Seismic Resurrection of 13 Storey Apartment Building. 66 Oxford Terrace, Christchurch

R. A Poole

Phoenix Consulting, Christchurch, New Zealand.

P.R Boardman

Structure Design, Auckland, New Zealand.

G. J Thomas

Russell Property Group, Christchurch, New Zealand.

ABSTRACT

This pre-cast concrete 13-storey apartment building at 66 Oxford Terrace, Christchurch was designed in the early 2000's and completed in 2005. It suffered serious damage to some components on Feb 22nd 2011. It was vacated and stood empty until 2020 when it was purchased on an "as is where is" basis by Russell Property Group of Auckland, a company who relish taking on hard jobs. The building has considerable architectural merit, has a great site location, ~~,~~ an outstanding outlook. Whole floor apartments are highly sought after.

The engineering design fell short in both concept and detailing.

The resurrected building is base isolated just above ground floor, Level 00, and has been strengthened from the foundations below basement to Level 03, so it is now above 100% NBS. It has been extended at Level 11 and the roof, thoroughly refurbished architecturally, and was re-occupied in December 2023.

1 DESCRIPTION OF SITE AND BUILDINGS

We are concerned here with the apartment tower, but I need to establish the site context shown on the architectural site plan. (Figure 1). The site extends from Tuam Street to Oxford Terrace just east of Montreal Street and overlooks the 2010/2011 Earthquake Memorial. The basement and ground floor L00 cover the whole site. The 12-storey apartment tower fronts onto Oxford Terrace and there is a two-storey separate shop-house building on Tuam Street. Both sit atop the podium but the apartment tower extends to the basement. The Tuam Street building is not part of this paper. Note the large balconies on the Oxford Terrace frontage extending from L02 to Ll1.

The structural drawing of the ground floor, S1-500 shows the total ground floor structure. (Figure 2). The shaded area has been rebuilt in-situ. The orange outline is the apartment building and the green outlines the shop/house building. The pink is the boundary and the area between this boundary and the two buildings is the ground floor podium.

2 DESCRIPTION OF THE APARTMENT BUILDING: ARCHITECTURE & STRUCTURE

The next drawing is an architectural floor plan of a typical floor. (Figure 3). Note there is a generous central kitchen/ living space; there are three bedrooms with en-suite bathrooms, a study and a small laundry. To cap it off is the 30m^2 balcony. A master stroke in the resurrection was the decision to glass off the west end of the balcony as a Winter Garden, which also improves the utility of the balance of the balcony. Looking at the plan, I do wonder how architectural minds work? No doubt the building is more interesting as a visual feature in the city scape, but I wonder about the complexity of the plan. There are 24 separate exterior wall surfaces. An engineer would have adopted a much simpler "squarish" plan which would have made the design and construction much easier.

I now refer to the structure of the tower and drawing S1-503 (Figure 4) and note the following:

a. The main floor spans E/W for 9.15 metres from west wall to core wall and is Rib & Infill flooring, 75 topping on ex 25 timber and 225 ribs @ 900 c/c.

b. The east bay of 6.13m is 75 topping on 75 Unispan.

c. The existing lateral load resisting walls are in orange. The east and west walls carry the N/S earthquake and are obviously generous. E/W earthquake is carried by the core walls in conjunction with the east wall flange - imagine a lop-sided box girder bridge. This element of the structure was always struggling, it is 6m "deep" and 40m high above the foundations. To compound the "structural injury" it has door openings to give access to the lift and stairs, not unreasonable, but at ground floor there are three doors leading into the stairwell, so it becomes a veritable "pepper pot". Two of these doors were necessary, the third was bad architectural planning.

d. The final elements are the 6 secondary walls. These are shown in pink. Generally, they are external walls and they support the floors and they spring from the ground floor L00.

e. The blue walls extend from the basement to L03 and are the essential elements of the strengthening system.

f. I will address the foundations as part of the strengthening system.

g. I refer now briefly to the new structure at the top of the building. The original penthouse on Levels 10 & L11 consisted of (for reasons I cannot fathom) a living floor on LI0 and bedrooms on L11 enjoying the best views? We have added considerably to L11 floor as described in drawing S1-511 (Figure 5) and to the roof as indicated on S1-512 (Figure 6). The new configuration includes 2 separate full floor apartments on levels L10 & L11.

3 STRUCTURAL SHORTCOMINGS - ORIGINAL DESIGN & CONSTRUCTION

These were significant and included the following:

a. A ductility factor of 5 was assumed, 25% more than the traditional 4, but the detailing was woefully inadequate.

b. The building was designed on the assumption the shear walls would spring from the basement foundations. However, the building was in fact built into the ground floor, so creating an unintended nutcracker effect. This imposed very heavy shears on the ground floor and caused severe damage. See composite elevations ex S1 - 403 (Figure 7).

c. The building has generous east and west walls to resist N/S earthquakes. However because of the long windows they are coupled shear walls but the detailing did not recognise the associated ductility demand. The west wall was omitted in the basement to accommodate car-parking. I believe another structurally sympathetic solution was available. Note drawings S2-403 and S2-405 (Figures 8, 9).

d. I mentioned earlier the deficiency of the original E/W resisting system of core walls (Figure 10). It did however extend comfortably to a reliable foundation system, essentially a "hockey stick" foundation beam extending across the apartment building (Figure 11).

e. In the N/S direction there are 6 secondary walls which spring from the ground floor and support the upper floor slabs and in one case most of the load from the substantial balconies (Figure 10). They are generally 180 thick with a single layer of reinforcing. They have no ductile capacity and were vulnerable to compression failure, just like the Pyne Gould Corporation building, which collapsed in the February 2011 earthquake. These walls cannot avoid going along for the seismic ride, but they were not designed to sustain any earthquake loads. The concern is that they could fail in compression or overload the beams they sit on at ground floor level. The February 2011 Earthquake did in fact engender a spectacular shear failure of one beam.

f. Overall, the surprising thing about the building's behaviour on February 22nd 2011 was that it behaved better than the frailties outlined above would indicate. The ground floor suffered badly, and there was modest diaphragm stress in the slab toppings at the western core wall where one would expect it, but elsewhere it was mainly hair- cracking and the ground floor beam shear failure.

g. Another factor emerged during the early phases of construction when we tested a batch of grout sleeves used to connect precast wall panels. These tested out at only 40% of target capacity, which provided another tricky challenge.

4 STRENGTHENING THE BUILDING

The credit for the basic solution of turning the building into a rocking shear wall building belongs to Peter Boardman of Structure Design, Auckland. This is achieved by building new walls against existing structural walls on the east and west sides, and around the core, and encompassing Tectonus energy absorbing fuses into these new walls just above ground floor. Refer again to S1 - 500 (Figure 10) the structural ground floor plan. Tectonus devices are essentially tension devices, which when stretched engage opposing serrated plates. There are powerful springs, which oppose the lateral expansion provoked by the serrations and return the device to the neutral position when unloaded. These were devised by Pierre Quennevile of Auckland University and his team of bright young PhD graduates. They have been used on various low-rise structures in NZ and Canada, including the new Nelson Airport Terminal building. However, we believe this a first for multi-storey buildings and certainly for a major resurrection. There are several other major ramifications resulting from this solution.

The other major advantage of this solution was that the Tectonus devices were able to be tuned so that stresses in the upper levels were limited to existing capacities. Hence the wall strengthening was limited to basement to L03. L03 to Ll2 did not require strengthening.

a. The foundations on S1 - 400 (Figure 11) were an odd combination of pads, a major "hockey stick" beam under the service core, several short piles and screw piles under the podium. The ground was very good with sandy gravel at around 3.Sm below ground level, about 1m below the basement slab, and there was no evidence of the tower being out of vertical. Locating the Tectonus fuses just above the ground floor eliminated the nutcracker effect but there were still substantial shears in the ground floor, much of which has been rebuilt, and substantial uplift/compression forces transferred through the basement walls to the foundations. The existing foundations were integrated with a new raft linking them all and thankfully avoiding the need for tension anchors, not easy to install in gravel with a relatively high water table matching the Avon River across the street.

b. Drawing Sl-401 (Figure 12) shows the new basement walls in blue required to enhance the existing walls in orange.

c. Drawings Sl-500B (Figure 13) and S2-600 (Figure 14) show the steel trusses installed under the ground floor to enhance its capacity. Note there are also shear forces from the Tuam Street shop/house building to contend with in the ground floor diaphragm.

d. Drawing S1-500 shows the Ground floor diaphragm (Figure 15). The red area has been rebuilt. The new seismic walls are shown in blue, the new secondary walls in purple (more detail below), the existing walls are in orange, the shop/house Tuam Street building is in green, and under floor bracing in yellow.

e. The 1/F has been substantially rebuilt and extended as indicated on Sl-501 (Figure 16).5

f. The secondary walls have posed a formidable challenge. See drawings S2-102 (Figure 17) and S2-103 (Figure 18), which indicate the extent of the re-built walls and the steel falsework required to facilitate this rebuild. Supporting a 300 tonne load from the 12-storey wall on temporary steelwork does focus the mind.

g. I mentioned earlier the deficiencies identified in the grout sleeve connecting the precast wall panels. The solution adopted to address this problem was to post tension the building in 5 locations on the plan, in the four "corner columns" and in the stairwell. See copy of S1-503 (Figure 19). A clever solution but challenging to achieve. Drilling a 150 diameter core 30 metres down a column proved difficult, as one suspected, despite assurances to the contrary. Existing columns had to have 2m sections top and bottom demolished to accommodate the live and dead anchorages.

