National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendations

Date: August 21, 2003

In reply refer to: R-03-16 through -19

Mr. Robert Ovrom
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The National Transportation Safety Board is an independent Federal agency charged by Congress with investigating transportation accidents, determining their probable cause, and making recommendations to prevent similar accidents from occurring. We are providing the following information to urge your organization to take action on the safety recommendations in this letter. The Safety Board is vitally interested in these recommendations because they are designed to prevent accidents and save lives.

The recommendations are derived from the Safety Board's investigation of the collision of the two cars of the Angels Flight funicular railway in Los Angeles, California, on February 1, 2001, and are consistent with the evidence we found and the analysis we performed.[1] As a result of this investigation, the Safety Board has issued seven safety recommendations, four of which are addressed to the City of Los Angeles Community Redevelopment Agency. Information supporting these recommendations is discussed below. The Safety Board would appreciate a response from you within 90 days addressing the actions you have taken or intend to take to implement our recommendations.

About 12:17 p.m. on February 1, 2001, the two cars of the Angels Flight funicular railway (Angels Flight) collided in downtown Los Angeles, California. The accident resulted in 7 injuries and 1 fatality among the 20 passengers aboard the two cars and injuries to a pedestrian. The Angels Flight Operating Company estimated monetary damage to the cars at $370,000 with an additional $1.2 million to replace the funicular haul system.

The National Transportation Safety Board determined that the probable cause of this accident was the Yantrak Company's (Lift Engineering's) improper design and construction of the Angels Flight funicular drive and the failure of the City of Los Angeles Community Redevelopment Agency, its contractors (Pueblo Contracting Services, Yantrak, and Harris and Associates), and the California Public Utilities Commission to ensure that the railway system conformed to initial safety design specifications and known funicular safety standards.

[1] For additional information, see National Transportation Safety Board, *Uncontrolled Movement, Collision, and Passenger Fatality on the Angels Flight Railway in Los Angeles, California, February 1, 2001*, Railroad Accident Report NTSB/RAR-03/03 (Washington, D.C.: NTSB, 2003).

Postaccident inspection of the Angels Flight drive mechanism revealed that the *Sinai* car stopped ascending and began its uncontrolled descent when the drive axle for the car's cable drum became disengaged from its driving planetary gear. When the Angels Flight operator saw the car begin to descend the grade, he pushed the stop button on the operator's console, which should have simultaneously activated the service and emergency brakes. But the service brakes, which operated on the drive train, had no effect on the freewheeling cable drum that was no longer connected to the drive train mechanism. The emergency brake would have stopped, or at least slowed, the rotation of the cable drum had it applied, but it was found to be inoperative. The cars themselves were not equipped with track brakes that could have operated independently to significantly slow the car or bring it to a stop before the collision. End gates on the cars may have prevented a passenger from being ejected from the end of the *Olivet* car when it was struck by the *Sinai* car. Finally, rescue efforts were hampered by the absence of emergency walkways that would have facilitated evacuation of injured passengers.

The splines on the *Sinai* planetary gear receiving hub were found to be stripped, which prevented the gear from engaging the axle shaft. This allowed the axle shaft to rotate within the planetary gear hub and rendered the cable drum (connected to the other end of the axle shaft) freewheeling. Testing revealed that the steel used for the receiving gear hub was much softer than the steel used for the axle shaft. The difference between the hardness of the receiving gear hub and that of the axle shaft likely contributed to the failure of the gear by accelerating the damage to the softer gear hub splines. The presence of metal shavings on the *Sinai* car axle shaft indicated that damage to the planetary gear hub splines had been occurring for some time before the accident.

The failure of the *Sinai* planetary gear receiving hub may also have been accelerated by the daily brake tests conducted on the system. The Angels Flight Operating Company vice president tested operation of the brakes by placing the cars in operation and then activating the system service and emergency brakes to bring the cars to a stop. Under normal conditions, the service brakes would have stopped rotation of the motor shaft while the emergency brakes simultaneously stopped rotation of the two cable drums. But the postaccident investigation revealed that, for some period of time before the accident, only the service brakes were operable. During the daily brake tests, the service brake activated to stop the driven sun gear, but without emergency brakes, substantial dynamic forces acted on the cable drums and various components of the drive system.

