Building an Icon –
Constructing the New Jackson Hole Tramway

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Abstract

The iconic Jackson Hole Tramway was replaced in 2008 with great success after nine years of analysis and planning that determined that the system, built in 1968, had reached the end of its life. The construction methods and schedule were both aggressive and creative. The experiences gained through the planning and construction of the new tramway are noteworthy and can help to guide the planning of future projects. The challenges associated with the Jackson Hole terrain, location and weather were compounded by the system length, market conditions, and the complexity of this project. Through an understanding of the tramway's unique construction techniques and specific examples of challenges and how they were overcome, the lessons learned on this remarkable project may streamline future aerial ropeway projects. Specific examples of successes and challenges will be dissected. The challenges will be examined for their causes and their corrective actions. Additionally, possible alternative methods that would have allowed these issues to have been avoided will be discussed. This paper will conclude with an evaluation of the construction process as a whole in which the project schedule and philosophies will be discussed.

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History of the Tramway

The Jackson Hole Mountain Resort (JHMR) was founded in 1962 by Paul McCollister, Alex Morley and Gordon Graham. The area, modeled after a European ski village, shortly thereafter welcomed a tramway that would become world-famous. The original tramway system equipment was engineered by Robert McClelland. The tramway construction was completed for the 1966-67 ski season, offering the public unparalleled access to 4139 vertical feet of terrain. The tramway received major upgrades throughout the years, including cabins in 1989, a power system upgrade in 1993, a gearbox replacement in 1995, a gearbox rebuild in 2000, cabin hangers in 1999 and carriages in 2001. Other than these modifications, the majority of the tramway's equipment was operated and maintained for forty years, including the track ropes. (See Figure 1.)

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By the early 2000s, the then thirty-plus year old tramway was starting to show signs of age. Doppelmayr CTEC was commissioned by JHMR in 2004 to perform a detailed review of the tramway. Doppelmayr was asked to provide recommendations on what would be required to achieve another forty years of service out of the existing tramway. Doppelmayr identified several deficiencies needing corrective action. The most critical of these issues was the condition of the existing carriage track rope brake. The track rope brakes were largely ineffective due to the original design. The brake force was determined to be too low to stop the tram carriage under all possible failure conditions.

Jim Fletcher and Jamie Bunch, of Parametrix Consulting (Parametrix), were contacted by the resort to perform a system-wide assessment and review of the Doppelmayr report to determine if the tram was capable of continued operations. (See Figure 2.) Parametrix determined that the amount of upgrades required to bring the tramway up to industry standards was too extensive, and the tramway had basically reached the end of its useful life. The tram had reached "technical obsolescence." The obsolescence of the tramway had a cascading effect. Should the track ropes be replaced, it would be prudent to replace the tower rope saddle shoes. The saddle shoes are the brass liners that are in contact with the track ropes at each tower and terminal that dictate the curvature of the rope. If the saddle shoes were replaced, the new shoes should be updated to have a radius compliant with the modern standards. If the shoe radii changed, then the saddles supporting the shoes would need to be replaced with longer saddles, and consequently the towers may have needed modification. And of course, the tower foundations which were already in question would likely receive an increased load, further complicating the situation. The domino effect caused by upgrading a single component of the tramway could have carried through nearly the whole system.

Parametrix recommended that the system be operated no later than June of 2007, and that the most critical issues be corrected in order for the tram to be used to transport the public up until that time. Corrective actions included decreasing the operation speed, routine inspections of critical components, limitations on the number of passengers carried and the modification of the track rope brakes. The primary driver for the retirement date was the remaining life of the track ropes. The track ropes were in need of replacement, and this multimillion dollar cost could better be spent towards a new tramway rather than a temporary upgrade to an aged system.

In order to alleviate the track rope brake issue, the brakes were removed. The current trend in tramway construction is based on the theory that the design of a haul rope and its associated equipment should use a high enough factor of safety that a track rope brake is not required. In order to justify this significant modification, the haul rope sockets were thoroughly tested and it was determined that the factor of safety was sufficient.

Much of the underlying concern about the tram's condition related to the tower and terminal foundations. The foundation designs had utilized rock anchors that could not be inspected and much of the construction processes for these anchors were unknown.

Parametrix and JHMR worked together to develop a plan for the retirement and replacement of the tramway. It was determined that the tram would be replaced following the 2006/2007 winter season. This decision was made based on the Parametrix recommendations along with compliance with the overall construction schedule.

