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THE CHALLENGE AND THE COSTS OF RESTORING THE HISTORIC STONE MASONRY WALLS OF THE VICTORIA MEMORIAL MUSEUM IN OTTAWA

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ABSTRACT

The most recent restoration work on the stone masonry walls of the Victoria Memorial Museum in Ottawa started in 1989 with a detailed condition survey. After a lengthy delay due to lack of funding, the recommended repairs could finally be carried out between 1995 and 1997. The paper reviews firstly, the methodology used to document the condition of the walls, and secondly, it summarizes the findings and describes the recommended restoration philosophy. The paper provides details of the repair methods used and the costs associated with this major masonry restoration project. Finally, the experiences of the consultants and contractors with year-round masonry construction work is discussed.

INTRODUCTION

The Victoria Memorial Museum (VMM) was completed in 1910 for the National Museum of Canada. It is the largest of five public stone buildings designed by then Chief Architect, David Ewart of Public Works. The Tudor Gothic style museum is a four-storey structure, about 122 m long with widths varying from 20 m to 60 m. A partial view of the structure is shown in Fig. 1.

The exterior walls are constructed with a combination of dressed and rough sandstone on the outside, backed by an equal thickness of limestone. An interior clay tile wall covered with asbestos plaster provides the air barrier. The walls are not insulated. A cross-section of the exterior walls is shown in Fig. 2.

Two types of sandstone face the building exterior. Cut and smooth Wallace sandstone from Nova Scotia at windows, doors, parapets, plinth and carved work, and local Nepean sandstone for the rubble work.

During the building's 80-year service life, significant performance problems with its stone masonry walls were experienced. Differential foundation settlement has caused major vertical cracks through the masonry walls, and weathering of the sandstone units has resulted in spalling. The most noticeable spalling occurred at buttresses, at the upper level band courses and at the roof turrets. The band course spalling resulted in the disintegration of the original drip edge, thus reducing the water shedding capability in some of the most weather sensitive areas of the façade.

Extensive mortar cracking had occurred at the uppermost floor levels. Both, the original pointing mortar and the repair mortar, which was applied some 25 years ago, were cracked. All other wall areas exhibited moderate to fairly extensive mortar cracking and debonding of mortar.

CONDITION DOCUMENTATION

A detailed condition survey of the building envelope was carried out in 1989 to assess the extent and nature of the stone masonry distress. The visual inspection consisted of a close-up examination of the entire building surface from a crane. In addition, five areas were opened up, two from the exterior and three from the interior, to assess the condition of the stone masonry units through the thickness of the walls.

The as-found conditions were documented on rectified photography drawings. Recorded elements of distress included major wall cracking, cracked and deteriorated stone units, deteriorated pointing mortar, efflorescence staining, and deteriorated flashings and caulking. In addition, some 2,000 close-up photographs were taken to illustrate and further document items of distress.

The condition documentation revealed that 90% of the mortar joints were deteriorated and spalling and cracking of stone units had occurred over about 15% of the wall surface area. Deterioration of both, stone units and mortar was more pronounced at the upper floor levels.

The inspection openings revealed that some minor backface weathering of the sandstone units had taken place and it was speculated, at the time, that this type of deterioration was likely the result of some air exfiltration from the high humidity environment of the museum. A detailed monitoring program (Keller, 1995) carried out in 1993/94, indicated however, that the majority of the moisture in the walls is from exterior sources and that air exfiltration is only a minor contributing factor.

Based on the field evidence and the review of reports from earlier inspections, it became clear that major cracking in the masonry walls was attributable to differential soil settlement

(Crawford, 1953). Most of the large cracks were present at locations where the bearing pressure under the footing changes. Early monitoring efforts indicated that the most extensive settlement took place during the first five years after the building's completion in 1910. In fact, the settlements were so excessive that the top portion of the tower at the main entrance had to be demolished immediately after it was completed. More recent settlement readings indicated that ongoing movements are relatively small and secondary in nature. Nevertheless, readings at the front and side entrances indicated that these smaller structures are still being dragged down by the main building.

