A novel approach to the construction of a hotel with single storey basement using semi-top down construction

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ABSTRACT: This paper discusses the construction of an 8-storey hotel with basement at the site of River House, the former motor tax office in Chancery St. in Dublin city. An archaeological assessment at the site indicated medieval occupation and deemed the future basement area as possessing high archaeological potential that required investigations through an archaeological dig. In order to facilitate these investigations without unduly impacting the proposed opening date of the hotel, a novel semi top-down construction approach was proposed, a first in Ireland. This involved constructing a first-floor podium slab supported on pile-columns to bedrock that allowed the hotel bedroom levels to be constructed above ground level while the archaeological dig advanced below. The paper outlines the temporary and permanent structural solutions employed as well as the construction methodology adopted for the top-down works.

KEY WORDS: Top down construction, construction methodology, basement excavation, temporary stability, pile-columns

1 INTRODUCTION

This paper describes the construction of an 8-storey hotel with basement in Dublin city using a novel semi top-down construction methodology on the site of the former motor tax office.

The project was constructed under a design and build contract by MB McNamara Construction for the Hilton hotel group. Waterman Moylan Engineering Consultants (WM) provided civil and structural services on the project.

2 BACKGROUND

2.1 *Client and architectural requirements*

The project requirements comprised of an 8-storey hotel with 249 bedrooms over a single storey basement, with the top storey set back from each elevation. A double height entrance space at ground floor level with mezzanine area would accommodate a hotel lobby, reception and cafe/restaurant. Guest bedroom accommodation would be provided from mezzanine to Level 7. Basement would accommodate plant equipment, a gym and attenuation storage for surface water collected on roofs.

2.2 *Project and site constraints*

The site is located in Dublin city, within the zone of archaeological potential for Dublin and within the first recorded suburb north of the Liffey in the medieval suburb of Oxmanstown [1]. The site is located close to St Michan's Church, St. Mary's Abbey and St. Xaviers Priory which were established in the 11th, 12th, and 13th centuries respectively. The site is bound by the St. Michan's House housing development to the north, Chancery St. to the south, Greek St. to the west and St. Michan's Place to the east. At planning stage, an archaeological assessment indicated medieval occupation at the site. Because the existing building on the site did not have a basement, it was deemed likely that the future basement area would possess archaeological findings of interest, and the assessment recommended an archaeological dig be carried out across the site.

A 12-to-16 week period was allowed in the construction programme for the archaeological dig. Engagement took place with Dublin City Council (DCC) archaeology department on permitted substructure and the extent of the archaeological dig required. Piled foundations would be permitted, but the number of piles and their locations were limited to minimise the impact on potential archaeological findings.

The client had concerns that, depending on the findings, the archaeological dig may take longer than expected. The Contractor proposed a semi top-down construction technique in order to de-risk the hotel's opening date.

A site investigation uncovered up to 3.5m of made ground, on 1m to 6m of stiff clays and dense sandy gravels on mudstone rock. The existing ground level was 4.5m above sea level.

2.3 *Top-down construction*

The main benefit of using top-down construction is that it allows the superstructure to be constructed at the same time as the substructure [2]. In top-down construction, following installation of a perimeter retaining wall, structural pile-columns are installed as plunge columns with the column foundation forming a pile below ground level. Floor slabs are then cast progressively in a top-down sequence as excavation takes place below the previously cast slab. The floor slabs provide lateral support for the retaining wall as the excavation advances [3]. Refer to Figure 1. This construction technique was originally shown by Zinn [4] and further developed in Hong Kong. It is now a standard form of construction for deep basements globally [3], however to the author's knowledge, only one basement has been formed in this manner in Ireland to date. It is generally un-economic to use a top-down approach unless there are more than two levels of basement [2].

