The Great Salt Lake Causeway-

Its Recent History and Current Maintenance Program

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Abstract:

Since the completion of the Transcontinental Railroad in 1869, the Union Pacific Railroad has provided a vital link across the United States. With the decision to reroute the railroad in 1900, the Great Salt Lake became a critical link in the cross country route, one which poses difficult challenges to the maintenance staff and engineers who attempt to keep the trains running across this stretch of track. The history of the railroad in the Great Salt Lake area, the physical setting of the area, the design and construction of the crossing in 1900, the replacement of the center 12.5 miles in 1956, the overtopping in 1986, and the foundation failure and repair at MP748 will be discussed. We conclude with the on-going UPRR monitoring, maintenance, and repair program, including the settlement monitoring program, cleaning of the culverts, armor rock placement, and emergency repair preparedness.

INTRODUCTION

Since the completion of the Transcontinental Railroad in 1869, the Union Pacific Railroad has been a key player in the vital route across the United States. With the decision to reroute the railroad in 1900, the Great Salt Lake became a critical link in the cross country route, one which poses difficult challenges to the maintenance staff and engineers who attempt to keep the trains running across this stretch of track. The design and construction of the crossing in 1900, the replacement of the 12.5 mile trestle in 1956, the overtopping in 1986, and the foundation failure at MP748, were all controlled by the harsh natural environment and geologic history of the lake. These factors continue to affect the embankment's behavior and the on-going maintenance of the structure.

HISTORY OF THE GREAT SALT LAKE

The Great Salt Lake (GSL) is a remnant of ancient Lake Bonneville, which originally covered 20,000 square miles of western Utah and smaller portions of western Nevada and southern Idaho *(1)*. Like the current Great Salt Lake, Lake Bonneville was a terminal lake, with no rivers draining from it, for a long period of its history. Lake Bonneville was reduced in size by global climatic changes over the millennium to the current size of the GSL.

The location of the GSL is controlled by Basin and Range faulting, a series of roughly north-south trending faults, extending from eastern California through Nevada to Utah. This province comprises a series of faults, downblocks and upthrust mountains, producing the distinctive alternating pattern of linear mountain ranges and valleys. There are numerous north-south normal faults in the region of the GSL, of which two extend under the lake, as shown on Figure 1*(2)*. Subsidence between the faults has allowed deposition of as much as 12,000 feet of sediments, transported into the lake by its tributaries.

The water level of the GSL is controlled exclusively by inflow quantities and the evaporation rate. The GSL receives water from precipitation, rivers, streams, and groundwater. Figure 2 shows the variation in the lake levels in the last 150 years. Since 1847 when the lake levels began to be recorded, the levels have varied over a range of 20 feet *(3)*.

HISTORY OF THE RAILROAD

The building of the transcontinental railroad is considered one of the most important accomplishments in the United States in the 19th century. The dream to complete a railroad that spanned the United States was envisioned by many as early as the 1830s, and gained political momentum in the 1850's. At the end of the Civil War, the time was ripe to accomplish this dream. Authorized by the Pacific Railway Act of 1862 and heavily backed by the federal government, it was one of the crowning achievements of the presidency of Abraham Lincoln. Participants in the race to complete the transcontinental railroad were the two largest corporations at the time, the Union Pacific Railroad (UPRR) and the Central Pacific Railroad (CPRR). The UPRR advanced from the east, and the CPRR advanced from the west. After 1,756 miles of grueling construction, the two railroads joined at Promontory Point, Utah, just north of the GSL on 10 May 1869. Figure 1 shows the original route of the UPRR and CPRR in the GSL basin.

During the surveying of the transcontinental route, the CPRR decided that the route south of the GSL was not practical. The UPRR decided that building a causeway or bridge across the GSL, although preferable, would not be feasible. A route across the lake could not be built due to "the depth of the lake, the weight of the water, and the cost of building" *(4).* Therefore, the route of the railroad was forced to the north of the lake, which caused them to deal with adverse grades across Promontory Ridge.

BUILDING PROGRAMS

Route across the GSL-1900

The railroad functioned on the Promontory Line route for approximately 30 years, enduring the steep grades and sharp curves. However, this stretch of track had developed into a major bottleneck on the transcontinental line. In 1900, the UPRR decided to re-examine the possibility of rerouting the railroad by going across the GSL, thereby shortening the route from Ogden to Lucin by 43 miles and eliminating the adverse topography of the northern route. In 1900, the water level was at 4197 feet, 14 feet lower than in 1868, when the original decision was made to go over the top of the lake; this water level made a lake crossing feasible.

The construction of the dumped fill embankment, the "Lucin Cutoff", between Lucin and Ogden, began in 1902. The construction consisted of building a temporary wooden trestle from the east and west sides, placing railroad tracks on top of the trestle, and moving fill material by means of railroad cars. The fill material was side dumped from the cars until the material rose above the lake level and engulfed the piles. Once the embankments reached track height, the superstructure elements were removed, and the timber piles were left in place.

Approximately 28 miles of embankment, including 15 miles in the lake, were constructed in this manner between 1902 and 1904. However, the center 12.5 miles of the Rambo and Saline Fills could not be completed as designed; workers were unable to place adequate quantities of fill material on the soft sediments to bring the embankment above the water level. A design change was necessary and the decision was made to make this center section a permanent wooden trestle. At the time of construction, the trestle was the longest bridge across open water in the world *(5)*. As shown on Figure 1, we now know that there are tectonic faults on either side of this 12.5 mile section, causing a downward moving lake bottom, which filled with very soft, non-consolidated sediments.

