KEANE WONDER MINE AERIAL TRAMWAY STABILIZATION

Death Valley National Park

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by
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EXECUTIVE SUMMARY

The National Park Service and the University of Vermont have recently been engaged in a cooperative effort to stabilize the historic aerial tramway at the Keane Wonder Mine, located in Death Valley National Park. The project began with a structural assessment, conducted in partnership with the University's School of Engineering. The inspection took place between March 30 and April 4, 2009, and the findings are contained in the report, *Keane Wonder Mine Aerial Tramway Stabilization*, prepared by the School of Engineering in October 2009.

The results of that assessment form the basis for the development of the subsequent repair program. Structures were assessed with respect to life safety and resource preservation, and the deterioration conditions were documented. Three priority levels were designated (high, medium, and low) which reflect the urgency of the repairs indicated; based on the assessment criteria for each category, repairs to each structure were assigned a priority level. The scope of work for a pilot implementation project was then determined by selecting structures that were at greatest risk of collapse or would be directly accessible to visitors if the tramway were reopened to the public.

Towers 6, 8, and 9 were assigned a high priority, as they were found to be in danger of imminent collapse. Life safety repairs and improvements are primarily directed at protecting visitors; as the Lower Terminal's upper deck would typically receive visitor traffic, that structure was also selected for repair though it was assigned a medium priority in the initial assessment.

This report addresses the pilot implementation project, which began on March 8, 2010 and was completed on March 15, 2010. The University of Vermont conducted a field school during this time period, which included the completion of a number of repairs to the Lower Terminal and the cutting of parts for future installation on towers 6, 8, and 9.

The repairs were executed using traditional timber framing joinery and scarf forms used to construct the original tramway structures, following the repair strategies described in the 2009 assessment report. The tramway towers and terminals were constructed in such a way that the replacement of individual members could be done in the field, and evidence of historic repairs is abundant. Piles of discarded timber and hardware are found at many of the towers where damaged members were replaced. The decision to use traditional joinery recognizes that this is a solution that is economical of material, and preserves a vital connection to the traditional craft practices on which the original construction is based.

This report is divided into five sections, followed by supporting appendices. The first section briefly summarizes the tramway's history and significance. The second contains a discussion of the scope of work for the pilot implementation project. The third section discusses the deterioration conditions found on the structures included in the scope of work prior to the treatments performed. The fourth section documents specific repairs and the procedures used, while the fifth outlines future repair goals. Appendix A contains a copy of the letter report supplied by Leitner-Poma, a company which manufactures and installs cable lift systems, following an on-site consultation with two of their engineers. Appendix B supplies additional information drawn from the principal investigator's observations during the course of the repair work. The report is accompanied by a PowerPoint presentation that illustrates the repair processes and includes field school photodocumentation.

HISTORY AND SIGNIFICANCE

The 1904 discovery of the gold deposit that would become the Keane Wonder Mine marked the beginning of a gold rush in the Funeral Mountains. By 1906, development of a full-scale mining operation at the site was underway. A twenty-stamp mill was set up and a route for an aerial tramway was surveyed in that same year. The 1 ½-mile-long aerial tramway was constructed in 1907, and transported ore from the mining operation in the mountains to the processing plant at the base. The tramway is a double-rope, gravity-powered system built to a design supplied by Leschen Brothers & Company of St. Louis.

The Keane Wonder Mine was the largest gold producer in the region between 1908 and 1911,[1] but was sold and subsequently closed in 1912 amid newspaper speculation that the mine was played out. A series of efforts were made to reopen the mine; the first lasted from 1914 to 1916, and the mine then sat idle until 1935. Between 1935 and 1937, a company began reworking the old tailings piles with cyanide in an attempt to recover more gold. The mine was sold in 1937 and the majority of the ore processing machinery was removed and scrapped at that time. The tramway was refurbished in 1940 as part of an effort to reopen the mine again, but was abandoned in 1942 and acquired by the National Park Service in the 1970s.[2]

With most of the original structures and ropes intact, the Keane Wonder Mine maintains a high level of historic integrity, and was one of Death Valley National Park's most popular tourist destinations prior to its closure to the public. Nominated to the National Register of Historic Places, the mine is significant in the contexts of settlement and exploration, industry and commerce. The tramway represents a crucial piece in the interpretation of the mine.

[1] J. Latschar and D. Beery, "Keane Wonder Mine" (National Register of Historic Places Registration Form, United States Department of the Interior, 2008), 18.
[2] Ibid., 26.

SCOPE OF WORK

The project's initial goal was to conduct a field school to develop pilot repair techniques and provide training for Park Service staff, volunteers, and an intern from the University of Vermont.

During the conditions assessment phase, the investigating team recommended repairs for purposes of both resource preservation and life safety. With respect to life safety concerns, the investigators' assumption is that the site will be reopened to visitors. In both cases, the evaluation reflected the level of intervention needed to prevent total or partial collapse of a structure. The following designations target both goals and were used to develop a scope of work that addressed the most urgently needed repairs; these groupings reflect the imminence of danger posed by the deterioration condition:

> HIGH PRIORITY: A designation of High Priority indicates that repairs are intended to prevent an immanent collapse, or that failure to make repairs may result in serious injury or death.
>
> MEDIUM PRIORITY: A designation of Medium Priority indicates that repairs are likely to prevent a collapse in the foreseeable future, or that there is a low to moderate likelihood of injury if repairs are not made.
>
> LOW PRIORITY: A designation of Low Priority indicates a relatively stable structure despite deterioration of some of the members.

The university assembled a team of skilled woodworkers to lead the field school, and tower 6 was selected as the focus, with additional work to be done on the lower terminal. It was determined that of the three towers in most urgent need of stabilization, tower 6 was the easiest and safest to access and therefore the most suitable for this type of project.

The work originally planned for tower 6 required that the cables be lifted from the saddle beam. Lifting was to be done from an auxiliary tower constructed adjacent to tower 6. The new tower was built of dimensioned lumber because the individual pieces were light enough to carry to the site individually. But lifting the track cables from this lightweight tower proved to be impossible due to the tension in the cables in this section of the tram, and proximity to the long cable span between towers 6 and 7. The tension in the cables appeared to be the result of the collapse of beams supporting sheaves in the lower terminal and the free fall of the weight boxes that historically tensioned the cables. The decision was made to adjust the scope of work until these issues could be resolved. In consultation with the Park, the team shifted its focus.