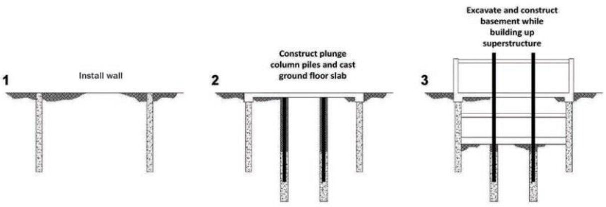

Figure 1. Top-down construction technique [2].

2.4 *Semi Top-Down Construction Approach*

The semi top-down construction approach developed for this project permitted the superstructure to be constructed at the same time as the substructure. However, given the basement was only a single storey deep and head room was required for the archaeological dig, a bottom-up approach was proposed to construct the basement, ground floor and mezzanine floors.

This approach would involve constructing a podium transfer structure at 1st floor level, 6m above ground level supported on pile-columns to bedrock. The precast concrete frame installation for the bedroom block could then commence, supported on top of the transfer structure, and the archaeological dig could take place at ground level concurrently. Once the excavation had been completed, the basement, ground floor and mezzanine structure could be constructed. Refer to Figure 2.

Typically, temporary works designs are carried out by a separate designer, however, WM took on this responsibility owing to the novelty and complexity of the semi-top down approach employed.

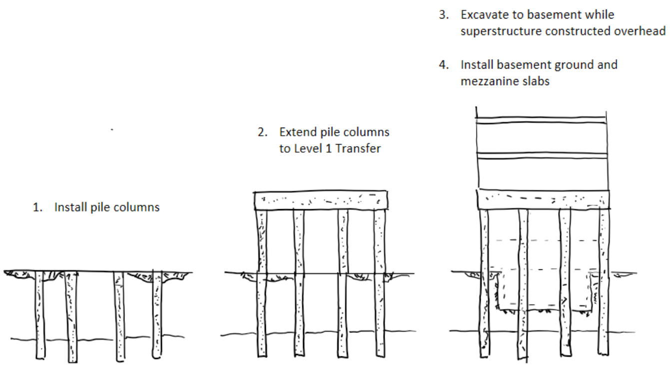

Figure 2. Semi top-down approach adopted.

2.5 *Structural scheme and detailed design*

The structural scheme for the building included a reinforced concrete (RC) frame at basement, ground floor and mezzanine, with a Level 1 podium RC transfer slab supporting a precast concrete frame constructed of twinwall panels and wideslab floors. The setback level 7 was constructed using a steel frame supported on a steel beam transfer structure. Foundations were piled foundations socketed into the mudstone rock below.

The design of the structure to take account of the temporary and permanent support conditions was complex. Two finite element building models were produced in SCIA in order to model both the temporary and permanent design scenarios. A second order analysis was also required to take account of second order effects. Design changes throughout the project required that both models be updated and structural elements re-checked in both temporary and permanent conditions.

2.6 *Archaeological findings*

During the excavation, a number of interesting findings were made. A ditch from the 10th century was found that was likely related to flood relief and water management of the marshy land adjacent the Liffey. Deep reclamation deposits were found dated between the 11th -14th centuries, showing that land towards Liffey had been reclaimed. During this time period, the site was used as a communal dumping ground. There were streets around it but no evidence of structures on the site were found. Waste pits were found containing medieval pottery, cooking pots, jugs and storage jars of Irish, English and French origin along with items of personal adornment, bone and antler waste. Another interesting finding was that oak was being burned in fires and this material was not saved solely for ship building or structural purposes. During the 15th to 17th centuries, the area remained as marginal ground and continued to serve as a dumping area. The first habitation and structures on the site date from the 17th to 19th centuries. Cellars were found under a terrace of 4 houses that faced onto Chancery Street. Here, a cobble floor, corner fireplaces and a redbrick base of a stairs were found. Wells associated with each structure were also found. [1]

3 METHODOLOGY

3.1 *Semi Top-Down Construction Scheme*

A scheme design for the top-down works was developed in conjunction with the Contractor and the geotechnical engineers on the project. A number of issues became evident at the outset. DCC archaeology wanted the number and size of piles installed through the ground to be limited The proposal made, was to use 640mm diameter piles socketed into the rock below in order to transfer the vertical loads to the ground. If steel columns were to be used as plunge columns to support the transfer slab in the temporary condition, very large UC sections would be required owing to their 9m long buckling length following the basement excavation. This steered the team towards using RC pile-columns, which, given their 640mm diameter, would be less susceptible to buckling. Another key part of the early design phase was how the later stage would connect to the early construction works.

