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Use of Floating-Slab Track Bed for Noise and Vibration Abatement

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Underground rail rapid transit systems can produce ground-borne vibration and noise from trains that creates intrusion in buildings located close to the underground facilities. This intrusion is usually a low-frequency (31.5- to 125-Hz range) noise or rumble transmitted via the intervening ground to the building structure. The use of floating-slab track bed, concrete slabs supported on resilient elements, to isolate the vibration of the rail support from the subway structure has been effective in reducing the transmission of vibration and noise to the surrounding ground and nearby buildings. This paper presents details on two types of lightweight floating-slab track bed; i.e., the continuous and the discontinuous designs. Some sections of continuous floating-slab track bed are in service at the Washington Metropolitan Area Transit Authority Metro System, and measurements of the reduction of the noise and vibration levels are presented.

Rail transit vehicles produce ground-borne vibration and noise that can and do create intrusion in nearby buildings, and this is particularly so for underground transit facilities that may be very near to buildings. This noise and vibration, which originates at the interface of the wheel and the rail, has been a significant problem along some subway corridors. With modern, lightweight vehicles and continuously welded rail, the vibration is seldom of sufficient amplitude to be felt as mechanical vibration or motion, and the only sensation is that of a low-frequency noise or rumble. But with older vehicles and jointed rail, the noise is sometimes accompanied by noticeable vibration.

Ground-borne noise can be reduced by vibration isolation of the track bed to interrupt the transmission path. The use of a floating-slab track bed, which consists of a concrete slab supported on resilient pads, can provide a vibration-isolated inertial base for support of the running rails. This design has been found effective in reducing the transmission of vibration and noise to the surrounding ground and nearby buildings in a manner similar to that of the inertial bases on springs that are used to support stationary machines. The use of floating-slab track bed provides for both reduced intrusion in nearby buildings and the placement of new rail transit subways in closer proximity to buildings.

A number of designs for vibration-isolated track bed have been developed ranging from heavy bridgelike structures with thick rubber support pads and damping applied to the bridge deck to relatively light concrete slabs without damping supported on thin resilient pads. Two basic forms of the relatively light slabs have evolved: (a) continuous slabs that are cast in situ and (b) discontinuous precast slabs. The original lightweight floating-slab design now in use in North America was developed in 1970 for the Washington Metropolitan Area Transit Authority and is of the continuous configuration. Trains have been operating on these slabs since 1975 with excellent performance. No operational information is yet available about the second-generation discontinuous-slab design, which was developed in 1974; the installations using it are not yet operational.

In the design of subway transit facilities, floating slabs are used only in critical areas where it is necessary to reduce ground-borne noise because of the critical proximity of buildings. These track beds add significantly to the cost of the subway structure, and their use is not appropriate except to avoid unacceptable noise intrusion.

DESIGN

The lightweight floating-slab design is based on the concept of the inertial mass-on-spring vibration isolator and uses a simple single-degree-of-freedom analysis for the vertical motion of the floating slab. A maximum deflection of 3 mm (0.125 in) under the static load of the train is generally imposed to limit the rail deflections to acceptable values. To avoid modal interactions and provide adequate control of the motion of the slab along with achieving a significant reduction of the ground-borne noise, the slab mass is made at least equivalent to the train mass and three times the bogie unsprung mass, considering the masses to be distributed over the vehicle length. The vertical fundamental resonance frequency for uniform motion of the slab, loaded with the bogie mass as a dynamic load, must be less than 16 to 18 Hz to provide reduction of the low-frequency audible sound. The design goal is generally 13 to 15 Hz; lower frequencies can be used only if greater rail deflection is allowed or if more space is used, to allow for the greater mass of the slab.

With a loaded resonance of 15 Hz for uniform vertical harmonic motion and a maximum live-load static deflection of 3 mm, the mass of modern rail transit vehicles leads to a design consisting of concrete slabs 275 to 375 mm (11 to 15 in) thick and 3.0 to 3.5 m (10 to 11.5 ft) wide and supported on 75-mm (3-in) thick elastomeric pads. The slabs must be completely isolated from the subway structure and, therefore, the lateral and longitudinal supports are also elastomeric pads. The lateral natural frequency is designed to be less than, but not less than half, the vertical resonance frequency for uniform motion of the slab. The dynamic vertical stiffness of the vertical and lateral support pads and any entrained air must all be included in the calculations of the resonance frequencies and the determination of the elastomeric-pad characteristics required to achieve the design goals.

