Dallas/Fort Worth Airport Train Critical Needs

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ABSTRACT

Many APM systems are approaching the end of their design service lives and extending the life of these systems is becoming a priority. As many APM systems surpass their design service lives, upgrading systems and performing repairs while maintaining acceptable levels of service will become a more common challenge.

The Airport Train Critical Needs Analysis and Implementation Projects for the Dallas/Fort Worth International Airport began in 1996 and continued through the end of 1998. The purpose of the work was to determine what actions were required to extend the reliable service life of the Airport Train System for 10 years and to implement those actions. All elements of the Airport Train system were evaluated during the investigation. The guideway and civil structures portion of the investigation included a comprehensive review of previous investigative reports, repairs and guideway maintenance methods and materials. Civil and structural elements included: entrapment rails, switches, concrete parapet walls, bridge abutments, elevated guideway deck, expansion joints, continuity joints, prestressed concrete box beams, columns and bent caps, drainage systems, on-grade guideway slabs, guideway base support, and slope stability. Based on field observations, guideway maintenance history, and AASHTO Code based calculations, repair and improvement recommendations were developed and implemented.

This paper summarizes the investigation phase of the work and presents an overview of the recommendations. One of the implemented repairs, made to degraded parapet wall running surfaces, is discussed in detail. Numerous repairs had been attempted in the past to address this persistent maintenance problem with little success. After reviewing previous repairs and evaluating several possible alternatives, a "Pilot Program" was recommended and implemented. An epoxy-sand grout was developed in cooperation with contractors executing the work. This repair was applied in selected sections of guideway and its performance was evaluated over a two-year period. That evaluation is now complete and the repair has been recommended to be implemented throughout the Airport Train system.

INTRODUCTION

The Dallas/Fort Worth Airport Train system (formerly known as "Airtrans") provides transportation between all airport terminals, North and South Reduced Rate Parking and the on-airport Hotel. It is the largest airport automated people mover in the world, and with regard to vehicle fleet size, route structure and guideway length, by far the most complex. Passenger service is provided over four overlapping routes, one of which is secure, with airport and airline employee service provided over two routes. All service is provided over a 24-hour period. A fleet of 66 passenger vehicles provides service to 33 passenger and employee stations located throughout approximately 14 miles of on-grade and elevated guideway. As the airport has grown, the Airport Train has evolved into a vital transportation link at DFW Airport.

As planning for a replacement APM system began, the end of the Airport Train's service life became foreseeable and it was clear that the existing system would have to remain in service until the replacement APM system came online. In 1996, airport management concluded that the Airport Train system should remain in operation for an additional ten years and initiated the DFW Airport Train Critical Needs Analysis. Lea+Elliott, Inc. and its subconsultants Charles F. Terry, Inc., Arredondo Brunz & Associates, Inc., and TerraMar, Inc., were retained by DFW Airport to evaluate the entire Airport Train system and recommend actions that should be taken to extend the system's service life for an additional 10 years while maintaining existing levels of reliability. The entire guideway system and all aspects of system equipment, including the availability of spare parts, were investigated. This was the first comprehensive investigation of the guideway system conducted since 1979.

After completion of the investigation and recommendation work, Lea+Elliott, Inc. and its subconsultant Charles F. Terry, Inc. were retained to implement the recommendations. Maintaining Airport Train operations while implementing the recommended guideway repairs required detailed planning and a cooperative effort by consultants, contractors and Airport Train maintenance and operations personnel. Coordination between those executing the work, airport operations, airlines and other airport personnel providing support for the effort were key to the successful implementation of guideway repairs.

This paper presents an overview of the Critical Needs Analysis and Implementation work associated with the guideway system and discusses the implementation process for one specific guideway repair in detail.

HISTORY

Original elements of the Airport Train guideway were constructed during 1972 and 1973. Vought Aeronautics was the prime contractor with General Portland Cement Company and Texas Bitulithic Co. as key subcontractors. Construction documents for the original guideway system were prepared by ABAM Engineers Inc. and are dated 1971 and 1972. The guideway system was expanded and modified in 1990 to add the secure AAirtrans Express route for American Airlines. An additional crossover connecting east and west sides of the airport was added to the system in 1997 and 1998. Lea+Elliott Inc. and Charles F. Terry, Inc. prepared the construction documents and Austin Bridge Company was the general contractor for both of these expansion projects.

