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PANEL CONNECTION DETAILS IN EXISTING NEW ZEALAND PRECAST CONCRETE BUILDINGS

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ABSTRACT

Following the 2010/2011 Canterbury earthquakes the seismic design of buildings with precast concrete panels has received significant attention. Although this form of construction generally performed adequately in Christchurch, there were a considerable number of precast concrete panel connection failures. This observation prompted a review of more than 4700 panel details from 108 buildings to establish representative details used in both existing and new multi-storey and low rise industrial precast concrete buildings in three major New Zealand cities of Auckland, Wellington and Christchurch. Details were collected from precast manufacturers and city councils and were categorised according to type. The detailing and quantity of each reviewed connection type in the sampled data is reported, and advantages and potential deficiencies of each connection type are discussed. The results of this survey provide a better understanding of the relative prevalence of common detailing used in precast concrete panels and guidance for the design of future experimental studies.

INTRODUCTION

Since the 1960s there has been significant use of precast concrete in New Zealand for a variety of structural components, including floor systems, walls, moment resistant and gravity load frames, as well as cladding panels [1]. Precast concrete construction in New Zealand grew in popularity in the 1980s due to several advantages, including increased speed of construction, optimised material consumption, reduction in onsite labour work, and improvements in quality control [1, 2]. In recent decades the availability of high-capacity transportation and lifting machinery has also made the installation of structural precast concrete panels more efficient, leading to even wider use of precast concrete elements [3]. The strength and stiffness of concrete walls against both vertical actions and horizontal wind and earthquake actions allow them to be used as a primary force resisting structural system in buildings.

Precast concrete walls display a mix of flexural, shear, rocking and sliding deformation mechanisms when they are subjected to lateral in-plane loads [4]. The characteristics of panel connections may influence the contribution of each mechanism, consequently altering the seismic behaviour of the shear wall. Therefore connection details have an important influence on the load-deformation behaviour of the wall and on overall seismic performance of precast concrete wall structures.

A study was undertaken to develop a large database of connections that have been used in New Zealand to fix precast concrete wall panels to foundations and to adjacent panels. The study sits alongside recent research that has focused on non-structural façade panels [5].

PERFORMANCE OF PRECAST CONCRETE BUILDINGS IN PAST EARTHQUAKES

Reinforced concrete precast panels have displayed varying levels of seismic performance in past earthquakes.

Many early precast concrete buildings were severely damaged during earthquakes occurring in the period from 1980 to 2000, such as the 1987 Whittier Narrows earthquake in California [6] and the 1994 Northridge earthquake in California [7], where 20 parking buildings using precast concrete construction were damaged. The poor performance of these precast concrete buildings was primarily attributed to deficient connection detailing.

The catastrophic events described above resulted in modifications to the design of precast concrete buildings in order to improve their seismic behaviour. Precast concrete structures in the four earthquakes of L'Aquila (2009) [8], Santiago (2010) [9], Canterbury (2010/2011) [10] and Emilia (2012) [11] performed with minimal damage incurred. Most of the damage that took place was confined to connection failures in low-rise industrial buildings or to non-structural cladding panels that were not designed to resist earthquake loads.

In general, precast concrete structures behaved adequately during the 2010/2011 Canterbury earthquakes [10]. Damage to precast concrete panels was generally confined to repairable small cracks but there were a considerable number of connection failures [10]. Several examples of panel failures that occurred in the 22 February 2011 Christchurch earthquake are shown in Figure 1. Although such panel failures were mostly confined to local damage and did not result in the collapse of any precast concrete buildings, the failure of large panels poses a major threat to life. In addition, economic losses to building owners and businesses resident within these buildings were significant due to repair cost as well as business down time [12].

NEW ZEALAND PRECAST CONCRETE PANEL SURVEY

A review was undertaken in order to develop a comprehensive understanding of the common typologies adopted in New Zealand for connections between precast concrete panels. This review was conducted by searching through drawings from

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precast panel manufacturers, in addition to the Auckland Council archives. A total of 108 projects in Auckland, Wellington and Christchurch that were completed between 2003 and 2014 were reviewed, involving more than 4700 precast panels. From the review it was established that structural panel detailing was usually dependent on the function of the precast concrete wall.

(a) Connection to bracing element

(b) Connection to steel frame

(c) Dislodged sealant between panels

(d) Steel plate connection between panels

Figure 1: Panel failures in the 2011 Christchurch earthquake [15].

Based on the reinforcement content and connection details, precast concrete walls can be divided into two groups: (1) walls in multi-storey buildings, and (2) walls in low-rise industrial buildings. The collected data represented 37 multi-storey buildings and 68 single storey warehouses. Examples of the use of precast concrete panels in a multi-storey building and in a warehouse are shown in Figure 3. The number of panels and the corresponding projects in each group are shown in Figure 2.

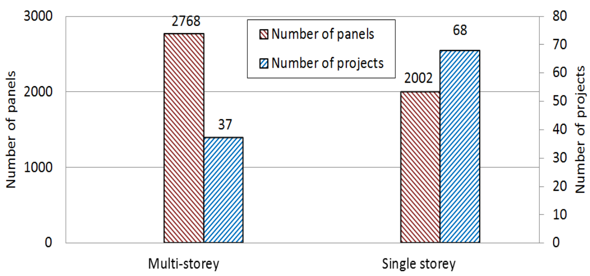


Figure 2: Quantity of panels and the corresponding projects for each type of project.

The majority of warehouse designs fall into being either nominally ductile structures or limited ductile structures [13]. Due to the low ceiling weight of warehouses the magnitude of the applied in-plane seismic forces to the panels is typically low. Consequently most of the factors relating to the reinforcement and thickness of the panels merely fulfil the minimum values required by the New Zealand Concrete Structures standard, NZS 3101:2006 [14]. However, this observation might not be true for the end walls in long warehouses, especially when the structure includes large doorway openings [13]. The structural thickness of these warehouse walls is commonly less than 200 mm, often reinforced with a single layer of bars with minimum allowed reinforcement content. Warehouse panels typically lack horizontal connections between panels and are often connected to the foundation with perpendicular dowels. Welded steel plate connections with limited strength are commonly used to connect adjacent precast concrete panels, or vertical gaps between panels are filled either by grout or a soft silicon sealant.

