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VIBRATION AND ACOUSTIC ISOLATION OF THE DALLAS CONVENTION CENTER

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ABSTRACT

The expansion of the Dallas Convention Center includes the world's largest column-free exhibit hall. The location of the hall required spanning four heavy-rail tracks and two light-rail tracks. Prior to construction, vibrations at a frequency of 4-5 Hz were measured on the ground as trains passed through the construction site. Conventional construction techniques would have allowed these vibrations to enter the exhibit hall resulting in unacceptable noise and vibration levels. To resolve this problem, an isolation system utilizing steel springs and rubber bearings was designed to reduce the vibration inside the exhibit hall. Noise reduction achieved through the vibration isolation system, choice of building materials, and acoustical glass eliminated concerns about the impact of passing trains. The determination of the isolation requirements and the design of the vibration and acoustic isolation systems are discussed in this paper.

INTRODUCTION

Expansion of the Dallas Convention Center required spanning four freight and two light-rail tracks (Figure 1). Above the tracks is the largest column-free exhibition space in the world as well as a pre-function area intended for socialization before an event. The noise and vibration caused by the passage of trains would have resulted in unacceptable conditions within the convention center if standard construction techniques had been used. Therefore, columns near the tracks were outfitted with spring isolators to reduce the transmission of noise and vibration into the structure. This paper discusses the design of the noise and vibration isolation system for the convention center.

BUILDING VIBRATION CRITERIA

General guidance on building vibration criteria is given by ISO (International Standards Organization) Standard 2631-2 and ANSI (American National Standards Institute) Standard S3.29-83. However, neither standard provides criteria for evaluating the subjective vibration experience that is the usual basis for design. As a result, Mike Fann and Associates collected vibration measurements at the Dallas-Fort Worth Airport terminal and parking garage in an effort to establish tolerance criteria. The perceptible floor movement that occurs in the terminal as people move across the tile floor was considered acceptable. However, the vibrations measured in the garage, while acceptable for vehicular traffic, are not subjectively considered acceptable over long periods for humans. Upon examination of the measured vibration in the terminal and garage and comparison with the standards, the ANSI vibration criterion was chosen as being the most appropriate for this project.

GROUND VIBRATIONS

Ground vibration measurements were performed prior to the construction of the convention center expansion. Measurements were collected at the pier closest to the railroad tracks, at a distance of 5.6 m (18.5 ft) from the center of the heavy rail lines. An analytical prediction scheme was then used to estimate the vibration levels in the convention hall based on the ground vibration. The structure piers are founded in bedrock below the soil levels present at the site and when constructed in this manner they will increase the structure stiffness and maximize the impedance mismatch between the ground vibration and the building structure. This in turn can decrease the vibration transmission by a factor of 3. Transmission losses up the columns can be expected to provide an additional loss factor of 1.4. Unfortunately however, building floor resonance will increase the vibration, although concrete structures typically have sufficient damping to limit such increases to a factor of 3. Figure 2 shows the predicted floor velocities for a structure without an isolation system, along with the vibration criteria. It was clear early in the project that the criteria would be exceeded for some frequencies unless an isolation system was provided.

VIBRATION ISOLATION DESIGN

Vibration isolation requirements were chosen based on the measured ground vibrations. The 22.8 m (74.75 ft) span has a natural frequency of 3-4 Hz while the 9.1 m (30 ft) spans have resonance around 11 Hz. As seen in Figure 2, significant ground motion occurs in these frequency ranges. Therefore, some type of vibration isolation, in these ranges, was required to ensure the building performed within the specified criteria.

The box beam span natural frequency of 3-4 Hz requires an isolation system with a lower natural frequency in order to reduce the vibrations transmitted to the structure. A 5 cm (2 in) deflection spring has a natural frequency of 2.2 Hz leading to a vibration transmission loss of between 40 and 70 percent. 5 cm deflection springs were specified for the column lines under the box beams (along the freight tracks – Figure 1).