Trestle Replacement-1950s

While the fills across the GSL performed adequately into the 1950s, the 12.5 mile wooden trestle was not aging well. Trains on the trestle operated under low speed limitations of 20 miles per hour to reduce impact loading and sway. New high speed locomotives, increasing axle loads, settlement and deterioration of the wooden trestle piles, frequent fires caused by the locomotives, and the subsequent increased maintenance costs, caused the Southern Pacific Railroad (SP), which took over this stretch of track in the 1920's, to decide that the trestle should be replaced or rehabilitated. Since the rail traffic had to continue during construction, it was decided that only a replacement option would work.

Feasibility and economic studies were performed to determine if the trestle should be replaced with a new concrete trestle or an embankment fill. A detailed engineering study concluded that a rock-filled embankment was feasible and the most economic alternative. In 1955, the SP hired International Engineering Corporation (IECO) to perform the geotechnical investigation and civil/structural design to replace the aging trestle, subject to review by a board of consultants and the SP *(5)*.

While the dumped fill embankment hadn't been successful in 1900, the advent of the new science called "soil mechanics" made the designers confident that this option would work. It was decided that the new section of the causeway would be constructed 1500 feet north of the existing railroad trestle. The north side was chosen because of the availability of rock and fill material from the ancient Lake Bonneville beach deposits on the west side of Promontory Point.

The engineers from IECO set up an extensive geotechnical investigation for the construction of the Causeway, which included the following:

- Building towers in the Lake to drill numerous borings to obtain samples for laboratory testing;
- Advancing probes from barges to define the salt layer;
- Doing vane shear tests off trestle and in borings;
- Drilling and testing soil beneath existing fills; and
- Full-scale test fill program, from the shore and in the lake.

With the information obtained from the testing program, they put together a geological cross-section of the new alignment, shown in Figure 3. IECO performed extensive analyses for slope stability, bearing capacity, and settlement to determine the optimum embankment and foundation design. The foundation soils were very soft, organic silty clays, underlain by Glauber's salt, a non-homogeneous salt formation material, ranging in thickness from 2 feet on the west end and 30 feet on the east end. The Glauber's salt was crystalline in some areas and highly interbedded with clay in others *(IECO, unpublished date)*.

Based on the results of the geotechnical analyses and the test fills, IECO developed three basic design cross-sections: for the embankment based on thick, homogenous salt; for the embankment built on thin salt; and for the embankment built on soft sediments, where no salt layer was present. To limit the volume of material used on the embankment, and therefore, construction costs, the causeway was designed and constructed with a Factor of Safety against bearing capacity failure of slightly greater than 1. This approach was based on the soil mechanics concept that the most unstable time for the causeway was at the time of construction; once built, the foundation soils would gain strength over time by consolidating and the factor of safety would increase. Despite the test fill program, many unexpected failures did occur during construction.

In 1956, Morrison-Knudsen Company (MK) was awarded the construction contract for the embankment, culverts, borrow source exploration, field engineering, and railroad track and signals. The total awarded contract was $53 million, and construction began in March 1956. It was a construction process full of superlatives and record-breaking activities. In order to provide rock for the construction, the largest non-atomic blast ripped through the hillside of Promontory Point. The most extensive land-locked flotilla of barges and boats worked on the project. The longest conveyor belt system was used to move old Lake Bonneville beach sand from a

Promontory Point valley to the awaiting barges. A construction camp was built in Little Valley, on the west side of Promontory Point, to house as many as 1,300 workers and their families.

Marine dredges carved out 20 to 45 feet of the submarine soils forming a trench for the embankment foundation. Huge bottom dump barges then placed quantities of sand and gravel for the outer part of the cross-section, with a core of quarry run rock fill. Underwater berms were used to enhance stability outside of the dredged trench. Figure 4 shows photos of the marine construction. The embankment and roadbed were completed in July 1959, 9 months ahead of schedule. The bottom of the embankment varied in width from 175 to 600 feet, and the height of the embankment averaged 70 feet. The total amount of material used for the embankment was 45.5 million cubic yards.

CAUSEWAY PERFORMANCE

1960 to 1980s

IECO had predicted that the new Causeway would settle during and after construction. The actual settlement rates are shown in Table 1*(IECO, unpublished date)*. IECO had predicted that the settlement would last for many years, but the magnitude would diminish with time; the former prediction proved correct, while the latter has not. The settlement, combined with the variable water level, required that the embankment be constantly monitored and leveled to maintain embankment stability and prevent overtopping. The maintenance during this time consisted mostly of leveling the track and maintaining the erosion protection.

In 1982, the water level in the Great Salt Lake began to rise due to increased precipitation and decreased evaporation, as shown in Figure 2. The SP developed a design for a rock-filled box car that would be used to protect the Causeway from the rising water level. These 'gabion-like' structures were constructed of scrap boxcars and quarry run rock. In August and September 1983, 1430 scrap boxcars were placed end to end on the north side of the embankment. The box cars provided protection for two years, which allowed time for the tracks and fill to be raised on the alignment *(5)*.

Hailey and Aldrich (HA), a geotechnical consulting group, was hired by the SP in the early 1980's to assist in designing methods to provide wave protection to keep ahead of the rising lake level and to analyze the effect of raising the embankment fill up to 10 feet in height. HA had a scope of work that included extensive field investigation and testing, engineering analysis, and preparation of comprehensive reports. In order to understand how raising the level of the embankment would affect its future behavior, it was necessary to compile and analyze the performance of the Causeway since its construction. They also instigated a testing program that included drilling geotechnical borings, installing piezometers to monitor the pore pressure in the sediments, and installing slope indicators to monitor slope movement. Extensive geotechnical laboratory testing, including consolidation and shear tests, was performed. Based on the results of these advanced geotechnical engineering investigations and analyses, the SP confidently raised the embankment height up 10 feet on these soft foundation sediments *(Haley & Aldrich, unpublished date)*.