Assisted by Parametrix, JHMR prepared a preliminary design for the new tramway and put the project out for bid. Doppelmayr CTEC was selected to design, fabricate and install the new tramway system equipment. Working with Garaventa, their Switzerland based subsidiary, Doppelmayr beautifully executed the design and construction of the tramway. Parametrix was retained as owner's representative by JHMR to assist the resort throughout the design, design review and construction phases. Parametrix was additionally responsible for the design of the tower and terminal foundation structures.

The following firms had significant roles in this project:

Carney Architects	Lower Terminal Architect
KL&A	Lower Terminal Structural Engineer
Zaist Construction Management	Construction Management
Nelson Engineering	Field Survey, Construction Observation, Testing
Crux Geotechnical Construction, Inc.	Tower and Upper Terminal Foundation GC/Driller
Gunderson & Stanley, Inc.	Lower Terminal Foundation GC

The Path to a New Tramway

The path to the new tramway was both challenging and rewarding. Many difficult situations were overcome through creative solutions and hard work.

> "We have a phoenix coming out of the ashes of an old machine here and we've got a new firebrand for all of you that's going to run you to the top of the mountain for the experiences of a lifetime." *Chuck Melichar*

New System Specifications

System Type:	Dual Lane Jig-Back	Cabin Capacity:	101 each
System Length:	11673 feet	Elevation Gain:	4139 feet
Track Ropes:	2.28 inches	Haul Rope:	1.69 inches
Drive Power:	2,000 hp	Operating Speed:	26-33 ft/s
Number of Towers:	5		

Planning the System

Planning a tramway with over 4,000 vertical feet of travel in a remote location presented some unique challenges. Spanning elevations of 6,300' to 10,400', the seasonal weather constraints played a large role in the system planning. The construction schedule was not only limited by the ski season, which ranged from December through April, but access to the upper towers and the upper terminal was limited more than 9 months of the year. Constructing a tramway in these conditions in a cost-effective manner prohibited the use of helicopters for all material transports, and the short construction season made foundation construction difficult. A creative solution was necessary. (See Figure 3.)

There was a desire to maintain the existing tramway alignment due to the limited road access on the mountain and the restrictions to constructing new roads. Of the five tramway towers, four towers had existing road access along with the upper terminal. Tower 2 was only accessible by helicopter. It was determined that the new tramway would not only utilize the existing alignment, but utilize the same tower locations to take advantage of the road access. While four out of the five towers had road access, the roads were inaccessible much of the year due to snow and would have required an unreasonable amount of time to transport all materials by road. The solution to this challenge was the use of the existing tramway as a material tram, or mobile crane, for as much of the tramway construction as possible. The tramway cabins were reinforced and holes were cut into their floors. A six-ton winch and diesel generator were placed in each tram car, and the construction cranes were born. The two tram cars hauled over 500 yards of concrete and 300 tons of steel, operating 10 hours per day, seven days per week. (See Figure 4.) Utilizing the same alignment and using the tram cars as mobile cranes formed a perfect marriage. It was decided that each new tramway tower would be located within close proximity of the existing towers, slightly up- or downhill. The lower terminal was located just below the existing terminal so that the tram cars could also access this area. Due to the base area usage plan, it was decided that the lower terminal should be located in approximately the same position as the existing lower terminal. This required the existing lower terminal to be demolished prior to initiating construction on the new lower terminal.

<u>Project Schedule</u>

Parametrix and JHMR proposed an aggressive construction schedule which was focused on limiting the tramway downtime. A schedule was developed in which the tramway towers and upper terminal foundations would be constructed in the summer of 2007, the lower terminal foundation in the winter of 2007/2008, and the system equipment be erected in the spring and summer of 2008 for a fall 2008 opening. This schedule made use of the efficiency of the material tramway. Additionally, the new tower materials were hauled to the tower sites at the end of the 2007 construction season on the same trucks that hauled the demolished towers back to the base of the mountain. This dramatically reduced vehicles trips on the mountain. The trucks that were utilized for this activity were all-terrain trucks specially modified for a flat bed. The tower materials were placed at their respective sites prior to spending the next 6 months under snow. The following spring, cranes were driven to each site and erection began. (See Figure 5.) In the case of Tower 2, given there was no road access to this tower, a needle crane was erected at this site and used for the tower erection. A needle crane is a narrow trussed crane that is guyed off and is assisted by a winch to lift the various tower members into position.

The lower terminal construction was planned to fit within a narrow window following the removal of the existing lower terminal structure and prior to it being required to support the track and haul ropes. In order for the construction of the tram to be completed in less than two years and for the tram to only be out of service for one ski season, the lower terminal building and system foundation structure was required to be constructed during the winter. This nontrivial feat was accomplished by building a temporary building structure around the site of the lower terminal building that could be heated and allow for concrete placement while exterior temperatures were as low as zero degrees Fahrenheit. This process was successful, and the concrete foundation that would soon support the lower terminal building structure and the tramway equipment was completed in the spring of 2008.

