INDEPENDENT ASSESSMENT ON EARTHQUAKE PERFORMANCE
OF
194 Hereford Street

FOR
Royal Commission of Inquiry into building failure
caused by the Canterbury Earthquakes

Report prepared by Peter C Smith and Jonathan W Devine
OF
Spencer Holmes Ltd

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Introduction

This report has been commissioned by the Royal Commission of Inquiry into building failure caused by the Canterbury Earthquakes to review the performance of the building at 194 Hereford Street, Christchurch during the Canterbury earthquake sequence.

The report is based on documentation provided by the Royal Commission of Inquiry into building failure caused by the Canterbury Earthquakes. No inspection of the building was possible before the building was demolished.

Location of Building

The site is at the south east corner of the intersection between Liverpool and Hereford Street. The location of the building in the Christchurch CBD is shown on the aerial photograph of Christchurch included in Appendix 1.

Site

A geotechnical desk study was undertaken on this site in February, 2005 by Tonkin & Taylor. This investigation was requested by the Christchurch City Council due to the concerns over the sites potential for highly liquefiable ground. The report concluded;

> *"most of the sub-soils in Christchurch are potentially liquefiable. In general, ground conditions most susceptible to liquefaction are shallow, water saturated, loose or soft well sorted silt and sand strata. Deposits where inter-bedded gravel layers occur with sand and silt strata are less likely to liquefy, and the generally well graded, dense gravel beneath Christchurch is considered non liquefiable.*
>
> *The sub-soils at 194 Hereford Street were identified on a local scale to be potentially highly liquefiable under an earthquake event. This was based on shallow groundwater levels and the inferred presence of sand and silt strata. However, if sub-soils underlying the site were found to comprise inter-bedded strata of gravel and well-graded dense gravels as encountered at 187 Cashel Street, the sub-soils would be less likely to liquefy. Such detail cannot be inferred from nearby site investigation data because of the known variability of the Christchurch soils.*
>
> *The building foundations shown on drawings (provided by O'Loughlin Taylor Spence Ltd) are typical shallow pad foundations. These were expected to be founded on the alluvial silts and sands above the ground water level. This type of foundation was not uncommon for a low-rise building. Many low-rise buildings in Christchurch were founded on shallow pads and several multi-storey buildings in the city centre were also known to be founded on pad foundations.*
>
> *Based on these desk study findings and the known shallow pad foundations, if any earthquake event occurred causing the soils beneath the site to liquefy, differential settlement of the building is a possibility".*

The site was assessed as likely to be underlain by predominantly silty and sandy silts at 2 to 5 metre depth. 10 to 15% of zone could liquefy.

Description of Building

The building at 194 Hereford Street had two levels and occupied the entire corner site (approx 205sqm). The Liverpool Street frontage was approximately 19.5 metres long and the frontage to Hereford Street was approximately 10 metres long. Refer attached plan in Appendix 2.

The ground level of the building contained a restaurant. A three-bedroom apartment occupied the first floor, with stair access only.

The building was built circa 1930 of un-reinforced masonry with lime-based mortar. The building was strengthened and retrofitted internally in 2005/2006. Retrofitting removed all internal partitions leaving the external masonry walls, first floor and foundations. The external walls to the street frontage were of cavity construction supported by double brick construction at first floor and treble brick at ground floor. Reinforced concrete bond beams were located over the window and door openings on both the ground and first floor.

Gravity System

Transverse steel portal frames were introduced to carry gravity loads at roof and first floor level. The frames were supported on new shallow pad foundations. The spacing of these portal frames varied between 3.2 metres and 4.1metres to meet the set out of the existing windows. No portal frames were installed to either the northern wall or the southern wall of the building where the original masonry walls carried the floor and roof loads to the original foundations. The retrofit was designed and constructed to enable a second floor level to be added at a later stage.

Seismic System

The building was strengthened laterally in the east-west direction using steel portal frames.

The seismic resisting system in the north-south direction relied on the strength of the east unreinforced masonry wall, with torsional loads being resisted by the portal frames. No additional seismic resistance was provided to the east or west walls.

Compliance

There is reference in the Christchurch City Council record sheets of the building being earthquake prone in 1994. The records indicate that the building was in a very original condition until February, 2005.

Substantial retrofit and upgrading was undertaken in 2005. According to the O'Loughlin Taylor Spence Ltd's letter of the 27th of April 2011, the portal frames were designed to 80% of the requirements of NZS 4203 with provision for an additional storey.