Between 1983 and 1986, a slope protection program was developed by the SP and their consultant to protect the entire GSL crossing from storms. The most vulnerable part of the causeway is on the north side and in the middle of the lake, where wind across the 40 mile long fetch can generate waves up to seven feet high. This slope protection consisted of an interlocked Armor rock (4 to 6 foot size) revetment and wall with the exposed outer slope at 2H to 1V. The Armor rock was placed on the face of the slope to dissipate wave energy and prevent wave erosion of the smaller underlying embankment rock. At the top of the slope, an interlocking Armor rock wall was also constructed on top of the box car gabions, to protect the tracks and ballast from erosion by the wave run-up. This design was completed on approximately half of the Causeway prior to the overtopping outage.

Raising the embankment level was a huge undertaking, taking place over 2 years. However, the water level continued to rise until March 1986, when many miles of the Great Salt Lake crossing were flooded by overtopping. In the areas where the permanent revetment and wall had been constructed, the causeway did not fail. However, the railroad was out of service across the causeway for 8 months, with traffic rerouted on other lines.

1999 to 2001

In 1999, Milbor-Pita & Associates (MPA), a geotechnical consulting firm (now part of Jacobs Associates-JA), was hired by the UPRR, who took over the causeway in 1996, to provide a comprehensive report on the state of the recently re-acquired GSL crossing. MPA's initial report identified three areas which needed further attention:

- Monitoring a slow bearing capacity failure at MP748 that had begun years earlier;

- Monitoring compression settlement of the Causeway, caused by fill placement over the decades;
- Designing and building wave and erosion protection along portions of the Causeway.

In early 1999, the area around MP748 was settling approximately nine inches per month and was being leveled regularly by the local surfacing crew. On 16 August 2000, a 1000-foot long section of the embankment at MP748 dropped 10 feet overnight. The UPRR was able to raise the track level four feet in one day to keep it above the water level, but over the next night, the track dropped down to water level again. The UPRR requested assistance from MPA, who identified the problem as a bearing capacity/lateral spreading failure.

In the short-term, MPA recommended that the embankment be widened, not raised, which slowed the rapid settlement of the track area. The settlement could not be stopped without a major counterweight berm construction program. While the latter was being planned, the decision was made allow trains to cross slowly through the area. This approach allowed the track to be re-opened under a slow order just five days after the failure. The UPRR re-routed some trains but generally had four trains crossing during the middle of the day and twelve to fourteen crossing at night.

While the short-term solution of keeping the trains running across the GSL was accomplished, a permanent solution to stabilize this portion of the Causeway was being designed and sent out to bid. The solution consisted of constructing two massive, rock-filled berms, one north and one south of the failure area, to prevent additional movement. The construction of the berms began on 12 Sept 2000 and was completed in late January 2001. The railroad partnered with the contractor to complete the work. The fill to construct the berms was delivered by two side dump car work trains, consisting of thirty cars each that came to the site twice per day, with two deliveries in the morning and two in the afternoon. Draglines, located on barges on each side of the causeway, spread the material out over the soft bottom sediments and excavators placed the armor rock on the outer edge of the berms for wave protection. Figure 5 is a photo of the final berm configuration.

After completion of the berms, MPA drilled three borings in the area to ascertain the cause of the failure. Based on the results of the borings, it appears that the salt layer, which was identified in the original design drawings of 1956 and in the borings from the early 1980's, is no longer present. It is suspected that the salt layer dissolved, which contributed to the failure, or broke into many pieces as a result of the failure. The actual failure mechanism is not fully understood at this time.

ON-GOING CAUSEWAY MONITORING

Settlement Monitoring

Since 2001, MPA (and now JA) has continued to provide on-going geotechnical support to the UPRR engineering and maintenance staff on the GSL crossing. The objectives of MPA/JA are to monitor the behavior of the causeway and provide geotechnical recommendations to the UPRR to:

- Prevent a catastrophic embankment failure which would result in track outage;
- Assist the railroad in complying with State and Federal agency requirements; and

- Perform maintenance on the Causeway in an economical manner.

To prevent a similar-type failure as that which occurred at MP748, MPA strongly recommended that a settlement monitoring program be re-established. The Causeway embankment does not settle at the same rate over its entire length, but is controlled by the thickness and consistency of the salt layer and sediments beneath the embankment. Therefore, monuments were established on the Causeway, and surveyors have measured elevation changes three times per year since 2002. This data is reduced, and the daily settlement rate is calculated and plotted against historical settlement rates.

Figure 6 is a compilation of historical settlement rates since the time of construction in the 1950's, showing the settlement rates which were known to produce failure of the embankment and those that didn't. If the rate is below 0.01 feet per day, or 3.4 feet per year, this settlement is considered consolidation. However, if the rate is greater than 0.01 feet per day, this is considered lateral movement, which could progress to an embankment failure. Counterweight berms, similar to those at MP748, would need to be constructed to reduce the lateral movement. The railroad is prepared to mobilize rapidly to construct these berms, if necessary.

There is a good correlation between the predicted settlement rates by HA in 1984 (shown in Table 1) and the current settlement rates, indicating that the science of geotechnical engineering has advanced considerably since the early 1950's.

Embankment Height Monitoring

As true with any embankment that is submerged on either side, as the water level drops, the effective stresses on the interior soil of the embankment are increased and therefore the factor of safety against bearing capacity failure decreases. The freeboard (height of embankment above the water level) which provides optimum wave run-up protection for the embankment has been calculated as eight vertical feet. Therefore, it has been MPA/JA's recommendation to the UPRR that when the lake level is low and the freeboard is greater than 8 feet, they should not raise the track to a fixed horizontal elevation, but should only smooth the low spots out in the track, keeping the freeboard as close to eight feet as possible. This provides adequate wave run-up protection while minimizing excessive weight on the underlying foundation soils.

