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SEISMIC RETROFIT STRATEGIES FOR HISTORICAL CLAY BRICK MASONRY SCHOOL BUILDINGS; BRITISH COLUMBIA, CANADA

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ABSTRACT

In 2005 the Government of British Columbia (BC), Canada, initiated a $1.5 Billion, 15 year program to seismically upgrade schools. The BC Ministry of Education (MoE), is currently in the process of seismically upgrading school buildings previously determined to pose medium or high risk to the life safety of the building occupants. The reference design earthquake level is for an Annual Exceedance Probability (AEP) of 1/2475. The inventory of school buildings includes many historical buildings, in the order of 80 – 100 years old, constructed with extensive amounts of clay brick masonry.

The MoE initiated a detailed study of three, representative, but different, clay brick masonry school 'heritage' buildings as part of developing a diverse set of seismic retrofit strategies for use by the general engineering community; this study is part of and contributing to the seismic retrofit program for the province's at-risk public schools.

Buildings "One" and "Two" each have two storeys plus a basement, non-ductile concrete frames, concrete floors, clay brick and hollow clay tile masonry infill exterior walls (portions with separate veneer), and hollow clay tile and clay brick interior walls. Building "Three" has two storeys plus a basement, clay brick masonry load-bearing walls, with a wood roof and floors. The study also evaluates four different approaches to mitigate the risk of the infill unreinforced masonry walls in Buildings "One" and "Two".

The study utilizes the MoE sponsored performance based approach to assessing and upgrading school buildings in BC, the "Technical Guidelines – First Edition", scheduled to be released in summer 2010. The assessment of these buildings provides a risk rating from Medium to Very High.

The study includes evaluation of a variety of upgrading approaches: refinement

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and enhancement of "conventional" concrete shear wall retrofit concepts used to date in North America; a base isolation retrofit which offers certain advantages including the reduction of earthquake damage to heritage-designated buildings; and advanced non-linear dynamic analysis and utilization of the inherent seismic "strength" of clay brick masonry construction. The study includes material testing, independent peer reviews, constructability input by contractors, and involvement of architectural, mechanical, electrical and costing specialists. This paper presents the different retrofit solutions developed, the estimated costs of each, and discusses some of the benefits and disadvantages of each retrofit solution; the paper is a summary of a full report detailing the noted study.

Introduction

The purpose of this paper is to present several life safe, cost-effective retrofit strategies for the seismic upgrading of clay brick masonry school blocks in BC. A "block" is defined as one independent structure in what is typically an amalgamation of blocks at any given school. The intent of this study is not to select or recommend one definitive retrofit solution from those evaluated. Each block has its own particular and often distinctive characteristics. The retrofit strategies outlined present options for the consideration of the engineer-of-record who has been engaged to prepare a seismic retrofit design for a clay brick masonry block.

The three retrofit concepts presented are:

(1) Shearwall retrofit concept developed by Genivar for Building "One";
(2) Base isolation retrofit concept developed by Sandwell for Building "Two";
(3) Load-bearing walls retrofit concept developed by TBG for Building "Three".

The retrofit construction cost estimates in this paper include all structural, architectural, mechanical and electrical work necessary for the proposed seismic upgrade. The cost estimates do not include associated costs such as consultants' fees, construction contingency, project contingency and taxes. Cost estimates excluding temporary relocation (portables) costs, and including ballpark estimates of temporary relocation costs are presented.

The retrofit concepts have been developed to conform to the provisions of the Technical Guidelines (TG) - First Edition currently under development for the Ministry of Education. The TG will be formally released in the summer of 2010. The performance of certain existing structural components in this study is based on preliminary results generated by the University of BC (UBC) research team that is drafting the TG.

Shearwall Retrofit Concept – Building "One"

The risk assessment of the existing building, based on the TG, indicates a "Very High" retrofit priority ranking. The retrofit concept developed is a refinement of a conventional concrete shearwall and foundation approach. A preliminary design for seismic upgrade of a typical concrete frame two storey plus daylight basement building with clay brick and / or clay tile walls was developed, as illustrated in Figure 1.1.