Structural concrete was the material chosen to satisfy the demanding durability requirements of the guideway system. Most of the on-grade elements are cast-inplace concrete. Precast, prestressed concrete box beams were used throughout elevated guideway sections. Grade supported abutments were cast on a 12-inch thick lime stabilized base. On-grade sections of guideway are supported on a 2-inch thick asphaltic concrete base, which is supported by a 12-inch thick lime stabilized base. There are no expansion joints within on-grade guideway sections. Vertical control joints were sawn into the outside faces of the concrete parapet walls at regular, closely spaced intervals to minimize random cracking.

Previous Studies and Reports

Soon after the system was placed into service, in March 1975, URS/Forrest & Cotton, Inc. of Dallas, Texas, reviewed the Contract Documents, made a visual inspection of the guideway system, and prepared a written report for Vought Aeronautics. They prepared a similar report dated April 30, 1976 for the D/FW Regional Airport Board. They also prepared two supplemental reports for the D/FW Regional Airport Board. Supplemental Report No. 1, dated January 17, 1977, discussed recommended repairs for parapet walls in on-grade sections of guideway and a repair for beam/column joints in elevated sections. Supplemental Report No. 2, dated April 5, 1977, discussed the actual process of making the recommended repairs, the good performance of the repaired elements, and recommended that similar repairs be made throughout the guideway system. Those recommended repairs were implemented soon thereafter.

In July 1979, fieldwork began on a study by ARE Inc., Engineering Consultants, of Austin, Texas. The scope of their work included on-site investigation, non-destructive testing, evaluation and the formulation of recommendations for repairs to the Airtrans guideway. Their recommendations included the establishment of a continuing evaluation program for the entire guideway network, and their report included a Guideway Maintenance Manual that was to be used as a basis for maintaining the integrity of guideway structures.

DATA COLLECTION

Discussions were held with guideway maintenance personnel to determine items that have required maintenance to the extent that train operations were affected. They also identified items that they expected would require future maintenance, and some items that were detrimentally affecting train operations, but that maintenance personnel were not able to effectively correct. Types of repair materials being used by the maintenance staff were discussed, as were the reasons that certain materials were being used while others had been tried and abandoned.

A brief tour was taken on Wednesday, October 30, 1996 to observe items highlighted in the discussions and to observe guideway locations that had been especially problematic to the maintenance staff. Several durability problems were observed, including locations where entrapment rail support bracket anchor bolts had broken out of concrete parapet walls and locations where these anchor bolts were severely corroded or broken. Degraded vehicle guidewheel running surfaces had been repaired with both concrete patches and stainless steel plates. Sections of concrete parapet wall were observed that had been either strengthened or completely removed and replaced. Abutment settlements were observed, as well as problems that result from these movements such as joint faulting (vertical steps across joints), excessive power/signal rail wear and undulating guideway profiles near grade-supported abutments. Cracking and shifting sections of concrete riprap were observed, as well as areas adjacent to on-grade sections of guideway that did not drain.

Field Investigation

Every section of both on-grade and elevated guideway was visually inspected between November 18, 1996 and December 2, 1996. Existing guideway conditions were documented using inspection forms developed for that purpose. Where possible, data were recorded to facilitate comparison with results documented in previous reports. Open joints within elevated sections of guideway were measured and compared with measurements included in the ARE, Inc. report dated January 1980. General information about cracks in on-grade guideway slabs was reported by ARE, Inc., and this was compared with the data recorded during the Critical Needs work.

Elevation surveys were performed along three sections of on-grade guideway on January 6 and 7, 1997. Guideway profiles were plotted from that data and compared with profiles included in the January 1980 ARE Inc. report. At the request of DFW Airport, live load deflection measurements were made along specific elevated guideway sections. To compliment these measurements, Airport Train empty weights were confirmed by weighing three Airport Train vehicles with portable truck scales.

