# REPORT ON PHASE 2, COMPONENT 2
# SEISMIC RE-EVALUATION
# CANADIAN CHANCERY
# BRIDGETOWN, BARBADOS

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Prepared for:

**DEPARTMENT OF FOREIGN AFFAIRS, TRADE AND DEVELOPMENT**
Lester B. Pearson Building
125 Sussex Drive
Ottawa, Ontario
K1A 0G2

Prepared by:


**J.L. RICHARDS & ASSOCIATES LIMITED**
Consulting Engineers, Architects & Planners
864 Lady Ellen Place
Ottawa, Ontario
K1Z 5M2


JLR No.  23423-27

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**SEISMIC RE-EVALUATION**
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## EXECUTIVE SUMMARY

The purpose of this Phase 2, Component 2 report is to provide an analysis and evaluation of three different seismic retrofit options for the Canadian Chancery in Bridgetown, Barbados. The report follows a Phase 2, Component 1 report which indicated that the existing seismic force resisting system (SFRS) in the Canadian Chancery would not meet the Post-Disaster performance objective specified by DFATD.

The report identifies three potential retrofit strategies: replacement of the existing tension braces, the addition of new tension only braced bays, replacement of the existing braces with tension-compression braces (Buckling Resistant Braces - BRB's) and the addition of friction dampers in new braced bays located adjacent to the existing braced bays. For each retrofit strategy the base shear was calculated, the magnitude of the seismic forces on the existing braced bays, columns, beams and connections was determined, the magnitude of any uplift on the foundation was evaluated and the amount of displacement and drift was determined. The installation and design procedures for each option are discussed, and results for retrofit options designed for 100% of the seismic load are presented. Implications of designing the SFRS to 150% of the design seismic load are also considered for each retrofit option.

From the analysis performed, it was determined that the installation of new friction dampers in new braced bays adjacent to the existing braced bays would be the most economical solution and offer performance corresponding to the post disaster occupancy performance level as required. This option requires no foundation work and seismic retrofit work would be confined to the braced bays where the friction dampers would be installed.

It is assumed that the initial upgrades to the diaphragm system will proceed in conjunction with the seismic retrofit to ensure the life-safety of the building occupants.

## 1.0 INTRODUCTION

This report presents the results of a re-evaluation of the Canadian Chancery in Bridgetown, Barbados. A seismic evaluation was performed on the Canadian Chancery as part of the Phase 2, Component 1 Seismic Evaluation. The results of that evaluation indicated that the Chancery does not have adequate capacity to resist the design seismic forces.

Based on the findings of the Phase 2, Component 1 seismic evaluation, DFATD decided to proceed with the Phase 2, Component 2 study. The purpose of this study is to develop three seismic retrofit options that would meet the performance objectives of the Canadian Chancery, considering a Site Class A as determined in the Geotechnical Investigation. The effect of increasing the design seismic forces to 150% (post-disaster occupancy performance level) is considered for each retrofit option. The Component 1 evaluation indicated that the existing lateral force resisting system (LFRS) has adequate capacity to resist the design seismic forces if they are reduced to 60% of the normal occupancy performance level, therefore retrofit options for this load case are not presented. The results of the Component 2 study for 100% and 150% of the seismic load level are discussed in this report.

The results of the Phase 1, Component 1 re-evaluation indicated that the existing roof and second floor diaphragms have the following deficiencies:

- Inadequate diaphragm capacity and connectivity to the supporting elements;
- Inadequate shear transfer capacity around the large central openings;
- Inadequate capacity of the existing perimeter chord element.

Retrofit strategies for the diaphragm elements are presented in Section 2.1. The retrofit options discussed in Section 2 assume that these upgrades will be performed.

The lateral force resisting system consists of steel braces, columns and beams at the exterior of the structure, supported on pad footings. The Phase 1 re-evaluation determined that the existing HSS columns at the ground floor level do not have adequate capacity for either the normal occupancy or post-disaster occupancy seismic design forces. At the second level, the existing columns do not have adequate capacity for the post-disaster occupancy performance level. The existing braces were determined to have inadequate capacity for both the normal and post-disaster occupancy seismic forces at the ground and second level. For both load cases the existing beams were determined to have adequate capacity to resist the design seismic forces.

The existing braces do not meet the slenderness requirements of CSA S16-09 for compression elements. Therefore it is assumed that they are only effective in tension. The following retrofit options are considered:

1) Maintaining the existing tension only bracing system:
   a. Replacing the existing tension only braces with larger elements or
   b. Doubling the number of braces in each direction.

2) Installing new Tension-Compression braces, considering the length of the braces, it is assumed that the existing braces will be replaced with buckling-restrained braces (BRB's).

3) Installing friction dampers in new braced bays adjacent to the existing braced bay locations.

## 2.0 SEISMIC RETROFIT OPTIONS

### 2.1 Initial Load Path Upgrades

Each of the seismic retrofit options outlined below requires basic upgrades of the diaphragm system in order to transfer the seismic loads from the diaphragms to the seismic force resisting system (SFRS) and foundations. These basic upgrades include improved capacity of the roof and second floor diaphragm, improved connectivity of the deck diaphragms to the SFRS, horizontal reinforcement around the second and roof level openings and replacement of the existing perimeter chord element and connectivity to the SFRS. Upgrades to these elements are critical to the performance of the Chancery during any seismic event. The existing roof and second floor configurations pose a significant threat to building occupants. Because the stability of the floor structures are so important to the life-safety of building occupants, the diaphragm upgrades described below should be implemented whether or not a full seismic upgrade is performed.

The details and magnitude of the initial load path upgrades are practically independent of the chosen design level (normal or post-disaster occupancy). The estimated cost for these load path upgrades is included in each retrofit option's cost estimate. These upgrades would include the following components.

### 2.1.1 *Roof and Second Floor Diaphragm Upgrades*

The roof diaphragm has inadequate capacity to transfer shear forces to the SFRS. Options to improve the capacity of the roof diaphragm include replacing the diaphragm or the installation of an additional steel deck diaphragm on top of the existing diaphragm with a suitable connection pattern (300 mm or less). This system can be installed on top of the existing diaphragm or the existing diaphragm can be removed and then replaced. This repair should be conducted in conjunction with the replacement of the existing roofing system. The second floor diaphragm has adequate capacity for the design seismic forces but is only welded to the joists at 600 mm spacing, which is unacceptable. The second floor deck should be re-attached to the joists at a minimum of 600 mm centres, which will result in a total fastener spacing of 300 mm per the Canadian Sheet Steel Building Institute (CSSBI) 7.8.4. The presence of the concrete deck at this level makes increasing the connectivity from the top of the floor difficult. However, access to the deck from below is possible between the joists. The deck should be fastened to the joists every 600 mm to increase the connectivity to the supporting elements. Cost estimates for the initial load path upgrades are provided in Section 4. It is understood that the existing roofing system requires replacement. It is assumed that the roof diaphragm upgrades will occur in conjunction with the roof replacement. Therefore no costs have been included for removing and reinstating the roofing system. Sketch SK-1 presents retrofit options for increasing the capacity of the roof and second level diaphragms.

### 2.1.2 *Reinforcement around Large Openings at Second Floor and Roof Levels*

Both the second floor and roof levels have large openings, which are not adequately secured to the diaphragm or LFRS. At the second level reinforcement is required between gridline F2 and H and A1 to E. The reinforcement will be effective in both directions in transferring seismic forces to the LFRS at the perimeter of the structure. At the roof level reinforcement is required between gridlines B and E. Reinforcement will be provided by horizontal bracing members. Sketches SK-2 and SK-3 present the horizontal reinforcement at the second floor and roof levels.

### 2.1.3 *Reinforce Capacity of Perimeter Chord Element*

The third component of the initial upgrade includes the replacement of the existing perimeter angle with a larger steel section to resist the tension and compression forces generated by flexure of the deck diaphragm. The existing perimeter element at the second level does not have adequate capacity to resist the tension forces generated due to the design seismic forces. The upper portion of the exterior wall will need to be removed to install the new perimeter chord member. The replacement element could consist of a steel plate welded to the existing angle at the second floor level, the area of steel required is approximately 500 $mm^2$ and 700 $mm^2$ for normal and post disaster occupancy respectively. At the roof level the drawings do not indicate a perimeter element. At the roof level a new continuous perimeter element could be installed and fastened to the existing edge beams. A continuous steel plate with an area of 700 $mm^2$ for normal occupancy and 1000 $mm^2$ for post-disaster occupancy, welded to the existing edge beams would provide sufficient capacity to resist the tension and compression forces at the roof level. Sketches SK-4 and SK-5 present the retrofit options for the perimeter element at the second floor and roof level.

### 2.1.4 *Foundation Upgrades*

The existing foundation consists of pad footings beneath the columns connected by strip footings/grade beams and concrete masonry foundation walls. The design seismic forces can cause uplift on the foundations. The amount of uplift varies and depends on the strength and stiffness of the SFRS. Foundation upgrades, if required, are discussed for each retrofit option.