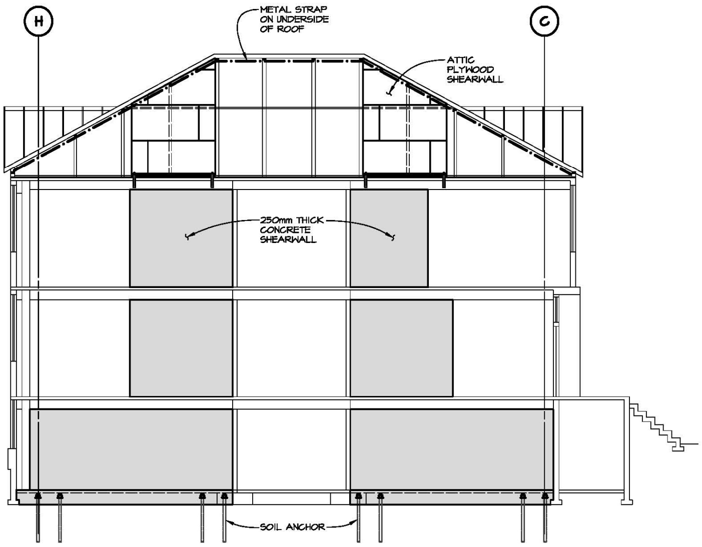

Figure 1.1: Concrete Shearwall Retrofit Concept

The school, constructed in two phases in 1910 and 1912, comprises concrete floor beams, one-way concrete slabs and concrete columns bearing on concrete basement walls, strip and pad footings. There is a wood framed pitched roof built over top of the upper floor concrete ceiling slab. Exterior walls consist of multiple wythe clay brick veneer with clay brick or clay tile backing. Interior partitions consist of unreinforced clay brick or clay tile with plaster finish. The total plan area, including all three levels, is 3630 m^2.

Concrete shearwall options were developed for both 1% and 2% interstorey drift limits. Option A for the 1% drift limit is more compatible with the non-ductile nature of this type of building, but the resulting design forces are higher. Option B for the 2% drift limit results in lower design forces and therefore fewer shearwalls and foundations are required. However, it requires further upgrade of the existing columns to improve ductility and replacement of clay brick and clay tile interior partition walls deemed unable to accommodate such deformations and still achieve life safety performance.

Option A also considered two alternatives for addressing the interior partition walls: Alternative 1 which involves removal of all interior walls and replacement with steel stud and drywall, and Alternative 2 which involves strong-backing one side of such walls with metal studs connected to the brick / tile. Option B only considered the ‘remove and replace’ approach (Alternative 1) since it is a concern that strong-backed walls (Alternative 2) may not remain intact under cycles of 2% drift.

Some key components of Options A and B are listed below:

(a) introduction of new concrete shearwalls within the existing floor plan of the school;
(b) new foundations including soil anchors below each shearwall;
(c) support of exterior clay tile / clay brick walls by strong-backing or dowelling;
(d) replacement or strong-backing of interior clay tile / clay brick partitions;

(e) improvements to connections of the wood roof to the upper concrete slab;
(f) new wood framed shearwalls in the attic space.

Some key advantages of this upgrade are that conventional construction will result in competitive bidding on the project and it is based on proven construction methods so there is a relatively low level of risk; the interior face of all exterior walls and one side or both sides of interior walls will receive new finishes, including new millwork and fixtures, where required; if all interior walls are removed, opportunities exist for reconfiguring room layouts; and the new shearwalls could potentially incorporate installation of handicap access (elevator). A key challenge and disadvantage of this upgrade results from the fact that its invasive nature requires relocation of students and staff for the duration of construction; also structural and non-structural repairs will be required following an earthquake.

Results of costing in Table 1.1 below indicate that upgrading for a 1% drift limit (Option A) is very similar in cost to upgrading for a 2% drift limit (Option B), with only a 4% difference in cost between the two options if removal of all clay brick / clay tile is considered for both.

