# EXPERIMENTAL INVESTIGATION OF SEISMIC STABILITY ON MASONRY WALLS AT BEAUHARNOIS POWERHOUSE

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**ABSTRACT :**

Seismic stability of facade brick-masonry walls of machinery building of Beauharnis Powerhouse near Montreal, Quebec, Canada, besides applied sophisticated analytical non-linear models, is also checked by experimental methods on site as well as by 1/3 scaled model on seismic shaking table, by simulation of expected earthquakes on the powerhouse location. Dynamic properties of machinery building were obtained by ambient vibration measurement. Based on these results a model of a representative part of the building, together with very specific facade brick masonry wall was designed and constructed in IZIIS Laboratory and then tested on the shaking table. The obtained results are very reliable and in good correlation with the analytical ones, which confirm the correctness of mathematical model..

**KEYWORDS:** frequencies, mode shapes, damping, shaking table, model

## 1.INTRODUCTION

During 2006 a bi-lateral project for experimental and analitical investigation of the seismic stability of the brick masonry walls at Beauharnois Powerhouse located in Quebec, Canada, was initiated. The project was realized in cooperation between "Hydroquebec", Montreal, Canada and the Institute of Earthquake Engineering and Engineering Seismology - IZIIS, Skopje, Republic of Macedonia. The main objective of the investigation was to evaluate the seismic stability of masonry walls of the machinery building at Beauharnois powerhouse acording to the new design codes in Canada. The walls have been constructed at the beginning of 20 century and they are under protection as a historical heritage. Following the main objective of the investigation the following activities have been carried out:

1. Experimental in-situ full scale testing of selected portion of the wall;
2. Experimental shaking table testing of reduced scale model of the wall in scale 1:3 on representative earthquake excitation;
3. Numerical modeling of the seismic stability of the walls applying sophisticated non-linear models.

## 2.DESCRIPTION OF THE BEAUHARNOIS POWERHOUSE

The Beauharnois power-plant is located on St. Lawrence River near Montreal. The power-plant consists of gravity dam, a powerhouse and a water intake structure. Presented on Fig. 1 is the aerial view of the powerhouse.The superstructure of the Beauharnois powerhouse consists of single bay steel frames spaced 5.1m along the length of 826m of the structure. The masonry brick walls, incorporating the columns of the steel frames, serve as enclosures. The height of the walls is 20m. Their thickness is varying form 0.3 to 0.6m and they accommodate a series of large window frames. The walls are built after completion of the steel structure and they are integrated with the majority of the steel frames. The way of construction of the walls is very specific.

Figure 1 Beauharnois power plant

## 3. IN-SITU TESTING BY AMBIENT VIBRATIONS

In the first phase of experimental testing, ambient vibration measurements were carried out in order to define the dynamic characteristics of the walls - resonant frequencies, mode shapes and damping coefficients for transversal (out-of-plane) direction. Three seismometers Ranger type, Kinematrics product, were used and the measured signal was amplified by four channel Signal Conditioner also Kinemetrics product. The amplified and filtered signals from the seismometers were than collected by high-speed data acquisition system which transforms the analogue signals to digital. Special software for on-line data processing has been used to plot time history and Fourier amplitude spectra of the response at any recorded point. For post-processing and analysis of the recorded vibrations at all measuring points ARTeMIS software was used. This software is based on the Peak Picking technique and Frequency Domain decomposition and has possibilities for good graphical presentation of the obtained data. For definition of dynamic characteristics of the walls a portion of the structure between the steel frames 86 and 88 was chosen, photo on Fig. 2, and 54 measuring points were selected for measuring the vibrations caused by the ambient, out of which 12 on the wall (downstream side), 12 along the height of the steel columns - down-stream side, 15 along the height of the steel columns - up-stream side, 3 on the roof truss frame and 12 on the up-stream concrete structure. Schematic presentation of the measuring points is given on Fig. 3.