REPAIR PHILOSOPHY

The objective of the repairs was to stabilize the masonry walls in their current condition and to ensure their structural safety and serviceability over the longterm.

As such, the work entailed the installation of control joints at major crack locations, the replacement and repair of cracked and spalled stones, the resetting of stones that had shifted out of position, the scaling of stones, and the repointing of all mortar joints. A special requirement was that the original beaded red mortar joints would be duplicated. As a further measure, the projecting band courses at each floor level and the window sills were covered with lead-coated copper flashing.

In view of the fact that structural movements are ongoing, although to a minor extent, renewed cracking was anticipated. Therefore, control joints were introduced at all major crack locations. Where existing cracks exceeded 25 mm in width, masonry sections adjacent to the crack were rebuilt to keep the control joint width to a maximum of 25 mm.

To ensure public safety until the repair program could be implemented, a 3 m high fence around the entire building was erected and an annual safety scan carried out. These scans resulted in the removal of several hundred kilograms of loose stone fragments over the span of six years.

The repair program was reviewed by FHBRO, the Federal Heritage Building Review Office, in charge of implementing Federal Heritage policy.

REPAIR PROGRAM

Tender Documents

The tender documents were developed using a combination of fixed and unit price work. The fixed price portion of the work included the site facilities, scaffolding, heating, hoarding and landscaping reinstatement. The masonry repairs were divided between fixed prices and unit prices as follows:

Fixed Price

- mock-up masonry repairs
- repointing of mortar joints
- flashing installations
- sealing of coping stone joints
- stone sounding
- sealants

Unit Price

- stone repairs
- control joint installations at major cracks
- deep backpointing of mortar joints
- stone cleaning
- stone scaling

In preparing the tender documents, the challenge was to develop stone repair details which were specific enough for a contractor to bid on, but general enough so that each type of repair could be designated on site to cover several similar types of distress.

To estimate quantities, 10 random wall areas, representing about 10% of the total wall area, were sampled and repair quantities extrapolated for the entire wall surfaces. Although the estimated quantities were expected to be quite accurate, some degree of uncertainty remained, particularly in regard to the partial and complete stone replacement work. While the condition documentation work visually identified spalling distress, the depth of stone deterioration and thus the type of repair required, could only be determined once the work had started. The following criteria were used to quantify each type of stone repair:

- where major spalling was documented, complete replacement was assumed for the Nepean stone, and partial or complete replacement for the Wallace stone, (depending on the size of the stone).

- in cases of minor to moderate spalling, 50% of the stones were assumed to require complete or partial replacement and 50% were assumed to only require removal of the loose material (stone scaling).

Stone Treatment

Stone Scaling

Stone scaling commenced with hammer and chisel work to sound each stone and remove loose or deteriorated fragments. On the Wallace stone, the surface was then passed over with a mechanical "needling" tool to smooth over rough edges and give the scaled surface a uniform appearance.

Stone Replacement

Nepean stone replacement was a straight forward operation, as it typically involved replacement of the entire stone. In a few isolated instances, deterioration was limited to a small portion of a larger stone. In these cases, the affected segment of the stone was removed and replaced, and a mortar joint added between the new and the old stone.

Wallace stone replacement involved both complete replacement, where deterioration had occurred over a significant area of the stone, and partial replacement. Complete replacement typically involved smaller stones at buttresses and building corners. Partial replacement, which was more frequent, was carried out Dutchman Style, or using composite patching techniques. For the Dutchman style repairs, typically 2 to 4 stainless steel pins, set in epoxy, were used to secure the new stone segment. A gap of about 3 to 6 mm was left at the exposed joint between the new and the old stone. The gap was then filled with the Jahn M70 restoration mix to better match the finish colour of the adjacent stone. See Figs. 3 and 4.

Crack Repairs

Crack repairs were carried out to salvage large stone units such as horizontal and vertical mullions and lintels at windows. Crack repairs were also employed to structurally secure significant stone fragments and to reduce water penetration into moderate to large stone cracks.

