



Figure 1. View of north and west faces of Vancouver Block during rehabilitation work.

Shotcrete Rehabilitation of a Vancouver, BC Historic High Rise Building

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A heritage high-rise building in Vancouver, Canada required rehabilitation due to corrosion of the steel frame and cracking in the masonry infill. Brick masonry was segmentally removed from the face of this 15-story-high building to expose the steel beam and column framing system. Steel corrosion products were removed by needle scaling and sandblasting. New steel plate was welded to the beams and columns where required to strengthen the structure to its original design. Rebar was installed in the previously brick-filled cover to the steel frame and a high quality, low permeability silica fume shotcrete was applied to encase the rebar and fill the void. The south side of the building was

rehabilitated using the dry-mix shotcrete process. The north face of the building was repaired using the wet-mix shotcrete process. Impressive features of this remedial work included pumping a wet-mix silica fume shotcrete up to 13 stories high, using standard wet-mix shotcrete equipment. This project represents a successful use of the shotcrete process to rehabilitate an architecturally important historic building.

Introduction

The Vancouver Block Building was built in 1911 and was one of the first high rise buildings constructed in downtown Vancouver, British Colum-

bia, Canada. It is a steel-framed structure with stucco clad brick masonry walls on the north and south sides of the building, and architectural terracotta hollow brick cladding on the east and west sides of the building. The building has an H-shaped footprint of approximately 22 m by 30 m (72 ft by 98 ft). With 15 floors and a central clock tower, the building rises to approximately 65 m (213 ft) above ground level. The building serves as an office building. Figure 1 shows the north and west elevations of the building.

Deficiencies

In early 1997, while preparing for paint work, cracks were discovered in the stucco and some terra-cotta elements, which warranted a more detailed investigation of the building envelope. The owner decided to investigate the causes of the cracking. During the course of this investigation, it became apparent that during decades of exposure to wind-driven rain and long periods of high ambient humidity, water had penetrated the stucco and brick masonry. Where such moisture remained in prolonged contact with the structural steel columns and beams, extensive corrosion occurred. The volume increase of the structural steel elements due to the corrosion widened cracks, which aggravated the moisture penetration problem.

Exploratory removal of brick cladding in selected locations confirmed non-uniform corrosion activity across the facades. While the investigators encountered pristine steel with undisturbed mill scale on the surface of beams and columns in some locations, in other locations severe corrosion pitting, knife edging, and even complete loss of I-beam flanges to corrosion was recorded. The overall degree of corrosion was sufficiently severe to warrant hiring of a structural consultant to plan the retrofit procedures. Figure 2 shows an example of severe corrosion in a steel column.

Rehabilitation Measures

The owner wanted the building to be rehabilitated to a structurally sound and aesthetically pleasing condition. Challenging for designer and contractor was the requirement to perform all repair work from the exterior of the building because the structure, which serves as an office building, could not be evacuated during rehabilitation. As a consequence, the contractor erected building-high scaffolding covering most areas of the facade on which the work was to be carried out at any given time. Access to areas which were unsuitable for the erection of scaffolding was provided by swing stages.

After erecting the scaffolding and installing the swing stages, work commenced by exposing the structural steel. This required removing brick infill where it covered steel columns and beams. The condition of some steel columns warranted temporary shorings in order to reduce the loads during the



Figure 2. View of corrosion in a steel column prior to repair.

time they were prepared for reinforcement. Figure 3 shows the removal of brick masonry on the south side of the building.

The requirement to conduct all repair work from the outside of the building required some innovative designs and construction technology for reinforcing the structural steel elements. In brief, after exposing the structural steel elements and removing corrosion products by needle scaling and sandblasting, customized steel profiles were welded to the webs of those beams and columns in need of reinforcement. Figure 4 shows a prepared column with installed new steel plates and rebar prepared for shotcreting.

The initial repair specification for the project



Figure 3. Installed scaffolding and removal of brick masonry on a column line on South face of building



Figure 4: View of a prepared column ready for shotcrete application. Note installed new steel plate and rebar.



Figure 5: Remedial work being conducted from a swing stage on north face of building. Note burlap wet cure of completed shotcrete repair.



