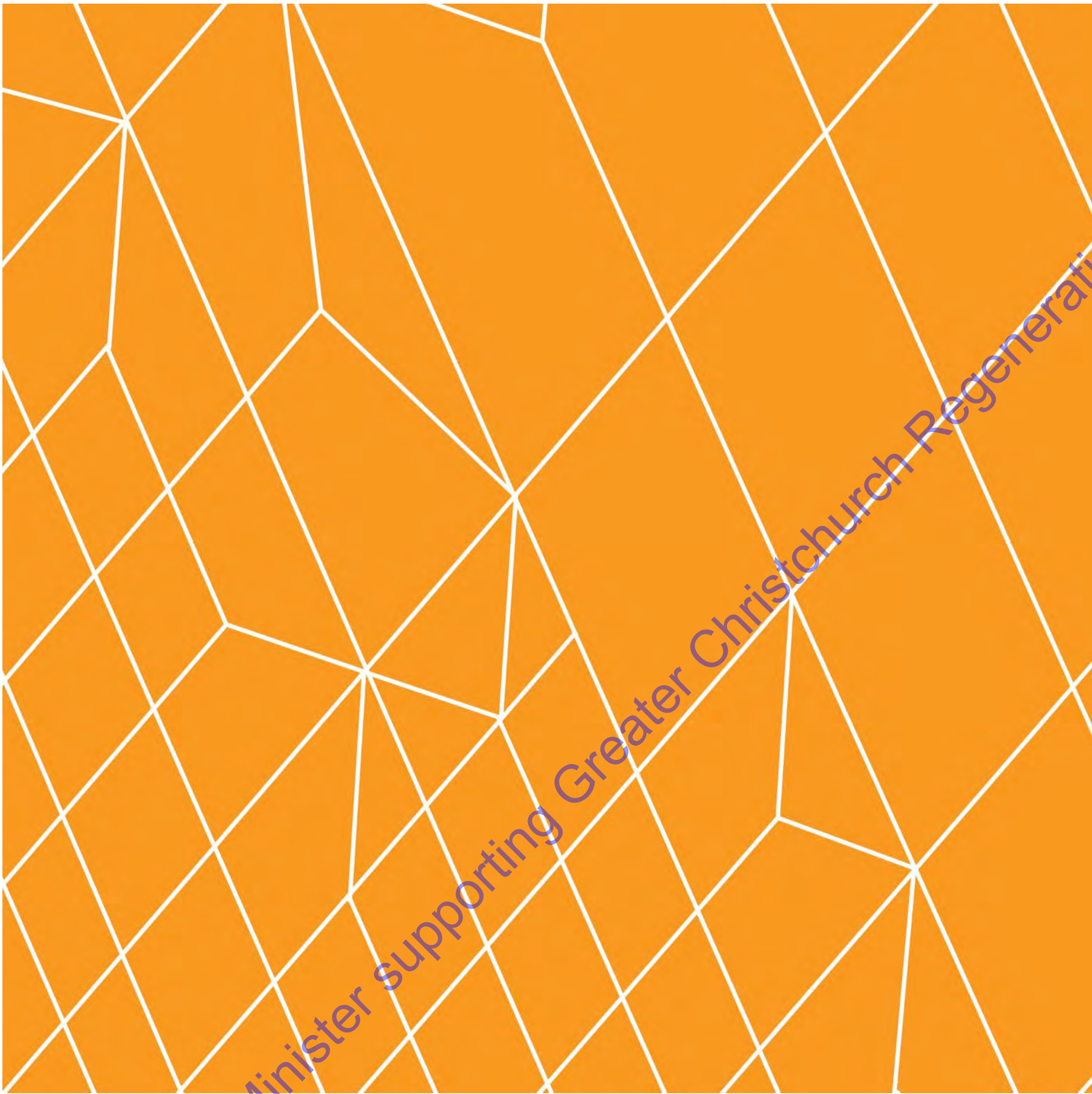
APPENDIX 5: THE STABILISATION AND REINSTATEMENT OF THE CATHEDRAL – CONCEPT REVIEW



ChristChurch Cathedral Working Group

The Stabilisation and Reinstatement of the Cathedral – Concept Review

Holmes Consulting

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Project 106324.05

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23 Nov 2016	3.0	Heritage NZ review note added

CONTENTS

Executive Summary

Holmes Consulting has been engaged by Resource Coordination Partnership to provide structural engineering support to the Government appointed Working Group investigating the stabilisation and reinstatement of the ChristChurch Cathedral. Holmes has been assisted by Adam Thornton of Dunning Thornton Consultants and Grant Wilkinson of Ruamoko Solutions.

The objective of the Working Group has been to identify "feasible, achievable and fully costed options to progress the reinstatement of the ChristChurch Cathedral." This report provides a contemporised summary of the proposed structural stabilisation and reinstatement works to achieve that objective.

In preparing this report, the engineers have reached a general consensus that the proposed concepts and methodologies offer a workable solution, subject to further design development as would be required for any project. There remain some issues of minor disagreement over detail, some of which may be resolved by design development and some of which are simply professional opinion. However none of this significantly affects either the project feasibility or the overall budget. As with all projects of this scale and importance, a full peer review of the completed design is recommended before final implementation.

In contemporising the stabilisation and reinstatement proposals, account has been taken of changes since the initial post-earthquake reviews. This includes both the general reduction in aftershock activity (noting that there is still a high than normal risk of local earthquakes which will extend for as much as 50 years or more) and lessons learned from the repair and reinstatement of similar buildings, notably the Arts Centre buildings which are of similar construction and architecture.

The stabilisation of the Cathedral has been reviewed, with the objective of maintain a level of safety broadly commensurate with an equivalent new building site. It is proposed to progressively stabilise the Cathedral, commencing at the west end of the building and then working through progressively with a combination of externally fixed buttressing, internal shoring and careful removal of high level falling hazards. Worker safety will be addressed by using crane supported man cages and elevated platforms for high level work and robust shielding for lower work until hazards are removed or secured.

A key feature of the reinstatement is that the building is to be base isolated. This offers a greater level of protection to both occupants and the building itself; and it reduces the impact of the repair and strengthening, by significantly reducing the earthquake loading demands on the structure. Even with base isolation, there is still significant strengthening work to be done as the building has incomplete load paths and is brittle, being constructed of unreinforced masonry. The strengthening uses a combination of techniques, including:

- Replacement of high level solid masonry walls with lighter stone veneer clad steel frames,
- Insertion of reinforced concrete skin walls behind the original 'ashlar' stone linings
- Grouting and centre-coring of the original walls in order to insert steel reinforcing into the masonry
- New steel bracing introduced (or replaced) into some roof planes to help distribute loads.

The principles of the ICOMOS New Zealand Charter are to be followed as closely as possible in determining solutions for the reinstatement. In particular, stone masonry will be repaired insitu where the damage is not too great and insofar as it is practicable to do so.

A new tower may be constructed alongside the Cathedral but seismically separated from it, as it will not benefit as much from the base isolation and is of entirely new construction. Such a tower could be made from a combination of reinforced concrete walls at low level with a braced steel structure above, clad with stone to maintain the appearance of the original.

Sketch drawings have been prepared of the stabilisation and reinstatement works and are appended to the report. These drawings have been the basis of the updated cost estimate. It should be emphasised that the purpose of the drawings is to provide the basis for a robust estimate rather than prescribe the final reinstatement solutions.

Report Prepared on behalf of Holmes Consulting Group LP by:

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Limited Review undertaken by:

Adam Thornton

For Dunning Thornton Consultants Ltd

Grant Wilkinson

for Ruamoko Solutions

1 INTRODUCTION

Holmes Consulting Group LP has been engaged by Resource Coordination Partnership (RCP) to provide structural engineering services in support of the Government appointed Working Group, headed by Geoff Dangerfield.

Adam Thornton of Dunning Thornton Consultants and Grant Wilkinson of Ruamoko Solutions have also been engaged to assist with the preparation of this report.

Further, we understand that Win Clark, acting for Heritage New Zealand, has reviewed the report. We have seen his comments and generally accept them, noting his general endorsement for our approach. We understand that Heritage New Zealand will be involved in further review as and when the project proceeds.

1.1 Background

The ChristChurch Cathedral was significantly damaged in the Canterbury earthquake sequence, commencing 4th September, 2010. The Lyttelton aftershock of 22nd February 2011 caused locally severe damage, including principally the failure of the spire, which in turn damaged the north aisle and north porch roofs; and the west wall. Subsequent aftershocks, in particular the two earthquakes of 13th June 2011, have caused additional lesser damage. However as the damage has aggregated, the Cathedral has become increasingly vulnerable.

The building has been permanently barricaded since the Lyttelton earthquake and a large timber and steel barrier was installed in 2014 along the northeast and southeast street frontages to allow the reopening of the square to traffic.

A series of temporary securing and strengthening options have been prepared since the earthquakes, exploring different levels of reinstatement and strengthening objectives, ranging from a pure restoration through to a full contemporary replacement. No firm decision has yet been reached.

In November 2015, the NZ Government appointed Miriam Dean Q.C. to facilitate discussions between engineers (Holmes Consulting Group, for Church Property Trustees and Dunning Thornton for the Great Christchurch Buildings Trust) on the cathedral's condition and engineering options for its "repair, restoration or replacement". The Dean report[1] concluded broadly that "*there was no significant engineering disagreement in principle and that the reinstatement of the Cathedral would be possible by a combination of repair, restoration, reconstruction and seismic strengthening*".

Subsequently the NZ Government has appointed a further Working Group, tasked with identifying "feasible, achievable and fully costed options to progress the reinstatement of the ChristChurch Cathedral."

On the 6th September 2016 members of the Working Group met with John Hare, Adam Thornton and Grant Wilkinson together with the quantity surveyors to the project[1], to workshop a number of engineering issues and in particular:

- Initial stabilisation
- Strengthening methodologies
- Potential internal modifications to improve sight-lines and level out the ground floor

[1] David Doherr (BBD), Julian Mace (Rawlinsons) and Lindsey Rhodes (Rhodes and Associates)

The workshop established a number of assumptions and then tasked the engineers with providing updated documentation (reports and sketches) that would enable the quantity surveyors to prepare fresh estimates for stabilisation and reinstatement together with options for modifications.

This report provides the updated engineering documentation. The report has been prepared by Holmes Consulting with review by Adam Thornton and Grant Wilkinson. In arriving at this point, there has been agreement over the general principles of the approaches described and the procedures being recommended. The engineers collectively agree that the design solutions and implementation methods described herein represent a workable solution, subject to further design development as would be required for any project.

There remains some lack of consensus between the engineers at a detailed level over some of the methodologies and solutions described. Some of these issues will be resolved through design development, some through further investigation on site and some are simply differences of professional opinion that will never be resolved. However, these are neither seen by the engineers as significant from a budgeting perspective and nor do they present a hurdle to the overall project feasibility.

For a project of this scale and significance, a comprehensive design and documentation process is required, following which a full robust peer review would be recommended. This process is reasonably assured of providing a positive outcome that will satisfy the brief requirements.

1.2 Scope of Work

The scope of work for the preparation of this report has included the following:

1. Review of previous schemes for the stabilisation and repair of the Cathedral, including the input provided by other parties.

2. Review learnings from other heritage building repairs completed since the earthquakes.

3. Update the temporary stabilisation and strengthening concepts to take into account the above and incorporating the most up to date design assumptions agreed at the Working Group meeting of 6th September.

4. Documentation and sketches suitable for the quantity surveyors to prepare and updated and robust estimate.

1.3 Limitations

Findings presented as a part of this project are for the sole use of the Government Working Group and Church Property Trustees. The outputs are preliminary and based on very limited observation and analysis. The outputs will be subject to review and modification during developed and detailed design. The findings are not intended for use by other parties, and may not contain sufficient information for the purposes of other parties or other uses.

Our observations are restricted to structural aspects only. Waterproofing elements, electrical and mechanical equipment, fire protection and safety systems, service connections, water supplies and sanitary fittings have not been inspected or reviewed, and secondary elements such as windows and fittings have not generally been reviewed.

Our professional services are performed using a degree of care and skill normally exercised, under similar circumstances, by reputable consultants practicing in this field at this time. No other warranty, expressed or implied, is made as to the professional advice presented in this report.

2 DESIGN ASSUMPTIONS

This chapter summarises the design assumptions that have been the basis of the updated review.

2.1 Design Input Assumptions

The following are the design inputs which to be adopted for the strengthening and reinstatement of the Cathedral:

	Element	Assumption	Comments
1.1	Importance Level	IL3 in accordance with NZS1170.5[2]	This is minimum requirement as prescribed in the New Zealand Building Code. IL3 is triggered by both occupancy numbers and the heritage status of the Cathedral.
1.2	Target load level	100%NBS	Not to be dogmatically applied at the expense of heritage. Consider minimum target of 67%, but note that base isolation (refer below) will heavily influence outcomes, and performance will be reviewed against intermediate load levels.
1.3	Base Isolation	Essential	Basis of assumption clarified below. Note that this is predicated by the views expressed at the workshop that the reinstated cathedral itself would warrant a high level of protection due to its heritage status. Note that base isolation may provide a greater degree of protection than the IL3 status strictly requires.

2.1.1 Seismic Design Loading

Seismic loads for new buildings are determined in accordance with the requirements of the Building Code[5], using the seismic loadings Standard, NZS1170.5. The loads vary according to factors including occupant numbers, use and structure type. This is discussed in more detail below. All new buildings are to be designed to meet or exceed the full design load determined in accordance with the Standard, for the nominal building life, generally not less than 50 years.

For existing buildings, there is some latitude in the selection of the target seismic load. At the low end, the target should exceed the threshold for earthquake prone buildings, in general terms, 33% of the equivalent new building design load. Beyond that, it is a matter for designers and building owners to settle on an appropriate level according to the objectives of the strengthening project and the risk appetite of the owners.

There are several important issues to note, in regard to the Cathedral, that inform the assumptions noted above:

1. The importance level is determined both from the number of people that may occupy the Cathedral (more than 300 people congregating in one area) and its heritage status—both contents and the building itself.

2. The target load level may be considered to be determined (subjectively) by both the extent of the repairs and strengthening (beyond simple restoration to exactly the same state as before the earthquakes) and the Church's desire to make the building as safe as reasonably practicable.

   It is desirable to adopt a pragmatic approach to the design load. In some cases, the impact in both cost and intrusion of adherence to a strict limit may be disproportionate to the benefit over a slightly lesser result. Equally, the option may sometimes exist to achieve far greater protection for only marginally greater investment.

3. Due to the significance of the building, and the extent of work being undertaken, it is desirable to target 100% of the equivalent new building design load, and to incorporate a damage avoidance philosophy but this can be adjusted if necessary for individual elements if the outcome is too intrusive or disproportionately expensive.

4. In addition, it is desirable to incorporate damage avoidance design features to minimise damage to the heritage fabric and features of the building.

2.1.2 Selection of Strengthening Approach

The reinstatement of the Cathedral entails a combination of repair, restoration, reconstruction and seismic strengthening, as noted in the Dean report[1]. There are a number of strengthening approaches that could be adopted. One of the most significant selection criteria is the extent to which strengthening may be concealed or exposed in the reinstated building. In this respect, one of the first key decisions is whether to base isolate the Cathedral.

Base isolation offers significant benefit in a number of regards. The effect of base isolation is to insulate the building from a significant proportion of the severe lateral ground movements from a large earthquake. This means that the superstructure of the building above the isolation plane[2] may be designed for significantly reduced seismic loads, approximately 25-30% of what would be required without base isolation. As well as improving life safety this reduces the visual impact and intrusion of the required strengthening work, although it will not eliminate it.

Base isolation also offers significant protection to contents and to vulnerable or brittle building elements that may otherwise not be practical to reinstate. This includes elements such as the crosses on the gables, some of which had been removed even before the Lyttelton earthquake.

A significant consideration driving this decision is the clerestory[3] (as well as some of the other high level walls). If the building were not to be base isolated, the seismic lateral force generated at this level would be in the order of twice gravity, as a lateral load. This would require considerable structural effort to resist and would inevitably result in significant structural bracing members being visible in the finished building. By comparison, base isolation may allow less intrusive techniques to be adopted that will be either fully concealed or comparatively unintrusive.

2.2 Building Configuration Assumptions

The following are the assumptions on key configurational alterations or retentions that are incorporated into the conceptual design, with further discussion to follow on some of the most significant considerations.

This list of assumptions is generally predicated by the assumption of base isolation as the strengthening/protection approach—by reducing the input seismic load to the building, much more latitude is offered in retention of building elements in their original configuration.

[2] The isolation plane for a building is formed at the level of the base isolators and is the level at which the majority of the earthquake-induced deflections occur. For the Cathedral, this will be below the ground floor, requiring that a clearance is provided around the building to permit this movement.

[3] The clerestory is the high level walls with windows, between the lower roof over the side aisles and the central high level roof over the nave or body of the Cathedral.

The structural assumptions are also generally predicated by the heritage objective that existing, exposed (to view) fabric should be left/repaired in place if practicable. However where large elements have collapsed (west wall and tower) then replacement with modern structure and stone veneer is appropriate.

	Element	Assumption	Comments
2.1	Clerestory	Retain insitu	Enabled by base isolation
2.1.1	Clerestory support (Nave) columns	Retain but explore options to reduce visual intrusion	Option 1: Replace with single slender steel column over part of the height where visual obstruction is occurring Option 2: Replace part height with composite steel column i.e. a number of smaller steel tubes. Note that these options may be relatively easily achieved during a base-isolation load transfer process however there could be strong objections in relation to heritage.
2.2	Side aisle walls	Deconstruct to window sills and reconstruct	The wall areas between the side aisle windows have been severely damaged while the eaves zone and the area below the sills are relatively undamaged. For budgeting purposes, reconstruction of the walls above sill level is assumed and will be verified on site.
2.3	Transepts	Retain external walls insitu where possible and practical	Enabled by base isolation
2.3.1	Transept Arches	Lighten above eaves level and between transept columns if practical	Reduces mass at high level, increase resilience.
2.3.2	Transept arch support columns	Retain but explore options to reduce visual intrusion	Consider using steel over portion of height. Probably only important for the western two columns
2.3.3	Transept gable walls	Reconstruct dislodged section and insitu strengthen the balance	Strengthening insitu may be possible with the base isolation option
2.4	Western wall	Construct new in steel and concrete with stone veneer	Original form not able to be reconstructed in original materials. Also integrates temporary works with final structure.
2.4.1	Rose window	Rebuild in white precast concrete	Not practicable to rebuild in stone and meet seismic design requirements
2.5	Western entry porch	Assume gone	Possible future replacement, tbd. Should make allowance to extend BI plane to include this space.
2.6	Upper roof	Retain in place	Basis of design. Subject to contractor methodology review
2.7	Lower (Side aisle) roofs	Assume stays at least for stabilisation works	It may be useful to locally remove in order to facilitate permanent repair and strengthening

	Element	Assumption	Comments
2.8	Nave, side aisle and transept floors	Remove and replace with a suspended floor slab and supporting beams	Will act as a diaphragm slab above the base-isolation plane.
2.8.1	Apse Floor	Also replaced as with the nave floor. Allow to form at new level to match Nave over majority of Apse, to line of rear chapel	Exact scope of relevelling may be reviewed with no impact at later date once principles established.
2.9	Bell Tower	To be reconstructed to similar form to original. Seismically separate from the main building superstructure	Assume not base isolated. Construction to be in concrete and steel (lighter weight) with stone cladding. Roof to be lightweight, possibly metal or slate cladding (not stone).
2.10	Vestries	To be determined. Assume retained for now	Acknowledge these additions may have low or intrusive heritage value, but they have function which would otherwise need to be placed elsewhere.
2.11	Visitors Centre	Out of scope, assume remaining	Need to ensure separation from base isolated structure.

