ENVIRONMENTAL NOISE AND VIBRATION CONTROL OF THE ROSE THEATRE, BRAMPTON, ONTARIO

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ABSTRACT

The Rose Theatre in Brampton, Ontario was to be constructed twenty meters away from a CN main railway line (which includes commuter and freight rail traffic) and on top of a pre-existing underground parking garage which was to remain intact and in operation during the course of construction. A full concrete slab could not be supported by the pre-existing parking garage columns; therefore, a transfer grid, designed by the structural engineer, was employed and as a result a typical "room-within-a-room" construction could not be conventionally achieved. Railway airborne noise is controlled to meet the interior objective of RC 20 by providing a "floating" shell enveloping the entire building. Exterior concrete pre-cast panels are resiliently supported and resiliently connected back to the building and the entire roof slab was vibration isolated from the structure. For railway-induced vibration, the building was supported on a transfer grid which was in turn supported by 250 mm thick rubber vibration isolation pads. The entire building, including exterior shell, stairs and elevators is vibration isolated from ground-borne rail vibration. The measured vibration levels (and the noise radiated by vibrating surfaces) in the theatre were controlled to well within the design objective.

RESUME

Le théatre Rose de Brampton devait étre construit à vingt mètres d'une voie principale du CN (sur laquelle circulent trains de marchendises et trains de voyageurs) et en aplomb d'un parking souterrain pré-existant devrant rester intact et opérationnel durant toutes les étapes de la construction. Il était impossible de faire supporter une large chape de béton par les colonnes du garage pré-existant, il a donc fallu que l'ingénieur conçoive une grille de transfert si bien que construire une "pièce au sein d'une autre" sur la modèle conventionnel ne pouvait étre envisagé. Les bruits ambiants provenants de la voie ferrée sont maitrisés à l'aide d'un "bouclier flottant" enveloppant tout l'édifice en vue de respecter un objectif interieure de RC-20. Les panneaux extérieurs en béton préfabriqué sont montés sur supports isolants et connectés au bâtiment par isolants. La dale du toit a été isolée de toute vibration de la structure. En ce qui concerne les vibrations provenant du chemin de fer, l'édifice prend appui sur une grille de transfert elle-mème s'appuyant sur des tampons de vibration en caoutchouc de 250mm d'épaisseur. Tout l'édifice, envelope extérieure, escaliers et ascenceurs inclus est à l'épreuve des vibrations imprimées par les rails. Les niveaux de vibration measurés (et les bruits diffusés par les surfaces vibrantes) dans le theatre ont été ramenés bien en-de-ça des objectifs du design.

1 INTRODUCTION

Swallow Acoustic Consultants Limited (SACL) was the Acoustic Consultant for The Rose Theatre, Brampton project. All acoustics, noise and vibration control aspects for the theatre were addressed (auditorium room acoustics, mechanical noise control, environmental noise control). This case study discusses the environmental noise and vibration control aspect of the project. Please also refer to a companion paper titled "Acoustic Design of the Rose Theatre, Brampton".

The Rose Theatre is located in the vicinity of Queen Street East and Main Street North, Brampton – approximately twenty metres from a Canadian National (CN) main railway line. The railway line includes commuter (GO) train and freight train traffic. The freight trains are powered by up to four locomotives, which produce very high sound levels, particularly in the low frequencies.

Pre-design noise and vibration measurements at the site indicated that both the railway airborne and structure-borne (through ground vibration) noise were of great concern, and extensive noise and vibration control was required to meet the objectives in the theatre.

The site contained a pre-existing underground parking garage, which The City of Brampton requested remain fully operational during construction. In addition, the allowable mass of the theatre was constrained to not exceed the structural capacity of the pre-existing parking garage columns. For this reason, a transfer grid, designed by the structural engineer, was employed and as a result a typical "room-within-a-room" construction could not be conventionally achieved, as it would require a gap in the transfer grid – a structural impossibility.

The environmental noise control design consisted of vibration isolation of the entire support structure of the theatre and the entire exterior shell including stairs and elevators.

