Repair of Counterweight Trunnions on Strauss Bascule Bridge

by Ulo S. Pessa

General

In the spring of 1982 the writer was called upon to perform a mechanical inspection of a heel trunnion type (Strauss) bascule over the Passaic river near Newark, New Jersey. This structure, built in 1915, has been in continuous service for 70 years and is operating currently at about 100 openings a year.

A schematic layout of the bascule is shown in Exhibit 1. The construction, typical of heel trunnion type bascules, consists of a 115 foot long bascule leaf which pivots on two main trunnions (LO). The leaf is counterbalanced by a counterweight attached to a counterweight truss, which in turn pivots on the counterweight trunnions (panel point 22). The leaf and the counterweight truss are connected by counterweight links with pinned connections at each end. This design has the advantage of dividing the dead weight of the leaf and the counterweight between the abutment and Pier 2. The leaf, being balanced, has no reaction at Pier 1. The reaction at Pier 2 is equal to the weight of the moving leaf and that at the abutment is equal to the weight of the counterweight and its frame.

The leaf is moved by operating struts, pinned to the trusses at panel point UI and extending to the tower, where their racks mesh with the operating pinions.

Examination of the operating machinery revealed that, after 70 years, the original gear train was still in place. Most of the gears were heavily worn but span openings were trouble free and relatively smooth. In contrast, it was immediately evident that something was drastically wrong with the counterweight trunnion bearings.

Investigation of Counterweight Trunnions

A section through one of the two counterweight trunnion bearings is shown in Exhibit 2. Each trunnion consists of a bearing, a sleeve which rotates in a bushing inside the bearing, and a pin which passes through the sleeve. The pin is force fit into the sleeve and rotates with it. Both ends of the pin project beyond the bearing and pass through holes in the counterweight truss gussets. The pin is force fit into the holes in the gussets as well. The entire weight of the counterweight and the counterweight truss is introduced into the pins at this point and is distributed by the sleeves over a wider area. Bearing pressure on surfaces subject to rotation is thus considerably reduced.

In order to prevent relative rotation between the counterweight truss and the sleeve (and pin), horizontal holes have been drilled through the sleeve and through the counterweight truss gussets. Turned sleeve bolts fitted into the holes fasten the sleeve to the counterweight truss members. The ends of the pins are threaded and fitted with nuts which hold the pin assemblies in place.

A preliminary inspection of the counterweight trunnions revealed open holes at some of the sleeve bolts. The nuts and ends of the bolts were missing at these locations, but remnants of the bolt were visible inside the sleeve. At other locations sleeve bolts, apparently broken, had "walked out" and extended as much as seven inches beyond the face of the gussets. Also, the nuts of a number of the sleeve bolts were missing.

At locations where portions of the bolts together with their nuts are missing, bolt holes are exposed and can be inspected. It was noted that none of the bolts have sheared in the plane between the sleeve and the gusset, but that most have broken at locations approximately one to two inches into the sleeve. As a result, the joint between the sleeve and the gusset can be visually examined. It was found in all cases that the holes in the sleeves did not line up with those in the gussets. The misalignment of the holes was found to be about 1/2 inch at one counterweight trunnion and 1/4 inch at the other. Obviously, slippage had taken place between the sleeves and the gussets.

There were at least two open holes at each end of both counterweight trunnions. The misalignment in holes on any face was not equal, raising the possibility that some movement other than circular is taking place.

The open holes were also observed during operation of the bridge. This observation established that there was motion between the sleeves and the gussets when the span was raised and lowered. The misalignment in the holes was reduced by about a half when the span was in the open position. However, when the span was subsequently returned to the seated position, the original misalignment reappeared.