Uplift generated at the foundation level can be resisted by post-tensioned rock anchors or by transferring the resulting shear forces through the existing grade beams to adjacent bays. The shear capacity of the existing grade beam was investigated to determine if it is possible to engage more than one bay to resist uplift forces. The capacity of the grade beam was found to be approximately 50 kN, which is inadequate to transfer the shear forces without strengthening of the beam. It is assumed that due to the relatively small uplift forces (generally less than 200 kN) and close proximity (footing level) of bedrock that it will be possible to resist the uplift forces with one rock anchor per location and that the installation of the rock anchors would be straightforward and accomplished with the available equipment. Therefore in this report it is assumed that rock anchors will be used to resist uplift.

## 2.2 Option 1a): Replace Existing Tension Only Bracing

Tension only bracing is an economical bracing scheme, for one and two storey buildings when brace buckling will occur. Retrofit Option 1a) consists of the replacement of the existing tension only braces with larger tension only braces. The ductility and overstrength factors, $R_d$ and $R_o$, would remain 1.5 and 1.3 respectively for this option. This option does not require the construction of a new braced bay. It has the advantage of limiting work to the area of existing bays. The level of effort required between 100% of the seismic design forces and 150% seismic design forces is fairly minimal. For the post-disaster occupancy performance level, column and connection retrofits are required at the ground and second levels. Replacement of the brace elements requires mitigation of tension forces at the foundation level for both performance levels. Table 1 below describes the details of the retrofit strategy for Option 1a) Replace the Existing Tension Only Braces.

**Table 1: Option 1a) - Replace Existing Tension Only Braces**

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Braces at Ground Level | Yes | Yes | Replace existing tension only angle with a larger tension only element. |
| Replace Braces at Second Level | Yes | Yes | Replace existing tension only angle with a larger tension only element. |
| Replace/Retrofit Columns at Ground Level | Yes | Yes | Increase Axial capacity with plates welded to the columns. SK-6. |
| Replace/Retrofit Columns at Second Level | No | Yes | Increase Axial capacity with plates welded to the columns. SK-6. |
| Replace Beams | No | No | |
| Replace Brace to Columns Connections at Ground Level | Yes | Yes | Remove existing gusset plate, replace with a larger plate with more weld area and adequate bolts. |
| Replace Brace to Columns Connections at Second Level | No | Yes | Remove existing gusset plate, replace with a larger plate with more weld area and adequate bolts. |
| Replace Connection at Base plate | No | Yes | Increase size/number of anchor bolts at base plate. |
| Tension Forces Requiring Mitigation | Yes | Yes | Install rock anchors. |

## 2.3 Option 1b): Addition of New Braced Bay Locations

The addition of new braced bays adjacent to the existing braced bays distributes the seismic forces over a greater number of elements. However, because the bays are adjacent to each other, this scheme creates an increase in the column loads between the bays. Sketch SK-7 presents the plan layout of the proposed additional braced bay locations. The existing steel frame elements would be used to support new braces, the connections could be designed accordingly. The ductility and overstrength factors, $R_d$ and $R_o$, would remain 1.5 and 1.3 respectively for this option. Table 2 describes the details of the reinforcement scheme for Option 1b), the addition of new tension only braced locations. Doubling the number of braced bays decreases the magnitude of the mitigation efforts required for the existing braced frames. For the normal occupancy design level no retrofit is required for the existing braces, columns or connections. For the post-disaster occupancy performance level the existing braces and connections require replacement at the ground floor level. For both performance levels, the existing baseplates and anchors must be replaced and rock anchors are required to resists uplift forces at the foundation level. The addition of new braced bay locations increases the stiffness of the structure and decreases the inter-storey displacements to less than 0.025 hs, which satisfies the NBCC code requirements for the post-disaster occupancy performance level.

**Table 2: Option 1b) - Addition of New Tension Only Braced Bays**

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Braces at Ground Level (existing) | No | Yes | Replace existing tension only angle with a larger tension only element. |
| Replace Braces at Second Level (existing) | No | No | |
| Replace/Retrofit Columns at Ground Level | No | No | |
| Replace/Retrofit Columns at Second Level | No | No | |
| Replace Beams | No | No | |

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Brace to Columns Connections at Ground Level | No | Yes | Remove existing gusset plate, replace with a larger plate with more weld area and adequate bolts. |
| Replace Brace to Columns Connections at Second Level | No | No | |
| Replace Connection at Baseplate | Yes | Yes | Increase size/number of anchor bolts at baseplate. |
| Tension Forces Requiring Mitigation | Yes | Yes | Install rock anchors. |

## 2.4 Option 2: Installing New Tension-Compression Braces (BRB's)

Due to buckling requirements, designing conventional braces to behave as tension-compression elements in the Chancery building requires the use of considerably stockier elements to resist the design seismic loads in compression. As a result, the forces which the other elements in the load path (columns, connections and foundations) are required to be designed to, resist increases considerably.

Buckling Restrained Braces (BRB's) are designed to have the same capacity in tension and compression. These braces are designed to yield at a specified load which can be matched very closely to the required capacity to avoid over-design and subsequent inefficiency/over-construction in the remainder of the load path. If the existing braces are to be replaced with tension-compression braces it is recommended that buckling restrained braces be used. One BRB could replace the existing cross-bracing in each bay. However, due to the increased capacity of the brace elements in compression, the seismic behaviour of a single BRB would be very similar to the existing tension only cross-braces; specifically, the dynamic period and stiffness of the BRB would be very similar to the existing structure. The ductility and ovestrength factors, $R_d$, $R_o$ are 4.0 and 1.2 respectively for this option.

Table 3 describes the details of the reinforcement strategy for Option 2, installing new tension-compression braces. The retrofit required for normal occupancy and post-disaster occupancy are identical. CSA S16-09 requires Class 1 or 2 columns in buckling restrained braced bay locations. The existing columns are Class 3, and therefore are not permitted with this system. The columns should be replaced or retrofit to provide increased capacity as required, the addition of steel plates welded to the existing columns should provide adequate capacity and meet the design requirements of CSA S16-09. The use of BRB's requires the installation/retrofit of the existing columns, new brace to column connections and rock anchors with greater uplift capacity than the previous two retrofit options. However, the benefit of installing BRB's compared to tension only braces can be seen when considering the shape of the cyclic loading (Hysteresis curves). BRB's have stable, non-degrading strength under cyclic loading. Tension only braces on the other hand have pinched, degrading strength loops under cyclic loading. The behaviour of tension only braces gets worse the more cycles of loading they are subjected to, whereas BRB's display consistent energy dissipation through many cycles of loading. This behaviour is presented in Figure 1 below. What this means is that during a real earthquake BRB's provide a much higher level of performance and protection than the corresponding equivalent strength tension only braces. Sketch 8 presents a concept design of a BRB.

**Table 3: Option 2 - Installing New Tension-Compression Braces (BRBs)**

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Braces at Ground Level (existing) | Yes | Yes | Replace Existing tension only angle, with a single tension-compression BRB. SK-8 |
| Replace Braces at Second Level (existing) | Yes | Yes | Replace Existing tension only angle, with a single tension-compression BRB. SK-8 |
| Replace/Retrofit Columns at Ground Level | Yes | Yes | Columns are Class 3 – not allowed with $R_d$ $R_o$=(4) (1.2) |
| Replace/Retrofit Columns at Second Level | Yes | Yes | Columns are Class 3 – not allowed with $R_d$ $R_o$=(4) (1.2) |
| Replace Beams | No | No | |
| Replace Brace to Columns Connections at Ground Level | Yes | Yes | Existing connections will be inadequate for BRB's. |
| Replace Brace to Columns Connections at Second Level | Yes | Yes | Existing connections will be inadequate for BRB's. |

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Connection at Baseplate | Yes | Yes | Increase size/number of anchor bolts at base plate. |
| Tension Forces Requiring Mitigation | Yes | Yes | Install rock anchors. Magnitude of uplift is up to 2 times greater than other options. |

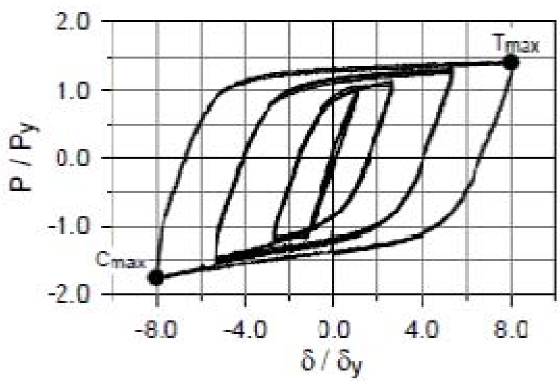



**Figure 1: Hysteresis Loops of BRB's**
**(Humar, Adams, Tremblay, Rogers, Halchuk, Proposals for the Seismic Design Provisions of the 2010 National Building Code of Canada, 2010)**

## 2.5 Option 3: Installing Friction Dampers in New Braced Bays

The SFRS of the Bridgetown Chancery could be further improved by the installation of friction dampers installed within new braced bays adjacent to the existing braced bays (for location see Sketch 7 from Option 1b). Friction dampers dissipate seismic energy by increasing the damping of a structure. Increased damping has the net effect of lowering the force function, as illustrated in the equation of motion below:

$$m\ddot{u} + c\dot{u} + ku = f(t)$$

$$m\ddot{u} + ku = f(t) - c\dot{u}$$

Where m is mass, c is damping, k is stiffness and f(t) is the force function. The incorporation of friction dampers in the seismic upgrade could reduce the seismic force by 50%, which would significantly reduce the impact of the upgrades in terms of schedule, economics and intrusiveness to the building occupants.

