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Brick Veneer/Steel Stud Walls
- A Repair Solution -

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ABSTRACT

The paper describes the investigation and subsequent repair work carried out on the brick veneer/steel stud masonry walls of a highrise apartment building in Calgary, Alberta. The paper deals with the original design details, with workmanship deficiencies and with the selected repairs.

INTRODUCTION

For the past 20 years, brick veneer/steel stud (BV/SS) walls have been used extensively in North America as an economical exterior wall system both for commercial and residential construction. Since the construction of these walls preceded the development of adequate design, construction and inspection standards, serious concerns have been expressed by building officials, consultants and contractors over the longterm safety, serviceability and durability of this form of construction. A survey conducted on behalf of CMHC (Keller, 1986) established that by 1986, approximately 1000 buildings had been constructed in Canada; of these 42% were residential and 58% commercial or industrial. More than 34% of this apparent inventory was more than 4 storeys in height. The survey showed that no standardized procedures existed for design and inspection during construction. In addition, a number of practices that we now know are deficient were reported as relatively commonplace. For example, exterior insulation was not used on two thirds of the projects reported, 72% of the brick ties did not connect directly to the stud and on 22% of the projects, corrugated brick ties were used.

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A follow-up building condition survey across Canada (Keller, 1990) was carried out in 1988 and it also showed that the steel stud construction was frequently substandard, using essentially interior partition technology. Corrosion of metal components was of concern as the steel stud assembly was not generally protected effectively against exposure to moisture. This concern was compounded by observations of poor detailing with respect to moisture penetration from the exterior and the potential for condensation in the stud space. Corrosion of brick ties was often noticed and where strip ties were used, their service life appeared to be significantly shortened.

Although the industry has become more aware of the past shortcomings and significant improvements were made during the last 6 to 8 years in the construction of BV/SS wall systems, there remains a very large inventory of BV/SS walls which is likely structurally inadequate and vulnerable to premature deterioration and potential failure. Efforts are currently under way to repair or upgrade some of the earlier BV/SS walls using a variety of approaches. The solutions selected are typically governed by the as-built conditions but also by the state of the art in brick veneer/steel stud repair technology.

This paper describes a new approach to the rehabilitation of these walls which will, hopefully, be a useful addition to the library of successful solutions. The original design details, the as-built conditions and the repair method used to correct the deficiencies of the BV/SS walls of an 11-storey apartment building in Calgary are presented.

ORIGINAL DESIGN DETAILS

The building was constructed in 1981. The design of the BV/SS wall was governed by the 1977 Alberta Building Code. The details and specifications for the BV/SS wall system were shown in the architectural drawings, see Fig. 1.

AS-BUILT CONDITIONS

A detailed inspection of the exterior wall system was carried out in 1993 to provide the basis for the development of the repair details. The as-built conditions are listed below:

<u>Exterior Wall Construction</u>

- ½" (12.7 mm) interior drywall
  10 mil (0.25 mm) polyethylene vapour barrier
  3⅝" (92 mm) steel stud with bat insulation
  ½" (12.7 mm) exterior drywall
  building paper
  ½" - 2" (12.7 - 50 mm) cavity
  4" (102 mm) standard clay brick

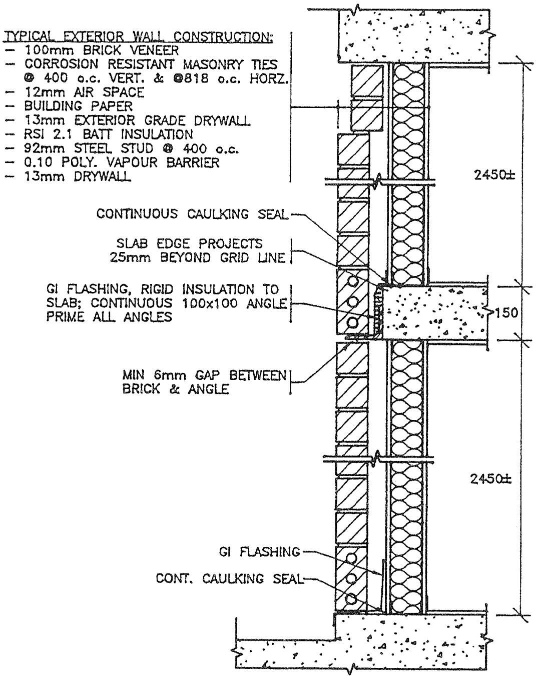

Fig. 1 Original Design Details of BV/SS Wall

- drywall secured to studs with 1¼" (32 mm) long, ⅛" (3.18 mm) diameter drywall screws at about 16" (406 mm) vertical spacing