(a) Multi-storey building

(b) Warehouse

Figure 3: Examples of precast concrete panels in New Zealand.

Precast concrete walls in multi-storey buildings are often designed to resist larger loads than for the panels used in warehouses, and consequently have larger reinforcement content. Depending on the structural properties of a multi-storey building, wall thicknesses may vary from 150 mm up to 400 mm. The heights of panels are typically the same as the storey height, and horizontal connections are usually used at each storey level to join panels together.

Most existing precast concrete panels have a thickness of less than 200 mm, and it was found that 77% of precast panels have a thickness of between 150 mm and 200 mm. The most commonly used panel thickness (44%) is 150 mm with single layer reinforcement. In these panels both vertical and horizontal reinforcement usually fulfil only the minimum reinforcement content requirement of the sections specified in the New Zealand Concrete Structures standard [14]. Twenty five per cent of the surveyed walls had a thickness of 200 mm.

Utilising a single layer of bars in the centre of panels is the most common approach to reinforcing precast panels, as a single layer of reinforcement positioned at the mid-depth of the section often satisfies minimum reinforcement requirements [15]. Correspondingly, 66% of precast concrete panels in the sampled data were reinforced with either a single layer of bars or with pre-fabricated mesh reinforcement, as shown in Figure 4. In multi-storey buildings the number of panels that had a double layer of reinforcement was almost the same as the number of panels having a single layer of reinforcement.

In addition to panel details, the detailing of connections between precast concrete panels and other structural elements of the buildings was reviewed, with the three categories of assessed connections being: (1) wall-to-foundation connections, (2) horizontal connections between panels, and (3) vertical connections between panels. Several commonly used connection details were identified within each category and the characteristics of these connection types are described below.

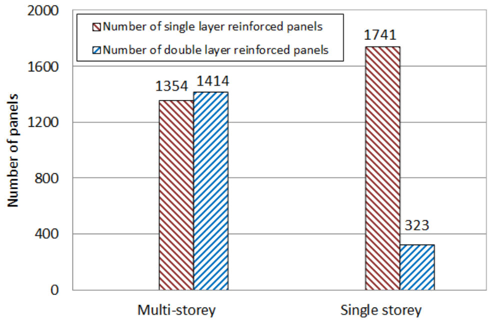


Figure 4: Quantity of single and double layer reinforced panels.

WALL-TO-FOUNDATION CONNECTIONS

Different detailing is used to connect precast concrete walls to their foundations based on the type of structure and the magnitudes of the loads applied to the connection. These connection types are generally based on one or a combination of the following three categories: (1) dowel connections, (2) grouted connections, and (3) post-tensioned connections. The quantity of each type of wall-to-foundation connection and the corresponding number of projects are shown in Figure 5. By far the most commonly used wall-to-foundation connection detail in New Zealand is based on the use of dowels. This type of connection accounts for 66% of such connections.

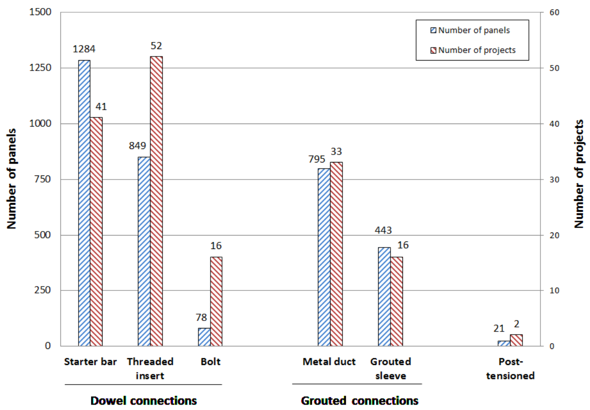


Figure 5: Quantity of each type of reviewed wall-to-foundation connection.

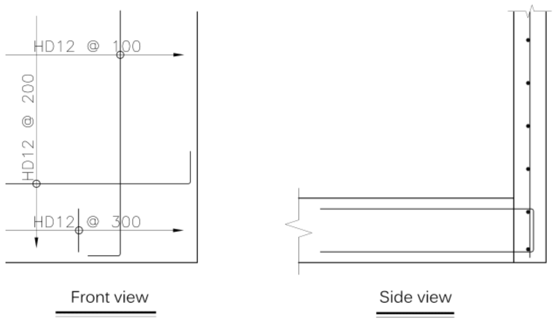
Dowel Connections

In dowel connections, bars anchored inside the panel are subsequently cast into the foundation in order to provide the structural connection. Dowel bars are anchored into the foundation using different methods, such as starter bars with 90 degree standard hooks, threaded inserts, or bolts. The numbers of each type of dowel connection between wall and foundation are compared in Figure 5, displaying that starter bars and threaded insert connections are the most commonly used method to join panels to the foundation.

Dowel connections are simpler than other types of wall-to-foundation connections and there is no requirement for extra equipment for grouting or post-tensioning. The main drawback of using dowel connections is the shallow embedment of the connection bars inside the wall, which may lead to connection break out. These characteristics of dowel connections limit their use to warehouses and low-rise buildings which are usually subjected to lower levels of in-plane seismic loads.