Typical energy dissipating devices only reduce the design base shear which is used for the design of the energy dissipating elements comprising the LFRS. The elastic base shear, which is used to design the elements connected to the LFRS remains the same. However, by increasing the damping, friction dampers decrease the total elastic seismic force. This means that the elements outside of the LFRS can be designed for lower seismic forces. The main advantage of this system for the seismic design of the Bridgetown Chancery will be the probable elimination of mitigation requirements for the foundation system. Options 1 and 2 would require rock anchors at the foundation level, while friction dampers could be installed without increasing the uplift capacity of the foundation. This eliminates a significant source of time and cost to the project.

For this concept design report, it is assumed that the slip load of the friction dampers will be equal to seventy five percent (75%) of the brace yield loads and that equivalent damping of approximately twenty percent (20%) can be achieved. These values have been conservatively assumed for the purposes of this concept design report. Should this option be chosen for detailed design, a non-linear time history analysis will be performed to confirm the optimal slip load for the friction dampers and the resultant equivalent structural damping.

In order to achieve zero uplift forces at the foundation level it is assumed that one friction damper will be required for each functional braced bay, i.e., 1:1 and nine (9) new braced bays with friction dampers would be installed. However during detailed design, a cost analysis of removing and reinstating finishes versus the installation of rock anchors may reveal that the most economic solution may be to install for example, four (4) braced bays with friction dampers and then rock anchors at the remaining bays to resist uplift. Optimization of the design is outside of the scope of work of this concept report. However, if this option is selected for detailed design, all relevant combinations of friction dampers will be evaluated.

Table 4 describes the details of the reinforcement strategy for Option 3: Installing Friction Dampers in New Braced Bays. Design of friction dampers is not currently provided for in CSA S16-09. Therefore ductility and overstrength values are not available for this option. Non-linear time history analysis will be used to determine the optimal design and subsequent performance of the system, using techniques based on published research and JLR's previous experience designing similar energy dissipating systems. Based on the assumptions noted above, no retrofit to the existing structural system would be required if additional braced bays and friction dampers are installed. It is also probable that the initial load path upgrades could be reduced in magnitude up to thirty percent (30%) in conjunction with this option.

Sketch 9 provides a concept design of the proposed friction damper installation.

**Table 4: Option 3 - Installing Friction Dampers in New Braced Bays**

| | 100 % Normal Occupancy | 150% Post-Disaster Occupancy | Description |
|---|---|---|---|
| Replace Braces at Ground Level (existing) | No | No | |
| Replace Braces at Second Level (existing) | No | No | |
| Replace Columns at Ground Level | No | No | |
| Replace/Retrofit Columns at Second Level | No | No | |
| Replace Beams | No | No | |
| Replace Brace to Columns Connections at Ground Level | No | No | |
| Replace Brace to Columns Connections at Second Level | No | No | |
| Replace Connection at Baseplate | No | No | |
| Tension Forces Requiring Mitigation | No | No | |

*1) Assumptions made for the preparation of this report must be confirmed at the detailed design stage with non-linear time history analysis.*

## 3.0 SEQUENCE OF WORK

The sequence of work for any of the retrofit options is outlined below.

1. Install foundation upgrades (Rock Anchors), baseplates and anchor bolts as required for Options 1 and 2 and possibly 3. Excavation around the perimeter of the structure will be required. In order to minimize the time that foundation trades will be on site, it is assumed that the foundation work will proceed all at one time. This will mean that some of the excavation areas may be exposed for the duration of the project. As work is completed at a braced bay location, the excavations will be immediately backfilled and returned to their original condition as soon as possible, for safety and

convenience to Mission staff. A fenced off work area will be created and walkways will be re-routed for the duration of the works.

2. Proceed with initial load path upgrades. The removal of exterior finishes will be required. Upgrades to the roof deck and second floor slab system will require work from below. Scaffolding will be required to access these elements. It is assumed that this work will proceed in stages to minimize disruption to Mission staff. Safe work zones will be set up and hoarding will be used to minimize disruption to building occupants. Emergency egress routes will be provided.

3. Removal of exterior finishes in braced bay locations, as required to install upgrades to existing braced bays or new braced bays. It is assumed that work in the braced bays will proceed two braced bays at a time.

4. Remove interior finishes as required in braced bay or new braced bay locations. Provide an interior work area around existing and new braced bay locations.

5. Provide temporary swing space within Mission to accommodate space lost due to seismic project work.

6. Once the work has been completed the work areas will be returned to their original condition.

## 4.0 OPINION OF PROBABLE CONSTRUCTION COSTS AND SCHEDULE

A Class “D” Opinion of Probable Construction Cost was prepared for the proposed seismic retrofit based on the concept design described in this report and attached sketches and is based on Ottawa construction prices. An appropriate correction factor must be applied by DFATD to calibrate the values for the Bridgetown construction market. Unit prices were obtained from the 2013 Hanscomb Yardsticks for Costing, through discussions with contractors, building material suppliers and from JLR’s experience and knowledge of the construction industry. Class “D” opinions of probable construction costs are typically considered sufficient for making correct investment decisions and obtaining project approvals; and are typically considered to have a low level of precision (approximately +/- 20%). Please note that in providing opinions of probable construction cost, JLR has no control over the cost or availability of labour, equipment or materials, over market conditions or the contractor's selected construction methodology or pricing strategy.

## 4.1 Option 1a) - Replace Existing Tension Only Bracing

The overall Class "D" Opinion of Probable Construction Cost for seismic retrofit Option 1a) replacing the existing tension only bracing for the Canadian Chancery in Bridgetown is $725,000.00 for the normal occupancy performance level including a 10% fee for general requirements, mobilization and fees and a 20% contingency. A summary of costs is provided in Table 5 below.

**Table 5: Option 1a) - Replace Existing Tension Only Bracing**

| Activity | 100% Design Seismic Forces | 150% Design Seismic Forces | Schedule |
|---|---|---|---|
| Foundation Upgrades: | | | |
| Excavation and Backfill | $5,000.00 | $5,000.00 | 2 weeks |
| Walkways and Detour Routes | $15,000.00 | $15,000.00 | 1 week |
| Install Rock Anchors | $80,000.00 | $80,000.00 | 1week |
| Landscaping to Reinstate Grounds to Original Condition upon Completion of Work | $30,000.00 | $30,000.00 | 1 week |
| Total | | | 4 weeks |
| Initial Load Path Upgrades: | | | |
| Scaffolding and Secure Work Zone | $30,000.00 | $30,000.00 | 2 weeks |
| Second Level Diaphragm Upgrades | $12,500.00 | $12,500.00 | 4 weeks |
| Roof Level Diaphragm Upgrades | $25,000.00 | $25,000.00 | 2 weeks |
| Horizontal Reinforcement around Openings at Second and Roof Levels | $20,000.00 | $20,000.00 | 4 weeks |
| Installation of Perimeter Elements at Second and Roof Levels | $17,000.00 | $17,000.00 | 4 weeks |
| Total | | | 8 weeks |

| Activity | 100% Design Seismic Forces | 150% Design Seismic Forces | Schedule |
|---|---|---|---|
| LFRS Upgrades: | | | |
| Removal of Interior and Exterior Finishes in Braced Bay Locations | $100,000.00 | $100,000.00 | 9 weeks |
| Provide Swing Space | $75,000.00 | $75,000.00 | 2 weeks |
| Retrofits to Existing Braced Bays | $40,000.00 | $60,000.00 | 9 weeks |
| Reinstate Interior and Exterior Finishes | $100,000.00 | $100,000.00 | 9 weeks |
| | | | 29 weeks |
| **Subtotal** | **$549,500.00** | **$569,500.00** | **36 weeks** |
| General Requirements, Mobilization and Fees (10%) | $54,950.00 | $56,950.00 | |
| **Total Construction Cost** | **$604,450.00** | **$626,450.00** | |
| Contingency (20%) | $120,890.00 | $125,290.00 | |
| **Total Construction Budget** | **$725,340.00** | **$751,740.00** | |

All excavation will be completed prior to beginning the works so that foundation trades and rock anchor installation can occur at one time. Swing space will be set up in one location per floor, where space adjacent to the braced bays can be swung while the work takes place. Once a bay is complete, the excavation will be closed up and reinstated. About three weeks will be required at each bay location to remove finishes, complete the work and reinstate finishes. If two bays can be retrofit at the same time, the schedule could be shortened by ten (10) weeks. The diaphragm upgrades would occur while the LFRS works are being performed.

## 4.2 Option 1b) - Addition of New Braced Bay Locations

The overall Class “D” opinion of probable construction cost for the seismic retrofit Option 1b) the addition of new tension only braced bays adjacent to the existing braced bays for the Canadian Chancery in Bridgetown is $838,000 for the normal occupancy performance level including a 10% fee for general requirements, mobilization and fees and a 20% contingency. A summary of costs is provided in Table 6 below.