2 DESCRIPTION OF FACILITY

The theatre consists of a 5,950 square meter (64,000 square feet) main space with an 880 seat Auditorium and 160 seat Secondary Hall. The Auditorium is in a horseshoe shape with a single shallow balcony designed for excellent sight lines and acoustic properties. The stage contains a full fly-tower. The Secondary Hall is intended both as a separate venue for film, dance, recitals and as a rehearsal space for the main auditorium. The main entrance hall's exterior envelope consists of a dominantly glazed exterior envelope, while the rest of the theatre's exterior is made up of pre-cast concrete panels.

3 CRITERIA

The design goal was to attenuate environmental noise transmitted into the Secondary Hall and Auditorium to inaudible sound levels. Because the noise criterion due to HVAC in the Auditorium and Secondary Hall was selected to be RC-20, the objective to control the railway noise and vibration was therefore selected to be approximately RC-15 (or to below perceptible sound levels in the auditorium).

The environmental noise control design was limited to rail and road traffic noise, as these sources were determined to be the major environmental noise sources affecting the site. Other sources, such as aircraft noise were determined to be rarely audible in the vicinity of the theatre.

4 MEASUREMENTS AND ASSESSMENT

Pre-design noise and vibration measurements were taken at various locations on site – particularly at locations on the parking garage column caps.

Sound level measurements indicated that the dominant noise source was freight train traffic, with high levels of low frequency noise – Approximately 105 dBL at 80 Hz. Freight trains were measured to be in the range of 90 dBA at the approximate location for the nearest exterior wall (northwest corner of the building). The sound levels at the southeast side of the building were measured to be approximately 85dBA, partly contributed by the train noise reflected off the existing buildings facing the theatre. The measurement at this location was significant as this is the location of the entrance hall, which consists of a glazed exterior wall, with the major concern being that the noise would be transmitted into the entrance hall, continuing into the Auditorium and Secondary Hall. The frequency content of the measured train sound levels at the location of the north west corner of the theatre are included with Chart 1.

Vibration measurements were conducted at several locations throughout the site – particularly at locations in the vicinity of the auditorium. Measurements were taken both at mid-span locations (where the vibration is greatest) and on column caps and retaining walls (where the theatre structure is supported) of the existing underground parking garage, located below the site.

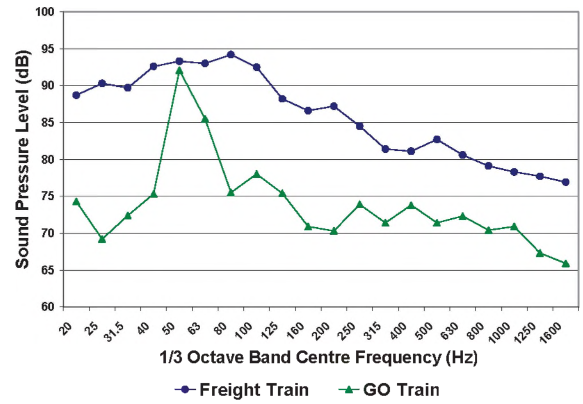

Chart 1: Train Sound Level Measurement Results; Rose Theatre Site, Brampton (2000).

Rail vibration was measured to be 0.15 mm/s RMS, with a maximum vibration velocity of 0.1mm/s at 31 Hz. A summary of train vibration measurements are included in Chart 3 (refer to Section 7.0). The corresponding sound pressure level resulting from the vibration of the ground was calculated to be at a sound level of approximately RC-45. Although some reduction via the building components was expected, a room located on the upper floor of the parking garage (i.e. the auditorium) would still be expected to exhibit sound levels on the order of RC 35 to 40 due to train vibration.

The results of the sound and vibration level measurements indicated that a standard (non-vibration isolated) construction of the theatre would exceed the design objective and train noise would be clearly audible in the Auditorium and the Secondary Hall.

5 ISOLATION DESIGN

5.1 Ground-Borne Vibration Isolation

The vibration isolation design was conducted using an impedance model method of calculation. The calculation models the ground-borne vibration propagating through the parking garage columns into the building. Vibration reduction occurs at impedance mis-matches, for example at the column/floor interface. Vibration isolation pads were introduced to the model at the top of the parking garage.