Typically, cracks were first sealed with modelling clay, then filled with adhesive. Trial repairs were made using epoxy and cementitious materials. However, the use of epoxy to fill cracks was rejected due to difficulties in injecting the material and because of staining of adjacent stone surfaces. On the other hand, cementitious Jahn M30 and M40 products were successfully used for the injections and any staining could be easily cleaned. After removal of the modelling clay, the top 12 to 20 mm of the crack was filled with the Jahn M70 mix so as to better match the surface colour of the stone. Where pinning was required, stainless steel threaded rods, set in an epoxy based adhesive, were used subsequent to the crack injection work. See Fig. 5.

Composite Patch Repairs

These repairs were carried out on Wallace stones using the Jahn M70 mortars. Only trained and certified applicators were permitted to do this work. Wallace stone samples were sent to the distributor of the Jahn material for developing custom M70 mixes for six different Wallace stone colour tones. Although only a limited number of composite patch repairs were intended at the design stage, after several successful trial repairs, these composite patch repairs were used more frequently. They proved to be particularly effective for smaller repair areas on sculpted stones. Experience showed that proper curing of these repairs is critical. Repairs had to be frequently wetted, and/or covered in plastic or wet burlap to keep the repair mortar and adjacent stone moist for several days. This was particularly true for smaller repair areas, and where the material was used to finish cracks and Dutchman repair joints as these smaller repair areas tended to dry out more quickly due to the higher ratio of surface area to volume of repair material.

Composite repairs made to the underside of stones, as well as deeper vertical repairs, were typically reinforced with stainless steel pins as shown in Fig. 6.

Repointing

Cutting Out

The specifications were written so as to permit the use of small grinding wheels and small pneumatic chippers for the cutting out of mortar joints, provided the contractor could demonstrate that these methods could be used without damaging the adjacent stone.

Typically, mortar removal started by cutting along the center of the mortar joint. Then the remaining mortar was removed using pneumatic chippers and hand tools. Narrower joints, some as narrow as 3 mm, had to be cut out with hand tools alone. The above approach worked reasonably well, but occasional stone damage did occur from the small grinding wheels.

However, doing all cutting out work with hand tools would have added considerable costs to this project, as the existing mortar was high in cement content, making the removal with hand tools extremely difficult where the mortar was still firmly attached to the stone.

Where mortar was deteriorated to a depth greater than 50 mm, the contractor was directed to remove the deteriorated mortar, and "backpoint" the joint prior to proceeding with finish pointing. A separate unit price was tendered for this back pointing work.

Pointing Mortar

The pointing mortar consisted of a 1:3 mix using Type N white masonry cement manufactured by Federal White Ltd. This selection was made based on the following considerations:

- good pre-construction flexural bond strength results using test prisms made from the Wallace and Nepean stone units
- good pre-construction test results for air content
- generally good freeze-thaw resistance reported for masonry cement mortar mixes
- manufacturer's confirmation of hydrated lime content in the masonry cement
- ease and uniformity of mixing, and better quality control
- good bonding characteristics, required for the installation of the coloured mortar bead

Deep pointing, finish pointing and the installation of the coloured bead each had to be approved by the consultant prior to proceeding with the mortar replacement work. The pointing details are shown in Fig. 7.

Although several masons with many years of experience worked on this project, none had ever installed a beaded mortar joint. Therefore, several mock-ups were required before a close match to the original bead was achieved. To obtain a satisfactory bond, the bead had to be installed approximately 1 hour after the finish pointing layer. After the initial set of the bead, excess mortar was carefully trimmed from each side of the bead with a razor sharp tool.

Attempting to trim the excess mortar while the bead was still wet resulted in the red staining of the adjacent white mortar and stone units.

