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Report of In Situ Structural Rehabilitation of Deteriorated Platform Concrete Washington Metropolitan Area Transit Authority With Vacuum

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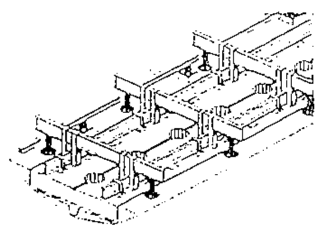
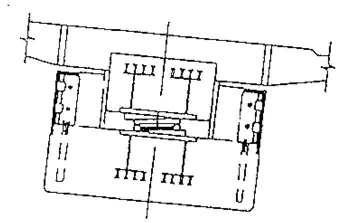
UNIQUE REHABILITATION AND RETROFIT PROCEDURES FOR RAIL-TRANSIT STRUCTURES





by

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Parsons DeLeuw, Inc.

APTA Rapid Transit Conference,

Miami, Florida

Structures Session

Complements of

June, 1993 TECVAC, Inc.

ACKNOWLEDGEMENTS

The rehabilitation and retrofit designs described in this paper were performed under the direction of Mr. Ado Valge, Assistant Director, Office of Engineering and Architecture, WMATA. He also reviewed the manuscript and provided valuable suggestions for its improvement.

The retrofit procedures were implemented under the direction of Mr. Alonza Clarke, Manager CIP Program and Mr. Don Painter, Manager Track and Structures.

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UNIQUE REHABILITATION AND RETROFIT PROCEDURES FOR RAIL-TRANSIT STRUCTURES

SYNOPSIS:

Rehabilitation and retrofit of aged and distresses rail-transit structures and facilities often calls for unique and innovative engineering solutions, if the requirements of the operating-system safety and reliability, and the construction economy, are to be optimally realized. The paper provides an overview of three such examples selected from the Washington Metro's heavy-rail system. The first project involves a unique bearing replacement design for a post-tensioned concrete guideway on the Yellow Line at National Airport. The retrofit procedure called for a non-stop 52-hour operation. Two bearings were successfully replaced in the mid- eighties. Two more are due for replacement during 1993. The second example deals with the rehabilitation of deteriorated platform concrete at an at-grade station. The concrete deterioration was caused by alkali-aggregate reaction and by the deicing salts, in conjunction with the freeze-thaw damage. The novel vacuum-impregnation method was used to successfully restore integrity of the affected concrete and thus obviate the need for platform demolition and reconstruction. The method was subsequently used for the rehabilitation of several other station platforms. The third example deals with the rehabilitation of settled floating slabs in tunnels. A unique design, dubbed as the Window Cutting Method was developed to facilitate the replacement of defective isolators with new vibration-isolator units. The repair procedure is capable of being implemented by Washington Metro's own maintenance forces. The method has recently undergone successful trials and is now used on a routine basis, to retrofit settled floating slabs in circular tunnels.

INTRODUCTION

Rehabilitation of major structures in rail-transit systems typically involves four steps, once a direct or indirect indication of structural distress has been determined through the inspection program. These steps include:

1. Investigation: An investigative phase whose objective is to determine, as accurately as possible, the likely cause or causes of the distress phenomenon. In its most comprehensive form this involves a review of the original design assumptions and procedures, review of shop, working and as-built drawings and any available construction data pertaining to the affected structure. Field inspection and surveys are performed to fully define the scope and severity of the problem, and to corroborate the inspection reports and the information contained in the as-built plans. A good investigative effort provides a sound basis for developing an optimal remedial procedure. The investigative program also helps in determining whether or not a temporary retrofit is needed on an emergency basis, before the permanent fix can be designed and implemented, to ensure the continued integrity of the affected structure.

2. Design: Development of a rehabilitation design that reflects the findings of the investigative program. Bid documents, in the form of Invitation-for-Bid (IFB) or Request-for-Proposal (RFP) are prepared by the Consultant per the owner's requirements. In the case of a perceived emergency, it is sometimes more expedient to have the work performed under a change order by a qualified contractor, already engaged on another construction contract. Sometimes the design package is prepared solely for the use of

the owner's own work force.

Preparation of rehabilitation design demands a close coordination between the Consultant and the owner's various departments such as Engineering and Architecture, Construction, Rail, Structures Maintenance, Safety and so on.

3. Construction: The implementation of retrofit design is performed such that any impact on the operating schedule is kept to an absolute minimum. Operating system safety during construction is ensured. Every effort is made to minimize the construction period.