The revised scope of work included:

- Three column repairs completed at the lower terminal, using traditional scarf joints to attach replacement timbers at the bases of columns where the original timbers had deteriorated.

- Cutting of a complete repair kit for tower 6 that includes columns, cross-braces, and sills.

- Cutting of partial repair kits cut for towers 8 and 9.

- Fabrication of replacement saddle beam struts for tower 6, 8, and 9 that were fitted for metal reinforcing plates to prevent the loss of relish found in the historic saddle beam struts due to weathering.

- The production of a PowerPoint presentation designed to serve as a step-by-step guide instructing Park Service staff in the techniques required to cut bladed scarf joints, a traditional type of joint that can be used for a variety of repairs throughout the tramway system (presentation is included as an appendix to this report).

- Development of alternative methods for lifting the cables. Additional expertise was sought from Leitner-Poma, a firm that specializes in the manufacture and installation of cable transport systems. The company provided a field assessment and conceptual-level designs for lifting the cables. (Leitner-Poma's letter report is included as an appendix to this report.)

CONDITIONS PRIOR TO TREATMENT

At the time of the initial assessment, tramway structures were deteriorated due to decay and weathering, as well as damage incurred when failures along the length of the cable system put new stresses on structures. The Condition Assessment Report assigned priority levels to each structure. Of the structures within the scope of work of this report, towers 6, 8 and 9 were assigned a high priority level, and the Lower Terminal was assigned a medium priority. Despite the lower risk level, the installation of replacement timbers occurred only at the Lower Terminal; this was primarily due to issues of access. The Lower Terminal is the easiest structure for visitors to access, and the same is true for the repair crew. The other structures require materials and tools to be moved by helicopter or carried over rough terrain.

Tower 6

Tower 6 is in poor condition (Figure 1). While the tower is characterized by deterioration conditions that are fairly typical of many of the tram towers, the level of deterioration combined with proximity to the cliff and the length of the cable span put the tower at risk. Conditions at the tops of columns and saddle beam braces are more severe than with most of the other towers. The northeast column is split in two places, and repairs have been attempted with bolts and steel angles; the split near the top of the column has compromised the bolted connection at the saddle. On the west elevation, one of the saddle beam braces is missing and the other is detached and performs no structural function. Relish is inadequate at all of the remaining columns and braces. Rotation of the saddle beam due to eccentric loading is apparent.

The north sill has a half-lap splice at midspan that has been reinforced with bolts and steel plates. The sill is decayed below the northwest column, and bearing plates are positioned so that they support the sill on either side of the column rather than below it. The built-up timber pier at the northeast corner is partly undermined due to its proximity to the cliff edge. The sill on the south elevation is in good condition, though displaced from its original position. Bearing plates appear to be mildly decayed.

On tower 6, diagonal bracing has been notched at overlaps. This differs from the construction of the other towers, and the reduction in thickness at the lap has resulted in failure of one of the braces on the north side. The other diagonal brace on the north elevation has lost its relish at the connection to the northwest column base. Diagonal bracing on the south elevation is attached to the sill rather than to the column bases, the horizontal tie-column connection has been lost, and the southwest column is displaced several inches from its original position on the sill as the result of sill movement. The horizontal tie at the base of the west elevation has failed, and many of the diagonal braces on the tower are split at bolted connections to columns.

Tower stabilization is of the highest priority and will involve improvement of foundation support at the northeast column and repositioning of the bearing plates at the northwest column; repair / replacement of diagonal braces and horizontal ties on the north, south, and west sides; connection of diagonal braces to columns on the south elevation to correct displacement of the southwest column and to recover and maintain original geometry at the tower base; restoration of brace and tie connections and repair of relish at the saddle beam connections using shear plates, and re-seating of the saddle beam in the column and brace housings.

Figure 1. Top of tower 6, showing dangling southwest saddle beam brace. Photo: UVM School of Engineering

Tower 8

Tower 8 is in poor condition and is in imminent danger of collapse, largely due to failure of the framed support on the west side (Figure 2). Because the tower terminates a long cable span and is connected by that span to another high priority tower (tower 9), the level of urgency is increased; the collapse of one tower may result in the collapse of the other. The timber girt in the secondary frame supporting the west side of the tower has split at both girt-sill connections. Due to rotation of the northwest column in the secondary frame, tower loads are partially taken up by cribbing beneath the north sill, resulting in deflection of approximately 1½ inch between the northeast and northwest corner columns. The bolted connection between the northeast corner column and the north sill has failed, and the column has fallen off the sill timber (Figure 3). Moderate to high levels of decay are found at southeast, northeast, and northwest corners, resulting in deterioration of column-sill, column-horizontal tie, and column-diagonal brace connections. Diagonal braces on the north and south sides are fastened to the sills rather than to the corner columns and do little to reinforce deteriorated column-sill connections. A slope of grain failure in the southwest column above the traction rope carriage has been repaired with 2x8 sisters fastened with nails. The heavier track cable has fallen from its saddle on the east side, and the tower is rotating in the direction of the load imposed by the west cable. The northeast column-saddle beam connection is without relish, due in part to the separation of the column from the north sill. The northeast saddle beam brace is missing, and the surviving braces have largely lost their relish.

Tower stabilization is of the highest priority and will involve repair of foundation support on the west elevation, including replacement of the secondary sill and restoration of braced frame connections; repair of decayed column bases and restoration of sill, brace, and tie connections to columns to correct displacement of the northeast column and to recover and maintain original geometry at the tower base; repair / replacement of damaged diagonal braces and horizontal ties, and installation of new bolted connections between diagonal braces and north and south columns; repair of the slope of grain failure in the southwest column using bolted sisters; reinstatement of the northeast saddle beam brace, repair of relish at the saddle beam connections using shear plates, and re-seating of the saddle beam in the column and brace housings.

