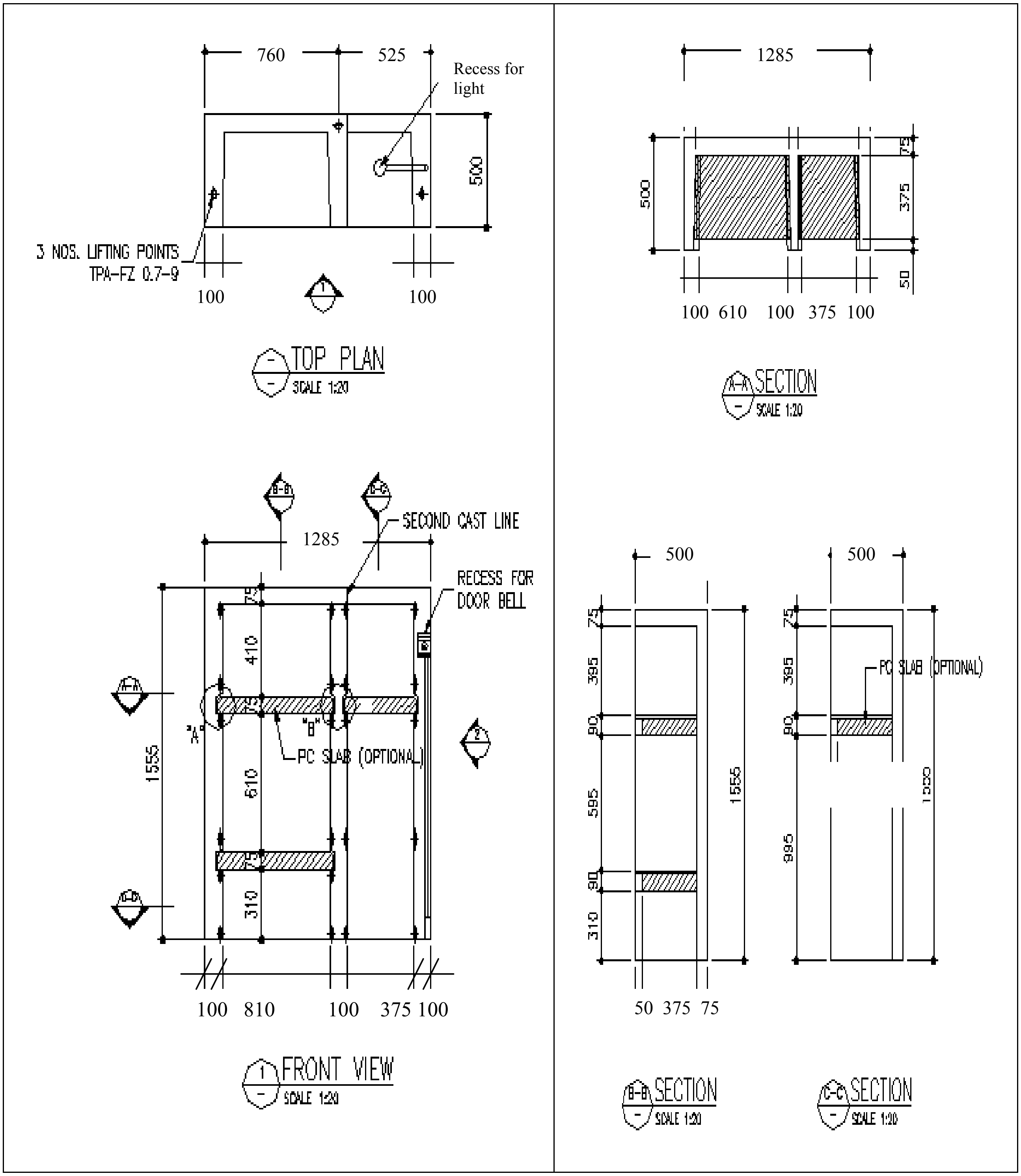


Figure 11.12a Details of meter chamber 2

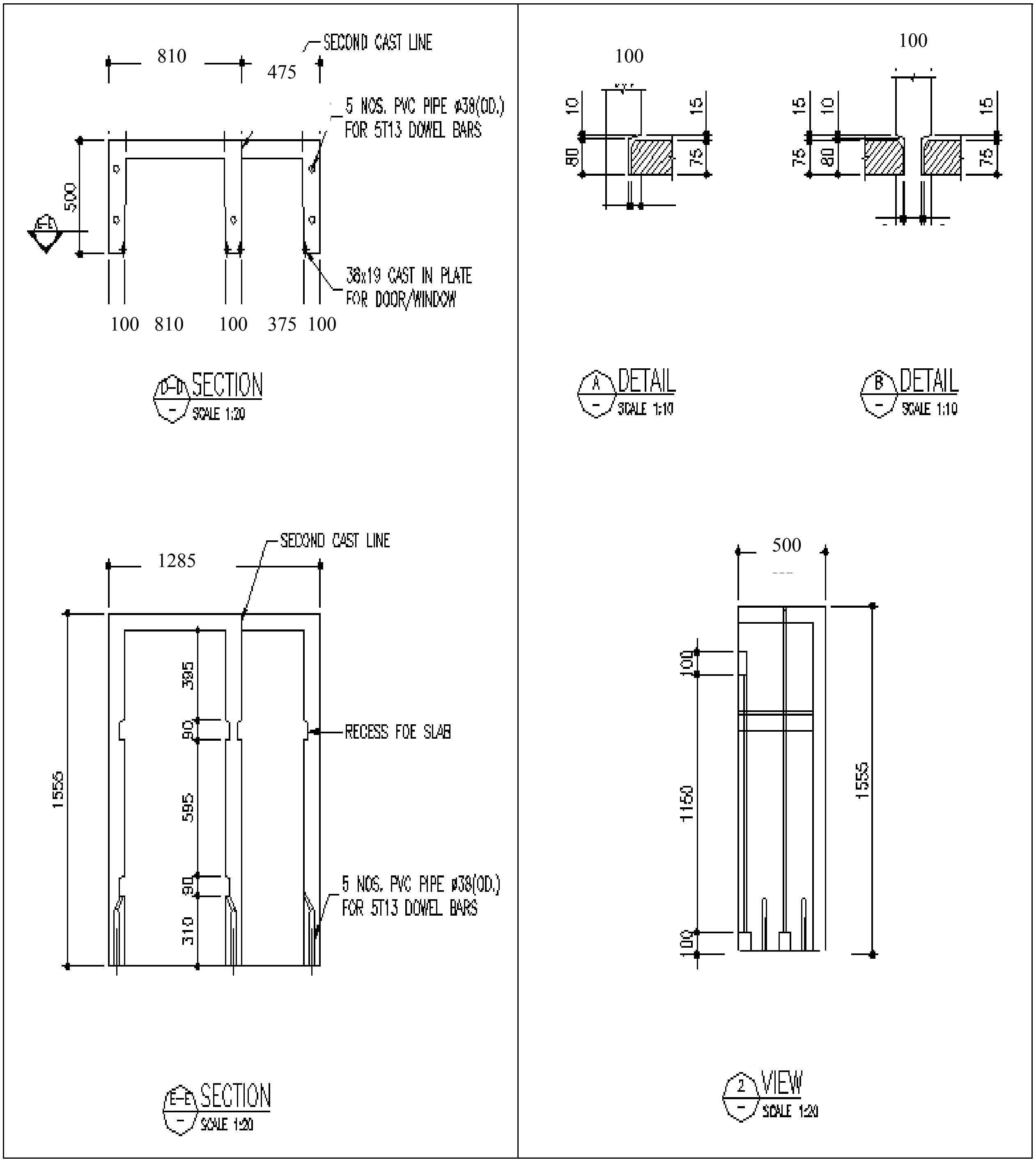


Figure 11.12b Details of meter chamber 2

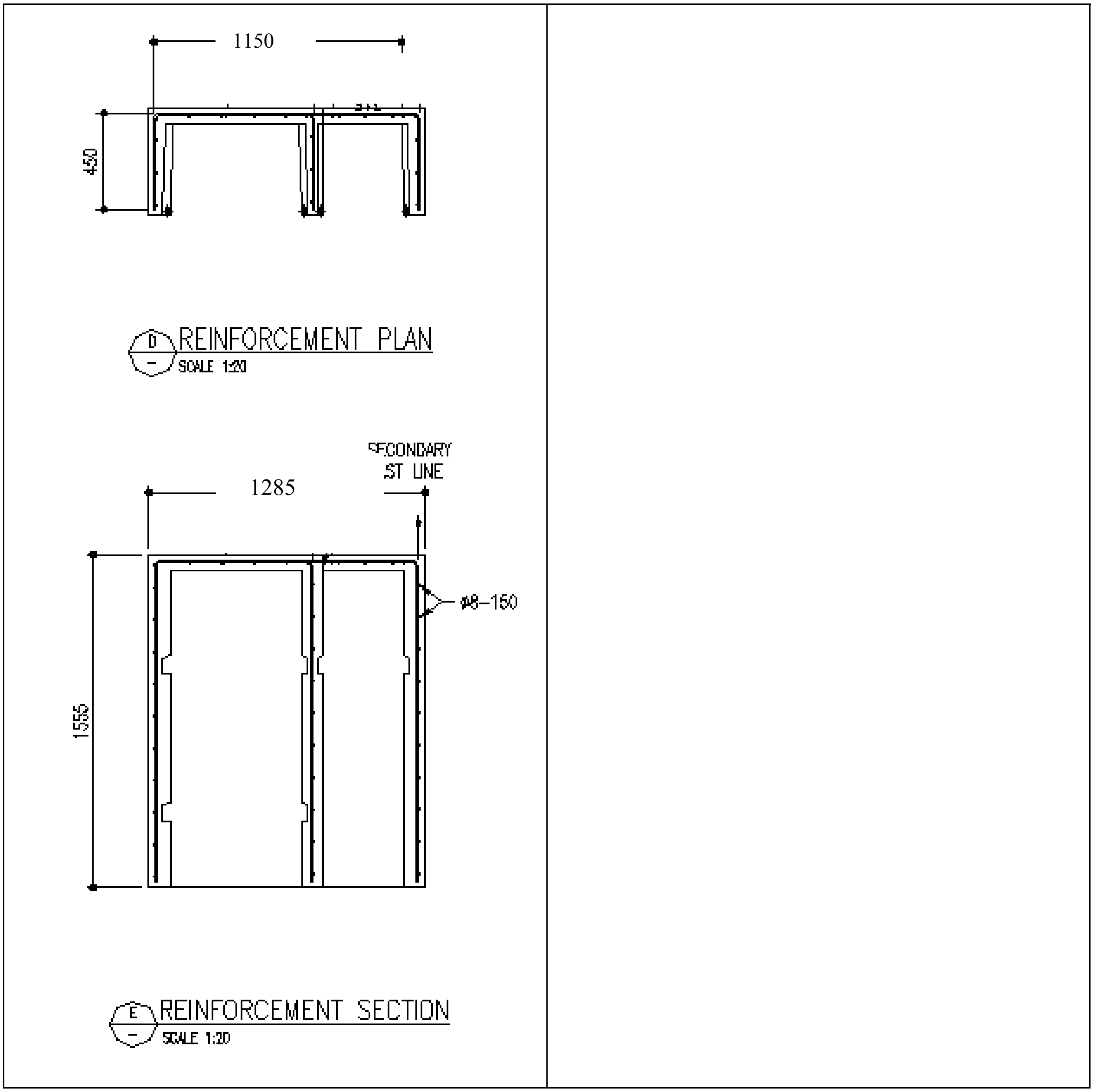


Figure 11.12c Details of meter chamber 2

11.4 PREFABRICATED STAIRCASE

The precast staircases proposed here are of standard sizes with tread sizes between 225mm to 250mm and risers between 150mm to 175mm. On the other hand, steel staircases can come in non-standard sizes to suit the architectural design.

Precast/ steel staircases can be fabricated to a range of various forms and shapes. There are three basic staircases profiles:

- Curved
- Straight
- Spiral profile

In the case of the terrace and semi-detached houses, these staircases can be fabricated in three ways:

- Type A for flight only
- Type B flight and top landing
- Type C flight and base landing

The erection of the staircase can either be on the critical path or non-critical path of the construction sequence. In each case, prefabricated staircases will result in better quality, accuracy and productivity. The prefabricated staircases can be installed quickly and messy, cast-in-situ works can be eliminated.

There are two main methods for fixing and installing the prefabricated staircases. The staircase can either be prefabricated together with the landing as a complete unit or it can be prefabricated separately and installed on site. The prefabricated staircase should be designed to ensure easily transportation and hoisting. However, in most cases, the size and weight are usually within the manageable capacity of the cranes.

