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MOVABLE BRIDGES AFFILIATE

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SESSION
WORKSHOP NOTES

Session (5-1)
"Self Destruction of a Strauss Bascule Bridge", John A. Schultz, Jr.,
Hazelet & Erdal, Chicago, IL.

SELF-DESTRUCTION OF A STRAUSS BASCULE BRIDGE

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At approximately 3:00pm Saturday, June 24, 1989, the Tayco Street Bridge over the U.S. Canal at Menasha, Wisconsin, raised to clear the channel for two small cruisers and an excursion boat. As the bridge started up, the two cruisers passed under the opening leaves. As the leaves approached the open position, the excursion boat with its 46 passengers started to accelerate toward the bridge when the operator heard a loud noise and noticed the south leaf becoming distorted. He immediately reversed his engines and was able to stay clear as the leaf crashed into the canal, narrowly averting a major catastrophe.

At 8:00 AM Monday, June 26, 1989, the Wisconsin Department of Transportation requested the firm of Hazelet + Erdal, Inc. to undertake an investigation, assisted by WisDOT personnel, to determine the cause of the failure.

The Tayco Street Bridge was a half through girder, double leaf Strauss type trunnion bascule bridge with a span of 125'-0" between trunnions, completed in 1928. It utilized a trunnion supported counterweight with each end hanging from bronze lined bearings in the girder webs. As a leaf opened, the counterweight was held vertical by the force of gravity and a parallelogram linkage arrangement. Each hanger on either side of each counterweight trunnion consisted of two 3/4" plates and one 1/2" plate to provide a total thickness of 2" in bearing.

The designer of this bridge, J.B. Strauss, had been associated with work on almost all types of early bascule bridges up until 1901, according to his own account[1]. Noting the inherant limitations associated with early bridges, that year he began to undertake the task to remove these limitations with a new design. He noted that the cast iron counterweight used by designers up until that time was very costly, and that deep pits were required for bridges designed with counterweights located below the roadway. To minimize the depth of these pits, designers were forced to shorten the distance from the pivot point to the counterweight and to proportionately increase the size of the counterweight, sometimes to a cost prohibitive degree. As a result of his study, Strauss substituted concrete

[1] Strauss, J.B., "Bascule Bridges", a paper presented before the Second Pan American Scientific Congress, Washington, D.C., December 27, 1915 to January 8, 1916.

in place of cast iron counterweight, which cost = 15 to 20 % of cast iron, pound for pound, at that time. This inovation, used on his first bridge built for the W&LE Railroad in 1904, was adapted for use by nearly all designers for new bridges by 1906. He also developed and utilized a suspended (pivoting) counterweight in all his bascule bridges which, when the counterweight was located below the roadway, kept the counterweight arm as long as possible while limiting pit depth. (See Figure 1.) This was the case at Tayco Street.

Upon arrival at the site of the collapsed south bascule leaf at approximately 1:45 PM, engineers from Hazelet + Erdal began their investigation. The bridge was found in the following condition (refer to Figure 2):

> The channel end of the south leaf was bearing on the bottom of the canal and the front wall of the south pier. The main trunnions were torn loose from their supports on the trunnion columns. The west bearing failure took place in the attachment to the column. The bearing appeared to be perpendicular to the girder web. The east bearing was also torn loose at its attachment to the column but the inboard cap bolts were also pulled apart. The trunnion and bearing assembly was sloping down to the east with respect to the girder axis.
>
> The west counterweight trunnion remained in its bearing, oriented approximately 10° from its normal "bridge closed" position. The portion of the trunnion protruding 3 inches from the west end of the bearing exhibited no indication of distress in the bearing area or keyway. The key, recovered from the pit, was intact. Rust patterns on the trunnion surface indicated that only the inside 3/4" plate of the counterweight hanger was in bearing. The east end of the trunnion protruding 3-3/8 inches from the bearing exhibited significant distress with a portion of the shaft torn off at the north face of the keyway and at the edge of the bearing area. Parallel abrasions on the east face, most probably caused by the hanger plate as it fell off the trunnion, were at about a 45° angle to the girder axis. The screws connecting the bronze bearing insert to the housing were all distorted in a clockwise direction indicating some minor rotation between the bushing and the housing. The key, recovered from the pit, was sheared so that the top portion was moved 2-1/2" at the rear face and somewhat less at the front face. The girder web at the bearing was distorted and the trunnion was sloping downward to the east.

