Photos courtesy RJC Engineers

Seismic Retrofit of Historic Courthouse

Precast concrete shear walls create a lateral system

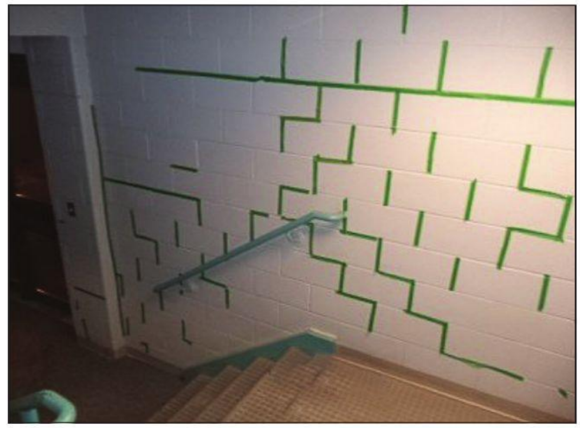
By Tim Van Zwol, P.Eng.

Cracking within existing concrete masonry unit (CMU) wall construction is common, and repairs will depend on the existing assembly, function, and condition of the mortar joints and CMUs. However, when wall cracks were observed within the stairwells of an Ontario courthouse, a building condition assessment by RJC Engineers (RJC), led to a seismic retrofit and construction of a new lateral force-resisting system (LFRS). For this seismic retrofit, a unique solution was required to maintain building operations during construction, and to ensure the new lateral system would complement the existing building esthetics.

Overview of the North Bay courthouse building

The North Bay Provincial Courthouse building, located in North Bay, Ont., was constructed in two phases. The first phase consisted of a courtroom and lock-up erected in 1888 as a two-storey brick building. In circa 1989, the second phase of the structure was built wrapping above and around the north, east, and west sides of the original building. The current building consists of a partial basement area and four stories above grade with a height of approximately 16 m (53 ft). In total, the interior floor area is approximately 9300 m^2 (100,000 sf) across all building levels.

The existing building foundation consists of reinforced cast-in-place concrete interior pad foundations and perimeter strip footings with perimeter concrete foundation walls, and a concrete slab-on-grade at the basement level. Columns are generally spaced on a 6 x 6-m (19.7 x 19.7-ft) grid. The building superstructure is constructed with conventional structural steel column and beam framing with a 150-mm (6-in.) thick concrete slab on steel deck. The concrete floor slabs are non-composite with the steel deck acting as a formwork surface only. The roof consists of an upper level near the centre of the building, and a lower level around the outside perimeter with a sloped transition in between. The roof structure consists of steel beam framing with metal roof deck. The building envelope consists of a brick veneer cladding system with horizontal precast bands located in between the windows. Five interior stairwells are located throughout the building footprint, and the walls surrounding the stairwells consist of CMU unit construction. The stairwell masonry walls do not provide vertical support for the adjacent floor slabs.



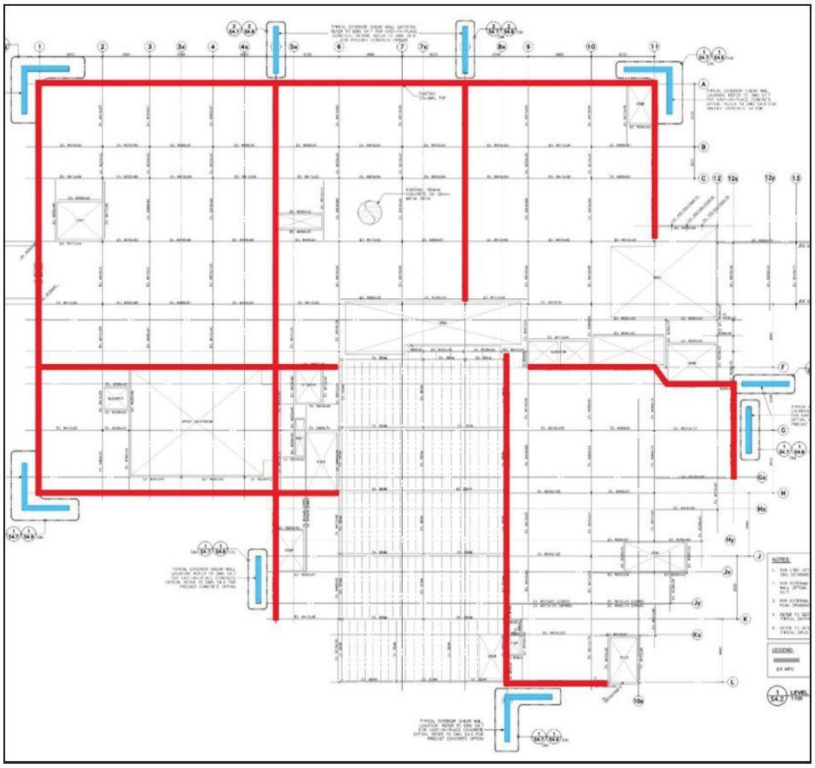
An overview of masonry cracking within the stairwell.