**Table 6: Option 1b) - Addition of New Braced Bay Locations**

| Activity | 100% Design Seismic Forces | 150% Design Seismic Forces | Schedule |
|---|---|---|---|
| Foundation Upgrades: | | | |
| Excavation and Backfill | $10,000.00 | $10,000.00 | 2 weeks |
| Walkways and Detour Routes | $15,000.00 | $15,000.00 | 1 week |
| Install Rock Anchors | $160,000.00 | $160,000.00 | 2week |
| Landscaping to Reinstate Grounds to Original Condition upon Completion of Work | $30,000.00 | $30,000.00 | 1 week |
| Total | | | 5 weeks |
| Initial Load Path Upgrades: | | | |
| Scaffolding and Secure Work Zone | $30,000.00 | $30,000.00 | 2 weeks |
| Second Level Diaphragm Upgrades | $12,500.00 | $12,500.00 | 4 weeks |
| Roof Level Diaphragm Upgrades | $25,000.00 | $25,000.00 | 2 weeks |
| Horizontal Reinforcement around Openings at Second and Roof Levels | $20,000.00 | $20,000.00 | 4 weeks |
| Installation of Perimeter Elements at Second and Roof Levels | $17,000.00 | $17,000.00 | 4 weeks |
| Total | | | 8 weeks |
| LFRS Upgrades: | | | |
| Removal of Interior and Exterior Finishes in Braced Bay Locations | $100,000.00 | $150,000.00* | 9 weeks |
| Provide Swing Space | $75,000.00 | $75,000.00 | 2 weeks |
| Retrofits to Existing Braced Bays | $40,000.00 | $55,000.00 * | 9 weeks |
| Reinstate Interior and Exterior Finishes | $100,000.00 | $150,000.00* | 9 weeks |
| | | | 29 weeks |
| **Subtotal** | $634,500.00 | $749,500.00 | **36 weeks** |
| General Requirements, Mobilization and Fees (10%) | $63,450.00 | $74,950.00 | |
| **Total Construction Cost** | $697,950.00 | $824,450.00 | |
| Contingency (20%) | $139,590.00 | $164,890.00 | |
| **Total Construction Budget** | $837,540.00 | $989,340.00 | |

**Add 4.5 weeks for 150% force level due to replacement of existing braces at ground level.*

The schedule for Option 1b) is similar to Option 1a) for the 100% design level. For the post-disaster occupancy performance level the existing braces at the ground floor level require replacement, in addition to the fabrication of the new braced bay which adds 4.5 weeks to the schedule. As in Option 1a) the addition of a new braced bay location would require three (3) weeks at each location.

## 4.3 Option 2 - Installing New Tension-Compression Braces (BRBs)

The overall Class "D" Opinion of Probable Construction Cost for Option 2, replacing the existing tension only braces with new tension-compression braces (BRBs) for the Canadian Chancery in Bridgetown is $1,062,000 for the normal or post-disaster occupancy performance level including a 10% fee for general requirements, mobilization and fees and a 20% contingency. A summary of costs is provided in Table 7 below.

**Table 7: Option 2 - New Tension-Compression Braces (BRBs)**

| Activity | 100% Design Seismic Forces | 150% Design Seismic Forces | Schedule |
|---|---|---|---|
| Foundation Upgrades: | | | |
| Excavation and Backfill | $5,000.00 | $5,000.00 | 2 weeks |
| Walkways and Detour Routes | $15,000.00 | $15,000.00 | 1 week |
| Install Rock Anchors | $160,000.00 | $160,000.00 | 2week |
| Landscaping to Reinstate Grounds to Original Condition upon Completion of Work | $30,000.00 | $30,000.00 | 2 week |
| Total | | | 5 weeks |
| Initial Load Path Upgrades: | | | |
| Scaffolding and Secure Work Zone | $30,000.00 | $30,000.00 | 2 weeks |
| Second Level Diaphragm Upgrades | $12,500.00 | $12,500.00 | 4 weeks |
| Roof Level Diaphragm Upgrades | $25,000.00 | $25,000.00 | 2 weeks |
| Horizontal Reinforcement around Openings at Second and Roof Levels | $20,000.00 | $20,000.00 | 4 weeks |
| Installation of Perimeter Elements at Second and Roof Levels | $17,000.00 | $17,000.00 | 4 weeks |
| Total | | | 8 weeks |

| **Activity** | **100% Design Seismic Forces** | **150% Design Seismic Forces** | **Schedule** |
|---|---|---|---|
| LFRS Upgrades: | | | |
| Removal of Interior and Exterior Finishes in Braced Bay Locations | $100,000.00 | $100,000.00 | 9 weeks |
| Provide Swing Space | $75,000.00 | $75,000.00 | 2 weeks |
| Retrofits to Existing Braced Bays | $225,000.00 | $225,000.00 | 6 weeks |
| Reinstate Interior and Exterior Finishes | $100,000.00 | $100,000.00 | 9 weeks |
| | | | 26 weeks |
| **Subtotal** | $804,500.00 | $804,500.00 | **33 weeks** |
| General Requirements, Mobilization and Fees (10%) | $80,450.00 | $80,450.00 | |
| **Total Construction Cost** | $884,950.00 | $884,950.00 | |
| Contingency (20%) | $176,990.00 | $176,990.00 | |
| **Total Construction Budget** | $1,061,940.00 | $1,061,940.00 | |

The schedule for the installation of new tension-compression braces is similar to Option 1b). However, because only a single brace is being installed at each bay, the time required to complete the retrofit of the braced bays is reduced by three (3) weeks. The budget for 100% and 150% force levels are identical because the same mitigating works are required for each option. The forces are just higher for the post-disaster occupancy force level.

## 4.4 Option 3 - Installing Friction Dampers in New Braced Bays

The overall Class “D” Opinion of Probable Construction Cost for Option 3, installing friction dampers in new braced bays for the Canadian Chancery in Bridgetown is $660,000 for the normal or post-disaster occupancy performance level including a 10% fee for general requirements, mobilization and fees and a 20% contingency. A summary of costs is provided in Table 8 below.

### Table 8: Option 3 - Friction Dampers in New Braced Bays

| Activity | 100% Design Seismic Forces | 150% Design Seismic Forces | Schedule |
|---|---|---|---|
| Foundation Upgrades: | | | |
| Excavation and Backfill | | | |
| Walkways and Detour Routes | $7,500.00 | $7,500.00 | 1 week |
| Install Rock Anchors | | | |
| Landscaping to Reinstate Grounds to Original Condition upon Completion of Work | $7,500.00 | $7,500.00 | 1 week |
| Total | | | 2 weeks |
| Initial Load Path Upgrades: | | | |
| Scaffolding and Secure Work Zone | $30,000.00 | $30,000.00 | 2 weeks |
| Second Level Diaphragm Upgrades | $12,500.00 | $12,500.00 | 4 weeks |
| Roof Level Diaphragm Upgrades | $25,000.00 | $25,000.00 | 2 weeks |
| Horizontal Reinforcement around Openings at Second and Roof Levels | $20,000.00 | $20,000.00 | 4 weeks |
| Installation of Perimeter Elements at Second and Roof Levels | $17,000.00 | $17,000.00 | 4 weeks |
| Total | | | 8 weeks |
| LFRS Upgrades: | | | |
| Removal of Interior and Exterior Finishes in Braced Bay Locations | $100,000.00 | $100,000.00 | 9 weeks |
| Provide Swing Space | $75,000.00 | $75,000.00 | 2 weeks |
| Retrofits to Existing Braced Bays | $135,000.00 | $135,000.00 | 9 weeks |
| Reinstate Interior and Exterior Finishes | $100,000.00 | $100,000.00 | 9 weeks |
| | | | 29 weeks |
| **Subtotal** | $498,150.00 | $498,150.00 | **33 weeks** |
| General Requirements, Mobilization and Fees (10%) | $49,815.00 | $49,815.00 | |
| **Total Construction Cost** | $547,965.00 | $547,965.00 | |
| Contingency (20%) | $109,593.00 | $109,593.00 | |
| **Total Construction Budget** | $657,558.00 | $657,558.00 | |

The schedule to install friction dampers is similar to the BRBs. Less time is required for site work with this option and the schedule could be reduced by another 4.5 weeks if two bays can be worked on simultaneously.

The probable construction costs are based on costs for construction in Canada. No consideration has been given to the following:

- Fees for JLR to complete detailed design;
- Cost of shipping construction materials to Bridgetown from Canada;
- Disposal of finishes removed from buildings;
- Available strength and properties of materials in Bridgetown;
- Cost of transporting necessary tools or equipment.

## 5.0 SUMMARY OF OPTIONS

Details associated with each retrofit option, construction costs, schedule of construction and implications on continued Mission operations have been estimated and are summarized in Table 9 below. The retrofit options presented in Table 9 are designed to resist 100% of the lateral force.