The outline methodology developed was as follows:

- Demolish existing structure and form piling platform at existing ground level.
- Install foundation piles and plunge kingpost piles around the future basement perimeter from piling platform.
- Construct RC ground beam forming a ring around the perimeter façade line.
- Extend piles inside future basement area to form pile-columns up to Level 1. A number of temporary pile-columns are required at core locations in the temporary condition. (These are to be demolished during permanent works following the construction of the cores).

- Construct RC walls to east and north facades to act as shear walls in the temporary and permanent condition.
- Construct rectangular RC columns to west and south off perimeter ground beams at ground level to support Level 1 transfer slab.
- Install Level 1 transfer slab.
- Install temporary bracing on western and southern facades between perimeter ground beam and Level 1.
- Commence construction of precast concrete frame supported on Level 1 transfer slab
- Concurrently, commence archaeological dig and single level basement excavation beneath the Level 1 transfer slab.
- Construct the basement slab and core foundations followed by the basement walls.
- Construct the core structures and tie into Level 1 transfer slab.
- Construct the ground floor and mezzanine slabs.
- Demolish temporary pile-columns and remove temporary stability bracing.

3.2 Communication of design intent

Given this was a non-standard sequence of building and the fact there was little prior experience of top-down construction in the Irish construction market, it was critical for all parties to clearly understand how the project was proposed to be constructed. The sequencing of works was therefore a key aspect on this project. The project was documented at BIM Level 2 [5], and the structure was modelled using Revit software. 'Phasing' functionality in Revit was used to model the various stages of construction. This meant that the technicians modelling the structure had to have a clear understanding of the construction process. Modelling in Revit allowed 4D construction sequencing to be developed using Navisworks TimeLiner where each structural element was linked to a date on the construction programme. This allowed the team to visualise the construction of the structure virtually with the aim of ensuring that each stage was fully understood. Refer to Figure 3.

It was a concern that early in the project an issue arose which indicated a lack of understanding of the methodology being adopted. This underscored the importance of educating all involved on the project on the design intent and methodology, and further measures were put in place in this regard.

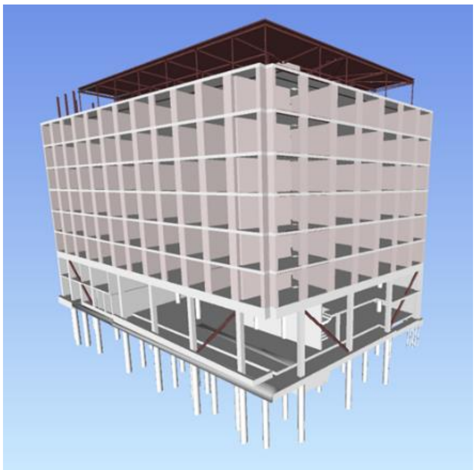

Figure 3. Extract of building from Navisworks model.

3.3 Piling

As outlined above, the sizes and locations of piles were limited based on discussions with DCC archaeology department. Piles would be 640mm in diameter, designed for a S.W.L of 3250kN, installed to an average depth of 10m below existing ground level, with a 3.5m rock socket into the mudstone rock below. The piles were C32/40 concrete, reinforced with 14 B32 vertical bars and B12 helical links at 150mm centres with 75mm cover. Four main pile types were required. Refer to Figure 4.