Table 1.1: Retrofit Cost Estimates (without relocation costs)

Option	Alternative	Retrofit Cost	Cost / m^2
A	1	$4.3 M	$1,190 / m^2
	2	$4.5 M	$1,230 / m^2
B	1	$4.2 M	$1,141 / m^2

With costing estimates this close, many other factors must be considered before making a final decision on which retrofit strategy to choose. This would include such items as compatibility of shearwall locations with building function, extent of non-ductile load-bearing elements, impact on building systems, etc. The basic costing does not include a number of items unique to the school that may be desirable to be replaced during the seismic work, and any project related requirements of the Authority Having Jurisdiction necessary to obtain a building permit.

A significant cost not included in Table 1.1 is the provision of temporary relocation space for the students/ staff during construction. This retrofit approach is extremely invasive and disruptive. It is considered essential that all students / staff be removed from the school for the duration of construction, assumed to be one school year.

Base Isolation Retrofit Concept – Building "Two"

The risk assessment of the existing building indicates a "Very High" retrofit priority ranking. The retrofit concept developed presents an innovative "non-conventional" approach involving base isolation (also termed "seismic isolation"). A preliminary design for seismic upgrade of a typical concrete frame two storey plus daylight basement building with clay brick and / or clay tile walls was developed, as illustrated in Figure 1.2.

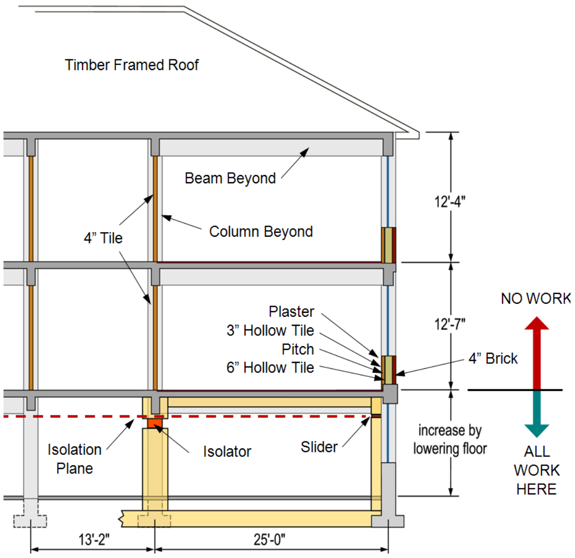

Figure 1.2: Base Isolation Retrofit Concept

The building, constructed in two phases in 1913 and 1929, consists of concrete floor beams, one way concrete slabs (either flat slabs or ribbed slabs with clay tile) and concrete columns bearing on concrete basement walls, strip and pad footings. There is a wood framed pitched roof built over top of the upper floor concrete ceiling slab. Exterior walls consist of multiple wythe clay brick veneer with clay tile backing. Interior partitions consist of unreinforced clay tile with plaster finish. The total plan area, including all three levels, is 3,760 m^2.

The concept of seismic isolation is to isolate a structure from the ground (source of earthquake excitation) and greatly reduce the transmitted earthquake load effects to structural and nonstructural components above a horizontal plane of isolation. Modern isolation systems have been around for over 30 years and now there are thousands of buildings and other structures around the world that incorporate seismic isolation as the means to mitigate earthquake effects. Three common types of isolators readily available on the market are Lead Core Rubber Bearings (LRB) isolators, Friction Pendulum System (FPS) isolators, and High Damping Rubber Bearing (HDRB) isolators. All are able to carry significant vertical loads, while accommodating significant lateral deformations. All provide varying levels of additional damping to further reduce earthquake effects. The LRB and FPS have been the most common isolators used to date. For this study LRB isolators are considered.