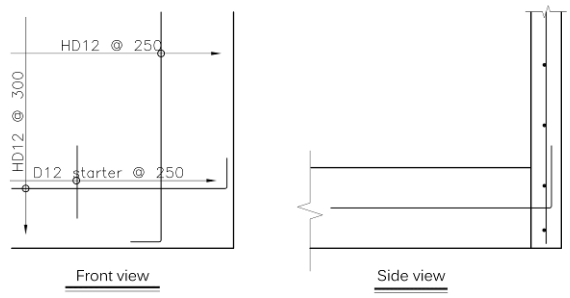
Connection with Starter Bars

In connections that use starter bars the connection bars are partially positioned within the panel during the manufacturing process, with the non-embedded portion of the bar being later placed inside the foundation at the construction site. Three connector styles have been used in connections with starter bars, being (1) hairpins, (2) standard hook bars, or (3) stirrups, or a combination of these styles. An example of each type of starter bar connection is shown in Figure 6. The appropriate type of starter bar to be utilised depends on the dimensions of the foundation and the level of reinforcement congestion in the connection zone. In shallow foundations hairpin starter bar connections (Figure 6a) are preferred to standard 90° hook bars (Figure 6b) in order to minimize the number of bar cuts. Stirrup connectors are utilised in strip foundations with limited width, as shown in Figure 6c.



*foundation reinforcement is not shown

a) Hairpin starter



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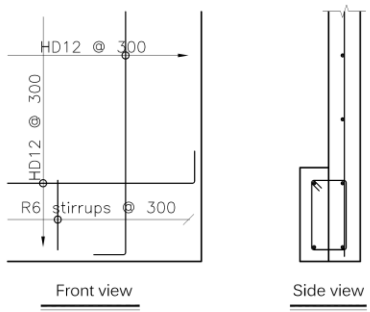
b) Standard hook starter



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c) Stirrup starter

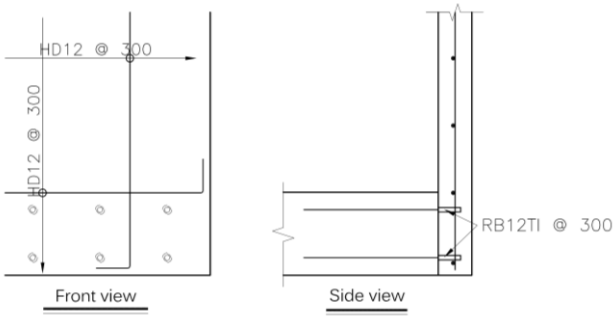
Figure 6: Examples of typical wall-to-foundation starter bar connections.

In order to facilitate transportation of the panel to site, connection bars are folded up to the panel face after the panel has been cast, and they are straightened to their original form on-site. Appropriate measures should be taken in order to prevent damage to the connection bars during both bending and straightening as well as during storage and transportation of the panels [16]. These measures potentially increase transportation costs. Relative simplicity, stronger anchorage, and lower costs make this type of connection the most commonly used method of connecting walls to foundations. According to the conducted review, starter bars are used in approximately 58% of dowelled wall-to-foundation connections.

Connection by Threaded Insert

The second method employing dowels in wall-to-foundation connections is to use threaded inserts. These inserts are placed inside precast panels at the factory and the foundation reinforcement is later connected to the insert after installation of the walls at the construction site. A sample detail of a wall-to-foundation connection using threaded inserts is shown in Figure 7a.

Shallow embedded inserts are a source of concern in terms of robustness of the connection and the potential to form brittle cone-shaped break-outs. There are a number of recommendations for solving this problem: placing spacers to provide a deeper connection to improve robustness and break-out strength of the connection, and/or using more vertical reinforcement in the connection zone to enhance the connection strength. In addition, if there is sufficient space in the connection zone, stirrups can be used inside walls to improve the connection robustness (Figure 7b). Although these solutions can prevent brittle failure of the connection, they are not in common use and are often difficult to achieve in thin precast panels of 150 mm or less. In the reviewed detailing, threaded inserts were used in 38% of dowel connections.



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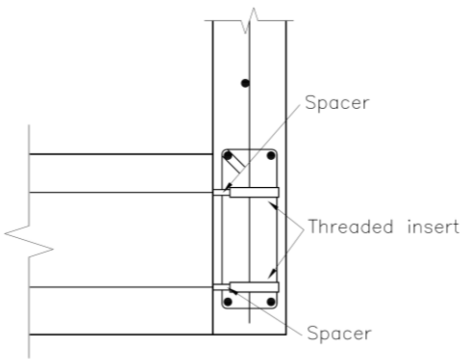
a) Conventional threaded insert connection



* foundation reinforcement is not shown

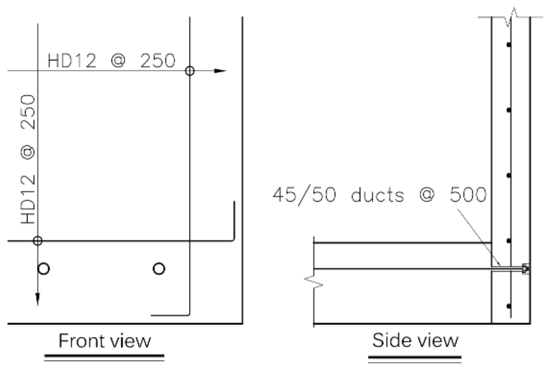
b) Detailing incorporating a stirrup

Figure 7: Examples of typical threaded insert wall-to-foundation connection details.

Panels with threaded connections have the advantage of easier storage and transportation and consequently decreased labour cost, but the cost of threaded inserts increases the overall wall manufacturing price. In smaller projects threaded insert connections are used more often than starter bar connections.

Bolted Connection

Bolted connections are the least commonly used type of dowel connection and are usually utilised in cladding panels. In bolted connections a series of perforations are prepared in the bottom of the wall during construction. After installing the walls at the site, foundation reinforcement is passed through these perforations, and the bottom of the wall is embedded in the foundation. In the case of boundary walls, after passing foundation reinforcement through the holes, the bars are bolted from the outer side of the wall, as shown in Figure 8. These connections generally have less strength than the aforementioned connections using starter bars or threaded inserts. In the reviewed panels, bolted connections were used in less than four per cent of panels with dowelled wall-to-foundation connections.



* foundation reinforcement is not shown

Figure 8: An example of a typical bolted wall-to-foundation connection detail.

