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

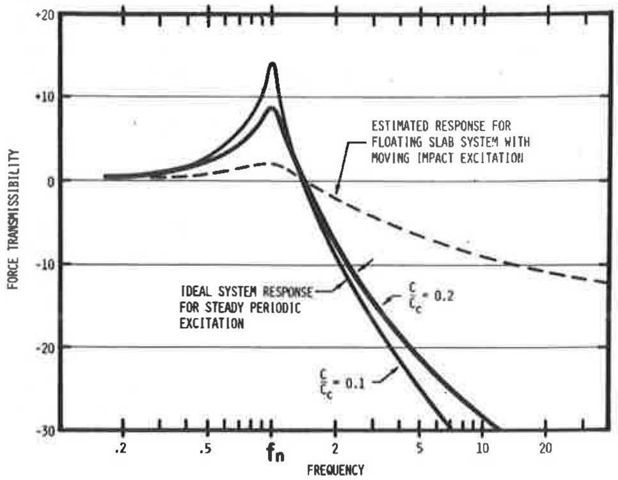
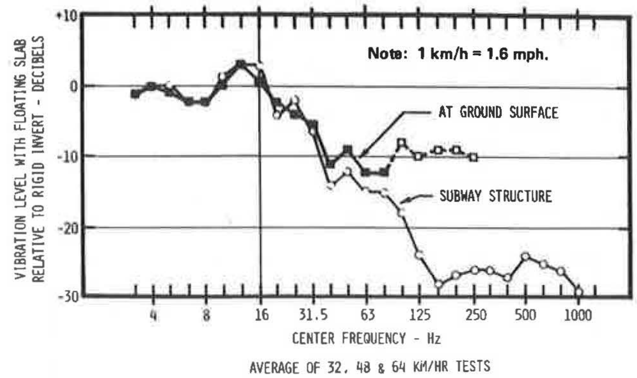


Figure 8. Insertion-loss performance of continuous floating-slab track bed as measured on surface and subway structure with two-car trains.



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.

For the last 15 years, members of the soils staff in the New York State Department of Transportation (NYSDOT) have provided informal assistance to the Delaware and Hudson Railway Company (D and H RR) in solving major soils and roadbed problems. The bases for this relationship are that the headquarters of both organizations are in Albany and that several NYSDOT engineers formerly worked for the railroad.

The D and H RR system in New York State extends from Pennsylvania to the Canadian border, as shown in Figure 1. New York is a glaciated state, and the major valleys contain soils deposited by large quantities of glacial-melt water as the ice sheet receded northward. The northern portion of the D and H RR is located in the Lake Champlain Valley, which contains plastic clays of limited strength and other water-laid deposits of coarser sand and gravel.

Both the embankment problems described in this paper were major failures that disrupted service and required immediate repair without taking the time for subsurface exploration and laboratory testing. Therefore, there was a need for a soils engineer having experience with similar foundation problems to advise on the most expedient and correct action to take.

The first embankment-failure problem occurred at Spar Mill Bay in 1963 and involved a 6.1-m (20-ft) high embankment located near the shore of Lake Champlain. Several days before the major failure, maintenance

Figure 1. Delaware and Hudson Railway Company system in New York State.

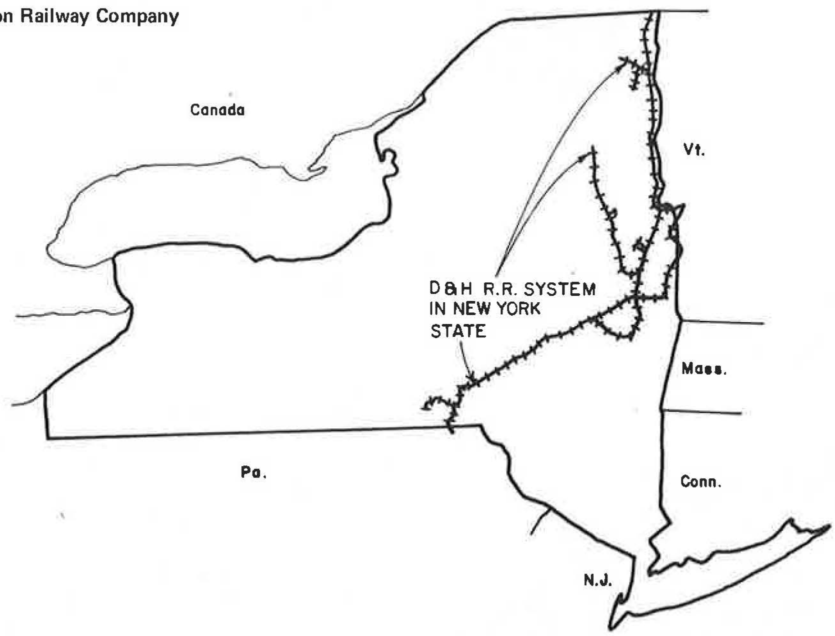


Figure 2. Section of slide: Spar Mill Bay.