Figure 2 Selected part of the structure for ambient vibration measurements

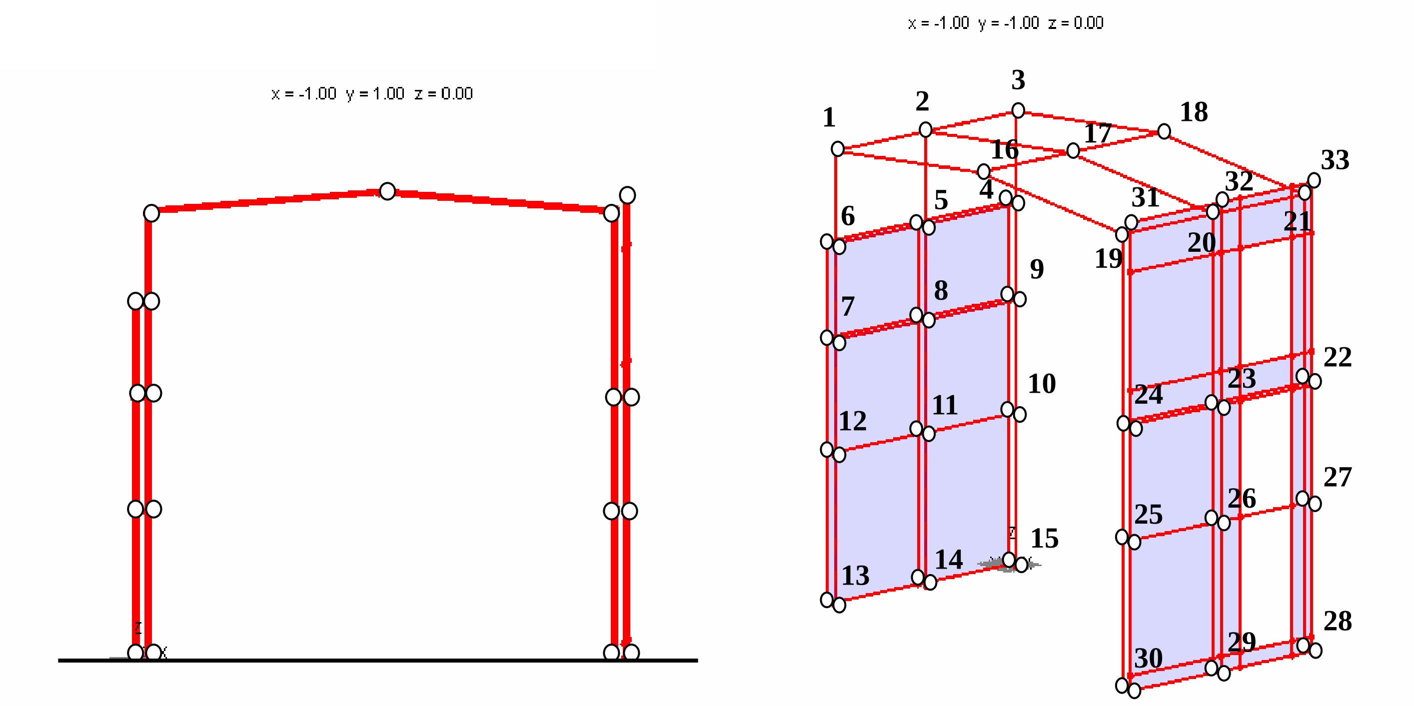


Figure 3 Measuring points on the selected portion of the Beauharnois powerhouse

Presented in Fig. 4 and Table 3.1 are the obtained dominant frequencies and damping coefficients, while mode shapes for selected frequencies, showing very clearly the way of deformation of the structure and the locations where the max deformations can be expected, are presented on Fig. 5 .