A review of the compliance documentation establishes that three separate building consents were issued by the Christchurch City Council for upgrades to the building, including earthquake strengthening. These consents were dated 15 February, 2005 (ABA10051163), 2nd November, 2005 (ABA10059508) and 30th July, 2007 (ABA10076671).

There is a record of an additional drawing dated the 15th of July 2004 which shows alterations to each level as well as an additional level being added. While the work was assigned a building consent (ABA10047467) , the consent was never fully processed as the owner advised that the work was not to proceed.

The Christchurch City Council issued code compliance certificates on 12th May, 2006 for building consents 10051163 and 10059508, a code compliance certificate for building consent 10076671 was issued on 15th August, 2007.

Christchurch City Council Policy on Earthquake Prone Buildings

We understand that the Christchurch City Council applied for and was granted powers under Section 301A of the Municipal Corporation Act in 1969 and that the Christchurch City Council adopted a generally passive approach to the upgrading of earthquake risk buildings.

There are no records of any communication between the Christchurch City Council and the building owners with respect to any Seismic Risk Building -Survey or Hazardous Appendage Survey.

The Christchurch City Council's first policy in respect to earthquake prone buildings was introduced in 2006.

This policy was reviewed in 2010.

Events Subsequent to 4th September 2010 Earthquake

The building is not recorded as being damaged in the 4th September, 2010 or 26th December, 2010 earthquakes

The building did suffer significant damage in the 22 February 2011 earthquake. (Refer photos Appendix 3).

The Christchurch City Council records of 22.03.2011 reports: "detached unreinforced masonry. Prop/brace else demolish."

O'Loughlin Taylor Spence Ltd's letter of the 27th of April 2011, titled 194 Hereford Street, Christchurch-Earthquake Damage Post 22 February, 2011, records the extent of damage to the building.

A summary of damage as noted in the letter from O'Loughlin Taylor Spence Ltd is as follows:

- *Collapse of the unreinforced masonry (URM) parapets from the North, West & South elevations.*
- *Collapse of the URM North façade at first floor level including two-thirds of reinforced concrete (RC) roof level bond beam.*
- *Collapse of the East URM parapet and fire wall at first floor level of North façade back to first steel portal frame.*
- *Collapse of southern external URM double skin cavity wall and its east return wall at first floor and outer skin at ground floor.*
- *Collapse of single level URM wall on south side of rear courtyard (area housed a cool room).*
- *Damage to the lightweight roof at north end.*

- *Breaks and damage to first floor URM corner columns in NW & SW corners.*
- *Additional cracking to the plasterwork of all remaining URM columns indicating distress to the brickwork however movement has been limited.*

O'Loughlin Taylor Spence Ltd commented that there was little other damage or distress to the remaining structure (Refer to the photos in Appendix 4).

No comment was made as to any liquefaction that was observed on the site.

A critical aspect of the failure was the separation of the masonry walls from the strengthening elements.

Structural Failure

The Royal Commission has been fortunate to have been forwarded video footage of the performance of the building during the 22nd February 2010 earthquake. The footage was taken from south west of the building. The footage establishes that an outward failure of the south wall initiated at the south eastern corner at parapet level, rapidly spreading across the south wall at parapet level. A progressive outward collapse of the south wall and the parapet to the west wall is recorded.

A review of the Police Operation Earthquake photographs taken of the building after 22nd February, 2011 earthquake and photos taken by Dr Jason Ingham, record the presence of the bolts installed through the un-reinforced masonry wall and parapets connecting the un-reinforced masonry wall to the floor framing at the future 2nd floor level. These bolts appear to be spaced at approximately 800 centres and to be provided with a 100mm x 100 mm square washer, presumably placed on the exterior of the masonry wall. The presence of the bolts in an apparently undamaged condition fixed to the timber framing suggests that the un-reinforced masonry wall literally disintegrated under the intensity of shaking on 22nd February, 2011.

