STEEL ENABLES ICONIC CATHEDRAL REINSTATEMENT

Christ Church Cathedral suffered extensive damage as a result of the devastating Canterbury earthquakes of 2011. In 2017, the decision was made to reinstate the Cathedral, an iconic Christchurch landmark and Category 1 listed heritage building. In 2019, the project team was appointed.

The Cathedral's reinstatement has been broadly described as one of the most complex heritage projects in New Zealand. It has also been compared to the Pike River recovery in terms of the vulnerable nature of the structure and the implications to health and safety, should there be an earthquake while being worked on.

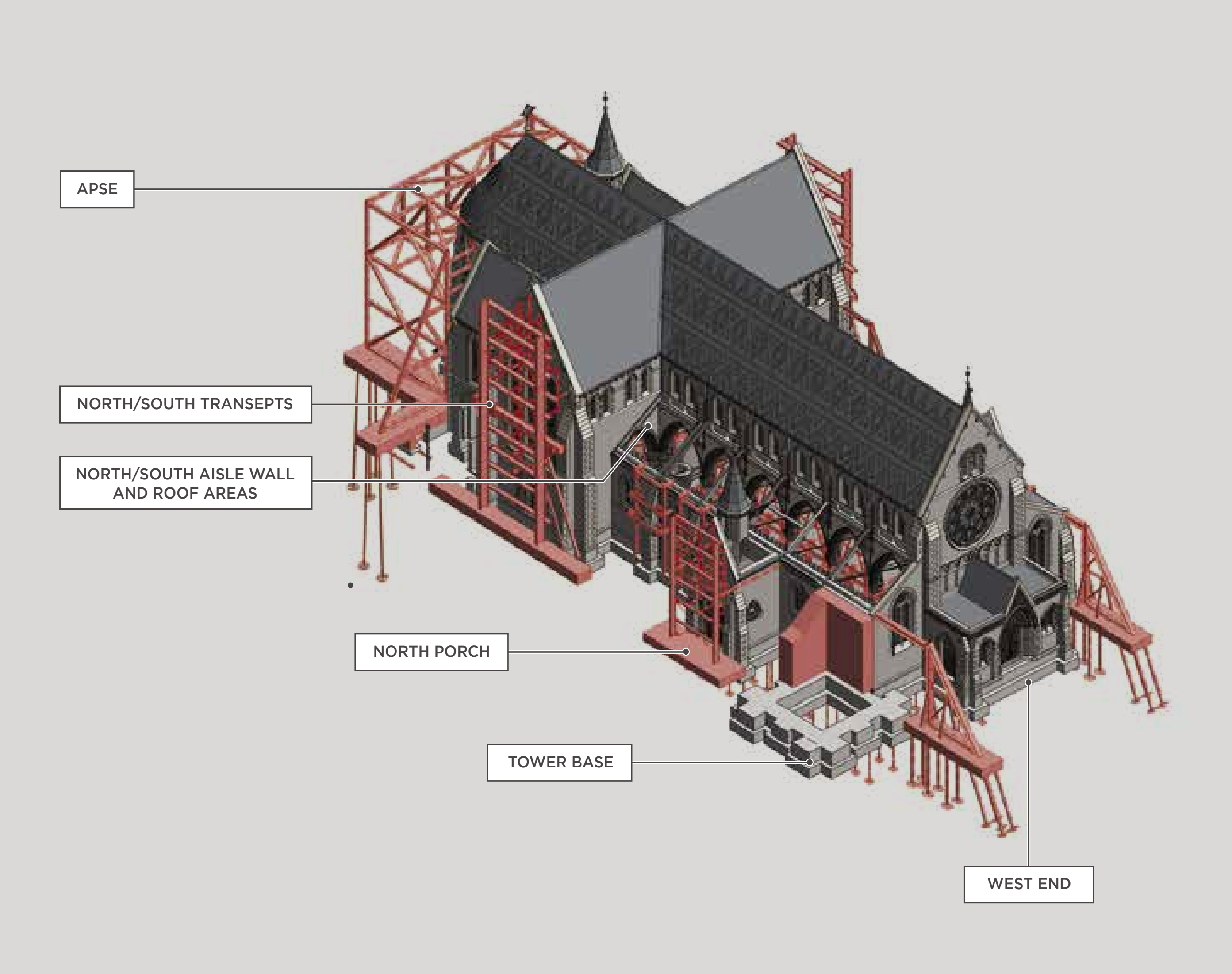
Prior to any physical work proceeding, considerable preconstruction planning and design was required. The project team gathered comprehensive information about the Cathedral – its history, how it was constructed, the ground conditions, previous restoration and strengthening work, and extent of the earthquake damage. The team also explored international standards and approaches to health and safety planning before it landed on the preferred approach for the Cathedral.