The adjacent bays are subjected to approximately the same forces. However, the structural system in these bays has a natural frequency close to 11 Hz. A 2.5 cm (1 in) spring system will adequately isolate the structure in these bays. The spring natural frequency is 3.13 Hz and provides approximately 85 percent isolation. As the distance from the source doubles, the ground vibration reduces by approximately 50 percent. Therefore, the second column line from the tracks is exposed to a reduced load, but still requires a 2.5 cm (1 in) spring isolation system. The third column line from the track experiences even less vibration and a neoprene pad isolation system was determined to be adequate. Overall, 23 columns have 5 cm deflection springs and 18 columns have 2.5 cm deflection springs.

In addition to providing the specified amount of vibration isolation, the spring isolator system had to act as part of the structural load path. The design requirements were that (1) the spring isolators would deflect the specified amount under the dead load and a live load of 4.6 kPa (100 psf); (2) the total live load deflection must be limited to 1.9 cm (.75 in); (3) the system must be able to carry a maximum live load of 16.8 kPa (350 psf); and (4) the deflection upon application of the dead load must be less than 0.6 cm (0.25 in).

The spring system was first designed for the specified displacement under dead load plus the expected live load. In order to limit the total deflection, adjustable limit stops were included in the design. After the dead load deflections were measured, the limit stops could be adjusted to allow only 1.9 cm of additional deflection. Since the limit stops would be engaged before the maximum live load of 16.8 kPa was reached, the limit stops were designed to safely transmit the maximum expected load to the structural columns. Finally, pre-loading bolts were designed to allow the spring system to be deformed to approximately the dead load deflection before installation. The structure would then be fabricated on top of the spring system and when the temporary supports were removed the springs would undergo minimal additional deformation to achieve the specified value. This minimizes stress and cracking in the structural concrete. Neoprene pads were placed under the spring system to ensure that some vibration isolation would be available, at least for higher frequency vibrations, even when the limit stops were engaged. The complete spring system is shown in Figure 3.

VIBRATION MEASUREMENT RESULTS

Floor vibrations were measured after construction during the passage of a freight train at 40 kph (25 mph) and a DART train. The measured values were also modified to simulate the passage of a freight train at the maximum allowable speed of 64 kph (40 mph). The measured and calculated floor velocities are shown, along with the floor vibration criteria, in Figure 4. The isolated floor meets the criteria even for the larger calculated vibration values, which are at least 50% below the allowable values.

The measured vibration is shown as velocity values in narrow bands to emphasize the vibration characteristics. The spring isolation effectively reduces the vibration at higher frequencies, almost completely eliminating vibration. A tonal is found at approximately 5 Hz, which is associated with the box beam natural frequency. Much of the input energy feeds this resonance, requiring the use of springs. The springs produced a reduction in vibration to approximately 50% below the criteria at the 5 Hz resonance frequency.

SOUND LEVEL MEASUREMENT RESULTS

Sound levels were measured at two locations, in Exhibit Hall F, 7.6 m (25 ft) from the south wall and centered over the freight tracks, and in the Pre-Function area, 3 m (10 ft) from a glass curtain wall, also centered over the freight tracks. Measurements were performed in coordination with the railroad train spotter allowing knowledge of the train speed, number of cars, and number of engines. The spotter also prompted heavy use of the horn during passage. The horns would not normally be used at this location.

A very large coiling door is located in the southeast corner of Exhibit Hall F. Sound measurements were made with the door both open and closed. Even when closed, the door has a lower sound transmission loss than the walls, making the door the primary sound path regardless of the door position.

Sound levels were collected so that the octave frequency band sound levels and overall A-weighted sound levels could be determined. The greatest concern in the Exhibit Hall and Pre-Function area is the possibility of speech interference from intruding noise. Therefore, the overall A-weighted sound levels (dBA) are of the most interest and are reported herein.