The outward appearance of the counterweight trunnions was such as to convince us that the deficiencies related to the sleeve bolts were not new but had been in existence for many years. This was confirmed in conversations with maintenance personnel. Nevertheless, the owner of the structure was concerned when the above deficiencies were pointed out and wondered about the safety of the structure. Although we were puzzled by the condition of the sleeve bolts, analysis of the way the counterweight trunnion functions led to the conclusion that there was no possibility of a structural failure at this time. Still, the condition of the joint could be expected to deteriorate at an ever increasing rate. The trunnions had been regularly maintained and appeared to be well lubricated. There was concern, however, that the grease grooves in the sleeves would be blocked because of the misalignment between the sleeves and gussets, which might result in rapid destruction of the bearings and joints. it was therefore agreed that further investigation of the counterweight trunnions was required to determine what corrective action could be taken.

It was possible to tell, by analyzing the data obtained, that at least seven of the eight sleeve bolts in each counterweight trunnion were broken at one end or the other. It was not immediately clear what forces were at work to break the bolts. Theoretically, the sleeve bolts should carry only shear from the friction in the bearing during operation of the span. With the bearing apparently well lubricated, it did not seem conceivable that forces due to friction were the cause of the failures. Suspicion centered on the original construction sequence of the structure. Since both the sleeve bolts and the pins are force fit into the counterweight truss gussets they would share the load if in place when the counterweight is poured. Therefore, the proper erection procedure, as we saw it, would have been to install the sleeve bolts only after the counterweight was completed. If this procedure was not followed and the sleeve bolts were in place when the counterweight was poured, there may well have been sufficiently high loads introduced into these bolts to explain the defects now in existence.

Regardless of the original cause of the sleeve bolt failures it was certain, because of the movements observed during operation of the span, that relative displacement was now taking place between the sleeves and gussets of the counterweight trunnions. This meant that the trunnion bearings no longer operated as designed. Movement was taking place along highly stressed, unlubricated surfaces between the pins and the counterweight truss gussets. What was happening was precisely what the sleeve bolts were designed to prevent.

Under these conditions rapid wear of the hole in the gusset as well as in the pin, could be expected. The pattern of misalignment between the open holes in the gussets and those in the sleeves had already aroused suspicion that the pin holes were enlarged. We now decided to verify this suspicion by removing the pin nuts in order to examine the area underneath.

The nuts for the 11 inch diameter pins are quite massive. In order to remove them a contractor had to be called in, who first fabricated a special wrench to suit the nuts. Even then, removal was possible only after heat was applied to the nuts. The removal of the nuts took two days. Replacement of the nuts was accomplished very quickly after the mating threads were cleaned and oiled.

Inspection of the counterweight gussets and ends of the sleeve pins after removal of the pin nuts confirmed that the pin holes in the gussets were indeed enlarged. Gaps between the pin and the hole in the gusset measured from 0.09 to .12 inches. The gaps generally extended over a 100 degree area tapering from a maximum at the center to zero at the ends. The location of the gaps in the lower right quadrant (when looking at the end of the trunnion with the leaf on the right hand side) was consistent with the direction of the loads on the trunnion in the span seated position.

After the completion of field measurements of pin holes in the counterweight truss gussets, the pin nuts were replaced and the bridge was returned to service. Bridge openings, suspended during the period when the pin nuts were removed, were resumed.

Possible Repair Schemes

It was clear that defects discovered would have to be corrected. Although the situation was not critical, delays would only result in further deterioration in the condition of the bearings. The owner agreed with this reasoning and we started to think of the details of the repair.

The plan was to jack the counterweight to remove the load from the counterweight trunnions, and then replace the counterweight truss gussets. We also planned to replace all the working parts of the bearings, consisting of the pins, sleeves, bushings, sleeve bolts and pin nuts.

This work could be done with the leaf either in the open or closed position. In our case, because of some unrelated simultaneous repairs to the bascule leaf, it was arranged with the Coast Guard to interrupt river traffic for a sufficient period of time to complete the work with the leaf closed. The counterweight would be jacked from temporary steel frames supported on piles driven into the approach roadway.

While the details of this repair were under consideration, we investigated an alternate repair which did not require jacking the counterweight. If this scheme proved feasible, the elimination fo the jacking frames and their support piles would probably result in cost savings.