It was agreed, for worker safety reasons, that the structure would be brought up to 34 percent of the New Building Standard (NBS) – it is a typical level for deeming a building no longer earthquake-prone and it is considered

THE FACTS

- 320 tonnes of structural steel supplied to date
- 22.5 tonnes, heaviest single assembly
- 110 tonnes, weight of heaviest structure
- 22m, highest structure
- 32m, longest beam
- 25,000-plus bolts used
- 2-tonne steel safety shelter purpose built for working in the danger zone

ARCHITECT – WARREN AND MAHONEY **STRUCTURAL ENGINEER** – HOLMES **STEEL CONTRACTOR** – VIP STRUCTURAL STEEL **BUILDER** – NAYLOR LOVE **CLIENT** – CHRIST CHURCH CATHEDRAL REINSTATEMENT LIMITED (CCRL)



an acceptable level of risk for the project to sustain and a precursor before strengthening to commence.

On the building's exterior there are several steel structures to prop and brace elements until it is strengthened. Physical works began in 2020, starting with demolition of the visitors' centre, and north and south vestries. Other major work fronts are the west end, south transept and north porch, followed by the north transept, side aisle walls, roof, apse and the crossing, and the interior clean up. The partial deconstruction of some badly damaged sections is required to make safe, manage collapse hazards and allow a more efficient strengthening phase.

Once safe to enter, there will be a clean-up job to do; there is a lot of rubble inside from when the tower and west wall fell inwards when the earthquake hit, and 2,000-odd pigeons have lived in there for more than 10 years, which presented a biohazard to the site.

When the stabilisation phase is complete in late 2022, it will have taken two-and-a-half years. Then the next strengthening phase of the reinstatement work can be undertaken safely.

The reinstated Anglican Cathedral, and the supporting buildings that will form the Cathedral Quarter, will look similar and retain many heritage features; it will also be significantly more resilient. The Cathedral will be seismically strengthened to modern standards, base isolated to provide greater seismic resistance while limiting intrusive strengthening. By the time work is completed in 2027, it will be 16 years after the event so the new facility must also meet the demands of a modern congregation – it will be more comfortable, accessible and better equipped than before.

ABOVE: LOCATIONS OF MAJOR REINSTATEMENT WORK FRONTS.

RIGHT, TOP AND BOTTOM: STEEL PROPPING AND BRACING ELEMENTS BEING INSTALLED.

ABOVE: SOME OF THE STABILISATION STEELWORK WILL BECOME PERMANENT, INCLUDING THE STEEL SURROUNDING THE ROSE WINDOW IN THE WEST WALL

ARCHITECT

Warren and Mahoney is the project architect overseeing reinstatement of the Cathedral. The heritage component is a significant and complex aspect of the stabilisation phase. The devil is in the detail and work is monitored regularly to ensure it doesn't have a detrimental effect on the heritage fabric.

Every task that the contractor completes is done in accordance with an agreed methodology for each section of work. Communication is key. The team has weekly site meetings to discuss what is being done and how, and the architect reviews the work plans regularly. It requires oversight of details such as ensuring the holes bored through the 1,200mm-thick masonry walls to tie the stabilisation frame to the existing fabric with steel rods are dry drilled rather than wet drilled.

It takes a while for a heritage building to reveal its 'story'; the process typically involves accessing the structure to better understand how it was constructed but this hasn't been possible with the highly unstable Cathedral. Until stabilised, all work on the Cathedral has to be done externally, from a crane bucket or scaffold.

There has been heavy reliance on digital technology. A three-dimensional model of the building was generated using drones and point cloud surveys. The latter sends out millions of laser beams that return points as they hit surfaces, producing a 'map' of the existing building fabric, internally and externally. But for the tower, which completely collapsed, the team had to rely on less accurate historical records such as photographs and drawings to inform the design for the replacement tower.

Some of the stabilisation steelwork will become permanent, including the steel surrounding the rose window in the west wall. It was the first frame and the first permanent structure installed. Warren and Mahoney set the parameters for positioning the frame, which will eventually be concealed between two stone wall veneers. So, the former 1,200mm-thick, unreinforced masonry wall will be reinstated as a composite steel-masonry wall – it will look exactly the same but it will be stronger and lighter.

"STRUCTURAL STEEL OFFERS A QUICK WAY OF INSTALLING TEMPORARY STABILISATION EXTERNALLY TO MAKE IT SAFE FOR WORKERS TO ENTER THE BUILDING."