Figure 1 illustrates the cross section of the design for the continuous floating slabs developed in 1970 for the Washington, D.C., Metro box-section structures. This design uses 305-mm (12-in) thick slabs 3.4 m (11 ft 2 in) wide, supported on resilient pads spaced 600 mm (2 ft) on center. The support pads are 150-mm (6-in) square, load-bearing fiberglass, 150-mm diameter, round natural rubber, or 140-mm (5.5 in) diameter, round polyurethane, all 75 mm (3 in) thick. The side or perimeter isolation is a continuous pad of expanded neoprene or continuous strips of neoprene cemented in place. A detailed performance specification was prepared for use in purchase of the resilient pads to ensure long life and the appropriate stiffness range. The concrete is poured in situ by using a waterproofed sheet-metal form placed on top of the resilient pads and turned up at the sides.

Figure 2 illustrates the plan view of the design for the discontinuous floating-slab design developed in 1974 for use in an extension of the Toronto rail transit system. The cross section is similar to that shown in Figure 1. For box-section structures, this design uses individual precast concrete blocks about 300 mm (11.8 in) thick and 3.2 m (10 ft 6 in) wide, weighing 2500 kg (5400 lb) and supported on four resilient pads each. Side and end pads are provided for lateral and longitudinal restraint. For this design, the support pads are larger because only two rows at larger spacing are used. In the Toronto system, the support pads are of natural rubber, 330 mm (13 in) in diameter and 75 mm thick and spaced 760 mm (30 in) on center longitudinally. The side pads are 300 by 150 by 50 mm (12 by 6 by 2 in) and the end pads are 300 by 150 by 75 mm (12 by 6 by 3 in), both of natural rubber. The side pads are preloaded by about 15 kN (4000 lbs) via the slotted mounting angles and anchor bolts. Similar designs have been adopted for use in the Atlanta; Melbourne, Australia; and Hong Kong transit facilities. Support pads of 330 mm to 375 mm (13 in to 14.75 in) diameter have been used.

The use of either design in single-track round tunnels requires a narrower slab and, because of available space, the mass is usually less than that used for the box section, but still can be made adequate to give the desired results. An advantage of the discontinuous slab design is that it has no entrapped air, which results in a lower natural frequency than that of the continuous design for an equivalent static deflection under load.

The rails are fixed to both types of floating slab by using the same procedures and resilient direct-fixation fasteners as for standard rigid-invert installations. With the precast blocks, recesses for the rail-fastener anchor bolts can be cast in the block, which simplifies the rail installation.

Figure 1. Cross section of continuous floating-slab design.

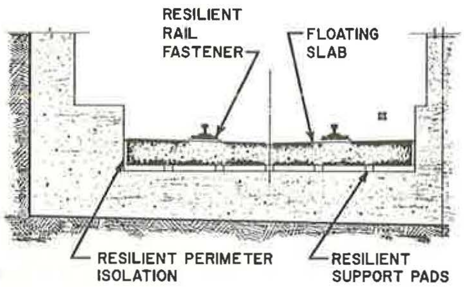


Figure 2. Plan view of discontinuous floating-slab design.