**Table 9: Summary of Retrofit Options**

| | **Retrofit Option 1a** | **Retrofit Option 1b** | **Retrofit Option 2** | **Retrofit Option 3** |
|---|---|---|---|---|
| ***Type of Retrofit*** | Tension Only Braces | Tension Only Braces | Tension-Compression Braces (BRBs) | Friction Dampers |
| ***$R_d$, $R_o$*** | 1.5,1.3 | 1.5,1.3 | 4,1.2 | NA |
| ***Base Shear (KN)*** | 1757 | 1757 | 714 | TBD |
| ***Inter-storey Drift Ratio, Indicating Damage to Finishes*** | <0.025, indicating damage | <0.01 hs, indicating minimal damage | <0.01 hs, indicating minimal damage | TBD |
| ***Estimated Construction Cost*** | $ 725,340 | $837,540 | $1,061,940 | $657,558 |

| | **Retrofit Option 1a** | **Retrofit Option 1b** | **Retrofit Option 2** | **Retrofit Option 3** |
|---|---|---|---|---|
| ***Estimated On-site Construction Time*** | 36 weeks | 36 weeks | 33 weeks | 33 weeks |
| ***Implications for Continued Mission Operations*** | Braced bay replacement can proceed one bay at a time. Lost space will be swung. | Braced bay replacement can proceed one bay at a time. Lost space will be swung. | Braced bay replacement can proceed one bay at a time. Lost space will be swung. | No foundation upgrades, disruptions around Chancery would be minimized. |
| ***Foundation Upgrade Required*** | Rock Anchors | Rock Anchors | Rock Anchors | |

## 6.0 RECOMMENDATIONS

The options analysis indicates that the most economical retrofit solution is the installation of friction dampers in additional braced bays adjacent to the existing braced bays. The key advantage of this solution is that no foundation work will be required. The diaphragm upgrades should still be performed; however, it is likely that the design forces may be reduced due to the increased damping of the structure. It is assumed that the initial load path upgrades and retrofit upgrades to the LFRS are completed concurrently to minimize the project schedule. The installation of friction dampers limits the extent of the retrofit work to the locations where the dampers would be installed. The existing braced bays do not require mitigation measures. Friction dampers provide more stable energy dissipation than the next most economical option, Option 1a) Replacing the Existing Tension Only Bracing. It is recommended that friction dampers are installed in new braced bays located adjacent to the existing braced bays at both the ground and second level. The friction dampers should be designed for 150% of the design seismic load or the post-disaster occupancy performance level. The cost of increasing the seismic design load to 150% is negligible and will allow the Mission to continue operation after the design seismic event. If this option proceeds to the detailed design stage it is possible that the number of friction dampers versus the installation of rock anchors could be optimized to find the cross-over point where sufficient damping is provided while minimizing the cost associated with the removal and reinstatement of finishes. This is a detailed design exercise, however; it would provide benefits to the project in terms of both cost savings and schedule.

## 7.0 SUMMARY AND CONCLUSIONS

Based on the findings of the Phase 2, Component 1 seismic evaluation, DFATD decided to proceed with the Phase 2, Component 2 study. The purpose of this study is to develop seismic retrofit options that would meet the performance objectives of the Chancery. Three different retrofit options were considered; replacement of the existing tension-only braces with new tension only braces, the addition of new tension only braced bays, replacement of the existing braces with tension-compression braces (BRBs) and the addition of friction dampers in new braced bays adjacent to the existing braced bays.

Approximate construction costs and construction schedules were determined for each retrofit option. In terms of economics and performance, the preferred retrofit option would be to install friction dampers in new braced bays adjacent to the existing braced bays. At the detailed design stage this concept would be optimized to determine the optimal number of dampers, slip load and damping while minimizing the resulting uplift forces, costs and schedule implications. The final design solution would include the minimum number of friction dampers and rock anchors required in the least number of bays possible, which would result in the lowest cost and the shortest schedule of installation for the Mission.

Prepared by:

J.L. RICHARDS & ASSOCIATES LIMITED

Jennifer Stephenson, P.Eng., M.A.Sc.

LICENSED PROFESSIONAL ENGINEER
J.A. STEPHENSON
100110088
Dec. 10. 2013
PROVINCE OF ONTARIO

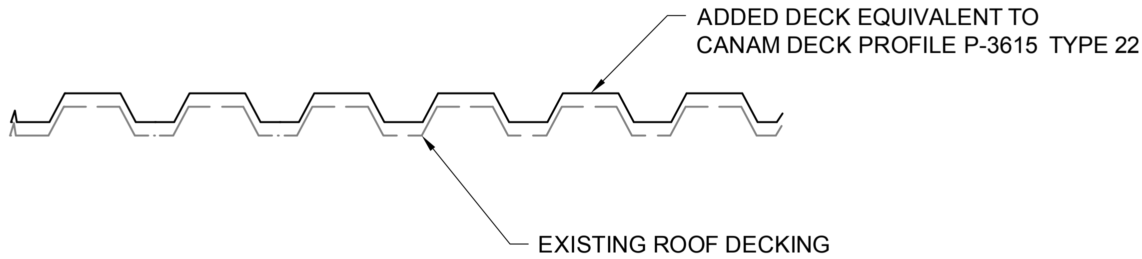
Reviewed by:

for

John R. Elliot, P.Eng.

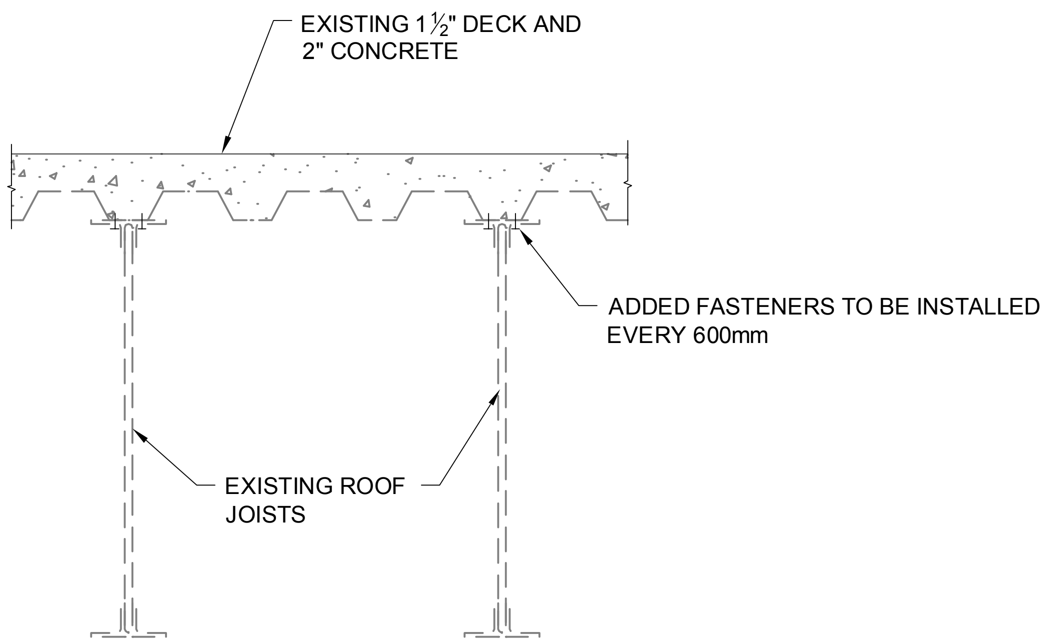
LICENSED PROFESSIONAL ENGINEER
R. M. LAMBERT
100058689
Dec. 10/2013
PROVINCE OF ONTARIO

**ROOF LEVEL DIAPHRAM UPGRADE**




NOTE: -ADDED DECK TO BE CONNECTED TO JOISTS EVERY 300mm
-SIDE LAPS FASTENED EVERY 450mm

**SECOND LEVEL DIAPHRAM UPGRADE**






| PROJECT: | DRAWING: |
|---|---|
| BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 | DIAPHRAM RETROFIT ROOF AND SECOND LEVEL |

J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

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|---|---|---|---|
| DESIGN: | JAS | DRAWING NO.: | SK-1 |
| DRAWN: | RLB | | |
| CHECKED: | JAS | JLR NO: | 23423-27 |
| PLOTTED: | Dec 04, 2013 | | |

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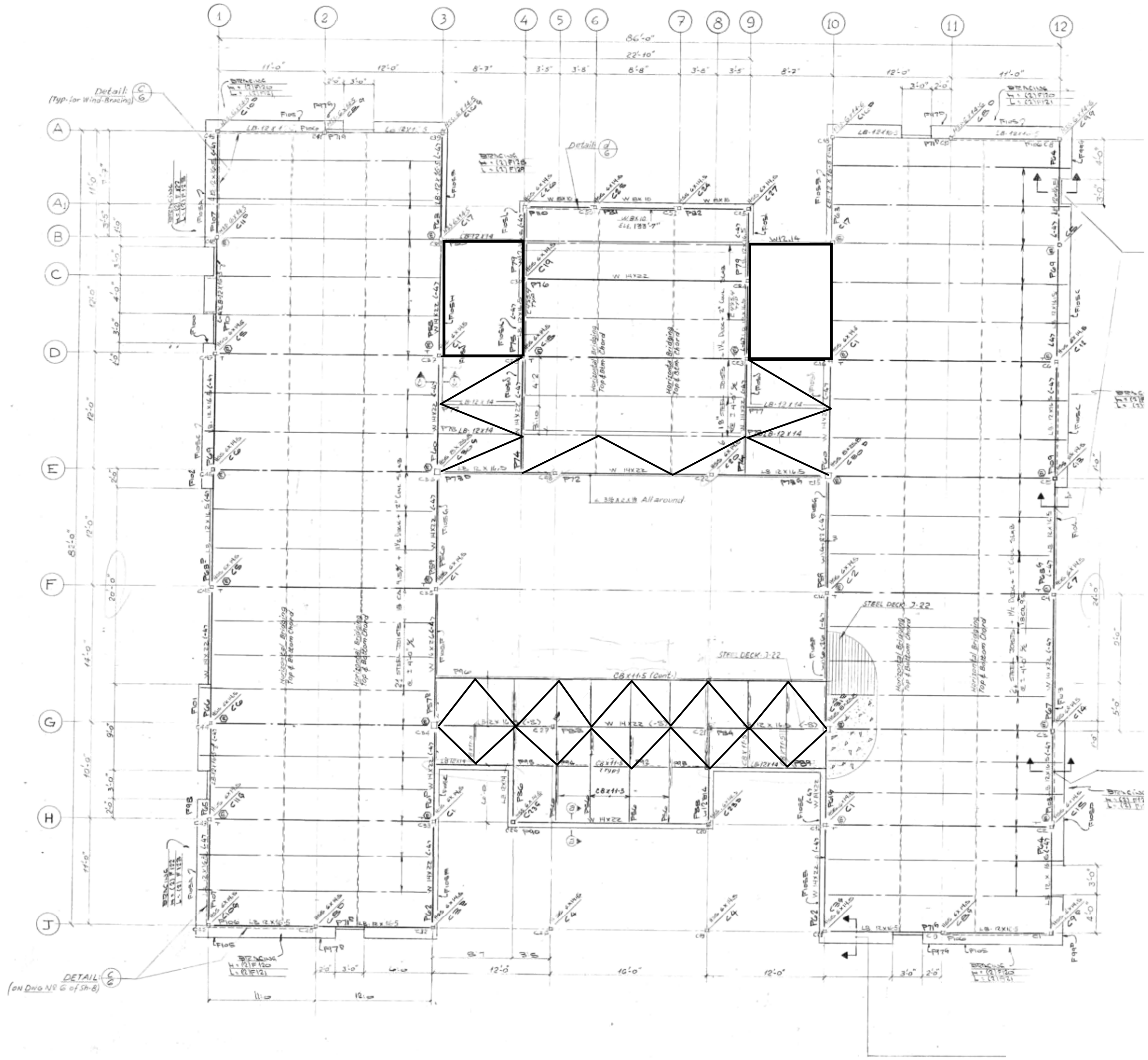