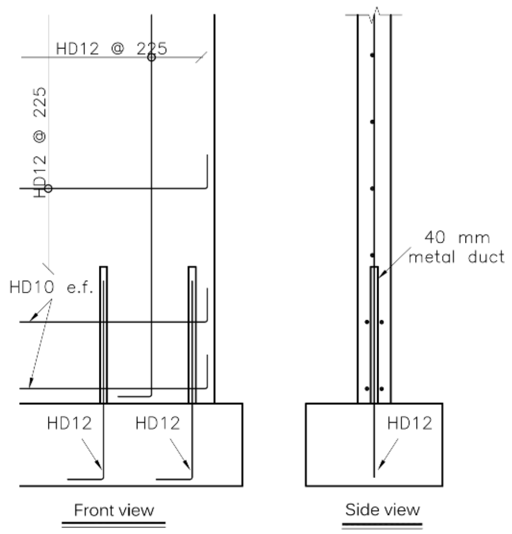
Grouted Connections

In the sampled data, grouted connections were used in 32 percent of wall-to-foundation connections, which were mostly used in multi-storey buildings. The vertical load path in grouted connections decreases the possibility of brittle connection failure, thus for seismic design these connections are more appropriate than dowel connections. Two types of connections, referred to as 'metal duct' and 'grouted sleeve' connections, have been in use in New Zealand.

Metal Duct Connection

Metal ducts are usually made of corrugated alloy to improve bonding between the duct and concrete. Metal ducts are placed inside the walls during casting and then connection bars from the foundation are placed inside the ducts during site installation, with the ducts then filled with non-shrink grout. An example of a metal duct connection is shown in Figure 9. The horizontal joint between panels and the foundation is also grouted to ensure even contact and to accommodate tolerances.

Metal duct connections are usually designed to be weaker than the panel to which they are connected, and in 87% of the surveyed walls containing this connection type the reinforcement content of the connection was lower than the reinforcement content of the vertical panel. This characteristic of the connection design occurs due to the panel reinforcement being governed by minimum reinforcement limits and the connection requiring less reinforcement than the panel in order to satisfy strength requirements, rather than being governed by an imposed minimum reinforcement limit. This characteristic, with the connection being the weakest element, may cause brittle failure of connections. Metal duct connections were observed in both single layer and double layer reinforced panels, as shown in Figure 10.



* foundation reinforcement is not shown

Figure 9: An example of a conventional metal duct wall-to-foundation connection.

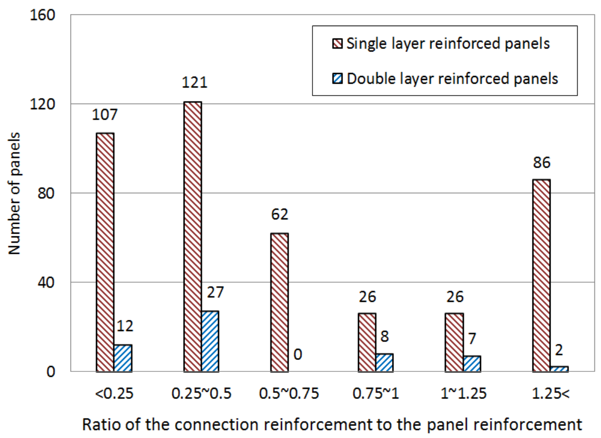


Figure 10: Ratio of reinforcement area of the connection bars to vertical panel reinforcement.

Where the spacing of vertical bars was equal to the spacing of metal ducts, bars were usually placed beside the ducts to form non-contact lap splices, as shown in Figure 11. However, despite splices with minimal separation distance between two bars having better load transfer, this detail was uncommon in the reviewed panels. Instead, metal ducts are usually placed at larger spacing than the spacing of the panel vertical reinforcing bars, resulting in the reinforcing bars not being positioned directly against the outside of the ducts. In addition, connection bars usually do not have the same diameter as the panel vertical bars, which leads to further concerns about the effectiveness of the splice as inadequate performance of the splice may result in connection failure at loads below the design strength. The spacing of panel vertical bars and connection bars are compared in Figure 12. Another concern related to the use of metal duct connections is loss of panel stiffness and strength due to the ducts causing a reduction of effective wall cross sectional area. This attribute weakens both the connecting bars and the adjacent horizontal reinforcement (see Figure 11) due to spalling of concrete around the ducts when the wall is subjected to large cyclic loads. This concern is directed particularly toward single layer reinforced panels where stirrups are not provided.

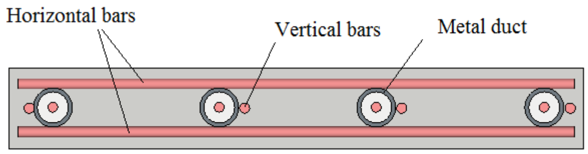


Figure 11: Cross section detail of a metal duct connection.

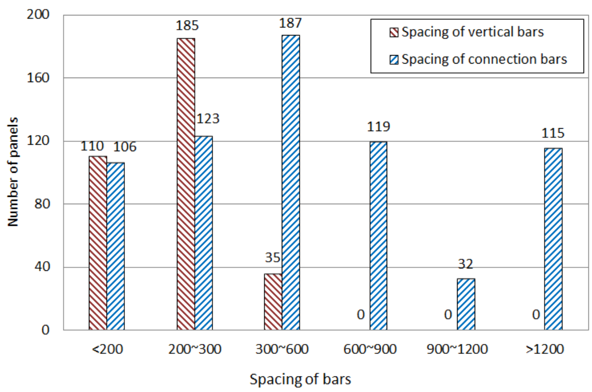
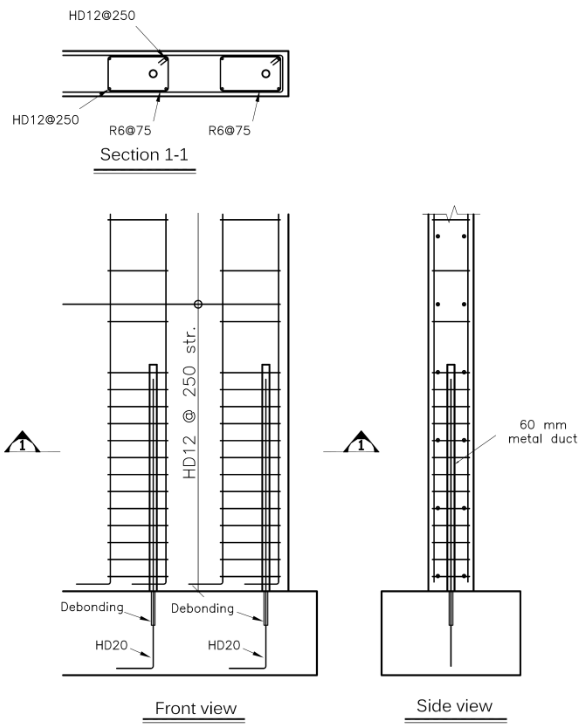


Figure 12: Spacing of panel vertical bars and connection bars (mm).