The code lateral load coefficient for a façade to an elastic responding structure in Christchurch at the time of the earthquake sequence was 0.86g. The façade was designed for a lateral load coefficient of 80% of the requirements of NZS4203, in 2005. The lateral load coefficient for a first floor wall in a two-storey building as in NZS4203 1992 was 0.56g. The analysis of un-reinforced masonry construction in not covered in the NZ Building Code. The industry uses the New Zealand Society for Earthquake Engineering guidelines 'Assessment and Improvement of the Structural Performance of Buildings in Earthquakes' 2000 and Assessment and Improvements of Un-reinforced Masonry Buildings for Earthquake Resistance' 2011. Calculations using these documents indicated that a sound 225mm thick un-reinforced masonry wall spanning 3m from first floor level to roof level and effectively restrained at roof level would meet code requirements. Based on GNS Science records of measurements of accelerations in the Christchurch CBD during the 22nd February, 2011 earthquake, the building is likely to have been subjected to a ground acceleration of 0.9g. This level of ground acceleration equates to an acceleration of 1.25g at first floor level. The analysis assumes no vertical acceleration occurs when the wall is subjected to the horizontal acceleration. A review of the earthquake records establishes that high vertical accelerations did occur over the period of intense horizontal shaking. The above figures demonstrate that failure of the secured unreinforced lime mortar parapets and walls was almost inevitable under the intensity of shaking that occurred on the 22nd February 2010.

The near vertical fracture of the junction of the south wall to the west (Liverpool Street) wall and the near vertical failure of the inner skin at this location reflects on the poor quality of the original un-reinforced masonry construction.

Issues Arising From Review

Effectiveness of strengthening

The parapets on the east and west sides were fixed to a steel channel spanning between the main frames. The parapet to channel fixing being detailed as "M20 into sieves filled with Chemset injection technique at 800mm centres". The detail shows the anchor angled up at approximately 65mm into the outer veneer. Parapets to the north and south were also fixed to a steel channel fixed under the DHS roof purlins. A similar Chemset fixing to the east and west walls was detailed.

Upper level cavity walls were shown to have Hilti HY 20 injection system wall ties, again with a sieve/sleeve across the cavity.

The unreinforced exterior masonry walls were connected to the steel portal frame with M16 threaded rods at 400crs to each portal leg. The plans required holes to be drilled and threaded rods placed into the walls and fixed with an Epoxy Chemset Injection System or cement grout. The timber floor and the roof trusses were also fixed to the masonry wall using M16 threaded rods.

The objective of strengthening unreinforced masonry buildings has been to improve the performance of these buildings in the event of a moderate earthquake. The performance of unreinforced masonry in a severe earthquake has always been of concern. The strengthening of the building was effective in preventing loss of life during the 4th September, 2010 earthquake, and the 26th December, 2010 earthquake which are assessed as moderate earthquakes. We understand that the strengthening was also effective in limiting damage under those events.

The failure of parapets and the north and south walls in the severity of shaking that occurred during the 22nd February 2011 earthquake demonstrates the vulnerability of unreinforced masonry to the effects of severe shaking, and in particular the upper levels of unreinforced masonry construction to the effects of vertical accelerations during earthquake shaking. We consider it significant that the street façade to Liverpool Street was retained, presumably as a result of the strengthening work undertaken on the building and the presence of the steel columns.

The vertical accelerations that occurred during the 22nd February, 2011 earthquake would have significantly reduced the out of plane strength of lime mortar un-reinforced masonry north and south wall façades. It is appropriate to record that the axial load in the upper floor un-reinforced masonry walls is relatively low and that these walls were more susceptible to vertical acceleration effects under out of plane failure.

It is suggested that in the interests of public safety good practice introduce requirements for consideration of vertical acceleration effects for the upper storey of un-reinforced masonry buildings.

Upgrading of un-reinforced masonry buildings

The failure of the facades demonstrates the difficulty of securing low quality un-reinforced masonry to the strengthening element, particularly in the upper storey of un-reinforced masonry buildings.

After decades of no research being undertaken on unreinforced masonry construction, the University of Auckland has recently undertaken some worthwhile research on un-reinforced masonry buildings as part of the retrofit project. It is suggested that further research be undertaken on developing improved methods for assessing and securing un-reinforced masonry construction to reduce future facade failures.

Epoxy fixings

The photos taken by Dr Jason Ingham clearly show that the epoxy anchored steel dowels were left projecting from the steel members. Noticeably, the steel members were relatively straight and the majority of dowels did not have any masonry attached, but the epoxy surrounding the dowels is clearly evident. (Refer Appendix 4).

The separation of some of the epoxied dowels from the un-reinforced masonry wall appears to have occurred with minimal distress to the steelwork indicating that the fixings either had a low strength or that the wall effectively disintegrated under the severity of shaking.