<u>Temporary pile-columns</u> – Indicated in grey.
Located within the footprint of the future basement at core locations. These pile-columns would support the Level 1 transfer slab in the temporary case but would be demolished down to basement level following installation of the cores. They would also support a base foundation below the cores.

<u>Permanent pile-columns</u> – Indicated in yellow.
Located within the footprint of the future basement these would support the Level 1 transfer slab in both temporary and permanent cases. The basement slab, ground floor slab and mezzanine slab would be connected to these later.

<u>Perimeter piles</u> – Indicated in red and green.
Located outside of the basement, these would support RC walls (shown in red) and columns (shown in green) around the façade. A perimeter ground beam would be cast along the façade line at ground floor level connecting these piles.

<u>Kingpost piles</u> – Indicated in blue.
Located around the perimeter of the basement. These were piles with a UC section plunged with them during installation to form a king post retaining wall, consisting of precast concrete planks spanning between the UC sections be installed while the excavations for the archaeological and basement dig advanced.

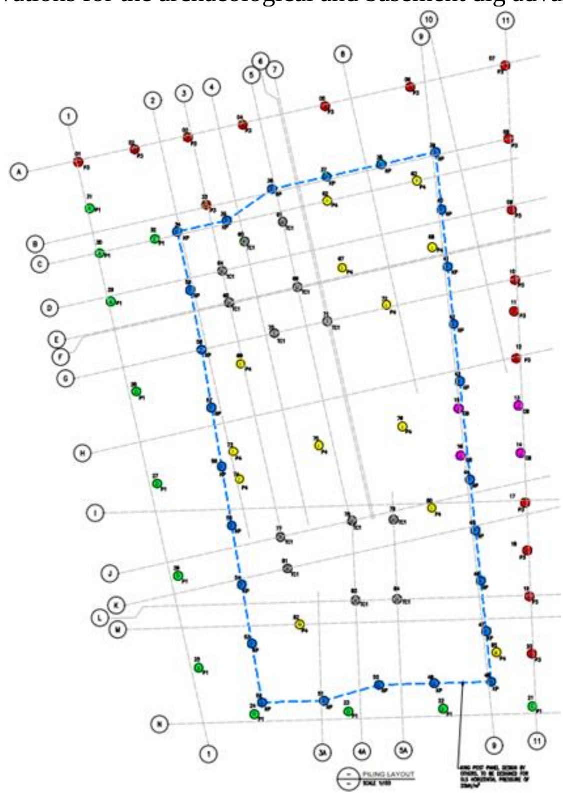

Figure 4. Pile types and locations.

3.4 Piling installation and tolerances

Positional and verticality installation tolerance were critical on this project. The positions that the piles were installed would dictate the final location of the pile-columns as the permanent columns had to be located directly over the piles. On more conventional projects, pile caps offer flexibility to correct positional installation inaccuracies. The architect also had to be somewhat flexible in this regard. Verticality tolerance was also very important, as the greater off vertical the piles, the higher the resulting eccentric moments on the pile-columns.
'Controlled' pile tolerances in accordance with Ciria C760 [2] were agreed with the piling Contractor as per Table 1. Pile inclination surveys were undertaken later to verify the design.

Table 1. Pile Tolerances.

Pile Type	Positional Tolerance	Verticality Tolerance
Temporary pile-columns	± 25mm	1/150
Permanent pile-columns	± 25mm	1/150
Perimeter piles	± 75mm	1/75
King post piles	± 25mm	1/75

In order for the piling contractor to achieve these tolerances while also having to drill metres into bedrock, an ODEX piling system was used. ODEX piles are formed in 2 stages. The first stage uses an ODEX hammer to drill through the soil and into the rock to form the rock socket. The bore is then backfilled with the drill cuttings. In the second stage, the pile is re-bored through the cuttings using conventional CFA piling techniques. The CFA piling requires little effort by the boring machine and therefore there is reduced heat generation, a shorter concreting process and easier installation of steel cages, which improves accuracy of pile installation [6].