To alleviate the concerns mentioned above, from 2011 onwards the Structural Engineering Society of New Zealand (SESOC) has recommended the use of additional longitudinal bars and stirrups around the duct in order to provide concrete confinement and an efficient non-contact splice [17]. Confinement increases the strength and ductility of the concrete and consequently prevents brittle connection failure. Another recommendation by SESOC is debonding of the connection reinforcement from the foundation concrete to prevent stress concentration in bars, as the debonded connection bars can undergo larger elongation before rupturing. Steel or plastic pipes are used to facilitate this debonding. In several cases identified in the survey, debonding tape was wrapped around the connecting bars to isolate the foundation concrete from the connecting bars. An example of the recommended detailing is shown in Figure 13. Whilst this debonded detail may improve the behaviour of the connection, it has a number of problems in practice. Due to the limited space around the duct it is difficult to place stirrups in walls of low thickness, which are commonly used in New Zealand. Furthermore, the stirrups increase the amount of reinforcement positioned around the ducts, which might result in difficulties when casting and compacting the concrete around the ducts. In the sampled data, metal ducts were used in 65 percent of grouted wall-to-foundation connections.

Grouted Sleeve Connection

Another type of grouted connection is based on using grouted sleeve inserts. As shown in Figure 14, these inserts are tube shaped and made of high-strength spheroidal graphite iron with two ports for grout injection and expulsion and a threaded portion positioned above in order to connect the extension bar. Grouted sleeves are placed inside the precast concrete panel and bars that project from the foundation are positioned inside the sleeves and then fixed in place by grout injection into the sleeves. The bars connected to the top of the grouted sleeve are extended by at least the bar development length. In most single layer panels the attached bars are usually extended to the top of the panel and function as panel vertical reinforcement, as shown in Figure 15. The grouted sleeve connections in double layer reinforced panels are detailed using either double layer grouted sleeve inserts or a single layer of inserts separated from the vertical reinforcement, as shown in Figure 16. Because two layers of grouted sleeve inserts cannot be accommodated in low thickness panels, single layer grouted sleeve inserts are more commonly used in New Zealand. In these panels the bars connected to the grouted sleeve have a length equal to the bar development length. The number of panels with continuous and non-continuous grouted sleeve connections, and the corresponding number of projects in which these details were used, are illustrated in Figure 17. The popularity of continuous and non-continuous connections in the reviewed panels was almost the same.



* foundation reinforcement is not shown

Figure 13: An example of SESOC recommended detailing for metal duct connections.

Figure 14: Grouted sleeve insert.

In most single layer reinforced panels with grouted sleeve connections, the extension of the grouted sleeve end bars forms the vertical reinforcement of the panel and hence the reinforcement content of the connection is usually the same as the panel vertical reinforcement. However in some cases additional bars are used in panels, which results in the reinforcement content of the panel being greater than the reinforcement content of the connection. In double layer reinforced panels the panel reinforcement is usually stronger than the connection reinforcement. In approximately 46% of the surveyed grouted sleeve wall-to-foundation connections the reinforcement content of the connection was lower than the reinforcement content of the panel. As shown in Figure 18, this type of design is more commonly used in double layer reinforced panels than in single layer reinforced panels.

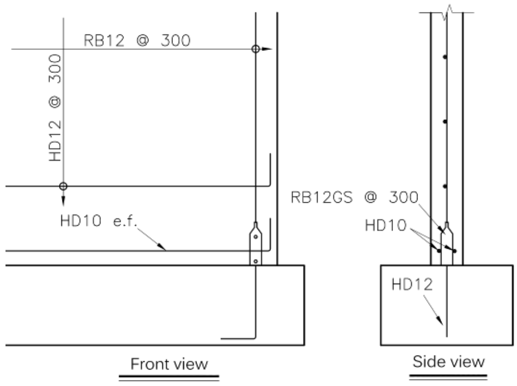


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Figure 15: An example of a single layer reinforced panel with a grouted sleeve connection.

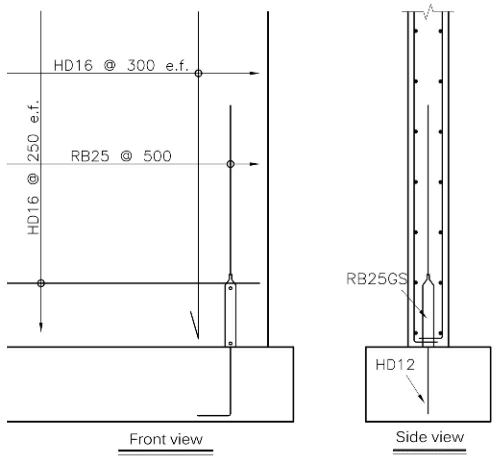


Figure 16: An example of a double layer reinforced panel with a grouted sleeve connection.

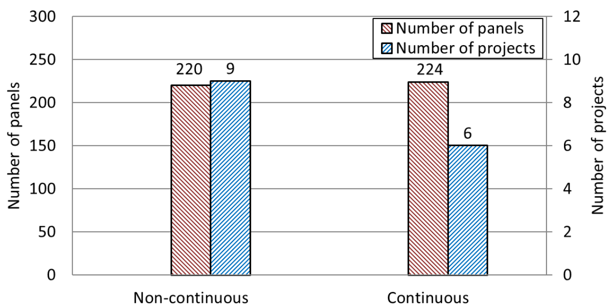


Figure 17: Quantity of each type of reviewed grouted sleeve wall-to-foundation connection.