The existence of voids below sections of on-grade guideway was also investigated at the request of DFW Airport. Ground penetrating radar was chosen as a cost-effective way to locate voids, and Pulse Radar, Inc. of Houston, Texas was contracted to perform a void detection survey throughout the entire guideway system. A short pulse radar unit was attached to an Airport Train vehicle above the wheel path and continuous radar data was recorded as the vehicle traveled through the entire guideway system. The radar unit was moved to the opposite wheel path and the process was repeated. The methodology used was consistent with ASTM D4748-87, Standard Test Method for Determining the Thickness of Bound Layers Using Short Pulse Radar.

FINDINGS AND RECOMMENDATIONS

The guideway portion of the Critical Needs Analysis included findings and recommendations for entrapment rails, switches, concrete parapet walls, on-grade guideway slabs, elevated guideway deck, prestressed concrete box beams, interior columns and bent caps, abutments, and the guideway drainage systems. Discussion of all of these items is beyond the scope of this paper. For brevity, degradation of the concrete running surfaces along the tops of parapet walls is discussed in detail. This discussion is intended to illustrate some of the considerations and challenges faced by designers and contractors implementing repairs on active guideways.

DFW Airport Train vehicles have hard plastic guide wheels at all four corners that roll along the inside face near the tops of concrete parapet walls. The forces imparted on the walls by these wheels are relatively small, but the walls must endure continuous cycles of this dynamic load. Significant degradation of these walls along the guide wheel paths was observed throughout the guideway system. Loss of cement paste and fine aggregates from the concrete surfaces and exposure of coarse aggregates was observed, as well as severe spalling at vertical cracks and other locations. The problem accelerates once initiated. Guide wheels roll over the exposed coarse aggregates, increasing the amount of wear to both the wheels and the concrete parapet walls. Since the guidewheels provide a steering input to the vehicle, the rough surfaces rattle the vehicle mechanical and electrical systems and in severely degraded sections can be felt by Airport Train passengers.

Airport Train Maintenance personnel had performed many different types of repairs to address this persistent problem, but no suitable repair had been found. Fast setting repair mortars were spread in thin layers over degraded sections of wall and small portions of wall had been sawn out and patched with similar repair mortars to cover areas where the degradation became severe. These repairs began to crack, spall and deteriorate over time. Once minor spalls developed, entire patches deteriorated due to guide wheels pounding over repaired surfaces. Degradation of the walls and of previous repairs is shown in **Figure 1.** As shown in the figure, neither of these previous repairs proved to be durable.

Other repairs had also been tried in the past. Thin, flexible plastic sheets were glued to sections of degraded wall. These sheets wore out or fell off. Epoxies were applied to the surfaces and they quickly cracked and delaminated. Thin, stainless steel plates were attached to the tops of walls in severely degraded sections using countersunk screws. These warped and cracked and also proved to be an inappropriate repair.

Figure 1: Previous parapet wall running surface repairs.

PARAPET WALL RUNNING SURFACE REPAIRS

The degradation of parapet wall running surfaces has been an ongoing problem with the DFW Airport Train guideway. Developing a repair that would satisfy all of the demanding criteria became one of the most challenging aspects of the work. A suitable repair would be durable enough to satisfy the 10-year service life criterion established for all of the Critical Needs work, would be economical, and would be implementable in a minimal amount of time. Implementation time was critical because the degradation was most severe in highly traveled routes, which were also the most critical to users of the system. It was also desired to recommend a repair that could be implemented by Airport Train maintenance staff on a small scale.

Implementation Time

As stated previously, implementation time was a critical consideration and several related factors influenced the development of the recommended repair. An optimum repair would be implementable in a four-hour nighttime shutdown. This goal dictated that power and signal rails could not be removed and would have to be protected during repair work. Similarly, trap rails, switch rails and other system equipment attached to the tops of the parapet walls could not be removed and there could be no interference between repairs and these elements. These considerations eliminated several options.

The minimal amount of time allowed for repairs significantly influenced the choice of applicable repair materials. Cementitious materials required relatively long cure times and had proven ineffective in previous repairs. Thicker steel plates recessed into the tops of the walls were also considered, but the time required to cut the required recess into the tops of the walls helped eliminate this option. Thicker steel plates would also have to be fabricated to match the vertical curvature of the guideway, which was not a practical option. Furthermore, installation of thicker steel plates would interfere with trap and switch rails and other system elements attached to the tops of the walls.