- where the cavity is less than about 1¼" (32 mm), mortar fins are in contact with the exterior sheathing

- brick ties are typically covered with mortar droppings

Steel Stud Details

Studs:
- 3⅝" x 1¼" (92 x 32 mm), 0.022" (25 gauge) 0.56 mm thickness, including galvanizing
- typical spacing 16" (406 mm) o.c., with 1 extra stud added within 8" (203 mm) of the window jamb
- no horizontal bridging

Tracks:
- 3⅝" x 1" (92 x 25 mm), 0.018" (26 gauge) (0.46 mm) thickness, including galvanizing

Typical Floor Height:	8'-0" (2438 mm)
Typical Stud Height:	7'-11¾" (2432 mm), stud/top track engagement typically ¾" (19 mm)
Track Connection to Slab:	mixture of tapcon style and power driven nails at about 12" (305 mm) o.c.; nails are 1" (25 mm) length, ⅛" (3.18 mm) diameter
Stud Connection to Track:	1¼" (32 mm) drywall screws, ⅛" (3.18 mm) diameter, typically installed at the interior side only.

<u>Brick Ties</u>

- corrugated strip ties fastened with 1¼" (32 mm) drywall screws, ⅛" (3.18 mm) diameter, fastened through the exterior drywall

  Horizontal spacing = stud spacing
  Vertical spacing 12 - 16" (305 - 406 mm) o.c.
  Tie width = 1" (25 mm)
  Tie thickness = 0.016" (0.41 mm), depth of corrugations = 0.079" (2 mm)
  Tie embedment in bed joints = 1½" - 1¾" (38 - 44 mm)

The survey of the brick veneer revealed the presence of cracking and spalling in many locations. Cracking was most extensive at building corners and at balcony slabs. Several inspection openings were made to determine the cause of the veneer distress. The evidence showed that the distress was attributable to the absence of "soft joints" at shelf angles and balcony slabs, as well as due to discontinuous shelf angles at building corners.

The detailed inspection also showed that poor detailing and workmanship practices were used in the construction of the steel stud walls. While corrosion of studs, tracks and screws was minor at the time of the inspection, premature repairs were anticipated. Significant concerns existed at this time about the undersized, poorly connected and inadequately braced studs' ability to resist design wind loads.

It is for this reason that the repair work included not only the repairs of the readily visible brick veneer cracks but also the stabilization of the brick veneer.

REPAIR PHILOSOPHY

Based on the evidence of cracking in the brick veneer, the veneer was clearly jammed between floor slabs at balcony recesses and in flat wall sections, the veneer was compressed between the ground floor slab and the roof slab. While there was no evidence of veneer buckling on this building, a two-storey high section of a brick veneer wall on a neighbouring building of similar construction had to be replaced a few years earlier due to this problem. For this building, it was concluded that a soft joint under the shelf angles was required both because of the risk of buckling and because of the observed cracking.

With the brick veneer jammed-in, the compressive stresses had the effect of strengthening and stiffening the veneer such that the steel stud back-up experienced very little load. With the introduction of a soft joint, the compressive stresses were relieved and the studs were subjected to significant wind loads for the first time.