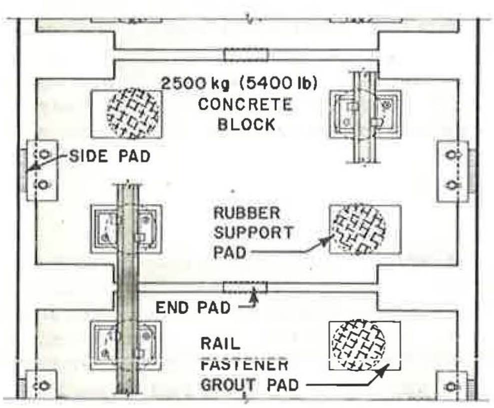
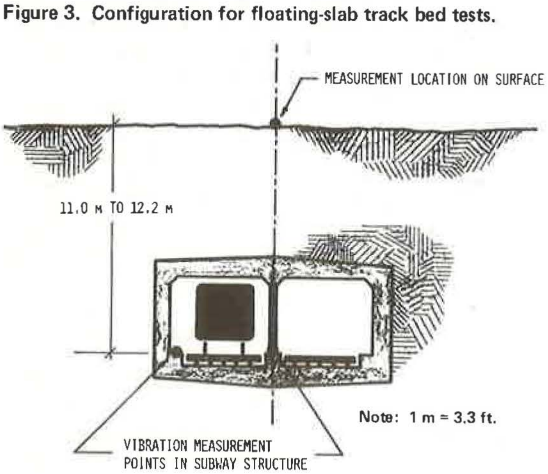


Figure 3. Configuration for floating-slab track bed tests.



RESULTS

Figure 3 illustrates the configuration that was used for tests of the effectiveness of the continuous floating slabs installed in the Washington, D.C., Metro subway structures. The rail was 11 to 12 m (36 to 40 ft) below the surface on a section of subway where there were uniform conditions and both a standard rigid track bed and a long floating-slab track bed. The tests were performed in October 1975; the results are shown by Figures 4, 5, and 6. A two-car train was operated at constant speeds of 32, 48, and 64 km/h (20, 30, and 40 mph) through the test area. The vibration was measured on the subway structure at the side curbs and center bench and on the ground surface by using a sidewalk or a parking-lot slab for mounting the accelerometer. Several accelerometer locations were used and the results averaged, although the differences between the results at the different locations were actually small.

Figures 4 and 5 illustrate typical results, showing the vibration levels by one-third-octave band and the reduction with the floating slab for frequencies above 20 Hz. These results showed only a small amplification of the vibration levels near the fundamental resonance frequency and a substantial reduction at frequencies above 31.5 Hz. At the surface, the background noise and vibration from surface traffic prevented obtaining accurate data for frequencies above 100 Hz with the floating slab.

Because the lightweight continuous floating slab is an undamped concrete plate, it can radiate the noise in the subway due to its bending-mode vibrations. The level of this noise could affect patrons riding in the cars and has been of some concern. During the tests, noise outside the train was also measured; Figure 6 illustrates the comparison of reverberant noise levels around the train with the continuous floating slab and the standard rigid invert for single-track slabs. The floating slab causes an increase in noise level, primarily low-frequency noise, outside the car, but the change in the noise level in the car interior is not noticeable and barely measurable.

Although several kilometers of discontinuous floating slabs have been installed, because the installations are not yet complete, no tests have been made with operating trains. Preliminary low-speed tests with towed cars indicate favorable performance. A reduction in the ground-borne vibration similar to that of the continuous floating slab is expected, and a reduced level of noise radiation in the subway is also expected because of the elimination of the large-area slabs.

One of the significant factors in the lightweight floating-slab design is that no special damping is used, only the natural damping of the resilient-pad material, the entrapped air, and energy radiation. The damping factor at the fundamental resonance of the continuous floating slab was expected to be 5 to 10 percent of critical and was measured to be 17 to 18 percent. For a single-degree-of-freedom system with a steady-state excitation, the amplification at the resonance of such a system would be expected to be 8 to 14 dB, as shown by Figure 7. However, for impact excitation, the amplification would be less than 1 dB with this degree of damping. At the time of the original analysis in 1970, it was estimated that the combination of train excitation, random impact, and periodic forces moving along the slab would lead to results between those of the steady-state response and the impact response—i.e., an estimated amplification at resonance of 2 to 3 dB, as shown by Figure 7.

Figure 8 shows the average results for the continuous floating slab plotted as a response function and indicates that the amplification at resonance is only 3 dB with a moving train as the vibration source and that the results above resonance are closer to those for a simple system than had been expected.