Pilot Program Recommendation

Fast setting epoxies seemed to be a possibility, but as stated previously, this had been attempted with little success. After reviewing the previous repairs, it was decided to attempt a similar but modified epoxy repair and implement a "Pilot Program" to evaluate its performance at a few guideway locations over at least a one-year period before implementing it throughout guideway system.

Several locations were chosen as representative of degradation observed throughout the guideway system and specific locations to be repaired were identified. An epoxy-sand grout was recommended to be troweled onto prepared surfaces and allowed to cure for 24 hours before allowing train traffic to cross repaired sections. The materials to be used and application means and methods were developed in cooperation with the contractors who executed the work. Previous epoxy repairs used straight epoxy applied to the degraded surfaces. The surfaces had apparently not been adequately prepared and it was believed that this contributed to the failure of the previous repairs. Thermal properties of epoxy relative to those of concrete were also believed to have significantly contributed to the cause of previous epoxy repair failures.

The initial recommendation was to mix a well-graded, oven dried sand with epoxy in proportions to create a very stiff, non-sag grout that could be troweled onto prepared vertical surfaces. The objective was to minimize the epoxy/sand ratio of the grout, which would move the thermal characteristics of the composite material closer to that of concrete and improve the wear characteristics of the composite material. The contractor submitted sieve analyses for two sand samples available from local home improvement centers. One sample was reasonably well graded, but had a small percentage of disproportionately large particles. The other sample was somewhat gap-graded and had generally smaller particle sizes. The well-graded sample was approved.

Establish Mix Proportions, Means and Methods

Trial batches of epoxy-sand grout were mixed and applied to unused sections of guideway located in the Airport Train maintenance area to test design assumptions. Surface preparation included grinding any exposed steel to a shiny metal condition and pressure washing with water to remove loose particles and bond-inhibiting substances. After surfaces were allowed to dry overnight, sheet plastic was used to mask off areas below the bottom of the surfaces to be repaired and to protect power and signal rails during the work. Surfaces were then primed with straight epoxy by brushing and stippling, taking care to fill all pores of the concrete surface. Immediately following the prime coat, epoxy-sand grout was troweled onto the walls keeping the total grout thickness as thin as possible. It was required that epoxy-sand grout be applied to the primed surface before the primer "skinned over" and the work was also being done during the heat of mid-summer to minimize the required cure time. This required workers applying grout to lag behind those applying primer by only a few feet. When the grout was troweled onto the primed surface, it forced some of the prime coat deeper into cracks in the wall while at the same time absorbing some of the prime coat into the stiff grout. The appropriate epoxy/sand ratio was established by the contractor as that which could be applied most effectively, and this was established by trial applications. Grout was cured for about 30 minutes before masking was removed.

The first trial applications revealed that the disproportionately large sand particles in the approved sand were problematic. They tended to gouge and streak the surface of the grout as it was being applied and generally made it more difficult to apply than expected. After discussing the results with the contractor it was decided to try the somewhat gap-graded sand and the entire process was repeated the following day. The gap graded sand, with its generally smaller particles, proved to be much more workable and was used in the Pilot Program applications. This exercise was invaluable in finalizing the grout mix materials and proportions and in proving the mix and application assumptions. It also familiarized the contractor and observing maintenance personnel with the entire process and prepared them for the final applications. **Figure 2** shows the epoxy-sand grout being applied to a section of parapet wall.

Figure 2: Epoxy-sand grout being applied to parapet wall running surface.

Pilot Program Repairs

Initially recommended Pilot Program repairs to parapet wall running surfaces were made during August and September 1998. During January 1999, similar repairs were completed in a section of guideway in which other parapet wall repair work was made. Additional repairs were made during October 1999 with unrelated Airport Train station work. The locations are summarized in the **Table 1**. Locations identified in the table refer to Airport Train control block designations.

Table 1. Parapet wall running surface Pilot Program repair location summary.