CURRENT MAINTENANCE EFFORTS

The maintenance staff and engineers are continually faced with challenges caused by the complex physical environment in which the causeway is located. The continued settlement is a direct result of the soft bottom sediments upon which the embankment was constructed. The track structure, signal, and equipment maintenance issues are a result of the harsh salt environment. Most of the equipment used by the UPRR forces on the causeway has been modified for use on the narrow embankment surface.

There are currently two full-time crews working on the Great Salt Lake crossing: a causeway crew responsible for maintaining the embankment structure, and a surfacing crew of three workers responsible for maintaining and aligning the track structure. The causeway crew, consisting of 10 workers, is responsible for the structural integrity of the causeway, placing rock for slope protection, performing culvert cleaning, and constructing road crossings. At times, an extra crew of ten workers is used on the causeway to change ties or perform rail changes of short length.

Maintaining construction and maintenance equipment on the causeway is a challenge due to the highly corrosive environment of the air and water. Even with regularly-scheduled equipment washing to remove the salt build-up, the physical structure of the equipment rusts away, shortening the life spans of the machinery. Any electronic components on the equipment corrode quickly, requiring constant repair. Maintenance of the equipment has become more difficult in recent years, with the introduction of electronically controlled hydraulic systems. On older equipment, manual levers controlled the hydraulic systems. While the hydraulic cylinders and valves can withstand the harsh environment, the electronic systems cannot. Because of this, the most reliable equipment currently out on the Great Salt Lake is the 1960's era road grader and a Jordan spreader.

Maintaining Fill and Embankment Integrity

The top priority for the maintenance crew on the GSL is maintaining the integrity of the fill and embankment against washout or other failure. The causeway crew provides routine maintenance to keep the embankment functioning, as well as working on special projects. The crew must ensure that there is adequate ballast for the track structure and that the slopes of the embankment are adequately protected.

To move the heavy equipment on the 20 mile crossing, depressed flat cars, pulled by a Brandt truck, are used. This is necessary because of the narrow width of the embankment access roads and to minimize the wear and tear on the equipment. To move rock and fill out onto the causeway, there is a work train that consists of 25 side dump cars moved with a Brandt truck. Once out on the causeway, the air dumps must be unloaded quickly and returned to a siding so normal train operations can resume. To facilitate this, there are two Cat 973 front end loaders (FEL) with side casting buckets. These FELs with articulated buckets can move dumped rock and fill away from the tracks more quickly because the equipment does not have to turn as frequently in the tight areas. A Jordan spreader is used to move fill away from the tracks and, at least once per week, to adjust the height of the fill and subgrade materials.

In the 1980's, approximately half of the new Causeway was covered with an interlocking rock wall and revetment (slope) system on the north side. In the areas where this wave protection was completed and the vertical settlement is low, the system has functioned well with little maintenance for over 20 years. Based on these results, the UPRR instituted a program to construct a similar protection system on the areas of the Causeway that had never been improved in this manner. The causeway crew is responsible for installing this system, which reduces overall maintenance costs and increases the longevity of the causeway. The key to constructing a rock slope that will last is to interlock the armor rock, not just dump the rock down the slope. To place the rock in this manner, a Cat 345 excavator with an articulating thumb and an experienced operator and crew are used.

Maintain Track Surface and Alignment

It is the top priority for the surfacing crew on the causeway to maintain the surface and track alignment to maximize the operating speed. Because this stretch of the railroad is operated without signals (dark territory), the Federal Railroad Administration (FRA) limits the maximum speed to 49 mph. Maintaining this stretch of track is complicated because of the varying rates of settlement of the embankment depending on location, and the recommendation to not increase the height of the embankment unnecessarily. The work consist for the surfacing crew is a Jackson 6700 standard ballast regulator and five ballast cars handled by a Brandt truck. Ballast is not manufactured at the Lakeside quarry, but is brought to the quarry by the Georgetown belt train and stockpiled.

Track Structure Maintenance and Signal Issues

While all elements of a track structure are subject to deterioration and wear, track materials on the GSL are subjected to higher rates of corrosion and decay due to the harsh saline environment and high mechanical stresses. Ties, tie plates, rail, anchors and spikes deteriorate rapidly, requiring more frequent maintenance and replacement. The signal department relies on constant contact between the rail and the wheel to activate signals. However, it is impossible to maintain a reliable signal through the rail out on the causeway because of rail corrosion.

Tie Maintenance

Railroad ties have a calculated tie life, depending on the physical environment, the mechanical stresses, and the loading to which they are subjected. On the GSL embankment, the average wood tie life is shortened because they are subjected to a harsh saline environment and to high mechanical stresses. Because of the settlement of the causeway, the surfacing crews must constantly be side dumping and tamping the ballast to smooth out the track. This constant work causes extra stress on the tie and track structure, resulting in more rapid deterioration.

The UPRR has been utilizing composite ties on the causeway because they withstand the saline environment and the mechanical stresses, and hold fastening devices, such as spikes and lags, better than the wooden ties. Currently 10 percent of the ties on the causeway are composite. While concrete ties could withstand the harsh causeway environment, they are not used on the causeway, because they would chip and break during rock and fill dumping operations.

Because of the high volume of revenue traffic on the causeway, it is preferable to perform most of the tie and track maintenance operations with off-track equipment under Form B protection, rather than use work windows monopolizing the track. Due to rapid deterioration, the ties on the causeway must be replaced frequently; this is done with an off-track excavator with a specially-modified tie head attachment. To improve portions of the track with fouled ballast, off-track equipment with cribbing buckets and under-cutter bars are used.

