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RENOVATION OF THE DULUTH AERIAL BRIDGE

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The Duluth Aerial Bridge in Duluth, Minnesota is a very important transportation link within the city. This structure crosses over the Duluth Ship Canal which is the only practical entry for lake vessels to the harbor from the lake.

This structure is also the only land link connecting the land area known as Park Point with the remaining portion of the city of Duluth.

This paper is being presented to make you aware of the problems and their solutions when it became necessary to renovate this bridge. The structure to be renovated is a span drive vertical lift truss span. It's span length is 385'-9" center to center of bearings. A 24' roadway islocated between the trusses and two 5' sidewalks cantilever outside the trusses. The two trusses are 27'-6" apart.

This paper will not attempt to discuss all of the items replaced. Nor will this paper attempt to describe all of the features provided as a necessary part of a complete installation. This paper will be limited to describing items critical to providing a proper solution to the problems associated with the bridge's critical position and it's historical significance.

A videotape on the interesting history of the site from the late 1800's to the present has been prepared by the Minnesota Department of Transportation. The history extends back to before the time of the existence of the man-made canal to the present renovation. The Minnesota Department of Transportation has kindly consented to allow the showing of this videotape as a part of this presentation.

As you were told in the videotape, the land area known as Park Point was originally a part of the mainland. When the harbor entrance was dug, this parcel of land became isolated with no means of land access to the rest of Duluth.

The videotape further explained the early history of the method of travel between Park Point and the rest of Duluth. Originally, boats were used as the method of travel. The boats were replaced by the original Duluth Aerial Bridge.

This aerial ferry system worked well until traffic demand started creating objectionable delays. At that time, the firm of Howard Needles Tammen and Bergendoff, under the former name of Harrington. Howard and Ash, was retained to improve vehicular access between Park Point and the rest of Duluth. The result was the present Duluth Aerial Bridge.

As the video showed, the present Duluth Aerial Bridge consists of a span drive vertical lift span which crosses the Duluth harbor entrance. The original ferry bridge towers and overhead truss was retained for two reasons. These were to both stabilize the lift span towers and to provide for an overhead utility crossing. Water, sewer, natural gas and electrical service lines continue to service the Park Point area via this aerial crossing.

The vertical lift span provides for two lanes of vehicular traffic and two five foot sidewalks for pedestrian traffic. The needs of marine traffic are also accommodated by the vertical lift span. Vertical clearances of 15 feet in the span down position and 135 feet in the span up position, between the extreme high water surface and low steel on the span, permits unrestricted marine traffic through the harbor entrance.

In the mid-seventies, the firm of Howard Needles Tammen and Bergendoff was again retained to inspect and make recommendations for necessary repairs to the mechanical and electrical systems on the bridge. The recommendations were to include methods to upgrade the system to provide for a current state-of-the-art drive system. The structural components were not included because the Minnesota Department of Highways had been conducting inspections and had been evaluating the vehicular live load rating on the bridge. The purpose of this paper is to report on the results of the recommendations made in the report. The mechanical drive system on the bridge was a commonly used span drive where the uphaul and downhaul ropes were attached to operating rope drums located at mid-span on the bridge. The reduction gearing and shafting were also located at this mid-span location.

The inspection revealed that all of the gearing was worn. The bridge tenders advised us that some of the gearing had previously been replaced. Although the gearing was not in a dangerously worn condition, it was recommended that all the gearing be replaced.

The electrical drive system was also a commonly used system at the time, with one exception. The electric motors were DC motors controlled by relays and resisters through a trolley drum controller. The one exception was the source of electrical power. An under the roadway room in the Park Point abutment housed one hundred and fifty three wet cell batteries which provided the electrical power necessary to raise and lower the lift span. Another room in this abutment housed an AC-DC motor-generator which provided electrical power to recharge the batteries. The electrical power and control interface between the lift span and the approaches was by several trolley wires mounted vertically on the Park Point tower and trolley pick-up shoes mounted on the span.

The inspection revealed that the relays which were all mounted on open front relay panels, were old and outdated with spares either difficult or impossible to obtain. In addition the electrical wiring between the trolleys and the machinery room were showing evidence of advanced insulation deterioration. The inspection confirmed that the batteries were nearing the end of their useful life. In addition, the bridge tenders reported that it was becoming more difficult and much more expensive to obtain and purchase replacement batteries. As a result of the inspection, it was recommended that the entire electrical system be replaced.