5 CONSTRUCTION OF THE EARTHQUAKE REPAIRS TO 66 OXFORD TERRACE

The major elements of the structural repairs include the following:

a. Demolition of the existing 200 basement floor slab to facilitate the construction of the integrating raft slab. Reinstatement of the basement floor (Figure 11).

b. Strengthening of columns from basement to ground level 00 (Figure 12).

c. Construction of new strengthening walls for 4 storeys from basement to L03. This includes the building in of Tectonus devices 450 above L00 floor (Figures 8, 9, 10).

d. Reconstruction of most of the L00 floor slab and L01 slab (Figures 15, 16).

e. Installing structural steel bracing under the L00 slab (Figures 13, 14).

f. Crack repair and installing FBP strengthening to floor slabs and walls. Enhancing connections of east and west walls.

g. Extending the L11 floor slab and the L12 roof, including the new balconies at both levels (Figures 5, 6).

h. Demolition and rebuilding of the lower one or two storeys of the secondary walls (Figures 17, 18).

i. Post tensioning the four corner columns and the south wall of the lift shaft within the stairwell (Figure 8).

j. Sawcutting the existing shear walls 450 above ground floor to allow the building to rock and engage to Tectonus devices.

6 COMMENTS AND CONCLUSIONS ON CONSTRUCTION OF THE REPAIR WORKS

a. The work has gone well but has taken much, much longer than anticipated.

b. Reasons for these extended construction times include:

   i. The inherent difficulty of working inside an existing building and adding to the existing structure.

   ii. The floors of this building provide a generous apartment, but are small in multi storey building terms, being an area of approximately 200m^2 plus a 30m^2 balcony. This limits the number of workers and trades you can accommodate on each floor. Also, the geometry is complex. Compare it with a standard rectangular plan office building and not the extent of external walls and complex joint issues and the 24 separate exterior wall surfaces.

   iii. Demolition of existing strong precast concrete and driIling starters is slow hard work.

   iv. Drilling a 150 core down a 30 metre existing column is as hard as it looks.

   v. Installing Tectonus anchors is precision engineering: I'm pleasantly surprised to report the carpenters loved the challenge and did a great job.

   vi. Installing substantial structural steel members under an existing floor with existing beams and services and complex geometry is very challenging. Again, I was amazed at the ingenuity and skill of the structural steel guys.

   vii. Adding to a structural steel roof, prefabricating as much as possible and getting the geometry right is also very challenging.

   viii. Covid Lockdowns did not help both the engineer and the builder.

   ix. For the authors it was worth the considerable and prolonged effort. Unlike the rest of the Christchurch demolition derby, we have saved a valuable building and we have done it in an innovative way. We may not be much richer but we have completed a very satisfying project with skill and innovation.

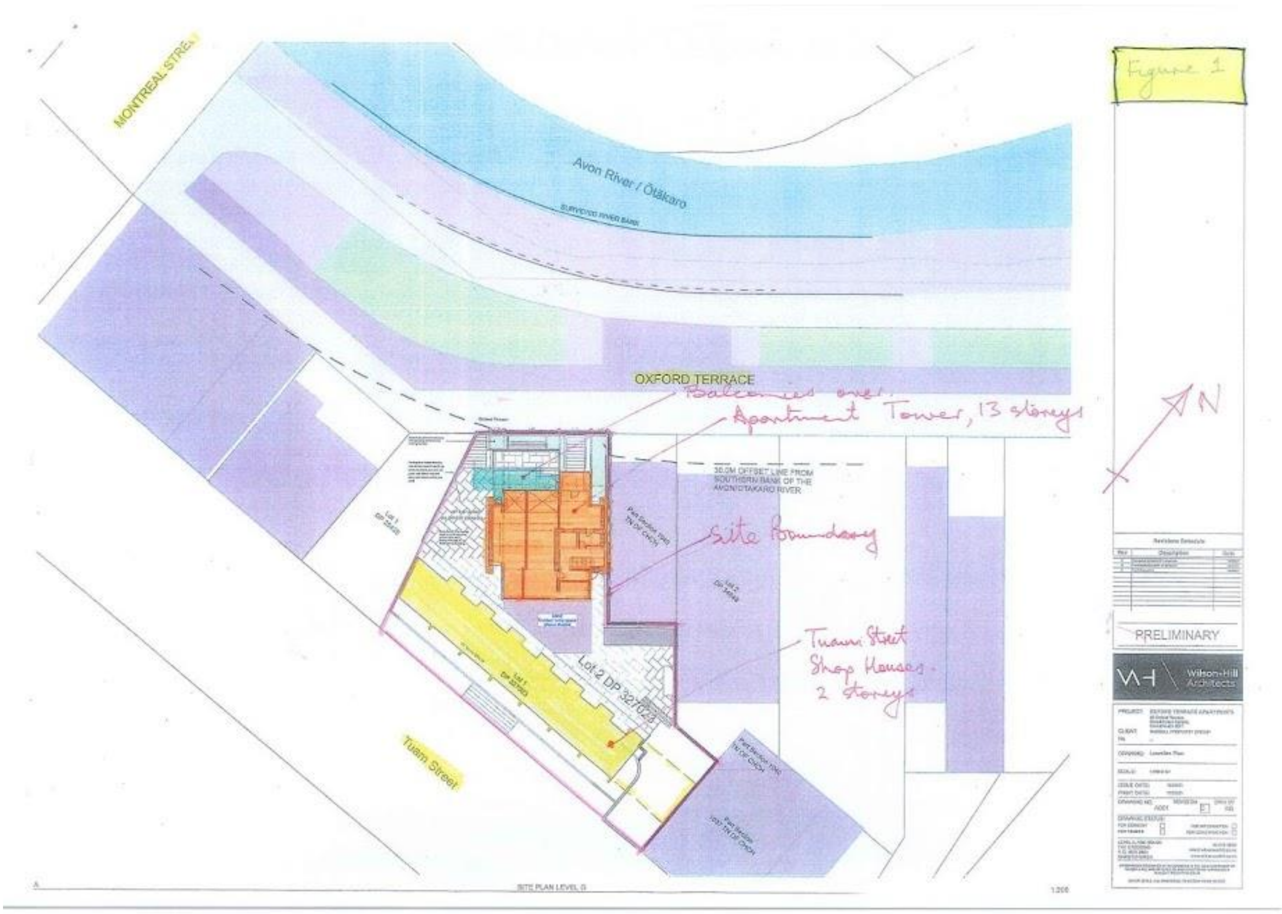
MONTREAL STREET
Avon River / Ōtākaro
OXFORD TERRACE
Balconies over.
Apartment Tower, 13 storeys
N
30.0M OFFSET LINE FROM SOUTHERN BANK OF THE AVON/ŌTĀKARO RIVER
Site Boundary
Tuam Street Shop Houses. 2 storeys
Lot 2 DP 327023
Tuam Street
Figure 1
PRELIMINARY
Wilson-Hill Architects
SITE PLAN LEVEL G

Figure 1


New balcony above
Existing Balcony above
APARTMENT TOWER
17,500
17,450
TURNER STREET SHOP HOUSES
STRUCTURAL FRAMING SCHEDULE
Figure 2
Wilson+Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS - LEVEL 00 FLOOR PLAN
PROPOSED LEVEL 00 FLOOR PLAN
FOR COORDINATION
20031
S1-500

Figure 2


Figure 3
AREA's
Interior 204 m²
Balconies 30 m²
Apartment Plan, Level 3
BC Amendment RFI
Wilson-Hill Architects
FLOOR PLAN LEVEL 03