Calculations indicated that a 20 dB reduction in the range of 25 to 80 Hz could be achieved by installing vibration isolation pads with a static deflection of 25mm. The calculated reduction of 20 dB in vibration was considered to be sufficient to attenuate vibration induced sound levels from RC-35 to RC-15, thus meeting the criterion in the auditorium. A schematic of the impedance model is displayed in Figure 1, and a chart of the calculated noise reduction is displayed in Chart 2.

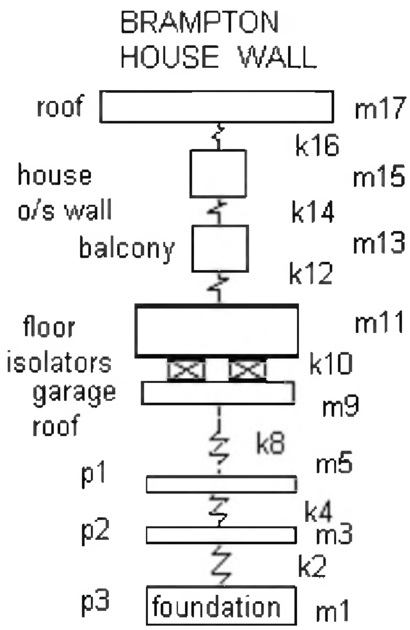

Fig. 1: Impedance Model Schematic

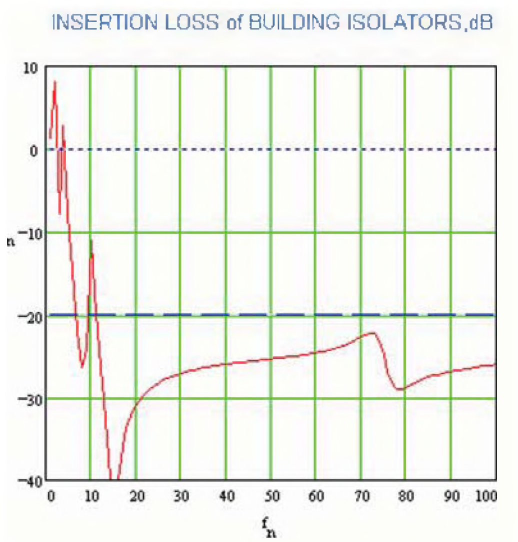

Chart 2: Calculated Attenuation through Bearing Pad Isolators

A transfer grid was designed by the structural engineer. As the vibration isolation pads cannot be loaded to the same stress as concrete, the existing parking garage column caps were increased in size to accommodate the vibration isolation pads. Refer to Figure 2 for a photo of a bearing point including isolation pads, and a view of the structural transfer grid. The building isolation pads are laminated steel and natural rubber, made in seven different load capacities. Column loads varied greatly so a selection of different pads was used at each column cap to match the load.

To accommodate for seismic loading, shear pads were also introduced to the design. The pads were installed pre-compressed between two plates by welded iron rods, and once in place the rods were removed. The provision for snow loading was also taken into account in the design of the roof isolation pads.

Fig. 2: Column Cap with Isolation Pads; Structural Transfer Grid Visible Above

5.2 Exterior Wall Isolation

Sound level measurements indicated that a conventional construction to attenuate airborne noise due to the rail traffic would be prohibitive (e.g. unrealistically thick walls and roof would be required). Therefore, a design incorporating a resiliently connected exterior shell for the theatre was investigated. The pre-cast concrete panels, which were also isolated from the ground by vibration isolation pads, were resiliently fastened to the structure. Refer to Figure 3 for a photo of the pre-cast panel vibration isolation, showing the gravity pad and the panel tie-back isolation. The exterior partition construction consists of the sandstone finish, pre-cast panels (225mm concrete) fastened resiliently to the structure via the vibration isolation system, semi-rigid insulation in the air space (250mm airspace) and an interior partition consisting of concrete block.