Figure 11.13 Precast Flight

Figure 11.14 Cantilevered precast treads

Figure 11.15 Steel plate forming treads and rises

Figure 11.16 Steel stringer beams with steel treads

Figure 11.17 Steel plates supported by centre column

Figure 11.18 Steel plates supported by tension rods

Figure 11.19 Steel plates supported on vertical steel channels

Figure 11.20 Steel plates supported on 2 steel beams

Figure 11.21 Prefabricated spiral staircase

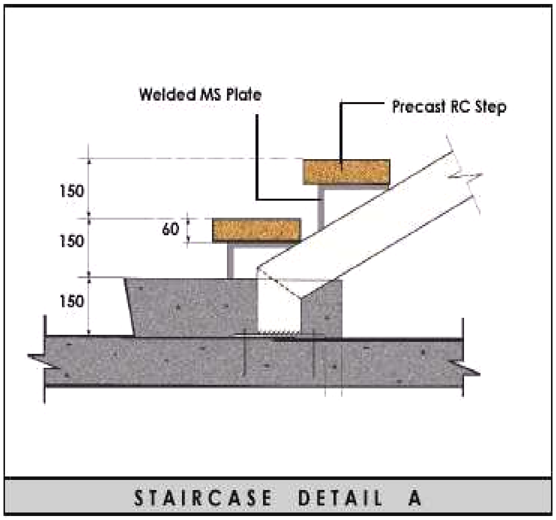


Figure 11.22 Details to staircase in Figure 11.20

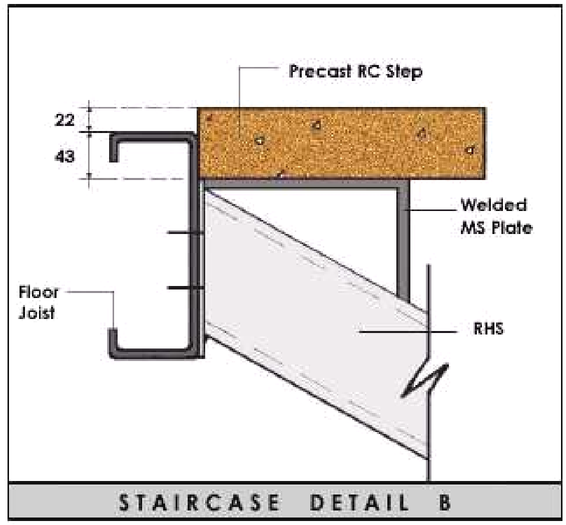


Figure 11.23 Details to staircase to frame connections

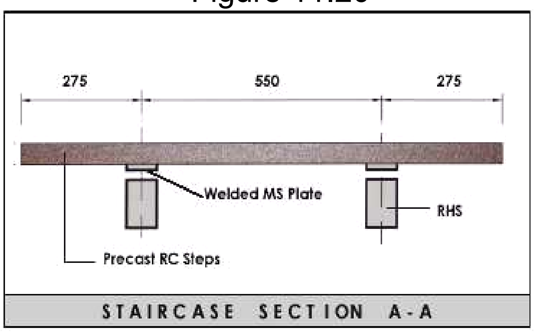


Figure 11.24 Details of prefabricated treads

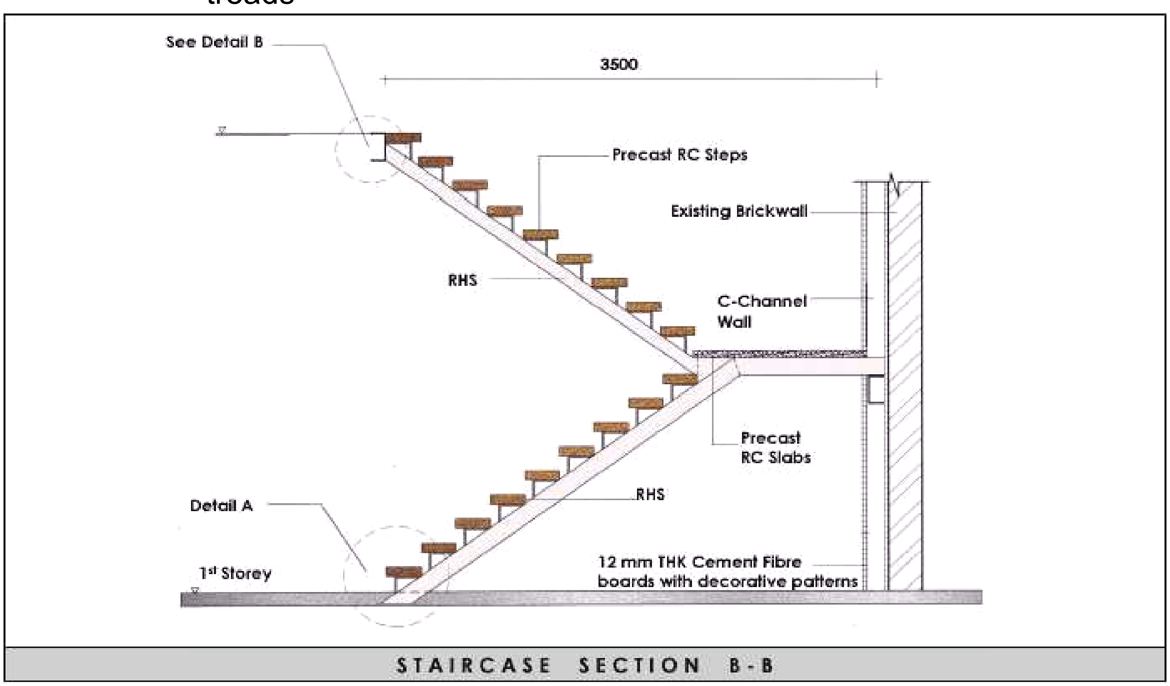
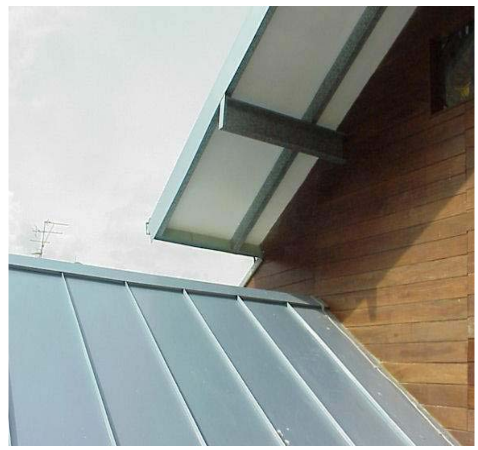


Figure 11.25 Sections of prefabricated staircase

11.5 METAL ROOFING SYSTEM

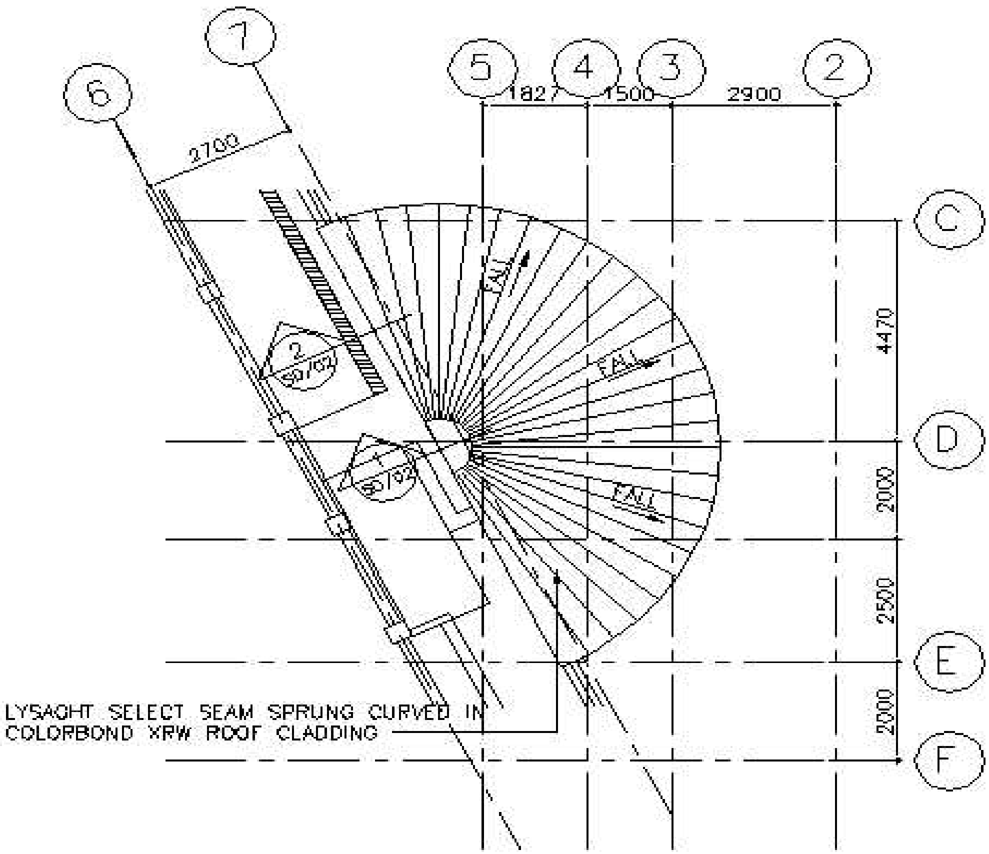
Over the years, metal roofing system such as corrugated metal and patented steel roof-deck materials have gain much popularity in landed housing from the common conventional timber battens and interlocking roof tiles.

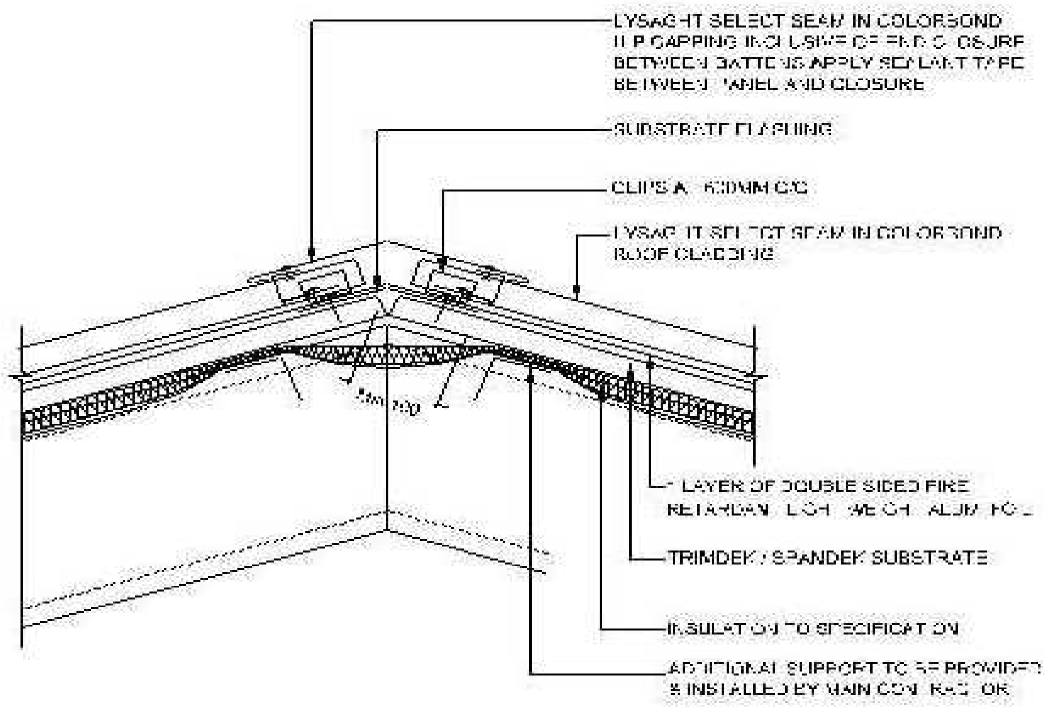
Corrugated metal may be insulated and surfaced with build-up covering. Metal plates formed with interlocking ribs which increase strength and stiffness are manufactured in many different styles. These decks are usually covered with a vapor seal, a rigid insulating board, and a built-up roofing. They are installed either with ribs up or with ribs down. With ribs up these results a smooth ceiling which maybe shop-painted with a baked–on enamel. If the appearance is objectionable with ribs down, an acoustical material maybe applied to the lower surface.

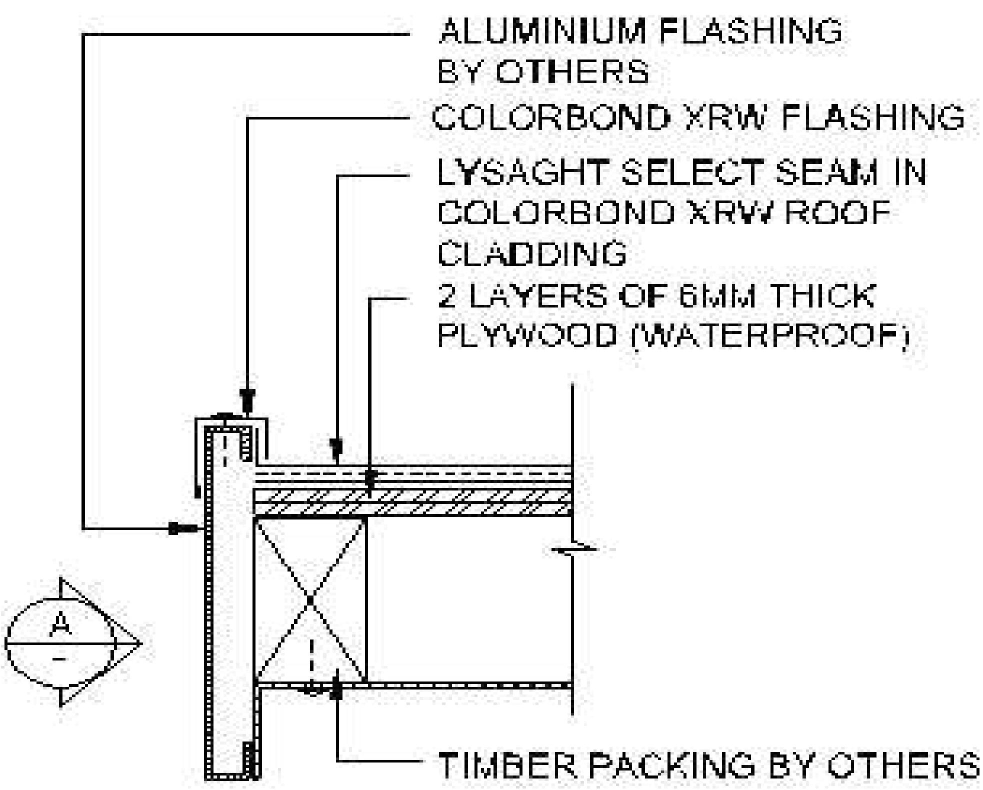


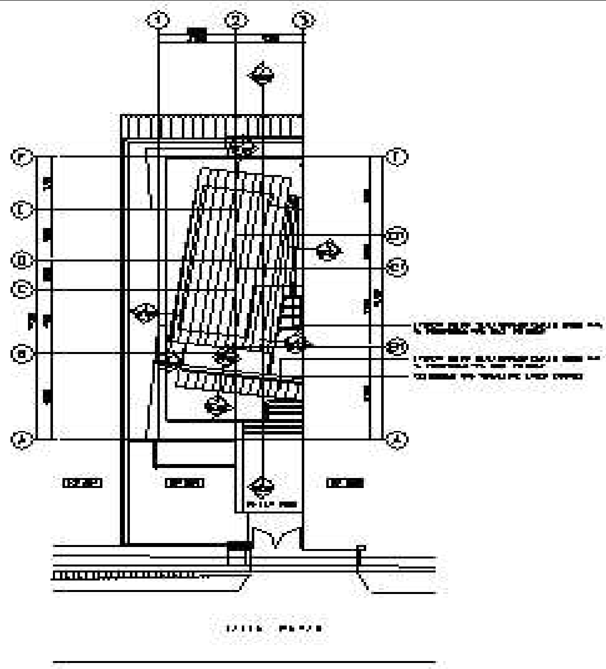
House at Upper Changi Road East
Architects: A-Alliance Architects

House at Sunrise Drive
Architects: LOOK Architects
Main Contractor: Good View Construction P L
Details recommended by BHP Steel Lysaght