It is possible that workmanship may have been a factor in the failure of the connection between the external walls and the strengthening works. Workmanship is an important aspect in the use of epoxy based fasteners. The Ramset technical information on Epoxy Chemset fasteners requires the holes to be cleaned with a hole cleaning brush and to remove all debris using a hole blower. The hole may be damp but no water present. The installation criteria are for the mortar to be at 15 to 30 degrees Celsius and the substrate to be at 0 to 43 degrees Celsius. Epcon anchors are even more restrictive requiring installation temperatures of the mortar to be at 18 to 35 degrees Celsius and the substrate to be at 5 to 40 degrees Celsius. (Refer Ramset Technical Data sheets Appendix 5).

If the Chemset epoxy was not placed in accordance with the manufacturers installation requirements, workmanship may have contributed to the failure of the north and west walls. Heightened industry awareness of the importance of workmanship and temperature in the use of epoxy fixing systems is required and increased construction monitoring or proof testing for quality assurance of these fixings seems justified.

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APPENDIX 1:

Site Plans

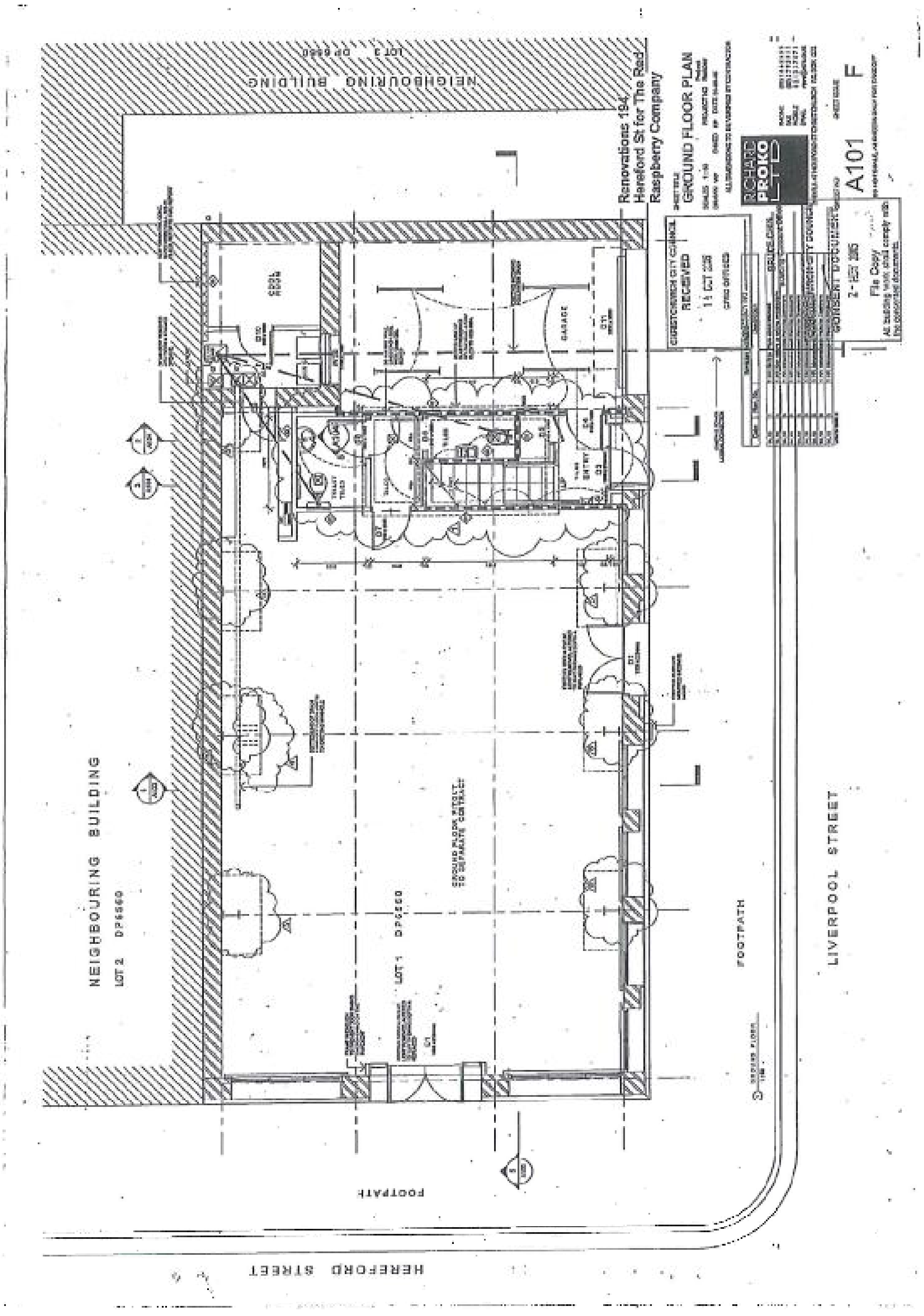

NORTH
Hereford St
Mw7.1 - 4th SEP 2010
No.194
Liverpool St
Woolsack Ln
Madras St

BUI.HER194.0030.10

APPENDIX 2:

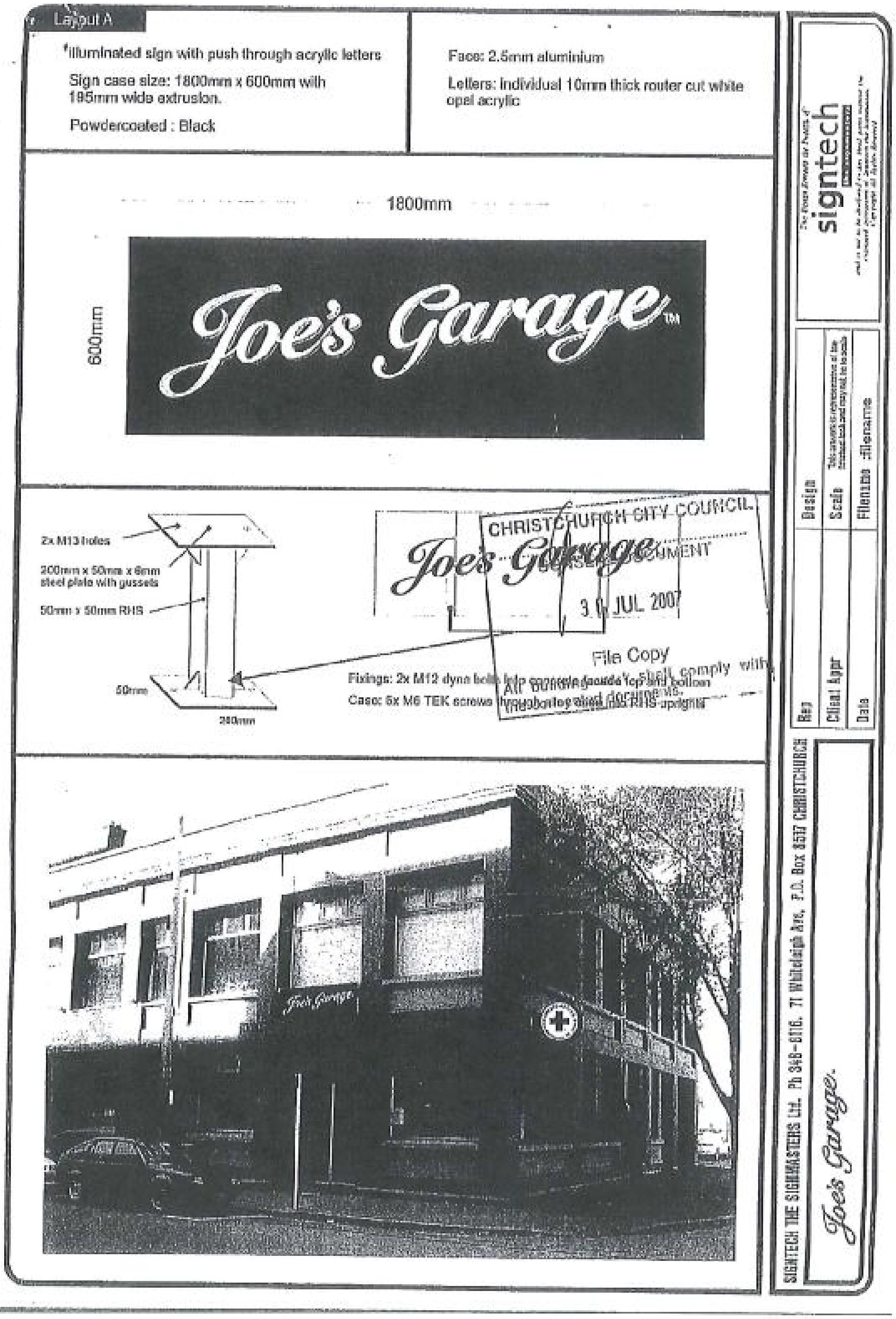
Plan of 194 Hereford Street

BUI.HER194.0030.12



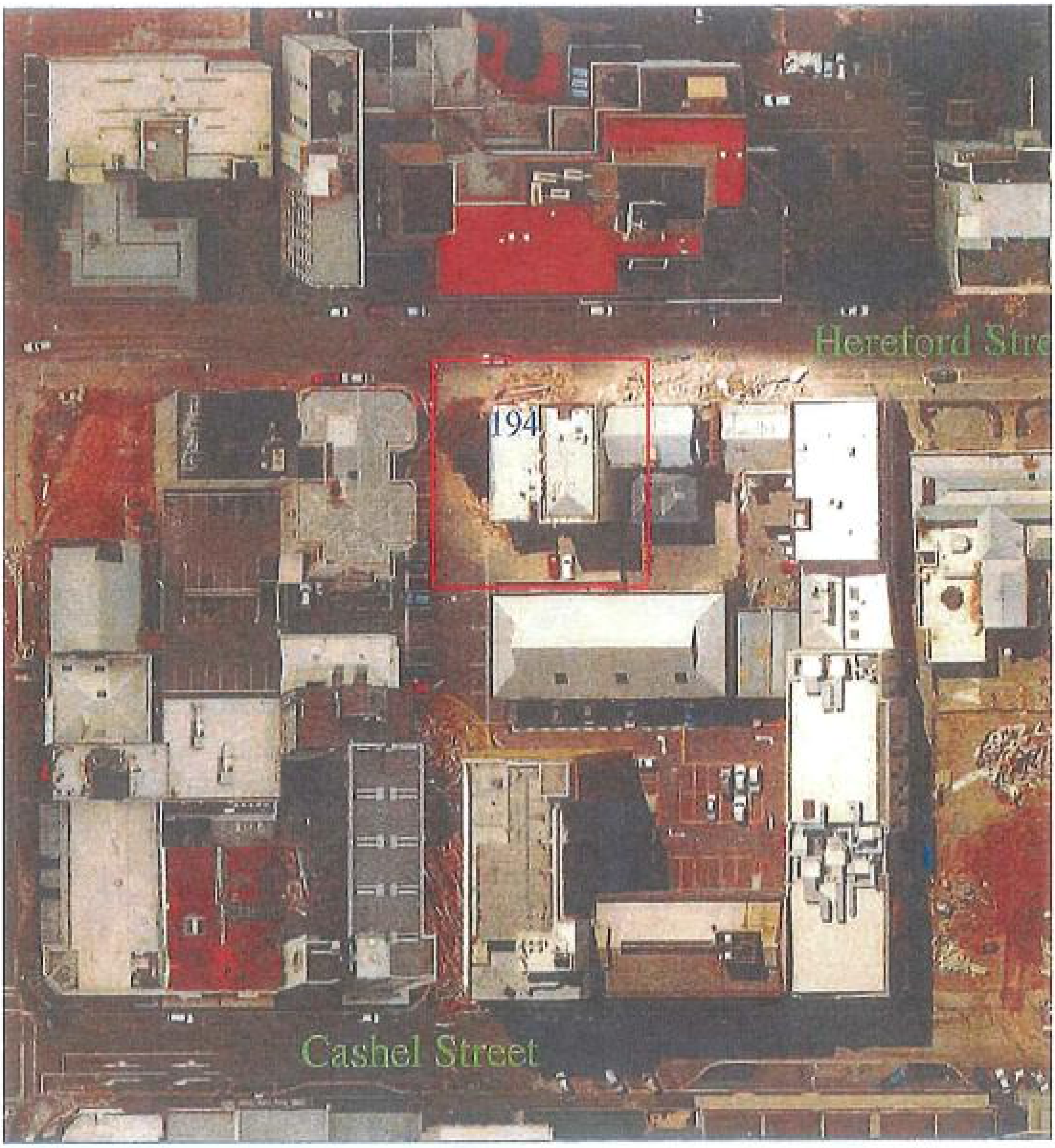
APPENDIX 3:

Photo of building before 22 February 2011 earthquake


Layout A
Illuminated sign with push through acrylic letters
Sign case size: 1800mm x 600mm with 195mm wide extrusion.
Powdercoated : Black
Face: 2.5mm aluminium
Letters: Individual 10mm thick router cut white opal acrylic
1800mm
600mm
Joe's Garage TM
2x M13 holes
200mm x 50mm x 6mm steel plate with gussets
50mm x 50mm RHS
50mm
200mm
Fixings: 2x M12 dyna bolts into concrete
Case: 6x M6 TEK screws
CHRISTCHURCH CITY COUNCIL
30 JUL 2007
File Copy
signtech
Design
Scale
Filename
Rep
Client Appr
Date
SIGNTECH THE SIGNMASTERS Ltd. Ph 348-6116. 71 Whiteleigh Ave, P.O. Box 8537 CHRISTCHURCH
Joe's Garage