In Figure 19 the spacing of vertical reinforcement and the spacing of connection bars are compared for grouted sleeve wall-to-foundation connections. The figure indicates that the bar spacing in grouted sleeve wall-to-foundation connections is often larger than the spacing of vertical reinforcement in panels when the bars are not continuous. This characteristic generates similar issues to those previously discussed for metal duct connections.

Grouted sleeve connections are used less frequently than metal duct connections and were encountered in only 35% of the surveyed grouted wall-to-foundation connections. The quantity of each type of grouted connection and the corresponding number of projects in the survey are shown in Figure 20. Metal duct connections are used more commonly in single storey buildings than are grouted sleeve connections. In contrast, in multi-storey buildings the number of grouted sleeve connections and metal duct connections is almost same.

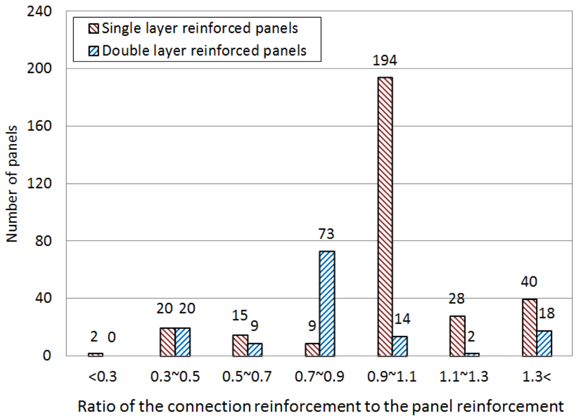


Figure 18: Ratio of reinforcement content at the connection, to vertical panel reinforcement content, when using grouted sleeve inserts.

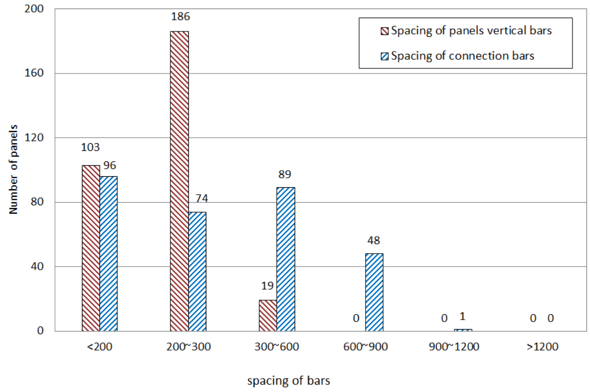


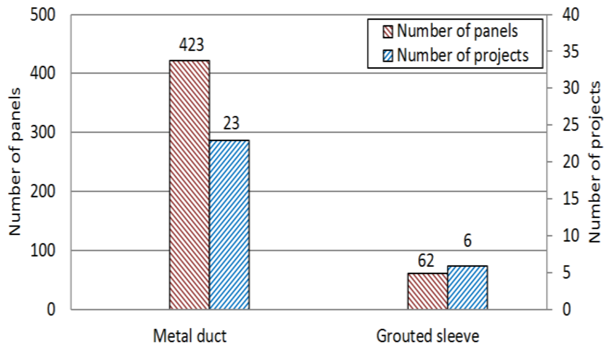
Figure 19: Spacing of panel vertical bars and spacing of connection bars in grouted connections (mm).

Figure 21 displays the quantity of each type of grouted connection in the survey for double layer and single layer panels. Metal duct connections are more commonly used in single layer reinforced panels but in double layer reinforced panels, metal duct and grouted sleeve connections are utilised to almost the same extent.

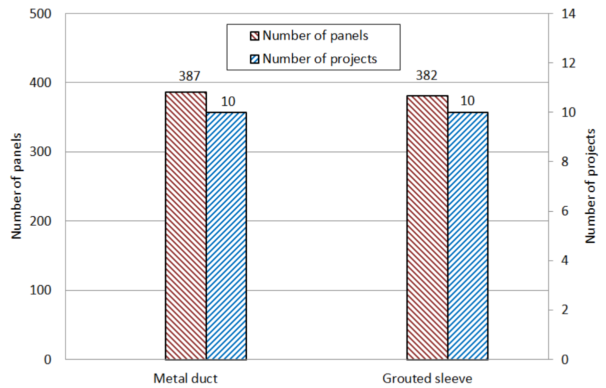
Unbonded Post-Tensioned Connections

Post-tensioned connections are prestressed using high-strength cables after installation of the walls on the foundation. The cables are usually extended from the bottom of the foundation to the ceiling, joining together several precast panels and the foundation. An example of this type of connection is shown in Figure 22.

Post-tensioned tendons allow the wall to rock and result in enhancement in the lateral deflection capacity of the wall [18, 19]. Post-tensioned walls are usually designed to be self-centering and experience little damage during earthquakes. The main drawback of post-tensioned connections is low energy dissipation of the system. This drawback can be solved by combining other types of connections with post-tensioned connections, which are then referred to as hybrid connections. Although post–tensioned connections have superior seismic behaviour relative to other types of connections, implementation into buildings has been limited because post-tensioning equipment is required and many designers are not familiar with the design procedure. Less than one per cent of precast concrete walls in the survey were connected to their foundations by post-tensioned connections. As this is a comparatively new type of structural system the use of post-tensioned connections may increase in the future.



a) Single storey buildings



b) Multi-storey buildings

Figure 20: Quantity of each type of reviewed grouted wall-to-foundation connection.