2.2.1 Repair Insitu or Reconstruct?

A balance is to be determined between retention and repair of damaged walls insitu, as opposed to careful deconstruction and reconstruction. There are several factors to this decision, which will vary from location to location:

- The extent and severity of existing damage. Where there is significant offset in the stone walls or piers, this may be indicative of greater internal damage.
- The aesthetic impact of the offset. Clearly this will vary according to the magnitude of the offset and the extent to which it will be seen.
- The potential impact of working around the offset on other elements, for example for the repair of windows.
- The relative cost of repairing in place compared to deconstruct-reconstruct. In the event that there is no or marginal cost difference then a repair-in-place methodology should be adopted.

The appended sketches indicate an assumed scope of repair or reconstruction that will be reassessed as construction proceeds. This is necessary in order to create a benchmark for the Quantity Surveyor's cost estimate. The intention is to provide an envelope for the scope of reconstruction which is unlikely to be exceeded and to progressively adjust this as work proceeds on site. This will be discussed further in section 5.

2.2.2 Usability Enhancements

There are other configuration assumptions that are intended to enhance usability of the Cathedral. These include primarily:

- Consideration of modifications to the nave columns. The alternative solutions being considered are intended to improve visibility throughout the nave and side aisles.

- Making the ground floor level over the majority of the floor area. Note that the raised floor in the transept crossing is not original and it is assumed that the original floor remains under the raised floor. The intention is to extend the level floor back into the apse, as far back as the steps to the chapel at the eastern end.

  Note also that the whole floor of the Cathedral will need to be removed in order to install the base isolation. This will clearly impact on the original tiling, which is likely to have been damaged through the earthquake and search & rescue operations. It is assumed that the tiling may be replicated, as it is unlikely that significant recovery will be possible.

3 LESSONS LEARNED

This section discusses some of the significant learnings that have come to light in the period since the earthquakes.

3.1 Arts Centre

The Arts Centre is currently the most significant heritage restoration of an earthquake damaged building in New Zealand and is significant on an international level. Holmes has been the structural engineer on the site and has acted as Principal Consultant for much of the work. This has placed us in a privileged position to learn and enhance our knowledge of such buildings and this experience will be available to the Cathedral.

There is a large number of variations in design approaches, construction techniques and procurement processes used across the site. The knowledge gained from that experience will be of great value to this project.

Some of the most significant learnings to come from the Arts Centre (and other sites) include:

1. Overall Management approach

    a. From the client perspective, clear objectives for the project need to be set and maintained from the outset.

    b. Clear heritage expectations must be developed early in the project. It is not practical to adjust this significantly as the project develops.

    c. This includes identification of the heritage priorities around the site and noting which areas or elements may be compromised—as compromise is inevitable. Spend the heritage money where it has the most impact.

    d. Generally, the cost of time is significantly greater than the cost of change, even more than for conventional projects. It is therefore important that decisions about change may be expedited.

    e. There must be a clear client-side management structure that provides both governance to the project and assigns management and decision-making control in a way that facilitates immediacy of response (preferably by keeping decision-making for the most part close to the site).

    f. Clear delegated authorities must be assigned so that decisions can be made or referred to a governance body if required. A key success point at the Arts Centre has been the ability of the client to make decisions on site for the most part—this has come from having a knowledgeable Site Manager with a technical background on the site. While the Cathedral does not have such a person now, it is important that this role is created.

2. Design and design management

    a. Almost all structural solutions are bespoke (from either a technical structural or a heritage/restoration perspective). It is important to accept and acknowledge that not all solutions are transferable, building to building or even area to area. It is common to find that the original construction is quite different for otherwise very similar areas as the original methods changed over time.

    b. It is an iterative process. We have found that even the analysis of the buildings must be repeated more frequently than normal design as undiscovered conditions are encountered and adjusted for.

c. It is not practical for a heritage reinstatement of this scale to complete design, procurement and construction as a linear process with complete certainty (i.e. full construction drawings on day one on site). There should be an expectation that the construction documentation is indicative of intent for the most part. No matter how much investigation is done before the work is commenced, there will still be a need to make adjustment.

d. This last point emphasises further the importance of integrating temporary support with the reinstatement design, in order to minimise the overall project duration and to ensure efficiency of the resource use.

e. It is critical to have a good working relationship between the designers and the Resource Management/Building Controls team managing approvals for the site. Although the project must be well documented, a practical change management process will be required and this relies to a great degree on partnership and trust.

3. Procurement and Contractor relationships

a. It is important that the site procurement strategy is aligned closely with the design deliverables strategy.

b. The procurement methodology is key and oversimplification in order to simplify management and reduce perceived client risk, is not productive. It is better for the client/consultants to be party to the management of the risk, in terms of the heritage outcome.

c. A good working relationship between the site superintendent and foreman, and the site engineer, is critical. It is inevitable that the design will need to be adjusted as work proceeds. This requires trust and partnership between these key individuals to create a solution-focussed working environment.

i. Key construction personnel should be contractually bound to the project, to the extent practical.

d. It is important for the Contractor to have a core of experienced and committed personnel on site. In our experience, some workers 'get it' and are keen to be involved but others find the work too hard and difficult. Continuity is important so it is key to develop core of skilled and experienced people on site and avoid having a revolving door of short-term contract labour.

4. Construction

a. All decisions about stone masonry must be made with care as the resulting outcomes are difficult to reverse. In particular this relates to decisions about whether to retain and strengthen insitu (requiring significant temporary support which can be highly demanding to work through) or to dismantle and rebuild either in the original form or with modern techniques.

b. On the latter, a method for reinstating gables using contemporary construction has been developed and employed on some of the less critical (from a heritage perspective) damaged buildings at the Arts Centre. For example, 12 out of 13 gables on the Old Boys High building are now constructed that way and are indistinguishable from the original form.

c. The original stone may be worked effectively if it has remained in reasonable condition. Oamaru stone (typically used for the decorative elements) is a relatively soft easily worked stone. It is often too damaged to repair but is easily replaced. The basalt that forms the majority of the field stone is very hard and often undamaged. It may readily be cut with the appropriate equipment—the Arts Centre imported special stone cutting equipment from the UK for this purpose. Some of this knowledge and possible equipment may be available to the Cathedral.

d. It may be necessary to develop new techniques on the site. A degree of experimentation will be required and it is critical that appropriate monitoring is in place for such situations and that the work is halted immediately if problems emerge. For example, at the Arts Centre, several new techniques for centre-coring were trialled on College Hall before a suitable technique was developed. It is important to employ sub-contractors who are experienced and have the capacity to learn and to work closely with the site engineer and contractor.

4 SITE CONDITIONS

4.1 Site Soil Profile

The Christchurch Cathedral is located in central Christchurch, which is typically characterised as a deep soil profile, class D in terms of NZS1170.5[2].

No specific geotechnical investigation has been completed for this report, but there is a significant body of information on the likely site soil profile from a variety of nearby sources. The most relevant of those is the geotechnical studies completed in 1994[3],[4] for the construction of the Visitors Centre to the north of the Cathedral.

A test pit was excavated against the Cathedral, showing the following profile:

0-0.1m	concrete paving (wire reinforced)
0.1-0.3	basecourse
0.3-0.5	brown sandy silt, firm, moist
0.5-0.8	brown silty sand with rare medium size gravel
0.8-0.9	brown sandy gravel, gravel fine to medium
0.9-1.2	brown medium sand
1.2-1.6	brown gravelly sand with lenses of fine to medium gravel
1.6-1.8	brown sand

The foundations to the Cathedral were located at 1.35 below the paving level, with the footing extending 450mm from the face of the wall. The soils were recorded as loose to compact. The material above 900mm stood vertically, but the sands below would not.

More general information from the Visitors Centre report time indicates a deeper profile of silty sands to 2.5-2.8m depth, underlain by gravels to a depth of approximately 10m, below which are sandy clay. The watertable at the time was located at approximately 2.5m.

Bearing pressures for design were provided at the time (refer Figure 1 below) and should be suitable for concept design purposes for the Cathedral reinstatement.

The liquefaction potential of the site was considered low at that time, but this should be re-evaluated against current criteria. However it should be noted that there was no evidence of liquefaction at the site through the Canterbury earthquake sequence.

A full geotechnical investigation is recommended for the site and will be required prior to Resource and Building Consent application. Allowance should also be made to obtain site specific seismic spectra and appropriate time-history records for the purposes of Base-Isolation design.

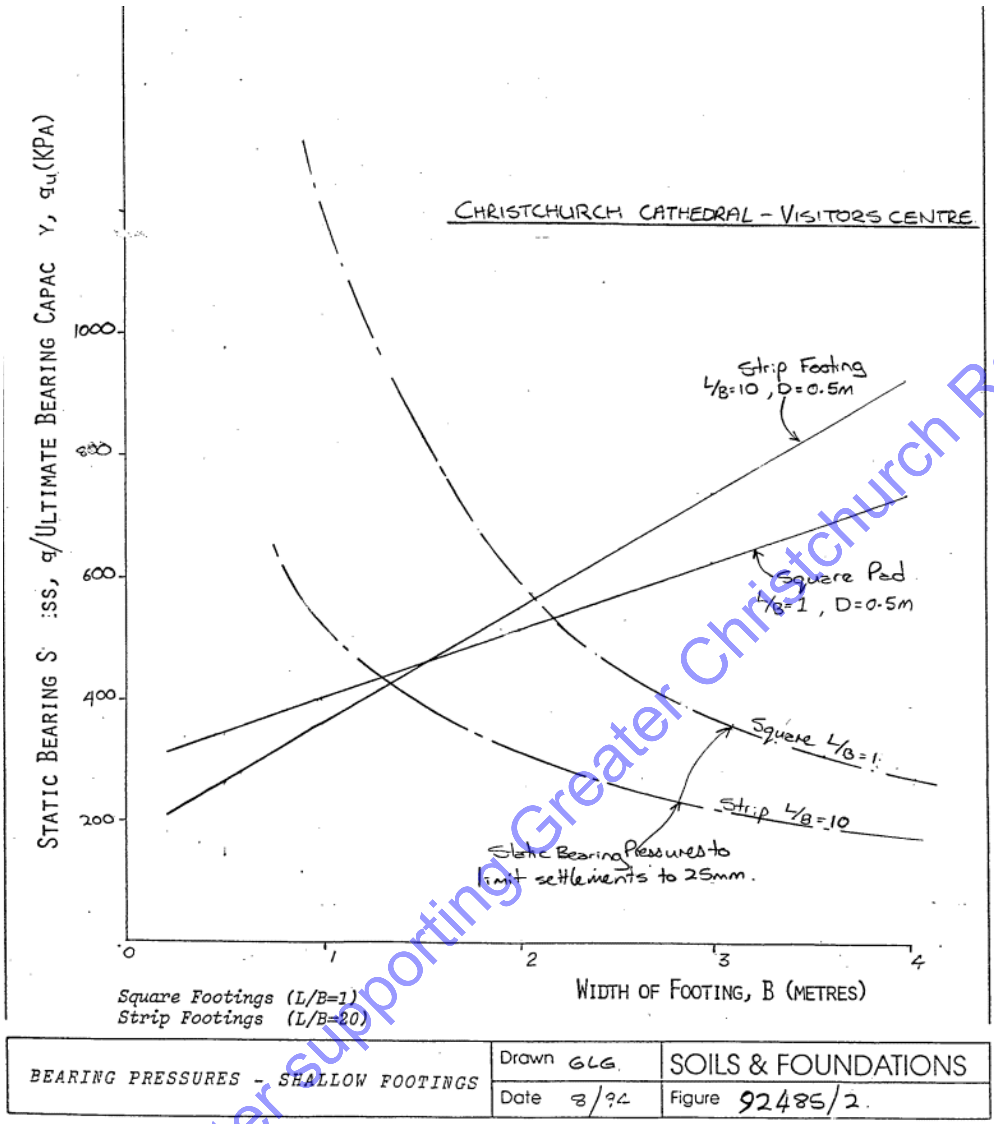

Figure 1: Recommended Bearing Pressures from the Visitors Centre, 1994

5 STABILISATION

This section discusses the principles of the stabilisation work and describes the general work sequence to be followed.

5.1 Objectives

The objectives of the stabilisation are generally:

1. To prevent further damage to the Cathedral until it is being reinstated.
2. To provide an adequate level of protection for workers during the reinstatement.
3. To enable access to the parts of the Cathedral being reinstated in such a way that the reinstatement can be efficiently implemented.

5.2 Guiding Principles

The principles that are to be followed in the further development of the temporary stabilisation are as follows:

1. Where possible, the temporary stabilisation measures must be considered in context with the strengthening. Hence it is important to advance the design of both in parallel.
2. Preference will be given to (in order of priority):
   a. Incorporation where possible into the finished reinstatement. For example, the steel truss support work over the western entry.
   b. Use of shoring and bracing elements that may be progressively relocated and used elsewhere on the site as work proceeds
   c. Elements that may be reclaimed and/or physically altered and adapted for alternative uses.
3. Where the stabilisation works abut and/or support heritage fabric, suitable protection should be given to the heritage fabric to minimise further damage.
4. The stabilisation works are to be designed on the basis that work may be suspended indefinitely and so must be suitably durable for a medium term.
5. The degree of protection provided by the stabilisation should be such that no worker is exposed to harm to a greater degree than might be expected on a conventional building site.

5.3 Proposed Sequence of Works

Proposed sequence of stabilisation works are summarised below:

5.3.1 Phase 1 External Stabilisation Works

Phase 1 stabilisation works are intended to address global building instability issues. Some aspects of the Phase 1 works are supplemented in the following phases when internal access to the Cathedral is available.

1.1. Remove existing steel frame and supporting concrete foundation beams from the western end of the building. Remove existing shipping containers.

1.2. Demolish and remove remnant west wall and rose window down the level of the porch, with long reach equipment, avoiding dropping loose material on the porch to the extent possible. . Remove loose masonry elements at western end of the structure.

1.3. Working with cranes and suspended baskets, lift and install new preassembled West Wall structural steel braced frame into the opening created in the west wall. The new West Wall Braced Frame is intended to act as a north-south bracing element at the western end of the Cathedral to transfer tributary north-south clerestory seismic loads to the existing reinforced concrete side aisle walls.

1.4. Connect new West Wall Braced Frame to existing clerestory roof. Using suspended baskets, deconstruct damaged portions of Clerestory walls, down to sill level of clerestory windows (first bay only).

1.5. Install new screw piles for new temporary clerestory structural steel braced frames. The Clerestory Braced Frames are intended to intended to act as a temporary bracing elements to resist east-west tributary seismic loads associated with the clerestory and transept. Note that subject to the condition of the porch after removal of the remnant west wall, the new foundation may be installed immediately to the west of the porch in order to allow deconstruction of the porch.

1.6. Construct new reinforced concrete foundation block for Clerestory Braced Frames. Will include the use of prefabricated reinforcing cages and self-equilibrating formwork. Erect new preassembled braced frames over.

1.7. Connect Clerestory braced frames: a) to existing 200 UC chord members (from 1999 strengthening) below side aisle roof. This will require removal of sections of slate at the top of the side aisle roof on the south side aisle. Initial connection to be via matching 250 UC section above level of parapet, with spacers down to chord member. b) At high level, to 4-RB32 with timber packers between buttresses (note that 2-RB 32 to be installed internally with interior works).

1.8. Deconstruct porch, retaining recovered material for future use. Complete balance of west wall bracing installation below level of porch roof. Note, this step assumes assessment at completion of phase 1.4, that porch materials are practically recoverable.

1.9. Remove loose masonry elements in the vicinity of the north and south transept end gables. Lift in new precast concrete foundation block for new temporary steel frames. New Transept Gable Securing Frames are intended to stabilise the badly damaged north and south transept end gables.

1.10. Lift and install new preassembled Transept Gable Securing Frames to north and south transept gables. Initially the existing roof level rose-head wall anchors are to be re-used to fix the top of the frame.

1.11. Remove loose masonry elements in the vicinity of the north porch. Lift in new precast concrete foundation blocks for the new temporary steel frame. North Porch Securing Frame is intended to stabilise the north gable of the North Porch.

1.12. Lift and install new preassembled North Porch Securing Frame. Initially the existing roof level rose-head wall anchors to be re-used to fix the top of the frame.

1.13. Continue to work around the Cathedral at high level from man baskets, removing or pinning loose masonry, ahead of other work at low level. (This includes elements such as gable capping stones, loose slates and ornamentation).

5.3.2 Phase 2 Internal Stabilisation Works – Nave:

Generally, loose masonry will be progressively pinned or removed (from west to east) using a boom lift before workers install heavy props and bracing elements from floor level.

Phase 2 stabilisation works related to internal works associated with the Nave. The intention is to progressively move from west to east.

2.1. Connect new West Wall Braced Frame to existing adjacent masonry piers.

2.2. Reconstruct portion of north aisle roof and wall damaged by tower. Construct new reinforced concrete capping beam and install new temporary 200UC rafters. Install new RB32 roof braces and construct new temporary light weight roof.

2.3. Replace existing damaged south aisle roof brace with a new RB32 roof brace.

2.4. Progressively shore clerestory piers and arches with new braced shoring towers and timber propping working from west to east. Loose masonry and ashlar is to be removed or pinned in place as the propping proceeds to minimise falling hazards

2.5. Progressively install timber propping to support side aisle rafters. Stabilise damaged north and south aisle wall piers with ratchet tie downs.

2.6. Deconstruct and temporarily reinstate damaged portion of North Porch roof. Existing Tower rubble in the North Porch Attic to be removed.

2.7. Shore arches, cover and brace existing windows openings with new timber framing and 16 mm plywood to reduce vermin ingress. Provide new or make good existing flashings as required to make the building weather tight.

Note that the interior of the Cathedral is contaminated with pigeon excrement and loose debris. This should be removed as work progresses, using appropriate handling techniques.

5.3.3 Phase 3 Internal Stabilisation Works – Transept & Apse:

Phase 3 stabilisation works related to internal works associated with the Transept and Apse. The intention is to progressively move from west to east.

Generally, loose masonry will be progressively pinned or removed (from west to east) using a boom lift before workers install heavy props and element bracing from floor level.

3.1. Progressively shore transept piers and arches with new braced shoring towers and timber propping working from west to east. Loose masonry and ashlar is to be removed or pinned in place as the propping proceeds to minimise falling hazards

3.2. Secure Phase 1.8 Transept Frame Foundation Blocks thru existing walls using RB32 through ties secured to double PFC walers behind.

3.3. Temporary strengthening of badly damaged southern gable wall pier using heavy duty fabric strops with timber packers. Loose masonry above working area is to be removed or pinned in place to minimise falling hazards

3.4. Provide temporary roof level RB25 cross-ties between the Phase 1.9 Transept Gable Securing Frames.

3.5. Progressively prop and shore remaining damaged piers and arches at the eastern end of the Cathedral. Loose masonry and ashlar is to be removed or pinned in place as the propping proceeds to minimise falling hazards

3.6. Temporary strengthening of badly damaged north and south walls of Apse using heavy duty fabric strops with timber packers. Loose masonry above working area is to be removed or pinned in place to minimise falling hazards. Core through existing walls as required for new wire rope.

3.7. Cover and brace existing windows openings new timber framing and 16 mm plywood to reduce vermin ingress. Provide new or make good existing flashings as required to make the building weather tight

6 REINSTATEMENT

This section describes the proposed reinstatement work and the general work sequence that will be followed.

6.1 Objectives

The objectives of the reinstatement are generally:

1. To provide a high level of protection to occupants and passers-by against injury and death.
2. To preserve and protect the heritage fabric of the Cathedral to the extent practicable.
3. To improve the seismic resilience of the Cathedral.
4. To provide a space that reflects modern worship needs, to the extent practicable.