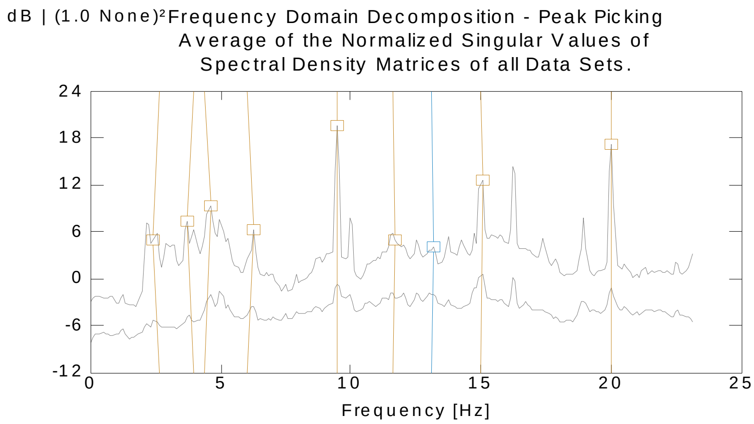


Figure 4 Peak Picking of the dominant frequencies

Table 3.1 Resonant frequencies and damping

| Mode | Freq. [Hz] | β [%] |
|---|---|---|
| Mode 1 | 2.65 | 9.348 |
| Mode 2 | 3.99 | 5.891 |
| Mode 3 | 4.39 | 6.412 |
| Mode 4 | 6.06 | 4.753 |
| Mode 5 | 9.47 | 0.604 |
| Mode 6 | 11.64 | 2.725 |
| Mode 7 | 13.09 | 1.813 |
| Mode 8 | 15.00 | 0.933 |
| Mode 9 | 19.98 | 0.299 |

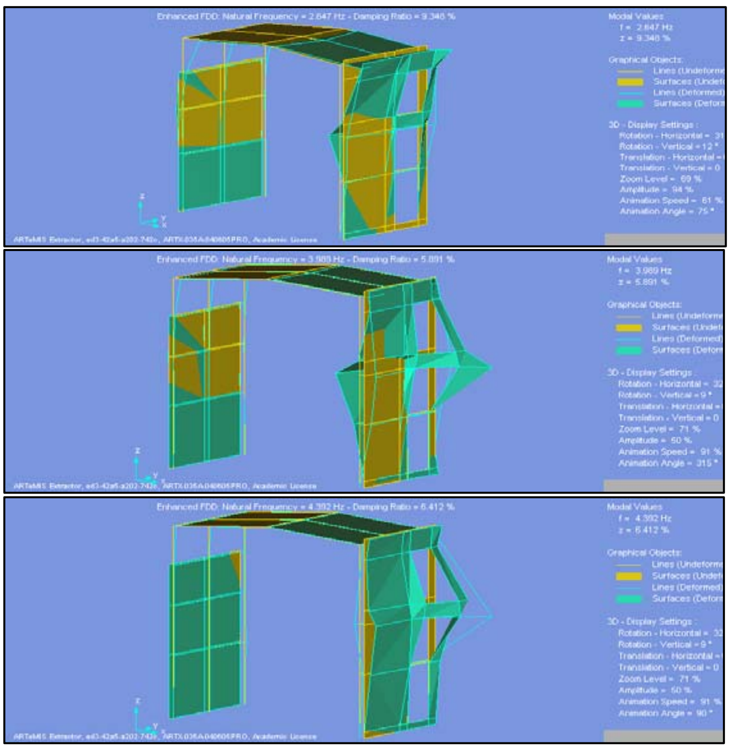

Figure 5 Mode shapes of vibration for the first three frequencies

## 4. LABORATORY SHAKING TABLE TEST OF A MODEL

The shaking table testing of a scaled model of the Beauharnois walls was performed on the two-componental seismic shaking table at IZIIS Laboratory, applying the excitation in horizontal and also in vertical direction with increasing intensities.

### *4.1 Design and Construction of the Model*

The selected portion of the Beauharnois powerhouse measured by in-situ ambient vibrations was designed according to the similitude requirements defined for model testing on a shaking table. Considering the prototype structure dimensions, as well as the dimensions and load capacity of the shaking table, the model was designed in geometric scale 1:3 and adequate model with artificial mass simulation was adopted, using the same materials for the model as are in the prototype structure: steel and bricks. The brick masonry wall was constructed following the specific way of conection between the bricks and the steel columns, Fig. 6. Its height was 6.5m. The final appearance of the model is given on Fig. 7.