The braking system on the span consisted of thruster type shoe holding brakes and a large drum band brake used to control the span while it was in motion. The band brake was operated by the bridge tender using a long lever at the control desk. The videotape had a scene showing an operator applying braking torque by pulling on this lever. It was recommended that the brakes be replaced when remodeling the rest of the mechanical-electrical system.

The Minnesota Department of Transportation structural evaluation of the lift span indicated that the bridge was in generally good condition but did list some deficiencies. It had been recommended that the bridge be either posted for load limits or restricted speed limits to reduce impact forces on the span. Reduced speed limit signs were in evidence during the inspection.

As previously mentioned, this lift span is the only vehicular and pedestrian access to the Park Point section of the City of Duluth. The Park Point area consists of residential, light commercial, nursing homes, a Coast Guard Station and a City park. It was therefore imperative that any remodeling or renovation of the bridge be undertaken in a manner which would not interrupt vehicular or prohibit pedestrian traffic crossing the bridge during construction.

The bridge is also a vital link for marine traffic. Access to the Port of Duluth harbor facilities by fully loaded lake and ocean going vessels is possible only by passage through the Duluth Harbor entrance and under the raised Duluth Aerial Bridge lift span. Water access to the Superior Harbor entrance was available, but navigation is difficult and channel depths were insufficient to permit passage of fully loaded commercial vessels.

One other criteria had to be considered in any renovation of this bridge. The bridge is on the National Registry of Historic Places. In addition, the citizens are proud of their bridge. It was therefore necessary to retain the appearance of the bridge as near as possible to its original appearance after the remodeling was completed.

Any renovation method, therefore, had to consider the restraints of no disruption to vehicular traffic, no disruption to marine traffic and minimal if any change in appearance. The problem of totally replacing the mechanical system and the electrical system and increasing the lift span's ability to carry live load while conforming to the restraints listed required a challenging solution.

Several concepts were studied. Replacement of the old and outdated drive system with a new system in the same location was not a viable alternative. It would have required the removal of the old equipment and the installation of the new equipment in sequence. The time necessary to accomplish this work would have violated the restraint of no disruption to marine traffic. Conversion of the lift span to a tower drive system with the machinery housed on top of the towers driving the counterweight sheaves was studied. This was also not a viable alternative. The available space at the top of the tower was insufficient to house the necessary mechanical and electrical equipment. Enlarging the top of the tower in order to obtain the available space would have resulted in increased wind loads being applied at a critical location.

This concept would also have violated the restraint of not changing the appearance of the structure. The concept studied and recommended resulted in a solution which conformed to all the necessary restraints and was economically feasible. It was recommended that the area of each lifting girder be enclosed. The new machinery could then be housed in these enclosures. A preliminary design and layout revealed that it would be possible to install the entire new electrical equipment without disrupting operation of the bridge using the existing drive system. This installation could then be undertaken without disrupting either vehicular or marine traffic. The preliminary design and layout further revealed that, by locating the new operating rope drums at the location of the existing uphaul and downhaul deflector sheaves, the remaining necessary mechanical equipment could also be installed without disrupting span movements while continuing to use the existing drive system. The removal of the existing rope deflectors and the installation of the new operating drums would require disruption of marine traffic. It was concluded that this work could be scheduled during the winter when marine traffic is minimal or nonexistent. By developing the novel concept of providing a modified span drive machinery system with a tower drive electrical drive and control system, it was possible to totally replace the drive system within the restraints imposed by the location and importance of this bridge.

One additional recommendation was made as a result of this concept. When the bridge was inspected it was noted that the main counterweight suspending ropes were showing some signs of wear. Although it was estimated that the ropes still had several years of useful remaining life, it was recommended that they be replaced during the renovation process. The reason for this recommendation was the fact that the counterweight would have to be independently supported for a short time when modifying the existing lifting girder. Being as this is a significant item of work necessary to replace the counterweight ropes, a considerable savings would exist if the ropes were replaced at the same time the lifting girder modifications were made.