Sequencing of Repair Work

At the design stage, the intent was to have the contractor first complete the cutting out of the mortar joints followed by stone sounding and scaling from the ground to the roof level at a particular wall section. For this purpose, the building perimeter was divided into 11 stages. After the mortar was cut out, the stones were assessed and repairs designated based on a set of specified repairs. Once the stone repairs were completed and accepted, repointing was to commence. This general sequence of work was outlined in the tender documents.

Over the course of the work, some adjustments to the sequencing were made to improve the progress of the work. The most critical aspect of the stone repairs was the replacement of sculpted Wallace stone. These stones had to be precisely measured, shop drawings prepared and sent to the off-site stone cutters. Since several weeks elapsed before the replacement stone was ready and delivered to the site, it was agreed that an initial assessment of the Wallace stone would be carried out immediately after the scaffolding was set up at a particular wall area and prior to cutting out of the mortar joints and the stone scaling work. From experience gained over the first few months of work, most of the Wallace stone replacement designations could be readily made at this time. The same could not be done for the Nepean stone, since, unlike the Wallace stone, Nepean stone that appeared to be sound, often was defective when hammer sounded. Also, edges of the Nepean stone could not be checked sufficiently for soundness until the mortar joints were cut out.

Once the initial difficulties were worked out, the sequence of work over a particular wall section proceeded as follows:

- initial Wallace stone assessment by engineer
- cutting out of mortar joints from top down
- stone sounding and scaling from top down
- review of joint cutting and scaling by engineer
- Nepean stone initial assessment and Wallace stone final assessment from top down by engineer
- removal of stones designated for replacement
- replacement/repair of Nepean and Wallace stone from top down
- regular reviews of stone repairs by engineer, including checks for any additional repairs, or any adjustments to designated repairs.
- deep backpointing where required
- finish pointing and colour bead installation from top down
- final inspection by engineer

Assessment, Designation, Recording

Stone assessments were done by the engineer using a combination of visual inspection and hammer sounding. Each repair type was numbered, and the repair area and applicable repair number were marked on the stone. The rectified photographic record sheets used for the condition documentation work were scanned into an AutoCAD computer system for the purpose of recording the repair designations. These records formed the basis of the data sheets which were prepared for each wall segment for the purpose of recording the repairs.

These data sheets were again used for inspection and payment certification purposes. At the end of each month, completed repairs were checked off on the data sheets. The AutoCAD system was automated to generate the value of the unit price work completed for each wall section. Statistics on the number of the various repair types designated and completed for each wall area were readily generated.

Major Wall Cracks

The survey work identified several major settlement cracks around the building. These cracks extended from the foundation to the roof level and they varied in size from 10 mm to 50 mm. The repair strategy called for the introduction of control joints at these existing crack locations. These control joints were achieved by raking out the mortar joints to a minimum depth of 25 to 50 mm and installing backer rod and caulking.

In some cases, the path of the cracks through the mortar joints and stone could be readily followed from the ground to the roof. In cases where major cracking passed through window head stones and horizontal mullion stones, these stones were pinned together and the control joint routed around the ends of the stones. In other cases, where cracking was sporadic over the wall areas, rather than attempting to predict where further cracks may occur, the decision was made to repoint these cracks.

STONE SUPPLY

Wallace stone was obtained from the original quarry in Wallace, Nova Scotia. Stone was purchased in advance of the work by Public Works Canada as the stone had to be seasoned for a minimum of 6 months prior to use. Since the original Nepean stone quarry was no longer operational, a substitute stone (Brown Covey Hill) was obtained from the quarry in Hemmingford, Quebec. The contractor was responsible for transportation of the stone from the quarry to the site.

No problems were experienced with the Nepean stone substitute supply throughout the course of the work as stone could be delivered within a few weeks of ordering, and the quantity available on site was readily monitored. The Wallace stone proved much more difficult to monitor. The contractor had Wallace stone delivered to a stone cutter, who awaited the contractor's orders for sculpting of the stone. Initially, the contractor elected to have several shapes carved at once, in anticipation that they would be required over the duration of the work. Unfortunately, there was no way of monitoring how much stone the cutter used to make these shapes, and early on in the project the contractor indicated that a substantial quantity of stone had been used up but little had been delivered to the site. To improve the situation, the contractor had standard stone block sizes cut and delivered to the site. From these standard stone blocks, all flat stone and simple sculpted shapes were cut on site, while only the more complicated rounded shapes were cut by the off-site stone cutter.