A second factor of importance for the costs and construction complexity of the lightweight floating-slab designs is that no special precision is required for the concrete invert surface in the subway. The standard tolerance and finish for concrete surfaces is adequate and appropriate for supporting the resilient pads. With the continuous slab, the sheet metal form bends when the concrete is poured, so that each pad is loaded uniformly even though the concrete invert may be uneven. With the precast blocks for the discontinuous design, the use of rubber-sheet shims, 3 or 6 mm thick as required, under one of the four pads for each block is sufficient to adjust the supports to a plane and give essentially equal loads on each pad. The need for the shims is determined by using a four-point jig placed at the location of each block during assembly.

During the construction of the continuous slabs, the support pads are cemented to the concrete invert to maintain their position during the placement of the metal form and concrete. In the precast discontinuous slab design, pockets are provided in the bottom of the block for mechanical retention of the support pads. The rubber pads are cemented to the blocks to hold them in place during installation of the block. The shim pads are not cemented or otherwise retained. Dynamic load tests have shown that no fastening is necessary to hold the rubber pads or shims in place after the load of concrete is applied.

Figure 4. Subway-structure vibration levels with two-car Metro train passing at 64 km/h (40 mph).

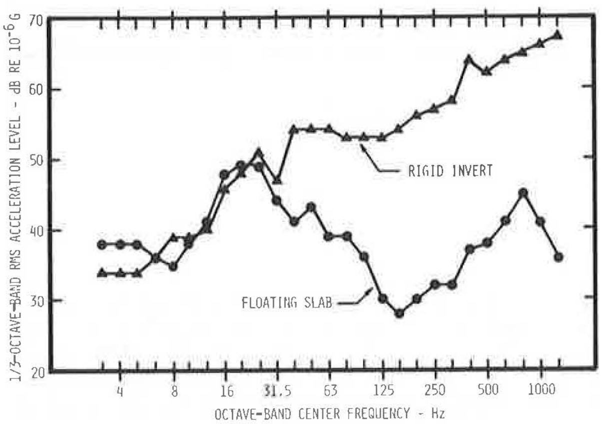


Figure 5. Ground-surface vibration levels with two-car Metro train passing at 64 km/h (40 mph).

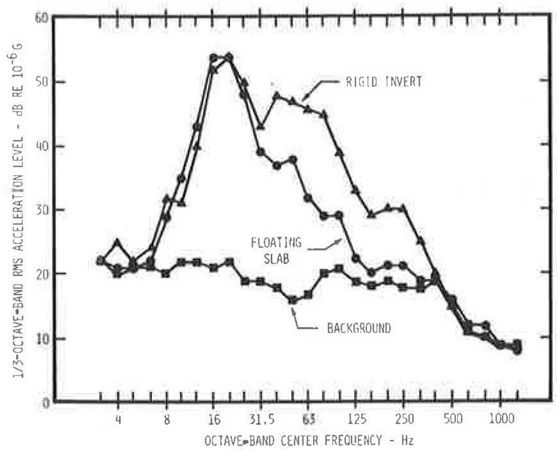
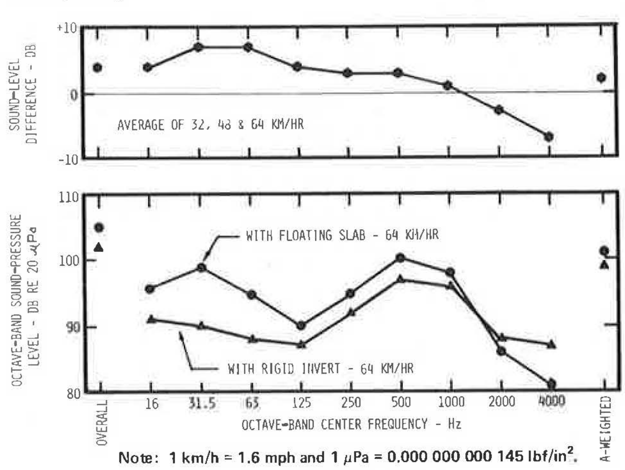


Figure 6. Average wayside noise level in subway with two-car Metro trains passing.



Note: 1 km/h = 1.6 mph and 1 μPa = 0.000 000 000 145 lbf/in².