Given that the largest volume of concrete, other than the lower terminal, existed at the upper terminal, and this was the furthest distance to travel by road, a concrete batch plant was placed at the top terminal location. The batch plant consisted of a hopper and mixer which could supply up to three yards of concrete per batch. (See Figure 6.) The concrete was transported by the material tram cars by means of a suspended concrete bucket lifted and lowered by the in-car winch. It was realized early in the process that the small batch plant was insufficient for the volume of concrete that needed to be placed, and a cement mixer truck was driven to the upper terminal site and utilized as batch plant. The concrete mix was transported to the top of the mountain by a combination of road vehicles and with the material tram in super-sacks. The super-sacks contained the cement, aggregate and admixtures in the proper proportion for a batch of concrete. Water was available 1,000 feet below the top of the mountain from a natural spring. The water was trucked from this spring to the top of the mountain and stored in a temporary pond. By batching the concrete at the top of the mountain, the number of trips that the material tram was required to make was lowered, and the tram cars could be utilized for concrete delivery rather than hauling concrete from the base of the mountain.

Tower Foundations

The transportation issues on the mountain played an important role in the selection of the foundation type for the new tramway's tower foundations. While the existing tram cars made a capable haulage system, there was a limited amount of material that the existing system could transport. Constructing gravity foundations was not an option, given the capacity limitations of the mobile crane and the time required to transport concrete to each site on the mountain. Additionally, due to the varying soil types at each tower site and at the upper terminal, drilled shaft foundations would have been a challenge to construct. For these reasons, micropile foundations were selected for the tower foundations and the upper terminal bollard anchors.

A micropile foundation consist of a small borehole, ranging from six inches to twelve inches in diameter, and with enough depth necessary to transfer the axial loads on the pile to the soil through friction along the sides of the pile. Following the drilling of the borehole, a large diameter threaded rod is inserted into the borehole. For the tower foundations, the rod was inserted full depth into the borehole. During the drilling process, a steel casing is advanced with the drill-head to stabilize soils. Following the drilling, the casing is partially retracted leaving a section approximately ten feet in length at the top of the borehole, protruding several feet. This casing provides additional shear resistance for the pile by increasing the area of steel at the interface with the ground level. The micropile is then grouted with a high strength grout. The grout provides a friction surface with the soil and transfers this friction load to the threaded rod. A large plate is placed on top of the casing, above the ground, and a nut is threaded onto the rod. The piles are then typically encased in a pile cap which is loaded by a structure. (See Figure 7.) The micropiles for the Jackson Hole Tramway project utilized a Class I multiple corrosion protection system. The threaded rods were encased in a plastic, ribbed encapsulation in which grout separated the rod and the encapsulation. This created a triple layer protection system for the threaded rods, helping to ensure a long service life.

Each tower leg for the newly constructed Jackson Hole Tramway utilized four micropiles below each tower leg with a pile cap measuring sixty inches cube. These pile caps included cast in place anchor bolts to secure each tower leg. The micropile boreholes were drilled with a small track-mounted, pneumatic drilling rig which was light enough to be transported by the material tram. This expedited the foundation construction process, as the rig could be quickly moved over rough terrain between each of the foundations of a tower or from tower to tower. The material tram also delivered the micropile materials and concrete by way of a suspended bucket to each foundation site. Temporary steel platforms that could be carried by the material tram were utilized to create a level surface for the drilling rig where required. The adjustable legs of the platform could conform to any surface. (See Figure 8.)

The advantage of the use of micropiles was not only the small scale of the drilling equipment, but the ability of the drilling rig to drill through varying soil conditions. Given the elevation change of this project, the soils changed from the alluvial fan deposits of low plastic clayey gravel with cobbles and boulders at the lower terminal to bedrock consisting of sandy dolomite at the upper terminal as the terrain moved through 5 different geologic formations. Additionally, the geologic formations were dipping at a significant angle, creating varying soil conditions even within the footprint of a single tower. Micropile construction techniques deal with these varying soil conditions much better than the large diameter drilled shaft foundations that are typical. The drilling rig utilized a percussion drill head with compressed air that would flush the pulverized rock, or sand alike, out of the hole. Utilizing this technique, the drill head would not need to be changed for a single hole varying from sand to bedrock. This increased the speed of construction and ultimately lowered costs.