The east counterweight trunnion bearing was almost completely torn loose from the distorted girder web. It too was sloping downward to the east. The trunnion was found in the counterweight pit adjacent to the main trunnion support column.

The west girder tail cover was torn loose from its supports and was resting at the top of the girder. The east girder tail cover was torn loose and thrown completely free onto the sidewalk, left and forward of the operators house.

Refering to Figure 3, the racks and pinions showed no significant evidence of damage. Shafts S1 also appear to be undamaged. Gears G2 and their companion pinions Gear G3 were severely damaged with deformations in the teeth of both sets of gears. The beams supporting bearings B2 and B4 were severely deformed with the web torn completely loose from the flange on the west beam.

The counterweight hangers were bent and showed other evidence of distress. (See Figure 4). The outside hanger for the west girder was bent out about 3° and had evidence of bearing failure at the upper portion of the trunnion bore on the inside plate. Close inspection of the bore also indicated that only the inside 3/4 inch plate of the three plate (3/4", 3/4", 1/2") assembly had been bearing for a significant period of time. Grease build up of up to 1-1/4" on the inside of the plate corroborated this finding. There was no evidence of distress in the keyway in this plate. The inside hanger was bent inward about 9° and exhibited considerable distress in the upper area of the trunnion bore and at the key way. The plates were distorted and separated as they partially sheared the key during their clockwise rotation around the trunnion. The bearing area showed evidence of the hanger sliding off as it rotated. There was no evidence of fresh lubricant on the east hanger plate.

The inside hanger for the east girder was bent about 4° to the west while the outside hanger was bent to the east about 25°. No distress was noted in either of these plates in the trunnion bores or keyways.
The counterweight was resting on the pit floor at a skew of about 4.5° and about 12 inches east of its normally projected position. (See Figure 5). The southwest corner was in a position consistent with an opening of 59°. This does not agree with other evidence which indicates the girder was open to approximately 45° when the inboard hanger

came off the trunnion. Considering the friction between the hanger plates and the trunnion, and shear value of the key, it is probable that the counterweight was hanging out of vertical. However this can account for only about 5° of opening if one assumes a friction coefficient of 0.8 and ultimate strength of the key at 50,000 psi. The counterweight concrete was cracked at the top in the area surrounding both outside hangers and sustained considerable damage at the west end and the northeast corner. The damage at the west end indicates initial impact occurred on the southwest corner, consistent with the feeling that the west end of the counterweight was out of vertical at the time of failure. A bounce forward after impact could well account for the apparent inconsistency in counterweight location. A section of the east trunnion column pier was spalled as a result of impact from the northeast corner of the counterweight.

The evidence indicates that the outboard hanger on the west trunnion had been bearing on a single 3/4" plate for a significant period of time. See Figures 6 & 7. When the final lift was made, the west counterweight trunnion seized in its bearing after approximately a 10° rotation. As the girder continued to rotate about the main trunnion, the counterweight hanger was being forced out of its vertical orientation exerting a very high torque load on the interface between the counterweight trunnion and the hanger plate assemblies. Concurrently, the hanger at the east girder maintained its vertical orientation and the counterweight link at the center of the bridge was exerting a force to maintain the vertical orientation. This combination of forces was sufficient to cause the single plate in bearing on the outboard side of the girder to move outward until it failed in edge bearing and slipped completely off the trunnion. This happened very soon after the bearing seized since there was no evidence of distress in the keyways or the key at this location. With the full component of the west counterweight support on the inboard side of the girder, the span continued to rise. The eccentric load on the trunnion caused a distortion in the web and a twisting of the girder so that the trunnion was sloping significantly downward to the inside. As the span continued to open, the inboard hanger rotated about the trunnion. As it sheared the key, the hanger plates separated and started sliding off the trunnion. The shearing action on the key indicates a rotation of about 2-1/2 inches which corresponds to approximately 25° of opening prior to the key being pulled or forced out of the keyway. The hanger stayed on the trunnion for an additional 10° of rotation before releasing and dropping the west end of the counterweight. Some movement occurred between the bronze bushing and the housing but is accounted for in the approximate measurement of a 10° rotation of the trunnion with respect to the girder axis prior to seizure.