WINTER CONSTRUCTION WORK

Construction work was carried out through the winter of 1995/96, and through part of 1996/97. The contractor's initial schedule indicated that work during the coldest winter months would primarily consist of joint cutting, stone scaling and stone removal work. However, slow progress over the first 6 months of work required the contractor to continue stone repairs and pointing work throughout the entire winter. This required consistent monitoring of temperatures within the heated enclosures. A minimum temperature of 10°C was specified however, measurements showed that temperatures varied from about 5°C to 15°C over the height of the scaffolding. Quality control and engineering review were extremely critical during this time period. Completed areas of work had to be recorded and monitored to ensure that temperatures were maintained above freezing. The clerk of works typically checked the air temperature in the enclosures each morning, and in a few instances found that temperatures had dropped below freezing due to malfunctioning heating units and/or hoarding tarp failures during high winds. The affected wall areas were recorded, and designated for re-inspection and assessment in the spring. Any signs of freezing damage could then be identified and repaired.

QUANTITIES AND COSTS

Repair costs for the fixed and unit price work are summarized in Table 1 with additional information on quantities given in Table 2. The actual quantities for Unit Price Work were within 20% of the estimated quantities, except for the Nepean stone replacement work, where the estimated quantities were exceeded by a factor of 4. This discrepancy was due to two factors:

- sounding of a substantial number of Nepean stones which appeared to be in satisfactory condition exhibited large delaminations
- the Nepean stone deterioration frequently extended deep into the body of the stone, leaving no option but to replace the unit.

The increased quantity of Nepean stone replacement was the main factor leading to a 22% overage in the value of the unit price masonry work, and a schedule extension of about 6 weeks. However, the Unit Price Set of repairs were sufficient to cover all types of stone distress. Costs for the sculpted stone repairs were typically about double that for flat stones.

The initial contract excluded the Apse walls (about 20% of the total area) due to lack of funding, but upon completion of the original contract, extra funds were approved by PWC and the Apse was added to this project. Given the prior experience on the main building, the contract documents for the Apse included the following changes to the fixed and unit price work:

- stone scaling was converted to a fixed price item. Although the overall value of this item was relatively small, a great deal of time was required by the contractor, engineer and clerk of works to measure and verify the scaling quantities.
- cleaning of pigeon staining was converted to a fixed price item. This change was made to avoid past disputes on cleaning methods and measurements.

CONCLUSIONS

The exterior masonry wall restoration work at the Victoria Memorial Museum was successfully concluded in the Fall of 1997. Except for the Nepean stone replacement work, the masonry repair costs were on budget. Given the monitoring results which indicated that the moisture within the masonry fabric was primarily from external sources, the repair measures and the addition of metal flashings on the band courses and window sills are expected to stabilize the rate of deterioration and thus preserve this beautiful structure for many years to come.

Although a decision was made by Public Works to carry on with the repairs through the winter months, experience clearly showed that winter weather masonry construction requirements are often difficult to control and unless there is diligent and full-time site review carried out by the consultant, there is a high risk that newly finished work is damaged by frost action.

This project also showed that disputes with the contractor can be significantly reduced if special care is taken in detailing and quantifying as many repair details as possible.

REFERENCES

Crawford, Carl B., 1953, "Settlement Studies on the National Museum Building", Proceedings of the 3rd International Conference on Soil Mechanics and Foundation Engineering, Switzerland.

Keller, H. and Laviolette, S., 1995, "Moisture Conditions Across Stone Masonry Walls - A Case Study", 7th Canadian Masonry Symposium, McMaster University, Hamilton.