Condition survey assessment and remedial concepts

Cracking within the interior stairwell wall mortar joints and CMU was initially observed by building management staff. Prior to RJC's involvement with the building condition assessment, third-party investigations concluded there were no geotechnical or building foundation concerns at the site. RJC was initially retained in 2014 to complete a building structure condition assessment to review and document the masonry wall cracking within the stairwells. The scope of work included:

- a visual site review of the as-built conditions;
- assessment of the available construction drawings and geotechnical reports;
- a lateral structural analysis of the building; and
- the development of potential remedial concepts.

Based on the findings of the structural condition assessment, it was determined the building had no clearly defined LFRS, and the existing beam-to-column steel connections did not have sufficient lateral capacity to meet the requirements of the *Ontario Building Code* (*OBC*). In lieu of a well-defined bracing system, it appeared, incidental lateral utilization of the concrete masonry walls within the stairwells was occurring, even though they were not originally intended to be part of a LFRS. Lateral engagement of masonry walls and the calculated lateral deflections under wind and



The outline of the building footprint with layout of external precast shear walls (blue) and internal steel drag struts (red).

seismic loading would result in cracking. Further, it was resolved the building structure was at risk of severe damage or partial collapse if subjected to a design seismic event.

An equivalent seismic static analysis was completed using the following criteria (the seismic loading was calculated to govern above the calculated wind loading):

- R_d (ductility-related seismic force modification factor) equals 1.5; R_o (overstrength-related force modification factor) equals 1.3 (shear wall conventional construction);
- Building period equals 0.4 seconds;
- Site Class 'D'– poor soils; and
- Seismic base shear equals approx. 11 per cent of building weight.

The next phase of the investigation was to review potential remedial concepts to address the lateral stability of the existing building. Requirements for a successful retrofit scheme included ongoing operation of the facility during construction and maintaining overall building function and esthetics once the project was complete. Although temporary relocation of the courthouse services and construction of a new building at the site was considered, the preferred approach of the main stakeholders was to retrofit the existing building. However, this is not a frequent or common solution. Four schematic seismic retrofit options for the existing building were considered and are outlined below.

Moment frames

This remedial option considered the retrofit of the existing beam-to-column bolted connections and upgrades to the existing concrete pad footings supporting the interior columns. Under this scenario, the existing beam-to-column connections would be retrofitted with steel plates and additional welds in order to form moment connections at designated locations.

Drawbacks to this approach included construction and accessibility challenges associated with footing upgrades within the interior of the building. Additionally, the structural analysis confirmed, the calculated lateral deflections would likely result in continued cracking of the repaired masonry walls, due to the relative flexibility of a moment frame lateral system.

Reconstruction of stairwells

This remedial option had investigated the reconstruction of the five interior stairwells using reinforced concrete shear walls to resist the calculated lateral loads. It is important to note, the building stairs have varying levels of security/accessibility requirements depending on who is it (*i.e.* public, building staff, police, and/or persons on trial).

Significant challenges relating to constructability were identified with this approach. Additionally, it was determined it was infeasible to shut down any one stairwell during construction and still meet *OBC* exiting standards and building functionality requirements (*i.e.* separating public, staff, police, etc.) within the courthouse.

Interior bracing

This option reviewed the addition of interior braced bays within the building footprint. However, due to how the existing rooms and hallways were designed within the building, and changes in layouts from floor-to-floor, it was impossible to find enough suitable locations for braced bays from the roof level down to the foundation.

External precast concrete shear walls

With this retrofit scheme, the vertical lateral elements were placed outside of the building footprint. There were 13 external precast concrete

Shear wall installation during construction.

shear walls positioned around the perimeter of the structure, with designated reinforced beam drag strut 'load paths' at the floor levels to transfer the inertial seismic forces. Nine of the precast shear walls were orientated parallel to the existing building walls and four were set perpendicular to the existing walls. Shear wall orientations and locations were selected to maximize efficiency of the new lateral system.

This option had a distinct advantage by having the shear walls constructed outside of the building footprint; this would simplify construction access, minimize building disruption during construction and the interior room, and hallway/room layouts within the building would remain unchanged after construction was complete. The interior work could be phased and completed off-hours in order to maintain building operations during the weekdays.