Table 1 summarizes the measured overall A-weighted sound levels in both Exhibit Hall F and the Pre-Function area. With the coiling door closed, very little difference is seen between the background noise and the sound level during train passage or whistling. When the coiling door is open, the low frequency noise of passing trains can be noticed but it is not overly intrusive, while the horn is clearly noticeable. In the Pre-Function area the train noise is likely not noticeable unless the train is seen passing under the area through the glass wall. The train horn is moderately loud, but under normal operation the horn is not in use.

SUMMARY AND CONCLUSIONS

The vibration response to both the freight train and DART operations, individually and combined, is lower than the design objective. Neither operation generates any noticeable vibration within either Exhibit Hall F or the Pre-Function area. With concentrated effort, in an empty hall, a slight perception of the motion is possible. During normal operation the vibration is not evident and does not interfere with the intended functioning of the facility.

The acoustic performance of the facility is also acceptable. Within Exhibit Hall F, with the large doors closed, the passage of a train is acoustically imperceptible. Without the sounding of a train horn, the sound of freight or light-rail train passage is also not intrusive in the Pre-Function area. Overall, the design and construction have successfully accommodated the placement of the facility over the railroad tracks.

REFERENCES

American National Standards Institute (ANSI). (R1996). *Guide to the evaluation of human exposure to vibrations in buildings*, Washington D.C.

International Organization for Standardization (ISO). (1989). *Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock-induced vibration in buildings*, Geneva, Switzerland.

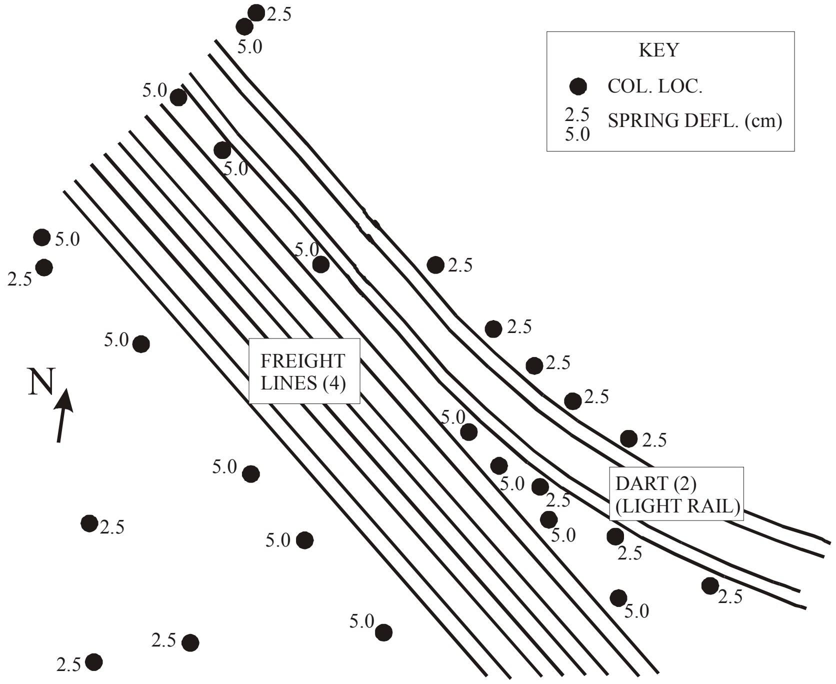

Figure 1. Partial Site Plan.