Rail Maintenance

The saline environment on the crossing corrodes the steel components of the track structure, causing a general weakening, and sometimes failure, of the system. The individual components can corrode alone, and where two components touch, the electrolysis between them contributes to further corrosion. The tie plates and rail will split and fracture. Rail anchors corrode and allow excessive lateral and longitudinal movement of the rail and ties. On the causeway, it is necessary to "solid anchor" the track structure, that is, anchor every tie instead of every other tie, as is the norm. Where the rail spikes touch the tie plates, the throats of the spikes corrode; the spike heads fall off, rendering them useless.

Signal Issues

The corrosion of the rail on the GSL crossing is also a signal department problem. Normally, a current is sent down each rail, and the solid and continuous connection between the track and the wheel completes the circuit. The signal department relies on constant contact between the rail and the wheel to activate signals. However, on the GSL, the corrosion of the rail does not allow for this connection to be made. Therefore, the entire causeway is operated without signals. Any other electronic devices on the embankment are also difficult to maintain. Circuit boards, signal lights, wiring and the metal cabinets require constant maintenance due to the corrosive effect of the saline environment.

Access Roads

There are unpaved access roads which parallel the railroad tracks on top of the embankment. Maintaining these access roads is critical to the efficient cross-lake movement of railroad crews, equipment, and supplies, and minimizes the use of hy-rail equipment for these purposes, allowing the rails to be kept open for train usage. The only alternate route from one end of the crossing to the other is to go around the south end of the Lake, a distance of 127 miles requiring 3 hours travel. The access roads erode and rut due to wave action, large volumes of heavy equipment usage, and high vehicular traffic. An operator and road grader are employed almost full time keeping the access roads smooth and passable.

Lakeside Rock Quarry

The Lakeside Quarry is located on the west side of the GSL crossing, as shown on Figure 1. It is the UPRR's responsibility to maintain this quarry as a source of rock for the causeway and in compliance with MSHA safety standards. The UPRR typically partners with a contractor, who does the blasting, sizing, grading, and places the rock in piles by size. The UPRR specifies what size of rock is required and stockpiles enough rock in the quarry to be used for an emergency repair, should it be necessary. The UPRR monitors the contractor's blast plans so the desired size of rock is obtained. There are two UPRR FELs at the quarry to load the rock material into the side dump and ballast cars.

Culvert Maintenance

In the 1950's, the designers thought that lake water would be able to flow freely through the rock-filled embankment, causing no significant difference in the lake level on the two sides of the embankment *(IECO, unpublished date)*. Most of the fresh water flows into the south side of the lake. Prior to construction of the embankment, the salinity on the north and south sides of the lake was approximately twelve percent. Two-fifteen foot wide by twenty foot deep culverts, located at MP744.94 and MP750.53, were placed in the causeway at the time of construction to facilitate boat traffic. Over the years, it became apparent that the water did not flow freely through the embankment, resulting in salinity on the north side of the lake of approximately twenty six percent (at the dissolved solids saturation level) and on the south side of the lake of eight to fifteen percent. The Rambo Bridge was constructed in 1984 to reduce the four foot water level difference between the south and north sides, which it accomplished, but did not result in a significant mixing of the waters from the north and south.

Over the years, the culverts became totally submerged due to settlement and blocked with embankment material. At the request of the United States Army Corps of Engineers (USACE) in 2003, the UPRR agreed to clean the culverts in an effort to increase the flow of water between the north and south sides of the lake. To facilitate cleaning and to reduce the future accumulation of sediment and debris, walls constructed by filling gondola cars with rock and rock-filled breakwater berms were constructed adjacent to each culvert in 2003 and 2004. After completion of the breakwater berms, culvert cleaning operations were performed, using a large dragline bucket, to remove lake sediment, rock-fill, and miscellaneous debris. The insides of the culverts were inspected by a diver after the cleaning process to verify that debris and sediment have been removed.

After the initial cleaning operation, the culverts have been inspected by a diver on a semi-annual basis for two years (2004 to 2006) and on an annual basis since that time. After major storm events, the culvert entrances are inspected and visible evidence of blockage is removed. The need for additional cleaning of the culverts is determined based on the inspection. To date, there has been no significant accumulation of debris in the culverts. The UPRR continues to keep the USACE informed of the status of the culverts.

CONCLUSION

The Great Salt Lake Causeway continues to be a critical link in the transcontinental railway system. The design and construction of the crossing in 1900, the replacement of the 12.5 mile trestle in 1956, the overtopping outage in 1986, and the bearing capacity failure at MP748, were all a result of the environmental and geological/geotechnical setting of the lake. The maintenance staff and engineers are continually faced with challenges caused by the complex physical environment in which the causeway is located. The continued settlement is a direct result of the soft bottom sediments upon which the embankment was constructed. The track structure and signal maintenance issues are a result of the extremes in weather and harsh salt environment. However, with on-going settlement and geotechnical monitoring and maintenance, it will be possible to keep this critical section of track open and trains running across the Great Salt Lake.