6.2 Guiding Principles

The principles that are to be followed in the further development of the reinstatement design are (in order of importance) as follows:

1. The ICOMOS New Zealand Charter is to be followed to the extent practicable.
2. The exterior of the Cathedral is to be retained or restored to its original appearance, with the exception of any elements noted in the assumptions in Section 2.
   a. Where elements such as gables need to be rebuilt, lightweight steel structure may be considered, with exterior and interior veneers of the original stone material. This will generally be limited to stonework above the main roof eaves level.
   b. Where the existing walls may be retained insitu, the exterior wythe should be retained in place, with strengthening being implemented from the interior face.
   c. Where walls are to be reconstructed, the original exterior materials should be used to the extent practicable.
3. The interior is to be retained or restored to its original appearance, with the exception of any elements noted in the assumptions in Section 2. Where applicable (and necessary) the interior shall have lower priority than the exterior.
   a. Where major elements of structure are being repaired or strengthened, the interior ashlar linings may need to be removed and may be replaced using modern techniques and materials. The original material will be reused to the extent practicable
   b. Preference will be given to methods which may retain significant features in place where practicable and where the cost impact of doing so is moderate.
   c. Where the replacement of interior ashlar linings is not immediately practicable, sufficient allowance will be made to restore the interior at a future date. (Note that the ashlar will get badly damaged during deconstruction so new limestone ashlar will be required (based on 1999 experience)
4. Ornamentation and appendages (for example crosses on gables, finials etc) will be reinstated to the extent practicable within the budget, or otherwise allowance will be made to reinstate them at a later date.

6.3 Proposed Reinstatement Methods

6.3.1 Background

The ChristChurch Cathedral was designed and constructed in an era before seismic design was considered. Compounding this, the form and materials of the Cathedral are inherently poorly suited for seismic resistance, with heavy unreinforced masonry (URM) construction, much of it at high level; and large open spaces with few lateral elements.

The existing walls were constructed using traditional masonry techniques of the time. Inner and outer wythes of cut stone were mortared into place and the gap between was filled with a weakly cemented random rubble infill. Some header elements were included in the wall as construction proceeded, linking the inner and outer wythes. Under strong seismic actions, this form of masonry is prone to brittle failure.

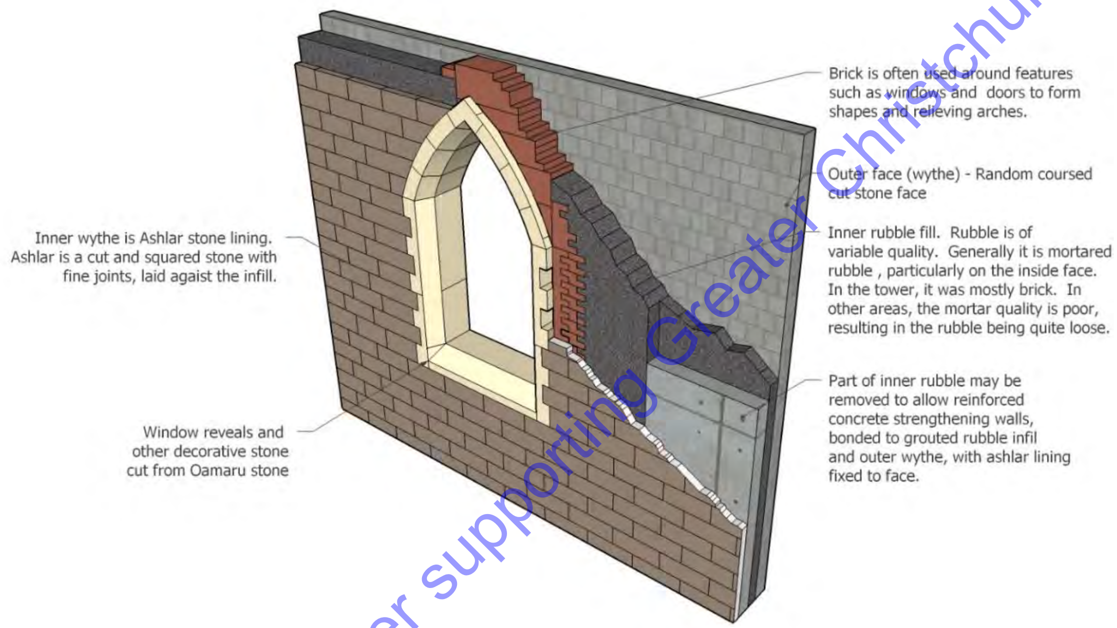

Figure 2: Typical Cathedral wall construction (from Dean report)

Other significant weaknesses of URM buildings of this era include:

- A lack of connectivity between elements which may resist seismic actions
- A lack of adequate seismic diaphragms to distribute seismic loads to supporting elements
- A lack of adequate foundations to resist seismic actions

In order to achieve the required level of seismic protection, damaged URM buildings generally require seismic strengthening to correct these weaknesses, as well as repair. It is important that the strengthening methods are compatible with the existing structure. This means that the stiffness of the new elements should be equal to or greater than that of the original building fabric, in order to ensure that the new structure takes the load and minimises damage to the original building fabric.

The proposed reinstatement will use a combination of conventional strengthening with base isolation. This work is described in more detail below, and in the sketches in Appendix A.

6.3.2 Strengthening

Strengthening work will inevitably require the introduction of extensive new structure into the existing building fabric to achieve the stated objectives. It is not feasible to repair and strengthen the cathedral to the required performance level without adding new materials, even with the introduction of base isolation.

Strengthening will probably involve a combination of techniques, which may include the following (note these descriptions have been reproduced verbatim from the Dean report):

- Reinforced concrete wall/frames: These would be inserted into the existing walls through a process of removal of the ashlar interior facing and part of the rubble infill. The reinforced concrete could then be cast against the remaining stonework before replacement of the ashlar facing, concealing the new concrete. It may be inevitable that some strengthened walls are made thicker than the original walls.
- Grouting of the stonework: This entails pumping of concrete grout under low pressure into the weakly cemented rubble infill. The stone rubble infill is 'fragile' at best and fragile and cracked elsewhere. Before strengthening commences, the stone walls that are to be retained will be grouted with a pozzolan/lime grout and drilled and pinned at regular spacings horizontally and vertically. This grouting is required before walls are cut back for the inserted concrete walls and the like.
- Centre-coring: Holes are drilled down the centre of solid or grouted masonry walls to insert reinforcing, which is grouted in place. This reinforcing may be post-tensioned to improve resistance to displacement.
- Fibre-reinforced composites (FRP): FRP is a thin layer of fibreglass or carbon fibre reinforcing that can be applied to the face of stone walls or epoxied into slots cut into the wall.
- Structural steel: Structural steel would be used primarily in bracing elements, such as in the roof, where more bracing would be required, and in tie elements that might be needed to augment some of the existing structure, such as roof elements. Generally all steel ties and pins to be embedded in the stone walls will be stainless steel.

The selection of which techniques to use will depend on a number of factors, including:

- The condition of the element being strengthened—whether the extent of damage allows insitu repair or not. The criteria that triggers deconstruct and reconstruct includes the amount of dislodgement, the seismic demand and strengthened capacity of the dislodged element, and the visibility of the damaged element (ie plan location and height)
- The location of the element in the building—with preference to light construction at high level, especially in areas where the element adds weight but not strength.
- The extent to which the element is required to resist earthquake actions in the strengthened building

A summary description of the proposed scope of the reinstatement works is included in Section 6.4 below.

6.3.3 Stone masonry repair

Repairs to the stonework may use a variety of methods, according to the severity of damage and the extent to which full aesthetic restoration was required.

Where damage is minimal, or the appearance and alignment are not critical, stonework may be repaired in place. Temporary support will be needed to the face of the stonework in question, the stone wall is grouted and pinned after which the interior ashlar stone lining and rubble infill may be removed and reinforced concrete inserted. This technique has been employed extensively at the Arts Centre during reinstatement work.

Where the damage or displacement is too great, the stonework may need to be deconstructed, recording the locations of all of the removed stone (again, as done at the Arts Centre). The stone may then be reconstructed, incorporating the reinforced concrete infill as construction advances. Depending on the location, this might be more economically done by removing all stone above the damaged area and rebuilding the entire upper section of wall, or by propping and bracing the stone above the damaged area and rebuilding only the damaged portion. This decision could vary according to cost and/or heritage priorities.

With the work either completed or currently in progress around the city, it is considered that there is sufficient skill and experience available in the Christchurch market to complete the required repairs. It is also important to note that although the quarries that produced the stone used on the Cathedral originally may no longer be open, there should be an adequate supply of stone available through saved material of alternative sources.

6.3.4 Base Isolation

Base isolation is being used primarily to provide greater protection for the heritage fabric. It will also minimise the introduction of new strengthening structures and reduce the demand on all of the historic building fabric and the new strengthening. In addition, base isolation will provide greater safety for occupants.

Base isolation is done by installing special isolation bearings under the stone walls and columns, at the level of the foundations. The bearings reduce the amount of lateral seismic force transmitted from the ground to the building, so that most of the displacement that would otherwise be imposed on the building instead happens in the bearings. Base isolation does not eliminate lateral seismic loading, but it will significantly reduce it to a much more manageable level. Base isolation has no significant impact on vertical seismic loading, which is generally, but not always, of lesser significance for masonry buildings.

A horizontal separation must be maintained or created around base isolated structures to enable them to move freely in moderate and large earthquakes. In the case of the Cathedral, this means that a suitable separation must be created to the Visitors' Centre and the new Tower, typically in the order of 500mm wide. This will also require the creation of a 'rattle space' around the building, although that will be covered with special sliding or hinged plates that allow both traffic and movement.

A further impact of the base isolation is that the entire ground floor will need to be replaced. However this also enables the new floor to be at a single level.

The installation of the bearings will be achieved by constructing two levels of new concrete sandwich beams on either side of the existing foundations, with 'finger beams' cut through the foundations in locations where bearings are to be installed. Ports are cut into the existing foundations to allow the finger beams to be installed, with a gap into which the bearings may be subsequently inserted. The load on the foundations is then transferred to the bearings using hydraulic jacking methods. As the installation of the bearings will be spread over a long period, the bearings are 'locked' until installation is complete, at which stage all of the bearings are unlocked in a continuous process.

A significant portion of the length of the original foundations will not be as deep as is required for the full double foundation. Continuous underpinning for the lower part of the foundation will be required. Also, for the isolated nave columns, it may be more cost effective to support the arches on new foundation beams and dismantle the nave columns and foundations, in order to build new lower and upper foundations with single tie beams rather than pairs of sandwich beams.

It is likely that all, or most, of the structural strengthening and restoration work would be completed before base isolation to reduce the risk of damage during excavation. In that case, strengthening to 100 per cent of building code would not be achieved until completion of base isolation.

Base isolation of heritage buildings following this general method was used, for example, in the strengthening work on New Zealand's Parliament. Although not commonplace in New Zealand, it is an internationally accepted practice, often preferred in cases where there are either valuable contents or heritage buildings that need protection.

6.3.5 Tower

A replacement tower could have a number of structural forms, according to the final design of the tower. A new tower of the form of the original will probably include a combination of reinforced concrete walls at lower levels with lighter structural steel above. Stone veneer cladding may be supported over the reinforced concrete and steel structure using modern stonework techniques.

The tower will most likely not be base isolated, as this will offer relatively little benefit to a new structure in this form, and may add significantly to the cost.

The tower location will have to shift northwards by approx. 1 metre to be independent from the cathedral and to include a 500mm seismic rattle space.

6.4 Preliminary Scope of Strengthening Work

The scope of work is presented in sketch form in Appendix A.

A high-level description of the overall scope of such work is as follows:

- Grouting and pinning the stone rubble fill in all stone walls that are to be retained.
- Underpinning of shallow foundations.
- Replacement steel bracing with augmented connections in the roof plane over the side aisles to upgrade or replace the strengthening inserted in 1999
- Reinforced concrete infill walls to the transept, apse and side aisle walls, extending down to the existing foundation level and tied into the new foundations
- Reinforced concrete buttresses, clad with original masonry, to replace the existing buttresses, tied through to the new reinforced concrete walls including new upper foundations to buttresses
- New reinforced concrete foundation beams cut into and sandwiching the existing foundations, in two layers to permit installation of the base isolation.
- New reinforced concrete or FRP overlays to the upper-level clerestory walls along the nave. Centre-coring will be investigated in the design phase as a less intrusive solution.
- Repair and protection of the stone columns to the nave (possibly including measures to increase visibility) It may be better to deconstruct and reconstruct these columns so as to allow the construction of new foundations.
- The addition of ties between existing and new elements to complete load paths to provide support to all of the parts of the building (Examples include gable ends and the tops of walls that must be tied back to the supporting roofs, possibly with additional steel supporting members where spans are too great.)
- Pinning and securing of vulnerable exterior and interior ornamentation, such as parapet capping stones, finials, window mullions and stone panels
- Install a base isolation system to the entire building. Together with two levels of foundations, foundation tie beams and ground floor 'transfer' slab.

- Centre core and reinforce the 'minaret' towers
- New 200 RC skin walls to the nave arches (to the side aisles) and integration to the strengthening works on the nave columns
- New white precast concrete rose window frame, post tensioned to act as a single circular window frame
- New 100mm tidy slab as a 'floor' to the base isolation sub-basement

The less heavily loaded walls, such as at the rear of the building adjacent to the apse, might possibly be upgraded using only grouting and centre-coring for a less intrusive outcome, or might require no work at all. Some heavy repair work is required to strengthen all those apse wall areas that have been cracked.

Work will take place progressively, with strengthened portions of the cathedral providing extra support for adjacent unstrengthened areas and allowing removal and reuse of the temporary steel bracing elements. In this way, appropriate levels of safety could be continuously maintained rather than having large work-faces open and unsupported, even for short periods.

7 CONSTRUCTION CONSIDERATIONS

7.1 Health & Safety

The principle objective is that the reinstatement of the Cathedral should represent no significantly greater risk to the health and safety of workers than would be found on a regular site. The most significant factor in this regard is the possibility of further damaging earthquakes, leading to the risk of masonry falling or toppling.

There have been a number of changes in the health and safety environment since the earlier reviews that were completed in the period following the Canterbury earthquakes. These changes include:

1. The introduction of the Health and Safety at Work Act, 2015. This has brought about broad changes to health and safety practices in New Zealand and its full impact is still to be determined. A key principle is the emphasis on managing risk, as opposed to simply eliminating hazard.

2. The Canterbury Earthquake Recovery Authority (CERA) has run its course, with the temporary powers that it had under the Canterbury Earthquake Recovery Act (2011) returned to the Christchurch City Council.

3. The incidence of aftershocks has decreased considerably from the immediate post-earthquake activity level and this has been reflected in the reduction of the return period factor (R) for the serviceability limit state loading.

Given these factors, a review is warranted of the overall approach taken regarding safety.

Stabilisation of the building (as covered in section 5) will result in the building being restored to a reasonable level of seismic resistance, noting that the Building Act[6] accepts that earthquake prone buildings may be upgraded over a period of time that significantly exceeds the anticipated construction programme for the full reinstatement of the Cathedral. Hazardous works during the stabilisation are to be implemented where possible from above, using man baskets and boom lifts. Where this is not feasible, steel fall barriers may be used to shield workers, although there may be very short periods of exposure.

It should be noted that work that ultimately requires a long period of exposure is no safer to complete in short shifts than in a continuous operation, and should be avoided.

Primary responsibility for the management of health and safety on site will fall to the contractor once work commences on site. There will need to be a site-specific health and safety plan, which will require monitoring and adjustment as work proceeds. All parties to the work will need to be involved in this process.

7.2 Construction

During construction, there will be significant temporary shoring and bracing required in order to complete the repair, strengthening and base isolation works. In conventional contracts, responsibility for the design of these works is generally allocated to the builder. This allows builders to adapt the construction process to their own plant and equipment and to the experience of their workers.

In a case such as this, our experience is that a closer collaboration is required between the engineer and builder in order to best integrate the design with the construction in a way that meets the objectives of the project.

This report discusses several of the key shoring and bracing components of the project, acknowledging that this will be subject to further refinement once a builder is engaged.

Key operations are discussed in more detail below, with sketches provided in the Appendices.

7.2.1 Nave Column Repair and Base Isolator Installation

Temporary column removal is required in order to complete both the repair to the columns supporting the nave and the installation of the base isolators. It is anticipated that this will be done one at a time in a progressive operation as the foundation system is installed. Steps will be as follows (with reference to Sketch ssk-3-01):

1. After the Nave and Side Aisle are stabilised (in accordance with Section 5), the removal of the ground floor for the new foundations may commence. Working in sequential fashion, the area between the columns and the outer walls will be excavated first without undermining the Nave columns. Excavation (with underpinning where necessary) is to proceed around the perimeter of the Cathedral, followed by installation of the two levels of foundation beams.

2. Shoring may now be placed to purpose built timber formers supporting the arches of the clerestory. The formers are to be installed using 'soft' packing to the underside of the arches to minimise further damage to the stonework. This may be high density foam or cementitious grout with heavy separating materials such as polythene between the grout and the stonework. The shoring should be hydraulically jacked to effect load transfer to the adjacent columns.

3. After a period of monitoring (for displacement and load), the first row of columns may be carefully removed for repair (if necessary), or re-supported from the new bracing system if the repair may be completed insitu. Excavation to the underside of the new foundation beams can now be completed.

4. The construction of the new foundation beams may now be completed, including the installation of the base isolators.

5. Reinstate columns (possibly with steel portions in order to increase visibility).

7.2.2 Side Aisle exterior walls

Depending on the condition of the walls, the sequence of work may take different forms. The work will proceed progressively form west to east, one bay at a time. In order to make it possible to install the reinforced concrete inner skin, the outer wythe will need to be secured in place and the decision will need to be made on a case-by case basis as to which piers may be repaired in place, with or without retention of the arch and wall above the window.

The most complex sequence of work will be as follows, based on the assumption that the upper wall may remain in place but that the pier must be rebuilt (with reference to sketch SSK 3-02):

1. Place timber (or steel) arch support in place (assuming the upper level of material may be repaired in position). Packing is to be placed similar to note 2 in 7.2.1 above. The shoring may need to be jacked to ensure load transfer.

2. Brace the wall externally, ensuring that the bracing may fully support the wall both laterally and vertically in absence of the piers.

3. Remove the ashlar layer form the inside of the wall. Seal and pressure grout the wall in sections from the bottom up using a cementitious or pozzolan based grout with appropriate additives to aid flow and reduce efflorescence.

4. Remove and record the stone piers between the windows, with 'needling' through the wall to resupport the sections above the piers. Remove the stone buttresses above and below the windows.

5. Sawcut the outlines of the inner wall face to be removed. Break back the inside face of the wall to a nominal depth of 200mm. Create a slot though the wall at the line of the buttresses.

6. Drill and epoxy connectors into the outer face of the wall from the inside to provide a composite connection to the new interior concrete lining. Place reinforcing, form the inner face of the wall and the buttresses and pour concrete up to sill level initially.

7. Erect outer stone work to the buttresses over the full height, pinned to the new concrete work below the sill level and into the existing stone facing. Drill and epoxy pins into the back of the stone over the height of the windows, in order to ensure composite connection/

8. Drill and epoxy connectors into the outer face of the wall from the inside to provide a composite connection to the new interior concrete lining over the remainder of the height. Place reinforcing and formwork and pour the concrete over the remaining height of the windows wall, up to the bottom plate, incorporating new fixings to the roof structure as required..

9. Remove the temporary supports and move to the next bay.

10. Replace the ashlar lining using modern stonework support techniques. Note that this does not need to happen in a continuous process from the strengthening and repair noted above

This process will be varied if the condition of the wall is suitable and subject to cost and heritage—the main consideration being the relative cost of supporting the wall above the windows in comparison with the heritage value and risk of retaining it in place.