Figure 2. Tower 8, northeast column, shown fallen from its sill. Photo: UVM School of Engineering

Figure 3. Tower 8, northwest corner of secondary frame showing failure. Photo: UVM School of Engineering

Tower 9

Tower 9 is in poor condition and is in imminent danger of collapse. Column failures, the generally poor condition of diagonal braces, and failures in secondary sill timbers make this tower one of the highest priorities for repair. Because the tower terminates a long cable span and is connected by that span to another high priority tower (tower 8), the level of urgency is increased; the collapse of one tower may result in the collapse of the other. There is little or no relish remaining on saddle beam braces and at the tops of the south columns. The north columns are deflected at scarf joints; this is at least partly due to a slope of grain failure at the northeast column joint. Gaps between the saddle beam and column and brace housings also indicate that the upper portion of the tower has settled with the north (uphill) bent more nearly vertical than perpendicular to cable loads.

Column bases and sills on the north elevation are severely decayed. At the base of the northeast column, connections are intact but there is crushing of the sill. At the northwest column, sill and column base are decayed and have shifted off the secondary sill. This movement has apparently resulted in a shifting of the south sill, so that southwest column loads are positioned over the west secondary sill several inches from the column that supports it. The secondary sill has failed, putting tower 9 at a high risk for collapse (Figure 4). In addition to failure of the west secondary sill, bearing blocks or plates that support the braced frame are decayed, and diagonal bracing of the frame on the south elevation has failed.

Tower bracing is in poor condition. One of the diagonal braces on the north elevation has been replaced with a 2 x 8 member; the surviving brace is of very poor quality due to large clusters of knots. On the west elevation, the diagonal brace once connected to the base of the northwest column has failed and the horizontal member at the top of the cross bracing has lost its connection at the north column. Diagonal braces are still attached on the east elevation though are ineffective in preventing deflection of the northeast column due to the slope of grain failure in the column. Horizontal members have failed on east and west elevations and tower roller carriages are collapsing.

Tower stabilization is of the highest priority and will involve repair of foundation support on the south elevation, including replacement of the secondary sill on the west and restoration of braced frame connections; repair of decayed column bases and restoration of sill, brace, and tie connections to columns to correct displacement of the northwest column and to recover and maintain original geometry at the tower base; repair / replacement of damaged diagonal braces and horizontal ties; repair of the slope of grain failure in the northeast column using bolted sisters; repair of tower roller carriages; and repair of relish at the saddle beam connections using shear plates, and re-seating of the saddle beam in the column and brace housings.

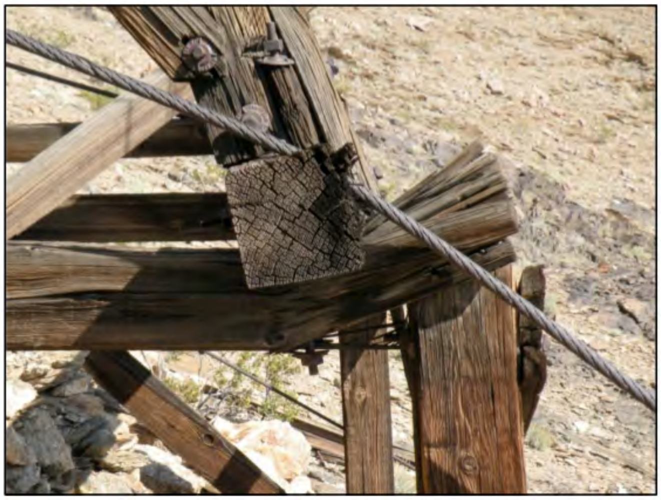

Figure 4. Failure of west secondary sill, tower 9. Photo: UVM School of Engineering

Lower Terminal

Several of the girts and joists that support the upper deck have reduced capacity due to decay and/or slope of grain failures. Floor beams supporting track cable sheaves have failed and were stabilized with steel sisters in the 1980s repair campaign. Deck flooring is badly deteriorated in places and unsafe for public use. The upper deck can be accessed at grade at the north end of the terminal, but is more than 30 feet above grade at the southern end, and requires a guardrail if the site is to be opened to visitors. On the lower level, the tall columns near the south end of the terminal are slender for the long, unbraced spans. Some of the braces are decayed at lower fastener locations. Conditions of column bases and bearing members are dependent to a large extent on the nature of the supporting structure. Where columns are supported on concrete foundation walls, they tend to be relatively dry and undamaged. Where columns and wooden bearing members have been covered by soil and debris, moisture contents tend to be high and decay of wooden elements relatively common (Figure 5).

While the condition assessment listed the overall preservation priority of the Lower Terminal as Medium, some of the individual repair needs rise to the level of High Priority, in part due to the proximity of the Lower Terminal to a publicly accessed trailhead. Terminal stabilization will involve reinstatement of missing bracing, consolidation of column bases and selected decayed bearing members, replacement of decayed bearing blocks and plates, and repair / replacement of deteriorated floor joists and decking.

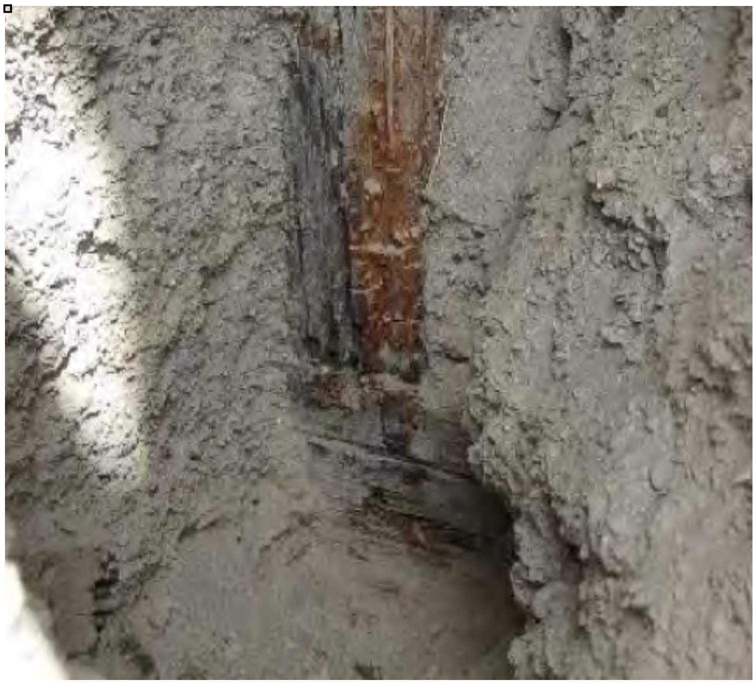

Figure 5. Base of column D8 prior to treatment, buried and severely decayed.