Location	Approx. Length m (ft)	Date Repaired	Notes
2WCL05	21 (70)	Aug. 22, 1998	6 hour cure
2WCL11	11 (35)	Aug. 22, 1998	6 hour cure
2WCL13	7.6 (25)	Aug. 22, 1998	6 hour cure; wall not pressure washed
2WNL07	24 (80)	Sep. 26, 1998	Wall also repaired and strengthened
2WCL13	25 (83)	Oct. 14, 1999	At new TrAAin station; added later
2WCL13	2 (7)	Oct. 14, 1999	Near new TrAAin station; added later
3ESL09	32 (105)	Jan. 14, 1999	Heat applied before and after application
3ENL01	12 (40)	Jan. 14, 1999	Heat applied before and after application

As shown in **Table 1**, three locations were allowed only six hours of cure time (instead of the recommended 24 hours) before Airport Train traffic was placed back into service on the repaired sections. At these locations, Airport Train maintenance personnel determined that the epoxy had sufficiently hardened. Because the epoxy was applied in the heat of the Texas summer, the grout had in fact sufficiently hardened after only six hours of cure time. All other repaired sections were allowed 24 hours minimum cure time. **Table 1** also shows that one of the 2WCL13 locations was not pressure washed before implementing the repair. This was due to contractor oversight, but it was recommended to proceed with the repair without the pressure wash to evaluate the necessity of that task. After completion of the repair at that section, the contractor reported that it was much harder to obtain the smooth finish without the grout slumping after it was applied. While this could have been attributed to several factors, it was the basis for the subsequent recommendation to continue the pressure wash surface preparation.

Contrary to the goal of performing epoxy-grout running surface repairs during summer months to minimize cure time, two of the Pilot Program locations were repaired during January. These locations were in a guideway section critical to Airline Operations that also required more substantial parapet wall repair and strengthening. This work required a two-day shutdown to complete and the construction schedule and shutdown dates were closely coordinated with the affected airline to minimize the impact to airline passengers. Enclosing the entire length of on-grade guideway in a plastic bubble and heating the air with kerosene heaters minimized the cure time required for the epoxy repairs, as well as for concrete placed to accommodate the repair and strengthening of the wall. This section of repaired parapet wall running surface is shown on the left-hand side of **Figure 3**. A close-up view of another repaired section is shown in **Figure 4**.

Figure 3: Parapet wall running surface repaired with epoxy-sand grout.

Figure 4: Close-up of epoxy-sand grout repair.

Evaluation and Recommendation

It was recommended that the repaired surfaces be monitored closely over at least a one-year period. Thermal incompatibility and freeze-thaw durability are concerns with this repair and consequently, evidence of curling or delamination of the epoxy-grout from the concrete surface would be considered a failure. Airport Train maintenance personnel, designers and other interested parties have monitored the repairs periodically since they were implemented. As of this date, no significant degradation of the repaired surfaces has been observed. Some gouging of repaired surfaces has been observed, but this was attributed to an excessively worn vehicle guide wheel. This repair has been recommended to be implemented throughout the guideway system.

SUMMARY

In 1996, the DFW Airport determined that its existing Airport Train system would have to remain in service for an additional 10 years and instigated the DFW Airport Train Critical Needs Analysis to determine what actions should be taken to attain that goal while maintaining the same levels of service and reliability that existed at that time. A field investigation was performed to assess the existing condition of the entire Airport Train system. Guideway observations were documented for future reference. Where possible, field recorded data was compared with that reported in previous investigative reports. Numerous recommendations for repairs were made and many of these were subsequently implemented.

This paper discussed one of the implemented repairs in detail; repairs made to degraded parapet wall running surfaces, which has been a particularly problematic condition. The degradation was observed throughout the guideway system and some of the most severe degradation was observed along sections of the most heavily traveled and most critical routes. Many different repairs had been attempted to correct this condition, but no suitable repair had been found. After reviewing previous repairs and evaluating options based on the criteria of economy, speed of repair and durability, an epoxy-sand grout was recommended to be applied over prepared surfaces. A Pilot Program was recommended and implemented at selected locations. These repairs have been evaluated for more than two years, have performed very well, and as a result, have been recommended to be implemented throughout the entire Airport Train system.