APPENDIX 4:

Photos of building after 22 February, 2011 earthquake


Hereford Stre
194
Cashel Street

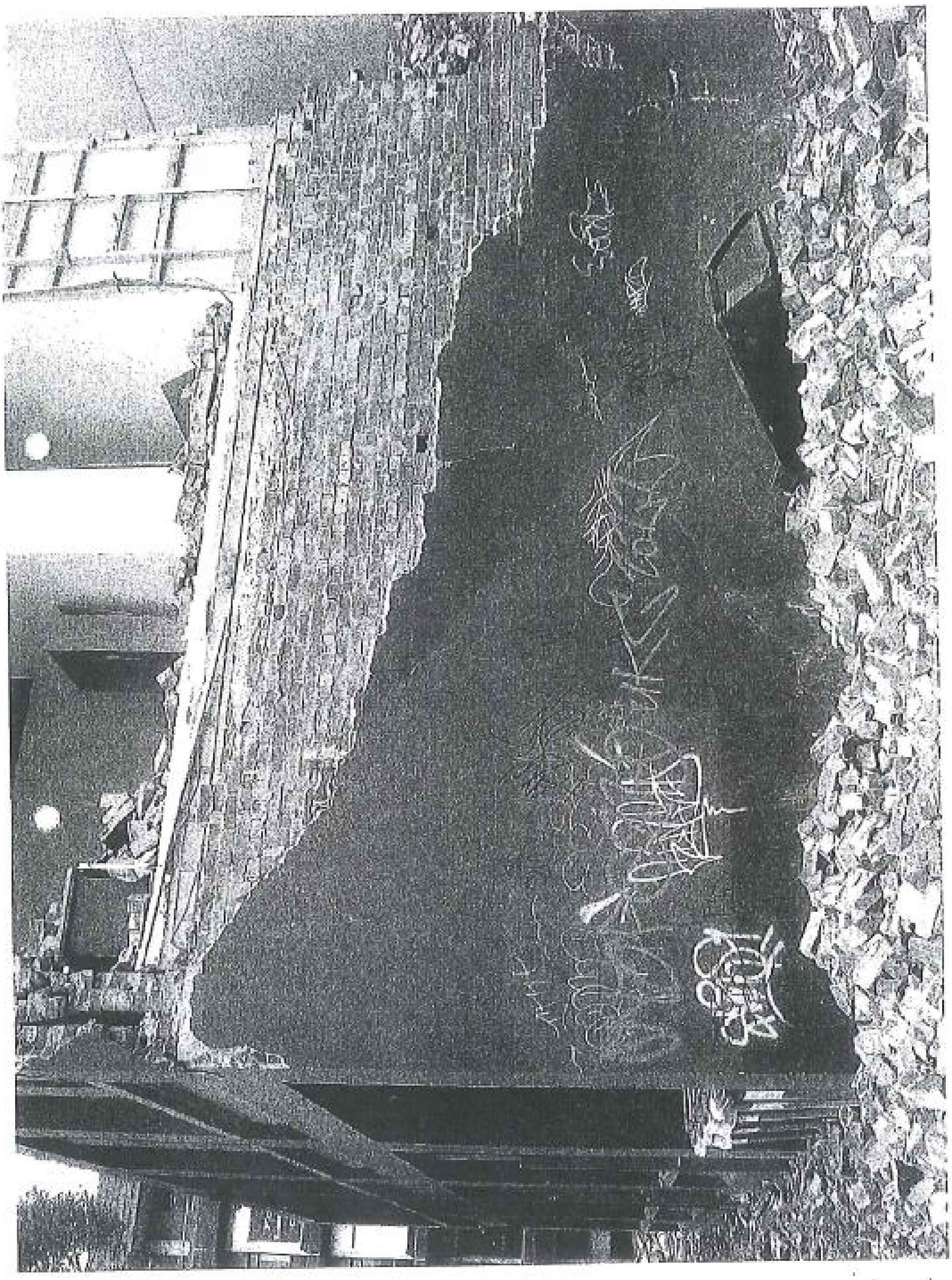
06

07

10

11

12



APPENDIX 5:

Ramset Technical Data Sheets
- Chemical Anchoring

Ramset™

Chemical Anchoring

Epcon™ C6 Series

General Information

Product

Epcon C6 Series are a chemical anchor system based on epoxy mortar. The two parts are dispensed and mixed in one action through a static mixing nozzle, which allows accurate mixing with no mess.