TREATMENT

A number of splices were pre-cut utilizing a bladed scarf joint, a type of traditional joint used in timber frame construction which enables two timbers to be joined end-to-end. This joint is found in the historic timber work at several tramway structures, used both as an initial construction method and also in historic repairs, presumably during the tramway's period of operation or during the 1940s refurbishment. The scarf joint allows replacement material to be spliced in, either by cutting into an existing member or (if applicable) using one side of an existing joint. The technique is also useful for joining two new timbers when a single piece of the desired length is not available. Several types of scarf joints exist and are found throughout the tramway system; the bladed scarf joint was selected as a type that creates a strong mechanical joint and is comparatively easy to learn. The PowerPoint presentation that accompanies this report contains detailed step-by-step instructions that will assist Park Service personnel in the use of this type of joint for future repairs.

Scarf joints were cut using portable circular saws and power drills to rough out material; framing chisels, slicks, and hand planes were used to pare the various faces of each joint to fit precisely. Existing historic hardware was used to fasten the joints completed during this two-week period (ogee washers, 3/4" and 5/8" bolts), but a source was located for structural washers and replacement bolts. Repairs were done using Select Structural lumber, a higher grade than much of what was found throughout the tramway structures (of the timbers which were graded during the assessment phase of the project, only half were assigned a grade of Select Structural. Refer to Table A-1 in the appendix of the October 2009 Condition Assessment Report for complete data on timber grading of the tramway structures). This better grade of timber is longer lasting, with a greater capacity than the material that it replaces, and also eliminates concerns of slope-of-grain failure or failure due to knots.

Lower Terminal Repairs

Work done on the lower terminal consisted of repairs to the ends of three columns located at gridpoints A2, D7, and D8. In each instance, the original timber had deteriorated at or below grade level. The bases of the columns were excavated and the tailings cleared from the vicinity. New sections were spliced in using scarf joints, and fastened with bolts and ogee washers. Replacement sill plates were installed at the base of the columns. The joints were adjusted individually based on the specific conditions at each of the columns.

Columns D7 and D8 (Figure 6) are located directly adjacent to a rock wall, making access difficult. The repair to column D7 used an existing half-lap joint; the joint was unfastened and the decayed lower portion of the column was removed. A new timber was cut to length and a matching half-lap was cut. Four bolts were used to secure the joint and historic ogee washers were reused.

The repair to column D8 used a bladed scarf joint with a single nose; this created a stronger mechanical joint than a half-lap, but made the process of fitting the new timber simpler than fitting a double-bladed scarf, as the surrounding rock restricted movement. A four-foot section of decayed timber was removed and a joint was cut and fitted on both members. Two bolts were used to secure the joint and historic ogee washers were reused.