The ability of the steel stud backup to resist the applied wind loads was reviewed analytically and a number of elements were found to be seriously overstressed:

Element	Overstress
Typical stud	294%
Sill track	412%
Jamb stud	1006%

Given the obvious structural inadequacy of the steel stud system to provide lateral support for the brick veneer, two fundamental repair options were reviewed: firstly, the reconstruction of the entire BV/SS wall system at a cost of \$2,000,000 or \$592/m^2, and secondly, the provision of adequate lateral support to the brick veneer using various stabilization measures. A number of alternatives were explored and a solution was developed to secure the brick veneer without reliance on the steel stud system. In addition, this solution was estimated to cost less than the complete reconstruction option and was less disruptive to building occupants.

The intent was to provide lateral support to the brick veneer at discrete locations using steel columns. The brick veneer would span horizontally between these supports or between these supports and concrete column locations where remedial steel anchors were installed to secure the brick to the structure. The brick veneer was designed to carry 100% of the wind load and the steel stud system was no longer relied upon to provide any lateral support. However, since the brick veneer has a vented cavity, the air barrier was still the interior drywall sheathing. Wind loads on the air barrier and on the punched windows were transferred to the brick veneer via the existing steel studs and brick ties.

The steel columns were installed from the interior by cutting 400 mm wide openings in the drywall. The retrofit anchors at concrete column locations were installed from the exterior directly through the brick veneer.

FLEXURAL TESTING

To determine the spacing of the steel columns, the flexural capacity of the brick veneer parallel to the bed joint needed to be verified. To answer this question, masonry specimens were removed from random locations on the building and tested in flexure using ASTM E518 and Drysdale et al, 1994 as a guide. A typical test setup is shown diagrammatically in Fig. 2. Eight specimens were tested with the tooled joint in tension and two specimens were tested in reverse. The test results are summarized in Table 1.

Table 1 Flexural Test Results

Specimen No.	Ultimate Strength (MPa)	Failure Mode
1	2.54	1
2	1.20	2
3	2.18	1
4	1.62	2
5	1.25	2
6	2.36	1
7	1.51	2
8	1.92	1
9	2.52	1
10	1.62	3
	$\bar{\sigma}$ = 1.87	

Failure Modes (Drysdale et al, 1994)

1. Cracking through head joints and masonry units in alternate courses
2. Cracking in toothed pattern along a combination of head and bed joints
3. Diagonal cracking - either stepped along combinations of head and bed joints or along the shortest path through units.

The mean flexural strength was found to be 1.87 MPa with a coefficient of variation of 27%. This results in a lower bound flexural capacity of σ = 1.37 MPa. (Mean strength less one standard deviation).

According to CSA S304-M84 (CSA, 1984), the allowable flexural tensile stress parallel to the bed joint for Type N mortar is 0.39 MPa. The actual lower bound strength inherent in the masonry veneer is 3.5 times this allowable value.

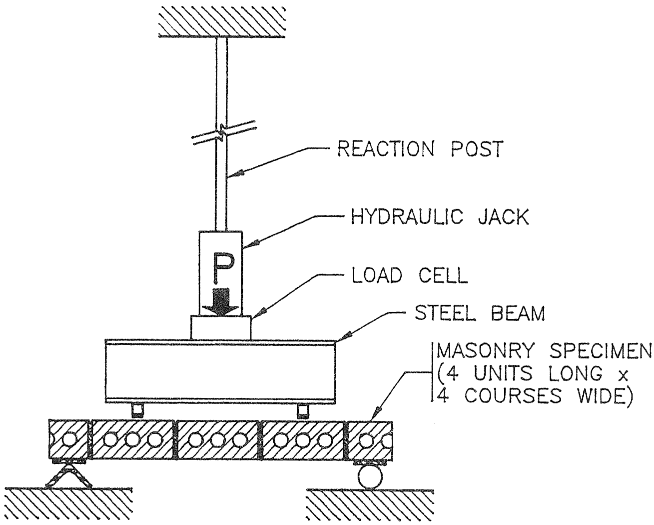

Fig. 2 Test Apparatus

Using 0.39 MPa for design, a lateral support spacing of 1.8m, for the new steel columns and anchorage at existing concrete columns, was derived. However, since window locations and other building features had to be considered, the typical spacing ranged from 1.2 m to 2.5 m. Using a design wind load of Pe = 1.08 kPa, the maximum flexural stress in the brick veneer ranged from 0.144 MPa to 0.625 MPa for the actual support spacings, and the associated factors of safety against ultimate failure ranged from 9.4 to 2.2.