Depending on design requirements, an isolation system can be a combination of isolators / bearings and sliders to achieve the same results at reduced cost. This is the case for this study. The key issues for utilizing seismic isolation systems in a seismic retrofit are cutting through building to create a horizontal plane, making superstructure independent of foundation; installing isolators and sliders at isolation plane while supporting vertical loads and developing details for an isolation plane for architectural, mechanical, electrical components to accommodate the fairly significant horizontal movements.

Some benefits of seismic isolation systems for retrofit of heritage buildings are that there is very little or no seismic upgrade required above the isolation plane; the building occupants can use the portion of the building above the isolation plane during most of the construction period; the structural and non-structural earthquake damage is significantly reduced (effectively eliminated) in comparison to conventional structures, enabling building use after an earthquake and significantly reducing post-earthquake costs; the system behavior is very reliable due to its controlled and pre-installation tested response; and there is less reliance on archaic materials that have uncertain properties. A key challenge is to determine by adequate materials testing and analyses that the as-is concrete frame and hollow clay tile partitions (above the isolation plane) are no longer a hazard for the isolation system's seismic response.

Two isolation schemes were initially considered, namely, (a) base isolation beneath the basement floor level (below grade), and (b) seismic isolation at a plane above the ground level. Scheme "A" (Isolation beneath basement Level, below grade) requires a new stiff diaphragm at foundation level as well as a 'moat' all around building to allow for differential movement between the building and the soil. The perimeter drainage and all incoming utilities need to be considered with regard to the expected displacement of the isolators. Significant work in and below basement is required to retain existing storey height. Scheme "B" (Isolation Plane above Ground Level) requires the reinforcement of existing concrete diaphragm at first floor and the appropriate details at stairs, windows, interior walls to allow for differential movements of isolators; however a 'moat' is not required. Internal below slab services, and all internal utilities crossing isolation plane (using flex joints) require consideration. There is significant work required in the basement, including reinforced or new columns and footings.

Scheme B was selected in this study as the preferred scheme due to the anticipated lower cost. Two different construction options were also considered regarding the main structural components in the basement supporting the isolators. Option 1 involves the demolition and removal of existing columns and foundations below isolation plane and replacement with new columns and foundations. Option 2 involves upgrading the existing columns below the isolation plane, and their associated pad foundations. Cost estimates indicated the costs were nearly identical for either option; the choice of which scheme is most suitable for a specific school will depend on basement, column, foundation, soil details. However, incorporating all new columns and foundations would be the preferred option, as this would eliminate reliance on the existing structural components with uncertain structural properties. The cost listed in Table 1.2 is for Scheme B, Option 1.

A simplified scope of work for installing the seismic isolation system is:

(a) demolish all partition walls in basement;
(b) remove existing slab on grade in basement and excavate for new tie beams and foundation modifications;
(c) reinforce concrete frame below the first floor,
(d) shore superstructure, cut at level of isolators and transfer gravity load to shoring;
(e) install isolators / sliders at isolation plane, transfer load to isolators / sliders;
(f) place new slab on grade and rebuild basement partitions using special stud walls with joint at isolation plane;
(g) make modifications to stairs, basement doors, electrical and mechanical services to accommodate horizontal movement at isolation plane;
(h) make minor upgrade in superstructure (school specific)

Table 1.2: Retrofit Cost Estimate (without relocation costs)

Option	Option Description	Retrofit Cost	Cost / m^2
1	Scheme B – Isolation Plane above grade	$5.7 M	$1,510 / m^2

Similar to Building "One" the basic costing does not include a number of items unique to the school that may be desirable to be replaced during the seismic work, and any project related requirements of the Authority Having Jurisdiction necessary to obtain a building permit.

As the invasive and disruptive work for this scheme can be carried out in summers when school is not in session and after school hours during the school year, it is considered feasible to have all students and staff in the upper two floors of the school remain in the school during construction. The construction duration is assumed to be 14 months: one summer, one school year, and second summer. Some temporary relocation space is still required for the functions disrupted in the basement (these typically do not represent the core teaching space in these older schools).