4. Monitoring: The rehabilitated facility is monitored as necessary to ensure that its structural integrity has been fully restored. Once this has been verified, the structure is returned to the routine inspection and maintenance program.

Dependent upon urgency and funding availability, major rehabilitation projects are often performed in several phases. Where feasible, a hierarchy is established as to which elements of the rehabilitation effort should receive priority over others.

The rehabilitation projects discussed herein generally embody the process described in the preceding. All case histories presented have unique features, as should be evident from the following narrative.

continued intermittently during the intervening eight years, should soon be completed, bringing this involved rehabilitation project to a successful conclusion.

CASE HISTORY 2: IN SITU STRUCTURAL REHABILITATION OF DETERIORATED PLATFORM CONCRETE

The Structural System:

Passenger station platforms, and other pedestrian areas accessible to patrons, are characterized by WMATA's familiar paver tile construction. The aesthetically-pleasing tiled surfaces make a strong and unifying statement in terms of WMATA's systemwide station architecture (Fig. 10). For typical platform construction, a six to eight inch thick reinforced concrete slab, supported by walls, serves as the primary structural support system. The slab is cast-in-place using 3,500 psi concrete. Along its longitudinal edges, adjacent to the tracks, the platform slab overhangs approximately 5'- 9 1/2". Customary construction has employed three to four inch thick non-structural setting bed over the structural slab to serve as a substrate for the paver tiles. In the original construction, the tiles were installed using latex-portland cement mortar. The tile jointing material was latex-portland cement grout. The platforms are typically provided with 18 inches wide granite edging, laid on one-inch thick non-structural setting bed. The aboveground station platforms are provided with transverse expansion joints typically at 50 ft on centers.

Problem Definition, Investigation and Findings:

During 1985, when a platform paver tile rehabilitation project involving several above-ground stations was being contemplated, it was discovered that several at-grade and aerial platforms exhibited deterioration of their structural slabs, in addition to the relatively more familiar paver tile, granite edge and setting bed distress (Fig. 11).

By far the most advanced deterioration was observed in the exposed areas of the Minnesota Avenue Station platform, located on the Orange Line. Using this structure as a starting point, an investigation was launched to determine the cause of concrete distress and to develop recommendations for remedial measures leading to the development of rehabilitation design.

An investigation was performed to determine the cause or causes of the deterioration. Concrete coring was performed for testing purposes. In some instances the Minnesota Avenue structural slab had deteriorated to such an extent that the core recovery with sufficiently long pieces for compressive testing was not possible. It was found that at some locations concrete strength had significantly degraded from the design value. In addition to the deterioration of the interior regions of platforms, the longitudinal edges of structural slabs and the underside of the overhangs also exhibited excessive deterioration. The concrete cores were analyzed at Construction Technology Laboratories (CTL). The petrographic examination performed revealed that among other things alkali aggregate reaction (AAR) was at work. The reaction was initiated by penetrating moisture. It caused expansion of susceptible coarse aggregates and their consequent microcracking. The expansive cracks radiated from the aggregate into the cement paste degrading the concrete microstructure and hence its strengths.

It was evident, that the platform concrete was exposed to very aggressive environment. During the winter, rainwater and snowmelt combined with deicing slats infiltrated the cement-grout setting bed, through the paver tile joints and through any cracks in the tiles, and through expansion joints. In addition to AAR, the moisture intrusion caused the setting bed and the concrete slab to deteriorate from freeze-thaw cycles. The testing also revealed freeze-thaw damage to the structural slab as well as the setting bed. Less than optimum air entrainment had promoted the freeze-thaw damage. Chloride contamination, from deicing salts, also contributed to some rebar corrosion.

Rehabilitation Procedure:

A variety of rehabilitation procedures were examined vis-a-vis the findings of the investigative program. In these deliberations, reliability of the future repair method was a primary consideration. A durable rehabilitation procedure was sought for the structural slab, and for the paver tile construction supported by it, to obviate the need for frequent paver tile and setting bed replacement, as had occurred in the past at some locations.

In a generalized sense, only two basic options were available: Remove the defective concrete and repour, or utilize a procedure capable of in situ restoration of concrete. Demolition of old concrete and then rebuilding of the affected portions of the platform would have been excessively intrusive from an operational viewpoint, besides being expensive. Therefore, it was decided to focus attention, at least initially, on an in situ repair method. Discussions with specialists in the concrete rehabilitation industry led to only one technology, namely the Vacuum Impregnation Method (VIM), that appeared capable of fulfilling the objectives of the rehabilitation program.