LEGEND

ADDED BRACING MEMBERS

NEW PERIMETER CHORD



J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

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| PROJECT: BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 | DRAWING: HORIZ. REINFORCEMENT SECOND FLOOR LEVEL | DESIGN: JAS | DRAWING NO.: SK-2 |
| | | DRAWN: RLB | |
| | | CHECKED: JAS | JLR NO: 23423-27 |
| | | PLOTTED: Dec09,2013 | |

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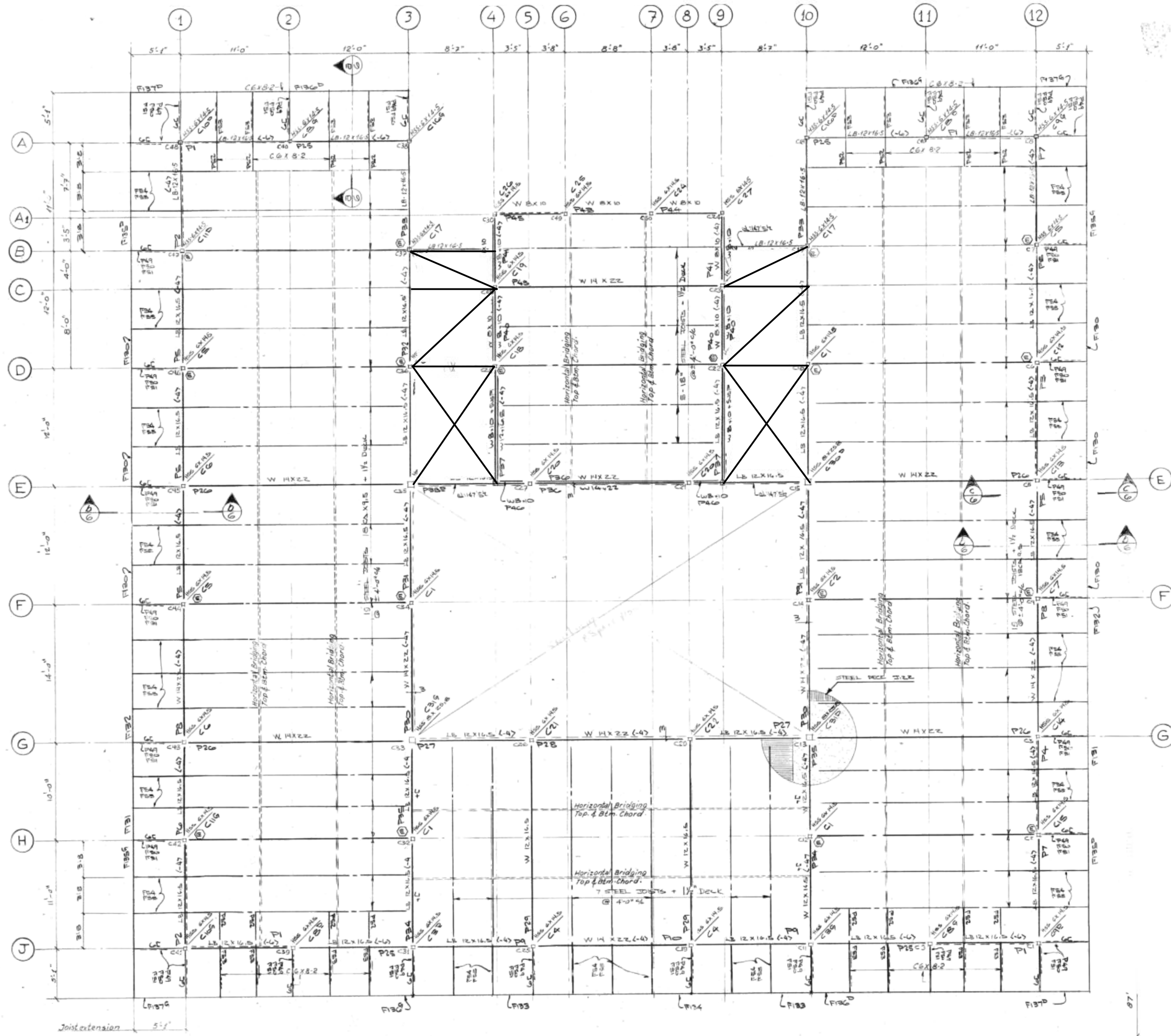


LEGEND

ADDED BRACING MEMBERS



J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

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|---|---|
| PROJECT: | BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 |
| DRAWING: | HORIZ. REINFORCEMENT ROOF LEVEL |
| DESIGN: | JAS |
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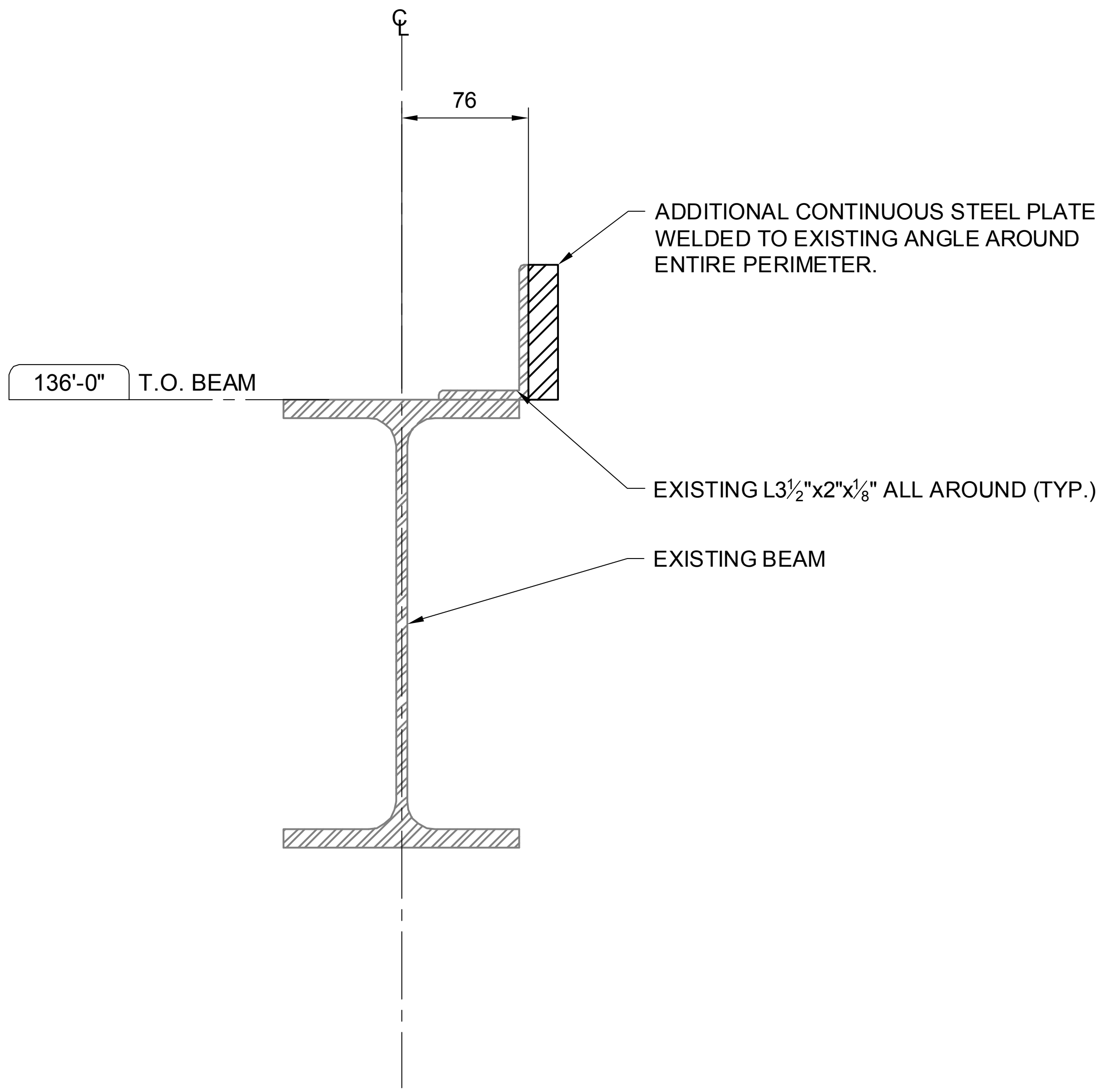




| PROJECT: | DRAWING: |
|---|---|
| BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 | NEW PERIMETER ELEMENT SECOND FLOOR LEVEL |