3.5 Perimeter ground beams

Following piling, a perimeter RC ground beam system was cast at ground floor level to form a ring on the façade line outside the basement. Continuity reinforcement was cast into the side of the ground beams to connect the future ground floor slab. In one location, the vertical load on a permanent pile-column was too great for a single pile, so two piles were introduced with a pile cap tied across the kingpost basement wall and into the perimeter ground beam.

3.6 Temporary and permanent pile-columns

The temporary and permanent pile-columns were formed by extending the piles as circular 640mm diameter columns by 6m from ground level to Level 1. Column splice reinforcement was left protruding at ground level from the installed piles to connect the columns. A unique aspect of this project was the division of responsibility for the pile-columns. The pile designer had responsibility for the design and detailing of the piles from ground level to rock, while WM had design responsibility for the columns from ground level to the Level 1 Transfer slab. Checks were completed by WM on the 9m long pile-columns, laterally restrained below basement level by the stiff clay and dense gravel strata overlying the bedrock. Reinforcement couplers were installed at the pile to column connection at ground floor level to facilitate the future ground floor slab connection. 500x450mm rectangular RC columns were installed around the southern and western façade line on top of the perimeter ground beam aligning over the perimeter piles below.

3.7 Reinforced concrete walls

RC walls, 6m high and 300mm thick were installed along the eastern and northern facades supported off the perimeter ground beam to support the edge of the Level 1 transfer slab and also to form part of the lateral stability system. To allow for future bedroom windows, soft spots were provided in these walls to allow for these to be cut out later.

3.8 Level 1 transfer slab

The Level 1 transfer slab was then cast, supported by the perimeter columns, temporary pile-columns, permanent pile-columns and the RC perimeter wall. Refer to Figure 5. This slab had to be designed for the temporary and permanent support cases based on the load bearing structure supporting it in each case. Load transfer from the temporary supports to the permanent supports was also a key consideration. During the design phase, it was agreed with the Contractor that following construction of the basement, RC core walls would be cast up to transfer slab level.

Figure 5. Image showing Level 1 transfer slab supported by pile-columns, RC walls and temporary stability bracing.

3.9 Temporary stability bracing

Lateral stability in the temporary case was provided by casting the RC walls along the northern and eastern facades and providing temporary steel bracing along the southern and western facades. The RC walls had to be increased in thickness to allow for the fact that they would be double height in the temporary case. The perimeter ground beams and piles were designed to transfer the wind loading from the building overhead to the soil via load sharing of the piles.
The temporary steel bracing was installed once the Level 1 transfer slab installation was complete. Refer to Figure 3 and 5. This was a critical aspect of the semi top-down works. Four

steel braces were provided each designed to act in compression to support the lateral loading in each wind direction. A compression bracing system was chosen over a tension system to provide stiffness and limit the lateral deflection of the structure overhead.

The braces were also designed to act in reversal to allow the Contractor remove one brace temporarily if required for access during construction, and also as a robustness measure in case a brace was damaged by impact during construction. The braces were painted in bright yellow to help prevent such a collision. At the connections, large compression, shear, and tensile forces were generated that had to be transferred from the Level 1 transfer slab into the RC column and perimeter ground beam. Refer to Figure 6. The bracing design and installation methodology had to be thought through carefully to allow for installation and removal following completion of the permanent works.

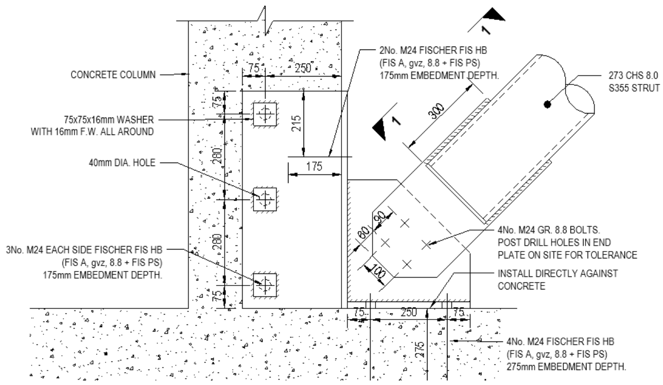

Figure 6. Temporary stability bracing connection.