Upper Terminal Foundations

The upper terminal foundations consisted of concrete bollard structures to tieback the track ropes, a concrete hoistway used to encase the haul rope counterweight and support the main terminal structure, and a number of small spread footings and micropile foundations to support the extensive walkways for the upper terminal. The bollard structures utilized eight rock anchors each for hold-down retention and sliding resistance. The rock anchors were constructed in a similar manner as described above for the micropiles with one key deviation; the rock anchors passed through the bollard structure foundation, and the anchors were pre-tensioned such that the cyclic loading of the track ropes would not induce fatigue into the rock anchor rods. (See Figure 9. and Figure 10.)

The upper terminal foundation structures utilized a significant amount of concrete totaling 500 cubic yards. This amount was kept to a more reasonable total through the use of rock anchors to restrain the track rope bollards. Without the rock anchors the volume of concrete that would have been required to resist the rope tensions would have been on the order of double what was used. The utilization of the batch plant at the upper terminal made this volume of concrete possible and reasonably efficient.

Lower Terminal Foundation

The lower terminal foundation structure was designed to support the lower terminal building as well as the tramway system equipment. The system equipment included the track and haul rope break-over frames as well as the drive bullwheel frame and ancillary equipment. Due to the nontrivial overturning loads on the lower terminal foundation caused by the rope tensions and amplified by a significant wind and seismic loads, it was challenging to create a foundation structure capable of resisting the required loads. To assist in this resistance, the existing track rope counterweights were lowered to the bottom of the counterweight pits and the walls of the existing counterweight pits were tied into the base slab of the new tramway lower terminal building foundation. This additional resistance provided approximately 27% of the total overturning resistance of the building structure. This solution saved approximately 265 cubic yards from the base of the foundation slab. (See **Error! Reference source not found.**.)

Removal of the Old Tram

The removal of the existing tram presented an equal number of opportunities for ingenuity as the construction of the system's foundations. The existing haul rope was utilized to pull the new track and haul ropes up the mountain. The existing haul rope was spooled on a winch at the top terminal and repeatedly pulled the new ropes to the top of the mountain. The remaining ropes were removed from the existing tramway by a sophisticated series of rigging that allowed the ropes to be first disconnected from the lower terminal and then spooled at a location just above Tower 1. This process occurred much unnoticed, but allowed access for the existing lower terminal demolition much sooner than would have been otherwise possible if the ropes been spooled and removed through the lower terminal.

Lessons Learned

Through the challenges of this tramway construction project, a number of lessons learned became evident. By sharing these experiences, we may be able to assist others in avoiding similar situations on future aerial ropeway projects.

Tolerances

This project, as with many aerial ropeway projects, brought people together from multiple continents and multiple backgrounds. This project was memorable both for the successes and the challenges. This project was an example of Swiss precision meeting rough construction head-on. The steel structures designed, fabricated and installed by the Doppelmayr team were in one word, precise. It was truly a pleasure to watch the erector-set of parts grow from a pile in a shipping container to an erected tower. What was so impressive is the ease with which this occurred. On the flip-side, the foundation construction was, while generally acceptable for typical building construction, not up to par with the requirements of a specialized system like a tramway. The steel was fabricated with tolerances measured in millimeters, while the concrete placement was measured in inches. It became apparent that the placement of the tower and terminal foundations was not adequate for the interface with the steel structures. It was a challenge to survey a steep remote slope. It was a challenge to place anchor bolts within the prescribed tolerances. It was a challenge to form and pour concrete in this tough environment and reach the quality that is demanded by a system with loads as high as a tramway.

The result of this mismatch of expectations and understanding was numerous field modifications to base plates and other interfaces. The lesson learned was two-fold. First, the foundation contractor must be made aware of the requirement for atypically tight tolerances and understand the importance of the interfaces being properly constructed. Second, an increase in the tolerances at interfaces would help prevent this problem. Doppelmayr had originally proposed a tower base plate requiring a very large block-out in the tower foundation. This base plate design would have accommodated deviations in the location of the anchor bolt pattern centroid of several inches. This design was rejected due to the size of the pile cap that this base plate would have required and consequently the volume of concrete. It is estimated that the increase in concrete would have been on the order of double the volume required for the selected design. In retrospect, this design may have alleviated the issues related to the bolt patterns being shifted from their precise location, but would not have accounted for the deviations within the pattern and the deviation of the anchor bolts from vertical. Perhaps a solution to this issue is not only a higher degree of precision in the placement of the anchor bolts, but oversized holes in the base plates and plate washers below the nuts to distribute the load. This solution may be a viable and cost-effective compromise.