When the west end of the counterweight dropped to the pit floor, it rotated transversely with respect to the east girder. At this point the inboard east counterweight hanger probably came in contact with the bottom flange of the girder and was forced off the trunnion. The total east half of the counterweight was then carried by the outboard hanger which forced the trunnion assembly out of horizontal and pulled the trunnion completely out of its bearing, releasing the counterweight and allowing the leaf to drop uncontrollably.

The cast steel housing, bronze liner and trunnion from the west girder were taken to the WisDOT material laboratory for dismantling. The bearing and trunnion were separated from the housing using a 400 ton press. Subsequently, the bronze liner was cut to permit separation from the trunnion.

Inspection of the trunnion and bronze bearing liner confirmed assumptions that the oil grooves were completely blocked. An analysis of the material in the grooves indicated the presence of bronze and steel shavings in a matrix of dried lubricant. Except for the area immediately adjacent to the juncture of the lubrication fill holes and the grooves, no lubricant had reached the surfaces of the trunnion and bronze liner for a long period of time.

It is probable that intermittent partial seizures in the past were responsible for the movement of the hanger plate assembly to its precarious position at the time of failure. The combination of bending and torsion in the hanger as a result of the seizure would cause lateral movement on the trunnion as the stresses were released. This failure might have been prevented if certain details had been different.

Several factors which contributed to the failure are examined in more detail as follows:

1. The design drawings for the counterweight trunnion called for a slot 1/2" from each end to permit a single keeper plate for both the key and the hanger assembly. In lieu of slotting, the trunnion was machined flat to the bottom of the keyway. This eliminated the restraint of possible hanger movement off the trunnion. Had the restraints been