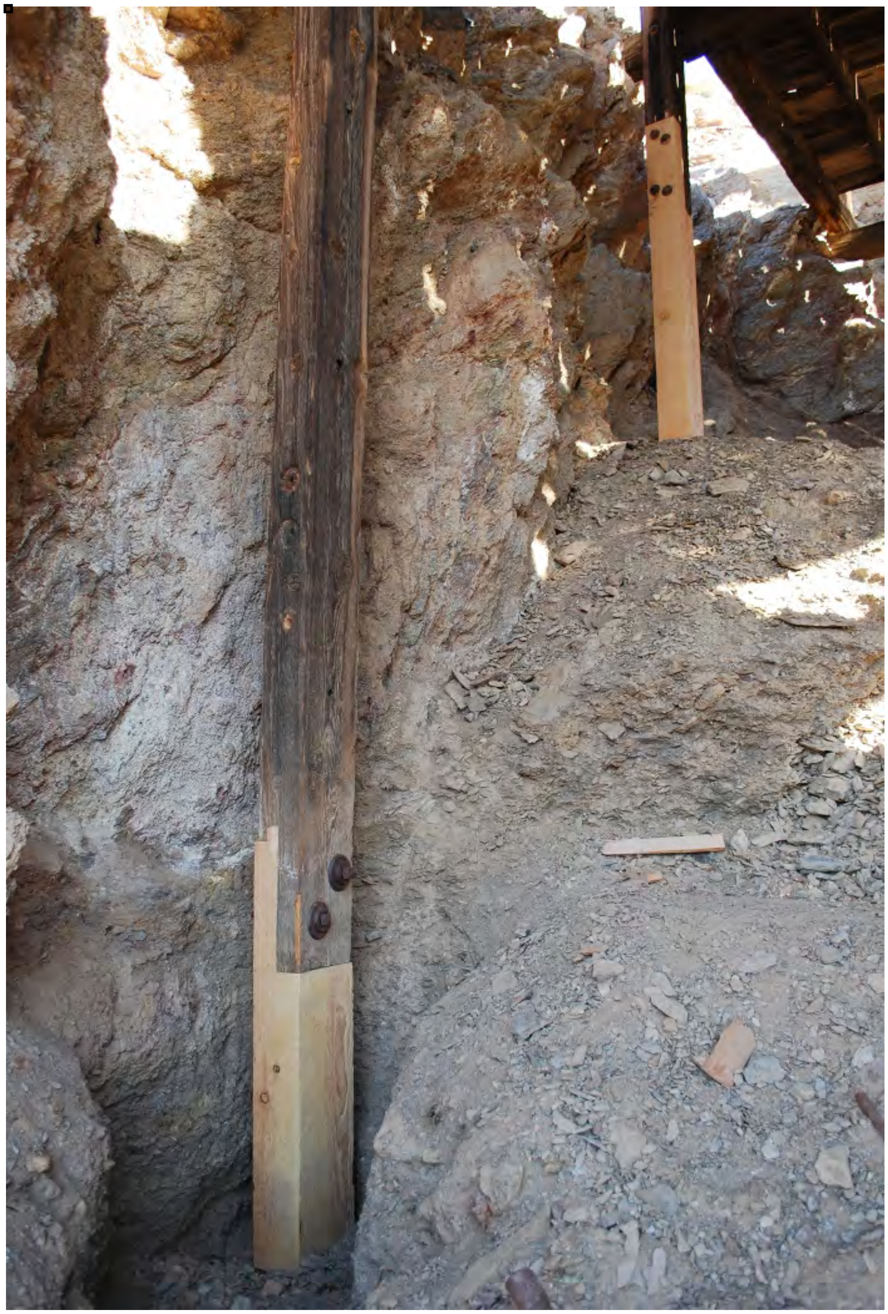

Figure 6. Column repairs at D8 (left) and D7 (right) at the Lower Terminal.

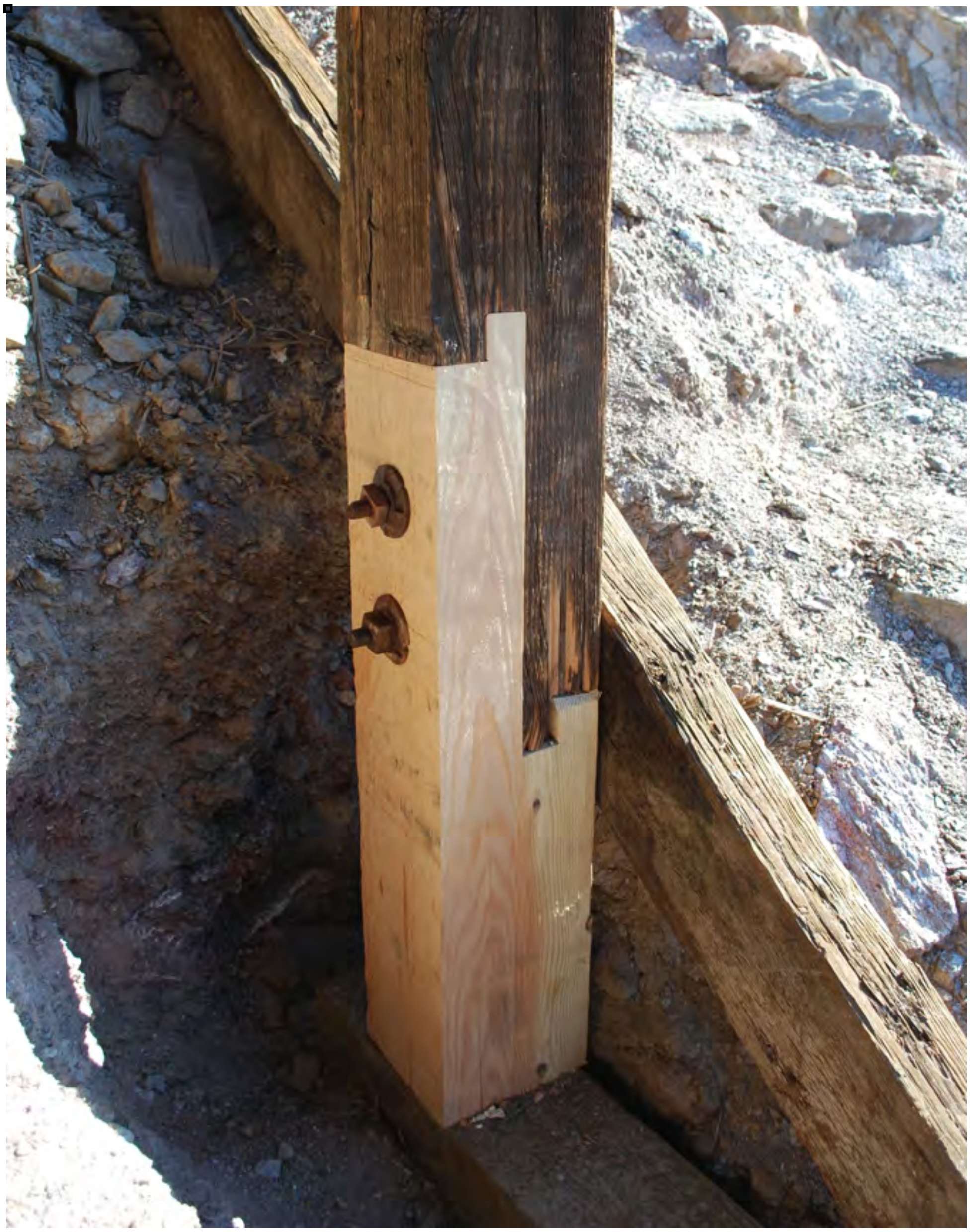

Figure 7. Column repair at A2, Lower Terminal.

Column A2 was easily accessible, and a double-bladed scarf joint was used to make the repair. A two-foot section of decayed material was removed and a replacement was cut to length. The joint was cut and fitted on both members and secured using two bolts with historic ogee washers.

Tower Repairs

A complete repair kit was cut for tower 6, which included replacement saddle beam struts (Figure 8). These will be reinforced with steel shear plates fabricated for the project in order to prevent recurrence of the loss of relish found on a number of the historic saddle beam braces.