3.10 Basement excavation and archaeological dig

A kingpost wall was used as the soil retention system during excavation. A battered excavation was discussed initially, however given the lack of space on site, a working platform around the perimeter of the excavation was required by the Contractor. The kingpost wall was formed by initially plunging 8m long UC sections with the 640mm diameter ODEX piles. As the basement excavation commenced, the concrete around the steel UC sections was broken out and precast concrete planks were lowered between the flanges of the steel sections. The precast concrete planks slide down between the flanges as the excavation descends and form a temporary support for the soil behind. Refer to Figure 7. The UC kingposts were integrated into the permanent works support system as detailed later.

Care was required while excavating around the pile-columns and as the excavation advanced, surveying and monitoring of verticality and movement was undertaken to ensure that the pile-columns had been installed within tolerance and that no lateral movement of the pile-columns was occurring.

Figure 7. Kingpost wall installation.

3.11 Basement and foundations

Following the archaeological dig and basement excavation, the lift pit bases were excavated down to rock level. This increased the effective length of the temporary pile-columns by a further 3m. A system of bracing was used to reduce the effective length of the temporary pile-columns during excavation. The bases were installed in a sequential manner, excavating around one pile-column at a time.

The RC basement slab was then installed. The concrete slab was thickened locally at the pile-columns and connected using two layers of dowelled reinforcement.

3.12 Permanent stability system

The original design for the permanent stability system was to install two RC cores from basement level to Level 1 transfer slab level that would act in conjunction with the RC shear walls installed along the north and east facades in the temporary case. Reinforcement couplers were cast into the underside of the Level 1 transfer slab to connect the walls to the slab. In order to place the concrete, it was planned to provide sleeves through the transfer slab, the RC walls would be cast between the temporary pile-columns and once installed the pile-columns could be cut back to the face of the wall. However, the Contractor requested for programming purposes that the design be changed to steel braced frame cores. A series of braced frames were designed to support the vertical and lateral loads in place of the RC cores. Refer to Figure 8. Additional RC walls were also cast in the permanent works at basement and ground floor level which contributed to the overall lateral stability of the structure.

Transferring vertical loads from the temporary pile-columns to the steel braced frames was a critical design consideration. Axial shortening of the columns in the steel frames was calculated and the impact this would have on the Level 1 transfer slab was assessed, which was at this point was carrying the precast frame over. A sequenced demolition plan was developed for the demolition of the temporary pile-columns along with monitoring, which ensured an orderly changeover of axial load to the steel frames. As there was no access for cranage of precast stairs at this point, the stairs from basement to Level 1 were constructed in cast in-situ reinforced concrete supported on the steel frames.

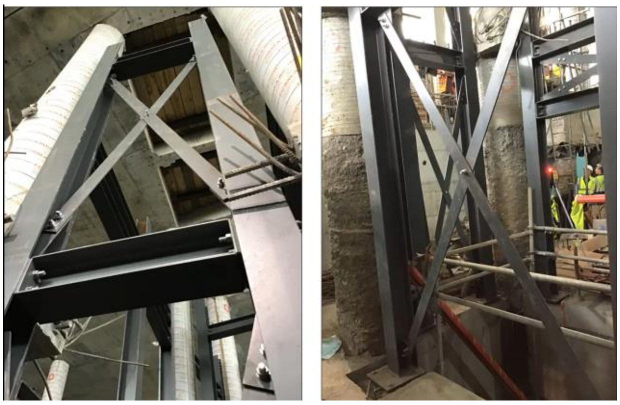

Figure 8. Images showing steel braced cores installed between temporary pile-columns.