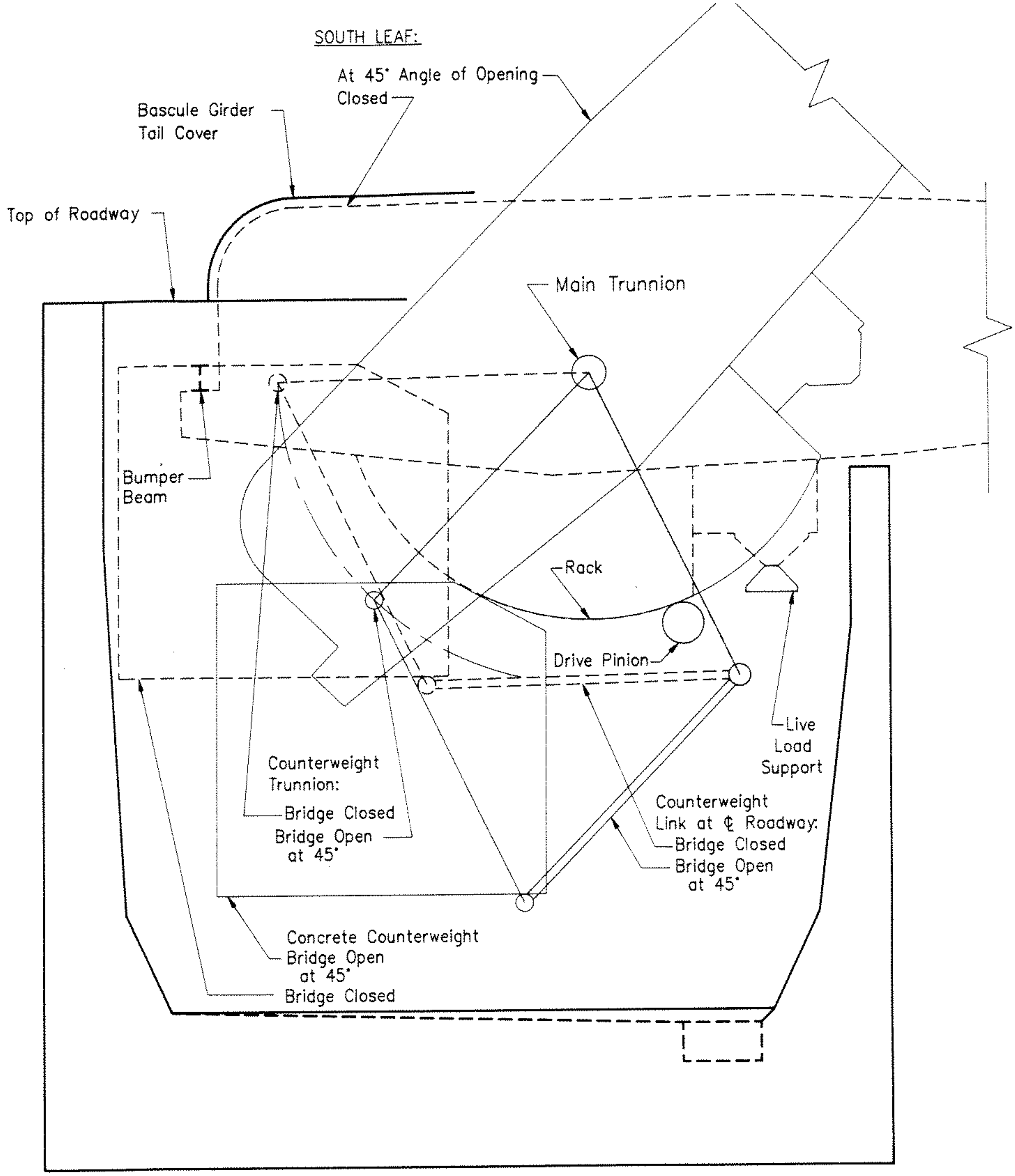
in place, the bearing seizure would probably have stalled the motor before the counterweight hanger could slip off the trunnion (Figures 6 & 7).

2. The trunnion details called for three oil grooves with drilled holes from both trunnion ends to the grooves. The outboard ends were to be fitted with alemite fittings for lubricant while the inboard ends called for pipe plugs. The plugs, which were installed, were intended to hold the lubricating oil in the grooves. No record is available with regard to the lubricants used in the years past, but at some point in time, grease was substituted for oil lubrication and this practice was continued. The lubricant in use at the time of the failure was MobilGrease HP, a multi-purpose extreme pressure automotive grease. When the lubricant was changed to grease, the plugs should have been removed. This would have allowed free movement of the lubricant through the grooves which would not only insure full coverage of the bearing surfaces, but would also purge contaminants that might enter the grooves. Their presence had to contribute greatly to the improper circulation of lubricant which permitted the complete clogging of the oil grooves. See Figure 6.

CONCLUSIONS

A critical factor contributing to this failure was the lack of any positive provision for preventing the hangers from coming off the trunnion. All bascule bridges with suspended counterweights should be provided with positive restraints to preclude the possibility of the hanger plates slipping off the trunnions or sensors that will alert the operator of any movement of the plates relative to the trunnions.

Most critical was the use of grease without removing the plugs for the lubrication of the trunnion bearings. Periodic checks should be made in such a modified application to insure proper flow of lubricant through their full length. Had the lubrication been satisfactory at all times, the hangers would never have moved on the trunnions and the failure would not have occurred.