Load-Bearing Walls Retrofit Concept – Building "Three"

The risk assessment of the existing building indicates a "Medium" retrofit priority ranking. The retrofit concept developed involves utilizing the existing inherent strength of clay brick masonry augmented with diaphragm strengthening, mortar reinforcing of certain masonry walls, and other local reinforcing of masonry piers and walls. A preliminary design for seismic upgrade of a typical load bearing clay brick masonry two storey plus daylight basement building with wood roof and floors was developed, as illustrated in Figure 1.3.

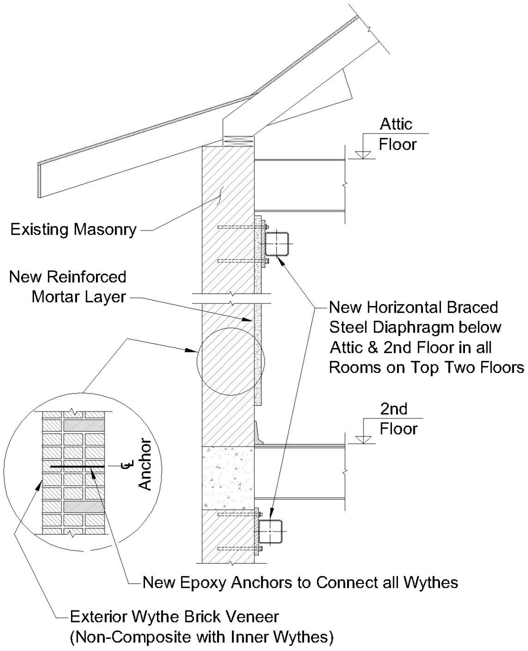

Figure 1.3: Load-bearing Clay Brick Masonry Blocks

The school was constructed in 1914 and is comprised of 3 to 5 wythe exterior and interior load-bearing clay brick masonry walls, with wood frame floor construction, founded on spread footings. There is a wood framed pitched roof built over top of the upper floor wood ceiling. The total plan area, including all three levels, is 1,730m^2.

Field testing has determined that the outer wythe of the exterior masonry walls is a brick veneer that is not composite with the inner wythes. The inner walls are assumed to have similar construction (plaster finish precluded exploratory investigation).

The overall retrofit priority ranking for has been set as lower than Buildings "One" and "Two" with the qualification that the vertical discontinuity of one masonry shearwall in the basement be rectified. The cost estimate is given in table 1.3.

The retrofit concept proposed for the building comprises the following primary upgrades:

(a) anchors installed in all walls to ensure composite action of all wythes and veneer;
(b) new horizontal braced steel diaphragms installed at the underside of the ceilings of the first and second floors to transfer lateral loads to masonry walls (lateral resistance by sliding shear behavior of exterior and interior brick walls)
  -ring beams in the basement to provide out-of-plane support for the masonry walls
  - anchors installed in the slender masonry piers between windows to ensure composite wythe behavior, plus steel columns to provide in-plane/out-of-plane support;
(c) new mortar layers 50 mm thick installed on the inside face of most masonry walls on the second floor to enhance the in-plane shear strength for the upper portions of these walls (below which dead load provides adequate sliding friction capacity);
(d) new concrete shearwalls installed in the basement to upgrade the discontinuity in one corridor masonry wall immediately below the main floor.

Table 1.3: Retrofit Cost Estimate (without relocation costs)

Option	Retrofit Cost	Cost / m^2
Basic upgrade as noted above	$3.26 M	$1,882 / m^2

The basis for the above noted cost is similar to that described for Building "One".

Temporary Relocation Space – All Buildings

Disruption to educational operations is not explicitly included in the scope of work of this study. However, the three retrofit concepts have differing educational impacts during retrofit construction.

The base isolation retrofit concept (Building "Two") has the lowest impact on educational operations. Both the shearwall retrofit concept (Building "One") and the load-bearing walls retrofit concept (Building "Three") require complete evacuation of students and staff for the full construction period. The base isolation concept will require evacuation of only the basement during the construction period (no disruption to classrooms in top two storeys).