In addition to specific interface issues, the Jackson Hole Tramway project had several issues related to the complex surveying required to construct the tower and terminal foundations. A system of more than two and a half miles in length, that requires fractions of an inch of accuracy over that length, is a challenging survey project. Because of the difficult terrain and distances involved, it was difficult to perform an accurate survey and "close the loop." Additionally, what is easy to construct in a piece of computer aided design (CAD) software is not necessarily easy to construct in the field. The tower foundations were designed to be battered in most cases and this presented a challenge for the survey crew. In the case of Tower 5, the tower consisted of two main legs with a pair of struts angled laterally away from the tower. These struts were to land on a pair of footings constructed not only at one batter angle, but at a compound angle in two directions. Translating plan coordinates to survey staking and communicating this to contractors was difficult and in several cases caused tower footings to be placed slightly off the plan position. While this did not affect the functionality of the tramway, the lesson to be learned here for designers is to consider how reasonable it is to construct complicated geometry in the field.

<u>Multiple Contractors and Responsibilities</u>

It is quite common in most construction industries to have a general contractor that hires multiple subcontractors to complete specific portions of a project. Concrete placement, steel erection and electrical installation are a few common examples of this. This process has both benefits and costs. On the positive side, contractors specializing in certain areas of construction are able to do what they do best. On the negative side, clear lines of responsibility for interfaces are not always unmistakable. What further amplifies these issues is when the individual contractors do not all work directly for the general contractor but separately for the owner. In this situation, the general contractor is no longer globally responsible and incentivized to produce and have those working for him or her produce quality work.

This second situation is fairly common on aerial ropeway system installations. The system supplier, often based in Europe, does what they do best; design and build a system. Where the system supplier understandably falls short is having a lack of local contacts and experience with the construction community for a particular project. Working in dozens of countries, this is to be expected. What tends to happen next is a natural division of responsibility. The system supplier, recognizing the inefficiency of selecting and managing contractors in another continent, requests that the owner supply the foundation infrastructure. The owner agrees and contracts with a local firm to construct the terminal and tower foundations. This situation can be further complicated by the owner also contracting with a different firm to design the foundations. This organization is again understandable, as a local firm is more likely to be licensed in a particular jurisdiction and also presumably has the knowledge to efficiently design the foundations. This arrangement is the situation that developed for the Jackson Hole tramway project under completely logical circumstances. What often happens next, and what happened in Jackson Hole, was that the local firm designs the foundations and the local contractor constructs the foundations. The system supplier then designs the system, fabricates the system equipment with their staff and subcontractors that they are familiar with and then finally, install the system on foundations constructed by others. The difficulty comes in when these interfaces meet. Throughout this process, if the needs of the system supplier are not fully met, a conflict arises.

The lesson learned on the Jackson Hole Tramway project is that if the system supplier is not willing to take on the design and construction of the system foundations, the system supplier should at a minimum have the responsibility to contract with the appropriate firms to do the design and construction work. In this situation, the system supplier is incentivized to have the designs and construction meet their requirements and has the responsibility to make sure this happens. Under this scenario, the system supplier also has the incentive to look for the most cost-effective solution to not only the system and the steel structures, but the interface and the foundations as well. In the case of the foundation block-out, it may have been the most cost-effective solution even considering the increased concrete volumes when the additional cost of properly constructing the pile caps and anchor bolts is considered. Dividing the project into separate responsibilities only has the potential to decrease efficiency and increase total costs.

<u>Design and Construction Documentation</u>

One of the reasons the existing tramway was retired at the time was, related to the uncertainty in the foundation structures, particularly the rock anchors. The main reason for the uncertainty was the lack of good documentation related to the design and construction of the rock anchors. Had the construction process and the design been better documented and those documents been available for review, it is possible that the system could have operated for a number of years longer under certain guidelines for inspection. This demonstrates the importance collecting and maintaining good, complete project documentation.

Collecting good documentation requires discipline and investment. The owner must invest in the additional construction observation, testing and supervision during construction. This requires, in most cases, near-full-time observation of all foundation construction activities, particularly during deep foundation construction, when the soils encountered determine the effectiveness of the foundation system. It requires ample testing of rock anchors, micropiles and concrete strength. It requires the supervision to alert the project team if activities occur outside of the planned construction, and that these modifications get fully documented.

Equally important is the maintenance of the documentation. The challenge is maintaining the documentation for close to fifty years. In today's information environment, maintaining good documentation is as simple as maintaining the electronic files, but even that has some challenges as media formats change and decay. Documentation preservation should be of key importance to a resort operator, as this alone can have a substantial impact on the life of a system.