CONSTRUCTION DETAILS

To account for slab deflections and variations in slab to slab height, as well as to facilitate easy installation of the steel columns without removing the baseboard heaters, a telescopic column arrangement was chosen. Typical column details are shown in Figs. 3 and 4. The layout of the retrofit steel columns and the location of the masonry anchors at concrete columns and concrete walls is shown in Fig. 5.

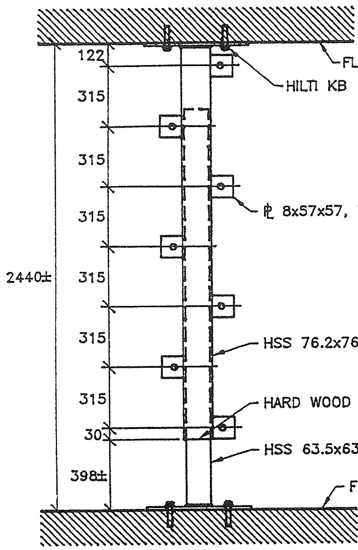

Fig. 3 Steel Column Details

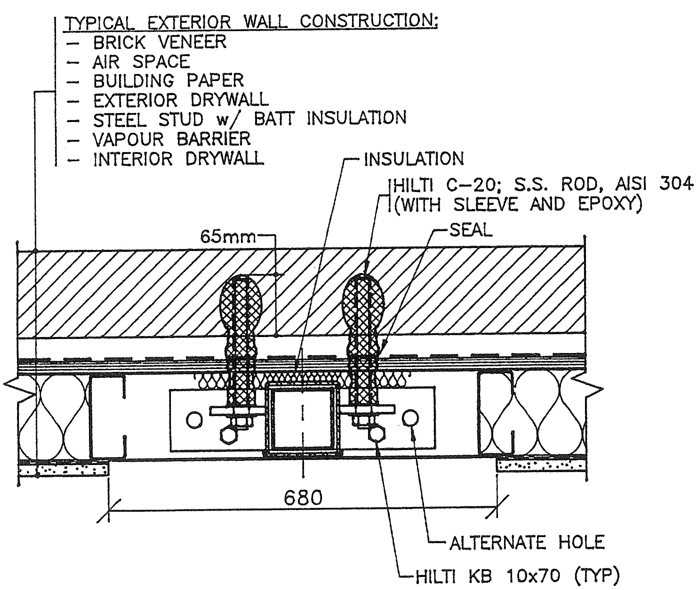

Fig. 4 Steel Column Installation Details

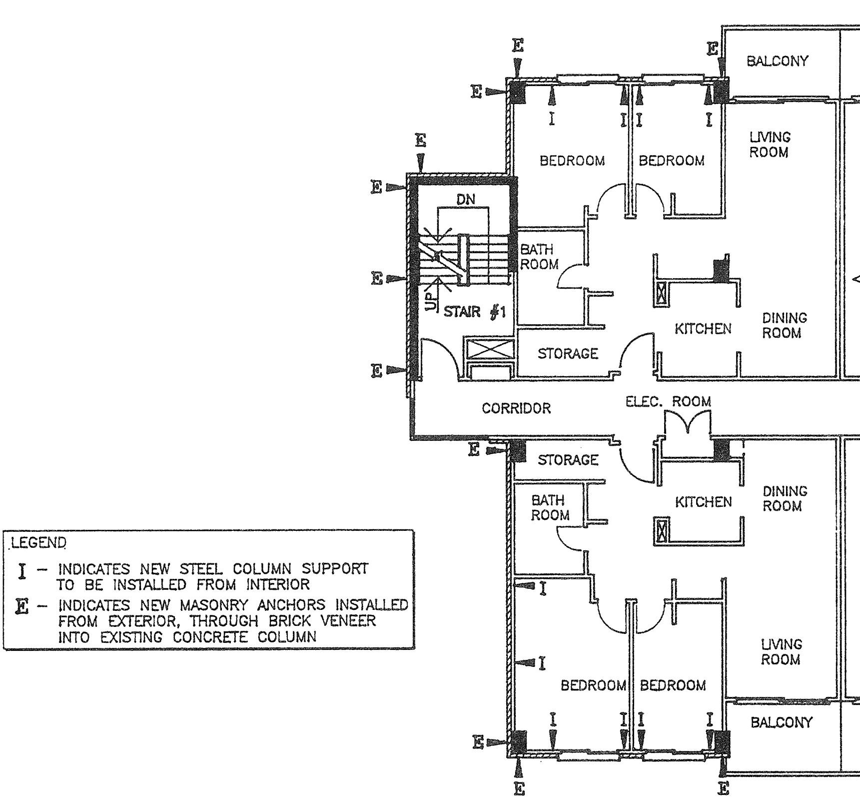

Fig. 5 Typical Layout of New Lateral Support for Brick Veneer

Use of a telescopic steel column made the installation very easy but it also brought up concerns about excessive mechanical play. In the absence of guidance for acceptable mechanical play, the CSA S304.1 (CSA, 1995) requirements for masonry ties were adopted. S304.1 specifies that deflections due to ½ the total mechanical play plus deformations at 0.45 kN be less that 1.0 mm. Analysis of the telescoping post detail indicated that shimming would reduce the total mechanical play to an acceptable range of 0.1 to 0.5 mm. See Fig. 3 for the location of shims.

A number of possible shimming details were considered including steel shims, epoxy grouting of the space between the inner and outer HSS and mechanical fasteners. After a period of field experimentation, a hardwood shim held in place with a bead of sealant was selected.

REPAIR COSTS

The repair costs presented are based on the contract value including all price adjustments made during the repair process. The building has 3530 m^2 of BV/SS walls. A total of 503 steel columns were installed at a cost of $163,000 ($324/column). Including the $31,000 spent on retrofit anchors at 285 concrete column locations, the total costs for the lateral stabilization of the brick veneer amounted to $194,000 ($55/m^2). The provision of "soft joints" and vertical control joints at critical locations cost $80,000. Therefore, the total costs associated with the brick veneer repairs were $274,000 or $78/$m^2$. This cost figure compares rather favourably to the unit cost of $592/$m^2$ for the complete reconstruction of the BV/SS walls, not to mention the added inconvenience caused to the occupants.