Figure 3

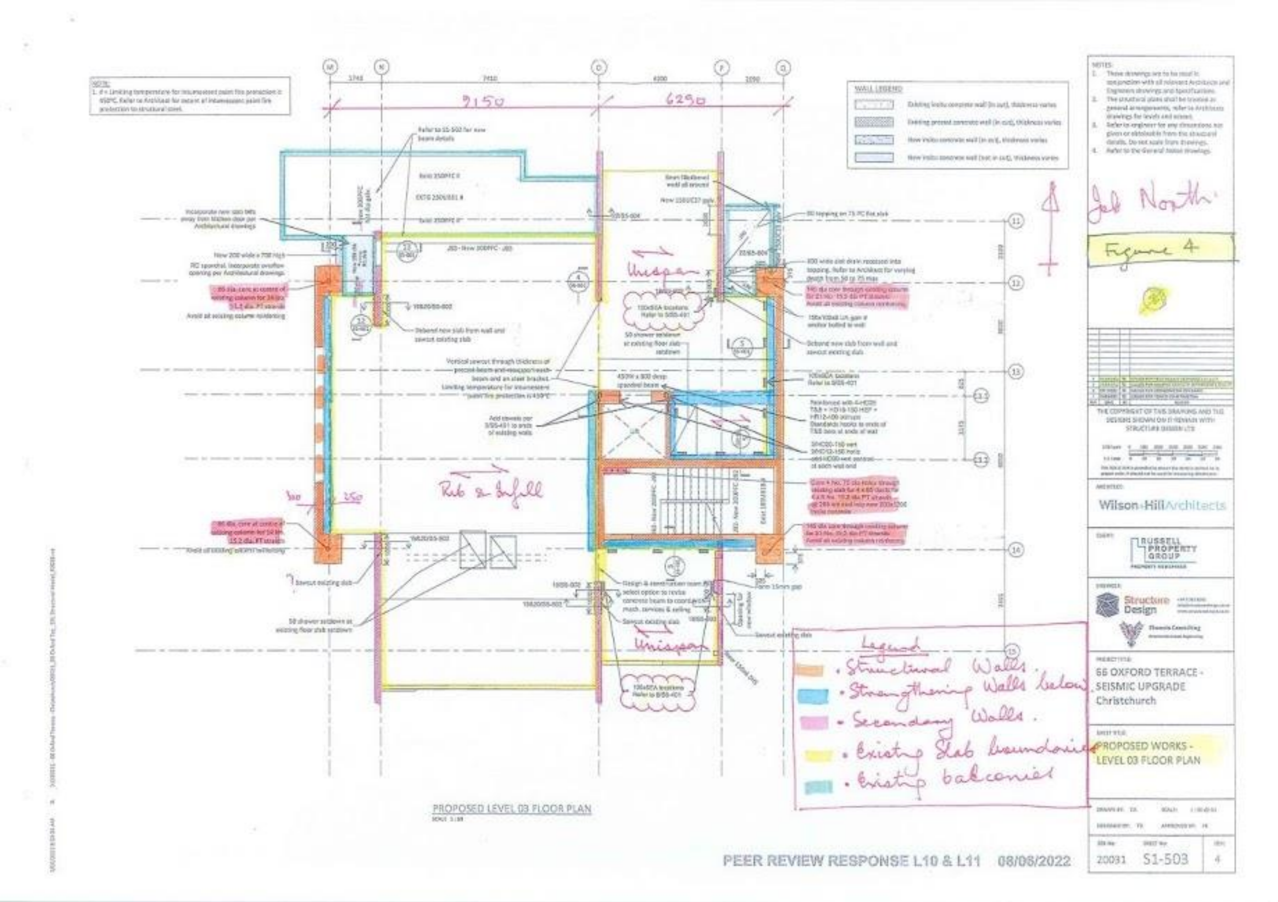
9150
6290
WALL LEGEND
Job North
Figure 4
Unispan
Rib & Infill
Unispan
Legend
• Structural Walls.
• Strengthening Walls below
• Secondary Walls.
• Existing Slab boundaries
• Existing balconies
PROPOSED LEVEL 03 FLOOR PLAN
PEER REVIEW RESPONSE L10 & L11 08/08/2022
Wilson Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS - LEVEL 03 FLOOR PLAN
20031 S1-503 4

Figure 4

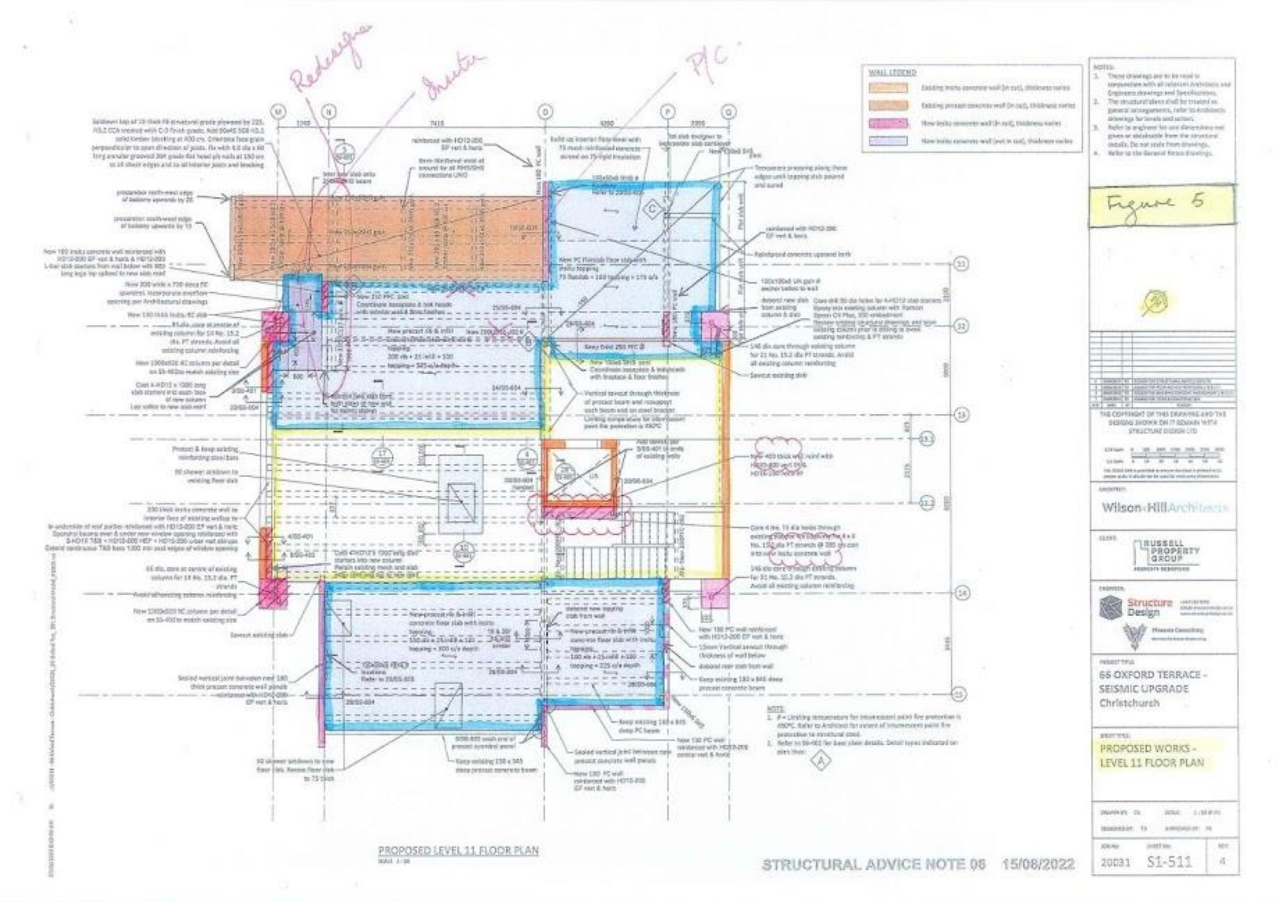
PROPOSED LEVEL 11 FLOOR PLAN
STRUCTURAL ADVICE NOTE 06 15/08/2022
Figure 5
Wilson+Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE
Christchurch
PROPOSED WORKS - LEVEL 11 FLOOR PLAN
20031
S1-511

Figure 5

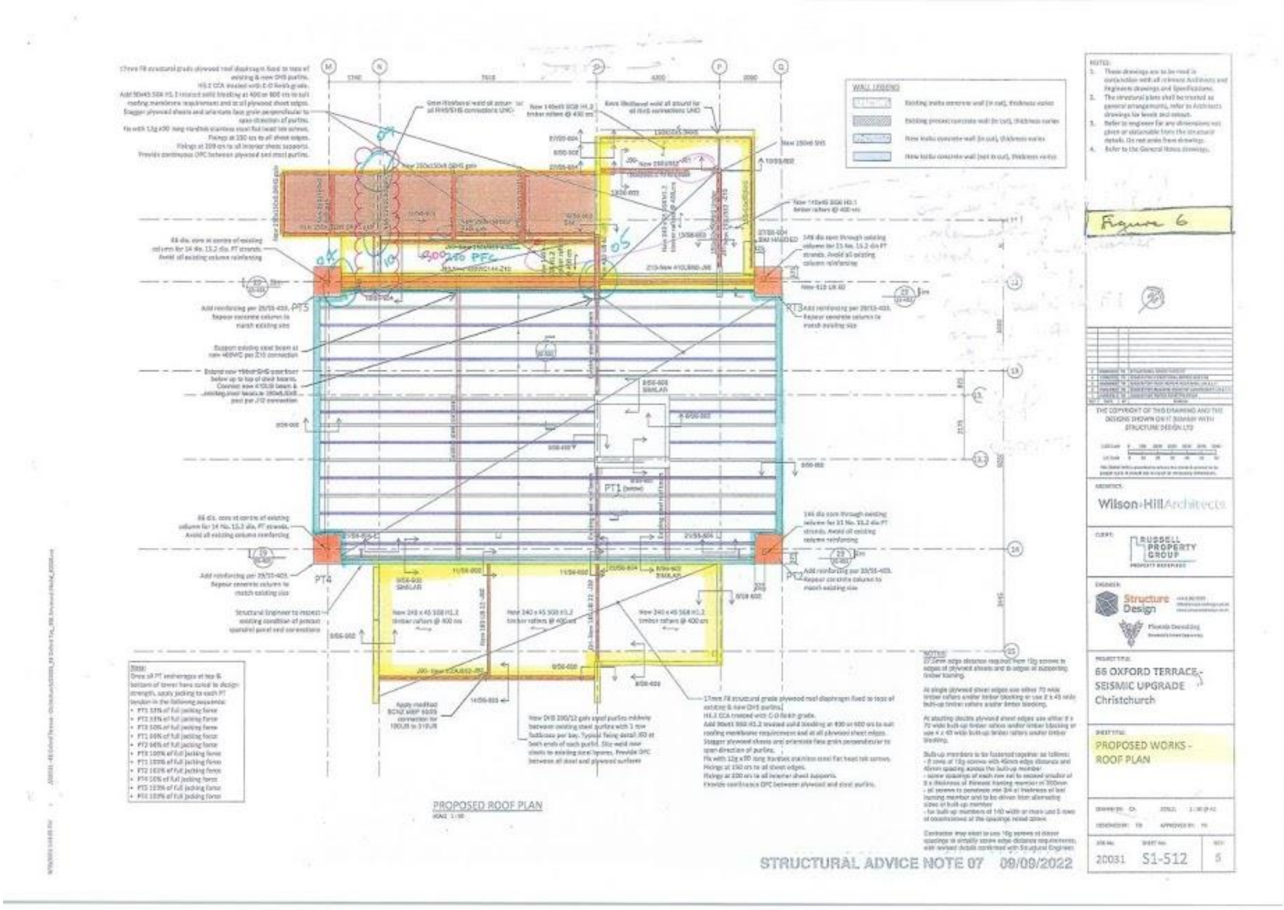
PROPOSED ROOF PLAN
STRUCTURAL ADVICE NOTE 07 09/09/2022
66 OXFORD TERRACE
SEISMIC UPGRADE
Christchurch
PROPOSED WORKS - ROOF PLAN
Wilson-Hill Architects
S1-512