This method had been used in Europe, and to a very limited extent in the U.S., to accomplish deteriorated concrete rehabilitation under a wide-range of conditions. This method is based on first creating a partial vacuum in the concrete, a suitable polymer resin is then introduced into the concrete-matrix . The resin fills the cracks, including microcracks down to 0.001 inch, and less. Upon its setting the resin bonds the cracked and fissured matrix into monolithic structural concrete of high strength.

Vacuum creation and resin injection is achieved by bonding vacuum and injection ports to the concrete area being repaired. By means of tubes, the ports are connected to a vacuum pump. After the vacuum has been drawn, resin is injected to fill all major cracks and subsequently to generally impregnate the concrete.

The full scope of the procedure includes three types of repairs. These are: vacuum injection of discrete cracks, flushing of concrete to impregnate the concrete and to fill closely spaced microcracks, and rebonding of any concrete delaminations. The vacuum process evacuates moisture from the concrete. Excessive water can be extracted by using nitrogen with vacuum. The concrete drying process can be monitored by using in-line hygrometers installed on the vacuum line. In terms of the rehabilitation needs of the Minnesota Avenue Station platform, the method offered the following advantages vis-a-vis the pressure injection procedure:

- Impregnation of concrete and efficient filling of microcracks would be achieved.
- No further damage to concrete microstructure would occur because vacuum rather than pressure would be utilized.
- No bubble formation with low viscosity, low specific gravity resins would be likely and hence improved bonding would be ensured.
- Lack of pressure pockets in dead-end cracks would facilitate higher fill ratio than pressure injection.
- It would be feasible to remove excess moisture from concrete, prior to impregnation and sealing, ensuring the retardation of AAR and rebar corrosion.

Despite the apparent advantages, it was recognized that no prior experience with this method existed on the WMATA project. Additionally, neither in Europe nor in the U.S. had this technique been used to restore concrete integrity in the presence of AAR. Accordingly, it was decided to perform a trial retrofit to verify the suitability of the method for the intended rehabilitation of structural concrete.
A 170-square foot area of deteriorated slab at Minnesota Avenue Station was selected to perform the trial retrofit. The trial was concluded in July 1985 (Figs. 12 thru 15). Low viscosity methyl methacrylate (MMA) resin was used to impregnate concrete and to seal the cracks. MMA was chosen because of its low viscosity, high strength, flexibility, and good bonding and wetting properties. MMA is not temperature sensitive and can be relatively easily mixed or modified. Additionally, fresh MMA can be easily bonded to the previously set MMA.

Control cores were taken before and 8-hours after the completion of the impregnation operation. The cores were tested to yield a compressive strength ranging from 6,400 to 7,200 psi. indicating that the method was completely successful in restoring the structural integrity of once highly deteriorated concrete whose compressive strength was significantly less than the design strength of 3,500 psi. In addition to the restoration of strength, the drying of concrete by vacuum and nitrogen, and its subsequent impregnation and sealing with MMA considerably lowered the possibility of future deterioration because the alkali-silica reaction cannot take place in the absence of moisture. Likewise susceptibility of rebar to corrosion was also significantly diminished.

It should be mentioned that in 1989 a test program, not related to WMATA project, was performed at Cornell University on mortar bars made of reactive aggregates and high alkali cement. The test specimens were exposed to highly aggressive environment. The results of the testing verified the ability of the vacuum impregnation method to limit the expansion of the mortar bars to within acceptable limits.

Upon successful completion of the trial-retrofit, the vacuum impregnation method was included in the bid packages to perform rehabilitation of several platform slabs, where presence of AAR, in its various stages of development, had been indicated by the core testing program.

In a typical vacuum impregnation operation, about 1,000 square feet of concrete slab is treated in one step. Typically 96 to 97 percent vacuum is utilized. The viscosity of MMA used varies between 5 to 15 centipoise. The various steps involved in the repair procedure include setting bed and paver tile removal, followed by sand blasting of concrete to expose cracks. Installation of vacuum and injection ports and netting and polyethylene shroud is next accomplished. Vacuum is drawn followed by filling of major cracks with MMA. After the discrete cracks have been repaired, mass impregnation of concrete is performed. At the completion of the impregnation operation, polyethylene sheeting and netting are removed. After the resin has set, setting bed is poured on the repaired slab to facilitate subsequent installation of paver tiles. Control core drilling is performed before and after the impregnation as a quality control measure.