Note that the description above does not include the process of installation of the foundations and base isolators. This may be incorporated into the procedure above or may follow at a later stage, according to the overall construction programme.

7.2.3 Transept Crossing

The arches above the transept crossings have suffered damage as the individual parts of the cathedral (nave, north and south transepts and the apse) have attempted to move independently. These high level walls have little or no beneficial strengthening effect but add considerable weight at high level. This is difficult to repair and strengthen effectively and will limit the effectiveness of the overall strengthening.

The preferred option for these arches is to remove the lining and demolish the inner stone work back to the line of the supporting structure (the four large columns supporting the crossing). The procedure will be generally as follows (noting that the temporary stabilisation described in section 5 will have been completed first):

1. Remove floor, excavate and pour temporary foundation pads below the crossing arches.

2. Place shoring from the new foundations to the level of the arch supports. Continue shoring up the faces of the arches to the timber roof structure, leaving working space to the arches. Jack the shoring as required to effect load transfer to the new foundation, for both the roof structure and the arches.

3. Remove the ashlar facing from the arches, from the top down to the large arch stones.

4. Remove the stone inner wall, commencing at the apex and working progressively down and towards the supporting walls. Sawcut a keyway into the face of the supporting walls/columns.

5. Fix vertical steel members up the face of the supporting walls/columns. He vertical steel members should have shear keys on the back face and are to be initially loose fixed, with drilled and epoxied threaded rods back into the supports. Grout behind the steel to ensure a continuous connection.

6. Site measure and complete fabrication of steel truss members to support the arch stones and ashlar lining. Erect in pieces according to equipment available (working from access along the nave from below). (Erection of final pieces to apex of roof structure may require limited removal of slate in order to drop pieces through roof – to be avoided if possible)

Resupport ashlar lining using conventional modern stonework techniques. This may take the form of stainless steel angle supports with kerfed fixings to the stone, supported on a Unistrut subframe bolted to the main supporting frame for the main wall lining; and epoxied bolts and hangers for the arch stones.

8 REFERENCES

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2. NZS1170.5:2004, *Structural Design Actions - Part 5: Earthquake Design Actions (New Zealand)*, Standards New Zealand.

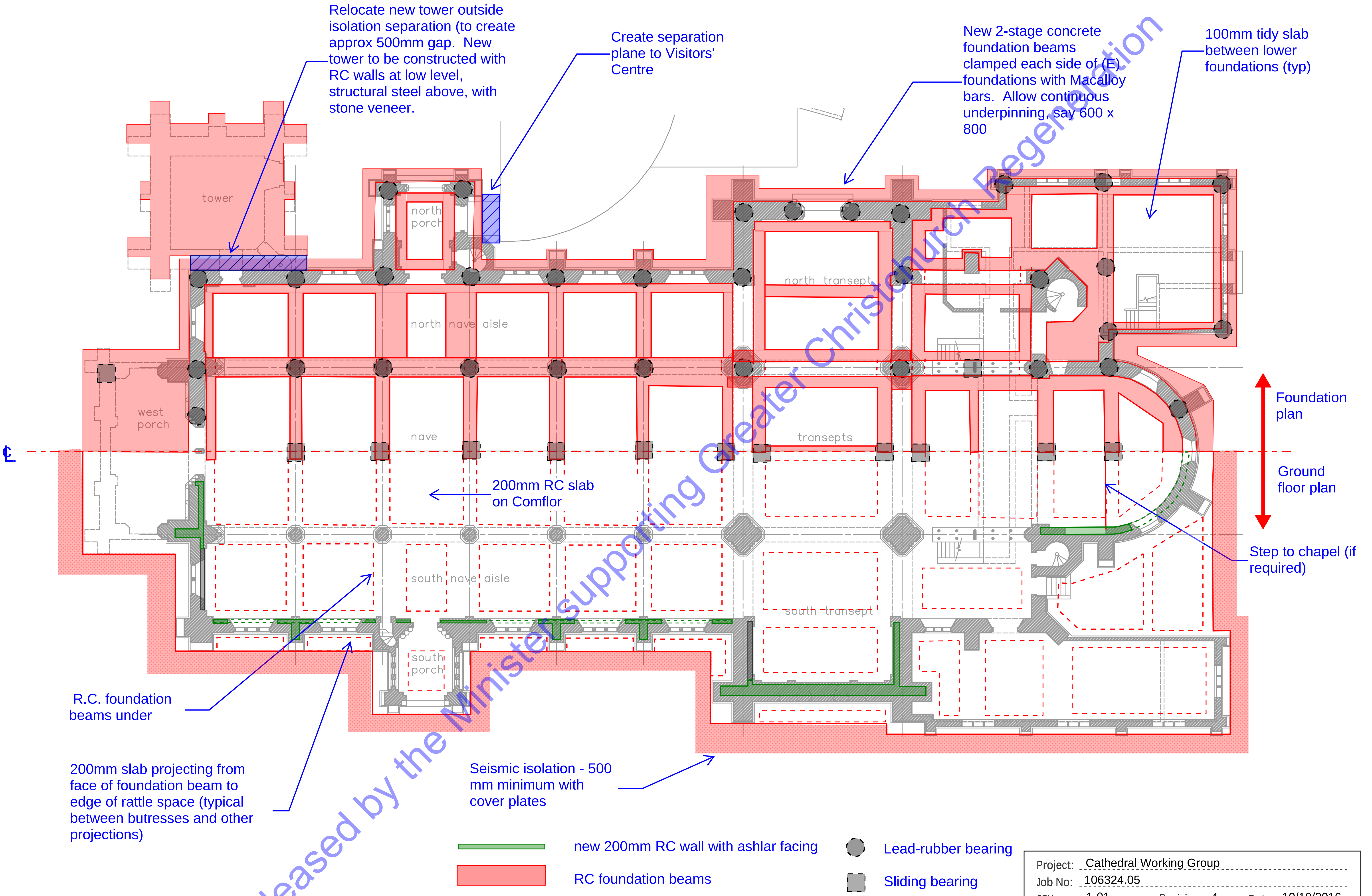
3. McCahon, I, *Cathedral Visitors Centre Soil Investigation*, Soils and Foundations, 9th August, 1994.

4. McCahon, I, *Cathedral Visitors Centre (supplementary report)*, Soils and Foundations, 5th December 1994.

5. NZ Building Code, Ministry of Business, Innovation and Employment.

6. The Building Act, 2004.

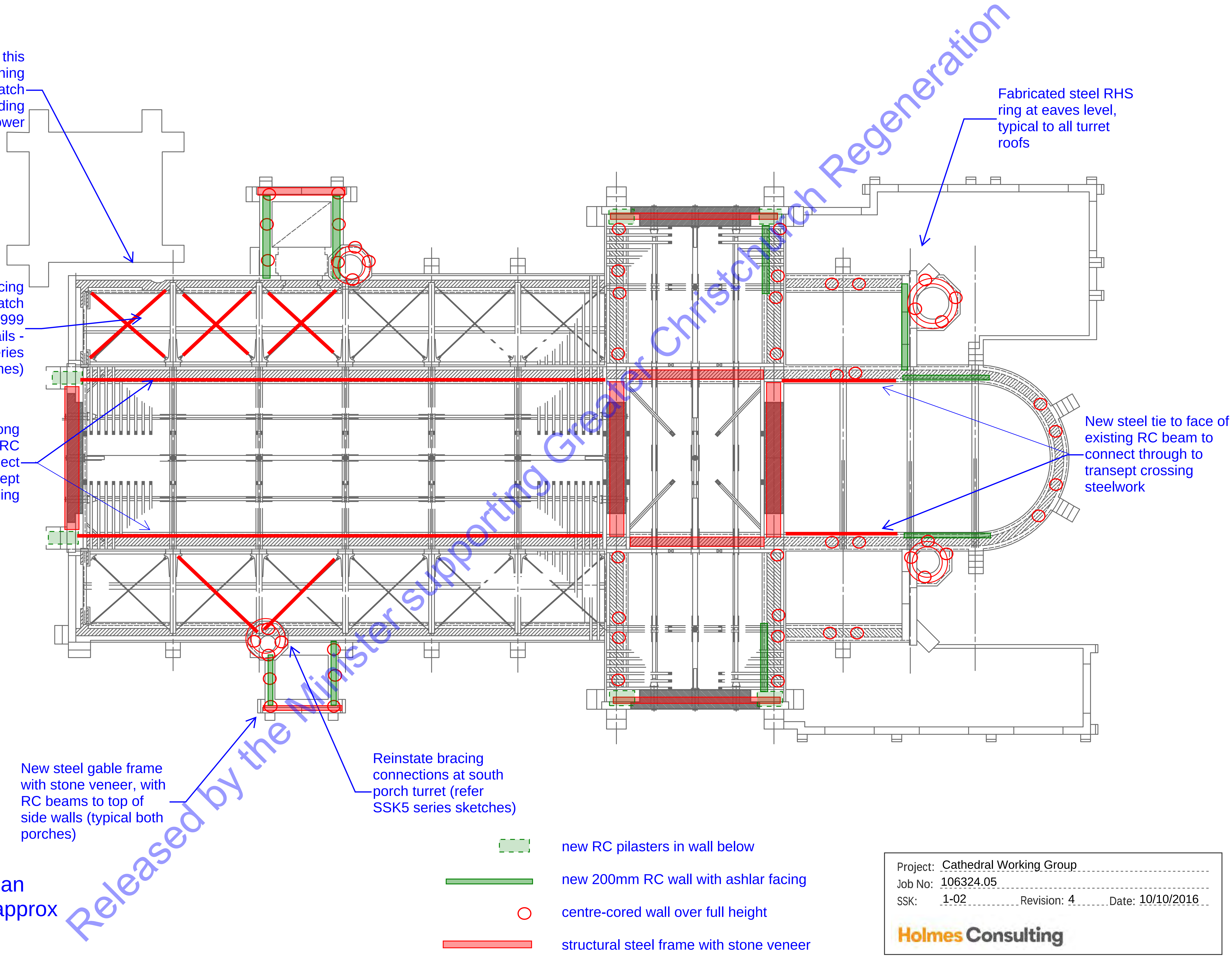
Appendix A - Sketches



Ground Floor and Foundation plan
1:200 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	1-01
Revision:	4
Date:	10/10/2016

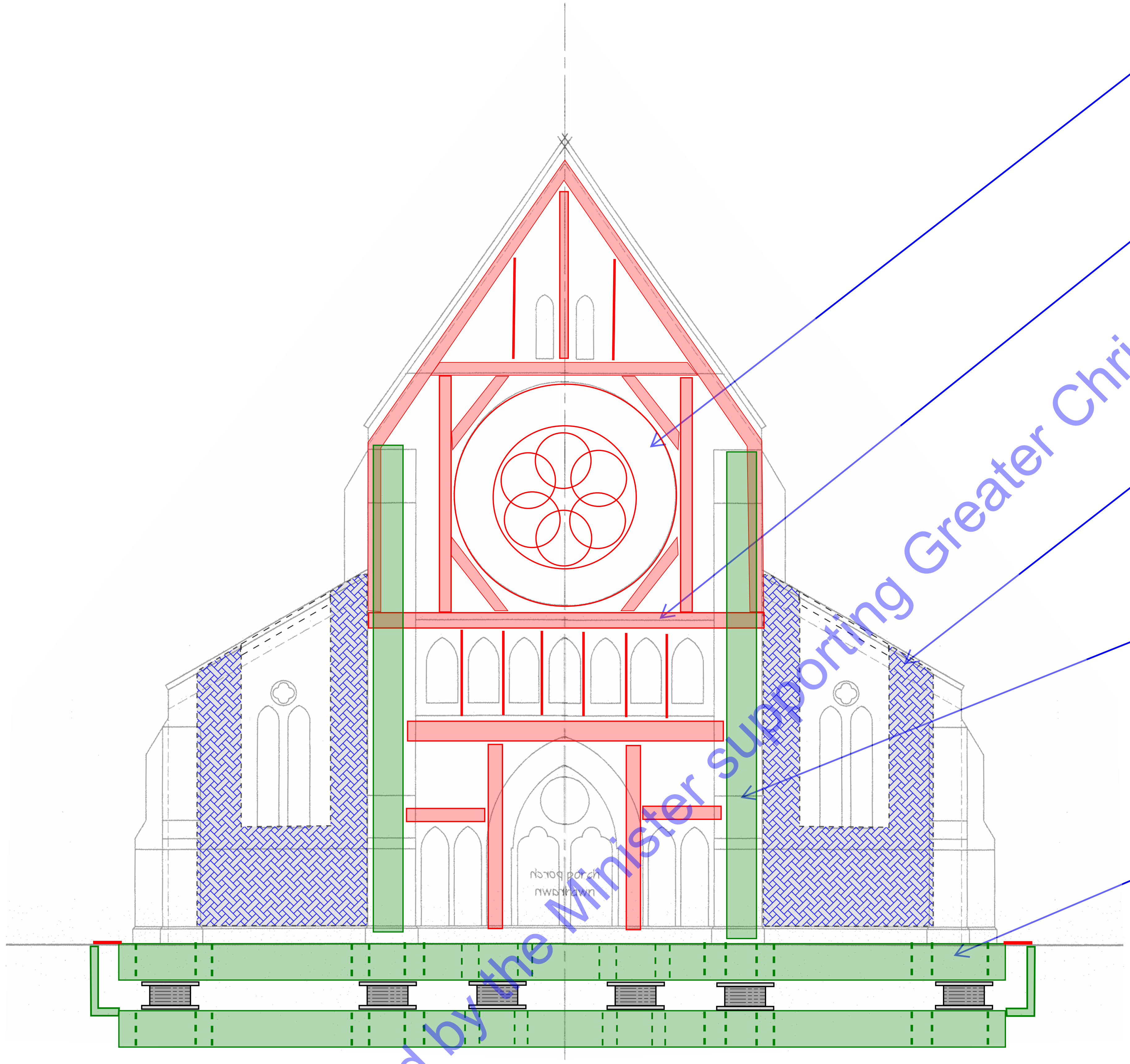
Holmes Consulting



Roof plan
1:200 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	1-02 Revision: 4 Date: 10/10/2016

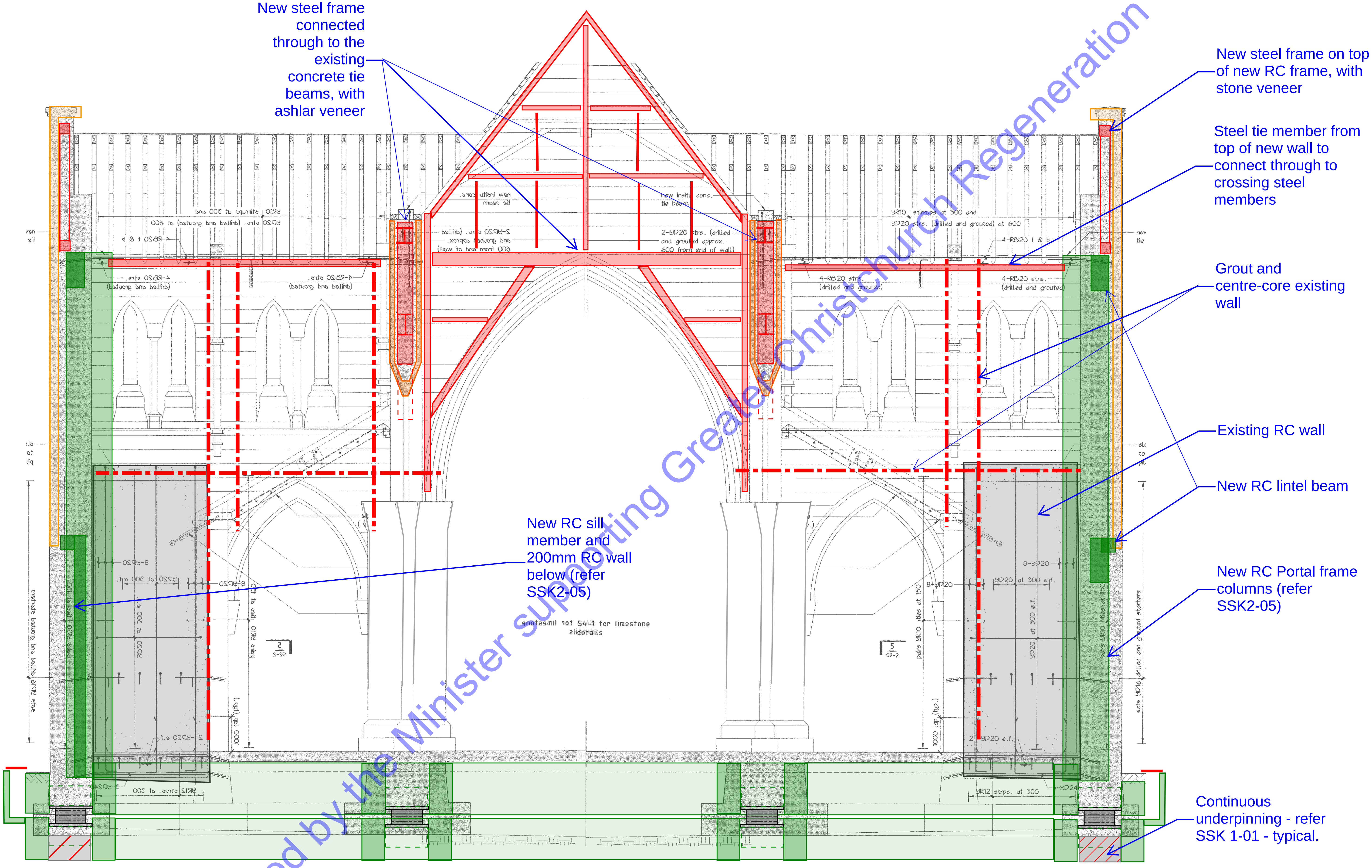
Holmes Consulting



West Elevation
1:100 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	2-01
Revision:	4
Date:	10/10/2016