Figure 6

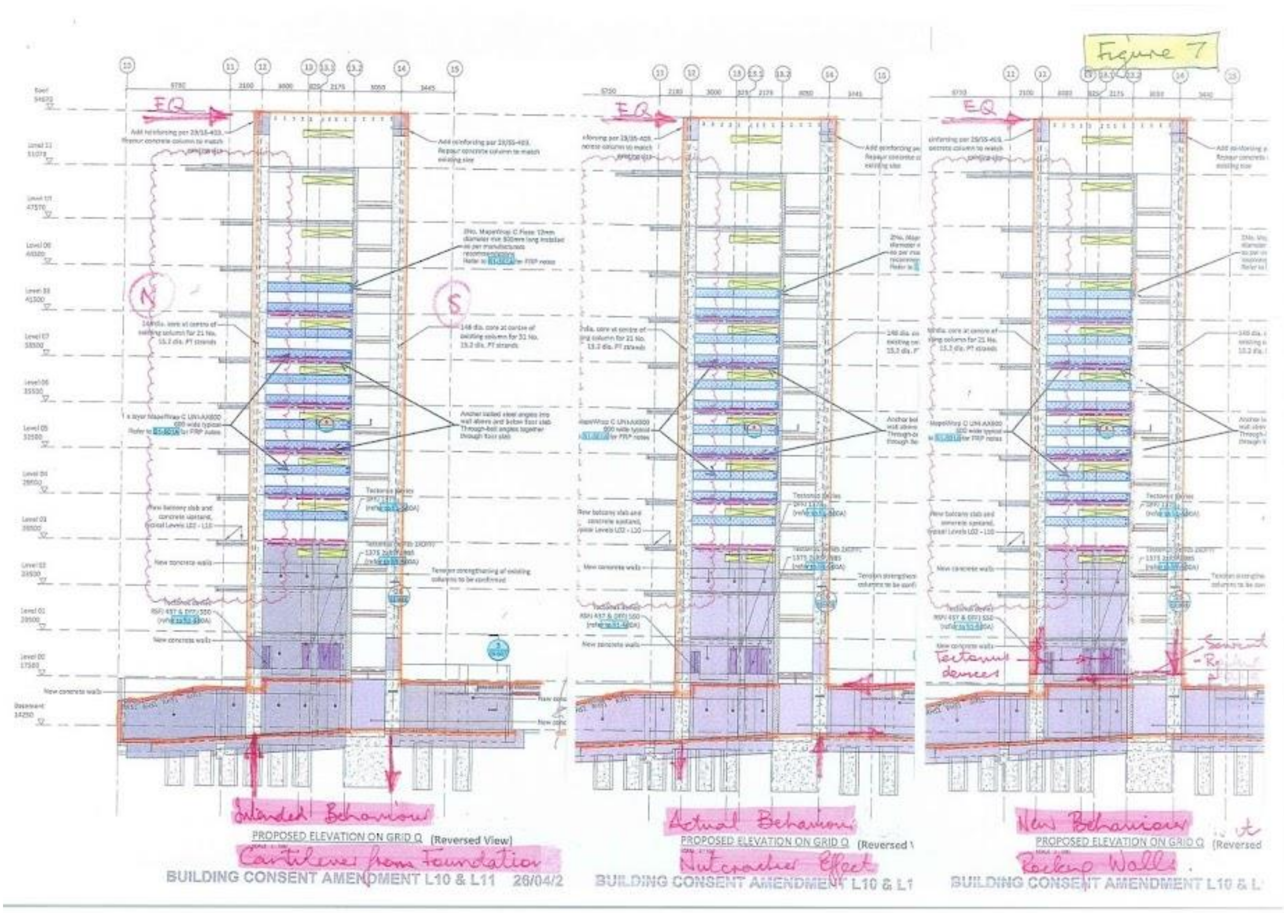
Figure 7
EQ
Intended Behaviour
PROPOSED ELEVATION ON GRID Q (Reversed View)
Cantilever from Foundation
BUILDING CONSENT AMENDMENT L10 & L11 26/04/2
Actual Behaviour
Nutcracker Effect
New Behaviour
Rocking Walls
Tectonus devices

Figure 7

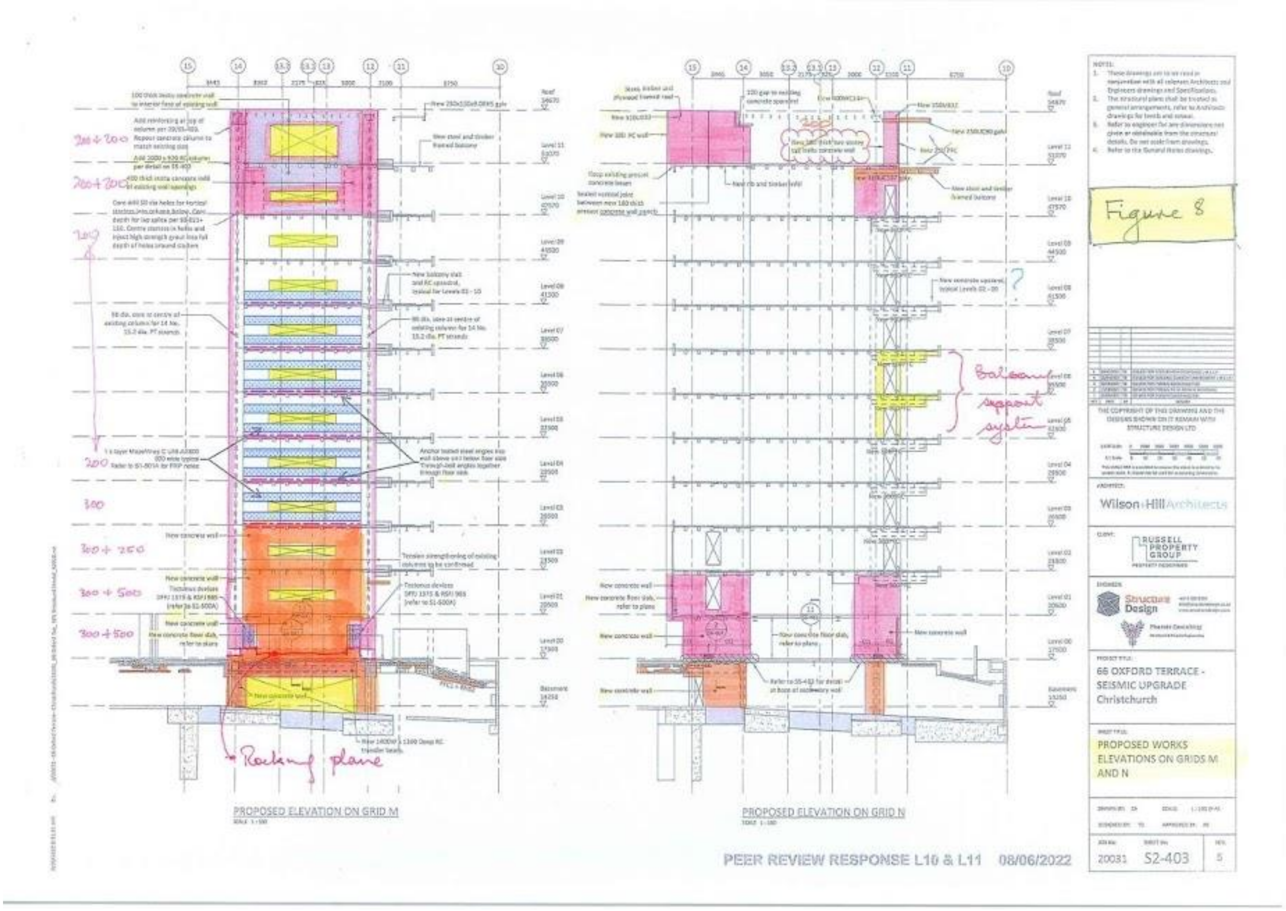
Figure 8
Rocking plane
Balcony support system
PROPOSED ELEVATION ON GRID M
PROPOSED ELEVATION ON GRID N
PEER REVIEW RESPONSE L10 & L11 08/06/2022
Wilson Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS ELEVATIONS ON GRIDS M AND N
20031
S2-403