Table 1 - Summary of Masonry Repair Costs

FIXED PRICE WORK		VALUE
1. Mobilization, Site facilities, Mock-ups, Protection, Clean-Up Supervision		$ 700,000
2. Scaffolding, Hoarding, Heating		$1,400,000
3. Repointing		$1,580,000
4. Lead-Coated Copper Flashings		$ 280,000
5. Sealants		$ 140,000
6. Miscellaneous		$ 30,000
	Sub Total	$3,960,000
UNIT PRICE WORK	**NO. OF UNITS**	**VALUE**
1. Wallace stone Repairs		
- scaling	500 m^2	$ 20,000
- crack repairs	865	$ 42,000
- crack repairs with pinning	294	$ 66,000
- composite patch repairs	2088	$ 317,000
- partial replacement	978	$ 270,000
- complete replacement	779	$ 135,000
2. Nepean stone Repairs		
- scaling	1600 m^2	$ 40,000
- crack repairs	4711	$ 138,000
- replacement	7248	$ 602,000
- resetting	91	$ 9,000
3. Stone Cleaning	300 m^2	$ 12,000
4. Control Joints	500 m	$ 2,000
	Sub Total	$1,651,000
	Grand Total	**$5,361,000**

Table 2 - Pertinent Building/Quantity Statistics

Item	Quantity
Building Perimeter	500 m
Masonry Wall Area	15,000 m^2
Flashing Length at Band Courses	2,800 m
Volume of Wallace stone used for Repairs	155 m^3 (5500 ft^3)
Volume of Nepean stone used for Repairs	92 m^3 (3250 ft^3)