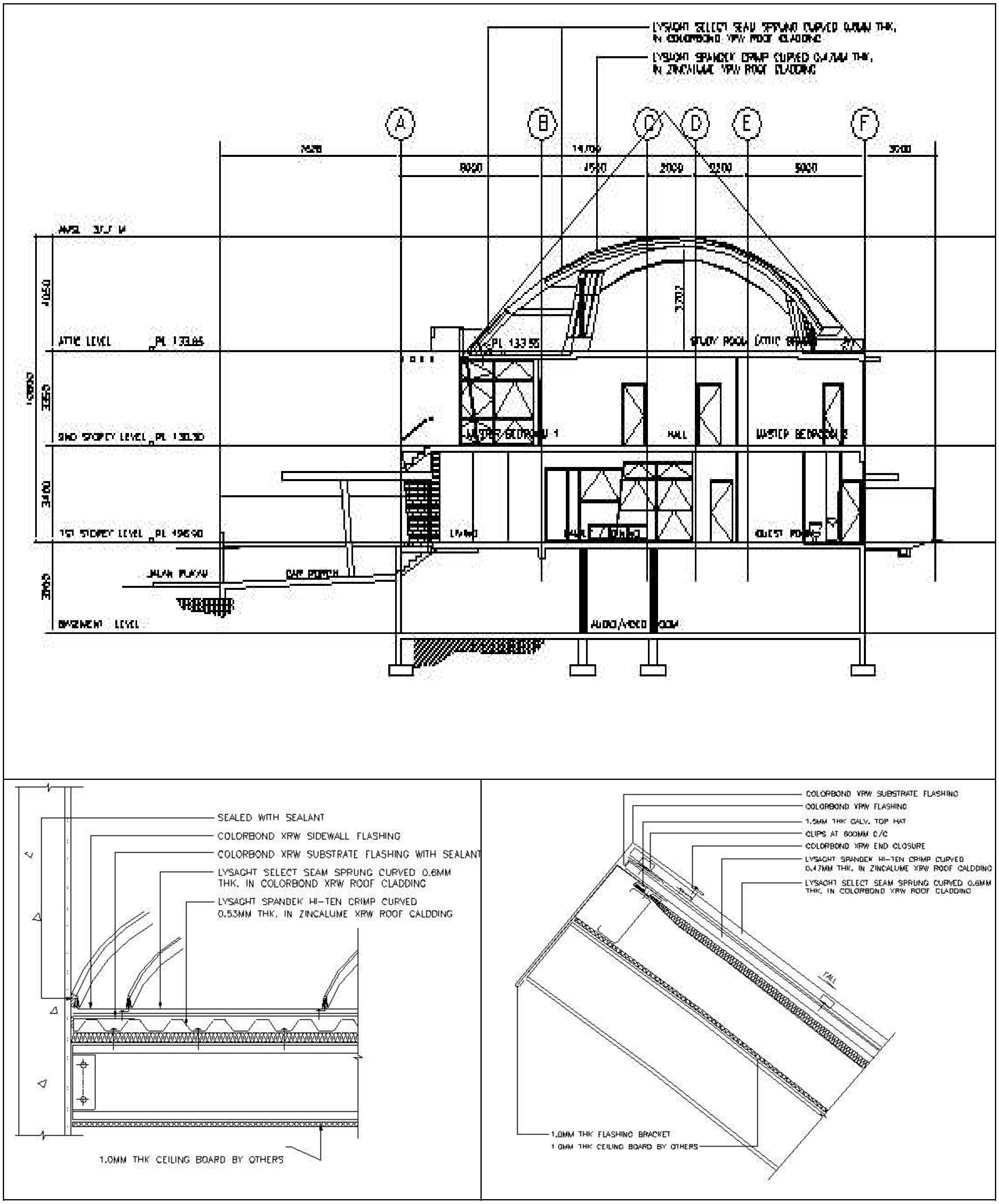


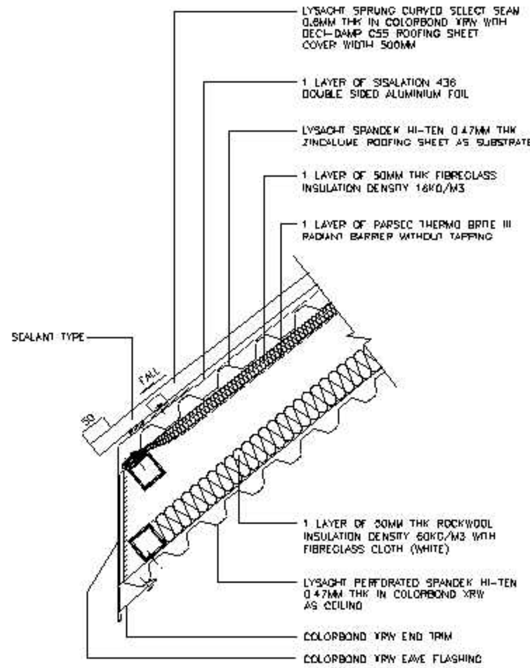

SUBSTRATE FLASHING
TRIMDEK / SPANDEK SUBSTRATE


ALUMINIUM FLASHING
BY OTHERS
COLORBOND XRW FLASHING
LYSAGHT SELECT SEAM IN
COLORBOND XRW ROOF
CLADDING
2 LAYERS OF 6MM THICK
PLYWOOD (WATERPROOF)
A
TIMBER PACKING BY OTHERS

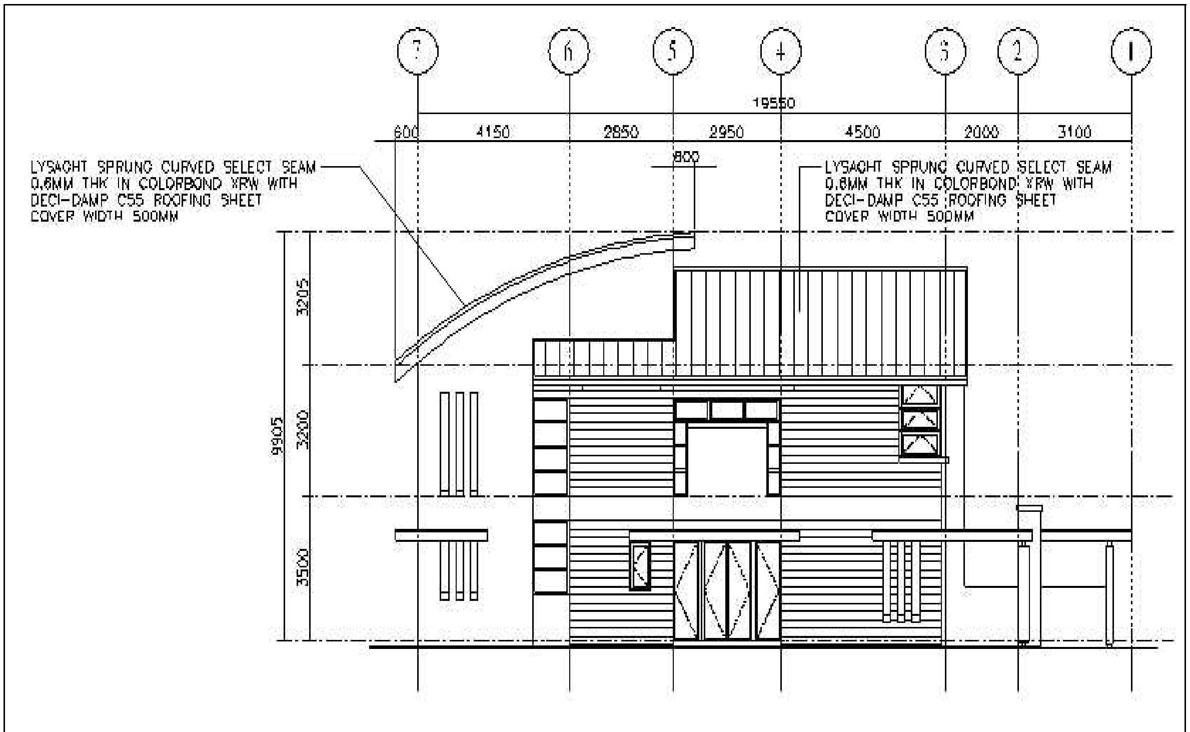


House at no. 35 Jalan Rukam
Architects: CLLA Architects P L
Main Contractor: Jimac Pte Ltd
Details by recommended by BHP Steel Lysaght

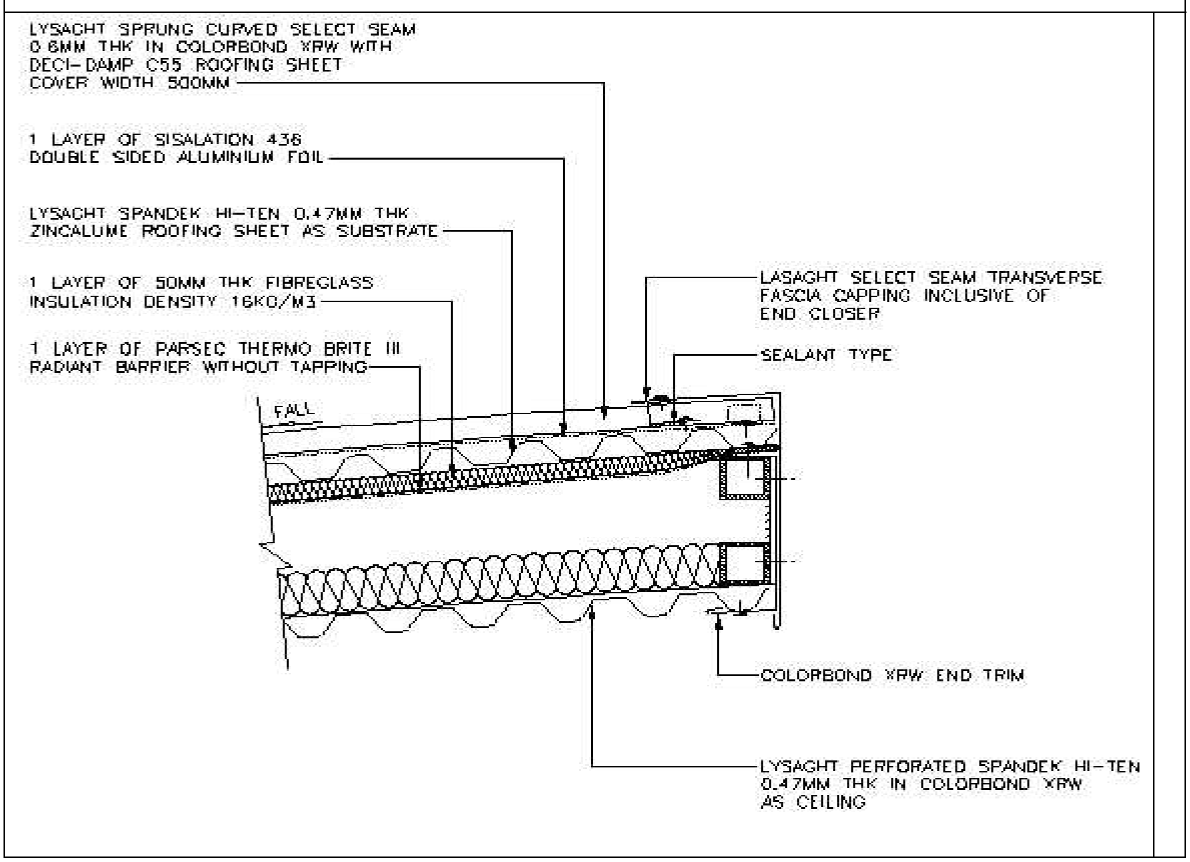

SEALED WITH SEALANT
COLORBOND XRW SIDEWALL FLASHING
COLORBOND XRW SUBSTRATE FLASHING WITH SEALANT
LYSAGHT SELECT SEAM SPRUNG CURVED 0.6MM THK. IN COLORBOND XRW ROOF CLADDING
LYSAGHT SPANDEK HI-TEN CRIMP CURVED 0.53MM THK. IN ZINCALUME XRW ROOF CALDDING
1.0MM THK CEILING BOARD BY OTHERS
COLORBOND XRW SUBSTRATE FLASHING
COLORBOND XRW FLASHING
1.5MM THK GALV. TOP HAT
CLIPS AT 600MM C/C
COLORBOND XRW END CLOSURE
LYSAGHT SPANDEK HI-TEN CRIMP CURVED 0.47MM THK. IN ZINCALUME XRW ROOF CALDDING
LYSAGHT SELECT SEAM SPRUNG CURVED 0.6MM THK. IN COLORBOND XRW ROOF CLADDING
FALL
1.0MM THK FLASHING BRACKET
1.0MM THK CEILING BOARD BY OTHERS



House at no. 73 Thomson Ridge
Architects: AXO Architects International



7
6
5
4
3
2
1
19550
600
4150
2850
2950
4500
2000
3100
600
LYSAGHT SPRUNG CURVED SELECT SEAM 0.6MM THK IN COLORBOND XRW WITH DECI-DAMP C55 ROOFING SHEET COVER WIDTH 500MM
LYSAGHT SPRUNG CURVED SELECT SEAM 0.6MM THK IN COLORBOND XRW WITH DECI-DAMP C55 ROOFING SHEET COVER WIDTH 500MM
3205
3200
3500
9905



LYSAGHT SPRUNG CURVED SELECT SEAM 0.6MM THK IN COLORBOND XRW WITH DECI-DAMP C55 ROOFING SHEET COVER WIDTH 500MM
1 LAYER OF SISALATION 436 DOUBLE SIDED ALUMINIUM FOIL
LYSACHT SPANDEK HI-TEN 0.47MM THK ZINCALUME ROOFING SHEET AS SUBSTRATE
1 LAYER OF 50MM THK FIBREGLASS INSULATION DENSITY 16KG/M3
1 LAYER OF PARSEC THERMO BRITE III RADIANT BARRIER WITHOUT TAPPING
FALL
LASAGHT SELECT SEAM TRANSVERSE FASCIA CAPPING INCLUSIVE OF END CLOSER
SEALANT TYPE
COLORBOND XRW END TRIM
LYSAGHT PERFORATED SPANDEK HI-TEN 0.47MM THK IN COLORBOND XRW AS CEILING

Chapter 12 CASE STUDIES

The following projects A, B, C and D are on-going projects or projects that were recently completed. These developments use prefabricated systems like precast structural steel or a hybrid system using steel column and flat plate system and light gauge steel frame. The projects have demonstrated a construction-efficient design with better quality and improved site productivity.

The subsequent projects E, F and G are completed projects using conventional cast-in-situ system. The project teams reviewed the possibilities of using a prefabricated system in these projects. It was found that a change to a more buildable precast system was possible with no major changes to the elevation or the interior layouts.

12.1 PROJECT A - 81 units 3-storey terrace dwelling houses and two semi- detached houses

General Information

Type	**:**	81 units of terrace houses & a pair of semi-detached houses
Storey	**:**	3-storey with a flat roof
Site Area	**:**	2.2 hectares
GFA	**:**	19,920 m²

<u>Background</u>

The developer has opted for precast construction to achieve better quality, consistency and better buildability. This project is sited along Ang Mo Kio Ave 1 with a site area of approximately 2.2 hectares. The land slopes 18 metres from one end to the other.

<u>Prefabrication solution</u>

The precast system consists of both structural and architectural elements such as party walls, facade walls, floors, staircases, meter compartment and planter boxes. RC pour strips were used at the wall joints and slab joints. The RC pour strips provide for a watertight connection and to minimize cracking at these joints.

To further reduce labour intensive finishing work, the end walls were constructed using facade brick tiles that were precast together with the RC walls.

<u>Issues Encountered</u>

The main challenge to the engineers and architects was the hilly terrain and the staggering site arrangement of the houses. Proper planning with precision in detailing and construction was vital to overcome the physical constraints. Facade design and interior spaces were slightly modified where necessary to adapt the precast system. However, the overall design concept has not been affected.

Project A

Figure 12.1 Erection of precast walls and planks

Figure 12.2 Use of 50-tonne crane for hoisting

Figure 12.3 Minor touching up of finishes

Figure 12.4 Elevation of completed houses

12.2 PROJECT B - A 2-storey semi-detached dwelling house

General Information

Type	:	In-fill semi-detached dwelling house
Storey	:	2-storey and a flat roof
Site Area	:	468 m²
GFA	:	355 m²

Background

The building is a two storey semi-detached dwelling house with a roof terrace. The designers have ensured a safe and economical structure that would fulfill its intended usage.