Figure 8

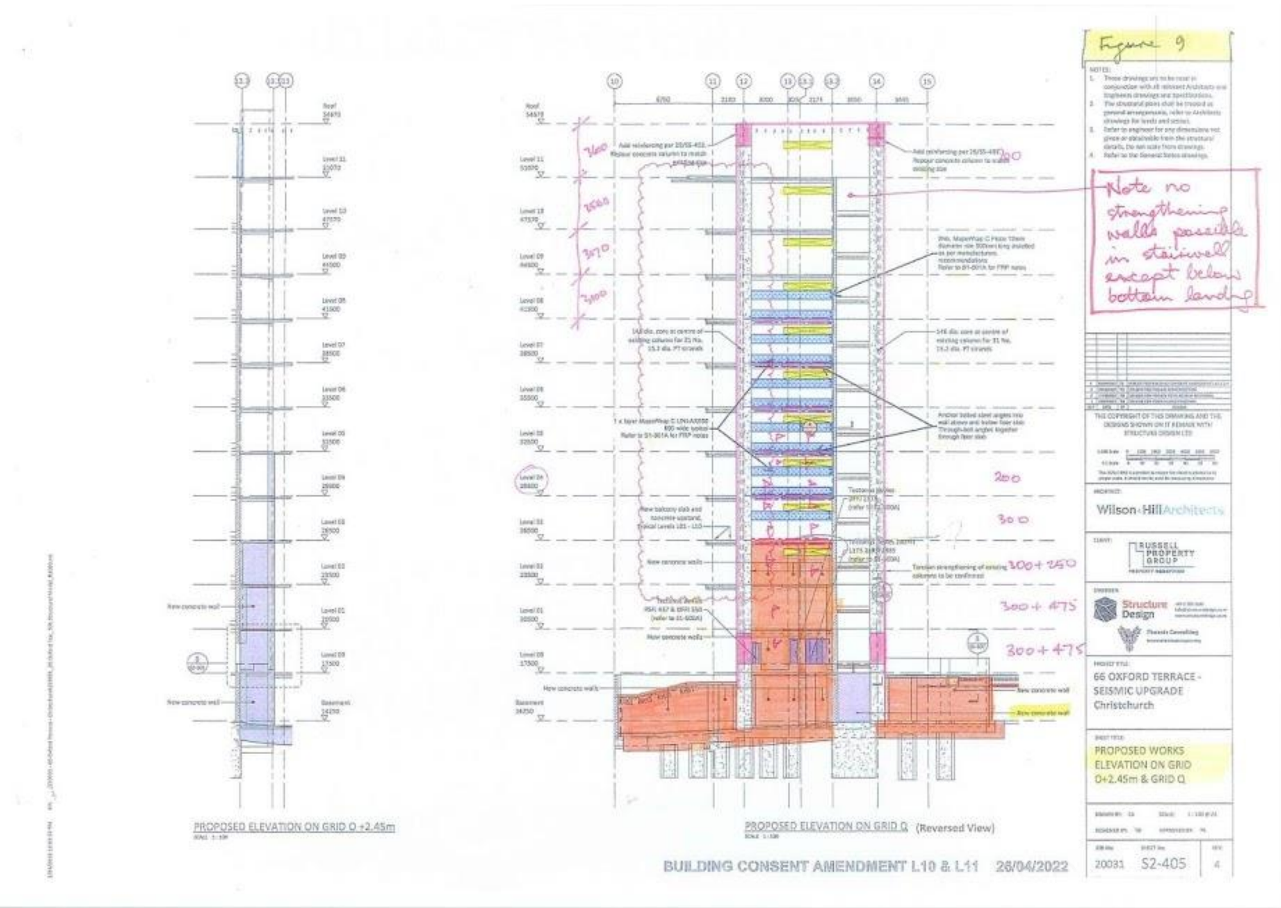
Figure 9
Note no strengthening walls possible in stairwell except below bottom landing
PROPOSED ELEVATION ON GRID Q +2.45m
PROPOSED ELEVATION ON GRID Q (Reversed View)
BUILDING CONSENT AMENDMENT L10 & L11 26/04/2022
Wilson Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS ELEVATION ON GRID Q+2.45m & GRID Q
20031
S2-405

Figure 9

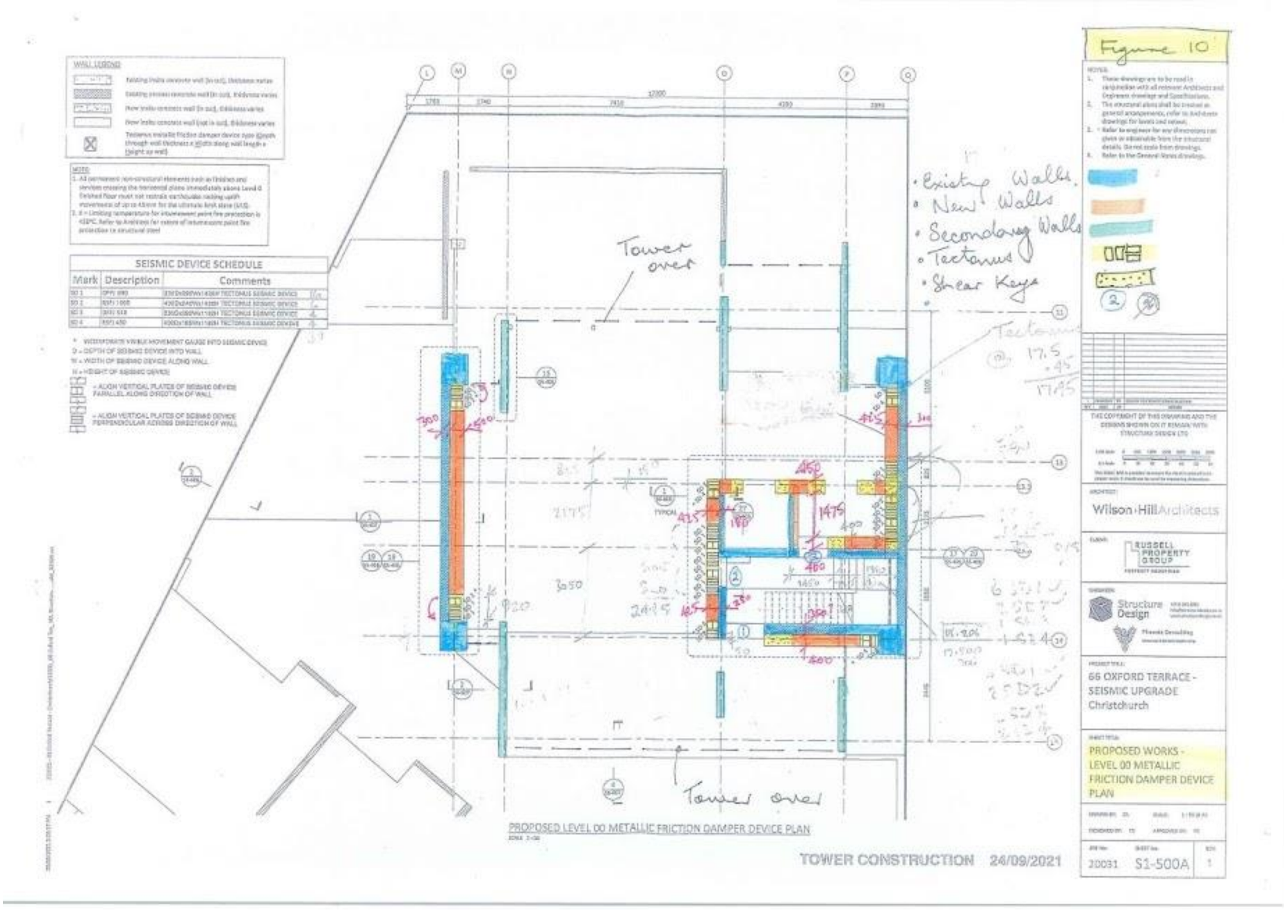
Figure 10
SEISMIC DEVICE SCHEDULE
Tower over
Tower over
Existing Walls
New Walls
Secondary Walls
Tectonus
Shear Keys
Wilson Hill Architects
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS - LEVEL 00 METALLIC FRICTION DAMPER DEVICE PLAN
PROPOSED LEVEL 00 METALLIC FRICTION DAMPER DEVICE PLAN
TOWER CONSTRUCTION 24/09/2021
S1-500A