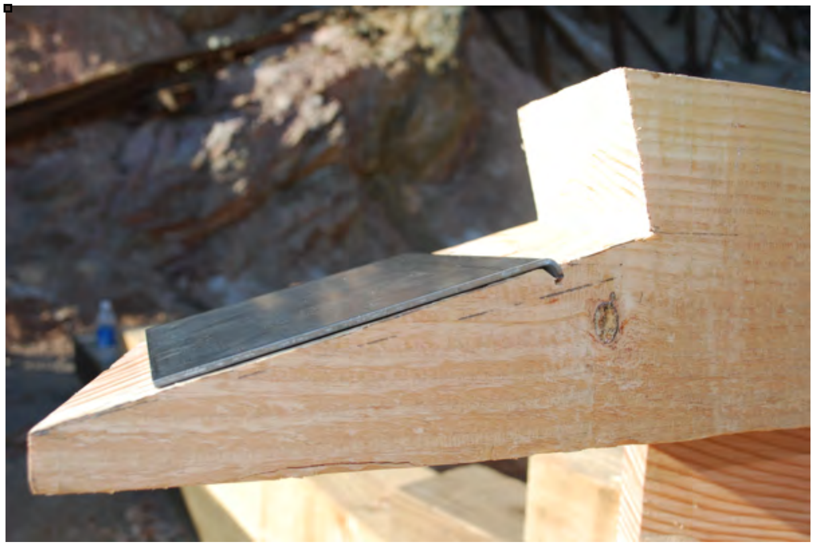

Figure 8. Replacement saddle beam brace with shear plate installed.

Tower 6	Qty.	Item	Dimensions
	1	Northeast column	8 x 8 x 18' - 2 1/2"
	1	North sill	8 x 8 x 12'-4"
	2	West saddle beam braces	
	2	North diagonal braces	3 x 6*
	1	North horizontal brace	3 x 6*
	2	West diagonal cross-braces	3 x 6*
	1	West horizontal cross-brace	3 x 6*
	2	South diagonal cross-braces	3 x 6*
	1	South horizontal cross-brace	3 x 6*

*cross-braces were cut to final size at the time of installation

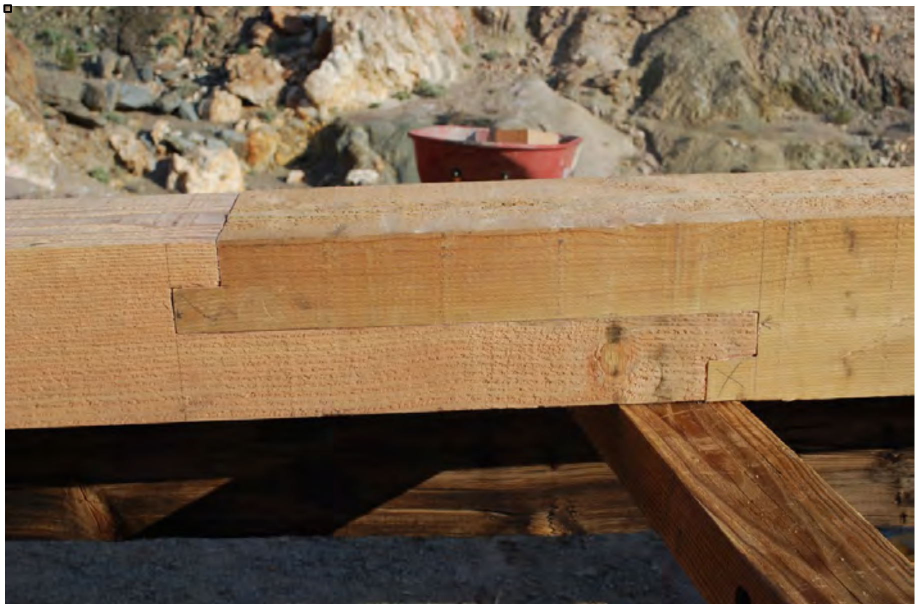

Figure 9. Bladed scarf joint splice for replacement column, tower 6.

A partial repair kit was cut for tower 8; replacement parts were required for both the braced support frame and the tower structure itself.

Tower 8	Qty.	Item	Dimensions
	3	Braced frame columns	8 x 10 x 54” 8 x 10 x 80” 8 x 10 x 70”
	1	West secondary sill	10 x 10 x 12’-0”
	1	North Sill	8 x 8 x 14’-0”
	1	North cross-brace	3 x 6 x 13’-4”
	1	Dutchman	8 x 8 x 8”

A partial repair kit was also cut for tower 9. Sills were not fabricated, as they did not require cutting. Two replacement timbers were cut for the northwest and northeast columns, each with one side of a double-bladed scarf joint pre-cut at its end (Figure 10).

Tower 9	Qty.	Item	Dimensions
	4	North and South cross-braces	3 x 6 x 17’
	4	East and West cross-braces	3 x 6 x 15’
	1	Northeast column	8 x 8 x 14’
	1	Northwest column	8 x 8 x 14’
	4	Horizontal braces	3 x 6 x 8’