The recommended mechanical-electrical replacement concept had an additional advantage. One of the reasons the bridge had a limited live load rating was the stresses in some of the lift span truss members. This concept permitted the removal of all the existing electrical and mechanical equipment from the center of the lift span. The resulting decrease in dead load at mid-span reduced the dead load stresses in the critical truss members sufficiently to permit unrestricted live loads on the span without any modifications being required to the critical truss members.

The firm of Howard Needles Tammen and Bergendoff was then retained to prepare final plans and specifications to replace the mechanical and electrical drive systems on the Duluth Aerial Bridge. In addition, the plans were to include the repair or replacement of any structurally deficient components of the bridge.

A structural inspection was conducted to determine members needing repair or replacement. As is the usual case for any steel structure fifty years old, numerous rivets were in need of replacement due to rivet head deterioration. The sidewalks were also in need of replacement. The sidewalk was composed of open steel grating which had been overlaid with asphalt. The sidewalk was replaced with a concrete filled steel grating. In order to prolong the life of this walkway the steel grating was zinc coated and the concrete was treated with a penetrating sealer. A few other members were replaced, but these replacement procedures were of a routine nature and will not be addressed further.

A structural replacement or repair difficulty was encountered as a result of the structural inspection. The roadway surface is composed of open steel grating supported on steel stringers and steel floorbeams. Significant corrosion of the top flanges of the supporting members had occurred due to the large amounts of saltwater which had passed through the open grating. The open grating was still in good condition and did not need to be replaced. Three stringers supported the roadway grating. One stringer was at the centerline of the roadway and the other two were near the curb line under the roadway. An analysis of the stringers at the curbs revealed that no repairs were needed. The analysis of the stringer at the centerline revealed that, because of the metal lost by corrosion, replacement was warranted. Because of the configuration of the stringers, it was impossible to remove a stringer and replace it. This would have required closing the bridge to vehicular traffic which was a restraint imposed by previously described conditions. The solution to this problem was to place two new stringers under the roadway, one on each side of the centerline. After these new stringers were in place and were carrying live load, the existing stringer at the centerline was removed. Using this procedure, the stringers were replaced without halting vehicular traffic. The Contractor was permitted to reduce traffic to one lane during the winter months when traffic was not as heavy. The stringer replacement was accomplished during this time in order that the new stringers could be hoisted up into position with wire slings passed through the open grating.

The stringer replacement procedures used had an additional benefit. By relocating the stringers away from the centerline of the roadway, the resulting load distribution to the floorbeams caused the stresses in the floorbeams to be reduced. An analysis of the floorbeams determined that the floorbeams could be retained with the stringers in their new location.

The drive machinery was designed under current AASHTO Codes with one exception. Considering the critical nature of the Duluth Aerial Bridge's location, and it's importance to both vehicular and marine traffic, the applicability of the provisions for ice loads in the AASHTO Code was considered to be inadequate. The amount of ice load to be applied to the structure was recommended to the City and was subsequently used in determining the maximum design loads required in the design of the machinery components.

The machinery components were designed and layouts were made in conjunction with the main drive motors in order to determine the best configuration. Items to be considered included whether they would fit in the available width of the machinery house, would the layout keep the size of the new machinery house from being objectionably large, and was the machinery capable of being installed within the restraints imposed on this project. As is the usual case, the most simple layout conformed to the restraint criteria best.

Similar machinery components were located within a machinery room at each end of the lift span. The new operating drums, one at each side of the span at each end, were to be placed as far from the roadway centerline as structural requirements would permit. This location fell within the requirement that the drums be located at the location of the existing operating rope deflector sheaves. The operating drum and drum gear was then mounted on a common structural frame with it's drive pinion. This operating drum and pinion assembly was then required to be shop assembled and tested. The reduction gearing required was then located at the centerline of the roadway. The reduction gearing selected was a commercially available parallel shaft enclosed speed reducer with dual input and dual output shafts. Each operating drum drive pinion was then coupled to the speed reducer by use of a floating shaft. Although floating shafts are commonly used for installations of this type, it was felt that it was a necessary component which made the installation at this site possible. The construction restraints required that the speed reducer be installed and the electric drive motors coupled to it prior to installing the operating drum frame assembly. The use of a floating shaft between these components would then permit limited shaft misalignment without reducing the life or capacity of the drive components. The capacity of a floating shaft to accommodate shaft misalignment made final installation of the machinery at different times a practical consideration.