Figure 10

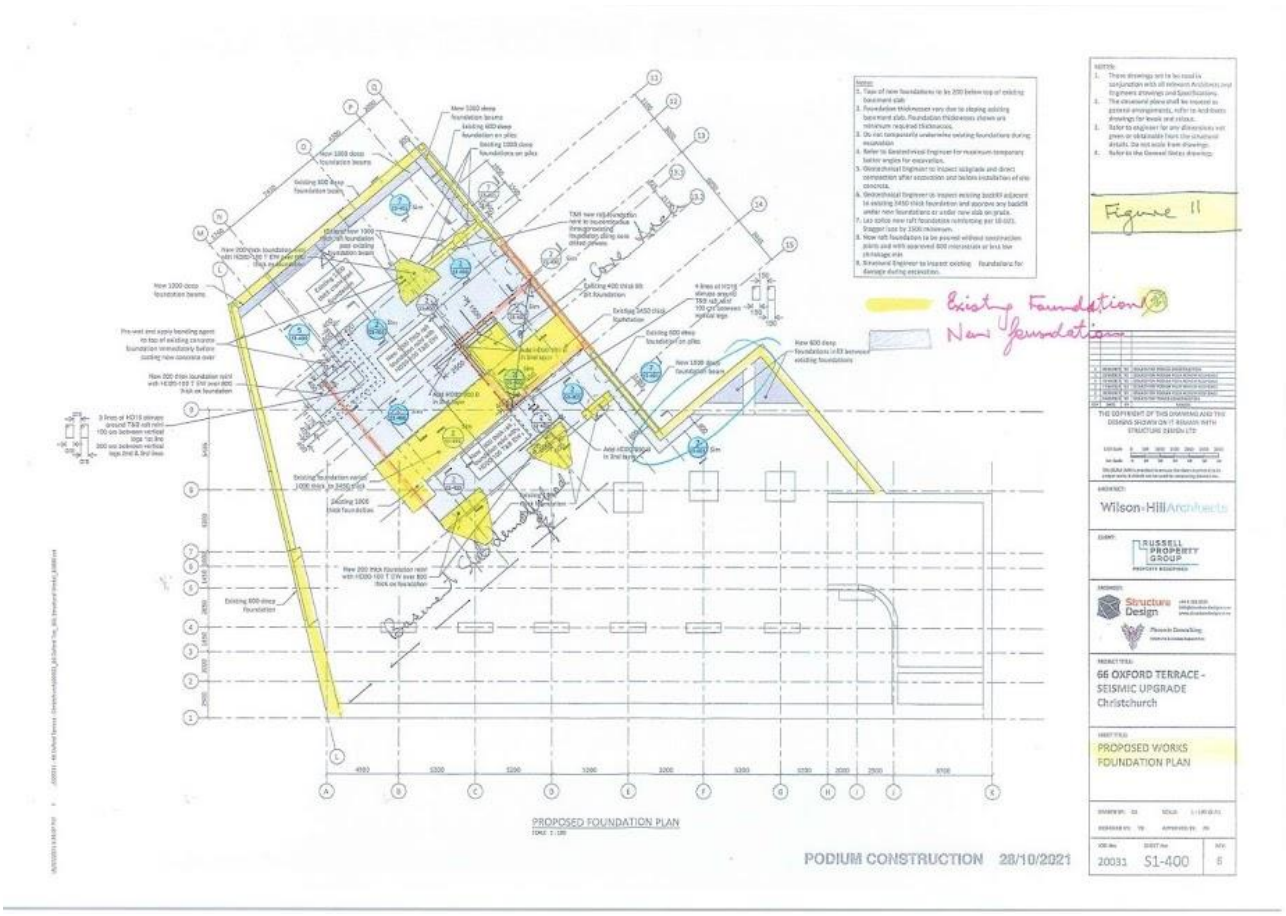
Figure 11
Existing Foundation
New foundation
Wilson-Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS FOUNDATION PLAN
PROPOSED FOUNDATION PLAN
PODIUM CONSTRUCTION 28/10/2021
20031 S1-400

Figure 11

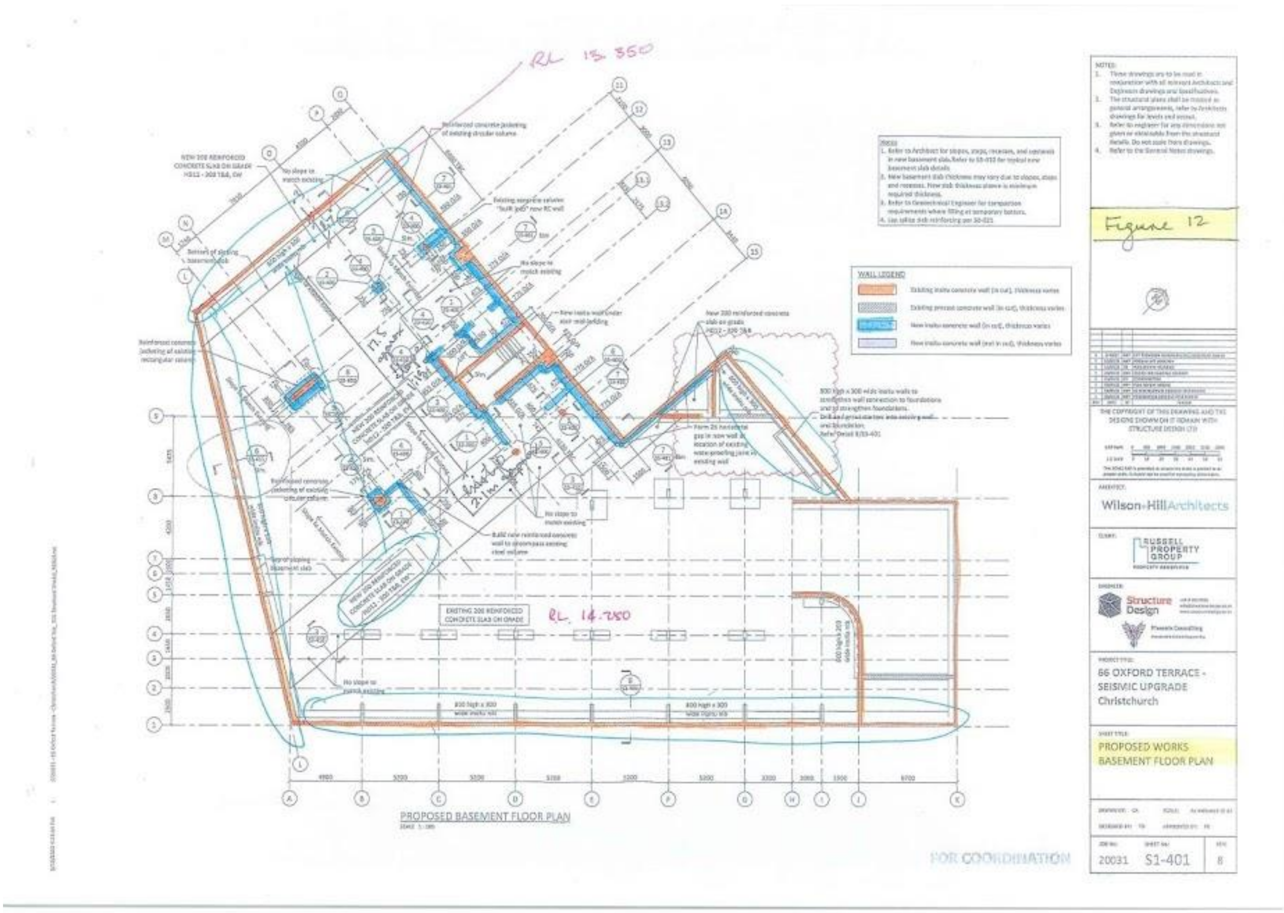
RL 13.350
Figure 12
RL 14.280
PROPOSED BASEMENT FLOOR PLAN
WALL LEGEND
Wilson-Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS BASEMENT FLOOR PLAN
FOR COORDINATION
20031
S1-401

Figure 12


STRUCTURAL FRAMING SCHEDULE
Mark
Comments
Figure 13
Wilson-Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS LEVEL 00 PODIUM SOFFIT BRACING (REFLECTED CEILING PLAN)
20031
S1-500B
7
LEVEL 00 PODIUM SOFFIT BRACING SETOUT PLAN
PODIUM CONSTRUCTION REVISIONS 23/09/2021