TIM HOLMES, ASSOCIATE, WARREN AND MAHONEY

ENGINEER

For the stabilisation phase, Holmes' role has been to design and monitor the structure required to bring the Cathedral up to 34 percent of the NBS; it was also instrumental in determining the NBS figure. There is no guidance in the Building Code for what percentage a badly damaged cathedral should be stabilised to before strengthening gets underway. So Holmes applied its engineering judgement and, in collaboration, agreed the figure with Naylor Love and the client, Christ Church Cathedral Reinstatement Ltd.

What the Code does make clear, however, is that temporary support structures must be designed to 50 percent of the NBS. What made this tricky for the engineering team was that the building was strengthened as recently as the '90s and 2000s. But if the aim was to return the building to its level of strength prior to the earthquakes it would still have sat below 50 percent. So the team's task has been to strike the right balance between stabilising the building sufficiently to safeguard the people completing the permanent work and avoiding any overdesign that would extend the project's already long duration and add more cost.

Structural steel frames are prefabricated off site in a workshop and once they come to site they are set in place and bolted together. It's quick and it has played a big part in how risk is managed, by limiting people's exposure to the building.

Because the team didn't have access to the inside of the Cathedral, each structural steel frame has been detailed in such a way that they can be attached to the exterior of the building. Linking beams, visible around the exterior, connect the frames to the building itself and form an 'exoskeleton'.

One innovation on site is the temporary sliding roof over the crossing. It protects the historical features within the crossing from the elements while still allowing stonemasons to deconstruct the heavy gable arches in line with the site's safety protocols and stabilise the specific work front. The assembly includes a plastic sheet over the top of a scaffold frame that slides open and closed on steel rollers and large steel upright connections into each of the crossing corners. Suspended in a cage on a crane, workers can be dropped down through the opening into the very heart of the building. A uniquely steel solution.

Steel's inherent adaptability has been a real asset on site, particularly as the existing building has so many unknowns. The Cathedral's structure has often been a lot different to what the team expected and there have been several instances when the steelwork has had to be modified on site to suit.

The material's high strength-to-weight ratio has been of significant benefit to the project. Given the high seismic mass of the existing masonry building, the heavier the stabilisation structure, the harder the system has to work. To keep within the stringent seismic movement tolerances for the existing building while limiting added mass, a steel framing solution made sense.

As already noted, some of the stabilisation framework will become permanent, including one of the most

OPPOSITE PAGE AND ABOVE: ONE INNOVATION ON SITE IS THE TEMPORARY SLIDING ROOF OVER THE CROSSING. IT PROTECTS THE HISTORICAL FEATURES WITHIN FROM THE ELEMENTS AND ALLOWS WORKERS SUSPENDED IN A CAGE ON A CRANE TO BE LOWERED THROUGH THE OPENING INTO THE HEART OF THE BUILDING.

LEFT: THE COORDINATION REQUIRED TO HAVE THE STEEL DELIVERED, ASSEMBLED AND INSTALLED ON SITE HAS BEEN INTENSE. IT TAKES MONTHS OF PLANNING TO LIFT A SINGLE FRAME INTO PLACE.

impressive parts of the stabilisation project – two 32m Steltech beams that were originally only going to be temporary. But the project team identified significant programme and cost efficiency in the later strengthening phase by upgrading this element in stabilisation.

Another feature of steel that is being considered is its reusability. The team has been exploring where the temporary steelwork can possibly be reused in some of the new builds that will follow.

"WE'VE ALREADY THOUGHT ABOUT HOW WE MIGHT BE ABLE TO REUSE SOME OF THE STABILISATION STEELWORK FOR THE NEW BUILDINGS THAT MAY EVENTUALLY GO ON SITE."

JAKE MAYSTON, STRUCTURAL ENGINEER, HOLMES

ABOVE: PLENTY OF EFFORT WENT INTO THE DETAILING AND PLANNING TO ENSURE WORKER EXPOSURE WAS REDUCED TO THE BARE MINIMUM DURING EXECUTION AND ACCESS TO THE BUILDING HAS ALL BEEN DONE BY CRANE.

BUILDER

Naylor Love is the main contractor for the stabilisation phase and was engaged early on as construction consultant to provide valuable input to the methodology and planning. Options analysis to find the best approach for each stage of the project has been complex on such a dangerous and unstable building. Naylor Love worked alongside Holmes and the heritage professionals to devise a workable concept design. As they advanced through the developed design, the Naylor Love team tested how the temporary structure would be built, what materials were available and the sequencing involved.

Unsurprisingly, the biggest challenge it noted is the building's instability. The earthquake left it misshapen; things had moved. Getting detailed measurements was critical to success, but without exposing workers to risk. Point cloud technology offered the required detail from a distance.