The electrical drive system selected for use on this bridge was a DC shunt wound drive motor with SCR drive controller. Two motors and two controllers were to be coupled to the speed reducer at each end of the span. Again the critical nature of this lift span was considered in determining the proper operating characteristics of the electrical drive system. The motors were specified to be 500 RPM base speed motors. Each motor was sized to be capable of hoisting the lift span under all code specified loads while running at it's base speed. It was also a requirement that the two motors at each end be electrically coupled to run together. Under this condition, the motors were to run at a speed greater than their base speed. The motor speed under two motor operation was required to be 870 RPM. This speed was established according to the AASHTO criteria which permits the time of lift to be 50% longer when operating with one motor than would be required under two motor operation. The motors and controllers were also required to have regenerative braking capability to assist in controlling the span under overhauling load conditions. Another requirement was that when operating under one motor at each end, the other drive controller at each end be electrically isolated in order to limit it's susceptibility to lightning damage. As a final requirement, both motors at each end were to be capable of operating together at base speed. This would permit operation of the span under extreme adverse conditions. The DC motors specified were variable horsepower, constant torque motors at or below base speed while they were constant horsepower. variable torque motors at speeds above base speed. Therefore, when the two motors are running at the specified 870 RPM, they would not have as much torque capacity as when running at base speed. However, a reduction of the RPM to a value below base speed would not increase the hoisting capacity of the motors.

Four brakes were provided in each machinery room. The brakes were specified to be thruster type shoe brakes, spring set, electrically released. Two machinery brakes were located at the coupling between the speed reducer and each motor by the use of brakewheel couplings. The two motor brakes were mounted on extended motor shafts. The required torque settings of these brakes was established with due regard to the AASHTO Codes and the designed ability to hoist loads in excess of the Code requirements. It was further considered, when sizing these brakes, that they must have the ability to stop the span at any time in the event of a power failure. It should be noted that under normal span operation, none of these brakes will be applied while the span is moving. The specified regenerative braking capability of the electric motors will control the span under overhauling loads.

It was mentioned previously, that the electrical operation of the lift span would be a tower drive control system. Traditional tower drives have power selsyns or similar speed control devices used to maintain the lift span in a level position. These were not mentioned when describing critical equipment being coupled to the drive system. The reason is, that these devices are not required with the control system provided. The control system specified was a programmable controller(pc) with math handling capability. Span movements and safety devices such as traffic lights, gates and barriers are controlled and sequence interlocked by the pc. The pc is ideally suited for this purpose and eliminates the necessity for many machine tool relays on the span. The bridge tender maintains control of the proper operation of the bridge by the use of push buttons mounted on a control console. The pc also is capable of monitoring and controlling the span position of each end of the lift span. High accuracy control selsyns and digital encoders transmits data to the control console displays and to the pc. Tachometers mounted on the motors also transmits speed data to the pc. The pc constantly monitors each end of the span's position. The pc then compares the positions to see if they are the same. If the positions are not equal, the pc will then transmit a signal to the motor controller(s) at one end of the span. This signal will instruct the controller to either increase or decrease its speed slightly as appropriate to regain a level span position. Continual monitoring of the relative positions permits the pc to apply varying correction factors to the speed control of one end depending on the magnitude of the error in span position. Again a pc is ideally suited for this application and eliminates the necessity of other expensive control equipment. The pc, it's associated input/output racks and a dual spare central processing unit was housed within the span control console. The spare central processing unit is electrically isolated and insulated from the structure to inhibit damage from a lightning strike.

The importance of this bridge was also considered when designing the electrical control system. I have just told you about how ideal the pc was in providing reliable methods to control, interlock, and to provide proper speed control. None of those statements are incorrect. However, any system, no matter how reliable, can fail. For that reason, a method of operating the span through a full sequence of operation without the use of the pc was provided as a back-up. The traffic lights, gates, and barriers can be operated without the use of the pc. In addition the span can be both raised and lowered by the use of separate speed control devices, connected directly to the drive controllers, for each end of the span mounted on the control console. It should be noted that the maximum available speed of the motors is greatly reduced to permit safe operation under this condition.