Holmes Consulting



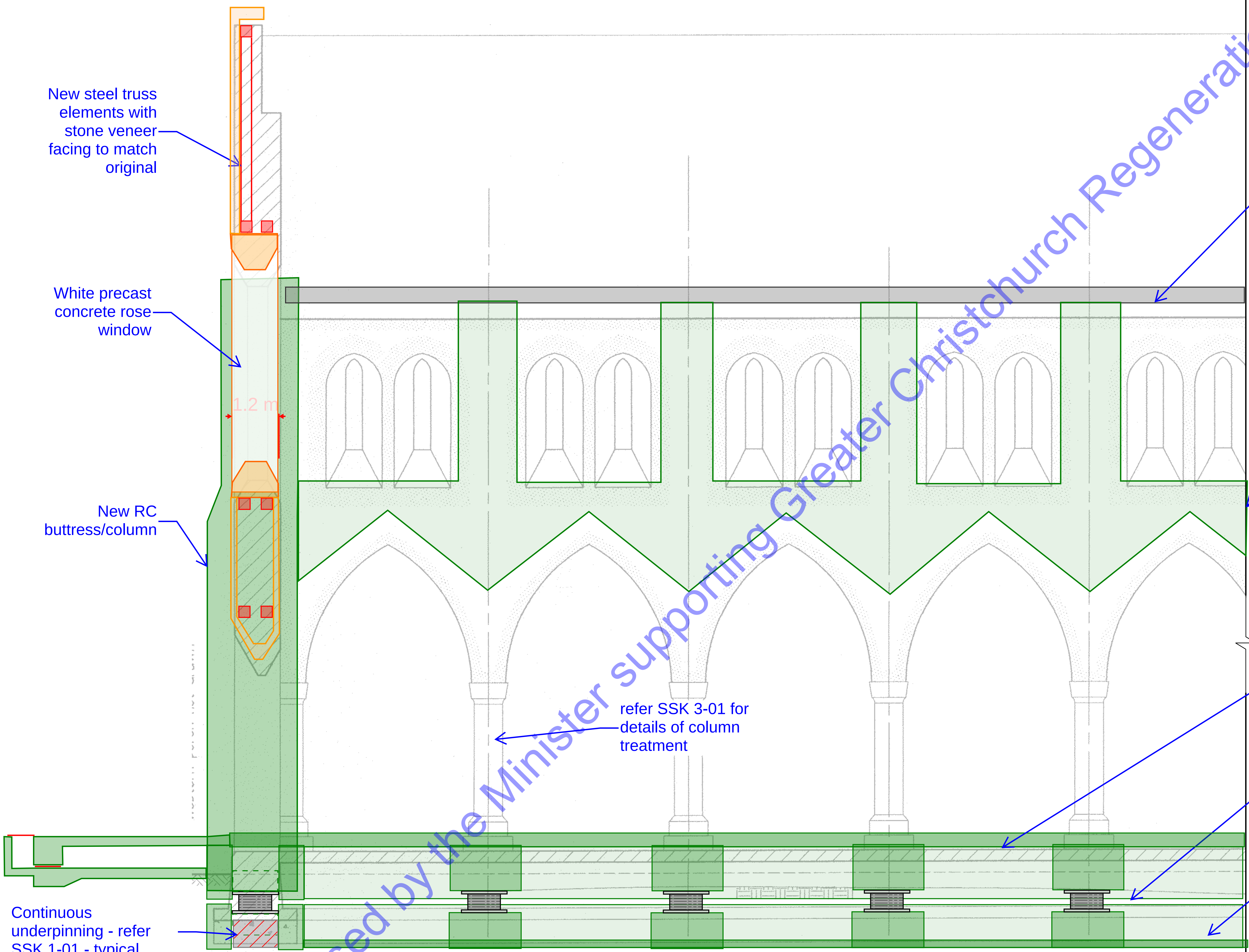
Lead-rubber bearing

Sliding bearing

West Transept Wall
1:100 approx

Project: Cathedral Working Group
Job No: 106324.05
SSK: 2-02 Revision: 4 Date: 10/10/2016

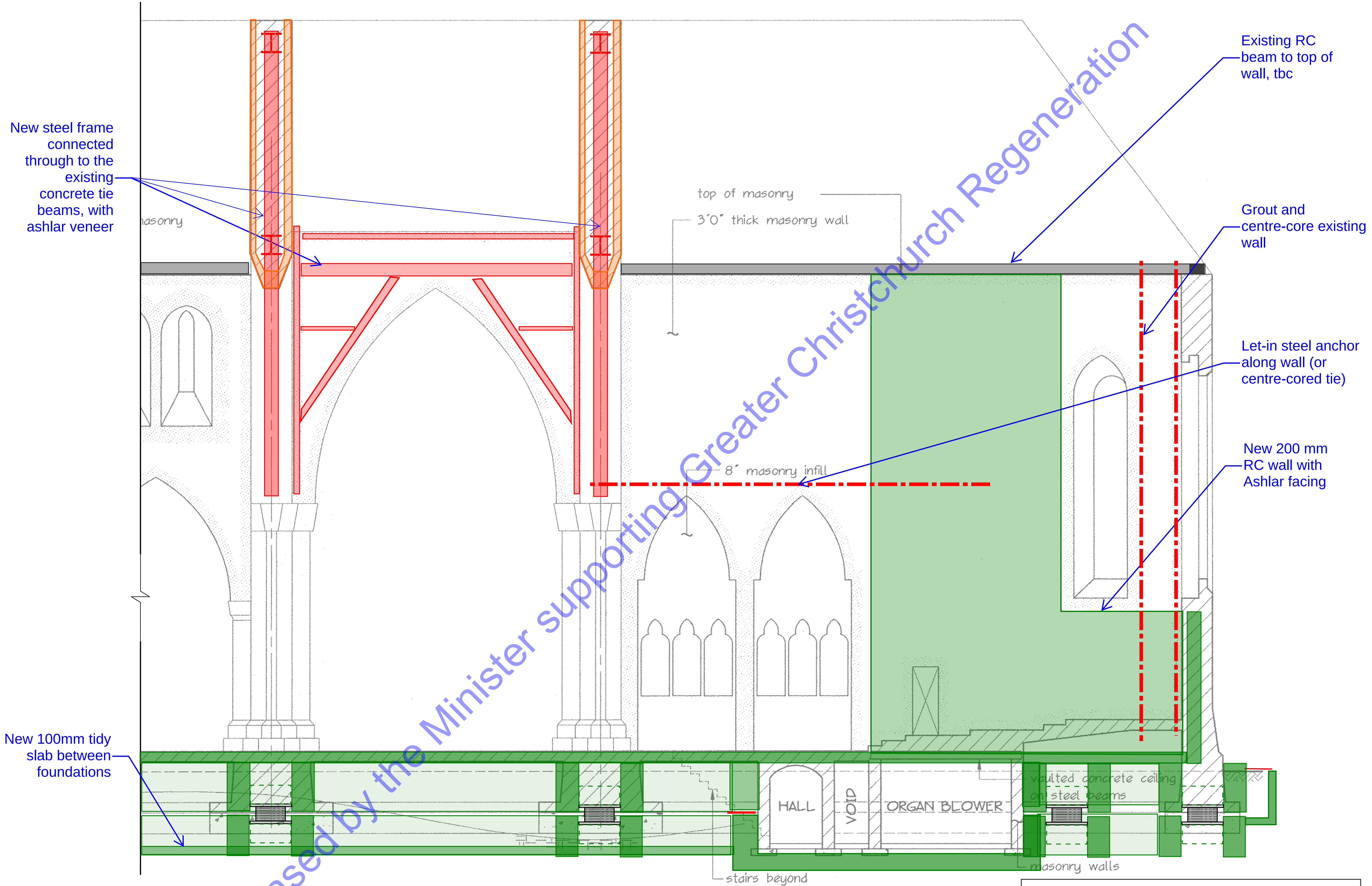
Holmes Consulting



Clerestory Wall
1:100 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	2-03 Revision: 4 Date: 10/10/2016

Holmes Consulting



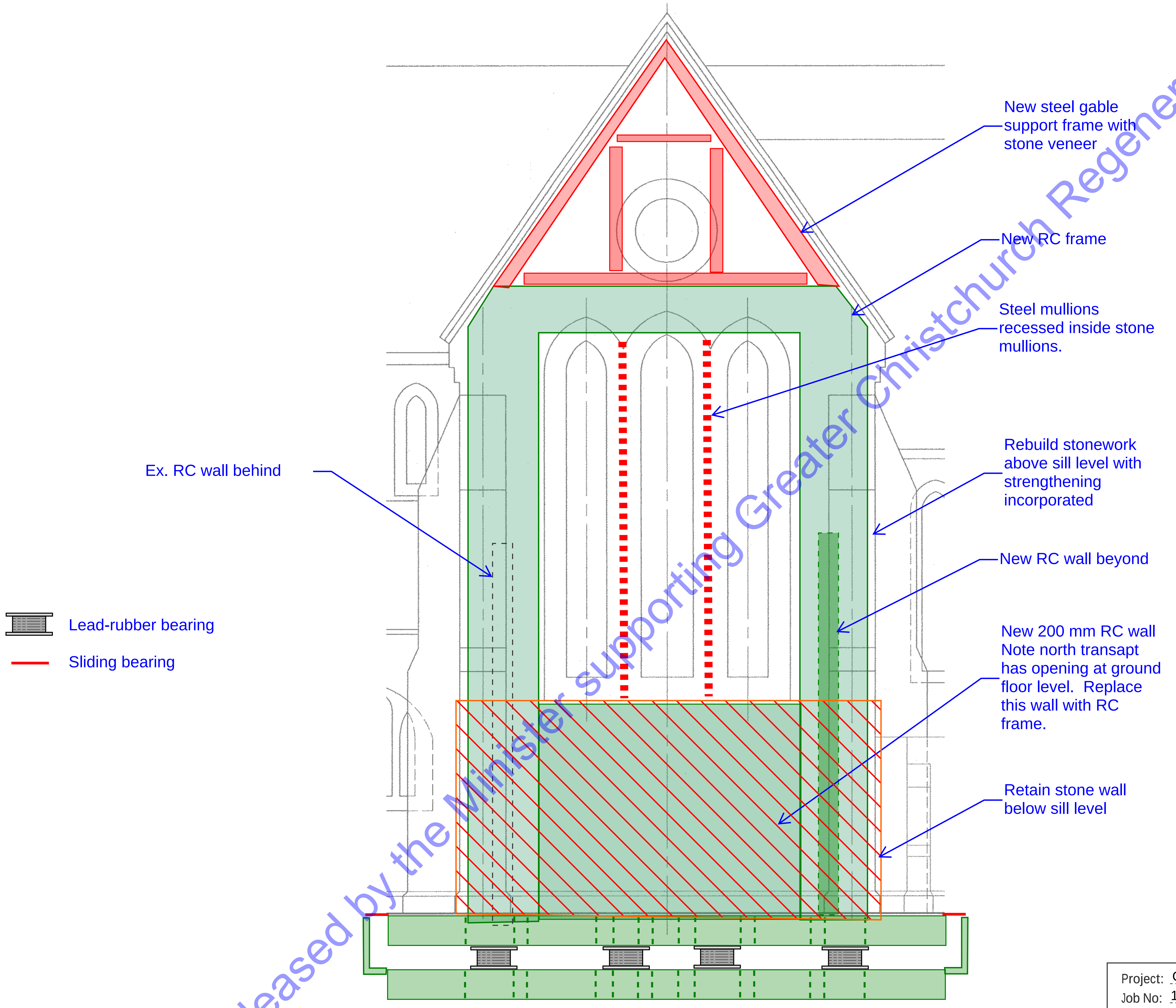
North Apse and Transept Wall
1:100 approx

Lead-rubber bearing

Sliding bearing

Project: Cathedral Working Group
Job No: 106324.05
SSK: 2-04 Revision: 4 Date: 10/10/2016

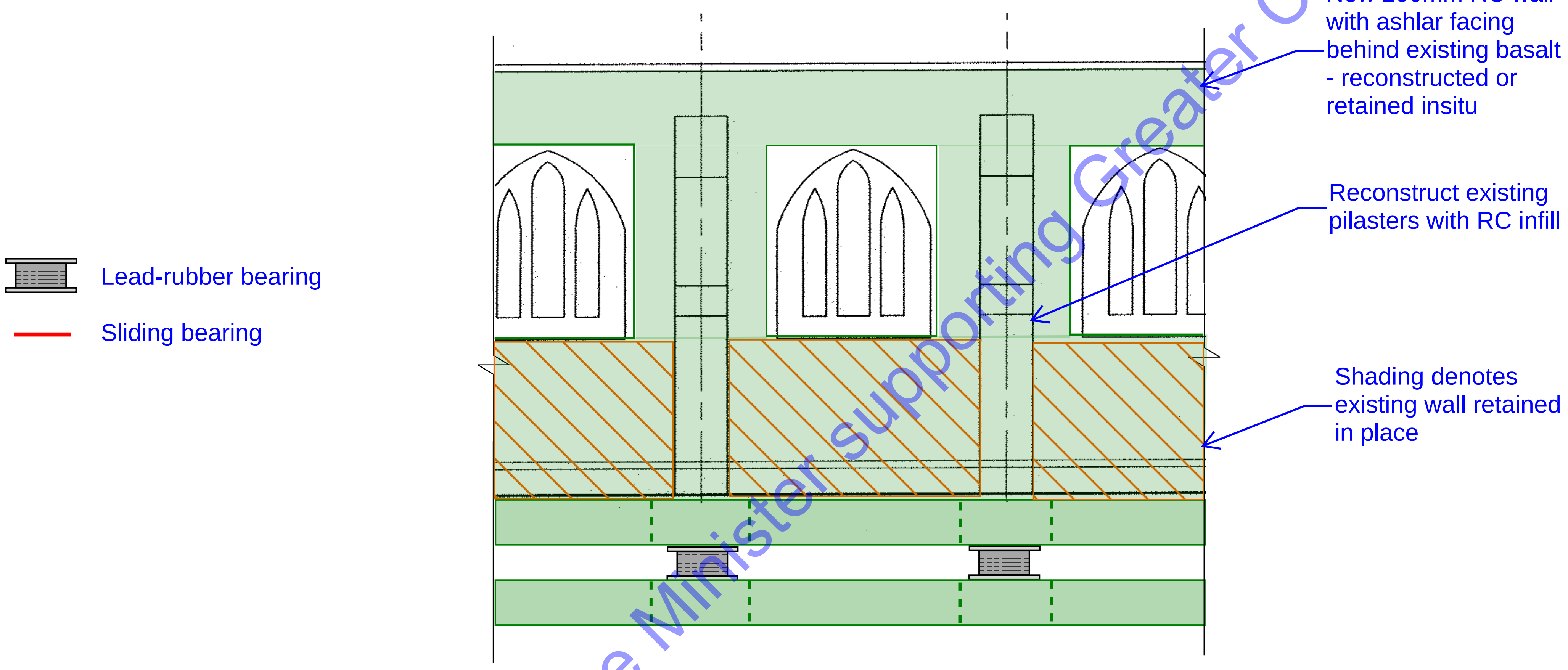
Holmes Consulting



South Transept Wall (North Transept wall similar)
1:100 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	2-05 Revision: 4 Date: 10/10/2016

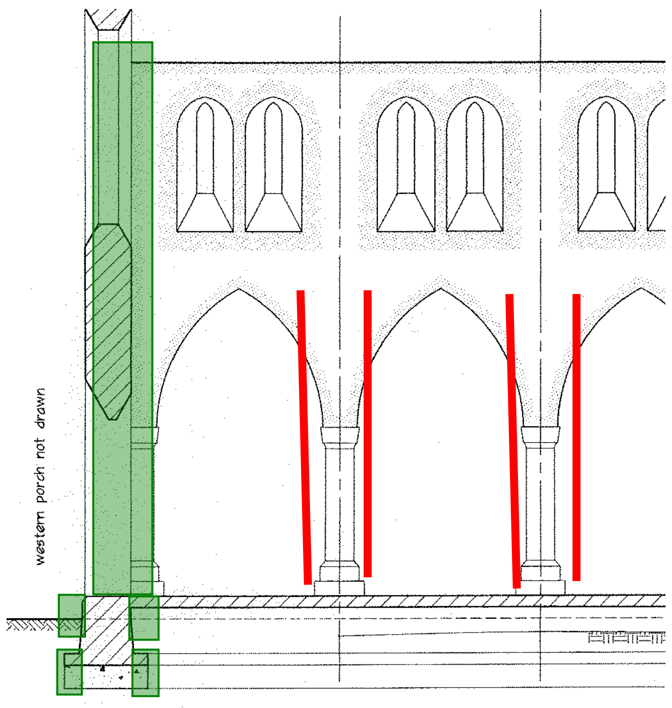
Holmes Consulting



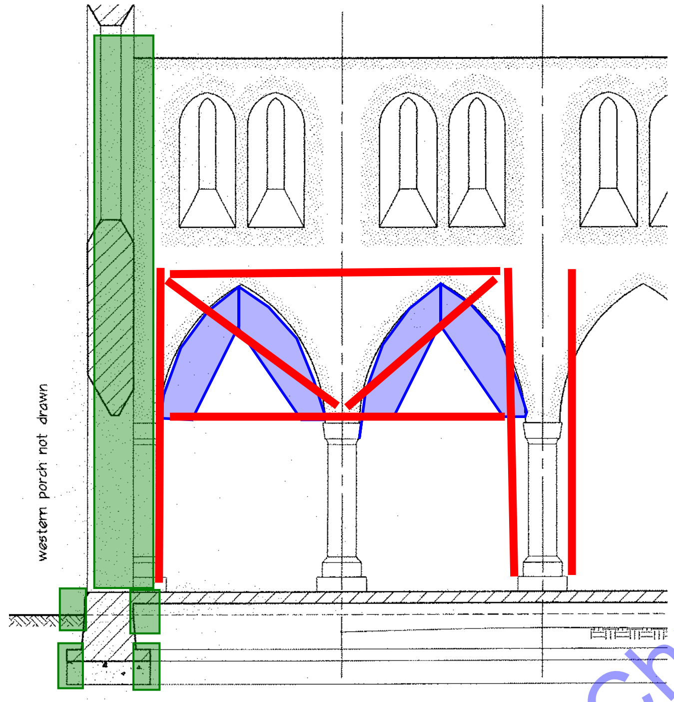
South Side Aisle Wall partial elevation
1:100 approx

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	2-06 Revision: 4 Date: 10/10/2016