The underlying idea of the alternate repair scheme was to replace only the pins and the sleeve bolts in the bearings without disassembling the bearings. This might be possible if one removed the broken sleeve bolts and reamed the holes through the gussets and several inches into the sleeves. The reamed holes would be sufficiently oversize to eliminate the misalignment, so that close fitting steel dowels could be inserted in all the holes. At this point, the counterweight trunnion pins would be removed and the entire load on the trunnion would be carried by the sleeve. Now the trunnion pin holes, in their turn, could be reamed. Again, the reamed hole would have to have a sufficiently large diameter to eliminate the misalignment between the gusset and the sleeve. New pins would then be inserted in the reamed holes. The diameter of the new pins would have to be such as to insure proper force fit in the gussets and sleeves.

While the above scheme seemed to offer some possibilities, there were many questions to be answered. We first investigated the feasibility of using the inserts in the sleeve bolt holes to carry the load on the trunnions. The original sleeve bolts were 1-3/4 inch diameter turned bolts. Since the maximum misalignment between the sleeve bolt holes and the gussets was 1/2 inch, the diameter of the new hole for the inserts would have to be 2-3/4 inch. The sleeves are hollow cylinders with a wall thickness of only 3-7/8 inches. However, the ends of the sleeves, where they are in contact with the trunnion pins, thicken to about 4-5/8 inches. The inserts would have to be confined to these thicker end rings of the sleeves. Even so, the minimum thickness of metal left towards outside and inside of the inserts would be only 3/4 inch and about one inch, respectively. This was judged to be just adequate from the standpoint of edge distances. It also appeared that, by making the inserts high strength steel, it would be possible to transfer the load through them into the sleeves.

The next question to be answered was the capacity of the sleeve itself to carry the load in question, which totaled 1,115 kips per counterweight trunnion with the leaf in the seated position. Under normal conditions, the load would be carried through the pin and the sleeve into the bearing, with the ends of the sleeves stiffened through being in contact with the pins. With the pins removed the support they provided would be lost, and the ends of the sleeves would have to be analyzed as hollow cylinders. Modeling the actual conditions would be complicated by the fact that there would be interaction between the sleeves and the gussets. With the pins removed, the gussets would be fastened to the sleeves with the aforementioned inserts. The inserts would be furnished with holes in the center to permit installation of sleeve bolts extending through the entire bearing from gusset to gusset. Nuts on both ends of the bolts would then hold the inserts in place.

A preliminary analysis of this system indicated that it would be capable of withstanding the imposed loads. However, this was based on the assumption that the sleeves themselves as well as the bushings were in good condition. In fact, the condition of these elements, being hidden behind the gussets and inside the bearings, was not know at all. It was thought that, to gain some idea of the condition of the sleeves and bearings, it might be possible to insert a fiber-optics probe into the sleeve bolt holes and also into the grease grooves. While this procedure would only permit an inspection at the holes and not throughout the entire bearing, it would at least give an indication of whether serious cracks or other deficiencies were present.

A firm specializing in fiber-optics investigations was contacted. It informed us that the planned investigation was feasible and that it was willing to undertake the job. Before such an investigation could be carried out, however, the existing sleeve bolts and their remnants had to be removed to provide access to the holes. A contractor was engaged to accomplish this task. The plan was to remove the sleeve bolts, inspect the holes, and then install new but temporary sleeve bolts while contract plans were being prepared for the final repair. Temporary sleeve bolts were fabricated for this purpose. Various diameters were provided in order to have a selection available to fit the open holes, which, being partially blocked by the misalignment, varied in size.

At this point, the repair method to be used had not yet been decided.

We were reluctant to proceed with the method which transfers the load to the sleeves without knowing more about the condition of the inner parts of the trunnion bearings. We felt that if the fiber-optics inspection raised any doubts at all, we would revert to the original plan of jacking the counterweight.