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TABLES

TABLE 1-Causeway Settlement Rates

Year	Predicted Settlement Rate (in/yr)	Actual Settlement Rate (in/yr)
During Construction	12	3 to 16
1961	No data	6 to 12
1964	No data	6 to 8
1969	No data	4 to 5
1975	No data	3 to 5
1982	No data	3 to 6
1984 to 1994	2 to 5	No data
1995 to 2014	1 to 4	2.5

FIGURES

Figure 1- Great Salt Lake Basin and Environs

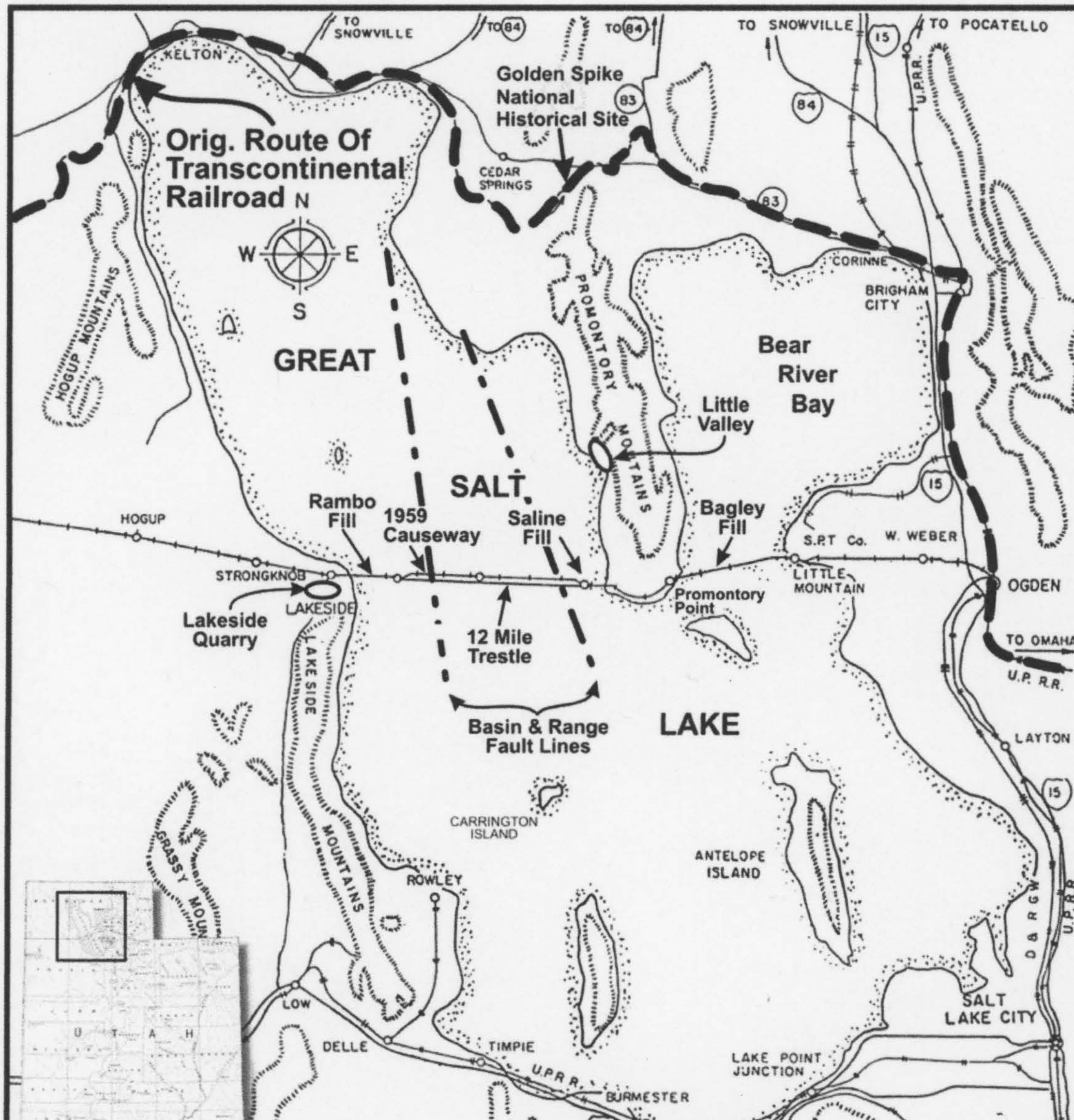

Figure 1: Great Salt Lake Basin and Environs

Figure 2- Historic Water Levels-1845 to 2007

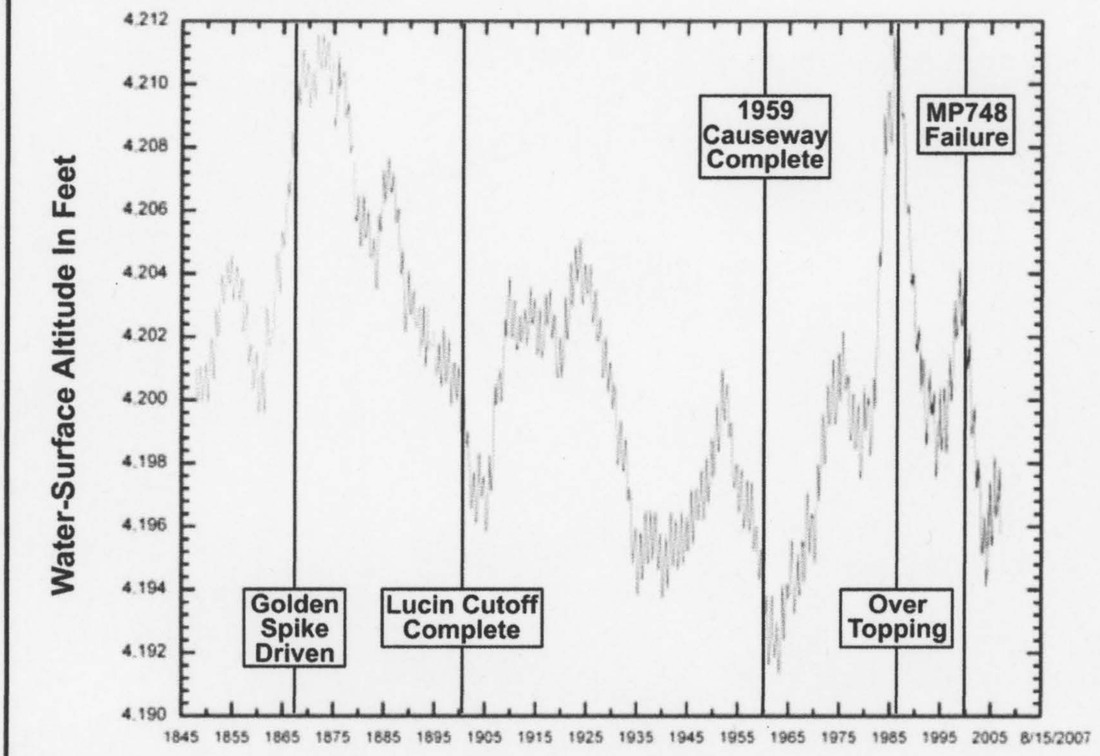

Figure 2: Historic Water Levels, 1845-2007

Figure 3- Geologic Profile of New Causeway Alignment

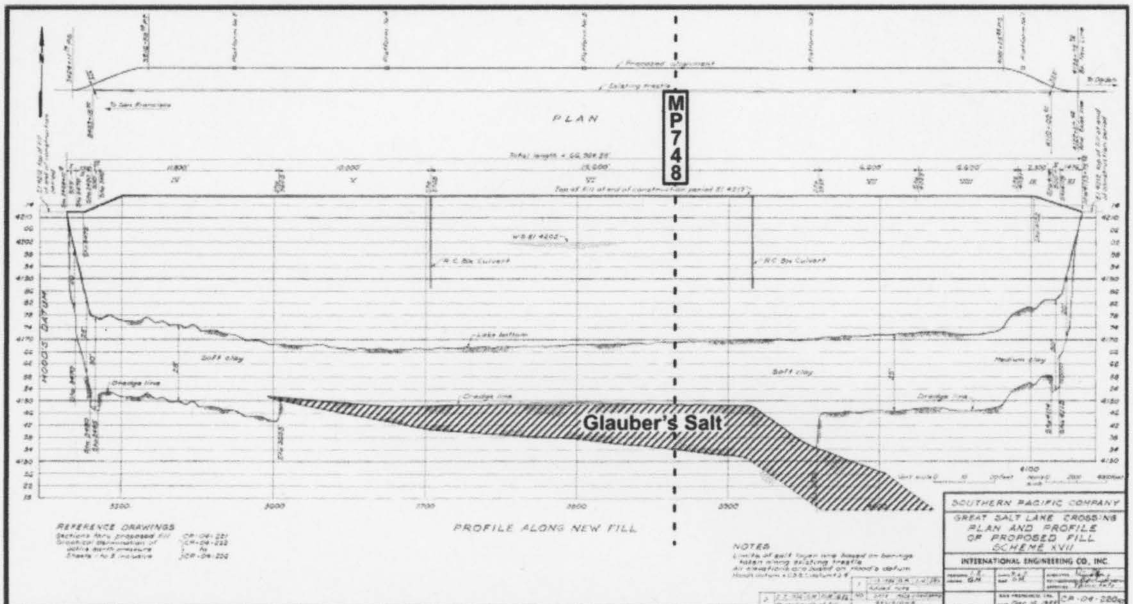

Figure 3: Geologic Profile of 1959 Causeway

Figure 4- 1950's Causeway Construction