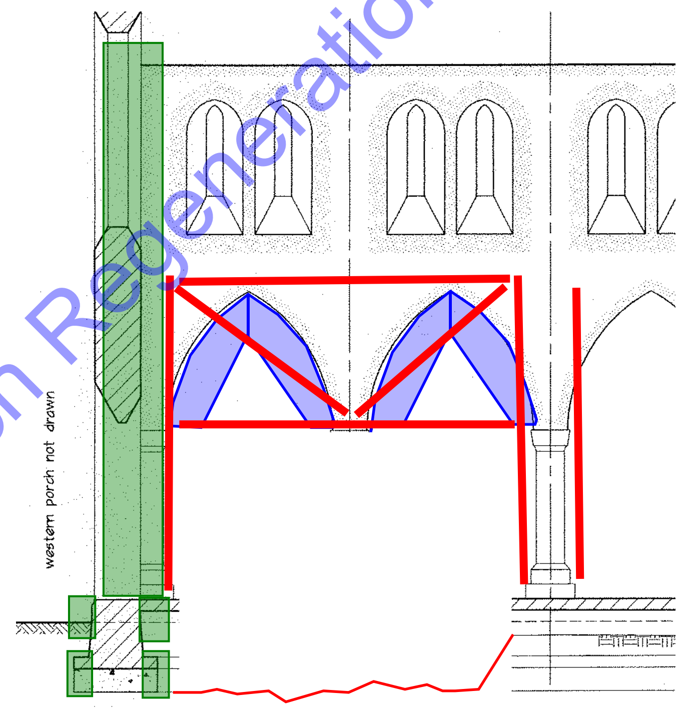
Holmes Consulting



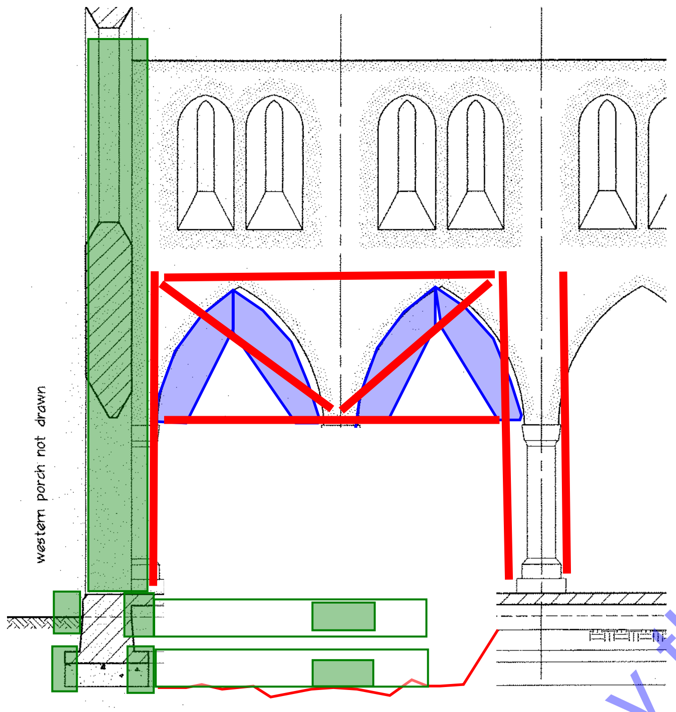
Step 1



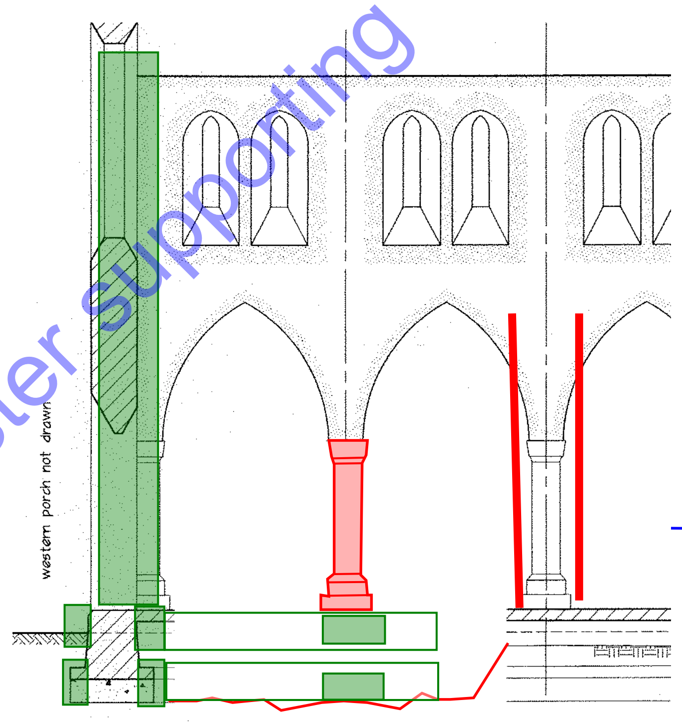
Step 2



Step 3



Step 4



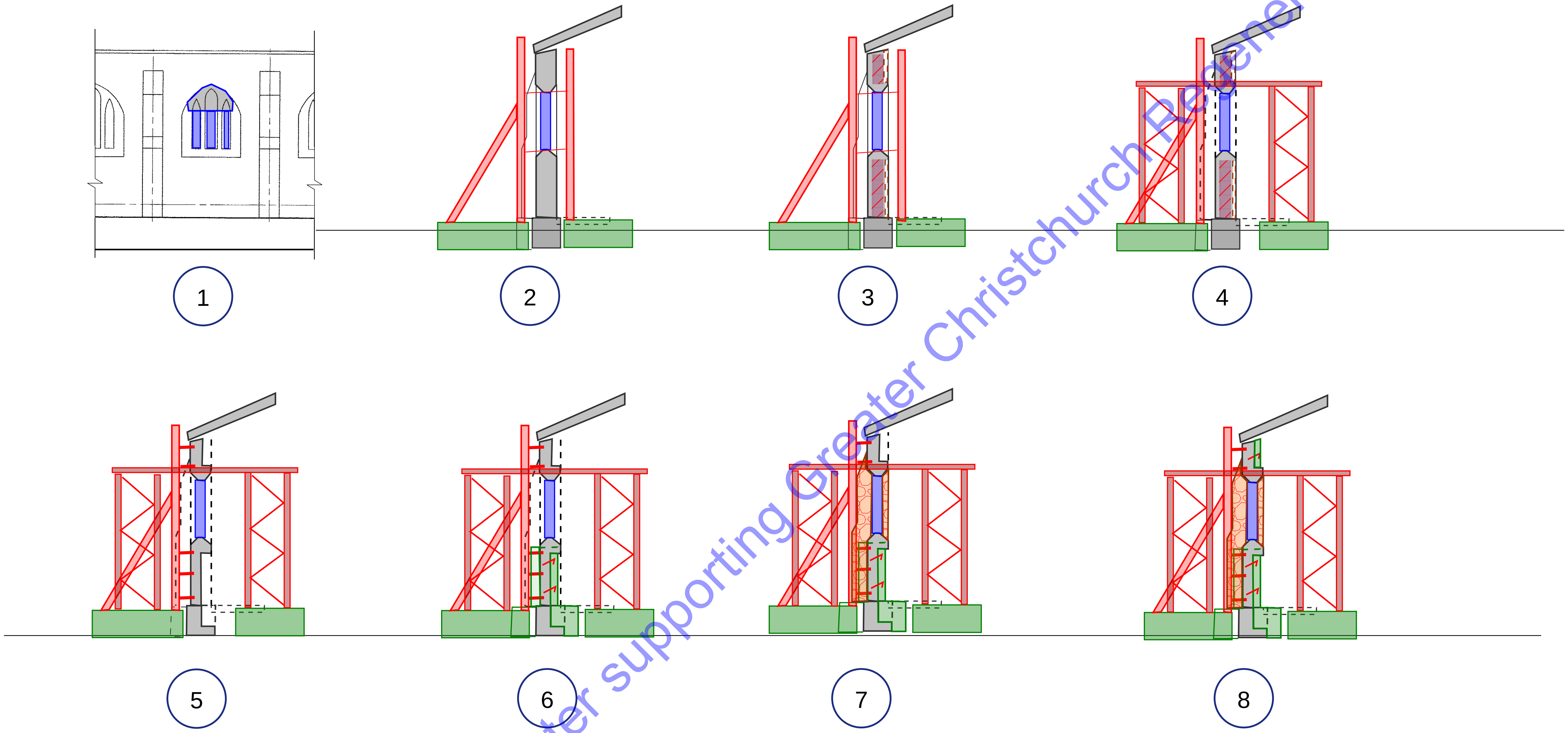
Step 5

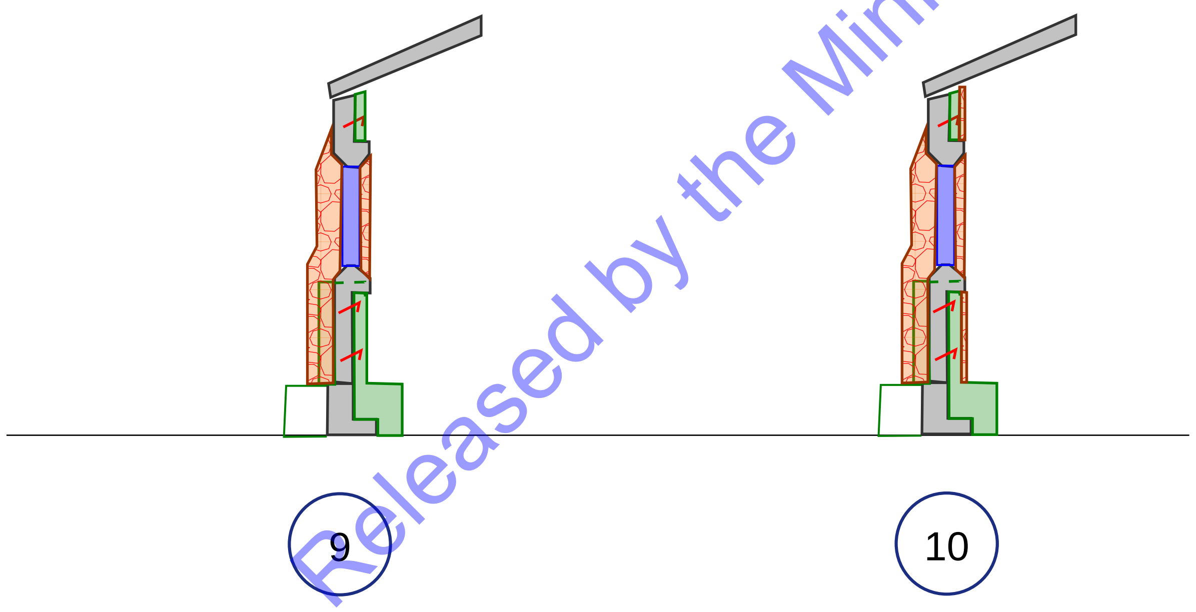
Replace column - refer to SSK 3-03 for steel alternative.

Notes:
1. Refer to section 7.2.1 of report for notes to steps
2. Column removal and support to proceed sequentially from west to east.
3. South and north sides may be worked on at the same time.
4. No more than one column on either side to be removed at any time.

Project: Cathedral Working Group
Job No: 106324.05
SSK: 3-01 Revision: 3 Date: 10/10/2016

Holmes Consulting

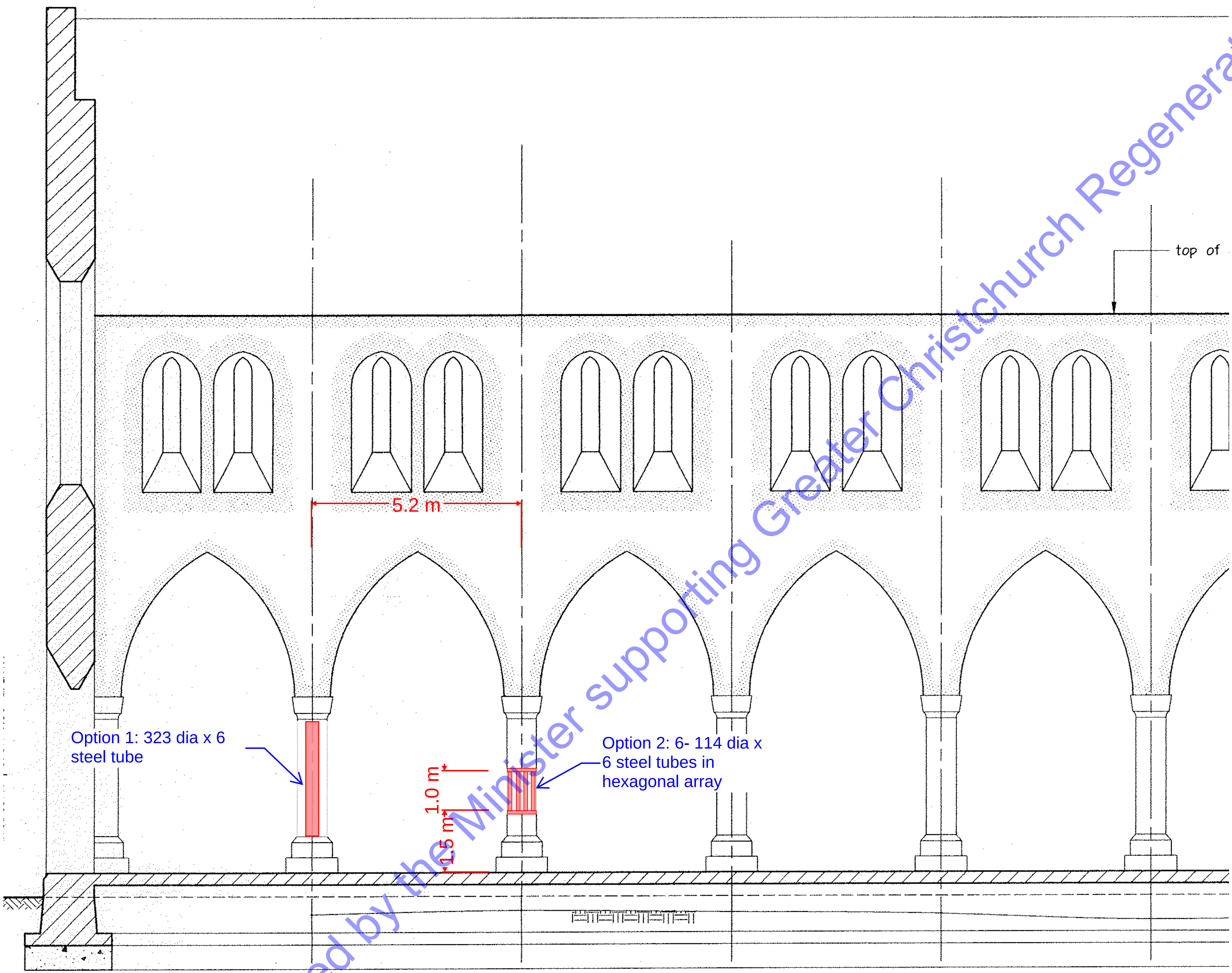




Note:
Refer to section 7.2.2 of report for notes to steps

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	3.02 Revision: 3 Date: 10/10/2016

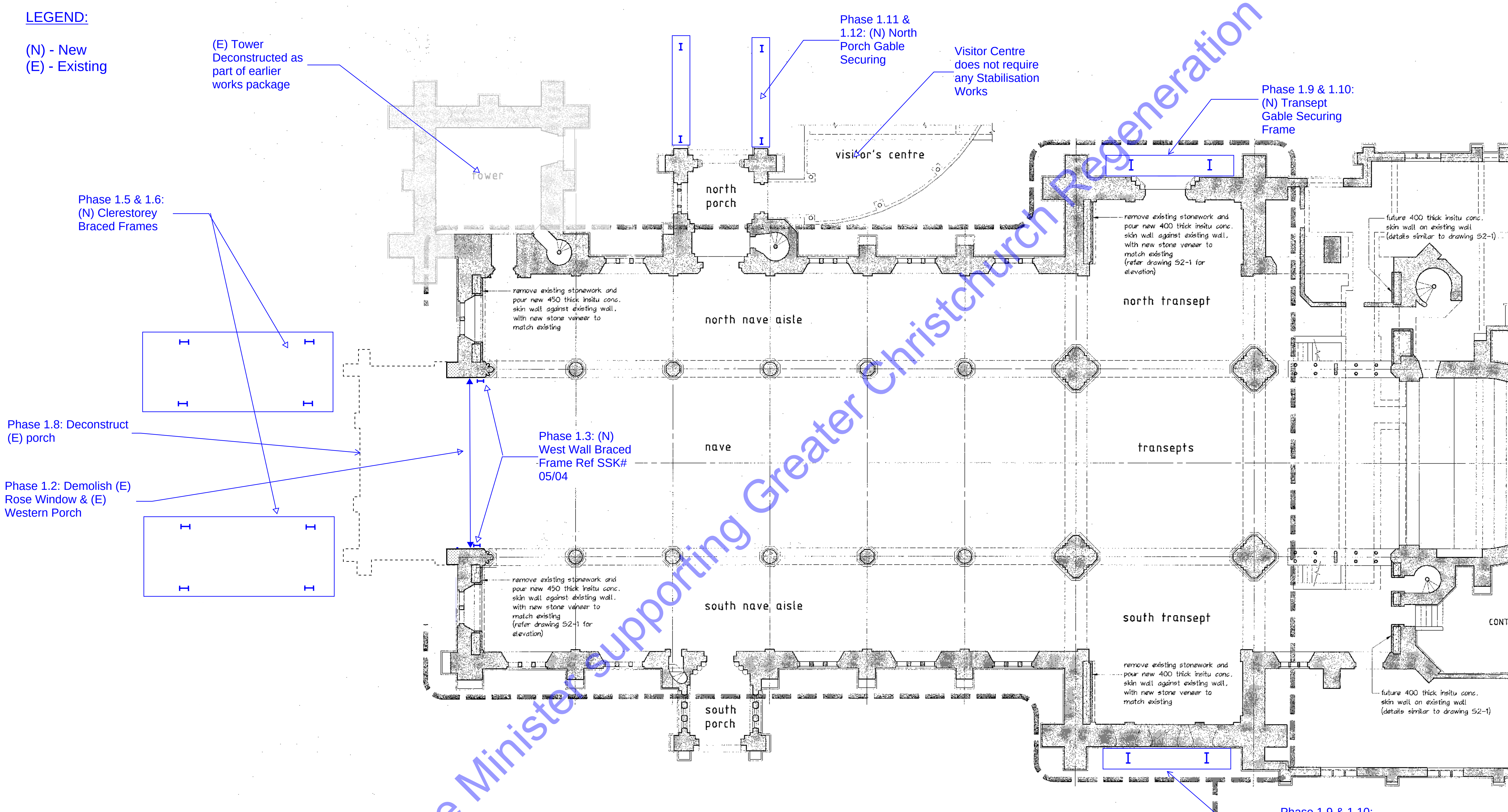
Holmes Consulting



Column replacement options
1:100 approx

Project: Cathedral Working Group
Job No: 106324.05
SSK: 4-01 Revision: 2 Date: 10/10/2016

Holmes Consulting

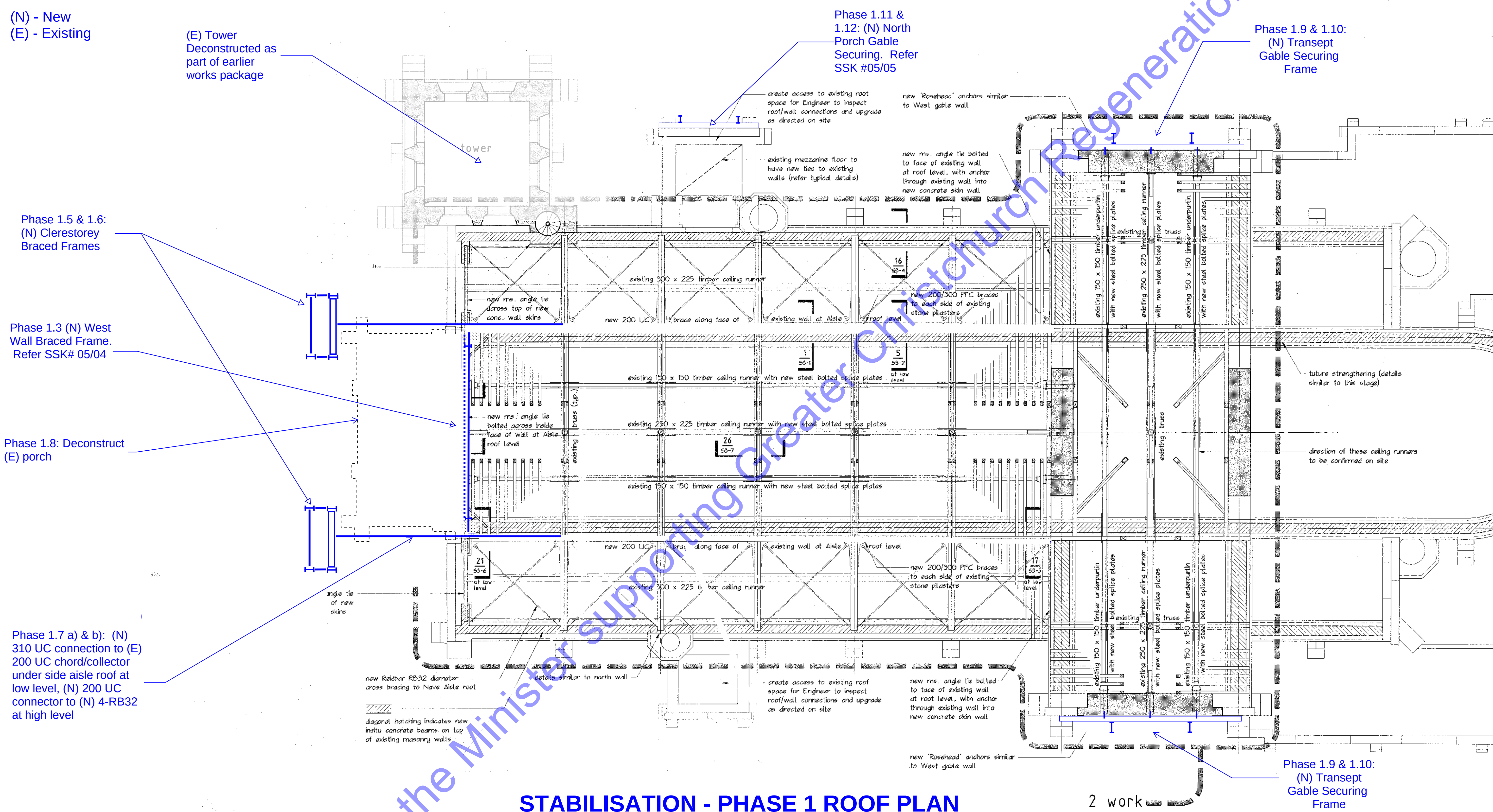


STABILISATION - PHASE 1 GROUND FLOOR PLAN

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-01 Revision: 4 Date: 10/10/2016
Holmes Consulting