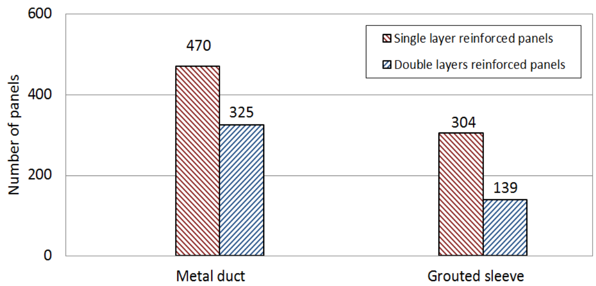
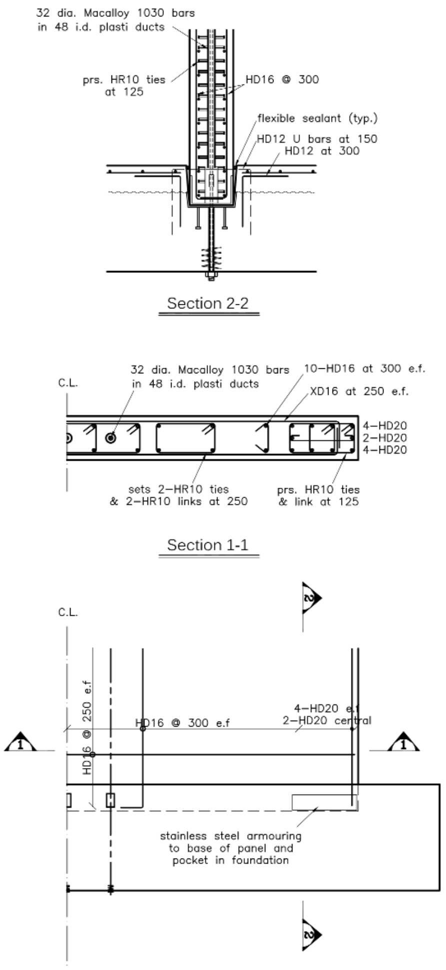


Figure 21: Quantity of each type of reviewed grouted wall-to-foundation connection in single layer and double layer reinforced walls.

WALL-TO-FOUNDATION CONNECTIONS

In New Zealand there are three different types of details commonly used for horizontal connections between precast concrete panels: (1) metal ducts (Figure 23), (2) grouted sleeves (Figure 24), and (3) welded steel plate connections (Figure 25). Metal duct and grouted sleeve connections are more commonly used for joining panels than are welded steel plate connections. Due to the lower resistance of this type of connection, the use of welded steel plate connections is limited to either panels with low stress levels or non-structural façade panels.



* foundation reinforcement is not shown

Figure 22: An example of a reviewed post-tensioned connection.

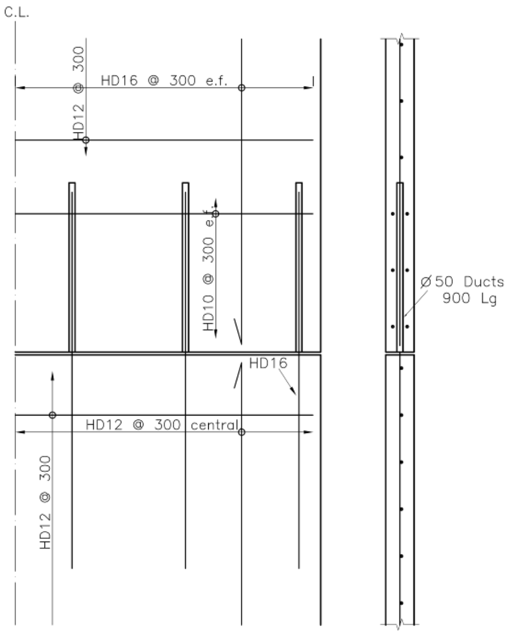


Figure 23: An example of a metal duct horizontal connection between precast panels.

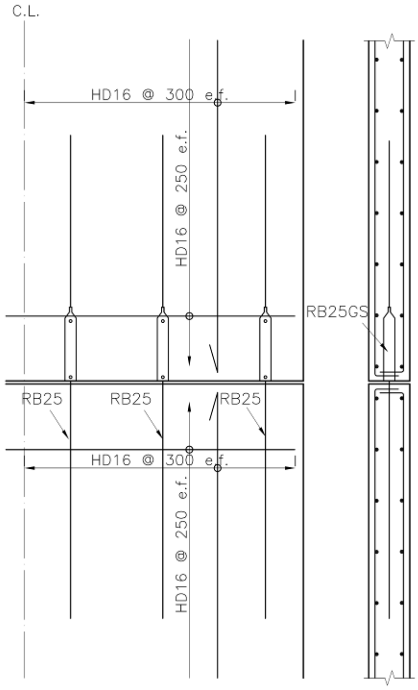


Figure 24: An example of a grouted sleeve horizontal connection between precast panels.

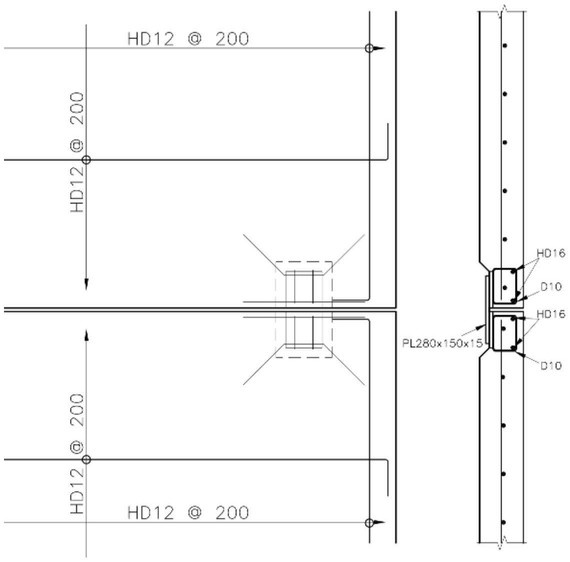


Figure 25: An example of a welded steel plate connection between precast concrete panels.