3.13 Ground beams supported over kingpost wall

The UC sections in the kingpost system were also utilised to support permanent works. The RC basement wall and slab were designed to be suspended or 'hung' off the UC kingposts via an RC ring beam cast around the top of the kingpost wall. This beam was also used to support the ground floor slab around the edge of the basement. The connection between the ground beam and the UC sections allowed for downward forces and potential uplift from hydrostatic pressure from the basement. A steel boot connection was developed to transfer vertical forces from the RC ground beam through bearing on the steel flanges and dowel action in the bottom bars that were fed through holes in the web of the UC. The connection was designed to eliminate the need for on-site welding, while providing adequate on-site tolerance. Steel stubs were fabricated in the factory and holes in the UC kingpost were mag-drilled on site to facilitate the bolted connections and also to pass reinforcement through the web to provide continuity to the reinforcement in the RC ring beam. Refer to Figure 9.

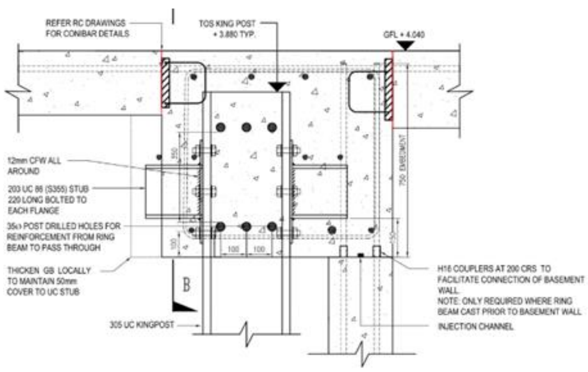

Figure 9. Kingpost to RC ring beam detail.

3.14 Ground and mezzanine floor slabs

At ground floor level, a system of reinforcement couplers and bars were cast into the permanent pile-columns and also into the perimeter ground beams to facilitate future connection of the slab. The Contractor cast a square section of slab at this level to aid constructability as can be seen in Figure 7. The couplers were designed to transfer the vertical load from the slab to the column in dowel action and provide continuity to the reinforcement. Additional shear reinforcement, or specifically hanging reinforcement transmitted the shear force back up to the top of the connection. Refer to Figure 10.

A similar connection system was provided at mezzanine floor level, however given there was no joint in the column at mezzanine level, the couplers were cast to the face of the column to facilitate the future connection of the slab. Following installation of these floors, the structure was now stable and the temporary stability bracing could be removed.

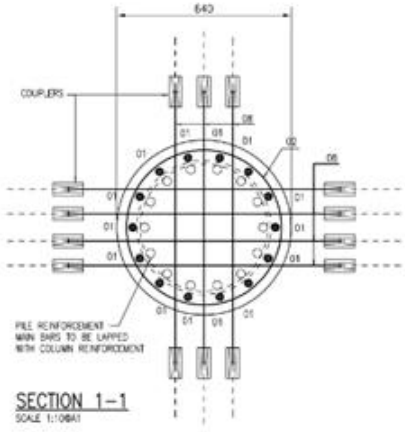

Figure 10. Ground floor slab to pile-column connection detail.

4 CONCLUSION & RECOMMENDATIONS

A risk of potential delays on this project led to a novel semi-top down approach being developed for the construction of this building. A number of innovative temporary and permanent structural design solutions were also developed in order to realise a successful project outcome.

Clear communication and understanding of the construction methodology and design intent was critical to the project and utilising BIM capabilities contributed to its success. However, an issue on site still arose due to misunderstandings with the unconventional methodology being adopted. This issue must not be underestimated on projects such as these. It is recommended that robust processes are put in place at the outset to ensure that all personnel involved in the design and construction of these types of projects are completely familiar with the specific project requirements. It is also recommended that a Resident Engineer be employed to supervise the works.

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