LEGEND:

(N) - New
(E) - Existing

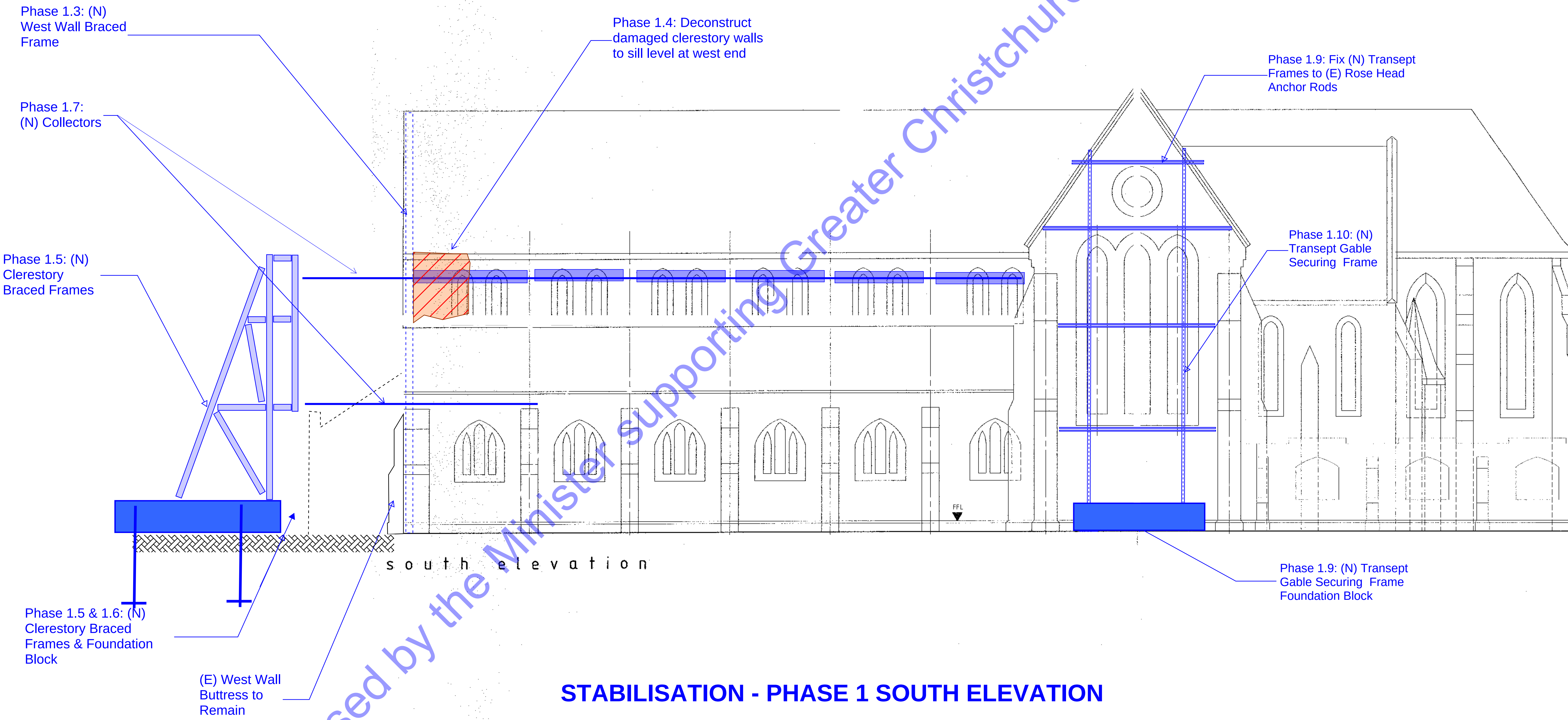


STABILISATION - PHASE 1 ROOF PLAN

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-02 Revision: 4 Date: 10/10/2016
Holmes Consulting

LEGEND:

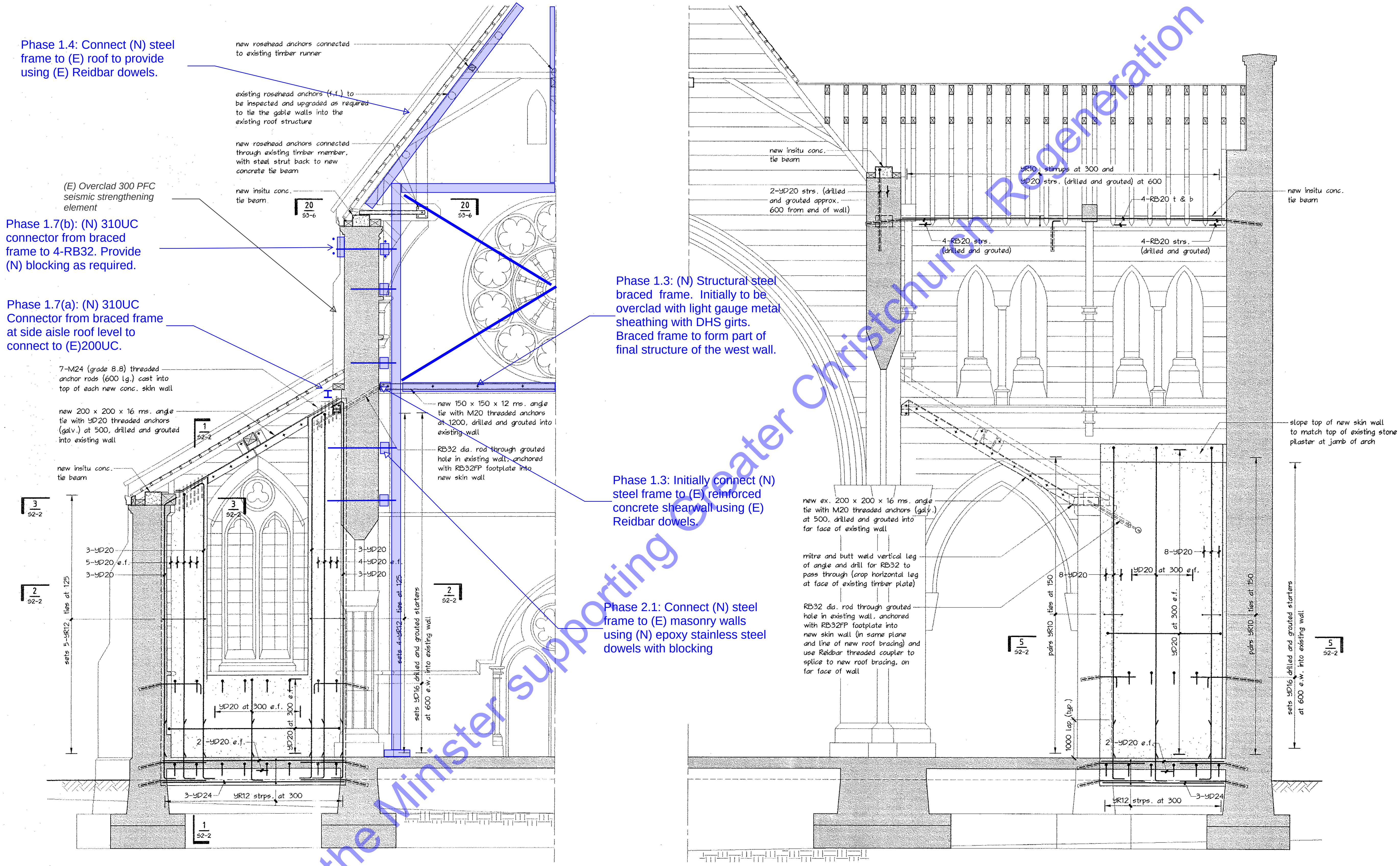
(N) - New
(E) - Existing



STABILISATION - PHASE 1 SOUTH ELEVATION

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	5-03 Revision: 4 Date: 10/10/2016

Holmes Consulting



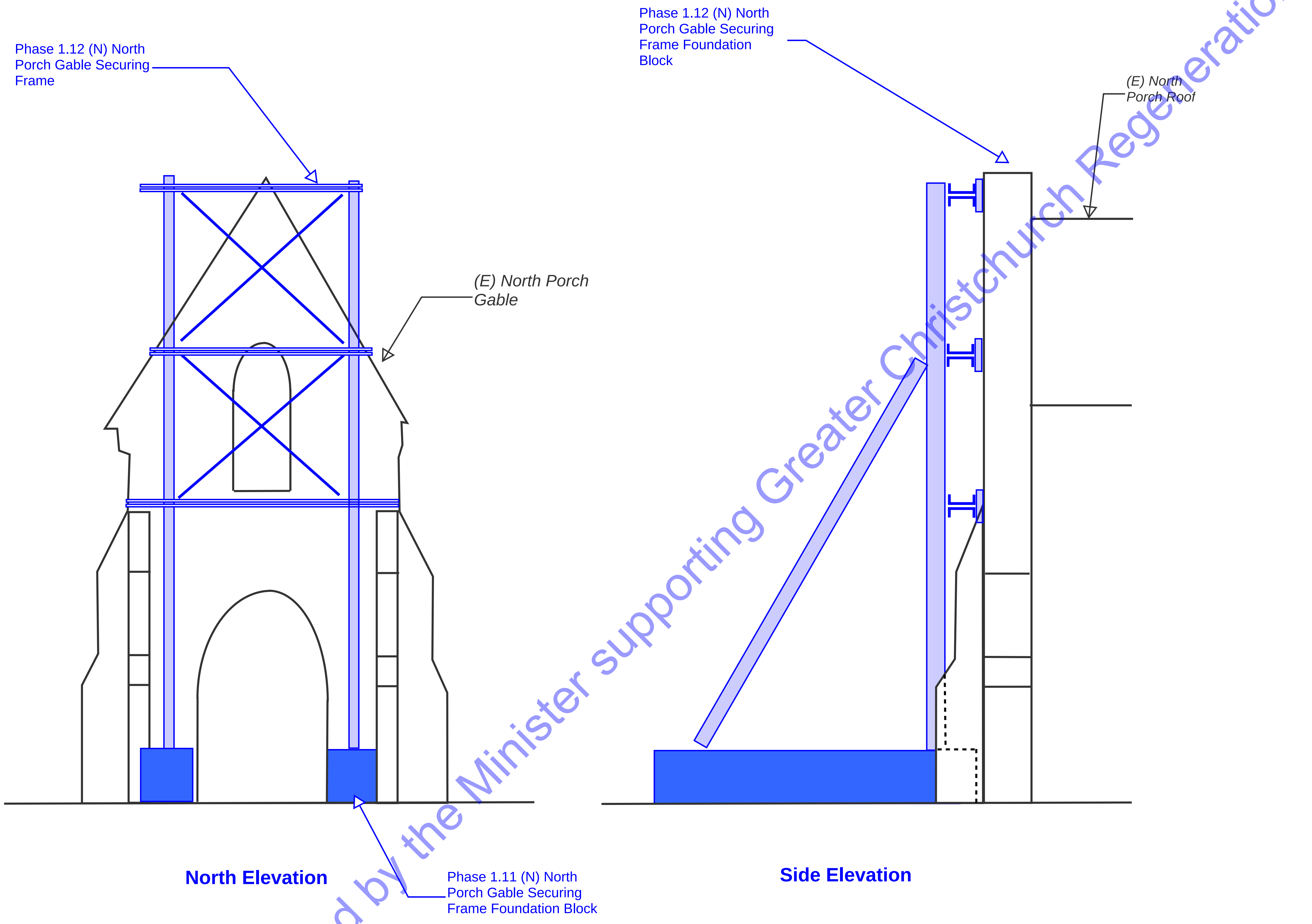
south nave aisle
north nave aisle

STABILISATION - PHASE 1 WEST WALL

transept, west wall – 400 thick conc. skin 1 : 5 0
transept, west wall – similar, opposite hand

Project:	Cathedral Working Group
Job No:	106324.05
SSK:	5-04 Revision: 4 Date: 10/10/2016

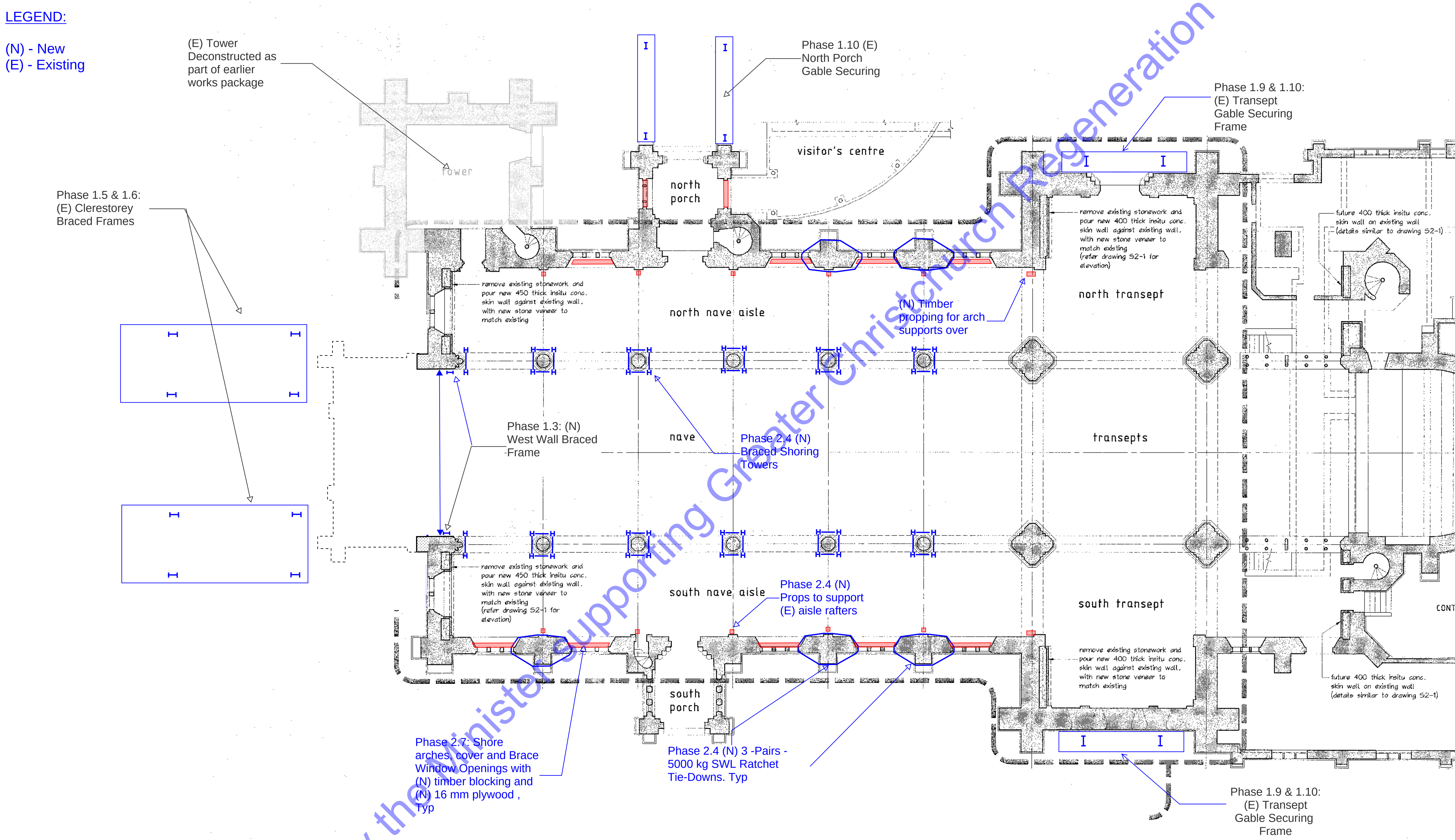
Holmes Consulting



STABILISATION - PHASE 1 NORTH PORCH SECURING FRAME

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-05 Revision: 4 Date: 10/10/2016

Holmes Consulting

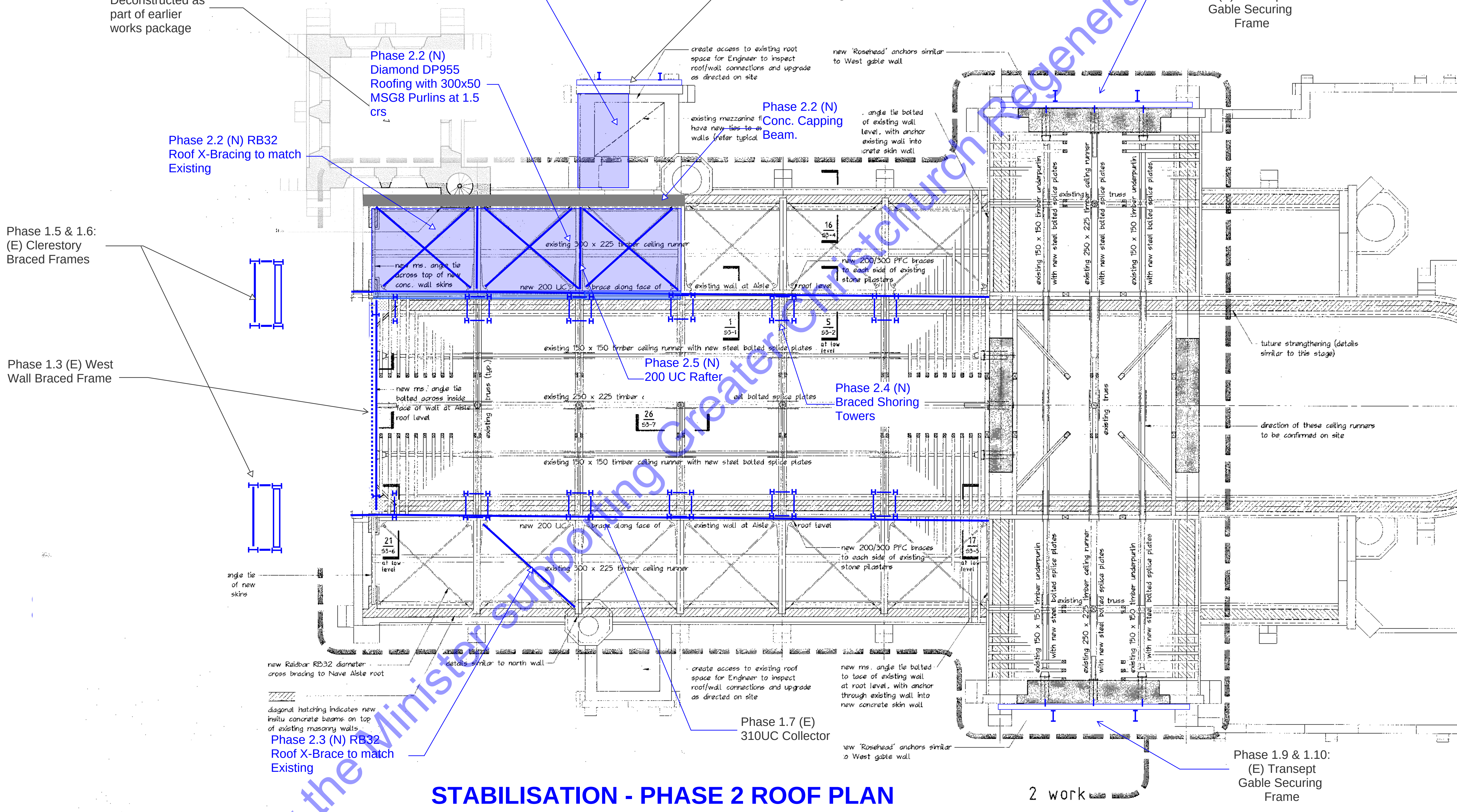


STABILISATION - PHASE 2 GROUND FLOOR PLAN

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-06 Revision: 4 Date: 10/10/2016
Holmes Consulting