Figure 13

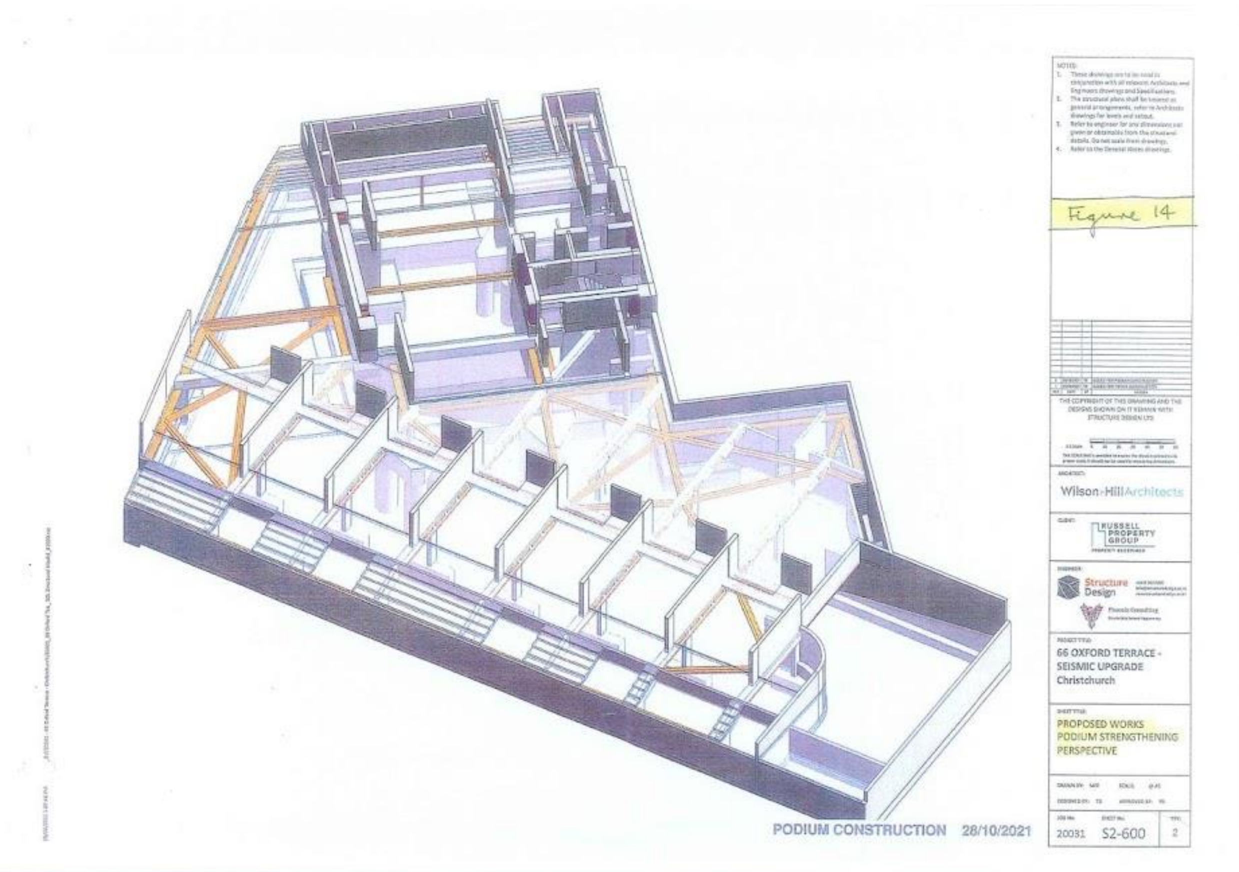
Figure 14
Wilson-Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE
Christchurch
PROPOSED WORKS
PODIUM STRENGTHENING
PERSPECTIVE
PODIUM CONSTRUCTION 28/10/2021
20031
S2-600
2

Figure 14

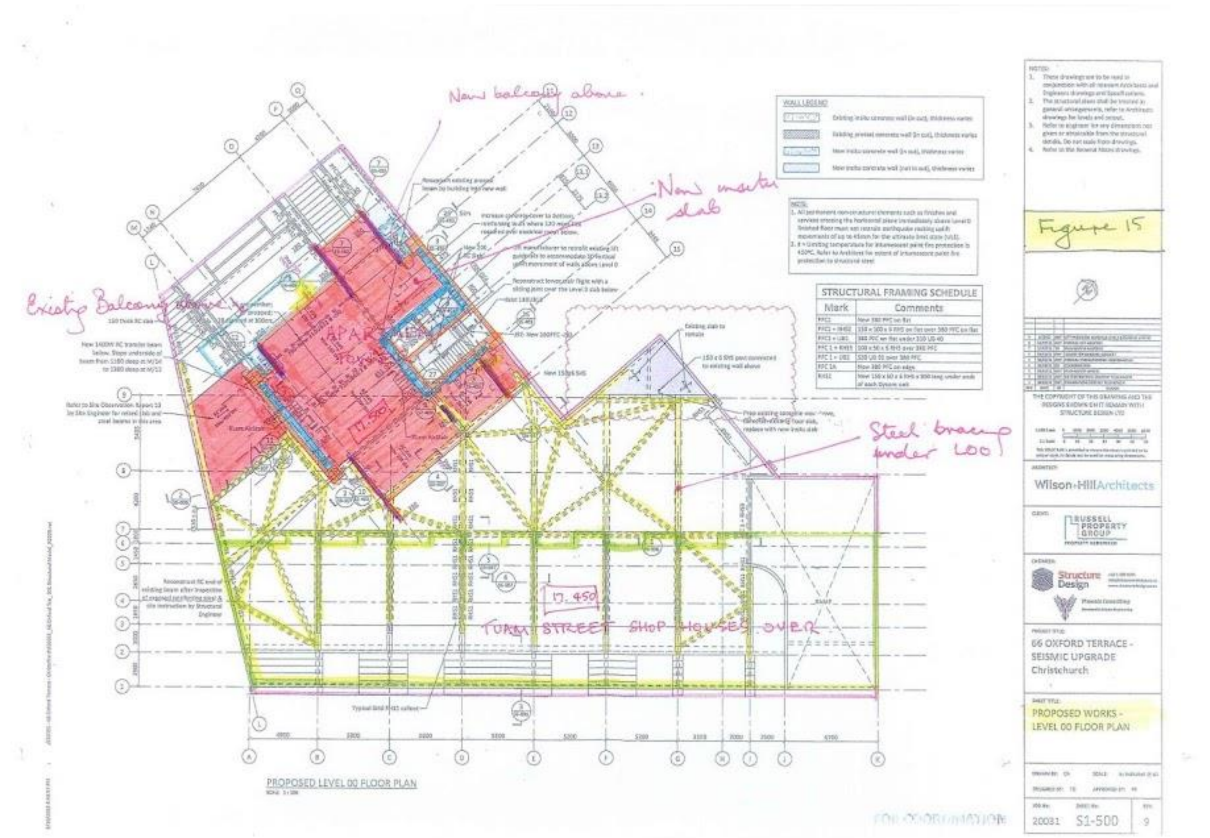
New balcony above
Existing Balcony above
Steel bracing under L00
Figure 15
STRUCTURAL FRAMING SCHEDULE
Wilson-Hill Architects
66 OXFORD TERRACE - SEISMIC UPGRADE
Christchurch
PROPOSED WORKS - LEVEL 00 FLOOR PLAN
PROPOSED LEVEL 00 FLOOR PLAN
20031
S1-500

Figure 15

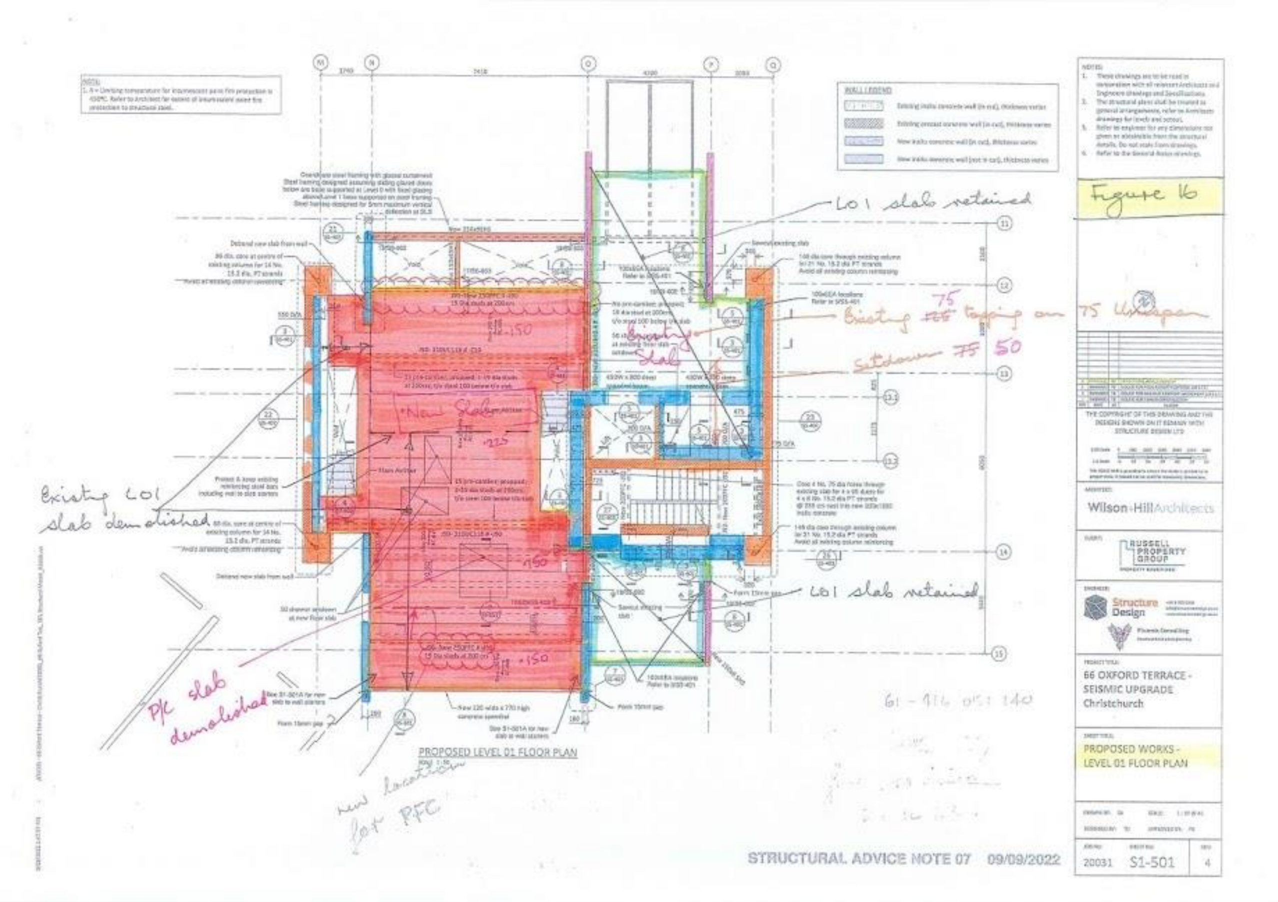
L01 slab retained
Figure 16
Existing L01 slab demolished
P/C slab demolished
new location for PFC
PROPOSED LEVEL 01 FLOOR PLAN
STRUCTURAL ADVICE NOTE 07 09/09/2022
Wilson+Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
PROPOSED WORKS - LEVEL 01 FLOOR PLAN
20031
S1-501