Prefabrication solution

The building comprised two types of prefabricated components, mainly the structural steel that carried the loads and the precast facade that enveloped the external facade.

The secondary steel universal beams were spaced to support the composite slab such that during casting no additional props were required. The main steel beams supported the secondary beams and transfer loads to the columns. The composite slab with its welded mesh formed horizontal ties and provided lateral restraint to the beams.

The hollow section columns were in-filled with concrete to achieve the minimum half-hour fire resistance.

Precast facade panels were cladded over the structures. Pre-determined groove lines and concrete coloured panels were used. Minimum plastering works were used for the external treatment as most of the labour extensive works were no longer necessary.

Issues Encountered

Prefabrication technology requires greater precision compared to cast in-situ concrete construction. In precast construction, only a +/- 5 mm tolerance is acceptable. Greater amount of accuracy must be achieved early in the design stage. Location of services must be predetermined as well as details for location of windows, skirting etc, must be decided up front to ensure no mis-alignment during construction stage.

Project B

Figure 12.5 Steel decking and prefabricated spiral staircase

Figure 12.6 Elevation

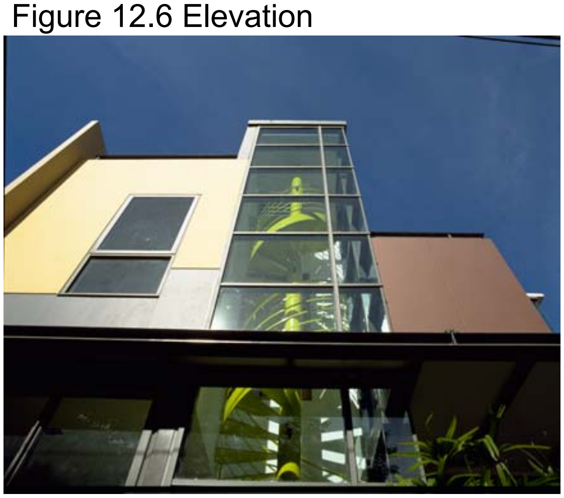


Figure 12.7 Interior layout

12.3 PROJECT C - A 3-storey semi-detached dwelling house

General Information

Type : In-fill semi-detached dwelling house
Storey : 3-storey with a metal pitch roof
GFA : 399 m²

Background

The building is a three storey semi-detached dwelling house with a metal pitch roof along Upper Changi Road East.

Description of a Prefabricated system

(a) Cost Study

A cost estimate study of the project indicated that if the technique was applied on a larger scale, such as 5 houses onwards, the cost savings could be significant. This was due to the high level of prefabrication and mass manufacturing inherent in the process and, of course, to the faster speed of construction. Faster M&E installation, faster architectural finishing work and reduced unskilled labour requirements meant lower costs all round.

The shorter construction period led to greater rental savings as well.

(b) Reduced Pollution

There was also significant reduction in the amount of construction debris generated as many major components were pre-fabricated in factories with very little wet work that required timber formwork, a major source of construction waste. Most components were handled easily without cranes and pulleys. There was also minimal disturbance to neighbours as piling was not required due to the lightweight structure.

(c) Ecological Considerations

The lightweight steel structure also demonstrated that the house could be adapted easily to accommodate ecological considerations such as recycling rainwater, harnessing solar energy and reduced air-conditioning. A 2300 litres tank allowed the owners to have a week supply of recycled rainwater for washing, gardening and koi pond use.

By having a mildly reflective metal roof with large roof airspace gap, good insulation and light cladding materials, it was found that the building retains much less heat compared to conventional RC buildings which tend to retain heat for a longer period. In fact the owners reported that they seldom turned on the air-conditioners during the day.

Issues Encountered

While there are many overseas examples of lightweight steel-framed house available, the architects noted that for various reasons the technique has never been used widely at all in Singapore, especially not for a one-off 3-storey house situation. The main reason for this is probably due to the lack of skilled tradesmen experienced with this method of construction. Secondly, many people dislike the "hollow" sound when they knock on the walls of a typical steel-framed house although they are well aware that the house is just as structurally safe as any conventional RC house.

The first problem cannot be solved easily nor quickly. It is an industry-wide problem that has to be tackled over years. The architects resolved the second problem with the application of denser insulation between fibre cement walls. A foreign visitor to the house noted that in developed countries where this form of housing is common, people do not seem to mind the "hollowness" even though they are typically taller and heavier than locals. It is very much a cultural phenomenon that will ease away when steel frame housing becomes more prevalent.

Hence, a change in the mindset is necessary since this system has proven to greatly improve the site productivity and is a more friendly construction method to the neighbourhood.

Project C

Figure 12.8 Light-gauge Steel Frame

Figure 12.9 External cladding to fibre board walls

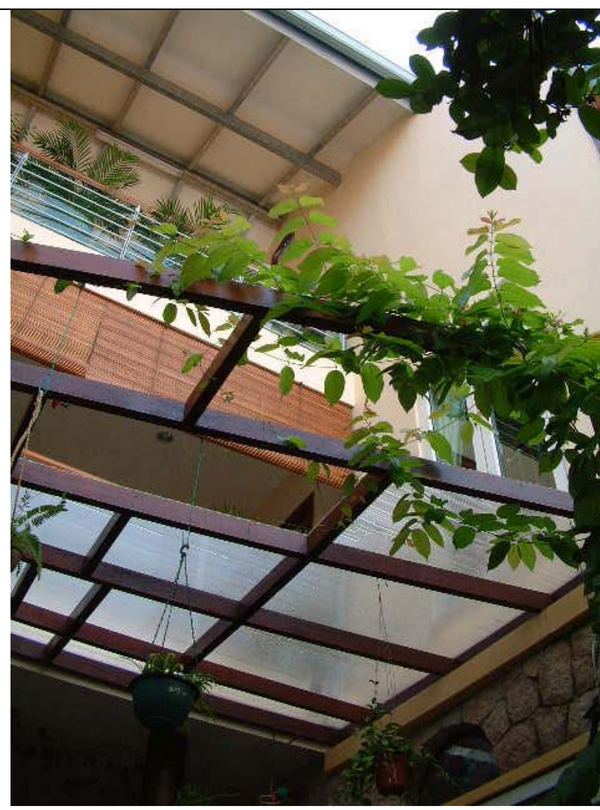


Figure 12.10 A view from the garden

Figure 12.11 Construction of first storey. Only the front panel used CIS construction, all other areas used light gauge steel frames

Figure 12.12 Construction of 2nd storey

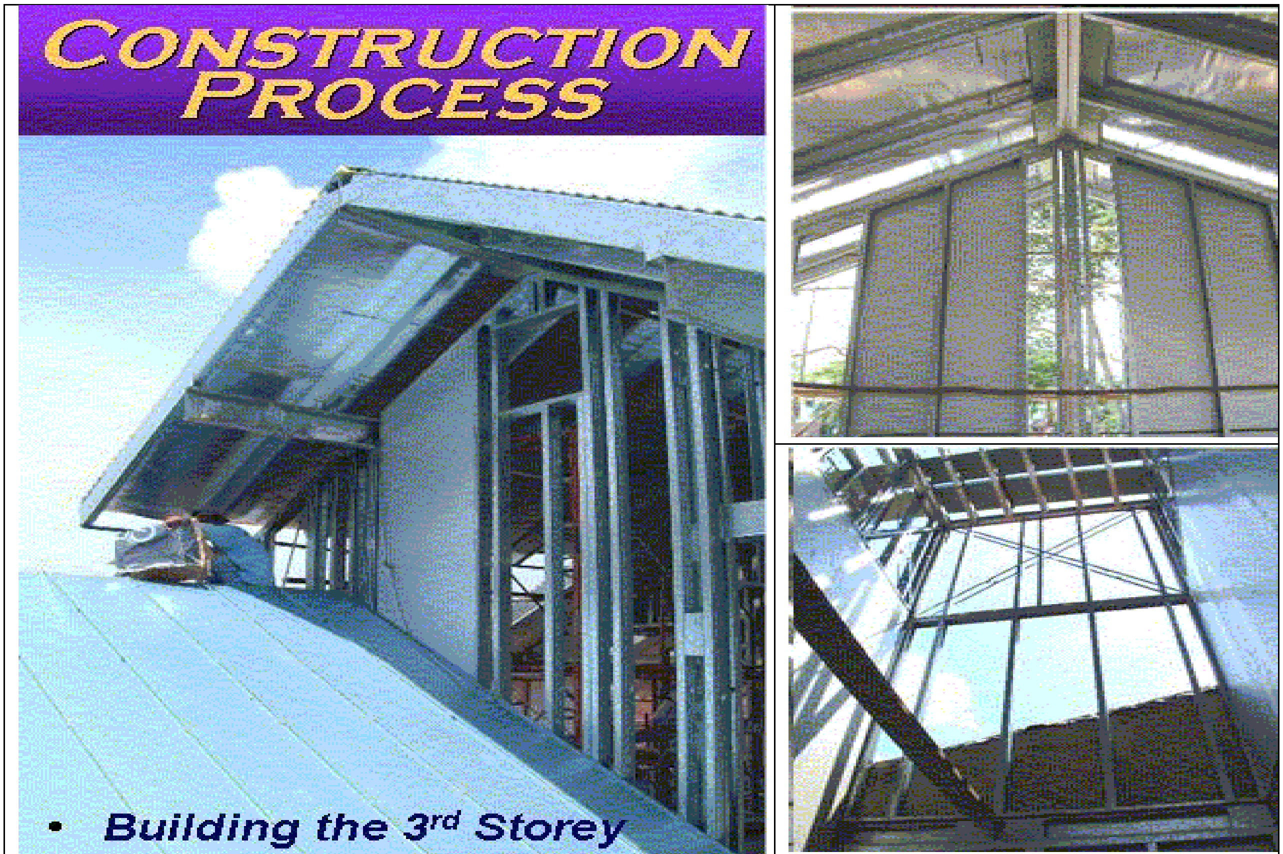


Figure 12.13 Construction of 3rd storey

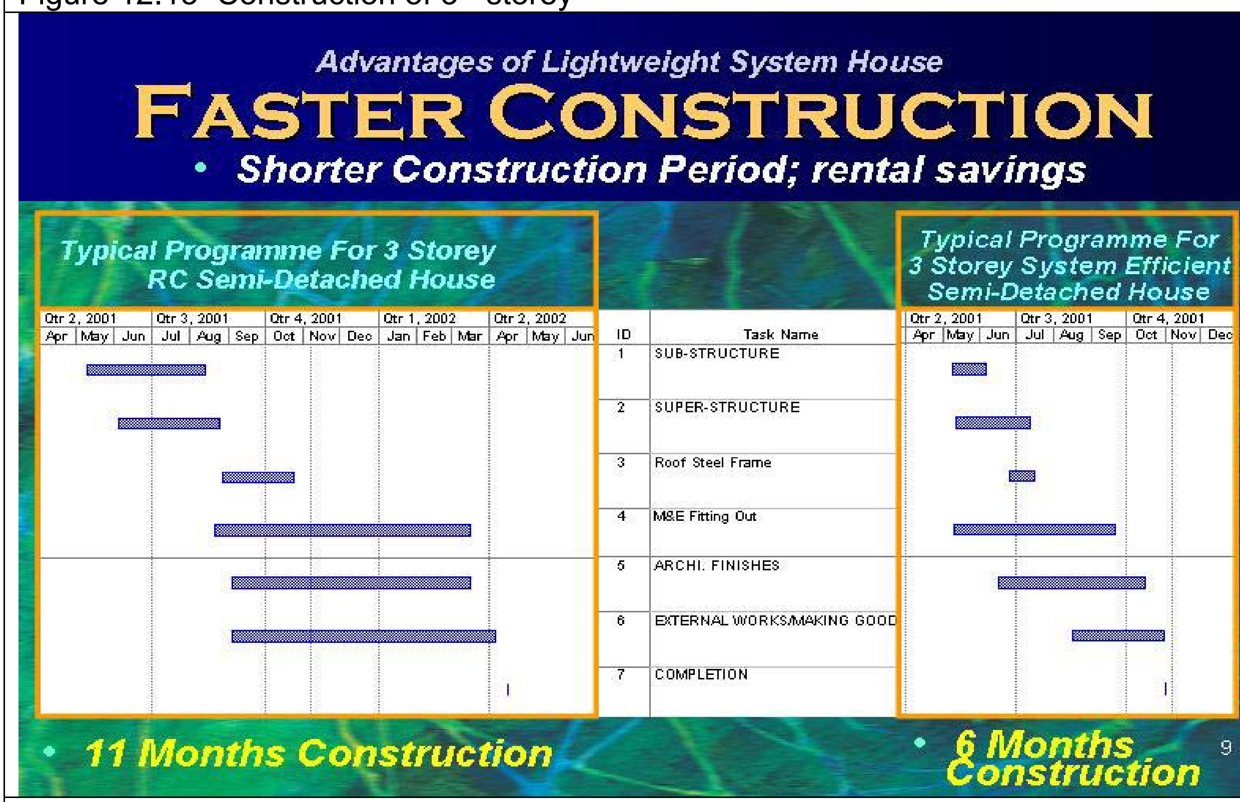


Figure 12.14 Comparison of project construction time between conventional RC system and light gauge steel frame system

12.4 Project D – New Terrace Houses

General Information:

Type	:	Landed Terrace Dwelling Houses
Level	:	3-storey
Site Area	:	66,195.17 m^2
Plot Area	:	220 m^2 (each plot)
GFA	:	218 m^2 (each plot)

Background:

This development comprises 264 units of terrace and semi-detached houses, which are built in 6 phases. So far 3 phases have been completed and phase 4 is in the planning stage. Conventional construction methods have been adopted so far in this development. Some thoughts have been given to explore the possibilities of using precast elements for the typical terrace houses through a case study.

The typical 3-storey units consisting of 5 Bedrooms with Living, Dining, Kitchen and Utility have been designed to conform to local standards. The household shelter shown in the proposal is not part of the original plans. They have been added to meet current building requirement for the purpose of this study. Other elements remain unchanged as in the actual project.

Development of Precast System:

In the new proposal, the overall layout has been maintained with some minor adjustments due to the inclusion of the precast household shelter. The wet areas have been kept at the same side of the plan and as much as possible the toilets have been stacked one above the other. Shower areas and balconies have been provided with 50mm high kerb instead of providing the structural drop to the slabs. Party wall, front/rear wall, boundary wall, staircase & meter box are precast units. In line with the BCA buildability guidelines, the floor to floor heights have been kept repetitive (except 1st storey) in multiples of 175mm (standard staircase riser height). The vertical joints formed at the junctions of the party wall with the front wall panel have been suitably concealed with GRC box-up.

Precast Findings:

1. The case study found that the party walls could be designed as precast shear walls due to the following advantages:

a) For terrace houses, there are no disadvantages to the use of precast shear wall.

b) In party walls, there is no necessity to cater for future openings, e.g. doorways and duct penetrations.

c) Vertical pour-strips between each shear wall panel is necessary to eliminate vertical joint lines.