In grouted connections, ducts or grouted sleeves are usually positioned inside the precast panel and connecting bars from the bottom panel are placed inside sleeves or metal ducts, similar to the wall-to-foundation connections described earlier. In a few cases the metal duct was positioned in the bottom panel and the projected bar from the top panel was placed inside the duct. Confining stirrups are recommended for use around ducts in order to enhance the strength and ductility of the connection [17]. In contrast to wall-to-foundation grouted connections, in horizontal joints grouted sleeve connections are more commonly used than are metal duct connections. Grouted sleeve connections were used approximately 50% more often than were metal duct connections. This difference in popularity was attributed to the use of shorter starter bar for grouted sleeve connections that facilitates panel transportation.

VERTICAL CONNECTION BETWEEN PANELS

In many cases the vertical gap between panel connections is filled with sealants only. In other cases various detailing is used to make load bearing vertical connections. Load bearing vertical connections can be divided into two groups: (1) welded steel plate connections, and (2) cast-in-place connections.

Welded Steel Plate Connections

In welded steel plate connections, embedded plates are placed at the edges of panels and are anchored by embedded bars or studs inside the precast concrete panel. After installation of the panels, connecting steel plates are welded to the embedded plates at the construction site. An example of a welded steel plate connection is shown in Figure 26. Increased construction speed and the lower cost of welded steel plate connections are the main advantages of these connections, whilst the need for onsite welding, lack of ductility, and eccentricity of load path of the connection are the main disadvantages of welded steel plate connections. Weld connection failure was observed in the 2010/2011 Canterbury earthquakes [10]. In addition, exposed welded plates make these connections more applicable for industrial buildings than for commercial or residential buildings.

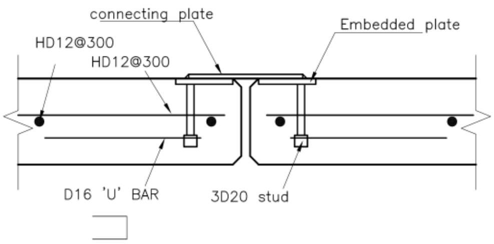


Figure 26: An example of a welded steel plate connection.

Welded steel plate connections are the most commonly used method of joining panels in single storey buildings, most of which are industrial warehouses. In the reviewed detailing welded steel plate connections were utilised in 78% of vertical load bearing connections in single storey buildings but in multi-storey buildings this type of connection was less used than cast-in-place connections. In the reviewed detailing welded steel plate connections were used in 45% of multi-storey buildings.

Cast-in-Place Connections

Cast-in-place vertical connections are usually constructed with significantly larger strength than that of the panels, such that the seismic performance of the system is similar to a monolithic reinforced concrete wall [3]. Various types of cast-in-place connections are used to connect panels vertically. The most commonly used type of cast-in-place connection in the reviewed detailing is shown in Figure 27a. In this type of connection horizontal starter bars that project from the ends of both panels are anchored to the cast-in-situ connection with 90° standard hooks. Vertical reinforcement is usually used in the connection zone to enhance connection strength. Sometimes, in order to reduce the width of the connection, hairpin starter bars (Figure 27b) are utilised. In a few cases threaded inserts were used instead of starter bars. In this type of connection threaded inserts are placed at the edge of the panels and reinforcement is placed to join the panels (Figure 27c). Threaded inserts were used in seven per cent of the reviewed cast-in-situ vertical connections. There is also a number of less commonly used detailing proposed in the guideline for structural precast concrete panels in New Zealand [20] that are shown in Figure 27d, Figure 27e and Figure 27f.

In the survey cast-in-place vertical connections were used in 17% of the single storey industrial buildings. The percentage rose to 47% in multi-storey buildings, which indicates that cast-in-place connections are more commonly used in commercial and residual buildings than in industrial buildings.

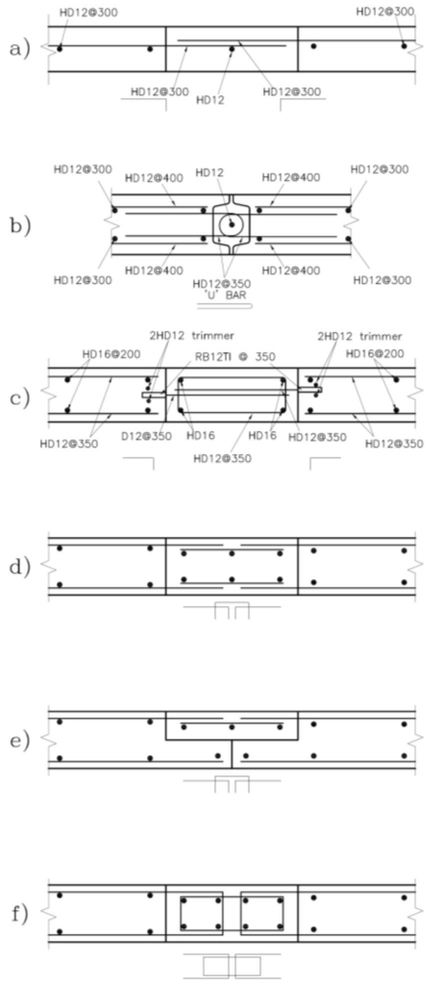


Figure 27: Examples of different types of vertical cast-in-place connections (plan view)

CONCLUSIONS

The following conclusions can be drawn from the review of more than 4700 precast concrete panels and their connections currently used in New Zealand.

1. Precast concrete panels with a 150 mm thickness which are reinforced by a single layer of reinforcement are the most common type of precast concrete panel in New Zealand.
2. In most wall-to-foundation grouted connections the reinforcement content of the connections is lower than the panel vertical reinforcement content. This issue was observed in metal duct connections more than in those with grouted sleeves.
3. In many cases when using metal duct connections the panel vertical bars are not properly spliced with the connection bars. This conclusion applies for both horizontal connections between panels and for wall-to-foundation connections.
4. Confining stirrups around metal ducts in low thickness panels are small in size (less than 100 mm) and the provided confinement may not be sufficient.

5. The recommendations for preventing break out of shallow embedded threaded inserts in wall-to-foundation connections were not encountered in the survey.
6. The use of threaded insert wall-to-foundation connections is generally more commonplace in smaller projects when compared to starter bar connections, which are more prevalent in larger projects.

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