We also suspected that the inherent difficulties in the field with the method of doing the work under load (not jacking the counterweight) would offset some of the savings. Removal of the counterweight trunnion pins was bound to be difficult. Installation of the inserts into the sleeves would not automatically transfer the load from the pin to the inserts. This would happen only after the pin had been removed. To remove the pins with the entire trunnion reaction on them seemed feasible only if the pins were destroyed and removed in pieces. Similar removal problems might also be encountered at the sleeve bolts. Although theoretically not under load, pieces of the broken bolts might be trapped between the gussets because of the misalignment of holes, requiring destruction of the bolts in order to remove them. Even after the removals were accomplished, a great deal of intricate and expensive field work would remain to ream the holes for the inserts and for the pins to the required diameter. The pin holes in particular would have to be exactly centered on the existing axis of rotation of the counterweight trunnions, requiring expert work by millwrights in the field.

The actual work of removing the sleeve bolts for the purpose of inspecting the sleeves soon ran into difficulties. After the initial removal of several broken ends of bolts, which were almost loose and could be removed with little effort, progress stopped. Attempts to remove the sleeve bolts by inserting steel rods into open holes (where pieces of bolts were missing) and pounding with heavy sledge hammers did not result in any movement of the bolts. Hydraulic jacks were then used in an attempt to pull out the bolts. This was tried on a number of sleeve bolts which already extended some distance beyond the gusset plate. The nuts on these bolts were removed and a steel plate washer was placed over the bolt. The nut was then replaced and two hydraulic jacks were installed between the gusset and the steel plate. Force exerted by the jacks placed tension on the sleeve bolts. The jacking force was gradually increased until the tension in the bolts approached the yield point. Despite this, no movement of the bolts could be observed. After several days of futile attempts it was concluded that, if we wanted to remove the sleeve bolts, they would have to be drilled out.

It was decided at this point to abandon the effort to remove the sleeve bolts for the purpose of inspecting the sleeves. Consideration was given to the possibility of including the removal of the sleeve bolts and inspection of the sleeves in the final repair contract. The actual method of repair, whether by jacking the counterweight or by accomplishing the repairs under load, would have had to be determined during the life of the contract and after the completion of the inspection. Therefore, new parts and construction equipment for both types of repairs would have to be on hand to avoid delays.

After weighing the advantages and disadvantages of this approach, it was decided to proceed with the repair by jacking the counterweight. It was felt that this would eliminate uncertainties and result in rehabilitated counterweight trunnion bearings consisting of entirely new moving parts. It was thought, also, that the potential field problems associated with the removal of trunnion pins and sleeve bolts under load, and the exacting field work required to ream existing holes in the field, would result in a higher cost for this alternative than originally envisioned.

Final Repair Contract

The repairs to this structure are presently under contract. Actual field work is scheduled to start in April of 1986 and to last for three months. During this period, the span will be closed to river traffic for 45 calendar days. It is expected that the counterweight trunnion repairs will be completed within the 45-day period while the leaf is in the down position.

The counterweight, which together with its truss weighs about 800 tons, will be jacked up to remove the load from the counterweight trunnions prior to the start of the work. Eight 150 ton hydraulic jacks will be used to jack against a temporary steel frame placed under the counterweight. In order to prevent damage to the abutment and wingwalls from the surcharge created by the weight of the counterweight, the temporary steel frames will be supported on piles driven into the approach roadway. The piles will remain in place after the temporary frame has been removed.

After the counterweight has been jacked to remove the load on the trunnions, the force in the links connecting the leaf to the counterweight truss will be zero. The leaf will now act as a simple span. It was designed, originally, to accommodate the resulting stress changes.