The existing control room was located at the center of the lift span. It was determined that the new control room would be located in the same location. An alternate location would have been simpler, however, the existing location provided the bridge tenders with maximum visibility of the approach roadways and the sidewalks. Any alternate location would have reduced the bridge tenders visibility and was rejected for that reason. Retaining the existing location under the restraints imposed by the critical nature of the bridge caused an unusual sequence of construction for the control house. The new electrical drive and control system had to be installed and made operational prior to removing the existing drive system from service. The new control console therefore had to be installed inside the existing control room within the available floor space. The console also had to be designed to permit it's installation either through the existing door or window openings. The other problem was that the existing machinery was housed both in a room directly above the control room and partially in the control room itself. The Contractor was then required to remove all of the existing machinery, electrical equipment, and the walls and roof of the control house while protecting the new control console from damage due to construction and the weather. After this operation was completed, the walls and roof of the new control house had to be erected without damaging the console.

The new machinery house also had to function as a new lifting girder at each end of the lift span. The reasons for this included the requirement that the span retain it's original appearance. The existing girder was a combination beam and truss arrangement that transferred the weight of the lift span from the trusses to the suspending ropes. It was possible to see through the lifting girder while from the roadway, however, visibility through this area was also restricted by structural members in the towers. It was concluded that because of this restricted visibility, solid walls in this location would be a minimal change which would not be objectionable. The view of the side of the side of the lift span was more critical. People were more used to the appearance of this location by day and by night. Accent lighting was used on the bridge as a night landmark feature. There was a large vertical gusset plate on the outside of the truss at the existing girder. It was decided that the shape of the new lifting girder wall,at this location, be the same shape as this gusset plate and should not be any larger than necessary. By necessity, the new end wall could not conform to all these restraints and still provide it's required function. An architectural treatment was provided which emphasized the original shape.

In order to conform to the agreed upon criteria and to prevent any encroachment on clearances over the roadway surface, the new machinery and electrical equipment had to be in the same location as the existing lifting girder which spanned between the lift span trusses. The new lift span walls had to replace the function of the existing lifting girder so that it could be removed to permit the placement of the new mechanical and electrical equipment. To further complicate this operation the work had to be accomplished without disrupting vehicular or marine traffic. A sequence of construction was developed which would conform to these constraints. The first item was to place the new machinery room end plates at the location of the existing truss gusset plates at the end of the truss. A minimal closure to navigation was granted by the U.S. Coast Guard for this operation. It was felt that the Contractor would want to provide an independent support for the counterweight when the gusset plate was disconnected. It should be pointed out that this gusset plate was used to transfer one-half of the truss weight to the lifting girder and from there to the suspending ropes attached to the counterweight. After the new end plates were installed, the new rear wall was installed. this wall had to be installed between the face of the tower and the existing end of the lift span. Framing this to clear the existing operating ropes and their deflector sheaves was a further complication. After this operation, installing the remainder of the new machinery house was easy. By locating the future access doors into the machinery house where the existing operating ropes were, the front wall could be installed. It was then required to install the new machinery room floor. This would then provide maximum protection to the traveling public while the remaining work was done. The existing lifting girder had two large vertical gusset plates on each side which were attached to the lift span truss and extended toward the center of the bridge. The anchorages for the suspending ropes were attached between these two gussets. The trussed portion of the lifting girder was also attached to these gussets. A new welded beam was designed to be placed between the top chord and the end diagonal of the lifting girder truss. This beam spanned between the front and rear walls of the new machinery house and was also attached to the ends of the existing lifting girder gusset plates. This new beam could then transfer the loads from the existing lifting girder to the walls of the new machinery house. The trussed portion and also the portion of the gusset plates below the new support beam of the existing lifting girder could then be removed. With the removal of the existing lifting girder, the new machinery house would now accommodate the installation of the new drive system. The roof of the machinery house could be installed at any time after the walls were erected. The design anticipated and permitted portions of the roof and it's framing to be left uninstalled until after the machinery and electrical equipment was in place to permit easier installation access.

As you can see, the restraints imposed by the location of and the critical nature of this bridge made the renovation of the Duluth Aerial Bridge a difficult and challenging project which required innovative, if not unique, engineering solutions. I feel that the firm of Howard Needles Tammen and Bergendoff can be proud of the role they played in bringing the renovation the Duluth Aerial Bridge to a successful conclusion.