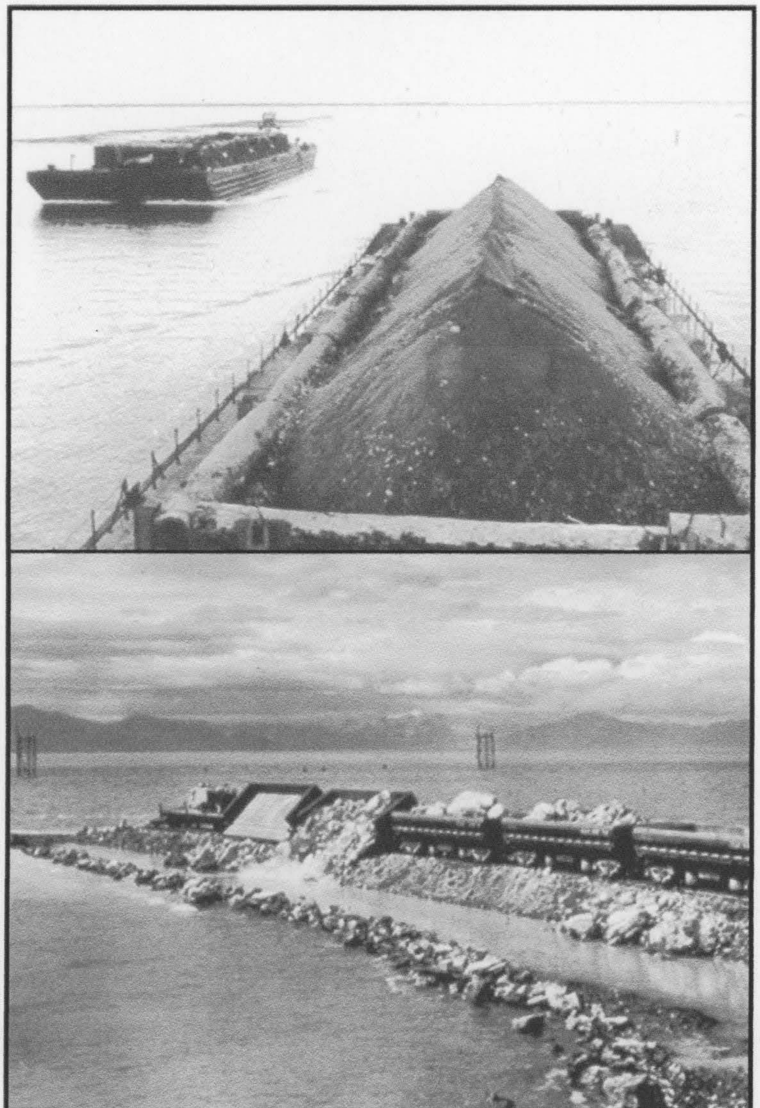

Fig 4: 1956-59 Causeway Construction

Figure 5- MP748 Final Berm Configuration

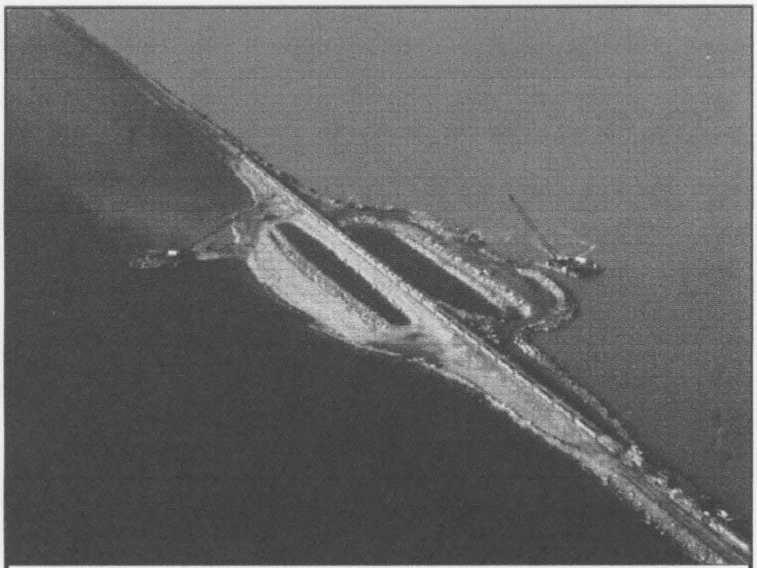

Fig 5: MP748 Final Berm Configuration

Figure 6- Historic Causeway Settlement Rates

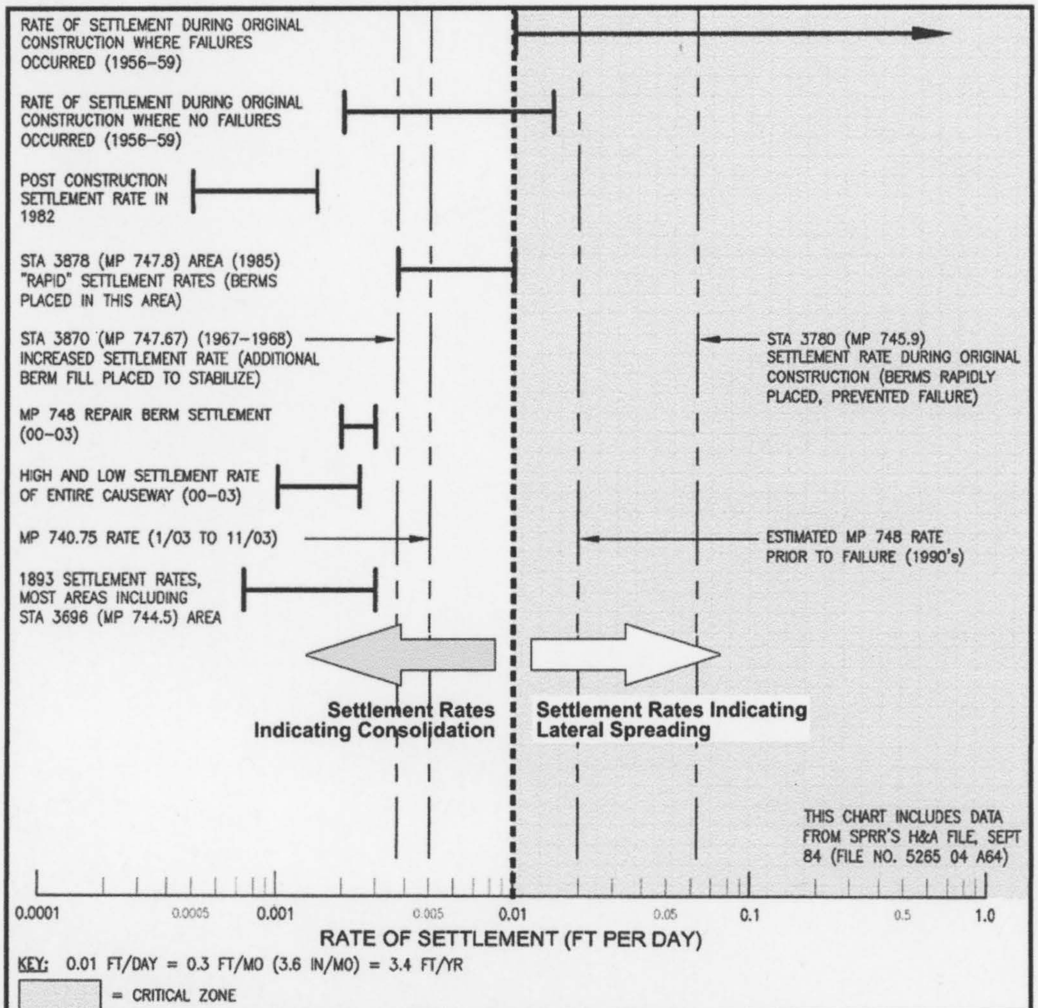

Fig 6: Historic Causeway Settlement Rates

TABLES

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