Finally, the investigation determined that the dynamic and transient forces acting on the various components of the drive gear system, including the axle and receiving gear hub splines, were greater than those calculated by Yantrak. Because these calculated loads were used to develop the specifications for the drive system components, the service life of those components, including the gear hubs and splines, would likely have been less than predicted even under normal conditions. Under the abnormal stress conditions posed by the daily brake tests conducted with non-functioning emergency brakes, the rate of damage likely increased, as did the likelihood of the kind of catastrophic failure that occurred in this accident. The Safety Board concluded that the planetary gear hub for the *Sinai* car failed because of one or a combination of the following: (1) the metal used in the manufacture of the gear hub was considerably softer than the metal used for the axle shaft with which it mated, causing deformation damage and eventual failure; (2) the drive train components, including the planetary gear hubs, were not designed for

the stresses to which the components were subjected during operation; and (3) the daily brake tests, which were conducted for some period of time without working emergency brakes, placed additional stress on the drive train components and accelerated gear hub damage.

Once the cable drum for the *Sinai* car became disconnected from the drive gear system, the car's haul cable was able to unwind freely as gravity pulled the car down the incline. The emergency braking system was designed to prevent such an occurrence by clamping against the cable drum flanges to stop the drum's rotation. Had the emergency brakes functioned when activated by the operator, the descent of the car would have been stopped even though the cable drum was no longer connected to the rest of the drive system. The Safety Board therefore concluded that had the Angels Flight emergency braking system been functional on the day of the accident, the brakes would likely have stopped the descent of the runaway car and prevented the collision.

Although the test procedure for the Angels Flight emergency brakes was conducted daily, the button that activated those brakes simultaneously activated the service brake. Therefore, this method of testing could not confirm that both braking systems were operational. The Safety Board therefore concluded that the brake system as designed was inoperable, as implemented was not fail-safe, and was further inadequate because the emergency brakes could not be activated independent of the service brake and tested separately, which would have revealed that the system's emergency brakes were inoperative.

Shortly after Angels Flight began passenger service, a problem was noted with overheating of the gearbox oil. The problem was severe enough that on numerous occasions, the system shut down automatically, leaving passengers stranded between stations. At these times, witnesses reported seeing passengers making unauthorized and unsafe evacuations from the cars over the unprotected elevated track structure. As a loss control consultant had noted, such evacuations were so dangerous to passengers that they should have been prevented even during emergencies.

But despite the hazard posed to passengers, the operating company did not establish operational practices that would have prevented the system shutdowns or egress onto the tracks. For example, the number of scheduled trips per hour could have been reduced to allow the gearbox to cool between trips while a permanent solution was researched and implemented. Instead, the system was kept operating for more than a year until the overheating problem was ultimately resolved by the installation of an oil cooler.

In addition to representing an inconvenience and possible hazard to passengers because of the system shutdowns, the overheating and vaporizing oil was also likely not providing optimal lubrication to the Angels Flight drive system. Within the first few months of operation of Angels Flight, the bearing seals had carbonized due to overheating and had begun to leak. The gearbox bearings and seals had to be replaced in 1997.

After the overheating problem had been addressed in 1997 and synthetic oil was used, the Angels Flight Operating Company never changed the oil. It did initially adhere to a regular fluids analysis schedule, sampling the lubricating oil about once every 4 months from 1997 to 1999. After three successive fluid analyses during 1999 showed an increased presence of iron in the oil,

the company that conducted the fluid analyses recommended in June 1999 resampling the oil after an additional 250 hours. However, although bearings were replaced and the drive system gears were inspected after the June 1999 analysis, the operating company conducted no additional fluid analyses. As a result, the lubricating oil went untested for 20 months while Angels Flight continued daily operation until the accident occurred.

The Safety Board is concerned at the lack of detailed guidance regarding the oil analysis program or maintenance procedures for the funicular drive gearbox. A postaccident fluids analysis test on February 28, 2001, confirmed the presence of elevated iron levels in the gearbox oil. In addition, ground metallic residue, containing both metal shavings from the sheared splines and small metal pieces from the ball bearings, was removed during disassembly of the gearbox after the accident, indicating that damage was occurring before the planetary gear hub splines failed. Therefore, if Angels Flight Operating Company personnel had continued the oil analyses, as required in the operations and maintenance manual, and if the cause of the elevated iron content had been investigated further, through a gearbox teardown, for example, they may have discovered the damage in the *Sinai* car's planetary gear hub splines.

The Safety Board concluded that by allowing Angels Flight to remain in normal passenger service for more than a year with an unresolved problem with overheating of the gearbox, which at times caused cars to stop unexpectedly between stations, the Angels Flight Railway Foundation and the Angels Flight Operating Company adversely affected drive system component integrity and compromised passenger safety.

As owner of Angels Flight, the Community Redevelopment Agency was responsible for contract negotiations, safety oversight, design changes, and safety certification. Additionally, beginning in 1991 with its selection of Parsons Brinckerhoff Quade & Douglas Engineering as a consultant, the Community Redevelopment Agency was responsible for the selection of many of the companies involved in the design and construction of Angels Flight. It hired Harris and Associates as construction manager and selected Pueblo Contracting Services as the general contractor. And even though the Community Redevelopment Agency did not hire Yantrak directly, it was responsible for the selection of the company in its role as overseer of the performance of its contractors and subcontractors and for monitoring how its money was being spent.