Fig. 1 Partial view of Victoria Memorial Museum

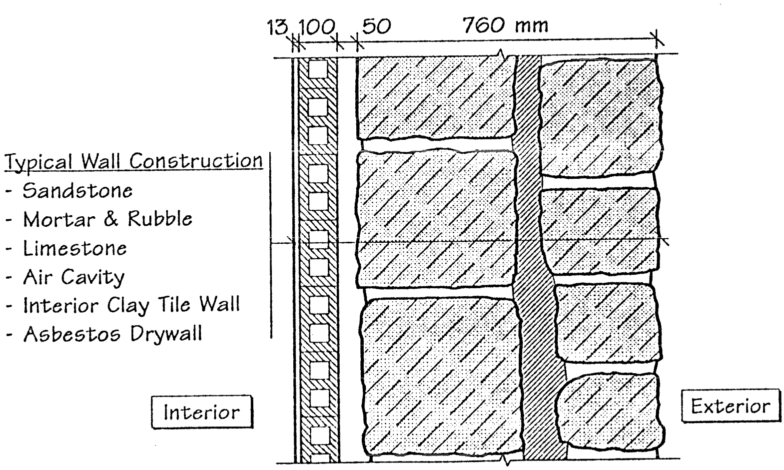

Fig. 2 Cross-section of Exterior Wall

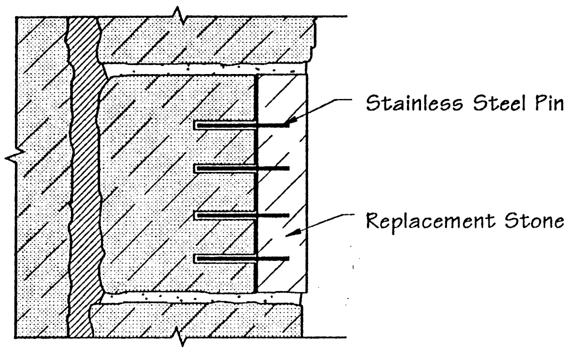

Fig. 3 Partial Flat Stone Replacement

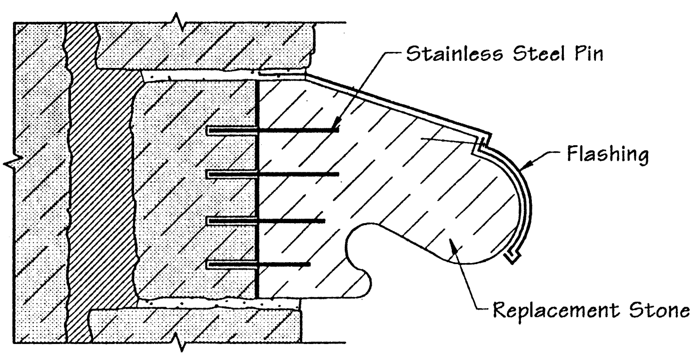

Fig. 4 Partial Stone Replacement at Band Course

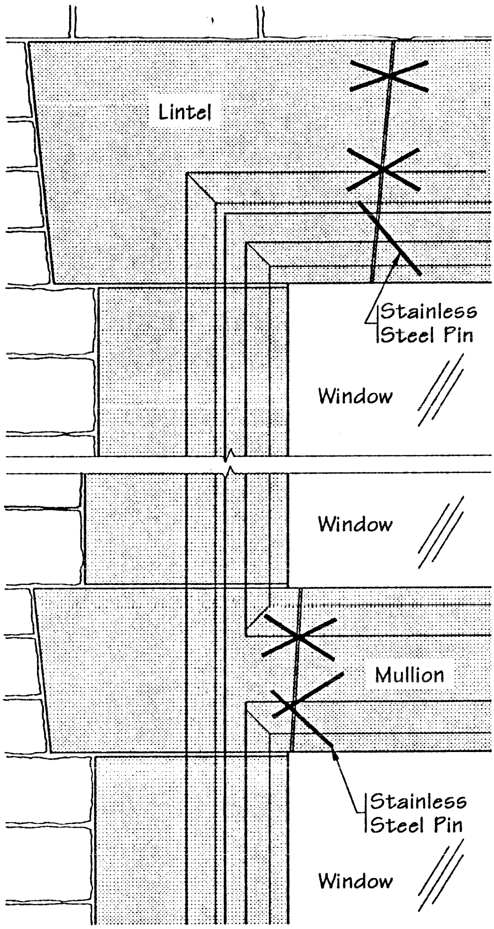

Fig. 5 Wallace Stone Repair at Window Lintel & Mullion Using Pinning and Crack Injection

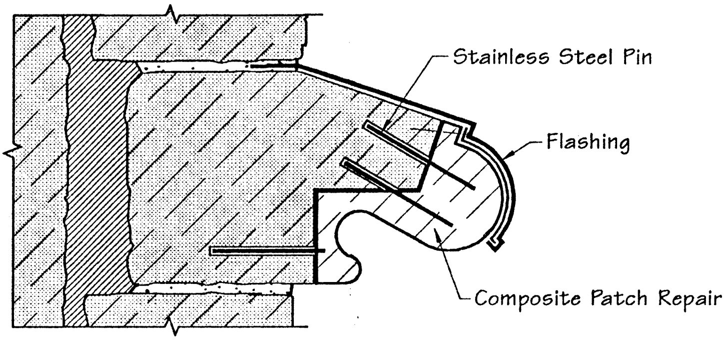

Fig. 6 Composite Patch Repair at Band Course

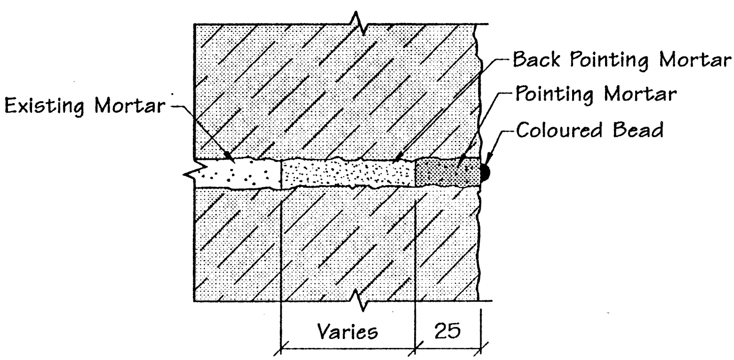

Fig. 7 Pointing Detail