LEGEND:

(N) - New
(E) - Existing

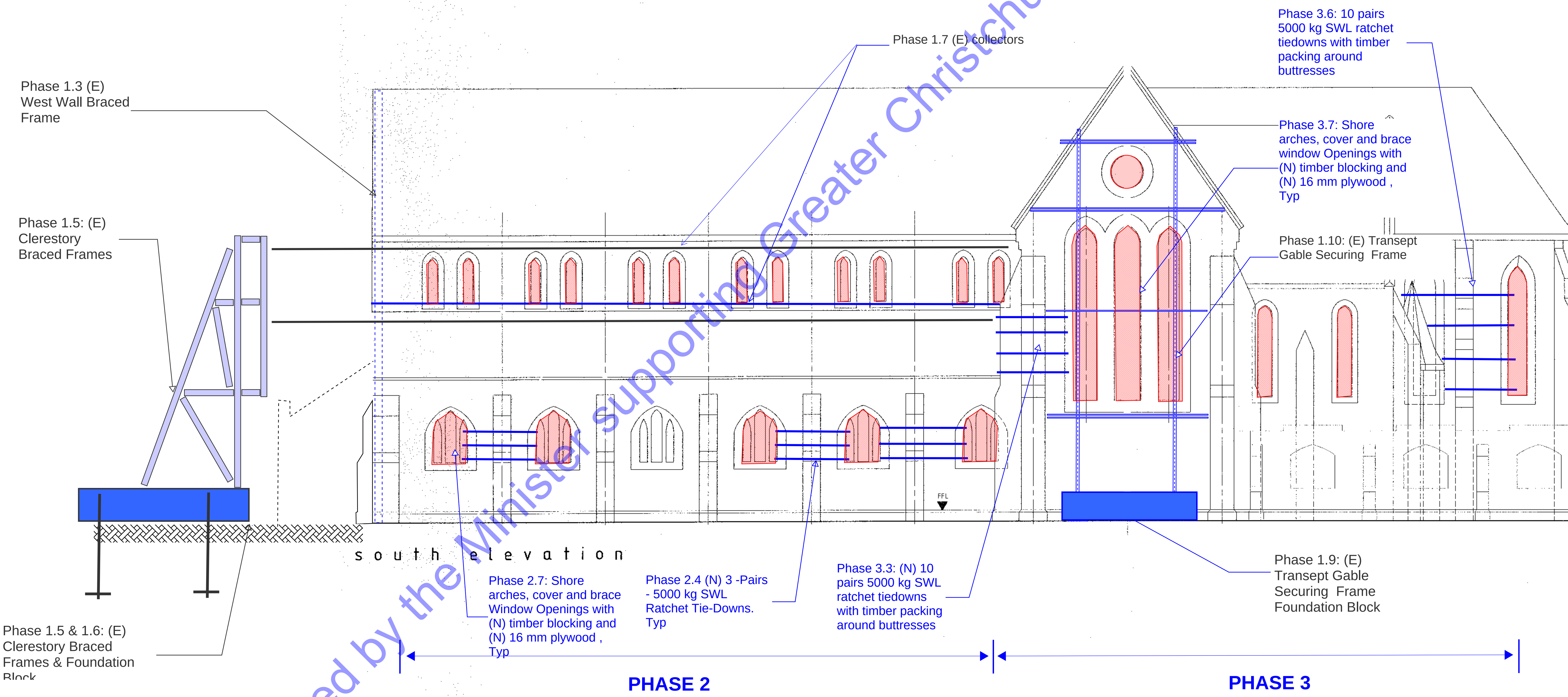


STABILISATION - PHASE 2 ROOF PLAN

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-07 Revision: 4 Date: 10/10/2016
Holmes Consulting

LEGEND:

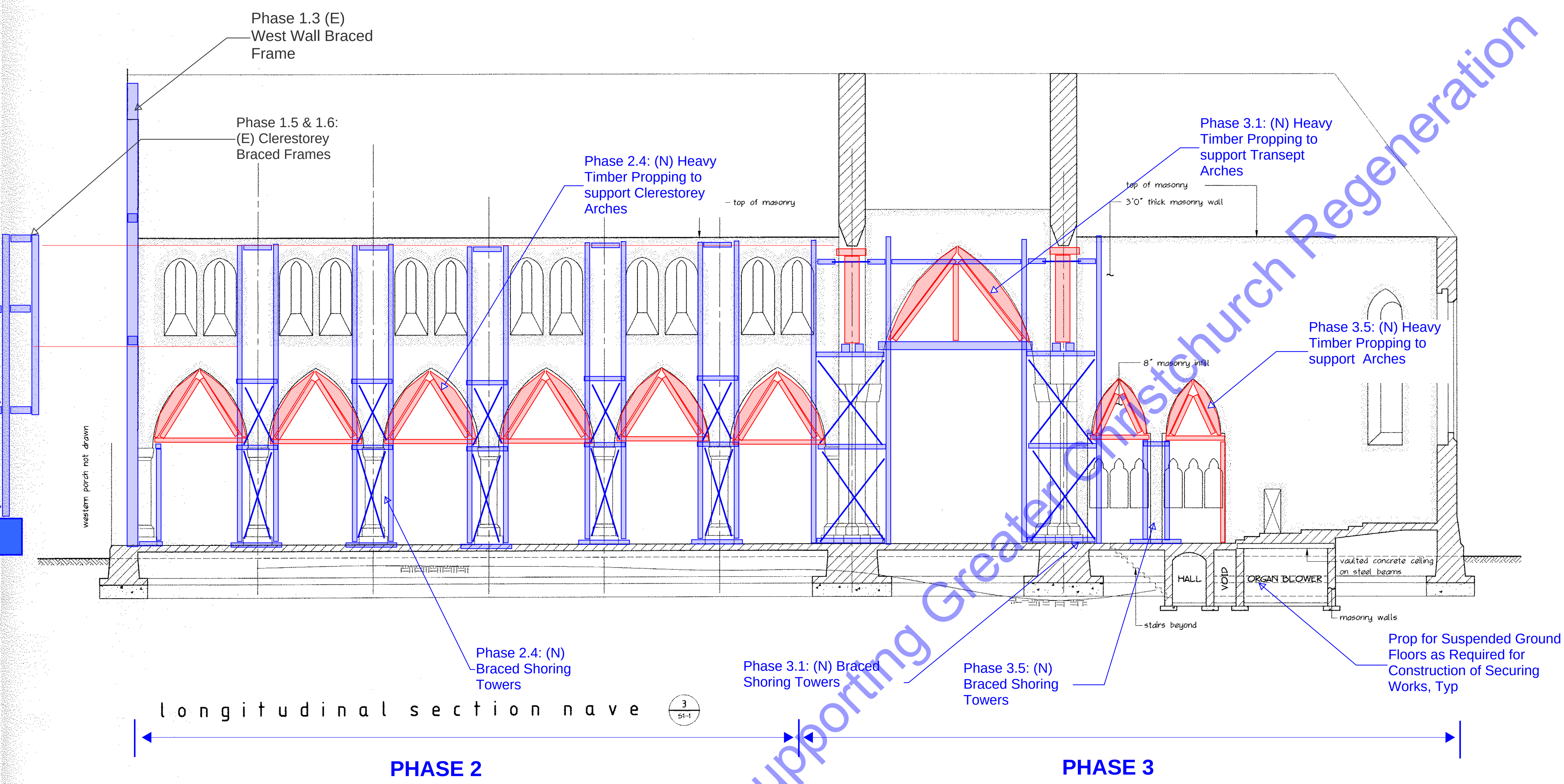
(N) - New
(E) - Existing



STABILISATION - PHASE 2 & 3 SOUTH ELEVATION

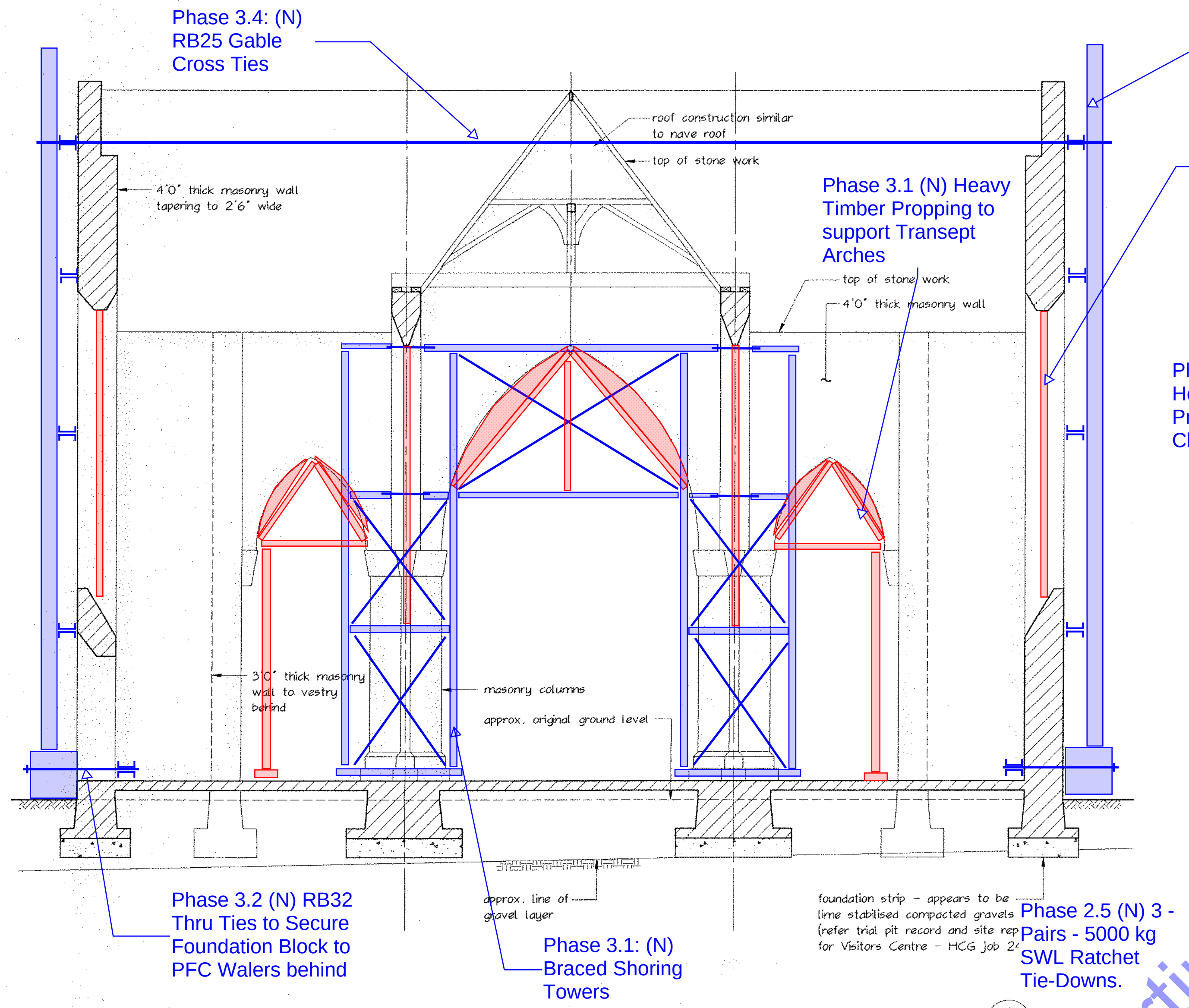
Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-08 Revision: 4 Date: 10/10/2016

Holmes Consulting

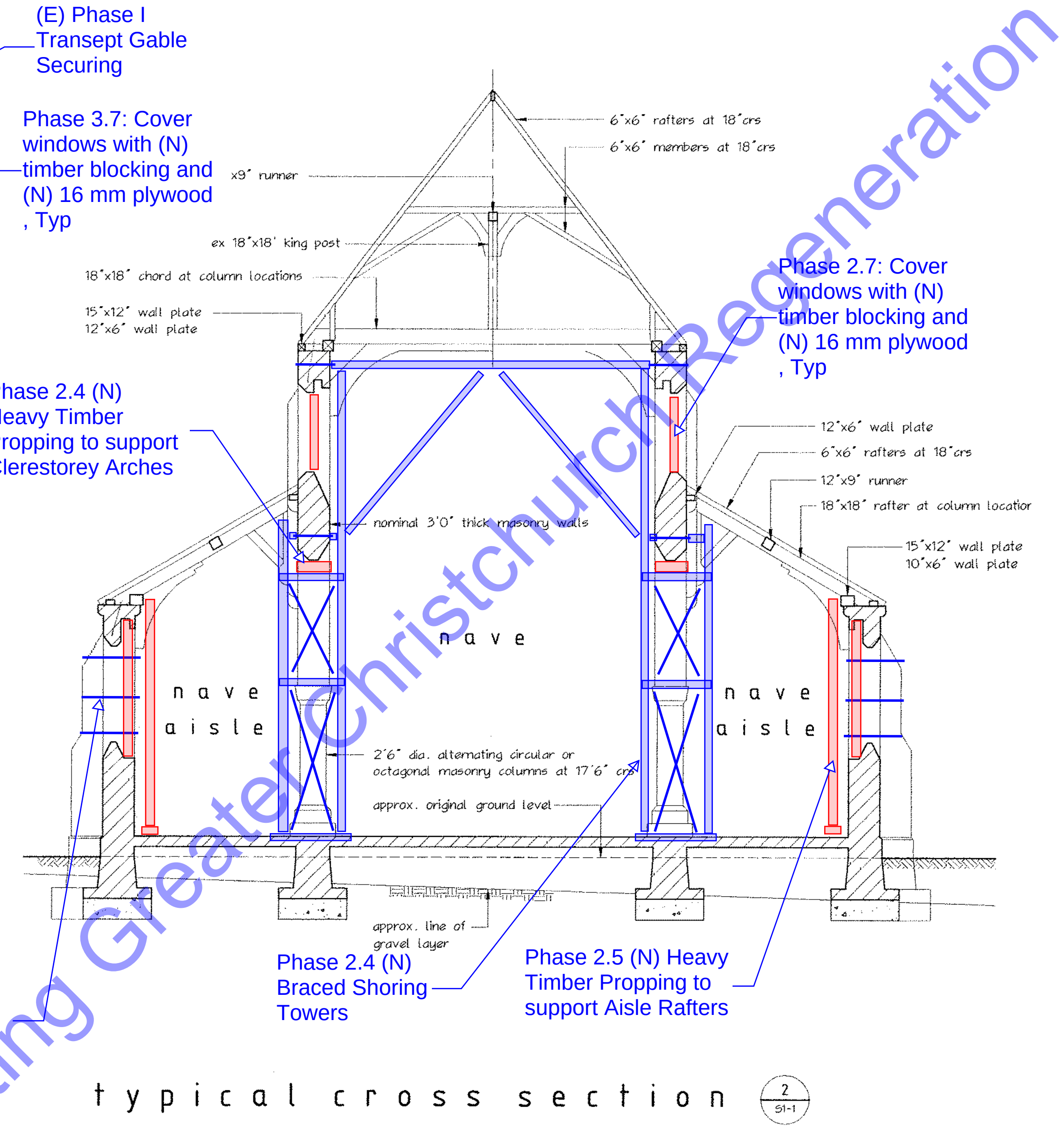


STABILISATION - PHASE 2 & 3 LONGITUDINAL SECTIONS

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-09 Revision: 4 Date: 10/10/2016
Holmes Consulting



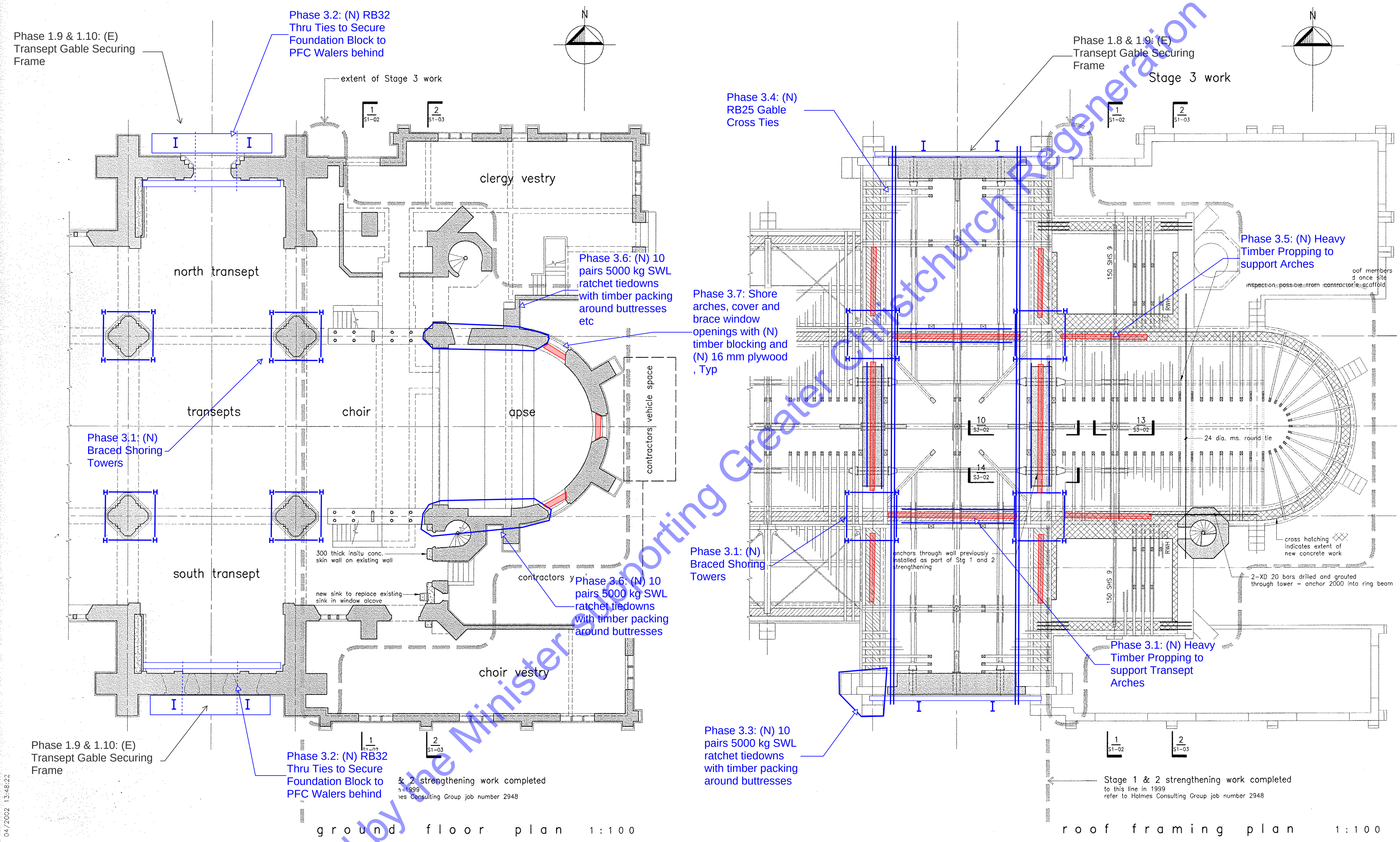
STABILISATION - PHASE 3 TRANSEPT SECTIONS



STABILISATION - PHASE 2 NAVE SECTIONS

STABILISATION - PHASE 2 & 3 SECTIONS

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-10 Revision: 4 Date: 10/10/2016
Holmes Consulting



STABILISATION - PHASE 3 GROUND FLOOR & ROOF PLAN

Project: Cathedral Working Group
Job No: 106324.05
SSK: 5-11 Revision: 4 Date: 10/10/2016

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