The specifications for the Angels Flight reconstruction called for both cars to be fitted with emergency track brakes, end gates on the cars to contain passengers, and an emergency walkway for the entire length of the tramway to facilitate the evacuation of passengers in the event of an emergency.

In a series of letters and memorandums, Yantrak argued that track brakes would be ineffective in this application and that, in any case, the design of the cars and trackway would not permit their installation. In its February 13, 1996, letter to Pueblo, Yantrak had said that track brakes could not be used on the split rail of the train bypass. The Safety Board noted, however, that the conceptual design specified track brakes only on the outer rail, thereby avoiding the shared (split) rail used by both cars. Increasing the diameter of the haul cable (rope) and other measures proposed by Yantrak did increase the safety factors associated with loss of the cable or car attachment. However, deleting the track brakes (a secondary safety device) ignored other

potential failure modes that were unrelated to the haul cables. Redundancy has always been a key factor in the design of transportation systems. For example, even though the original Angels Flight was not equipped with track brakes, it did have a safety cable designed to prevent a runaway car. Further, the guidance on funiculars existing at the time Angels Flight was redesigned and rebuilt (American National Standards Institute's tentative standards and the Colorado regulations) called for each individual car to be equipped with a braking system. A survey of funiculars worldwide also found that each system utilized cars equipped with braking systems or backup safety cables. The Safety Board therefore concluded that had the Angels Flight cars been equipped with track brakes or a safety cable in accordance with known funicular safety standards and redundant design principles, either of those safety features likely would have stopped the runaway car and prevented the collision even without working emergency brakes.

The original Angels Flight did not have a walkway adjacent to the trackway that would extend the entire length of the trackway. Such a walkway was included as part of the original reconstruction design specifications, but a conflict soon developed with the historic preservationist viewpoint. In addition, Public Utilities Commission staff and an insurance loss control consultant supported the view that the walkway would be an attractive nuisance more hazardous than the absence of the walkway. However, the Safety Board noted that an attractive nuisance can be averted in many cases with relatively simple measures, such as installing a fence with locking gates to restrict access.

Community Redevelopment Agency officials did require that alternatives to the walkway be included in the final design, including a combination ground-level and elevated stairway separated from the trackway, an auxiliary emergency power supply, reversible funicular controls, and a security system and fence. But none of these alternatives directly addressed the purposes of the emergency walkway, and because of the nature of the accident, these alternatives did nothing to facilitate access to and egress from the funicular vehicles. The Safety Board concluded that the absence of an emergency walkway hampered access by emergency responders to passengers in this accident, made difficult the evacuation of the injured, and increased the risk to both passengers and emergency responders.

As a result of its investigation of the February 1, 2001, collision of the two Angels Flight Railway cars in Los Angeles, California, the National Transportation Safety Board makes the following safety recommendations to the City of Los Angeles Community Redevelopment Agency:

> Before recommencing passenger service on the Angels Flight funicular railway, conduct a comprehensive review of the design and specifications for the Angels Flight drive system, then make the design or component changes necessary to ensure that the drive system meets accepted industry standards and engineering practices. (R-03-16)
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> Before recommencing passenger service on the Angels Flight funicular railway, require that the current Angels Flight emergency braking system (acting on the cable drums) be redesigned to allow it to be tested independent of other braking systems. (R-03-17)

Before recommencing passenger service on the Angels Flight funicular railway, require that the organization(s) responsible for operating and maintaining the Angels Flight funicular develop and follow detailed operating, inspection, and maintenance procedures to ensure the operational integrity of the system and safety of passengers. (R-03-18)

Before recommencing passenger service on the Angels Flight funicular railway, direct that the Angels Flight funicular be redesigned in accordance with all applicable funicular safety standards and include provisions for (1) emergency stopping under all foreseeable failure modes, including track brakes or some other independent backup system on the cars to prevent a runaway car if a failure occurs in the cable or its associated braking systems; (2) containment of passengers in the event of a collision; and (3) emergency egress and ingress for passengers and emergency responders. (R-03-19)

The Safety Board also issued safety recommendations to the California Public Utilities Commission and the American National Standards Institute. In your response to the recommendations in this letter, please refer to Safety Recommendations R-03-16 through -19. If you need additional information, you may call (202) 314-6177.

Chairman ENGLEMAN, Vice Chairman ROSENKER, and Members GOGLIA, CARMODY, and HEALING concurred in these recommendations.

Original Signed

By: Ellen G. Engleman
Chairman