Figure 7. Force transmissibility response for single-degree-of-freedom vibration-isolation system.

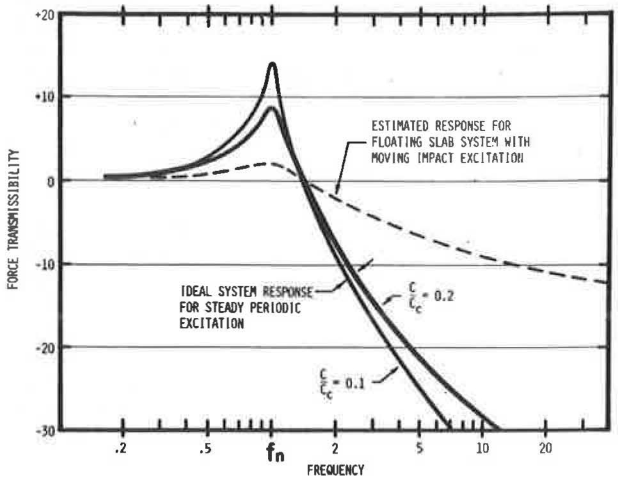
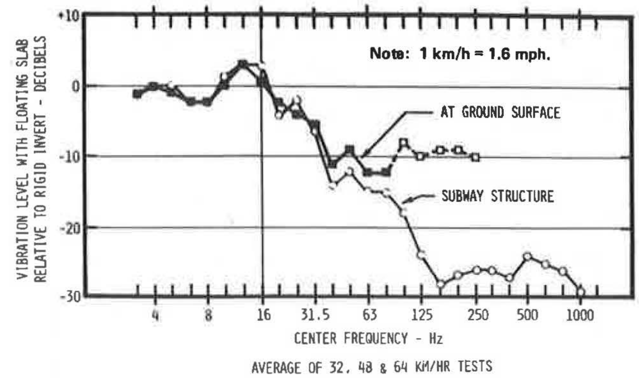


Figure 8. Insertion-loss performance of continuous floating-slab track bed as measured on surface and subway structure with two-car trains.



SUMMARY

A lightweight floating-slab design, requiring small space, has been developed that is effective in reducing ground-borne noise from subway transit trains. The design has two forms, one of which produces an approximately 15-dB reduction of the ground-borne noise in the low-frequency range that is most noticeable in nearby buildings and a more than 20-dB reduction of higher frequency noise. The installation, while requiring special techniques for placing the floating slab itself, requires no special tolerance or finish for the subway structure.

Assistance of New York State Department of Transportation to Railroad in Solving Soils and Foundation Problems

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This paper describes the informal assistance that soils engineers from the New York State Department of Transportation have provided to the Delaware and Hudson Railway Company for the solution of several embankment failures that interrupted traffic operations. Under the present New York State Railroad Service Preservation Bond Act, engineering assistance is available to the railroads, and soils engineers are investigating areas of recurring track maintenance problems caused by soils and water conditions. The goal is to develop solutions for permanent stabilization that will be more economical than continual maintenance. Geotechnical engineering can have a significant input into reducing some of the costs of track operation and maintenance caused by soils, water, and foundation problems. In this case, the service was provided by a highway geotechnical organization. Highway and railroad soils and foundations problems are shown to be similar.

This paper discusses the type of engineering assistance that a state Department of Transportation soils and foundation organization can provide to a railroad for the timely repair of foundation problems that disrupt operations and for other soils-related problems that require continuing maintenance.

Soils and foundation engineering has developed rapidly in the last 30 years. Many state transportation agencies have established units in their organizations to implement geotechnical engineering into the extensive highway design and construction programs over the last 2 decades. In this same time span, most railroads have not had major construction programs, and there has been little stimulus for them to develop soils and foundation expertise in their engineering staffs. Railroads and highways are similar facilities except for the travel way. Their problems with embankments, embankment foundations, and rock or earth cut slopes have similar solutions. Tracks and pavements are both located on the ground surface, and the travel ways are both subjected to the same climatic freeze-thaw and wet-dry cycles that affect the performance of the subgrade soils and the pavement or ballast.