J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
**& Associates Limited**
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

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| DESIGN: | JAS | DRAWING NO.: | **SK-4** |
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| CHECKED: | JAS | JLR NO: | 23423-27 |
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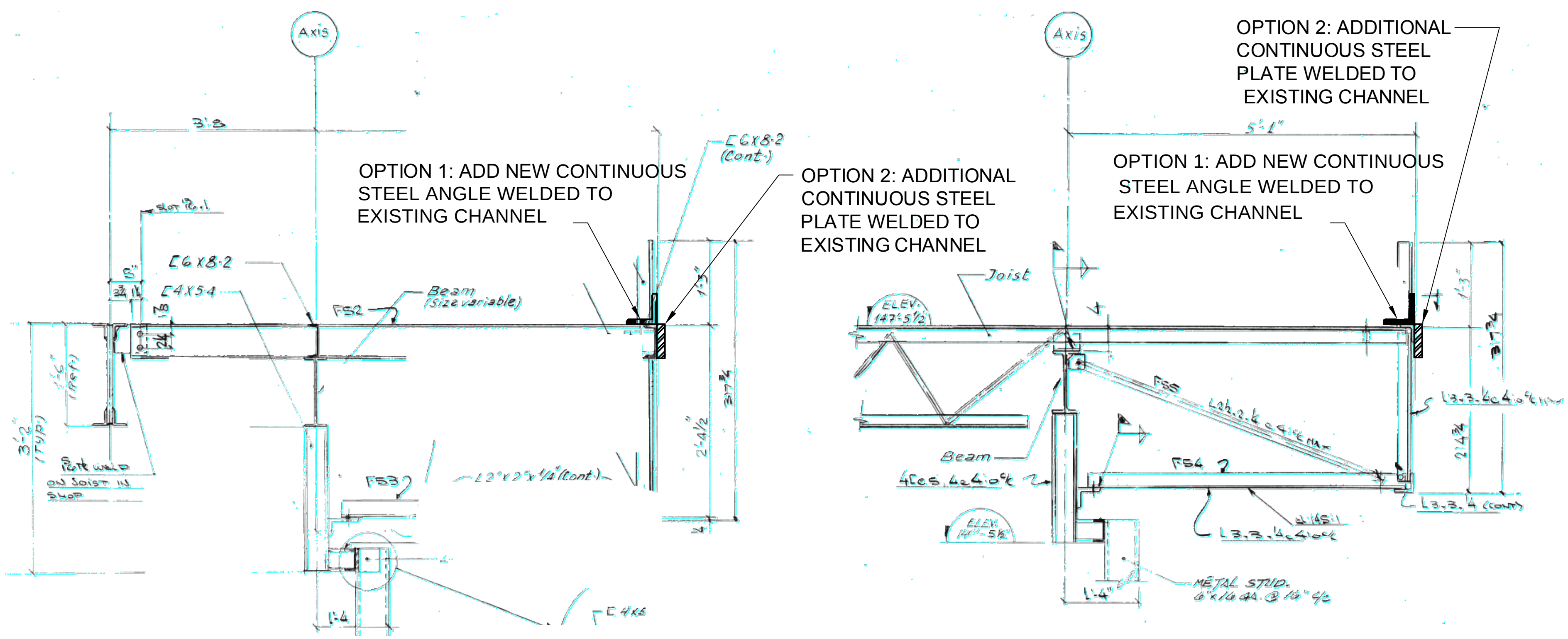


OPTION 1: ADD NEW PERIMETER ELEMENT IN CONJUNCTION WITH REPLACEMENT OF EXISTING ROOFING SYSTEM.

OPTION 2: ADD NEW PERIMETER ELEMENT. ADDITIONAL CONTINUOUS STEEL PLATE WELDED TO EXISTING CHANNEL.



J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

| PROJECT: | DRAWING: | | DRAWING NO.: |
|---|---|---|---|
| BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 | NEW PERIMETER ELEMENT ROOF LEVEL | DESIGN: JAS | SK-5 |
| | | DRAWN: RLB | |
| | | CHECKED: JAS | JLR NO: 23423-27 |
| | | PLOTTED: Dec09,2013 | |

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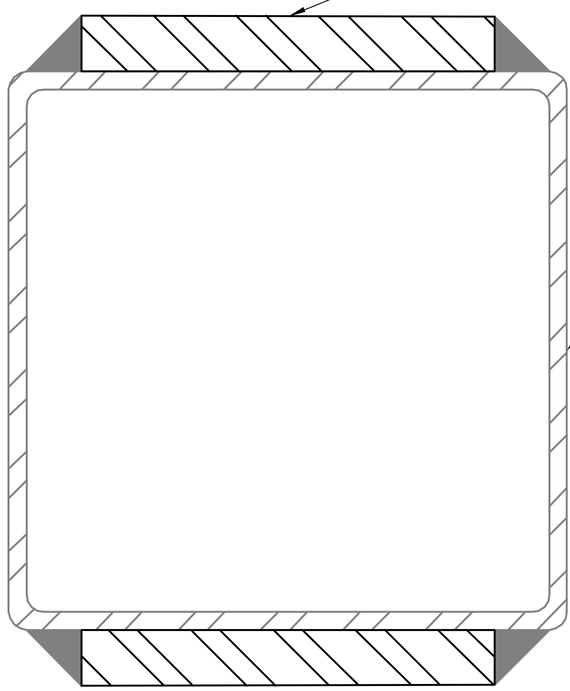




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|---|---|
| PROJECT: BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 | DRAWING: COLUMN RETROFIT |


J.L. Richards
ENGINEERS·ARCHITECTS·PLANNERS

**J.L. Richards & Associates Limited**
**864 Lady Ellen Place**
**Ottawa, ON Canada**
**K1Z 5M2**
**Tel: 613 728 3571**
**Fax: 613 728 6012**


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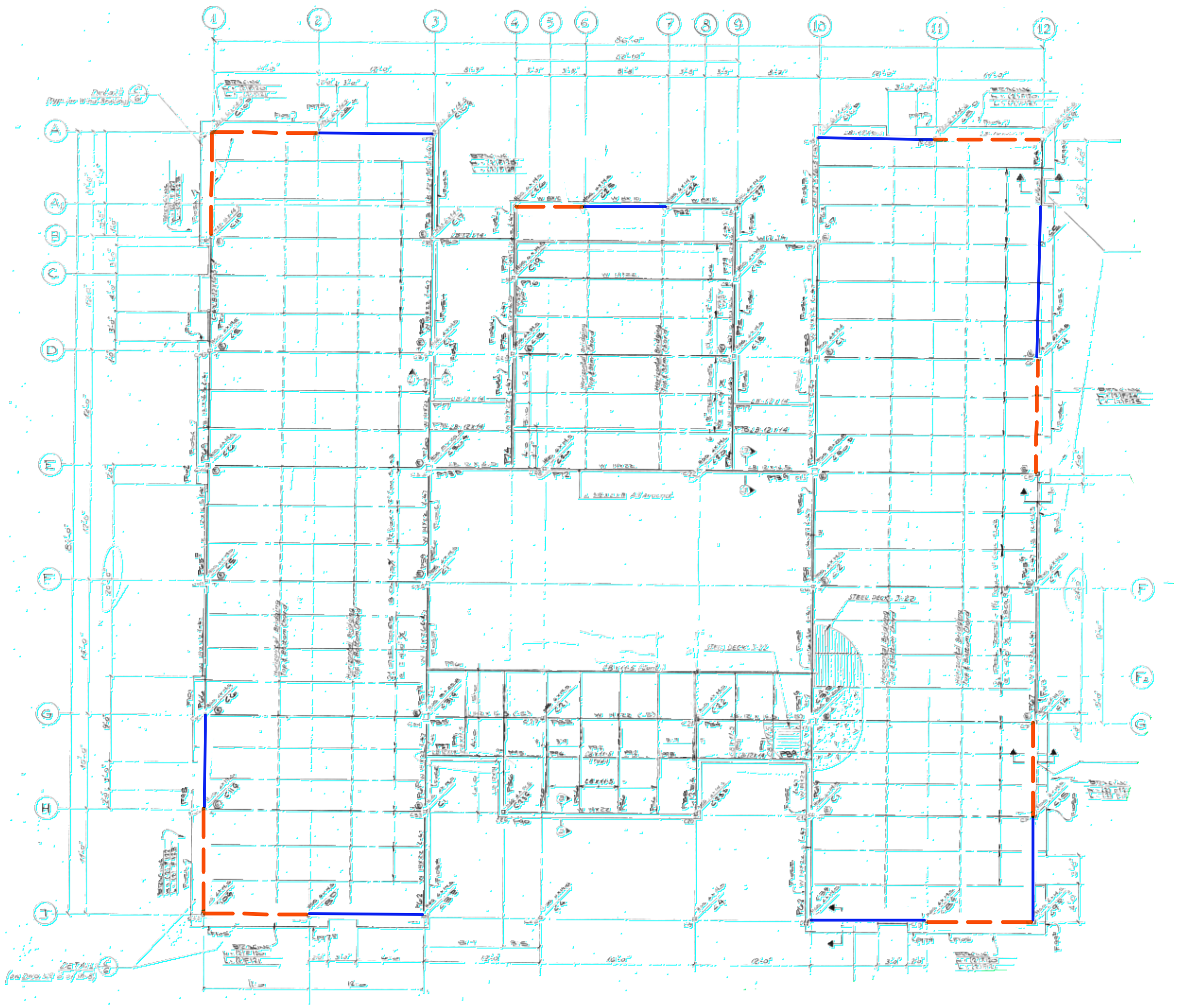