Based on the advantages outlined above, this option was ultimately the approach selected and used to develop construction drawings.

Construction of exterior precast shear walls

The seismic retrofit project started in January 2016 and was substantially completed by November 2017. The design team consisted of RJC as the prime consultant and structural engineers, Mitchell Jensen Architects as the architectural consultant, and Piotrowski Consultants Ltd., as the mechanical and electrical engineering consultants. The project was tendered and awarded to Kenalex as the general contractor (GC). The construction value of the project was approximately $14 million.

Due to the relative poor soils and bearing capacities at the site, the 13 shear-wall foundations consisted of a series of deep micro piles with cast-in-place concrete pile caps. Anchors with steel end plates were embedded into the concrete pile caps and would provide the connection for the precast shear walls above.

Each of the 13 shear walls were constructed using reinforced precast concrete, ranging in thickness between 475 and 550 mm (19 and 22 in.). The concrete mix for the precast shear walls was designed as 35 MPa (5000 psi), Exposure Class C-1. Mockups of the mix design were completed prior to full wall fabrication to select the colour pigment and texture (*i.e.* sandblasting) that best matched the existing precast bands at the exterior building walls. The formed side of the precast shear walls was exposed and received a medium sandblast finish with penetrating sealer to match the roughness and degree of aggregate exposure of the existing precast. All the precast shear walls were installed over a period of two weeks during nights to avoid interfering with court operations, and to mitigate impact of road closures.

Each of the shear walls consisted of three vertically stacked segments to meet handling and shipping requirements from the precast plant to the site. The walls were cast with embedded steel plates to facilitate beam connections to the building structural steel frame, and were strengthened with internal reinforcement and post-tensioned threadbars with couplers to interconnect the vertically stacked wall panels. At the construction joint between the panels, a 75-mm (3-in.) deep recess was formed on the exterior face to accommodate architectural granite panels. The construction joint recess and granite panel covering matched the elevation of the existing building precast bands in between the windows. As one of the main architectural features of the new precast shear walls covering the construction joints and threadbar grout ports, the granite panels also complemented the building esthetics by matching the existing brick veneer.

Interior construction: Phasing and structural components

The interior scope of work for the project was completed between January 2016 and May 2017. Placing the new lateral shear walls outside of the building footprint helped maintain full use and occupancy during construction, however, a significant amount of structural steel reinforcements within the building interior was also required. This work was typically completed during nights/weekends so

Overview of typical shear walls with granite panel recesses.

courtroom sessions and building use was not disturbed during the week. A 'swing space' was constructed at an unoccupied floor area within the building and was used for temporary relocation of separate building groups while work within their particular area was completed. In total, the interior scope of work was completed over nine separate phases. In some parts of the building (*i.e.* stairwells and corridors), work areas were required to be reopened after each night shift and occupied during the day.

The interior structural work generally consisted of reinforcements to the existing steel beam framing that would form a series of 'drag struts.' These would form the load paths required to transfer the seismic lateral forces generated within each floor and roof levels out to the external precast shear walls. Retrofit work consisted of steel plate reinforcements to the existing steel beams and upgrades to the beam-column connections along the designated load paths in order to withstand drag strut axial forces. Additional steel diaphragm connections between the steel beams and concrete floor slabs were also installed. At localized areas below the lower roof deck, horizontal cross bracing was installed above the ceiling to transfer lateral loads from the upper roof deck out to the designated drag strut locations.

Within the stairwells, cracked masonry joints were repointed, cracked masonry units were replaced, and an elastomeric coating was applied over the entire wall surface.

Conclusion

In summary, cracking observed within the stairwell masonry walls ultimately led to a complete building seismic retrofit of the North Bay courthouse. Although temporary and permanent relocation of the courthouse services was considered, the final desire of the main stakeholders was to keep courthouse services in the current location. External precast shear walls proved to be the preferred lateral retrofit scheme in combination with strategically phasing the interior structural work. Not only was the primary goal of keeping the courthouse services in the current location achieved, but also building operations were maintained during construction. The implementation of the seismic upgrades was successful, and the precast shear wall design complimented the existing building esthetics.

Tim Van Zwol, P.Eng., is a regional manager/associate with the building science and restoration group at RJC Engineers. Van Zwol has over 15 years of engineering consulting experience in new construction and building restoration, including a wide range of residential, commercial, institutional, and municipal projects. His project management expertise gained from new building construction and renovations enable him to take an active role in the investigation and rehabilitation of aging structures. Van Zwol can be reached via e-mail at tvanzwol@rjc.ca.