Safety, Oversight and Proper Equipment

Throughout this project, many challenges occurred, but what made this project so successful and allowed it to be completed on schedule was the system supplier's experience and common sense. Garaventa mobilized on site with more equipment that would be necessary to install the tramway, prepared for the unknown and the challenges of the Jackson Hole terrain. Garaventa knew from experience what the best solution was at each juncture and executed the plan without fail. A lesson learned throughout this project was the preparation and cumulative experience of the system supplier and contractors can make or break a project. Selecting the right firms from the start is very important. The success of the Jackson Hole Tramway project could not have been achieved without such talented and qualified firms.

The project area was challenged by weather and terrain, compounding to form dangerously muddy and icy roads. This presented the greatest challenges and the greatest opportunity for hazards. It was learned that the selection of the proper equipment and the application of great care were required to prevent injury and damage to equipment. This easily-overlooked area of construction was vitally important and should not summarily be dismissed on future projects.

The final lesson learned of this section relates to observation. It was experienced on this project that is was critically important for the owner to be represented by staff that could be on the mountain at all times to observe and stop construction activities, if necessary, to avoid problems and hazards. Staff with a working knowledge of the tramway equipment and construction techniques were vitally important to ensure that tolerances were met and safety was maintained. Having the authority to stop the construction is a key component of this observation, so the ultimate quality and functionality of the system is achieved. It is likely possible that many of the tolerance issues on this project could have been avoided if the owner's staff had the authority to stop construction when issues were observed rather than forcing rework or a substandard finished product.

Conclusions

In retrospect, the Jackson Hole Tramway project was a success. Many challenges were overcome on the path to a new tramway. The system that became an icon will now be available for generations to come to experience the magnificent Jackson Hole Mountain Resort. The tramway project was ruled by the project schedule, and decisions at each juncture were made to preserve the project schedule. Of course, costs were higher, but the intrinsic value of limiting the system downtime to a single winter season cannot be measured. The project team came together to create a special system and worked well across multiple continents and languages. For many, this project is only one of many aerial ropeway systems, but for most, this one is distinctive.

The above examples, challenges and lessons learned, will hopefully be helpful to others planning and constructing similar aerial ropeway systems. To summarize and conclude, the following is a reflection on the issues discussed in this narrative.

Challenge	Cause	Corrective Action	Lessons Learned
Site Access	Elevation, Terrain, Limited Road Access, Weather, Seasonal Closures	Micropile/Rock Anchor Foundations, Batch Concrete on Site, Needle Crane, Utilize Existing Alignment, Material Tram	Effective use of micropiles and rock anchors limited concrete placement. On site batching avoided concrete delays, expedited schedule. Material tram saved time and expense.
Project Schedule	Lack of Tram Disruptive to Mountain Operations	Winter Construction of Lower Terminal, Early Delivery of Tower Materials to Sites	Aggressive schedule drives up construction costs. Creativity and timely action by all parties make aggressive schedule possible.
Varying Soil Conditions	5 Geologic Layers	Micropile/Rock Anchors	The use of a small borehole drilling rig was much less susceptible to varying soil types.
High Lower Terminal Loading	High Seismic, High Wind, Rope Tensions	Use of Existing Counterweight Pit	Existing track rope counterweights and pit walls would have normally been abandoned. Co-locating lower terminals made use of these structures.
Survey, Tolerances	System Length, Complexity, Rough Construction	Base Plate Modifications, Strong Engineering Support	Designers should be aware of survey limitations and construction tolerances. Contractors should understand importance of quality, accurate concrete placement.

Challenge	Cause	Corrective Action	Lessons Learned
Contractor Responsibility	No Single Responsible Party for all Work, Lack of Communication about Objectives	Good Communication	System supplier should remain responsible for foundation design and construction or the owner's representative should oversee the entire project.
Documentation (previous tramway)	Lack of Document Management by System Operator, Lack of Construction Oversight, Lack of Testing	Maintain Electronic Data in a Durable Format; Provide Sufficient Construction Observation, Testing and Supervision	A lack of documentation played a role in the retirement of the existing tramway.
Safety, Oversight, Equipment	Lack of Oversight or Experience	Sufficient Equipment, Knowledge, Experience, Common Sense, Authority	Contractors must be experienced and prepared for the difficult challenges of the project site. Owner must have qualified staff present with authority to stop construction when quality, safety or functionality is going to be compromised by the methods observed.