Figure 6 The model of the wall under construction

Figure 7 The model of the wall ready for shaking table testing

### *4.2 Dynamic characteristics of the model*

Considering the adopted modeling technique additional mass of 5t was added on the top of the steel structure for correct simulation of the dynamic properties and simulation of the gravity forces.Before the seismic testing dynamic characteristics of the model were obtained measuring the ambient vibrations in selected points and processing the records by Artemis software. The obtained results are given on FigS. 8 and 9. The values of the dominant frequencies are in good correlation with the measured values for the prototype structure, according to the similitude requirements.

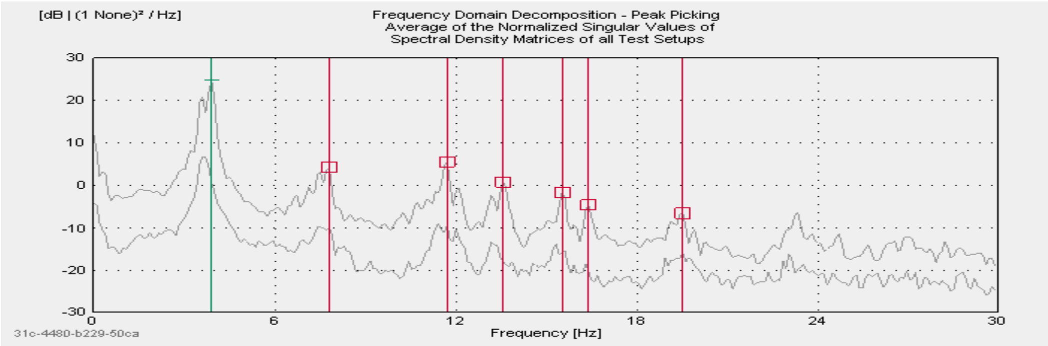


Figure 8 Peak Picking of the dominant frequencies

| Mode | Freq. (Hz) |
|---|---|
| Mode 1 | 3.906 |
| Mode 2 | 7.813 |
| Mode 3 | 11.72 |
| Mode 4 | 13.57 |
| Mode 5 | 15.53 |