Figure 16

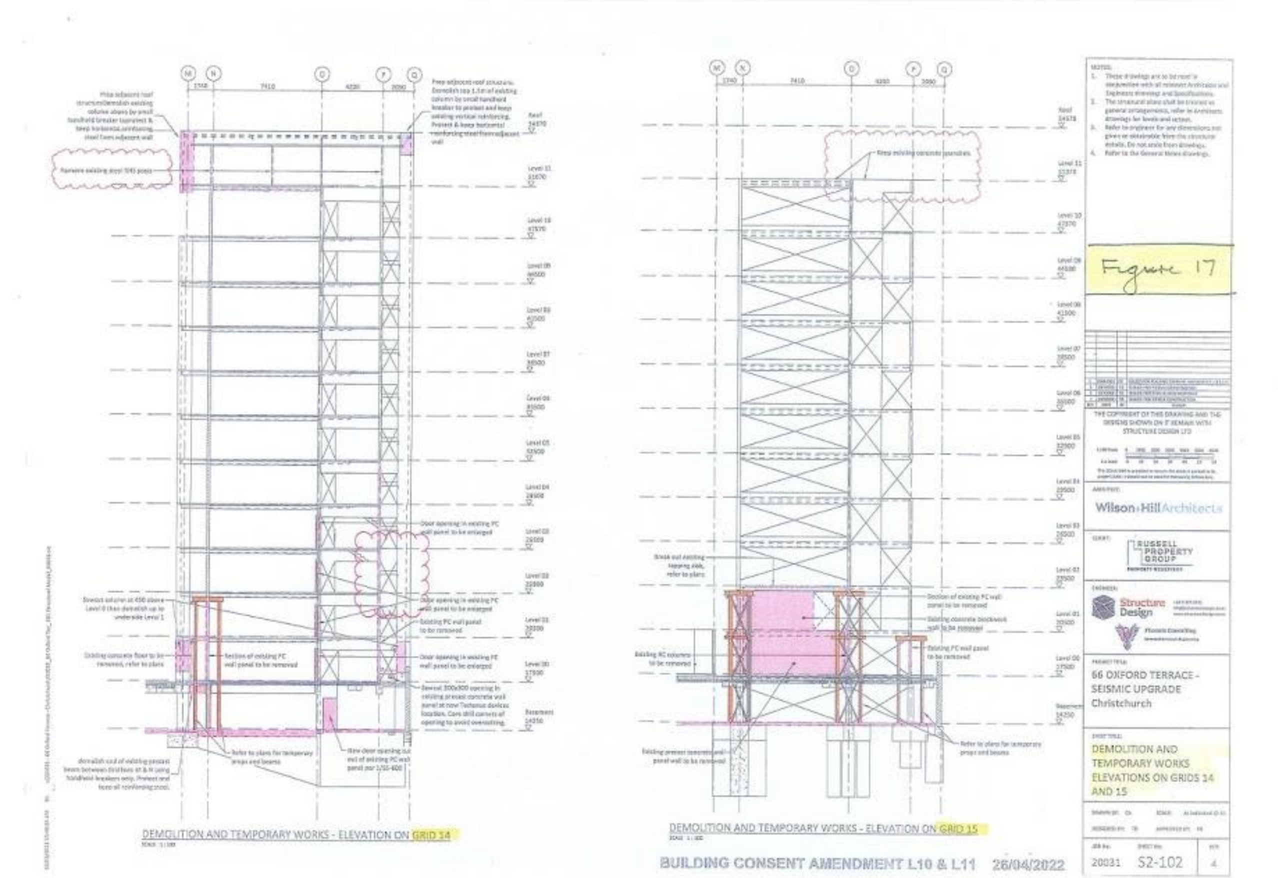
DEMOLITION AND TEMPORARY WORKS - ELEVATION ON GRID 14
DEMOLITION AND TEMPORARY WORKS - ELEVATION ON GRID 15
BUILDING CONSENT AMENDMENT L10 & L11 26/04/2022
Figure 17
Wilson+Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE Christchurch
DEMOLITION AND TEMPORARY WORKS ELEVATIONS ON GRIDS 14 AND 15
20031
S2-102

Figure 17

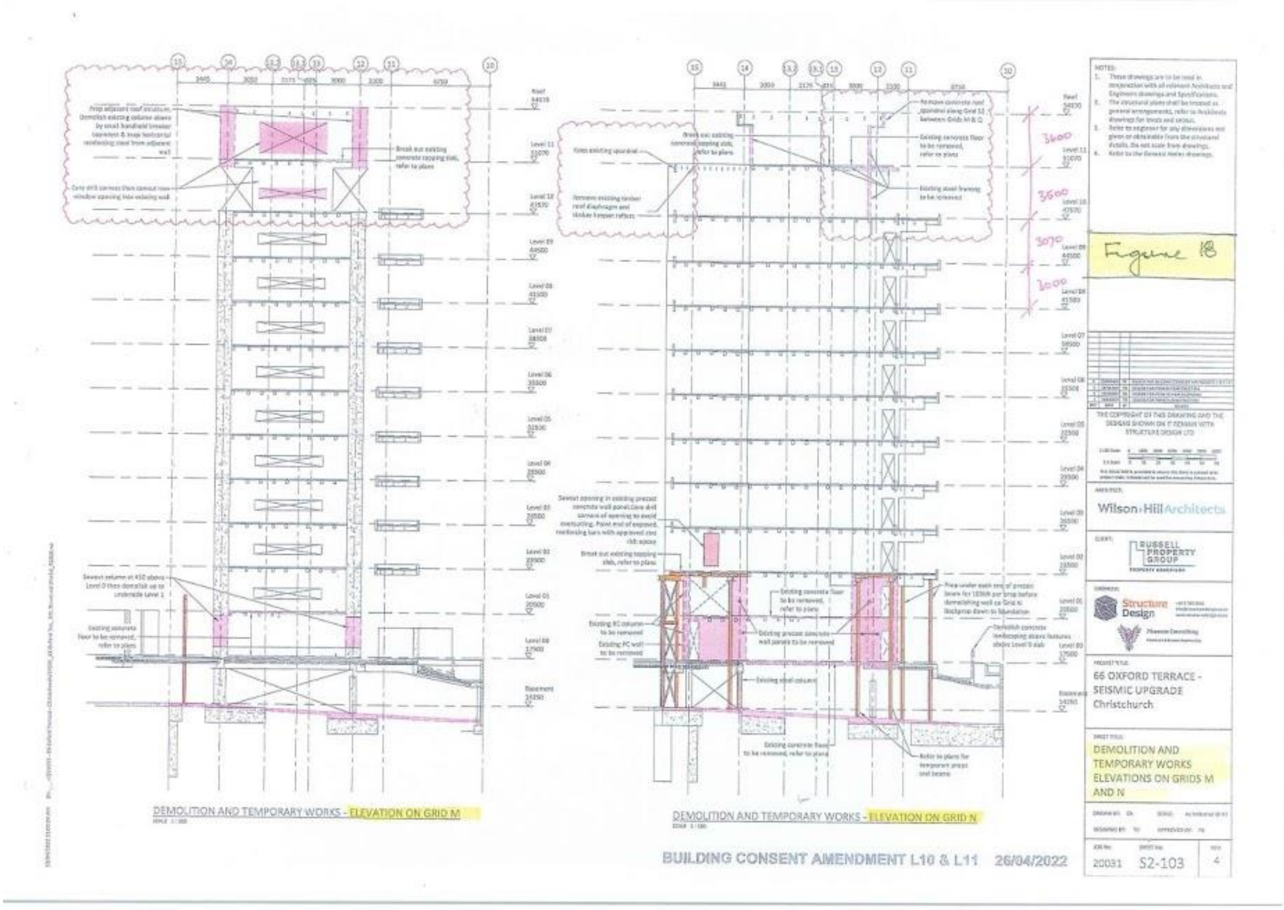
Figure 18
DEMOLITION AND TEMPORARY WORKS - ELEVATION ON GRID M
DEMOLITION AND TEMPORARY WORKS - ELEVATION ON GRID N
BUILDING CONSENT AMENDMENT L10 & L11 26/04/2022
Wilson+Hill Architects
RUSSELL PROPERTY GROUP
Structure Design
66 OXFORD TERRACE - SEISMIC UPGRADE
Christchurch
DEMOLITION AND TEMPORARY WORKS ELEVATIONS ON GRIDS M AND N
20031
S2-103
4

Figure 18