Structural stability and localised loose masonry have posed a real risk to worker safety, so access protocols were developed in collaboration with the engineer and CCRL, essentially requiring the Cathedral to be sequentially stabilised from designated zones around the structure. Plenty of effort went into the detailing and planning to ensure worker exposure was reduced to the bare minimum during execution and access to the building has all been done by crane as another control. This approach, in place of traditional scaffolds and scissor lifts, has added more complexity to the work. The benefit is that the crane can remain at a safe distance and elevate the workers, keeping them out of harm's way if an event were to occur prior to the building being stabilised.

The team was also cognisant of the heritage component. How, where and what connections are made to the Cathedral have been heavily scrutinised. Anywhere steel touches the masonry requires an initial buffering layer of foam to soften it against the masonry. Then pieces of timber are cut to fit, providing a secondary buffer between the steel and the stone.

The coordination required to have the steel delivered, assembled and installed on site has been intense. It takes months of planning to lift a single frame into place. The greatest limitation has been space, which is a massive premium on site. The busy constrained site is in the middle of town – next to a tram track and a busy road, and close to amenities including three hotels and a convention centre. And there are three large protected trees on site. People and cranes cannot get close to the Cathedral so the steel frames have had to be lifted into place from outside the site.

"IT'S A BIG, UNREINFORCED MASONRY BUILDING; THERE IS A LOT OF WEIGHT TO BE RESTRAINED. STEEL LENT ITSELF WELL TO THE TEMPORARY STABILISATION."

DARYL STRAWBRIDGE, SENIOR PROJECT MANAGER, NAYLOR LOVE

ABOVE: THE STEEL FRAME ON THE WESTERN FAÇADE IS CLAD WITH A TEMPORARY CANVAS BANNER FEATURING AN IMAGE OF THE REINSTATED WEST GABLE AND THE NEW ROSE WINDOW.

FABRICATOR

VIP Structural Steel's brief was to survey, measure, detail, fabricate and erect structural steel to stabilise the Cathedral. Surveying got underway well before site work commenced. Laser technology allowed measurement from a safe distance of 18m away to plot the building surfaces for the stabilisation frame design. This process was critical to ensure that what was modelled matched what was actually on site. This information was fed into the BIM model, accurate to the millimetre, to allow flawless installation.

The south transept stabilisation was the first frame to be installed and comprises two large columns, 15m long by 900mm wide, each weighing five tonnes. They were individually loaded onto a truck, transported to the painters then to site where they were assembled and erected. The complete frame stands 20m tall and weighs 24t. The lift involved rigging a 250t crane to the top of the frame and a 90t crane to the bottom.

Work on the western façade followed. It was severely 'quake damaged – close to half of the wall had collapsed, creating a gaping void into the Cathedral. An 18t structural steel frame – 13.2m high by 10.3m wide – was designed and fabricated to restore key structural load paths. While it won't be the biggest piece of steel installed, it is a key component of the stabilisation work and will be a permanent structural element, eventually housing the striking rose window. The steel frame is clad with a temporary canvas banner that provides protection from the elements and features an image of the reinstated west gable and the new rose window.

Installing the west-end frame required considerable preparation and planning. It provides lateral stability and is tied to the roof and clerestory. To do this it was fixed to the existing west wall buttresses, and carefully designed and measured to fix the permanent connections.

The west wall is one of just a few sections of steel that will be permanent. It has a steel plate fixed to the frame with the installation date as it is reported in the heritage documentation. Steel's light weight means that, once the frames are clad in heritage stonework as part of future reinstatement works, it will weigh considerably less than the former west wall.

Other steel frames involved in the stabilisation phase include the north transept, similar to the south transept supporting frame, and the apse, which wraps around the rear of the building.

"THE SUCCESS OF THIS PROJECT IS THANKS TO GREAT TEAMWORK. THE GOOD RELATIONSHIP BETWEEN ALL PARTIES HAS MEANT THERE HAS ALWAYS BEEN OPEN COMMUNICATION."

SAM EDINBURGH, MANAGING DIRECTOR, VIP STRUCTURAL STEEL

Glossary – cathedral architecture

Transept	Either of the two parts forming the arms of the cross shape, projecting at right angles from the nave.
Nave	The central part of a church, intended to accommodate most of the congregation.
Crossing	Junction of the four arms of a cruciform-shaped church.
Apse	The large semi-circular recess with a domed roof, typically at the eastern end of a church.
Clerestory	A wall with windows exposed above the roof of the side aisle.
Porch	Room-like structure at a church's main entrance.
Vestry	Room in which vestments and sacred objects used in the services are stored.
Side Aisle	One of the lateral aisles of a church, as distinguished from the central aisle or nave.

ABOVE AND BELOW: THE GREATEST LIMITATION HAS BEEN SPACE. THE BUSY CONSTRAINED SITE IS IN THE MIDDLE OF TOWN AND THERE ARE THREE LARGE PROTECTED TREES ON SITE.