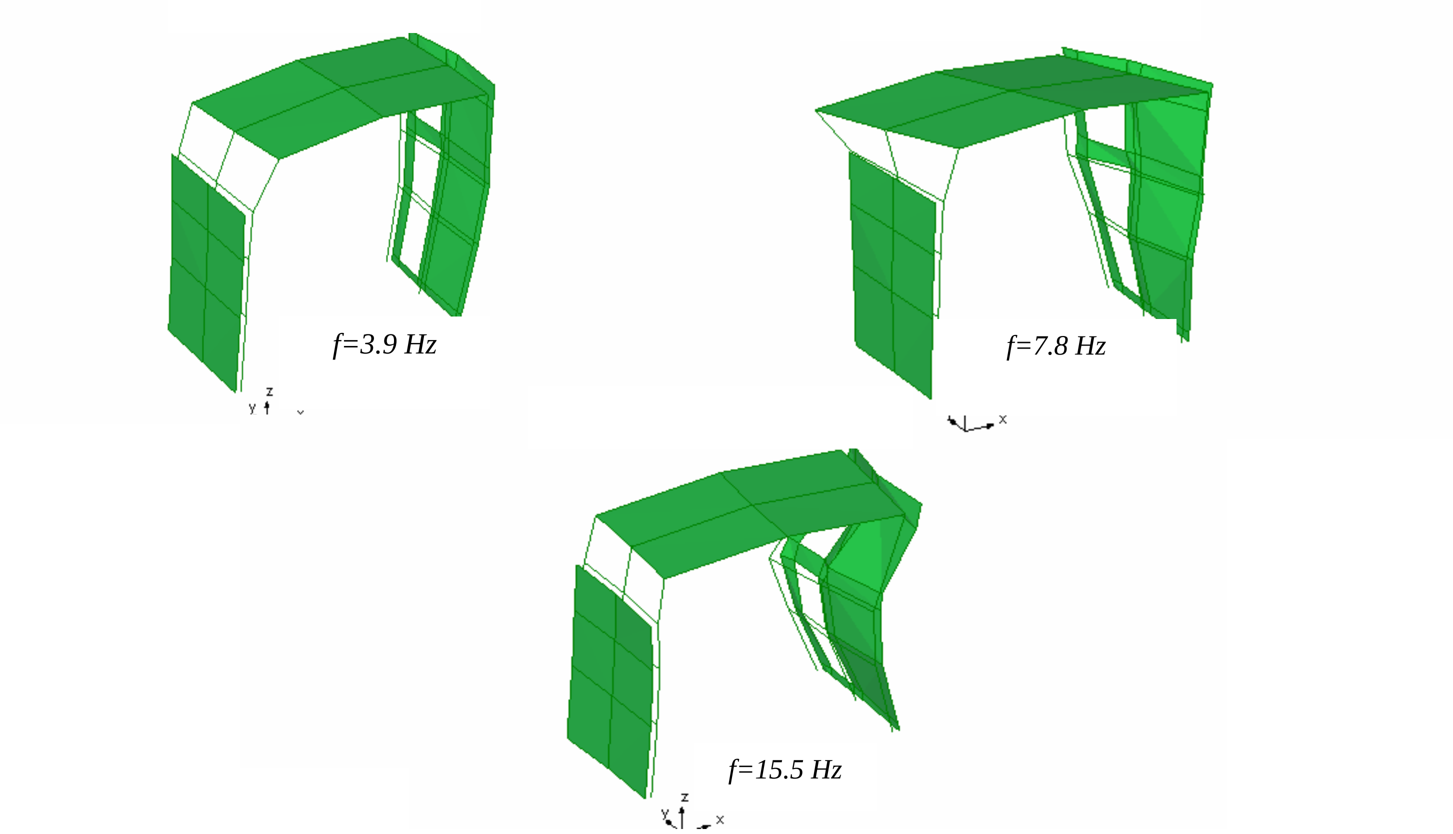


Figure 9 Mode shapes of vibration for the model

### *4.3 Seismic out- of-plane testing of the model*

The seismic excitation selected for the shaking table testing of the model was the representative accelerogram recorded in 1985 Nahanni, NWT earthquake of M6.8, horizontal component H1, with peak acceleration of 0.22g. For the seismic tests the model was instrumented for measuring the response in characteristic points. The total number of measured points was 21, while the total number of channels was 40. The real time recording of the model response was performed by 72 channel high-speed data acquisition system. Presented in Fig. 10 is the position of the instruments - on the wall, on the steel columns - up-stream and down stream wall.

The input intensity of 0.22g of the Nahanni NWT earthquake, H1, simulated by shaking table displacement with span 120, correspond to design earthquake. The acceleration on the top of the model was 0.4g, which is about two times amplification of the input acceleration. This indicates rather high stiffness of the wall, probably because of firm connection between wall and steel frame structure. First cracks occurred at span 450 which correspond to input acceleration 0.7g when top acceleration is 1.5g. The maximum span applied to the model, 700 (1.2g and top response 3.0g.), produced crack development at several places around the openings. Comparison between uni-axial with bi-axial out-of-plane excitation show more or less the same picture of model behavior. The recorded response parameters are close to the uni-axial response, which means that vertical component doesn't produce particular effect to the wall except to the roof structure. The selected time histories for the response of the model for the max expected earthquake intensity of 0.2g are presented in Fig. 11. Some damage details are given on Fig. 12.