Figure 6: Close-up view of shotcrete application on column line.



Figure 7: A look at the moist curing of shotcrete

required cleaning all structural steel to a white metal finish, applying a coating for corrosion protection, and forming and casting with a repair concrete to reestablish an even face for the facades. The rather stringent requirements for the preparation of the steel surfaces, as well as the need for the formwork and the interior brick and plaster walls to withstand several meters of hydraulic head from freshly placed repair concrete without appreciable deformation or leakage, threatened the planned budget. A specialty rehabilitation contractor was called in to assess the situation. He retained a materials engineering consultant to assist in convincing the project manager and the

owner of the merits of using shotcrete, rather than a formed and cast repair concrete, to encase and protect the structural steel exposed in the course of the repair. The owner decided in favor of using shotcrete after a mock-up test area demonstrated the suitability of the shotcrete process for repairing the building. Further, the shotcrete repair method eliminated the need for the corrosion protection system to the new and existing structural steel frame.

In consequence, shotcrete was applied to reestablish the original appearance of the facades as closely as possible after completion of repair of the structural steel frame. Each face of the building required

about 50 m³ (1766 ft³) of repair material. The applied shotcrete varied in thickness from 20 to 300mm (3/4 in to 12 in). Because the shotcrete was not required to carry structural loads, no structural reinforcement was required. However, in order to improve adhesion of shotcrete in the fresh state and to minimize shrinkage cracks, conventional reinforcement was installed in the beam and column cavities as shown in Figure 4. Figure 5 shows preparation for shotcrete work from a swing stage. Figure 6 shows shotcrete application in progress. In order to prevent damage to windows and dust ingress into the building during shotcreting, the contractor also provided custom made ply-

wood shutters for all windows situated in the repair zone.

The initial choice of shotcreting methods was the dry-mix process for its inherent advantages over the wet-mix process, such as greater ease of operation in the stop-and-go mode and lighter equipment to move up and down the scaffolding. The south face of the building was successfully repaired with this method. However, the amount of rebound inherent in the dry-mix shotcrete process became a nuisance, because it required frequent removal from the scaffolding. Furthermore, the repair on the north face involved working over a neighboring property which needed to be protected from contamination by shotcrete rebound and overspray.

To address this problem, the shotcrete work on the north face was executed using the wet-mix shotcrete process. The shotcrete contractor chose small-line wet-mix shotcreting equipment capable of pumping shotcrete the required 15 stories high (50 m) and over approximately 70 m (230 ft) horizontally. An adjacent 3-story high parking structure provided a suitable elevated working position for the pump, reducing some of the challenges of delivering shotcrete to all floors of this high-rise structure. The wet-mix shotcrete process produced significantly less dust and rebound compared to the dry-mix process employed previously. The use of dry-bagged premixed shotcrete and careful attention to work preparation and scheduling helped overcome the reduced flexibility of the site mixed wet-mix shotcrete method in this repair application, which required a stop-and-go procedure.

After cutting and trimming to line and grade and receiving a final trowel finish, the shotcrete surface texture blended well into the texture of the surrounding existing stucco finish. Quality control testing by the materials engineering consultant confirmed excellent hardened properties in the shotcrete. The shotcrete achieved 28-day compressive strengths of between 40 and 50 MPa (5800 and 7250 psi) and values of 4% boiled absorption and 9% volume of permeable voids in testing conducted to ASTM C692. Due to a good moist curing regime with saturated burlap, the shotcrete repairs remained mostly crack-free, though some hairline cracks appeared at shotcrete-brick interfaces. Figure 7 shows shotcrete in column moist curing under burlap. This shotcrete is expected to have excellent long

term durability and provide good corrosion protection to the rehabilitated structural steel frame.

After finishing the structural repair and the shotcrete work, the building received a new elastomeric paint coating. Figure 8 shows the completed north side of the building, after painting. All work was conducted with the structure fully occupied and used as an office building. The building has now been rehabilitated to close to its original impressive appearance and should be able to withstand the attack of many more of Vancouver's rainy seasons.

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Figure 8: View of north and west faces of Vancouver Block building after completion of shotcrete repairs and application of an elastomeric coating.

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