Diagrams/Photos

Figure 1 - Jackson Hole Tramway ca. 1966

Figure 2 - Strain Gauging Tower 2 Crossarm 2006

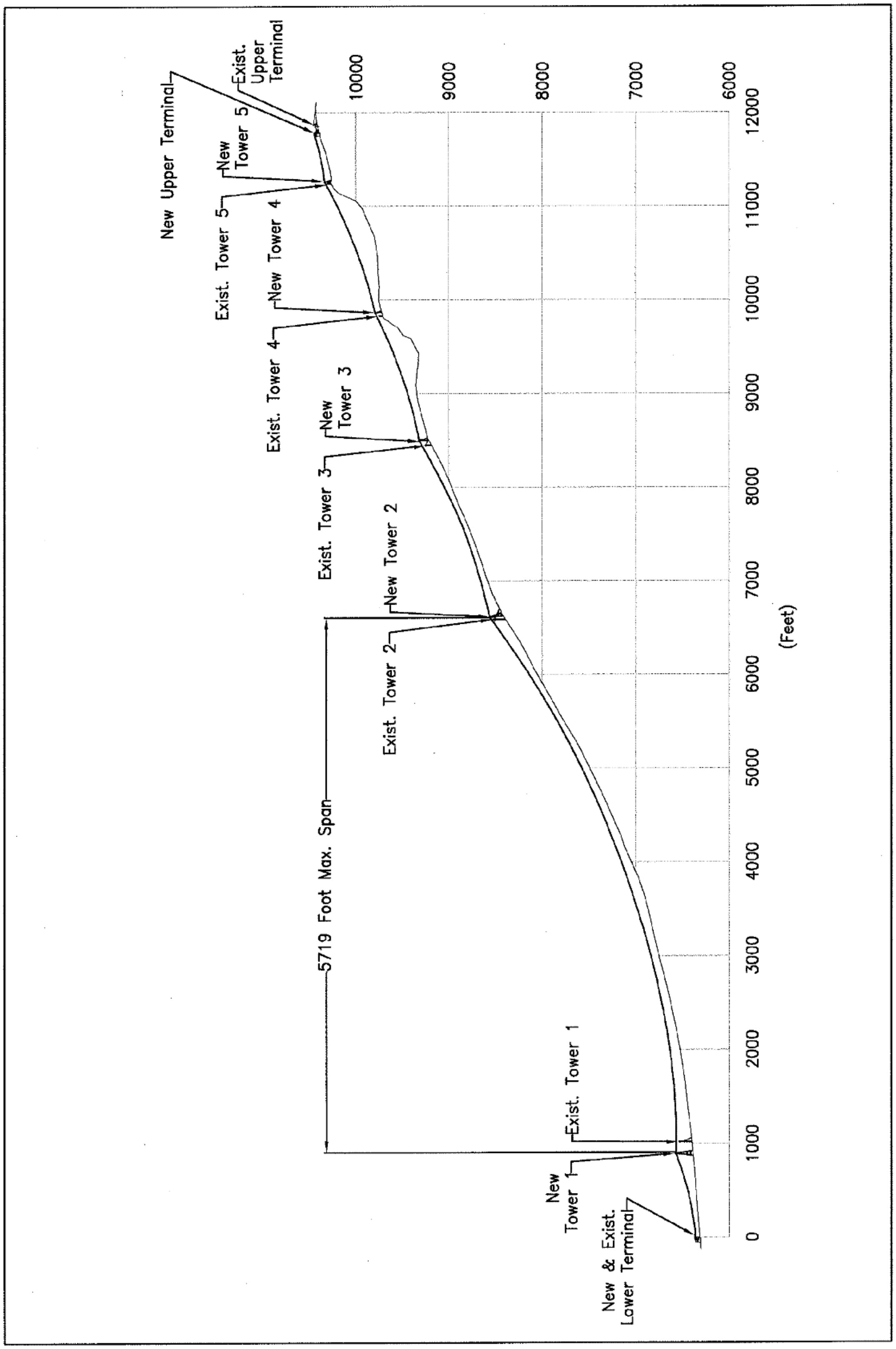

Figure 3 - Tramway Profile

Figure 4 – Concrete Placement with Material Tram

Figure 5 - Tramway Construction Schedule

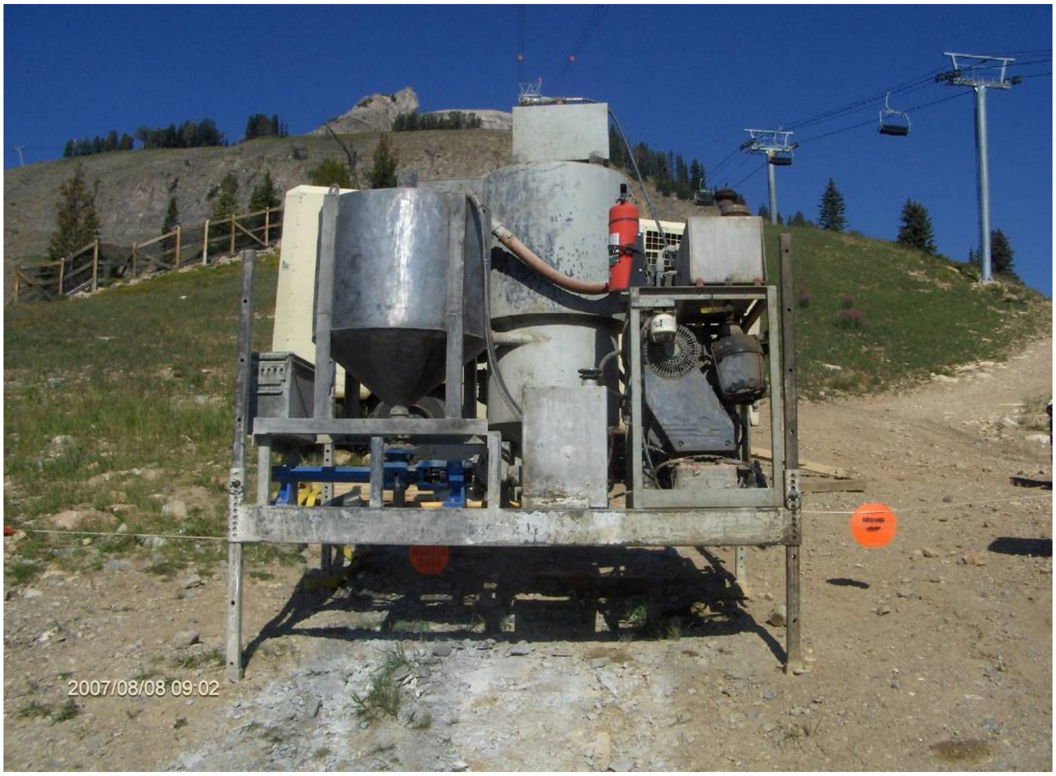