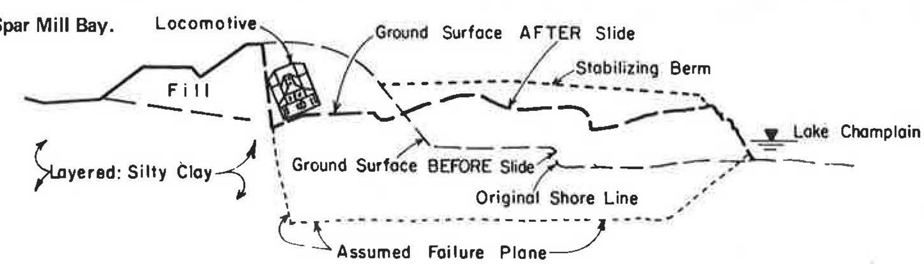


Figure 3. Location plan of slide: Spar Mill Bay.

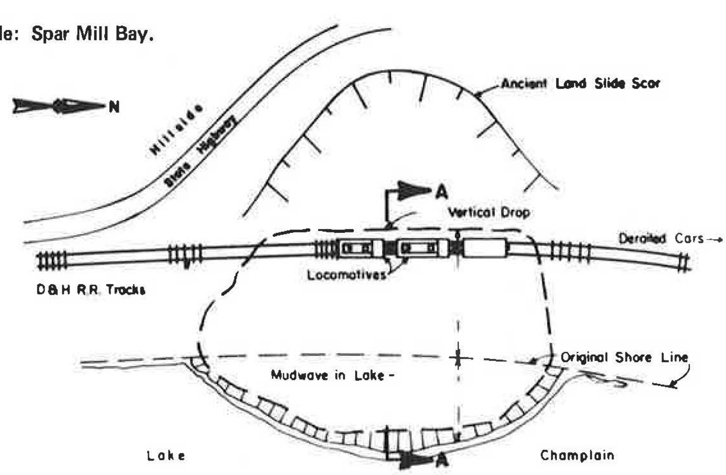


Figure 4. Embankment failure: Spar Mill Bay.

Figure 5. Mud wave: Spar Mill Bay.

crews had repaired some minor track settlement at the site. Additional settlement occurred, and the next day a northbound freight was derailed, scattering numerous cars along the track north of the future failure area. A work train was sent to the site, cleared the tracks, and unfortunately backed onto the unstable embankment-settlement area while waiting for orders. Suddenly, the embankment and locomotives dropped 6.1 m (20 ft) and simultaneously the bottom of Lake Champlain 45.6 m (150 ft) distant rose 3.5 m (12 ft) above the water. The details of this failure are shown in Figures 2 and 3. Figures 4 and 5 show the locomotives and the mud wave that exposed the lake bottom.

Soils engineers in NYSDOT were asked for an appraisal of the failure and recommendations for restoration of the embankment to reestablish main-line service. On inspection, it was found that the area was underlain by a layered silt and clay deposit and that the topography of the adjacent hillsides showed evidence that this was an area of ancient landslides. It was concluded that the initial settlements observed had been caused by minor movements in the underlying clay. Although the embankment had been stable for 30 years, high ground-water conditions may have cause minor plastic movements in the foundation soil and contributed to the settlement that caused the derailment. However, the major movement was caused by the mass of the locomotives and the vibrations of the idling engines. These vibrations apparently caused the liquefaction and complete loss of strength in an underlying silt layer that resulted in the spectacular failure. The recommendations were to construct a stabilizing counterweight berm over the mud wave to the elevation shown in Figure 2. After the berm was completed, the embankment was brought back to grade. This was done in 2 d, and the area has presented no problem during the last 14 years.

At a location further north at Port Kent, a failure occurred in the spring of 1971. At this location, the roadbed is on a side hill fill 12 m (40 ft) above Lake Champlain, as shown in Figure 6. The embankment was constructed 50 years ago against the face of a delta deposit of sand laid down by postglacial rivers flowing from the Adirondack Mountains. Suddenly, during the spring thaw, a portion of the fill liquified and slumped

Figure 6. Conditions before failure: Port Kent.