Experience to date with other buildings of similar magnitude has shown that the costs for the installation of steel columns, complete with interior drywall repairs and painting, range from $302/column to $444/column. The costs for the total wall repairs including retrofit anchors at concrete columns and re-instatement of interior finishes, range from $71/$m^2$ to $93/$m^2$ of BV/SS wall.

An average of 12 to 15 columns were installed per day using two teams of workers. Typically, 5 days were required from first to last entry in each apartment.

SUMMARY

A novel technique for the remediation of deficient BV/SS walls has been presented. The technique relies on the horizontal flexural strength (parallel to the bed joint) of the brick veneer and is used where the steel stud system is structurally inadequate either due to design and workmanship deficiencies, or due to premature deterioration of the steel elements.

Retrofit steel columns were installed from the interior in the steel stud space and the brick veneer was anchored to these columns using adhesion anchors. At concrete columns or shear walls, the brick veneer was secured using retrofit masonry anchors installed from the exterior. To verify the flexural strength of the brick veneer, masonry specimens were removed from random locations on the walls and tested on site using ASTM E518 as guide for testing.

The tests showed that the average ultimate flexural strength of the masonry exceeded the minimum allowable strength specified in CSA S304-M84 by a factor of 3.5. The steel column spacing was determined by using the minimum strength values stipulated in CSA S304-M84.

Using steel columns at discrete locations and allowing the brick veneer to span horizontally between supports without relying on the existing steel stud system for lateral support, proved to be a simple and cost effective retrofit option. The costs for this type of installation were \$55/m^2 of brick veneer wall. The intervention was minimal with the inconvenience to the occupants limited to 5 working days, including drywall repairs and painting.

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