In addition to the MMA impregnation of the structural slab, microsilica setting bed was used for the paver tile rehabilitation projects. On the more recently completed projects, polyurethane mortar and grout replaced the latex-modified portland cement mortar and grout for the paver tile installation. The rehabilitated slabs are reported to be performing well.

As a footnote, it should be pointed out that WMATA is probably the first rail-transit authority to include explicit anti-AAR provisions in its specifications, as a result of the investigation program described in the preceding. Since then, several major projects, including above-ground station platforms, have been constructed using these specifications. The AAR specifications represent one of the several steps taken by WMATA to further improve the durability of its concrete structures exposed to aggressive environment.

CASE HISTORY 3: REHABILITATION OF SETTLED FIRST-GENERATION FLOATING SLABS

Overview:

Floating slab construction has been utilized in the WMATA's underground system to mitigate the effects of groundborne vibration on adjacent buildings and their occupants. WMATA's floating slab design provides vibration-induced noise mitigation in the frequency range of 20 to 150 Hz. Floating slabs have been used in all types of underground structures including the mined soft-ground and rock tunnels as well as the cut-and-cover construction. A total of 69,000 linear feet of

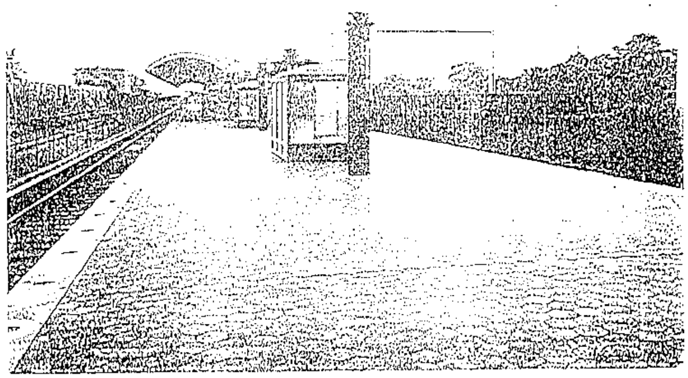

FIG.10

FIG.11

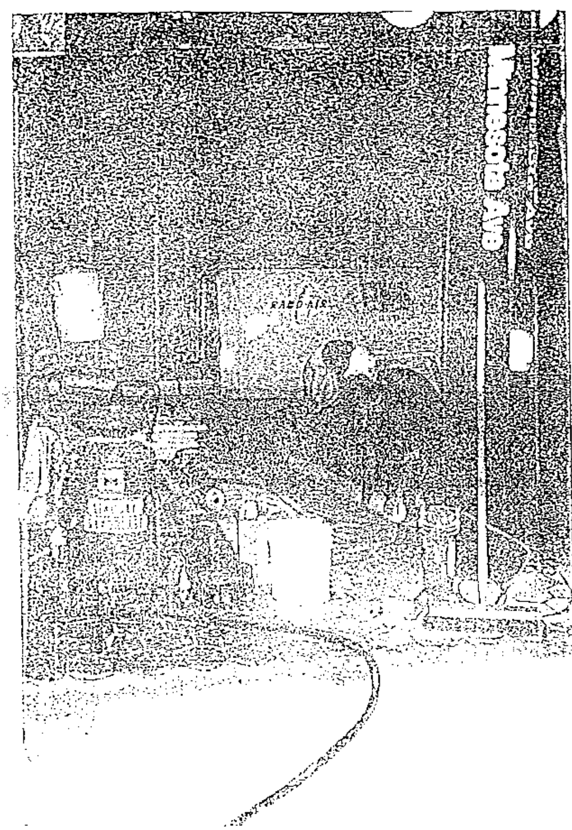

FIG.12

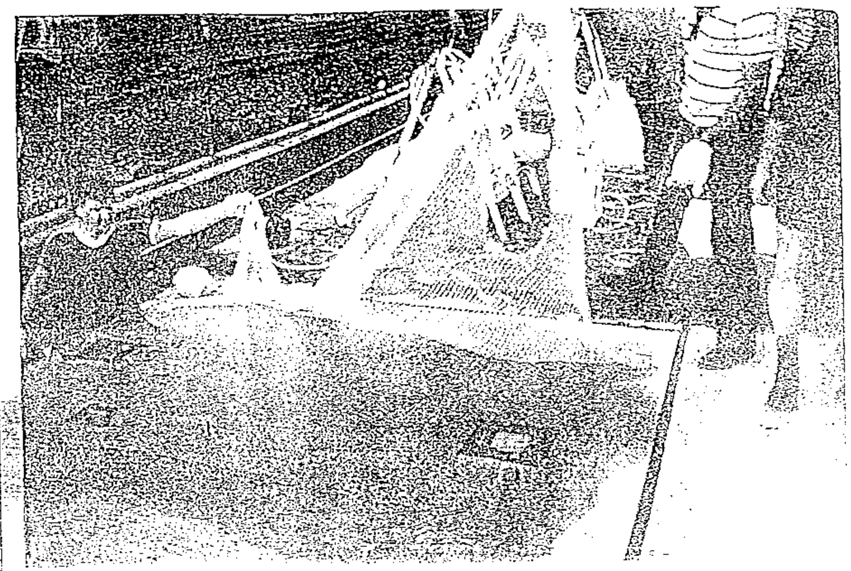

FIG.13

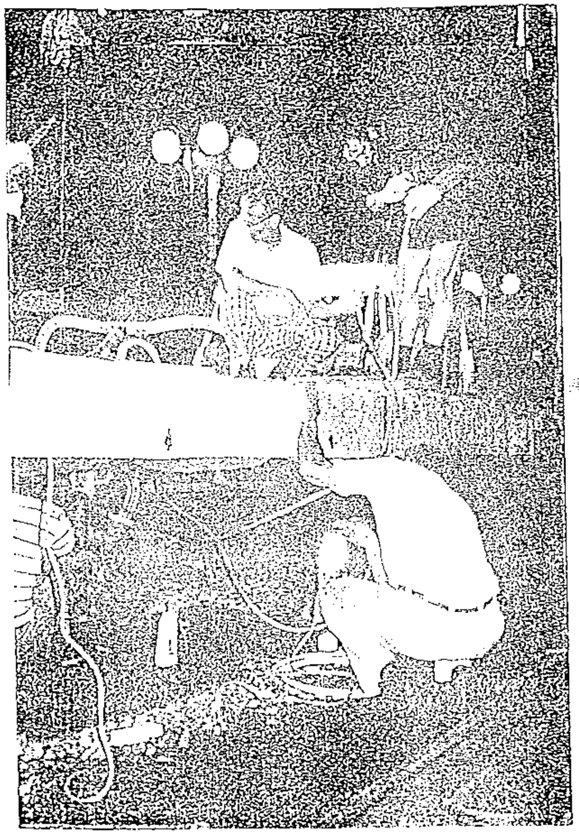

FIG.14

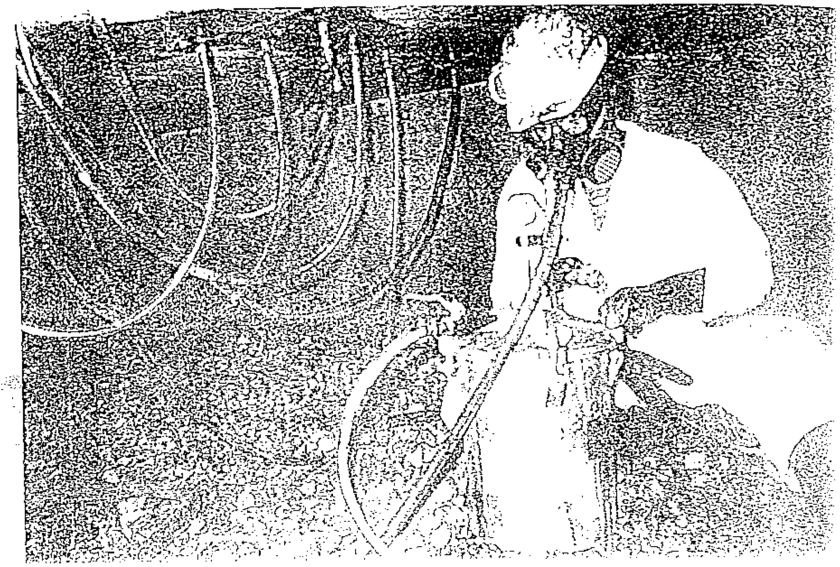

FIG.15