Fig. 3: Pre-Cast Panel Vibration Isolation

Calculations indicated that the "weakest link" of the exterior envelope would be through the extensive exterior glazing in the entrance hall. The train noise could reach a sound level equivalent to NC-45 in the entrance hall. This was taken into account when designing the vomitories; including upgrading the wall construction, and the installation of acoustic wall panels throughout the vomitory creating a sound lock to attenuate noise passing through an open door (i.e. a patron is entering/exiting during a performance).

5.3 Roof Isolation

The roof was supported on vibration isolation pads with a static deflection of 9mm. An off the shelf commercial isolation pad was selected for the roof isolators, and custom isolators were constructed to support the roof curb. To accommodate for the snow load, a "bobbin" was placed on the interior of the dome shaped pad in order to withstand the loading of high snow fall.

6 IMPLEMENTATION OF ISOLATION

6.1 Testing of Building Isolation Pads

Because the entire structure of the theatre was to be supported by the vibration isolation pads, extensive testing was set as a requirement to the manufacturer. Randomly selected building isolation pads were tested incrementally to 150% of the calculated load. Testing of randomly selected samples of each type of pad were witnessed by SACL engineering staff, and testing reports for all pads were also reviewed by SACL engineers.

6.2 Isolation Pad Placement and Pouring of the Transfer Grid Slab

Each bearing point of the structure was meticulously inspected to ensure that the proper vibration isolation pads and configuration of the pads were installed. The isolation pad serial numbers, type designation, and a photograph of the installation were taken and catalogued prior to pouring the transfer grid structure.

To maintain the isolation gap while pouring the concrete transfer grid, a variation of sand casting was employed: With the forms in place, the void was filled with sand to a level matching the top of the isolation pads. The sand was then mechanically compacted, and covered with a sheet of plastic. The concrete was poured in place, and once cured; the sand was washed out of the void leaving a clear isolation gap. A photo of a bearing point vibration isolation pad configuration, with the compacted sand also in place, is shown in Figure 4.

6.3 Construction Site Inspection

Weekly site inspection was conducted to ensure that the vibration isolation gap was maintained and free of flanking paths. As the techniques employed in maintaining the isolation gap were not typical, the contractors required on-going guidance in order to maintain the vibration isolation. For example, the piping and electrical conduit required an isolation detail when passing from the non-isolated parking garage to the isolated slab above.

Fig. 4: Structural Isolation Pads, immersed in Compacted Sand

7 SUBSTANTIAL COMPLETION – NOISE AND VIBRATION MEASUREMENTS

Noise and vibration measurements were conducted when the theatre was at substantial completion. Vibration measurements indicated that the noise resulting from ground-borne vibration in the auditorium would meet RC-15. The vibration measurements, referenced to the original assessment measurements are included in Chart 3.

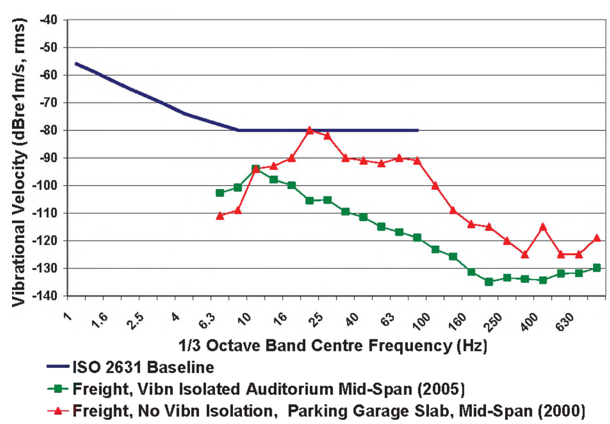

Chart 3: Freight Train Vibration Levels

SACL engineers listened for trains (during several freight train pass-by) in the auditorium and secondary hall. Subjectively, it was concluded that the train noise was inaudible in the RC-20 auditorium.

8 CONCLUSION

The noise and vibration control design met the objectives for environmental noise control in the Auditorium and Secondary Hall of the Rose Theatre Brampton.