

Building Isolation: Eliminating Subway Train Structure-Borne Sound at Shanghai Symphony Hall

By Dr. Keiji Oguchi

In this article I will continue our reporting on the new Shanghai Symphony Hall discussed by Yasuhisa Toyota in last month's issue. This time, I will focus on the measures we implemented to prevent structure-borne noise transmission from underground trains that run close to the hall.

Before I discuss the specifics of the Shanghai Symphony Hall project implementation, I will review the analysis process we use to determine the most effective strategy or combination of strategies for each project's vibration isolation. First, we investigate if there are ways to control the vibration at their source. Second, we try to situate the building as far as possible from the source of the vibration. Lastly, we isolate the vibration from the building by adopting a box-in-box or other structural design. In the case of Shanghai Symphony Hall, the project faced a location constraint because the project site is located in close proximity to underground train lines. Therefore, we focused our vibration isolation design on strategies that built the needed vibration isolation properties into the building's structural design.

The Shanghai Symphony Hall Building's Location

Shanghai Symphony Hall is located in the Hengshan - Fuxing Road area of the city's Xuhui District, a neighborhood designated as an historical and cultural preservation area where architecturally significant historic buildings and old sycamore trees still line the streets. A system of highways traverses land near the south, north and west sides of the hall's site and the Number 2, 7 and 10 subway lines run underground below the highways.

In particular, the Number 10 line runs very close to the hall's site at its south side and a segment of the train line runs below a portion of the hall's site. Because Hengshan - Fuxing Road area is a historical and cultural preservation area, buildings have a height restriction of 12 m. (39 ft), though its height can locally exceed this restriction. In the case of a concert hall, we aim to achieve a ceiling height greater than 12 m. high, so if the building height restriction is 12 m., our only option is to use a design that places a portion of the hall below ground. Such a design would, however, bring Shanghai Symphony Hall hall closer to the train line than if the project was built entirely above ground.

Adjacent to the north boundary of the hall's site is an area with low-rise homes. While we would have wished to shift the concert hall towards the north, the nearby residential housing also prevented us from creating physical distance between the hall and the underground train lines. We did not have the option of moving the hall's location along the "y axis" and we could only achieve the needed ceiling height by locating a portion of the hall below ground. As a result, the completed Shanghai Symphony Hall is a mere 7.5 m. (25 ft) from the Number 10 train line's tunnel, measured along the "y axis" and has an average distance from the tunnel of 15 m. (49 ft). The top of

the train line tunnel is nearly the same depth as that of the stages of the two halls in the Shanghai Symphony Hall building. (Figure 1 shows a plan view of the underground train line and the hall. Figure 2 shows a section view of the underground train line and the hall.)

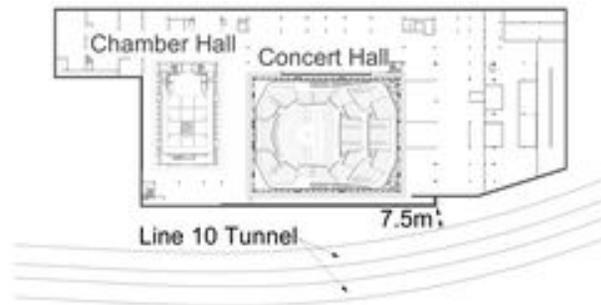


Figure 1: Plan View of Underground Train Line and Hall

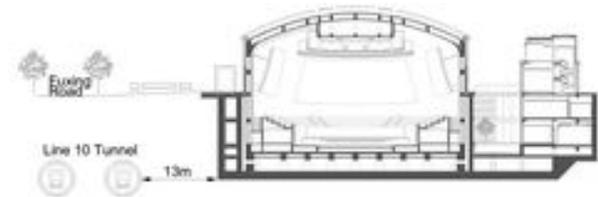


Figure 2: Section View of Underground Line and Hall

Vibrations Generated by Underground Trains

The Number 10 subway line is a new train line that the city of Shanghai built for the 2010 Shanghai World Expo. The Shanghai Symphony Hall project overlapped with the construction of this new train line and the hall project was informed that the rail line construction would include trackbed isolation—a design feature that would reduce the vibration generated by trains.

The Shanghai Symphony Hall project's schedule did not allow us to wait until the train line's completion to measure its vibration. Instead, we measured the vibration at another subway line that was already in operation and where a similar mitigation strategy had already been installed. Based on our findings at this similar location, we determined that we would need to reduce the vibration transmitted from the train line to the hall by approximately 20 dB in order to prevent the structure-borne noise caused by the transmitted train vibration from being heard during concerts in the new hall.

Vibration Isolation Strategy for Shanghai Symphony Hall

In Japan, a project to reduce vibrations by 20 dB would typically implement multiple strategies. For example, we might begin by constructing a slurry wall with vibration isolation mat around the building periphery. (Explained another way, for this part of the strategy we would insert flexible, rubbery material in a shallow moat surrounding the building.) Another part of our strategy might be to use box-in-box structural designs for designated rooms that require a specific level of quietness. These are just two examples among a number of typical structure-borne noise isolation methods.

For Shanghai Symphony Hall we proposed and implemented a building isolation approach that encased the Concert Hall and the Hall for Chamber Music in two separate concrete boxes, and we combined this strategy with placing each concrete box on a system of steel springs. We decided to propose this comprehensive strategy because of the below 3 considerations:



Figure 3



Figure 4

Steel Spring System

To reduce the train vibration by 20 dB with a box-in-box structure, that is with a mass-spring system, we would need to set the natural frequency of the mass-spring system of less than 5 Hz. Using a rubber for this system would not accomplish this, but the use of a steel spring system could achieve this objective.

Implementing the kind of box-in-box design typically used in Japan requires very specific construction management knowledge during installation of vibration insulation in the vicinity of the box-in-box structure. Japan has a number of specialty contractors with years of experience doing this work. In Shanghai, we did not have vendors with comparable experience. Installing the steel spring system would use construction methods that the local construction teams could implement with a high level of competency and that would achieve the required vibration isolation characteristics.

In general, box-in-box designs use lightweight multi-layer board as a primary material for both the sound isolation layer and the interior of a room. Shanghai Symphony Hall's Concert Hall uses solid and weighty materials in much of its interior design. We developed a building isolation approach using heavy materials and thereby matched the weight of the vibration isolation design materials to the weight of other materials used in the project.

The German company GERB was hired to develop the specifications, design the layout and procure the spring system as well as to manage the system's installation. This company has a local office in Qingdao, China. Construction of the building isolation system can be seen in the two photos that accompany this article

Achieved Quietness in the Concert Hall

A few days before the completion of construction at Shanghai Symphony Hall we measured the noise from the subway lines both outside and inside the halls in the building and we also did our own listening evaluations. In both halls, we obtained noise levels of less than NC-15 (measured with the hall's HVAC systems in operation).

Inside each of the halls, the human ear could not hear any train noise. However, when we stepped outside the halls in the building, we could surely hear the trains. When we measured the the structure-borne train noise at the outside

of the halls, it was between NC-25 and NC-30. We had validated the success of our design and its implementation.