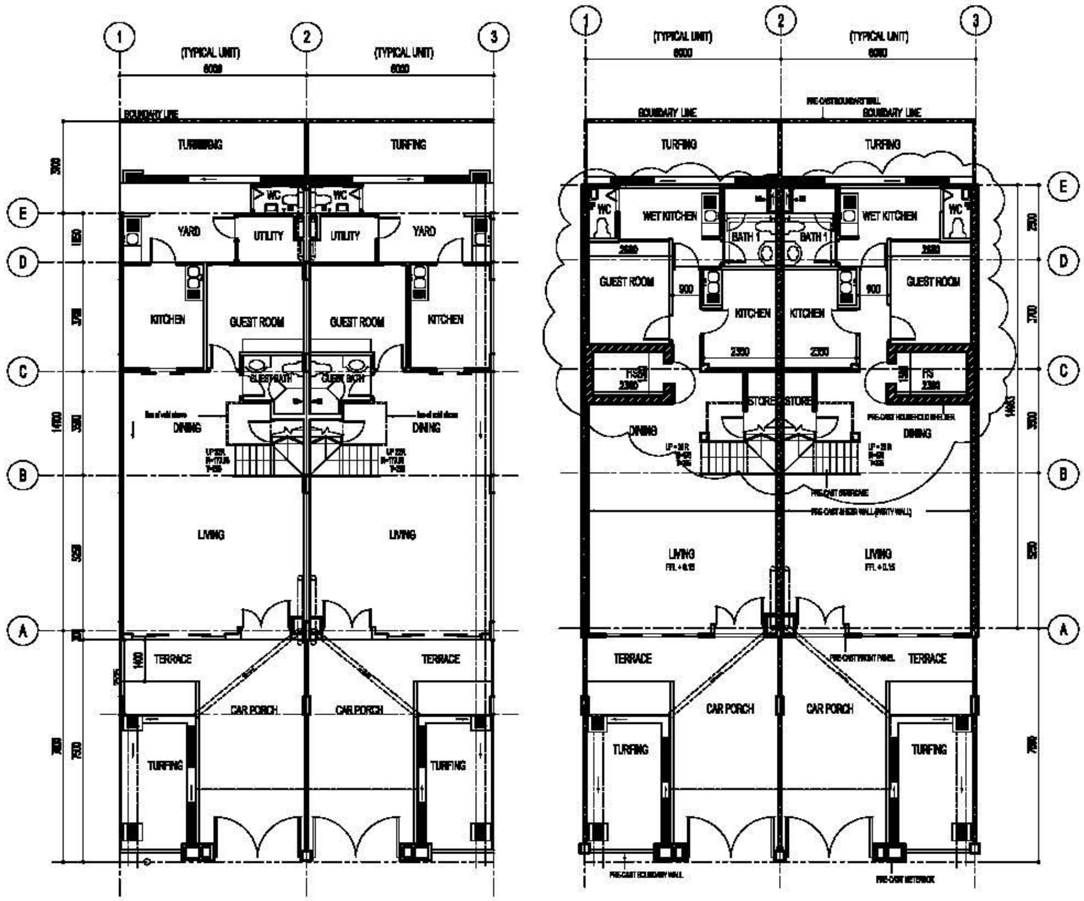
d) Precast columns can be used at the localised staircase/void areas to support the precast slabs.

2. Employing flat roof using precast panels have been found to be economical as against pitched roof where the laying of timber rafters, battens and clay roof tiles are labour intensive activities.

3. As an alternative to the flat roof, the precast panels could be arranged in an inclined manner on to the part walls to make a pitched roof. However clay tiles over the timber battens could not be avoided due to the waterproofing needs.

Conclusion:

The findings of the case study revealed that the precast system can be adopted with very minimum adjustments to the original layout plans.



EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

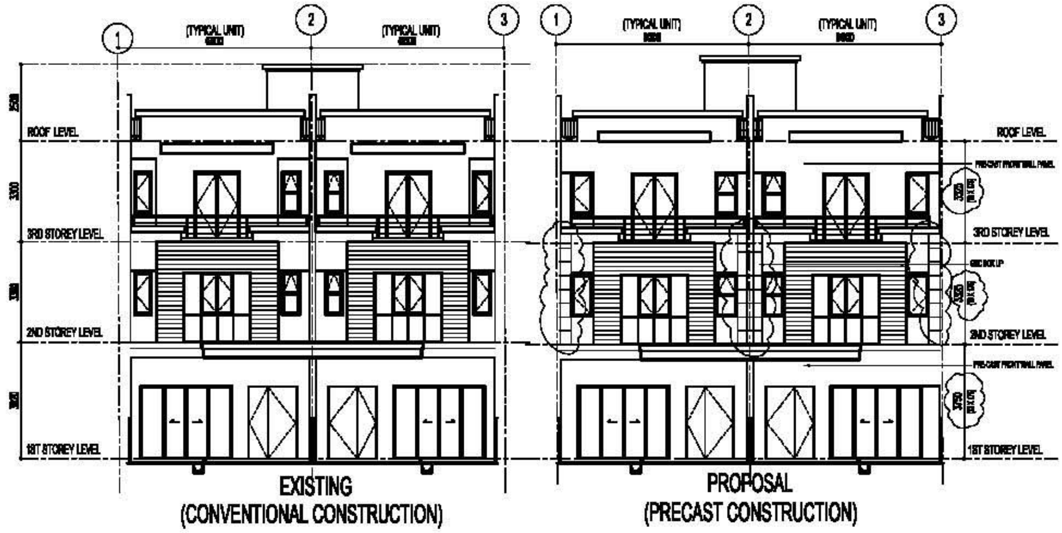
1ST STOREY PLAN

THE NEW PROPOSAL INVOLVES THE FOLLOWING IN THE 1ST STY: -

1. THE OVERALL LAYOUT HAS BEEN MAINTAINED WITH SOME MINOR ADJUSTMENTS.
2. PRECAST HOUSEHOLD SHELTER HAS BEEN INCLUDED.
3. WET AREAS HAVE BEEN KEPT AT ONESIDE TO MINIMISE THE LENGTH OF M&E PIPINGS.
4. PARTYWALL, FRONT/REAR WALL , BOUNDARY WALL, STAIRCASE & METER BOX ARE PRECAST

CASE STUDY - T2 TERRACE HOUSE

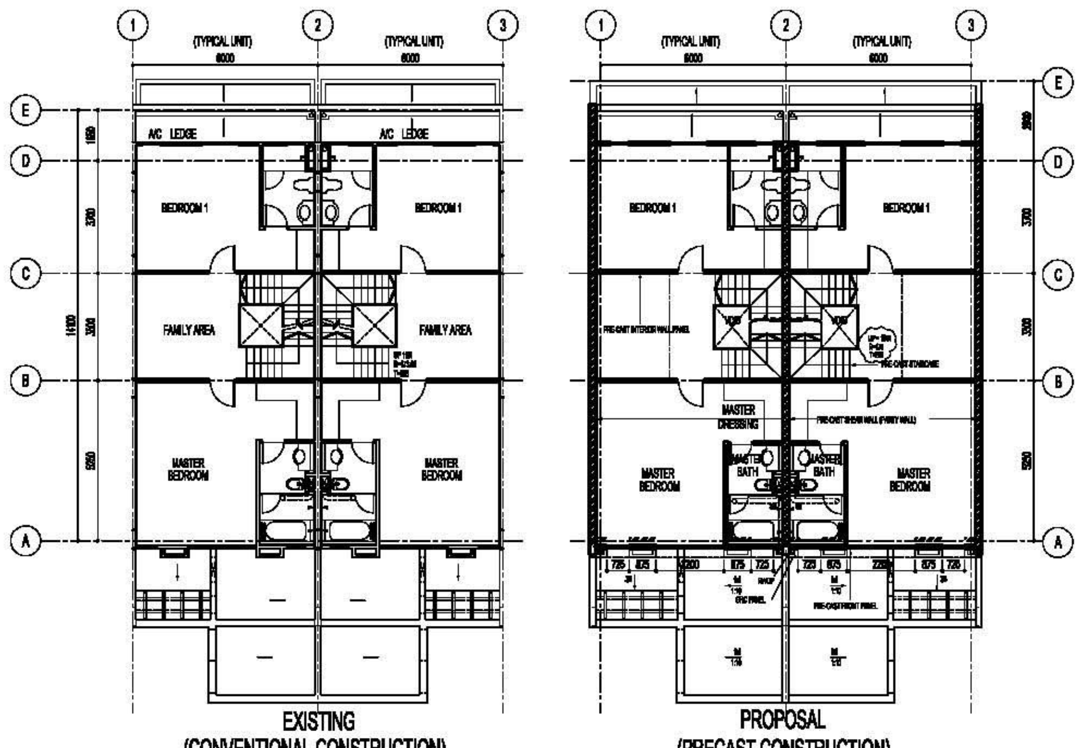
BCA STUDY ON DEVELOPMENT OF PRECAST SYSTEMS FOR LANDED HOUSES



FRONT ELEVATION

THE NEW PROPOSAL INVOLVES THE FOLLOWING IN THE FRONT ELEVATION: -

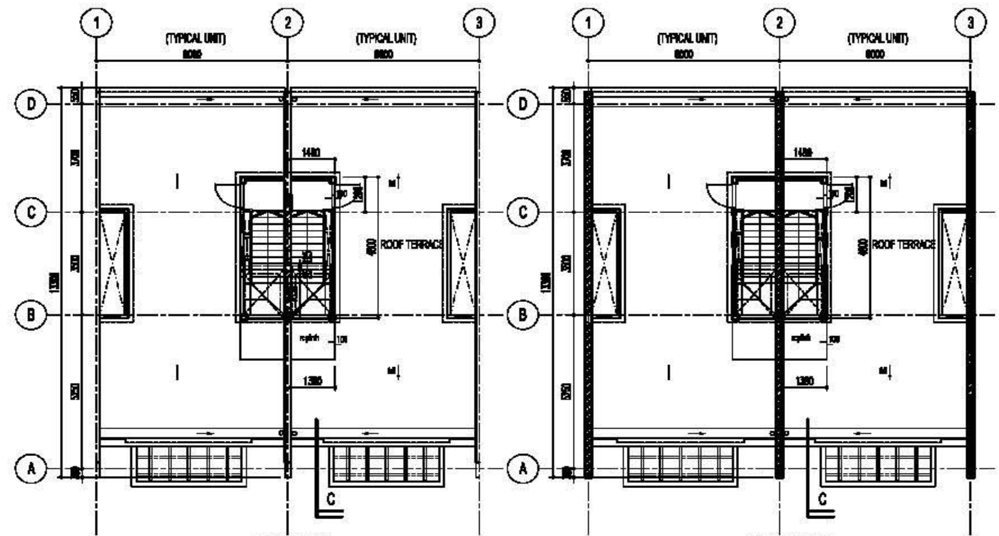
1. IN LINE WITH THE BCA BUILDABILITY DESIGN GUIDELINES THE FLOOR TO FLOOR HEIGHTS HAVE BEEN KEPT REPETITIVE (EXCEPT 1STY) IN MULTIPLES OF 175MM STAIRCASE RISER SIZE.
2. THE VERTICAL JOINTS RESULTED AT THE JUNCTIONS OF THE FRONT WALL PANEL WITH THE PARTYWALL HAVE BEEN SUITABLY CONCEALED WITH GRC BOX UP



2ND STOREY PLAN

CASE STUDY - T2 TERRACE HOUSE

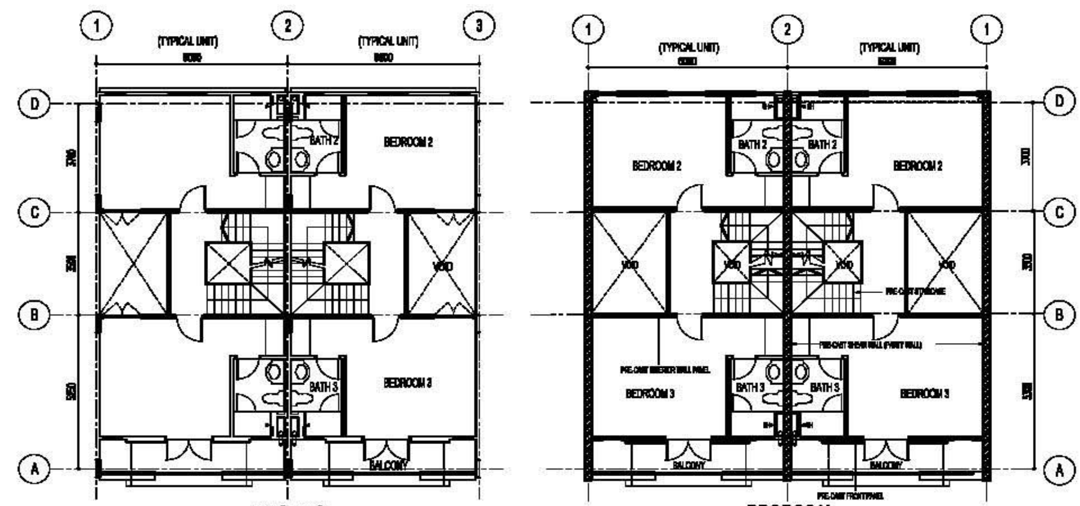
BCA STUDY ON DEVELOPMENT OF PRECAST SYSTEMS FOR LANDED HOUSES



EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

ROOF PLAN



EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

3RD STOREY PLAN

CASE STUDY - T2 TERRACE HOUSE

BCA STUDY ON DEVELOPMENT OF PRECAST SYSTEMS FOR LANDED HOUSES

12.5 Project E - In-fill Terrace Houses

General Information:

Type	**:**	A pair of intermediate in-fill terrace houses
Level	**:**	2-storey with an attic floor
Site Area	**:**	143 m^2 (each plot)
GFA	**:**	214 m^2 (each plot)

Background

This case study project is located within an existing housing estate. The brief calls for total reconstruction to two units of intermediate terrace houses for two separate clients. Both houses are 2 storeys with an attic floor and a pitched clay tile roof above. Space requirements are generally quite typical to local standards. Household shelters are not part of the original plans / building. They are added to meet current building requirement for the purpose of this study. Other elements remain unchanged as in the actual project.

As an in-fill project, existing party walls adjoining neighbours on both sides are not disturbed, i.e., the new buildings are structurally independent of their neighbours. New columns and beams are added next to the existing party walls to support the new structures. Conventional construction consisting of cast-in situ RC frames together with brick wall in-fill is used throughout the project.

Precast Findings

The pre-cast system consists of precast RC panel for the front and back walls, pre-cast party wall panels, precast floor with an in-situ topping. Other pre-castable items include staircase and planter boxes.