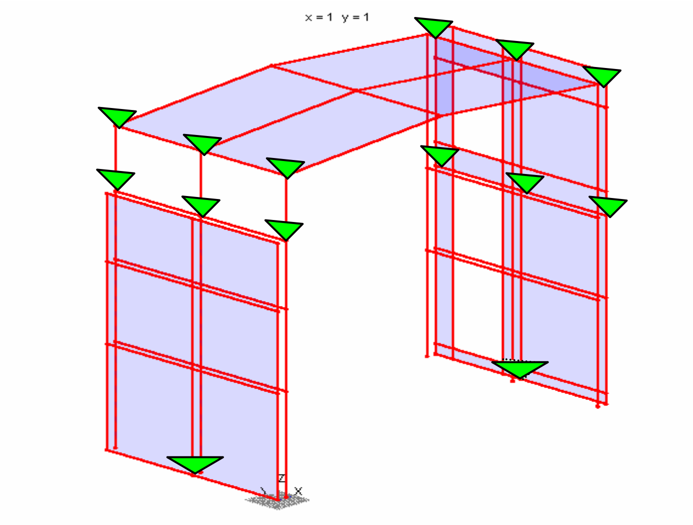


Figure 10 Position of measuring points

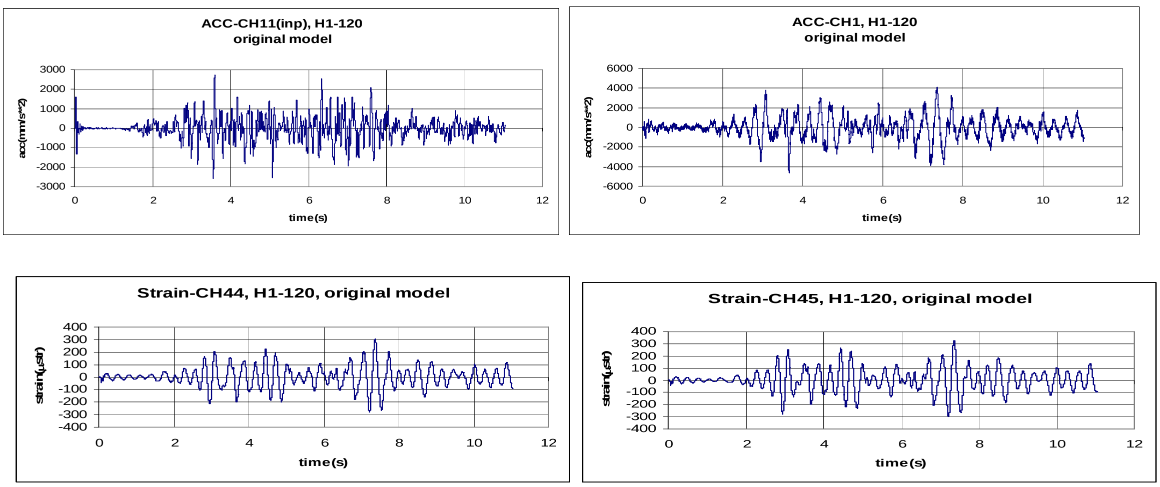


Figure 11 Selected time histories for the maximum expected earthquake intensity of 0.2g

Figure 12 Details of damage

## 5. CONCLUSIONS

- The experimental investigation of seismic stability on masonry walls at Beauharnois powerhouse consisted of two main phases: In-situ measurement of the dynamic properties of the powerhouse by ambient vibration method, and laboratory shaking table testing of 1/3 scale model of a segment of the powerhouse consisting of two spans.
- The geometry of the original structure was completely scaled 1/3, consisting of many details realistically simulated such us: brick layers, steel columns, openings, windows frames, steel connectors between the brick layers, number of the layers, brick dimensions etc.
- The material used for the model was: original steel for the frame structure, and reduced mechanical properties of brick-masonry wall, close to the similitude requirements according to Backingam theorem, valuable for adequate model with artificial –mass simulation model as well as true replica simulation model.
- More than 50 seismic tests have been performed considering design earthquake Nahanni NWT, H1, with time scaling factor of $3^{1/2}$, and acceleration scaling factor 1, accordingly to the model design rules. The intensity of the applied input earthquake excitation was from span 10-700 i.e. 0.05g- 1.2g. The design peak acceleration of Nahanni earthquake was 0.22g. (span120). The cracks development stated at 0.7 g input acceleration. It was concentrated around the openings. No collapse happened even for the strongest earthquake input. The relative displacement between the steel frame and wall at the location near point 22 was 1.8 mm and was visible during the test.
- Generally, based on all performed experimental tests, considering some simplification and assumptions in constructing details, as well as in design of the model, the global conclusion is that the existing wall is very well incorporated with the steel structure of powerhouse. The complementary stiffness of the steel frame and brick masonry wall produces interactive deformation of the system. Only local cracking and relative displacement between the wall and steel frames could be expected in case of strong earthquake.

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