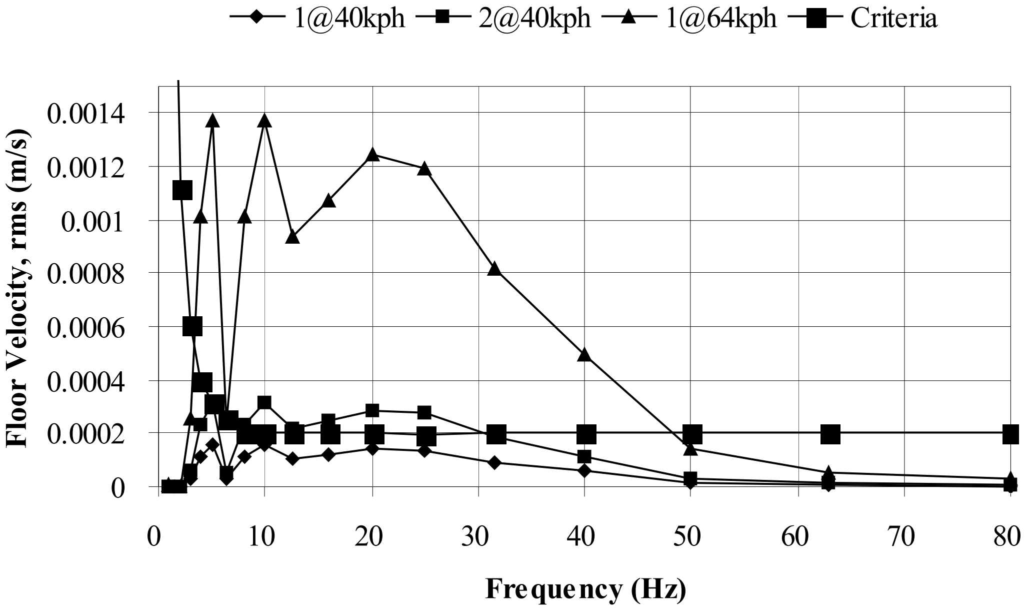

Figure 2. Measured and Predicted Floor Vibrations w/o Isolation at Various Train Speeds.

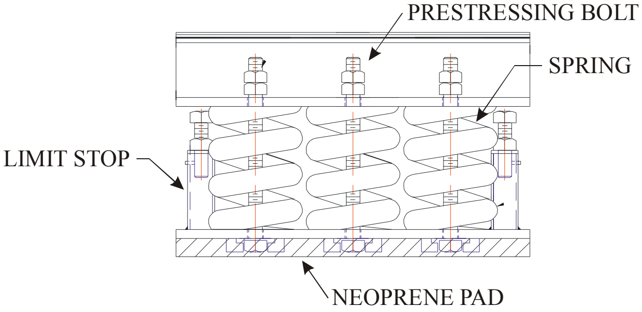

Figure 3. Spring Isolation System.

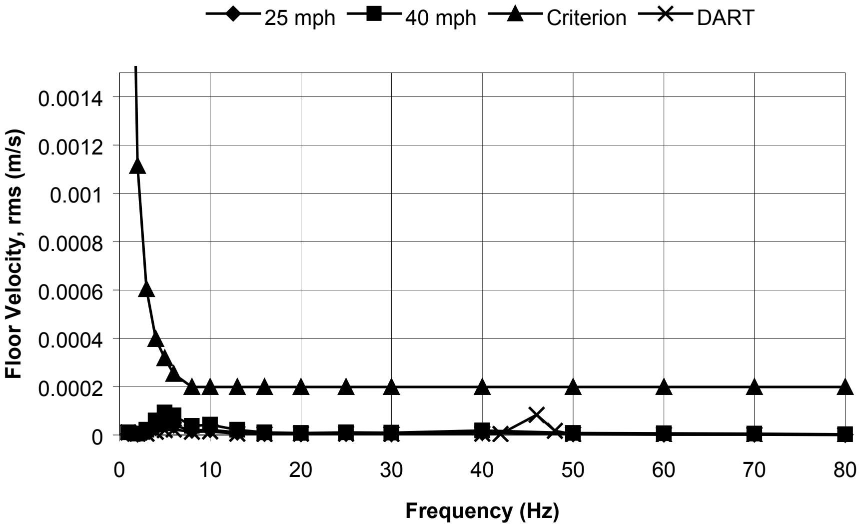

Figure 4. Measured Floor Vibrations.

Table 1. Measured Sound Levels

Location	Condition	Source	Overall Sound Level, dBA
Exhibit Hall F	Door Closed	Background	55-56
		Train	55-56
		Horn	56-58
	Door Open	Train	59-60
		Horn	67-70
Pre-Function		Background	48
		Train Engine	57-58
		Horn, Normal	59-65
		Horn, Extra Loud	72-76
		DART	50-52