Issues Encountered

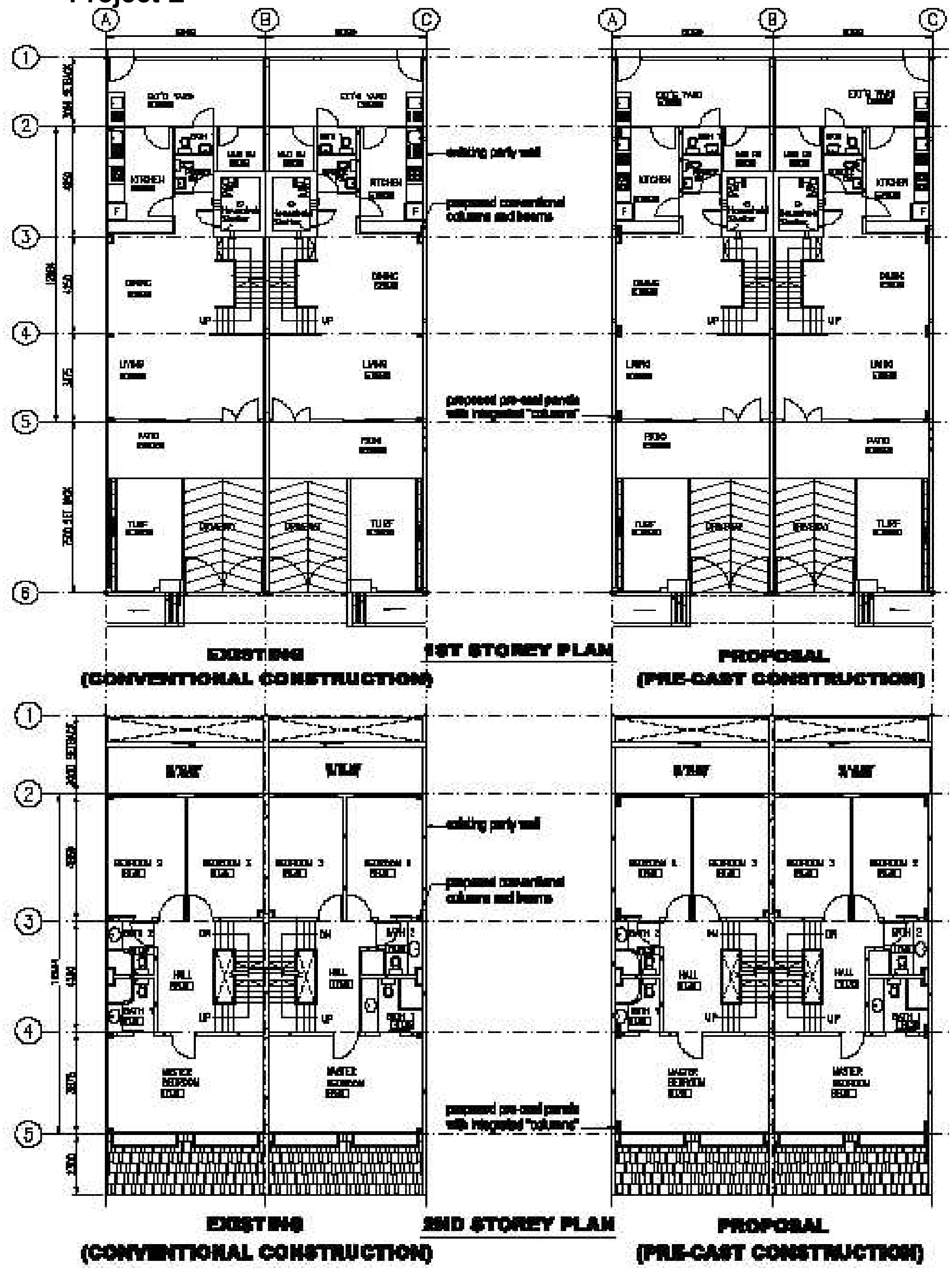
There is a concern with the ability to transport and hoist large pre-cast panels in an existing housing estate. A solution is to break up the front façade into two smaller panels at each floor for ease of transportation. Minor architectural adjustments are needed. Vertical groove lines are deemed acceptable and can be easily treated.

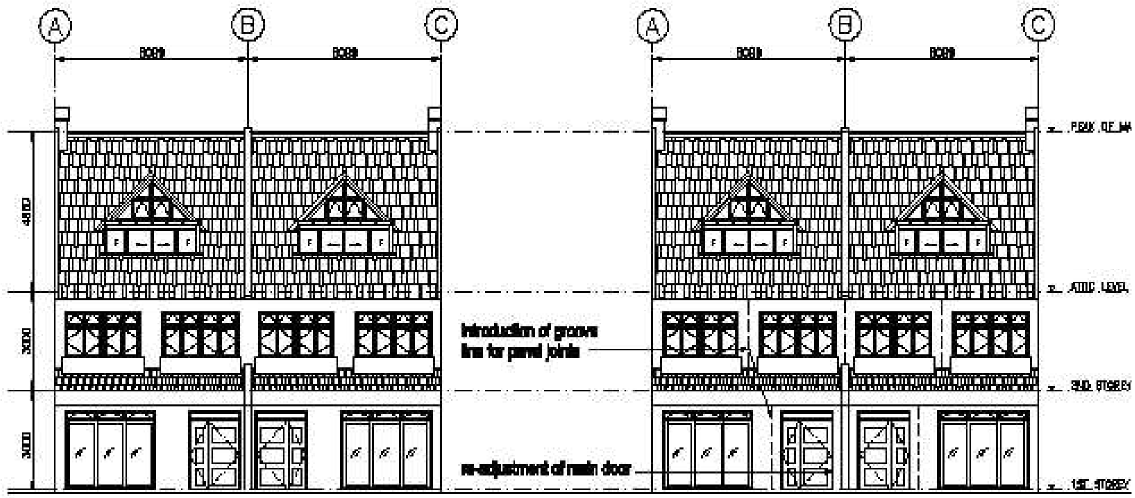
On plan, the new structural columns at party wall are replaced by precast panels with slightly larger footprints. Minor adjustments to toilet layout are needed to suit the structural elements.

Conclusion

This design of the building is such that it is quite easy to precast. Only very minor changes to original design is needed.

Project E

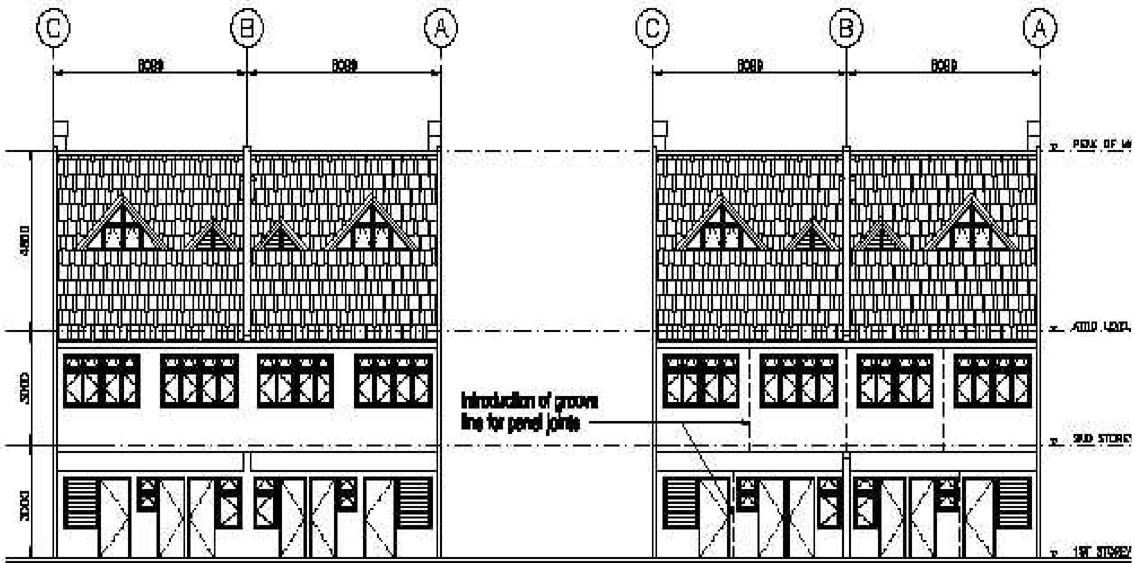




FRONT ELEVATION

EXISTING (CONVENTIONAL CONSTRUCTION)

PROPOSAL (PRE-CAST CONSTRUCTION)



REAR ELEVATION

EXISTING (CONVENTIONAL CONSTRUCTION)

PROPOSAL (PRE-CAST CONSTRUCTION)

12.6 PROJECT F - Semi-Detached Dwelling House

General Information

Type	**:**	In Fill Semi-Detached Dwelling House
Storey	**:**	2-Storey With Attic
Site Area	**:**	390.406m²
GFA	**:**	565.727m²

Background

The project is located within an existing housing estate. The building is a 2-storey semi-detached dwelling with an attic on an elongated site of approximately 31.2 metre depth and 8.6 metre wide. There is a total of 5-bedrooms (inclusive of a guest room at 1st storey). A household shelter is part of the building. Special architectural and design features such as a big foyer and a sculpture pool are added to the 1st storey.

Precast Findings

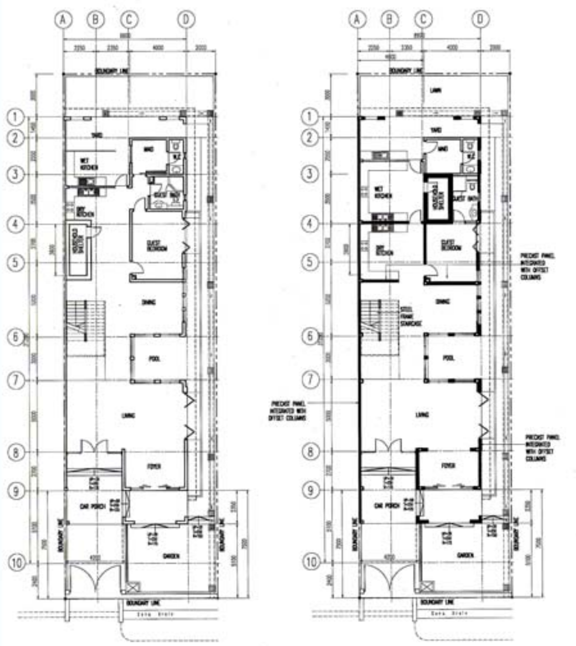
The precast system that is considered for this project is a combination of PC wall panel, precast slab and precast boundary wall. As for the architectural elevation feature, the adjoining wall have been re-designed to reflect the new features of the building as compare to the conventional types of construction.

Issues Encountered

There is no problem with transporting and lifting the large pre-cast panels in the existing site, as the panel walls have been broken up into smaller panels for ease of transportation, hoisting as well as installation. The wall panel could be treated with various finishes. The groove lines, which run vertically and horizontally can be acceptable and it is easily treated.

Conclusion

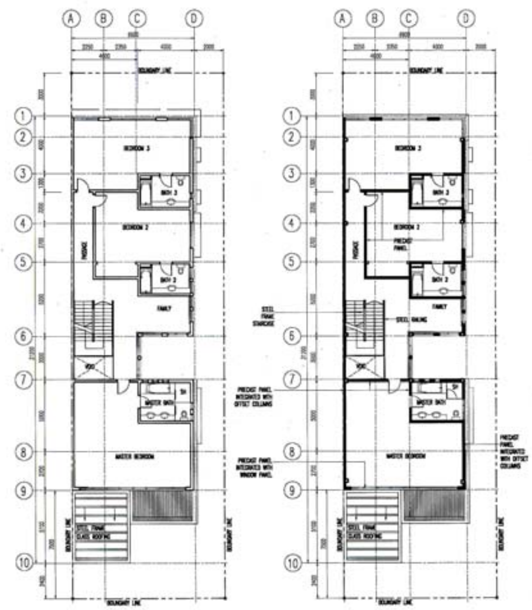
There is not much problem in implementing a pre-cast system for the building as only a minor change to the elevation of the building is expected.



EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

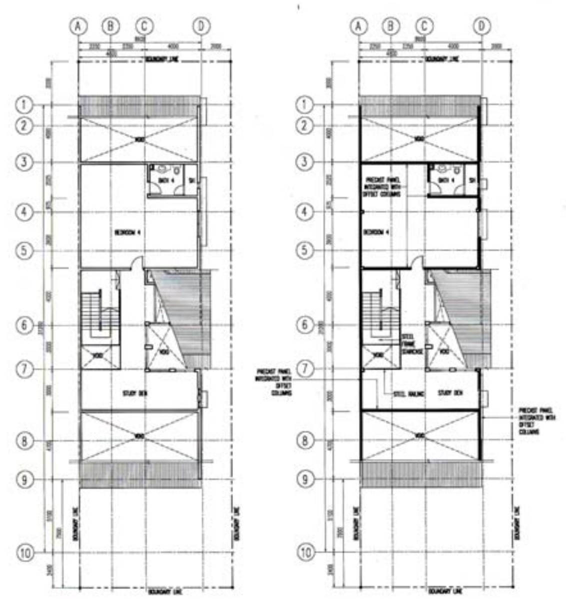
FIRST STOREY PLAN
SCALE 1 : 200



EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

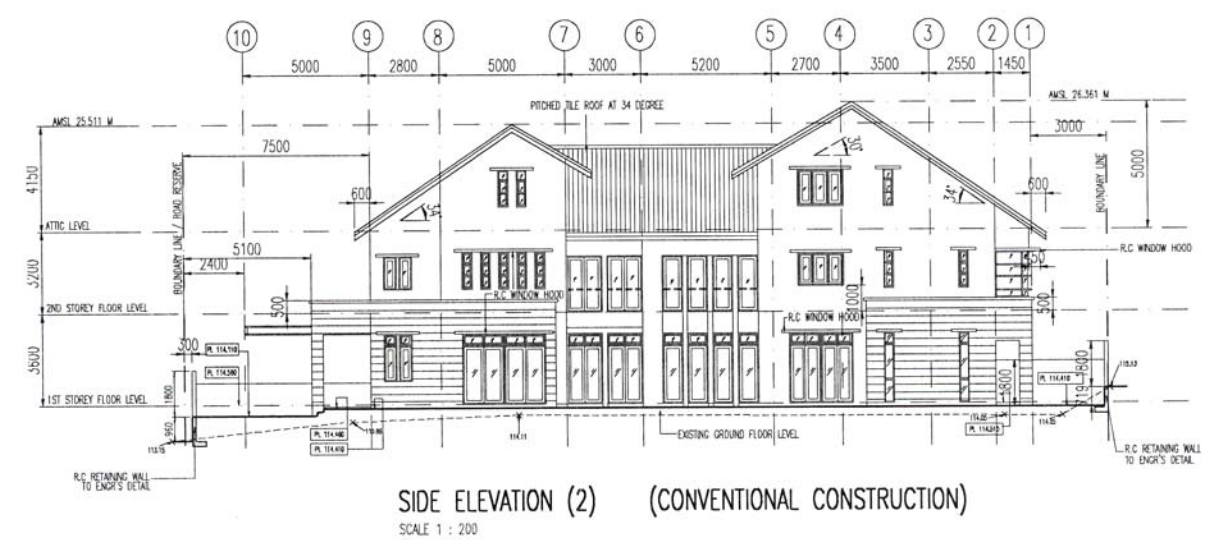
SECOND STOREY PLAN
SCALE 1 : 200



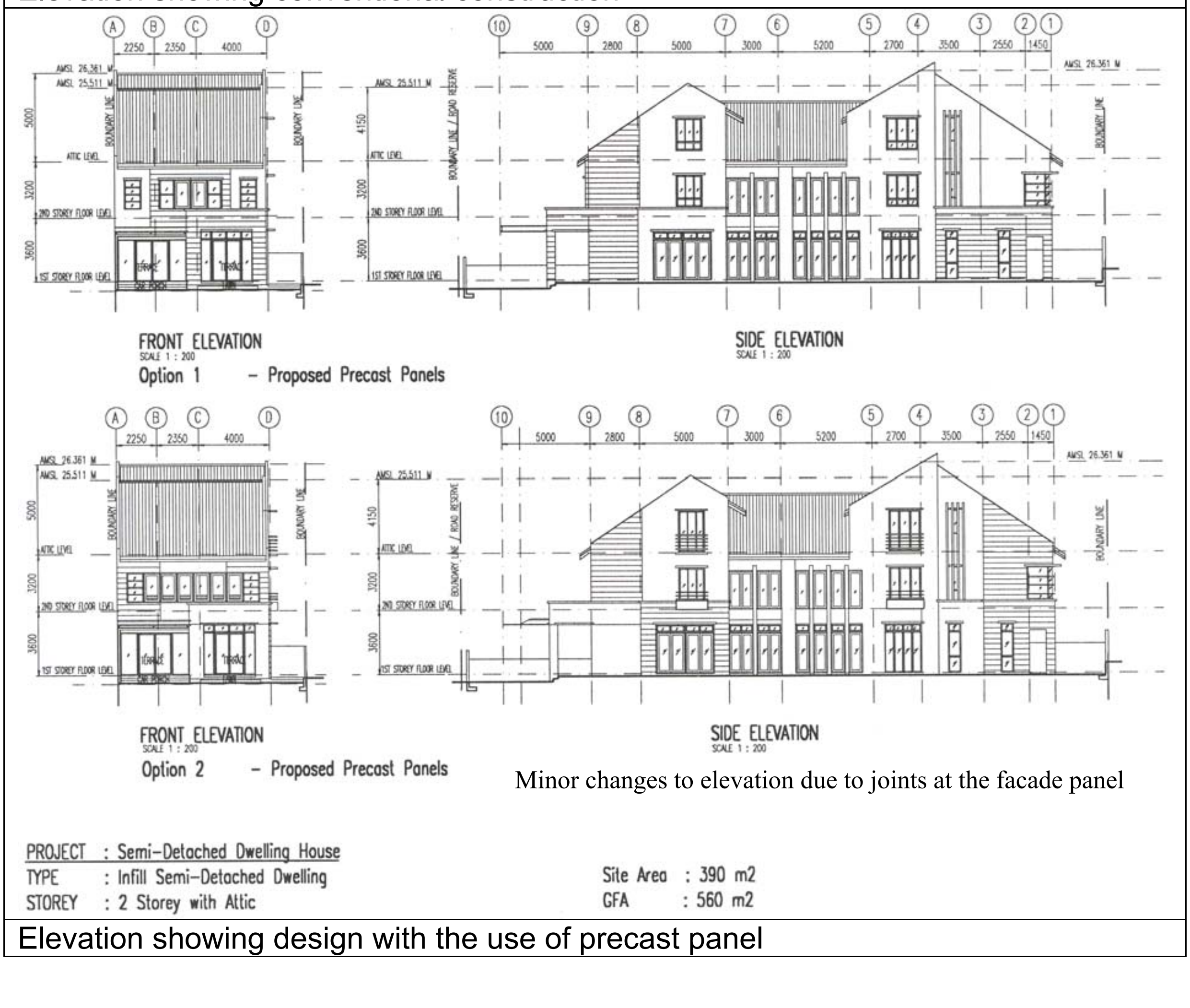
EXISTING
(CONVENTIONAL CONSTRUCTION)

PROPOSAL
(PRECAST CONSTRUCTION)