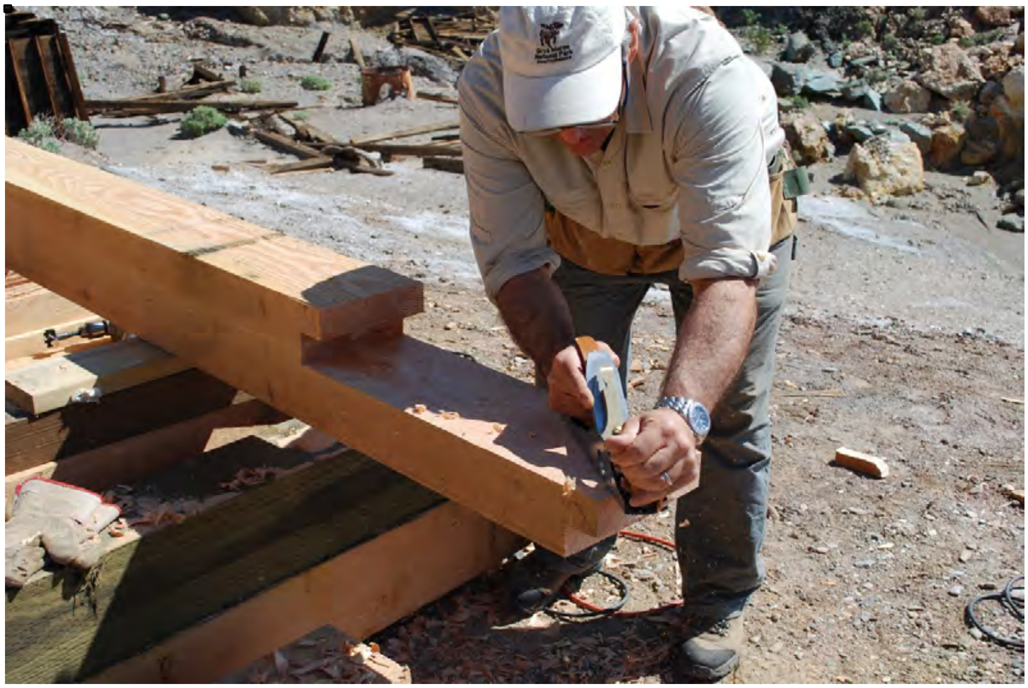

Figure 10. Planing face of scarf joint, replacement timber for tower 9

WORK REMAINING

The pilot implementation project represents the first step in a project that will ultimately require many phases in the years to come. At a minimum, repair kits should be installed at towers 6, 8, and 9 to accomplish the short-term goal of stabilizing the highest-risk structures in the tramway. Most of the rest of the tramway structures were assessed at high or medium priority and remain at risk. The 2009 condition assessment document *Keane Wonder Mine Aerial Tramway Stabilization, Death Valley National Park* contains detailed descriptions of deterioration conditions and the repairs needed for each of them. Appendix B of this report also contains additional information regarding future repairs, based on observation and investigation throughout the course of the repair implementation process.

APPENDIX A: Leitner-Poma Letter Report

April 7, 2010

Keane Wonder Mine
Line Structure Track rope removal

March 10, 2010 JF Mugnier and Rod Stocking visited the Keane Wonder Mine ore tram site. The purpose of this visit was to provide technical guidance on removal of the existing track rope from some of the line towers and general impressions of other structures. The removal of the track rope is to facilitate stabilization of the present tower structures.

The bottom station is located at an elevation of approximately 1,400', the top station elevation is approximately 2,500' and the approximate length is 4,800'.

The tram has two track ropes, one per side, of different sizes. The rope on the left side of the towers looking up hill appears to be 7/8" dia. 6X17 IWRC. The rope on the right appears to be 1 ¼" 6x17 IWRC. The ropes are attached to counterweights in the bottom station and ground anchors at the top station. The counterweight for the 1 ¼" rope is resting on the ground due to a failure of the head sheave supporting structure. The counterweight for the 7/8" rope is supported by timber cribbing to the ground.

The primary focus of this visit became an evaluation of the line tower loads and discussions of a safe procedure to lift the track ropes from the high priority line towers noted for repair 6, 8 and 9. The track rope is in all the tower saddles with the exception of the east side of tower 8.

After site review and calculations it was determined the vertical load of the track rope (right side 1 ¼") at tower #6 should be in the area of 2,500 lbs. The loads at towers 8 and 9 will most likely be higher but were not calculated at the time of this visit.

From this site visit we would recommend the movement of the track ropes be kept to a minimum.

In our opinion the ropes on tower #6 could be lifted using a mast hoist arrangement situated as close as possible to the base of the tower and still allowing room for the reconstruction, this mast hoist system would be used to lift the track rope only enough to allow for the reconstruction of the existing towers. The mast hoist systems would require guy wires and possibly cross bracing to insure stability throughout the reconstruction of the existing towers.

Tower #8 is the most difficult to deal with, the right (looking up hill) track rope is still on the saddle and the left is not. The ground under the right rope appears to drop off steeply making the placement of a mast hoist problematic and may require the addition of a jack leg(s) to help stabilize the mast.

Tower #9 could be handled much the same as tower #6 with taller mast.

During our site visit a hazard was found at the Breakover Station. At this station a ore car hanger is entangled in the haul rope and hooked on the wood cross member on the downhill side of the structure. The haul rope that is entangled is under tension from this hanger to at least tower #10 and possibly tower #8. Should this hanger pull through the cross member it could cause undesirable results further down line or catastrophic failures of structures down line. We would recommend this be stabilized prior to work commencing any where below this Breakover Station. This could be accomplished with the use of an anchor set up hill of the break over and attached to a tag line from below the hanger. The tag line could also be attached to one of the track ropes just uphill of the Breakover Station if an anchor is not a possibility.

After having ample time to digest this project we have to ask if it has been considered that the track ropes be removed and placed on the ground from the Breakover Station to at least a reconstructed tower #6 if not top to bottom.

We have searched for suitable mast for this project and have some possibilities however to determine the exact fit for a safe project of this nature will require additional engineering studies and review. It could also be necessary to revisit the site to obtain information to accurately determine the loads and site conditions at towers #8 and #9.

We hope this information helps with your decisions. LPOA is willing to help should you desire additional technical support or qualified rigging personnel to complete your project.

Rod Stocking
Service Manager

APPENDIX B: PRINCIPAL INVESTIGATOR FOLLOWUP

Following the conclusion of the field school in March of 2010, funding for additional work was made available through another contract; in this context, some of the University of Vermont crew were involved in the timber repairs to the upper and lower terminals and towers 8 and 9. Repairs were made in a series of three 2-week long mobilizations occurring in November and December of 2010, and March of 2011. While the repairs completed in this project are not included in the scope of the original task agreement, reporting requirements for the general contractor were limited to a set of as-built drawings that show repaired and replaced elements, but do nothing to capture the rationale for individual repairs. This addendum is included in UVM's project completion report to make the information accessible to future site stewards.

The scope of work in the 2010-2011 project was intended to address as many of the high-priority repairs (as outlined in the 2009 condition assessment document *Keane Wonder Mine Aerial Tramway Stabilization, Death Valley National Park*) as possible. It was understood that the available funds would not address all of the high-priority needs and that stabilization would be a multi-phase process. Towers 8 and 9 were selected primarily due to the condition of historic braced frames that supported them at sill level. The towers themselves were characterized by deterioration conditions typical of many of the tram towers, but failures in the braced frames placed towers 8 and 9 in imminent danger of collapse.