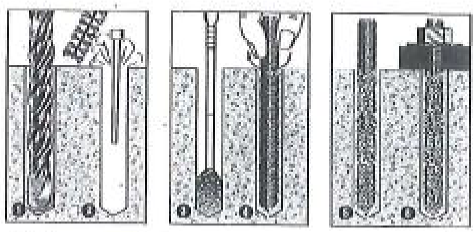
Features

- Superior strength in shallow embedment.
- Close to edge, stress free anchoring.
- Suitable for use with zinc plated, hot dipped galvanized or stainless steel Chemset Anchor Studs.
- Resistant to cyclic loading and vibration.
- Resistant to alkaline conditions.
- Suitable for use in core drilled holes.
- Superior strength with grade 5.8 steel Chemset Anchor Studs.
- Suitable for underwater installations.

Principal Application

- Structural beams and columns.
- Bottom plate and batten fixing.
- Installing sings, handrails, balustrades and gates.
- Racking
- Safety barriers.
- Stadium seating.
- Machinery and heavy plant hold down.

Installation



1. Drill recommended diameter and depth hole.
2. Clean hole with hole cleaning brush. Remove all debris using hole blower. Hole must be dry.
3. Insert mixing nozzle to bottom of hole. Fill hole to $^3/_4$ the hole depth slowly, ensuring no air pockets form.
4. Insert Ramset Chemset Anchor Stud/rebar to bottom of hole while turning.
5. Epcon to cure as per setting times.
6. Attach fixture.

Installation temperature limits:
Substrate: 5°C to 40°C.
Mortar: 18°C to 35°C

Load should not be applied to anchor until the chemical has sufficiently cured as specified.

Setting Times

Substrate Temperature	C6 Gel Time (mins)	C6 Loading Time (hrs)
40°C	–	–
30°C	4.5	1
25°C	5.5	1
20°C	7	1
10°C	20	2
5°C	40	3

Note: Cartridge temperature minimum 15°C.

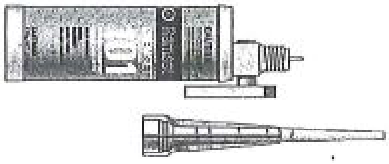
Ramset™ **Chemical Anchoring**

Chemset™ Injection 100 Series

General Information

Product

Chemset Injection 100 Series is a chemical anchor system based on polyester mortar. The two parts are dispensed and mixed in one action through a static mixing nozzle, which allows accurate mixing with no mess.



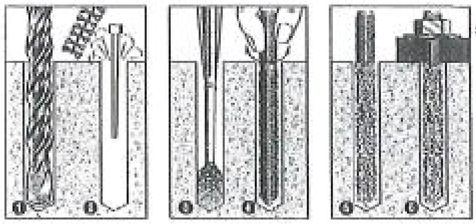
Features

- Close to edge, stress free anchoring.
- Close anchor spacing.
- Suitable for use with zinc plated, hot dipped galvanized or stainless steel Chemset Anchor Studs and Injection Rod
- Resistant to cyclic loading.
- Overhead installation.
- Fast cure.

Principal Application

- Structural beams and columns.
- Batten fixing.
- Installing signs, handrails, balustrades and gates.
- Racking.
- Safety barriers.
- Machinery hold down.

Installation



1. Drill recommended diameter and depth hole.
2. Clean hole with hole cleaning brush. Remove all debris using hole blower. Hole may be damp but no water present.
3. Insert mixing nozzle to bottom of hole. Fill hole to ³⁄₄ the hole depth slowly, ensuring no air pockets form.
4. Insert Ramset Chemset Anchor Stud/rebar to bottom of hole while turning.
5. Chemset Injection to cure as per setting times.
6. Attach fixture.

Installation temperature limits:
Substrate: 0°C to 43°C.
Mortar: 15°C to 30°C

Load should not be applied to anchor until the chemical has sufficiently cured as specified in the following diagrams.

Service temperature limits:
-10°C to 80°C.

Setting Times

Substrate Temperature	101 Gel Time (mins)	101 Loading Time (hrs)
40°C	4	0.75
30°C	7	1
20°C	10	1.5
5°C	30	5
0°C	40	7

Note: Cartridge temperature minimum 15°C.