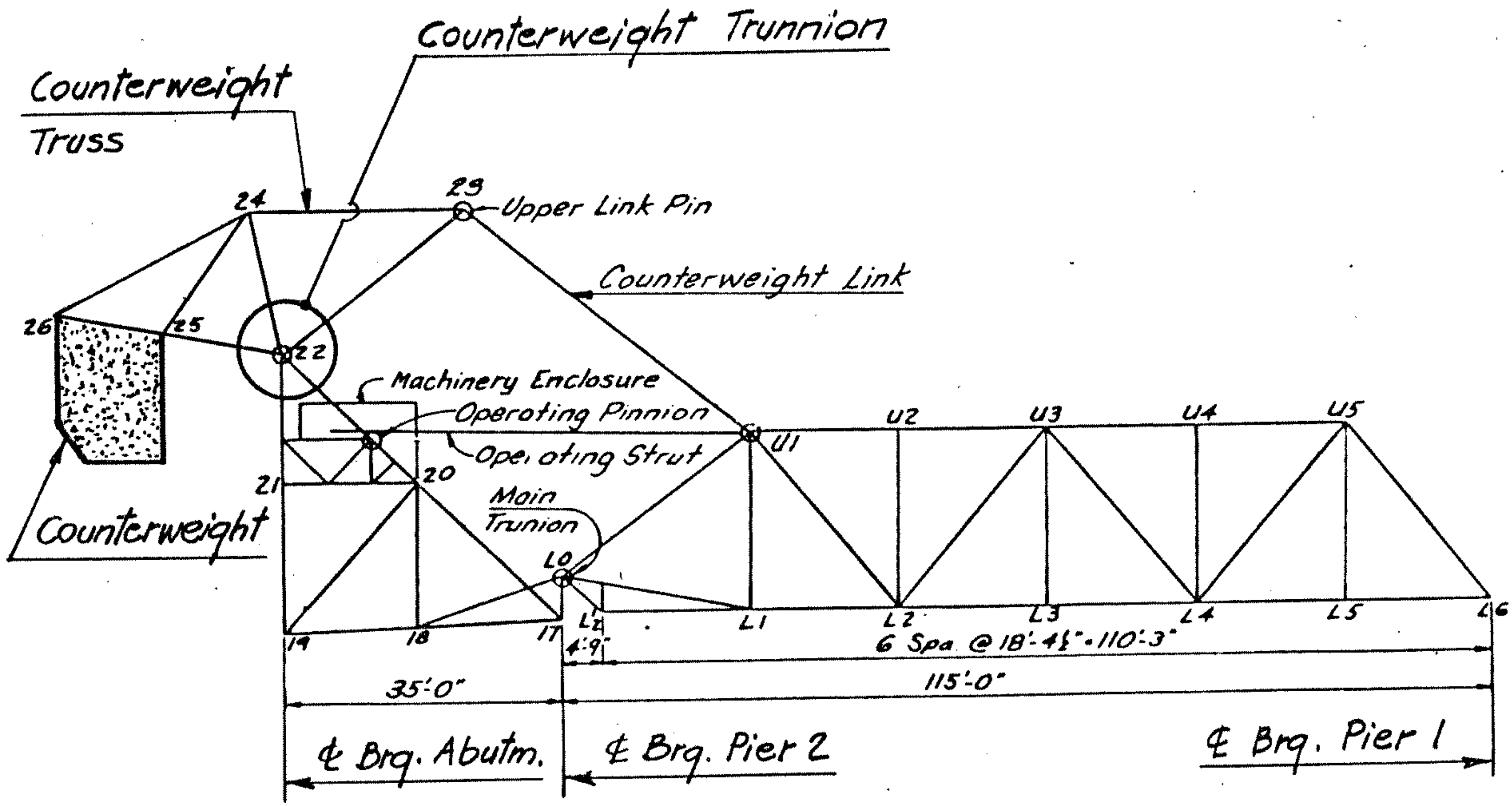
Work can then commence on the counterweight trunnion repairs. Counterweight truss members framing into the trunnion gussets will be connected with temporary ties. Rivets connecting the gussets will then be removed and the joint disassembled.

The holes for sleeve bolts and pins in the new gussets and sleeves will be drilled in the shop with each sleeve and its adjacent gussets and pin plates assembled.

High strength bolts will be used to replace rivets when erecting new components, except where countersunk heads are required, the Contractor has the option of using either countersunk rivets or specially made turned bolts with countersunk heads.