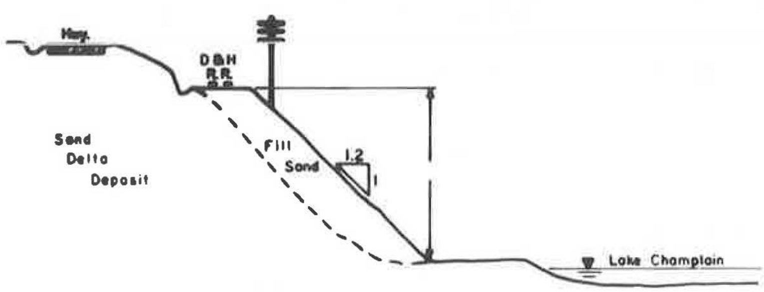
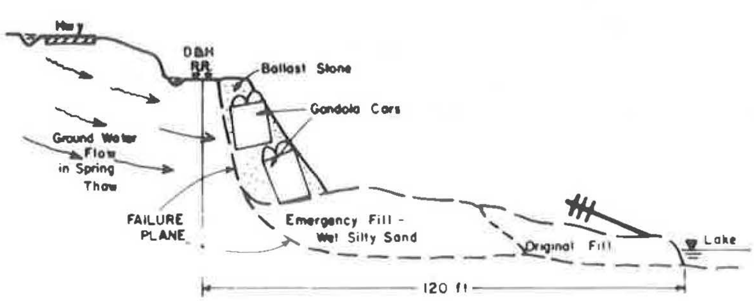


Figure 7. Failure and repair sequence: Port Kent.



into the lake. Railroad maintenance forces placed an emergency fill, but this also became unstable and flowed into the lake.

NYSDOT soils engineers were requested to make recommendations for stabilizing this failure of the main-line embankment. An examination of the site showed that groundwater was emerging from the slide face. This groundwater flow must have increased significantly immediately before the failure; the winter frost had just become completely thawed, and the accumulated surface groundwater could flow downward to the delta deposit where the natural direction of subsurface drainage was toward the lake. The embankment had less permeability than the natural deposit, and the groundwater head and seepage forces caused the fill to become unstable at its steep angle of repose, which resulted in the failure. The solution recommended was the reconstruction of the embankment with a pervious material that would allow drainage and a lightweight material that would reduce the load on the unstable fill. Readily available materials were ballast stone to provide permeability and a number of old gondola-car bodies to decrease the embankment weight. The embankment was constructed to grade with the cars upside down as shown in Figure 7. The main line was reopened to traffic in 2 d, and the embankment has been stable since then.

These two case histories demonstrate the potential for technical assistance that an experienced soils organization can provide to a railroad for the solutions of major foundation problems. This assistance was conducted on an informal basis.

In the past 5 years, there has been an increase in federal and state funding for improvements to existing railroad systems. In 1970, New York State voters approved the Railroad Service Preservation Bond Act, which authorized $250 million for the maintenance and improvement of rail transportation facilities and services. NYSDOT was designated to administer this program, and its engineering assistance is available for the identification and development of projects eligible for funding.

The D and H RR has recognized the value of the previous soils engineering services for their emergency problems. Under the new engineering-assistance arrangement, they requested a soils investigation of an unstable embankment area adjacent to Lake Champlain. Subsurface explorations and laboratory testing and analyses were conducted to determine the most economical method to provide a stable embankment, and a design report was prepared for the railroad.

Under the same engineering-assistance arrangement, NYSDOT soils engineers and D and H RR engineers and maintenance personnel have recently made a field survey of 160 km (100 miles) of main line track to locate areas of perennial maintenance problems caused by soil and water conditions. Some of the conditions causing maintenance problems are subgrade pumping of fine-grained soils, erosion of finer soils through riprap protection, unstable embankment foundations and cut slopes, and stream-bank erosion. A report is being prepared indicating the locations of the soils-related maintenance problems and suggesting methods of permanent stabilization. It is probable that the cost of some recommendations will be greater than that of continuing maintenance. However, for other problems, permanent stabilization may be economically practical, making long-term savings possible through reduction of maintenance costs.

This engineering-assistance arrangement does not obligate the railroad to comply with the NYSDOT recommendations to be eligible for state funds. The railroad is responsible for the final decisions and policies involving engineering operations. The geotechnical engineering services of NYSDOT are available to provide the most economical and adequate solution of maintenance and operation problems for the mutual benefit of the railroad and the state.