The additional costs associated with educational disruption (“Temp Acc”) are quantified in Table 1.4 by calculating the cost of providing temporary accommodation (portables) on site for the construction period. The combined cost estimate (“Total”) per m2 of floor space given in Table 1.4 provides a more representative cost for the three retrofit concepts.

Table 1.4: Cost Estimate Summary Including Temporary Accommodation

Block	Retrofit Estimate Cost / m^2		
	Basic	**Temp Acc**	**Total**
Building One	\$1,141 / m^2	\$322 / m^2	\$1,463 / m^2
Building Two	\$1,510 / m^2	\$48 / m^2	\$1,558 / m2
Building Three	\$1,882 / m^2	\$338 / m^2	\$2,220 / m2

The above temporary accommodation cost estimates are based on the assumptions of \$45,000 / portable and 26, 4 and 13 portables for Building “One”, Building “Two” and Building “Three”, respectively.

Heavy Partition Walls

Building “One” was used as the reference building to examine alternate methods of upgrading unreinforced clay brick or clay tile interior partition walls within a building. The clay brick walls were 104 mm thick, with plaster on both sides, with a floor to ceiling height of 3800 mm (effective h/t ratio of 36). The clay tile walls were 120 mm thick, with plaster on both sides, with similar floor to ceiling height (effective h/t ratio of 32).

The primary alternative methods of upgrade that were examined are:

(1) remove and replace with steel stud and drywall;
(2) strong-back one side of all walls with metal studs connected to brick;
(3) strong-back one side of all walls with metal studs connected to clay tile;
(4) confinement of wall with stud walls both sides;
(5) mid-height support of walls with horizontal HSS girt (and posts as necessary).

Costing of the alternatives is summarized below. The cost basis is similar to that presented for Building “One” previously. No upgrade of ceilings and flooring is included other than that required to locally accommodate the retrofit. Note that these costs have been included in the Building “One” cost estimates presented earlier; no such work regarding walls is required in Buildings “Two” or “Three”. This costing is purely for comparison purposes for upgrades that may only require addressing partition wall issues.

Table 1.5: Heavy Partition Walls Retrofit Cost Estimate Summary

Alternative	Cost / m^2
1	$320 / m^2
2	$401 / m^2
3	$474 / m^2
4	$341 / m^2
5	$324 / m^2

Results of costing indicate that the remove and replace alternative (Alternative 1) was the least expensive, even when considering the overall impact of removing all walls. This approach is also beneficial from a risk management perspective as this alternative is totally independent of the condition of the brick, tile or mortar, since it will all be removed. If the other alternatives are to be considered, extensive testing of the existing materials is recommended to confirm that the chosen upgrade method is feasible.

Conclusions

The advanced technical methodology embodied by the Technical Guidelines first edition (technical basis of this study) enhances the opportunities for generating cost-effective retrofit solutions that quantify and mitigate the risk to life safety to an acceptable level, as defined within the guidelines. The retrofit concepts detailed in this study demonstrate that retrofit solutions can be cost-effective for this problematic form of school construction (typically 50% – 80% of replacement cost).

A large majority of non-ductile concrete frame clay brick masonry blocks present a high risk to life safety for earthquake loading and require seismic upgrading as soon as possible to maintain acceptable life safety standards.

This study has determined that the base isolation retrofit concept is feasible for Building “Two” and can be cost-competitive with more conventional shear wall options if temporary accommodation requirements can be avoided for the upper two floors. Such an upgrade may provide enhanced seismic performance (not limited to life safety) at a relatively small incremental cost compared to conventional upgrades. This retrofit concept has the least impact on disrupting educational operations and has the potential to result in the least damage to both non-structural and heritage aspects of the building following an earthquake.

It is recommended to carry out “pilot projects” for the upgrades of Buildings “One” and “Two” to get as-constructed comparative pricing, and to fully develop scheduling/sequencing procedures and resolve all details. All results will be made available to the engineering community working with the MoE to upgrade similar school blocks in the future.