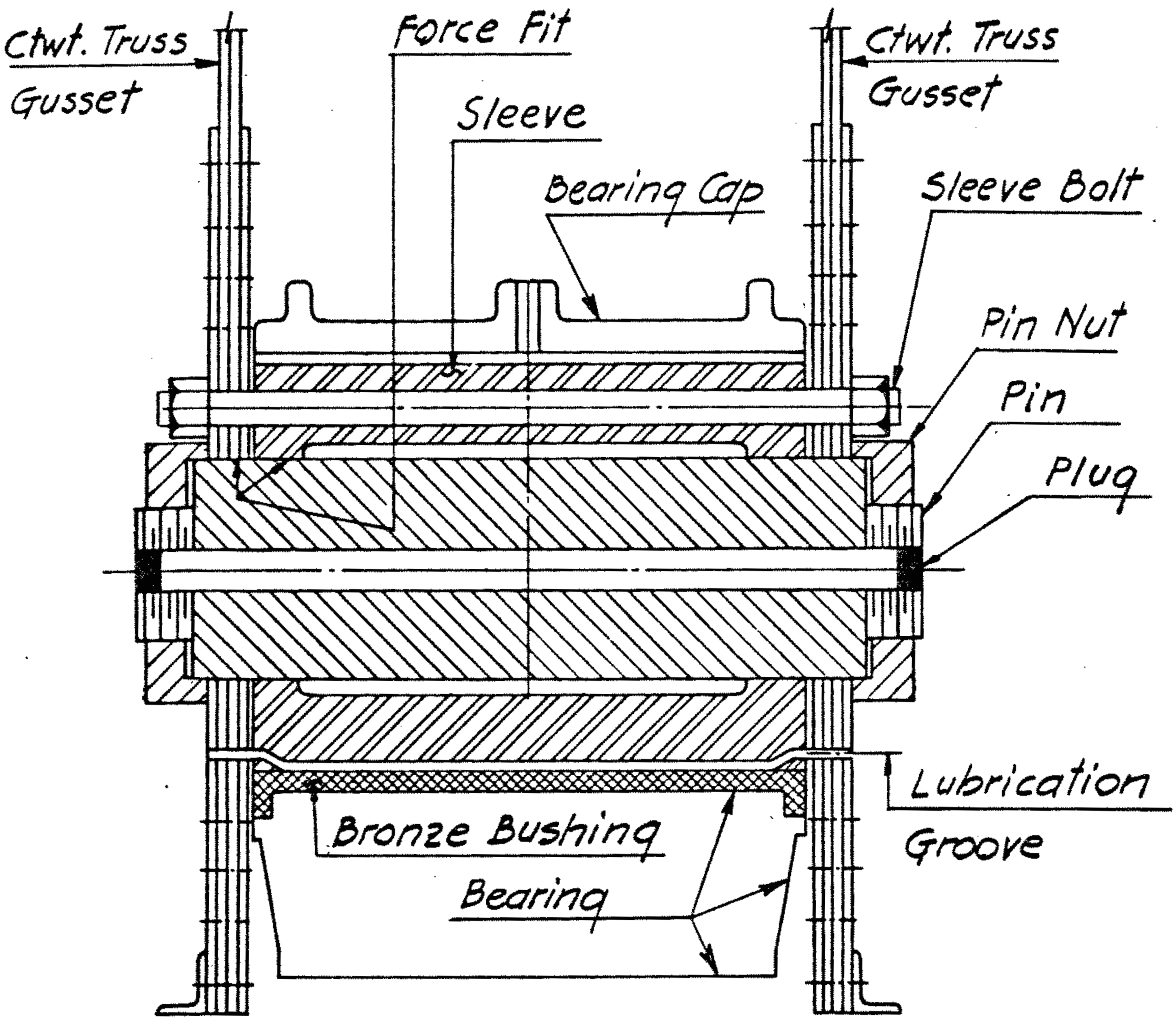
We expect that the counterweight trunnion bearings, after the completion of this repair, will outlast the bridge as a whole.

The bid cost of the counterweight trunnion bearing repair, including the cost of the temporary jacking frame and steel piles, is approximately $350,000.



BASCULE SPAN

EXHIBIT 1



SECTION THROUGH COUNTERWEIGHT TRUNNION