LEGEND

EXISTING BRACE BAY LOCATIONS

NEW SEISMIC BRACING LOCATIONS



J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

| | |
|---|---|
| PROJECT: | BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 |
| DRAWING: | PLAN LAYOUT PROPOSED ADDITIONAL BRACED BAY LOCATIONS |
| DESIGN: | JAS |
| DRAWN: | RLB |
| CHECKED: | JAS |
| PLOTTED: | Dec09,2013 |
| DRAWING NO.: | SK-7 |
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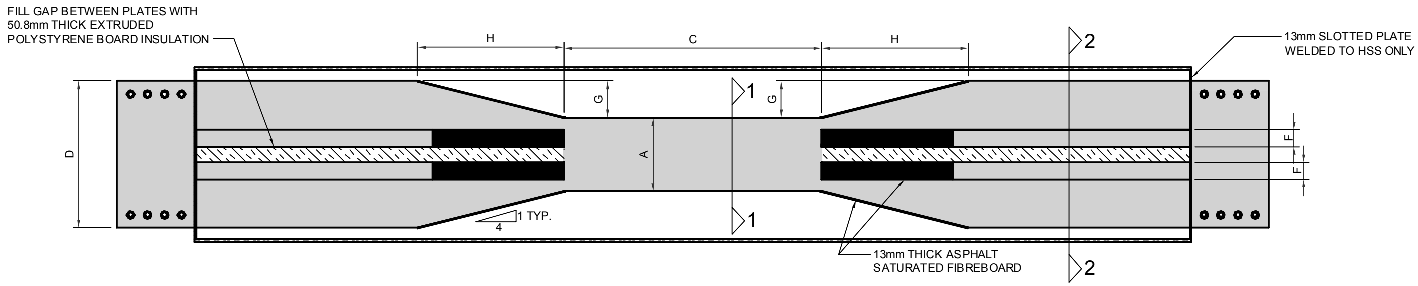


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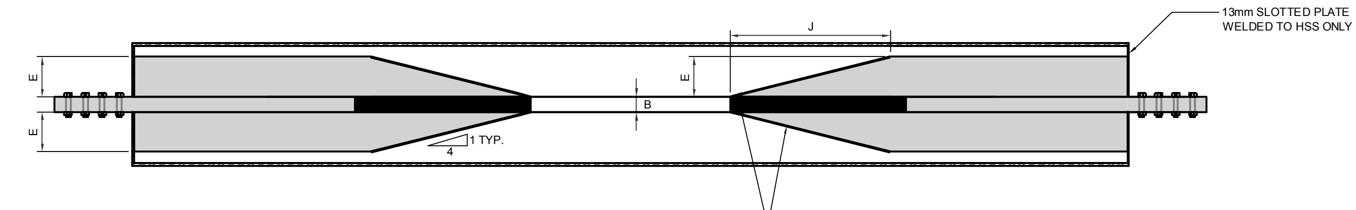
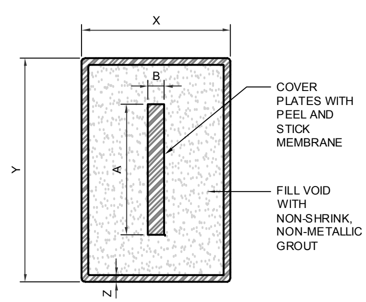
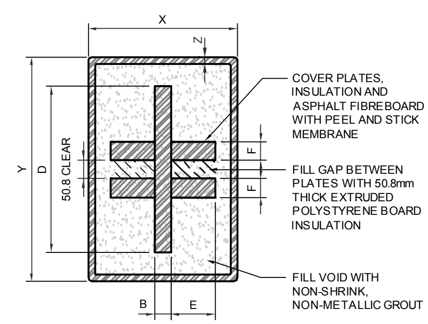



PLAN




SECTION 1-1




SECTION 2-2



J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

| | |
|---|---|
| PROJECT: | BRIDGETOWN BARBADOS PHASE 2 COMPONENT 2 |
| DRAWING: | CONCEPT DESIGN OF BUCKLING RESISTANT BRACE |
| DESIGN: | JAS |
| DRAWN: | RLB |
| CHECKED: | JAS |
| PLOTTED: | Dec04,2013 |
| DRAWING NO.: | SK-8 |
| JLR NO: | 23423-27 |

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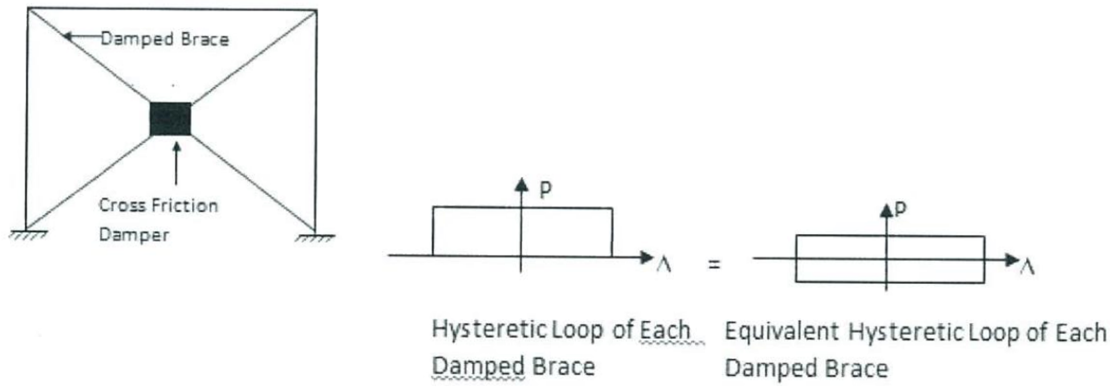


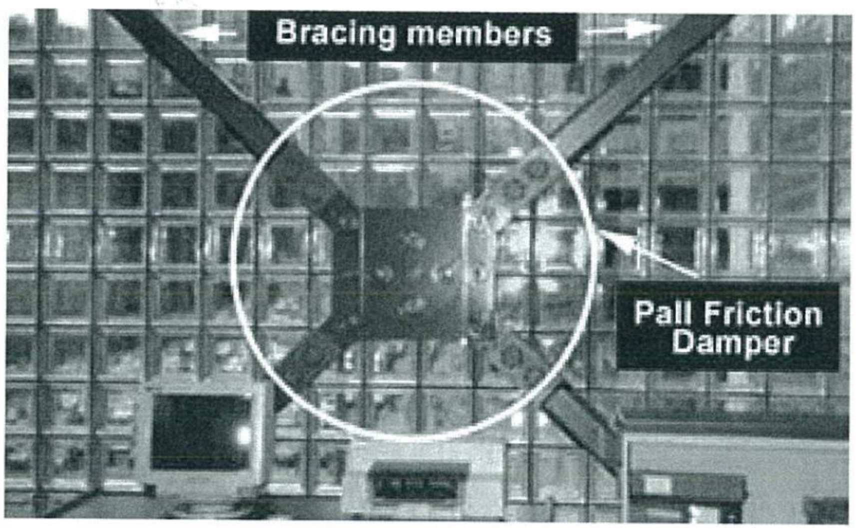


PHOTO & FIGURE:
PALL AVTAR & PALL TINA: "PERFORMANCE BASED DESIGN USING
PALL FRICTION DAMPERS. ECONOMICAL DESIGN SOLUTIONS." 2004.



PROJECT:
BRIDGETOWN BARBADOS
PHASE 2 COMPONENT 2

DRAWING:
CONCEPT DESIGN OF A
PROPOSED FRICTION
DAMPER INSTALLATION

J.L.Richards
ENGINEERS·ARCHITECTS·PLANNERS

J.L. Richards
& Associates Limited
864 Lady Ellen Place
Ottawa, ON Canada
K1Z 5M2
Tel: 613 728 3571
Fax: 613 728 6012

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|---|---|
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| CHECKED: | JAS |
| PLOTTED: | Dec 04, 2013 |
| DRAWING NO.: | SK-9 |
| JLR NO: | 23423-27 |

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