ATTIC PLAN
SCALE 1 : 200



Elevation showing conventional construction



Elevation showing design with the use of precast panel

Appendix

The following layouts were used for cost estimation in Chapter 2

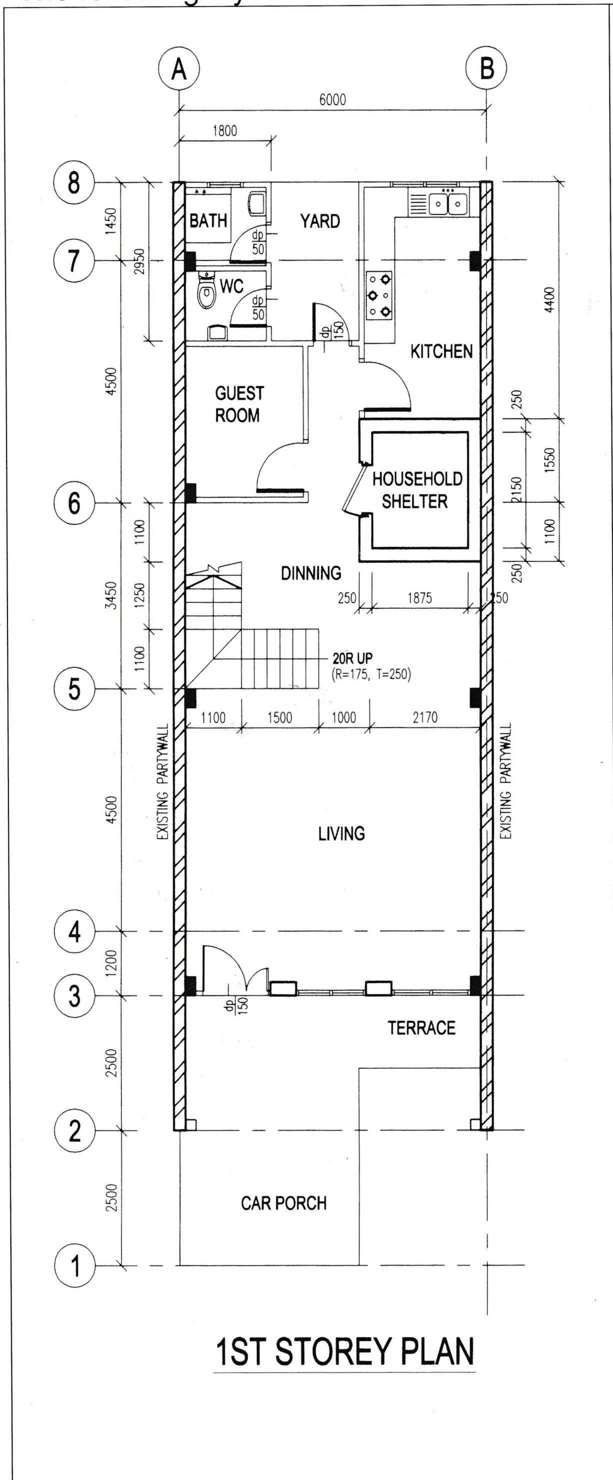


Figure 13-1 1st storey architectural plan

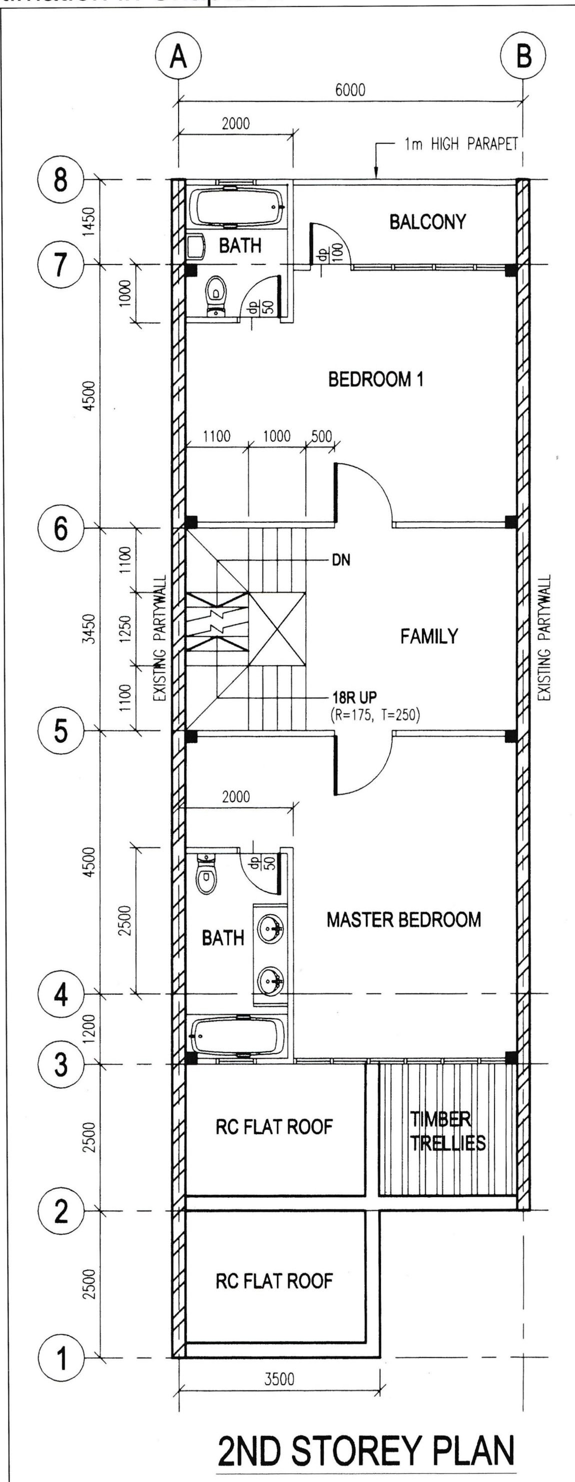


Figure 13-2 2nd storey architectural plan

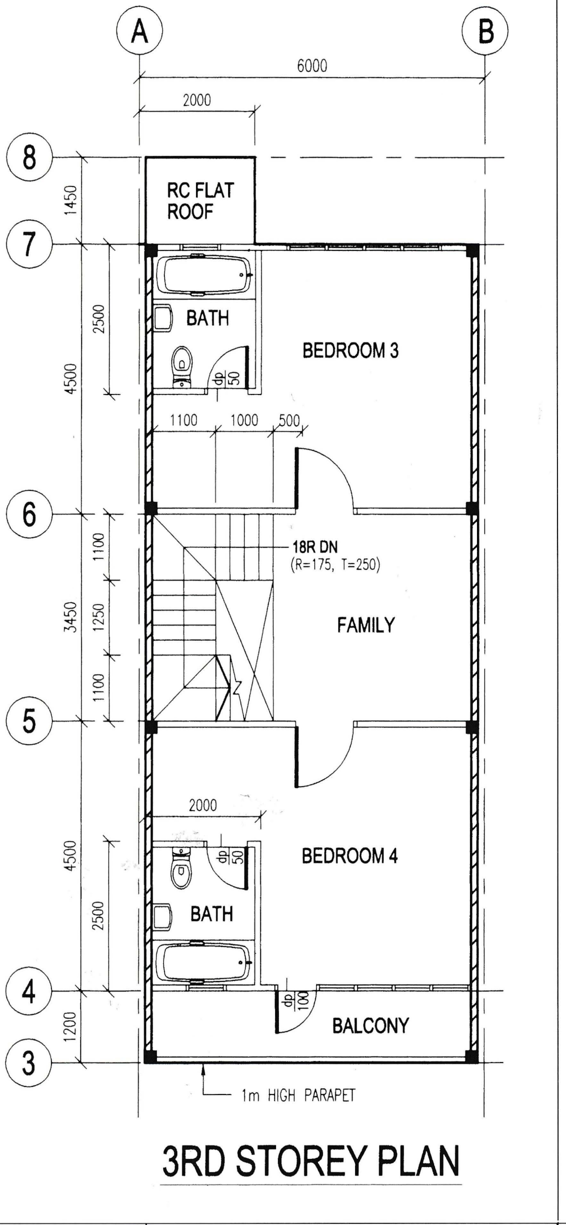


Figure 13-3 3rd storey architectural plan

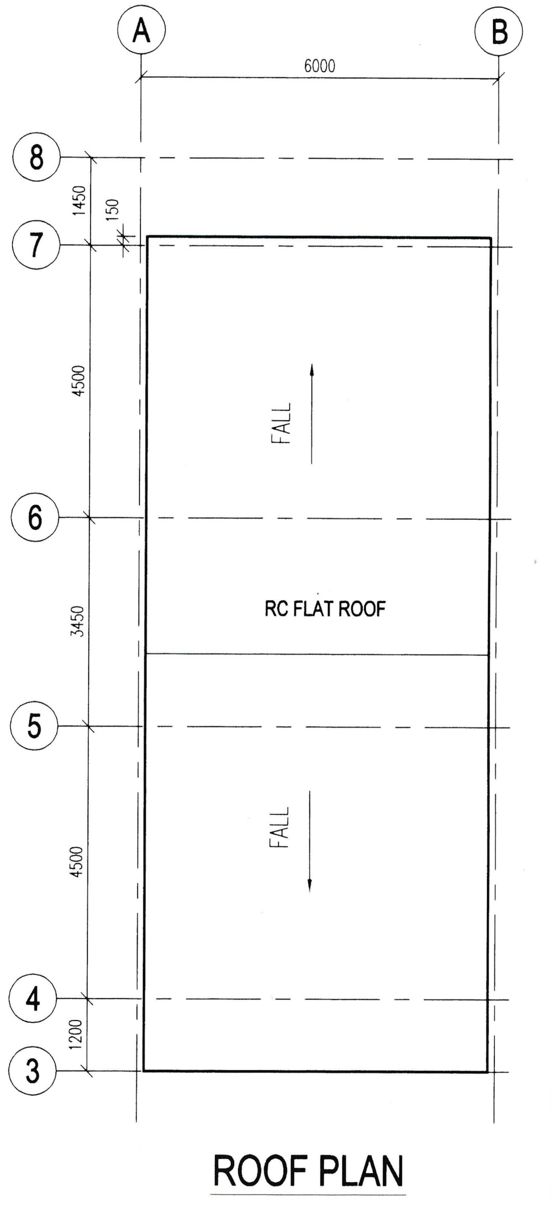


Figure 13-4 Roof plan

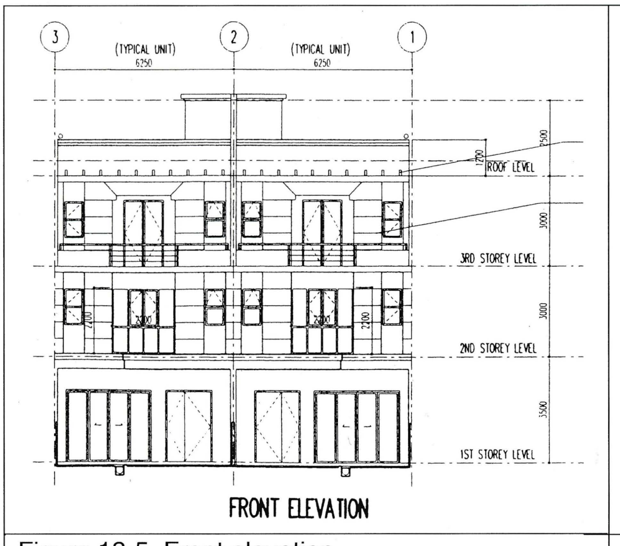


Figure 13-5 Front elevation

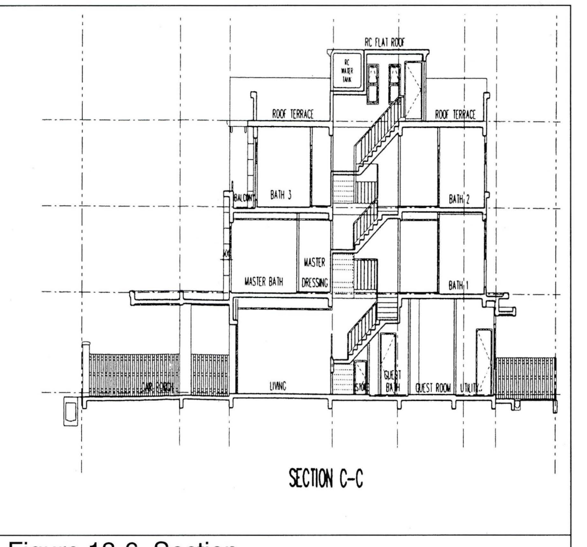
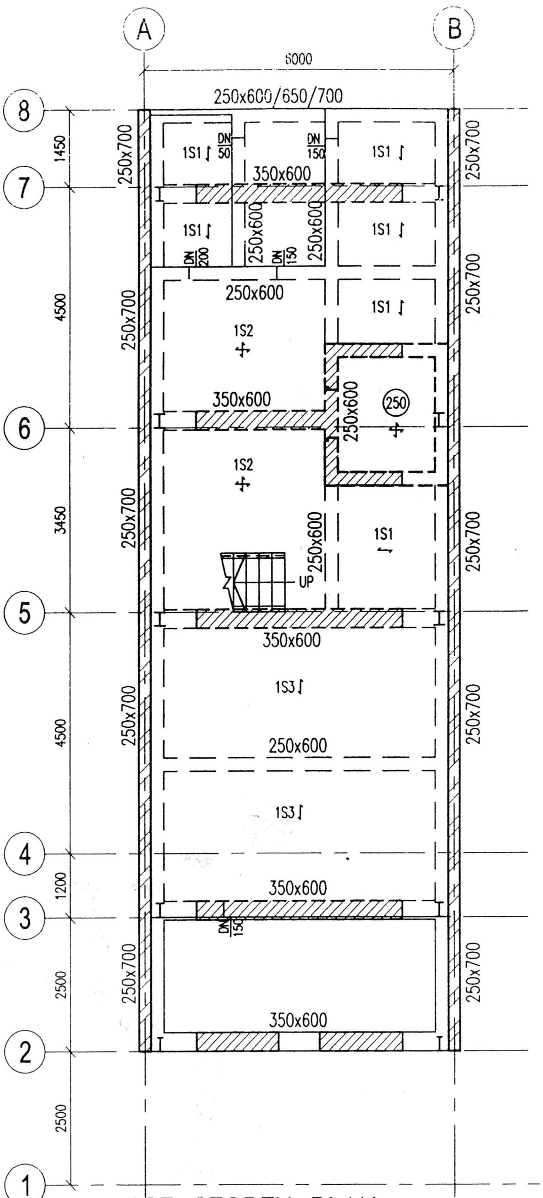


Figure 13-6 Section

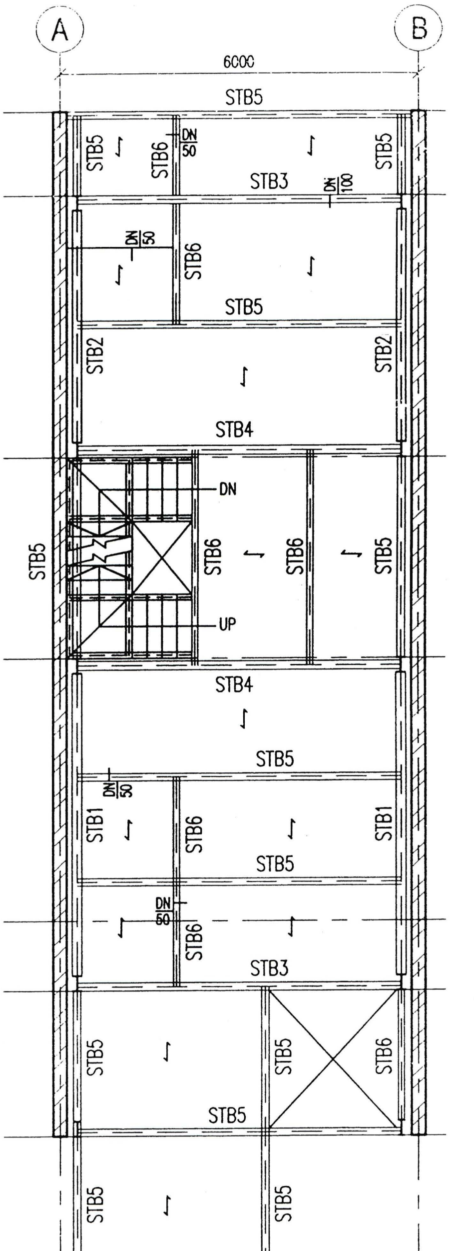


1ST STOREY PLAN

1. ALL SLABS TO BE 150mm THK. SUSPENDED RC SLAB.
2. ALL RC COLUMNS TO BE 250x250.
3. STAIRCASE STRINGER BEAM TO BE 203x102x19.35kg/m UB STEEL BEAM FROM 1ST TO 3RD STOREY
4. DESIGN LIVE LOAD, L.L – 1.5KN/m².
5.

GRID REF.	STANCHION SIZE
A/2 & B/2	254x102x22.32kg/m UB
A/3, B/3, A/7 & B/7	254x146x43.00kg/m UB
A/5, B/5, A/6 & B/6	254x203x58.04kg/m UB

Figure 13-7 1st storey plan - structural layout

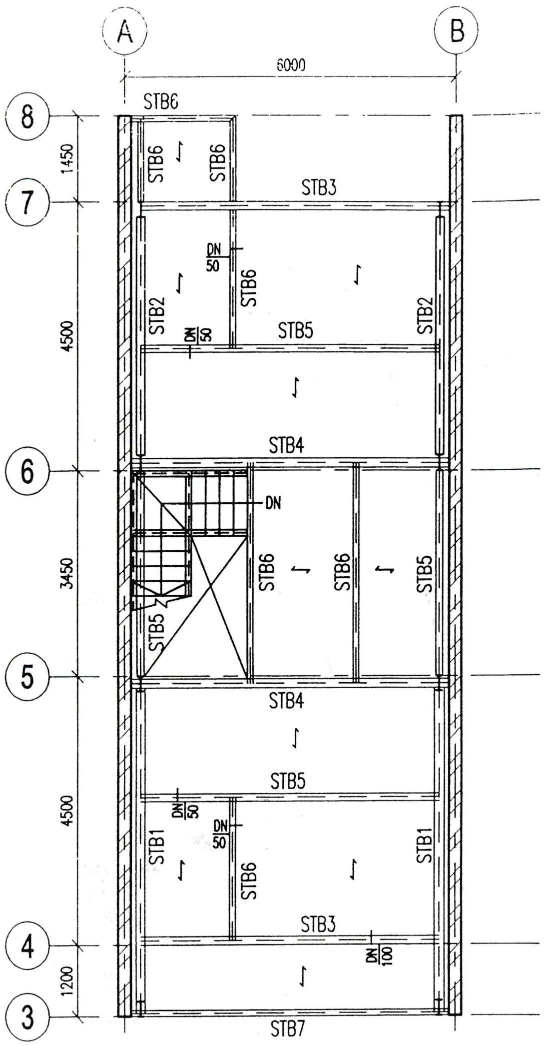


2ND STOREY PLAN

1. STB1 – 533x165x74.41kg/m UB STEEL BEAM
2. STB2 & STB4 – 457x152x52.09kg/m UB STEEL BEAM
3. STB3 – 406x140x46.13kg/m UB STEEL BEAM
4. STB5 – 356x127x39kg/m UB STEEL BEAM
5. STB6 – 254x102x17.86kg/m UB STEEL BEAM
7. DESIGN LIVE LOAD, L.L – 1.5KN/m².
8.

GRID REF.	STANCHION SIZE
A/3, B/3, A/7 & B/7	254x146x31.25kg/m UB
A/5, B/5, A/6 & B/6	254x146x43.00kg/m UB

Figure 13-8 2nd storey plan - structural steel system

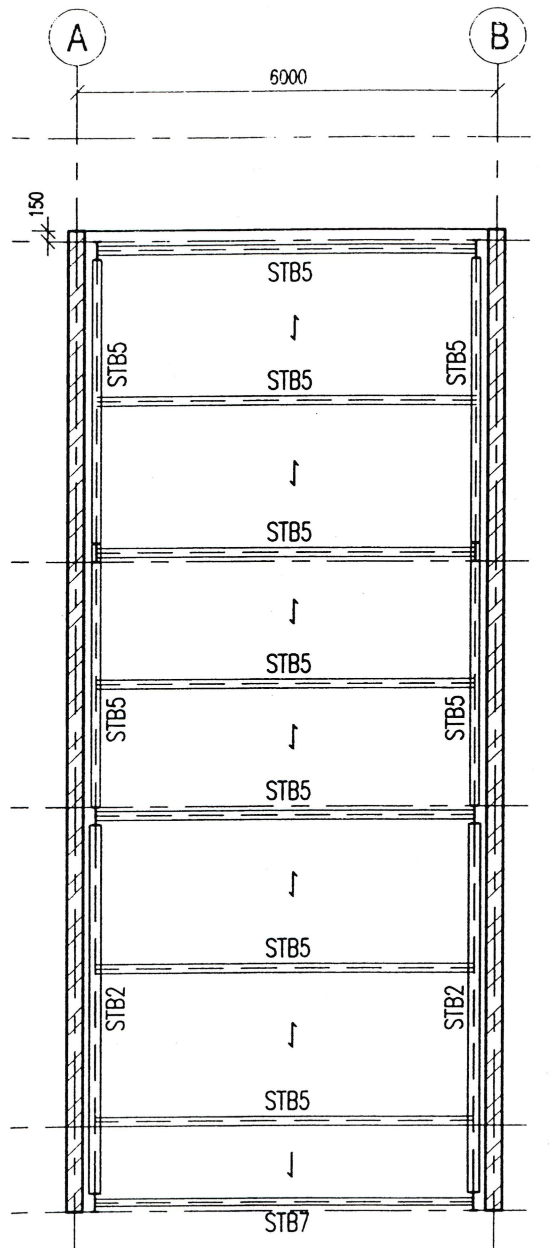


3RD STOREY PLAN

1. STB1 – 533x165x74.41kg/m UB STEEL BEAM
2. STB2 & STB4 – 457x152x52.09kg/m UB STEEL BEAM
3. STB3 – 406x140x46.13kg/m UB STEEL BEAM
4. STB5 – 356x127x39kg/m UB STEEL BEAM
5. STB6 – 254x102x17.86kg/m UB STEEL BEAM
7. DESIGN LIVE LOAD, L.L – 1.5KN/m^2.

8.

GRID REF.	STANCHION SIZE
A/3, B/3, A/7 & B/7	254x146x22.32kg/m UB
A/5, B/5, A/6 & B/6	254x146x31.25kg/m UB



ROOF PLAN

1. STB2 & STB4 – 457x152x52.09kg/m UB STEEL BEAM
2. STB3 – 406x140x46.13kg/m UB STEEL BEAM
3. STB5 – 356x127x39kg/m UB STEEL BEAM
4. STB7 – 305x102x25kg/m UB STEEL BEAM
5. DESIGN LIVE LOAD, L.L – 1.5KN/m^2.

Figure 13-9 3rd storey plan - structural steel system

Figure 13-10 Roof plan - structural steel system

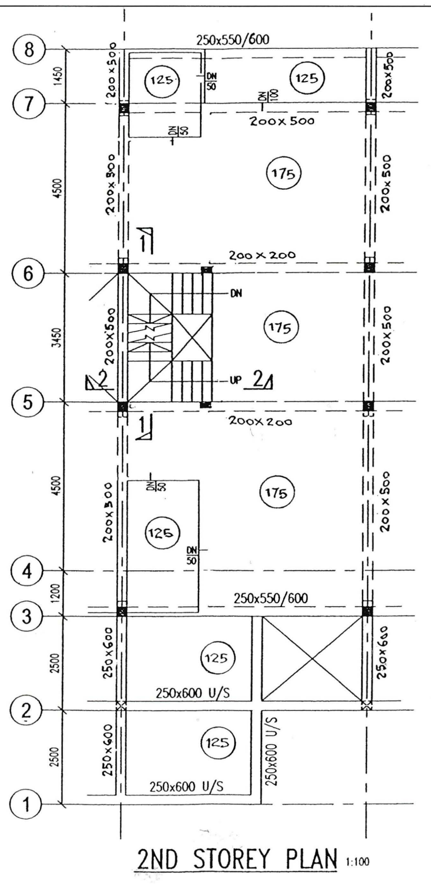


Figure 13-11 2nd storey plan – Flat plate with steel column

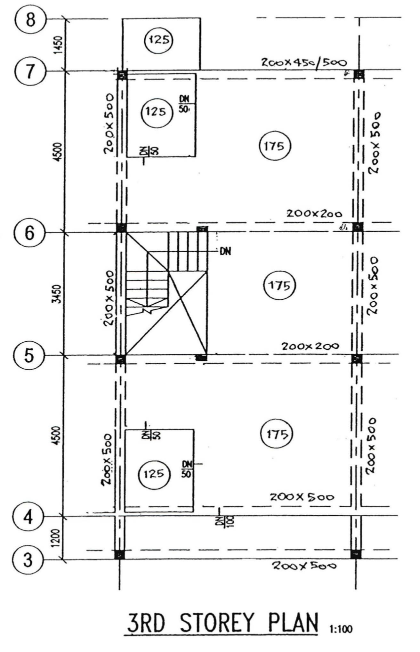


Figure 13-12 3rd storey plan – Flat plate with steel column

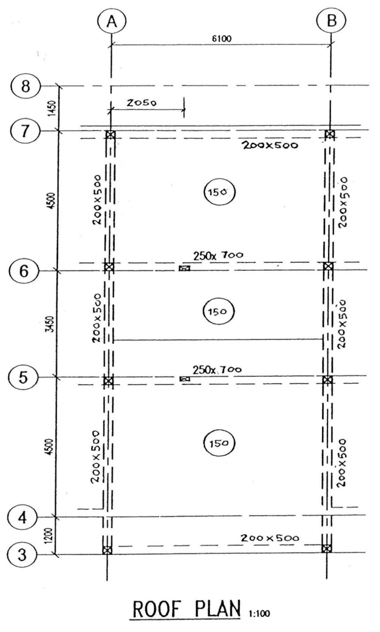


Figure 13-13 Roof storey plan – Flat plate with steel column