While the upper terminal was repaired c.1980 in a project that addressed management of cable loads at failed timbers in the south bent, ongoing decay of column bases on the structure perimeter was resulting in distortion of the frame and failures in girts and braces attached to the columns. The lower terminal was included in the scope of work because of its proximity to the trailhead at the lower end of the tram route. Work on the lower terminal was to focus on bracing of tall slender columns on the east elevation and repair of deteriorated floor frame elements. Floor frame repairs necessitated removal of much of the wooden deck, which was replaced in kind.

The crew used structural staging for picking cables and supporting the towers while they were being repaired. For towers 8 and 9, structural staging was erected inside the tower frame and used to support cribbing for jacking the saddle beams. With the track ropes seated in cable saddles, saddle beams were jacked level. In both cases, this resulted in some rotation of the towers as columns adjusted normal to the saddle beams. With cable loads supported, individual elements could be removed for repair and then reinstalled. The staging is relatively lightweight, flexible in terms of adapting to site conditions and tower geometry, and easy to move by helicopter. Since nearly all the towers require some repair, the park might consider purchasing its own staging. This could be moved from tower to tower according to repair priority and stored onsite at the end of each job. Similarly, there is a need for cribbing at each of the towers to be repaired. The park could obtain cribbing and the stack could be moved as needed until the completion of all repairs. This is more economical than flying items in and out at the end of each job, and would reduce the expenses associated with mobilization and the beginning and end of each phase.

The repair strategies developed initially in the condition assessment report and then implemented on a limited basis during the field school, still seem appropriate after implementation on a larger scale. For columns, scarfed repairs mimic the original construction, and in some cases it was possible to introduce new material at existing scarf locations. Where braces could not be salvaged, they were typically replaced; replacements were generally made with wood of the same species but of higher quality. This should help to address failures at knot clusters, for example. Connections were bolted, as in the original construction, and every effort was made to maximize relish at connections. Where possible, diagonal braces were carried across sills and through-bolted to them. This strategy for connecting towers to sills was one of two employed historically in the construction of the towers, and with respect to durability was more successful than bolting from sills to column bases. This latter strategy required access to the bottom of the sill and so was not feasible in a repair context, and in most cases vertical bolt holes in the column bases were extensively decayed.

Loss of relish at tops of columns and saddle beam struts was addressed by the addition of metal reinforcing plates let into dadoes cut across the grain of the column or strut. Bolted connections were made through the plates. These plates were used in the housings cut in saddle beams struts and columns whenever possible, though in some cases housings no longer fit properly and plates were more effective when located on exposed surfaces.

On Towers 8 and 9, small changes were made to the braced frames that support the towers at sill level. New bracing was introduced in order to resist movement of the towers in the direction of the cable axis. This resulted in two different configurations of the braced frames, because of differing orientations of the braced frames. At tower 8, an additional column was introduced in the braced frame for adding connections to the long diagonal braces, reducing the tendency to buckle. At tower 9, additional braces were added between the columns and sills of the braced frame. In both cases, the original bracing had already been replaced in earlier repair campaigns. Modest changes in these ground level frames seemed acceptable given the expected improvements in durability.

The replacement of diagonal braces on the long slender columns of the lower terminal contributes stiffness, and has returned this portion of the structure to its original configuration. Decayed and/or failed joists and girts at the deck level were replaced in-kind or sistered, depending on access and the condition of the wood above. No repairs were made to the failed oak beams that supported cable sheaves; repairs to these elements will require that cables be slacked. Cables and sheaves were stabilized in a c.1980 repair, and restoration of the wooden elements is not a high priority need.

After repairing column bases at the upper and lower terminals, excavations were refilled with tailings at the request of the park. This was to eliminate the hazards associated with having several open pits at each site. Because the park has had mixed results with the use of borates-based wood preservatives, column bases were not treated. Instead, columns were placed on bearing plates consisting of Douglas fir 3 x 12s laid over pressure-treated lumber in contact with the rock or soil. It was felt that the rate of decay was acceptably slow, and that periodic inspection was the most practical way to manage the problem of deterioration. Inspectors should be alert to settlements in the structure that signal shortening of the columns, and regularly scheduled direct inspection (requiring excavation) of columns in zones subject to high moisture contents (all of the columns repaired in this project can be considered to be located in high moisture zones).

At the time of the initial assessment report, it appeared that the ore bin of the upper terminal was listing to the west perhaps as the result of decay in the west columns. In the course of making repairs, it became apparent that as the columns on the east side of the bin decay and shorten, the bin bears against the terminal structure to the east and is forced out of plumb to the west, with hinging of the structure at the juncture between the columns and framed portion of the bin. The situation was addressed by repairing the east columns; these columns should be included in periodic inspections of the upper terminal.

In the structural modeling of the towers (described in the condition assessment report), cable loads were found to improve the resistance of the towers to wind. However, the structural models did not fully capture the complexity of the interaction of the cables with the towers. During our six weeks in the park we had the opportunity to observe movement of the cables associated with temperature changes and high winds, and came to appreciate the role that friction and other forces between cables and saddles may play in the rotation of the towers.

Tension in the track ropes between the lower terminal and tower 6 is high, perhaps the result of the failure of the beams supporting cable sheaves in the lower terminal and the sudden lurching of the weight boxes, and the pay out of cable into the canyon span between towers 6 and 7. In their report dated March 10, 2010, Leitner-Poma suggested removing the track ropes from the lower towers to eliminate significant stresses induced in the towers due to the taut cables.

It is highly unusual to find an historic aerial tramway with cables still intact on the tram towers. Interpretation of the site and visitor experience of the tramway with its cables in place is preferable (and more historically accurate) to an experience of isolated tram towers having no visible connection to the mining operation at the top of the mountain or the processing operation at the foot of the mountain.

The role of the cables in the structural behavior of the towers is not thoroughly understood. The structural interaction of cables and towers are issues commonly addressed in transmission line engineering analysis. To maintain the historic integrity and character of the Keane Wonder Mine tramway, we recommend that Death Valley National Park consider conducting an engineering study of the cables and their interaction with the tram structures for the purpose of optimizing tension in various segments of the line, reducing the risk of catastrophic failure, and developing techniques for monitoring and maintaining those conditions. The School of Engineering at the University of Vermont and its team has the capabilities to conduct this study.