Figure 6 - Batch Plant at Upper Terminal

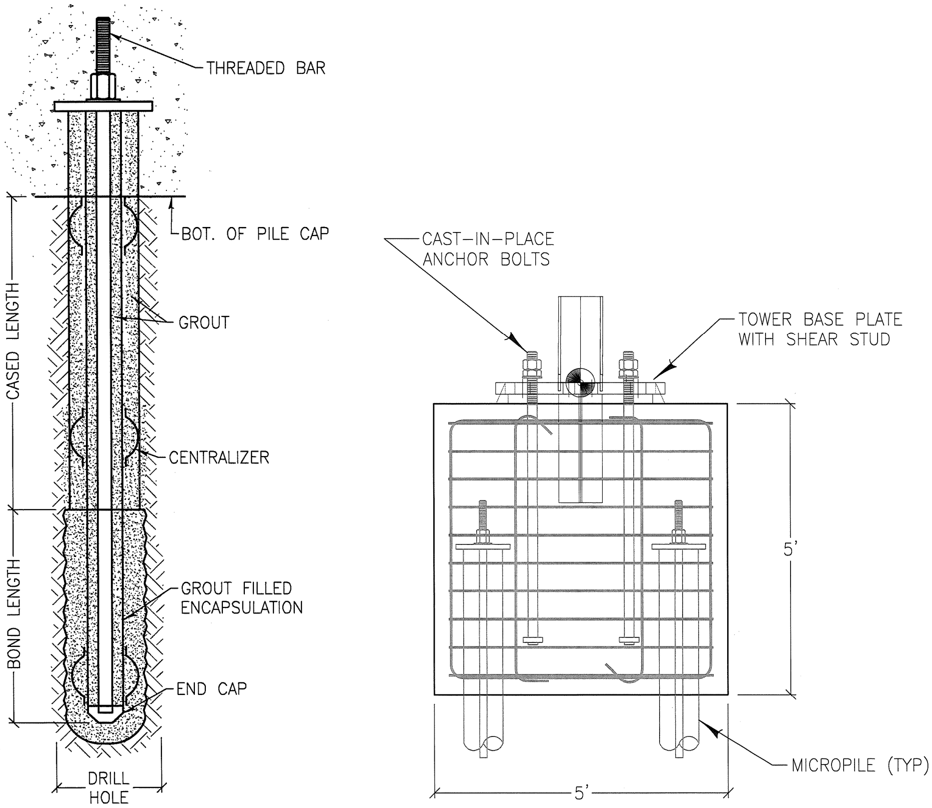

Figure 7 - Micropile Diagram & Pile Cap Elevation

Figure 8 - Micropile/Rock Anchor Drill Rig

Figure 9 - Upper Terminal Bollard Structure

Figure 10 - Upper Terminal Haul Rope Counterweight Hoistway