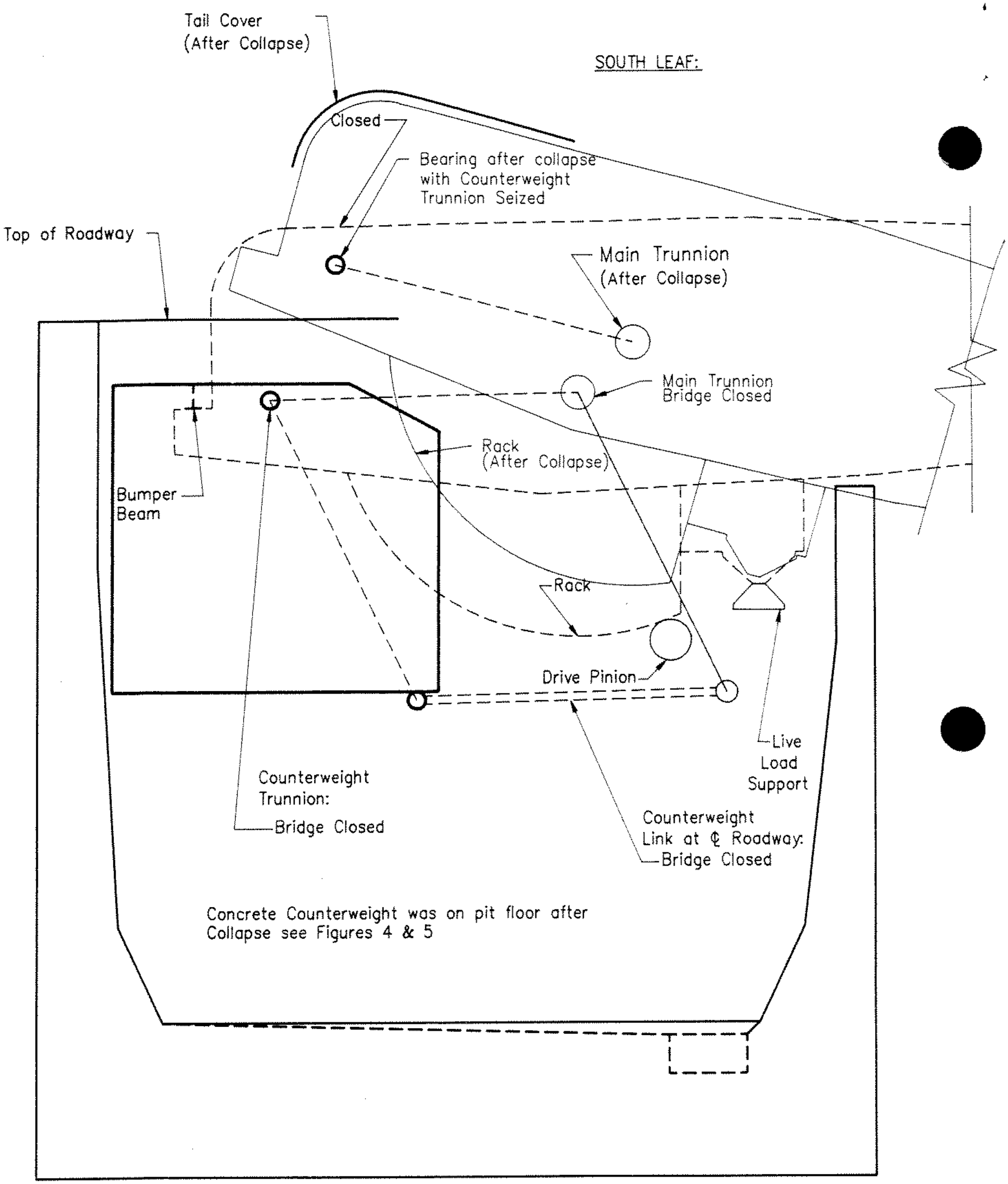


SECTION THROUGH COUNTERWEIGHT PIT

SHOWING BASCULE LEAF AT 45° ANGLE OF OPENING

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN

FIGURE 1

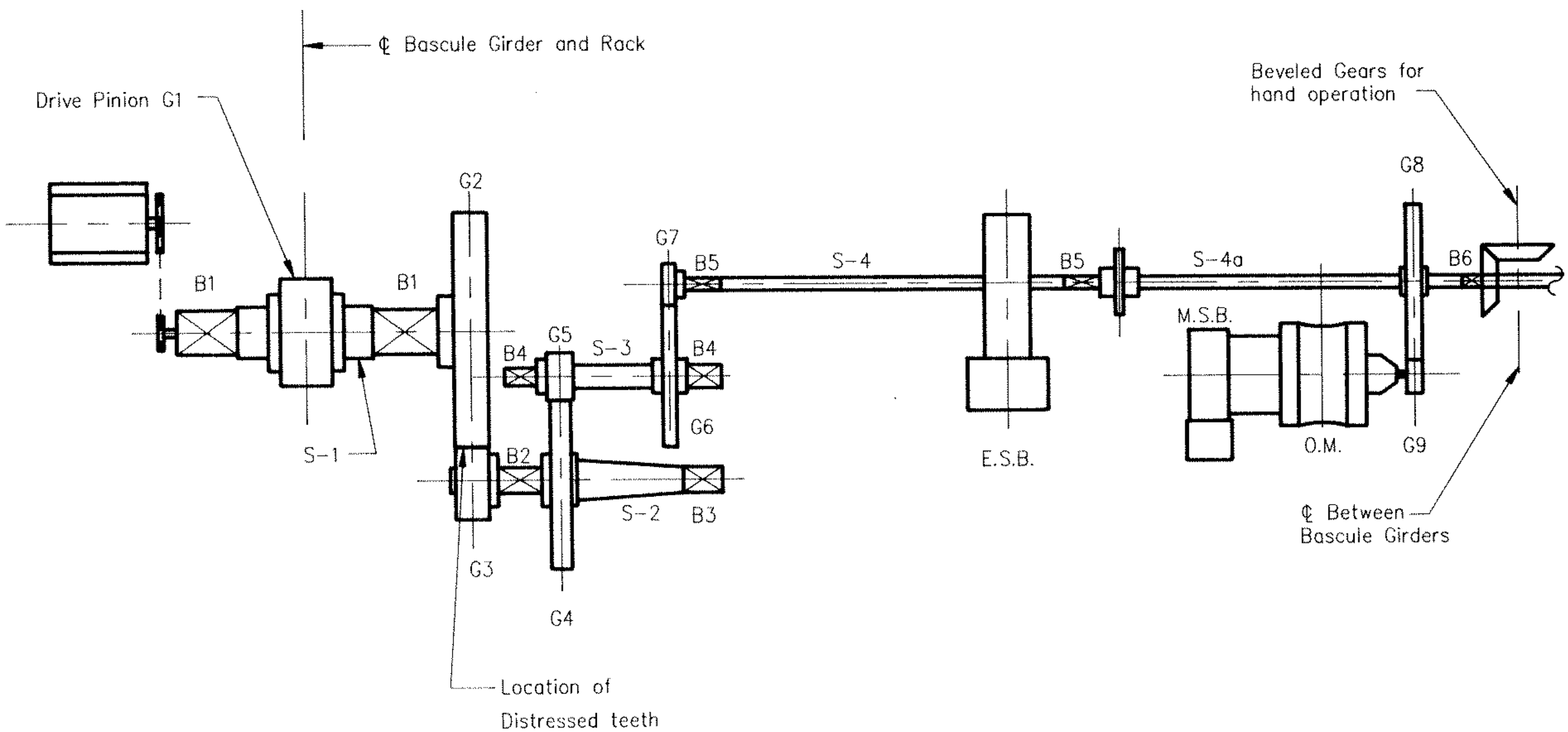


SECTION THROUGH COUNTERWEIGHT PIT

SHOWING BASCULE LEAF AFTER COLLAPSE

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN

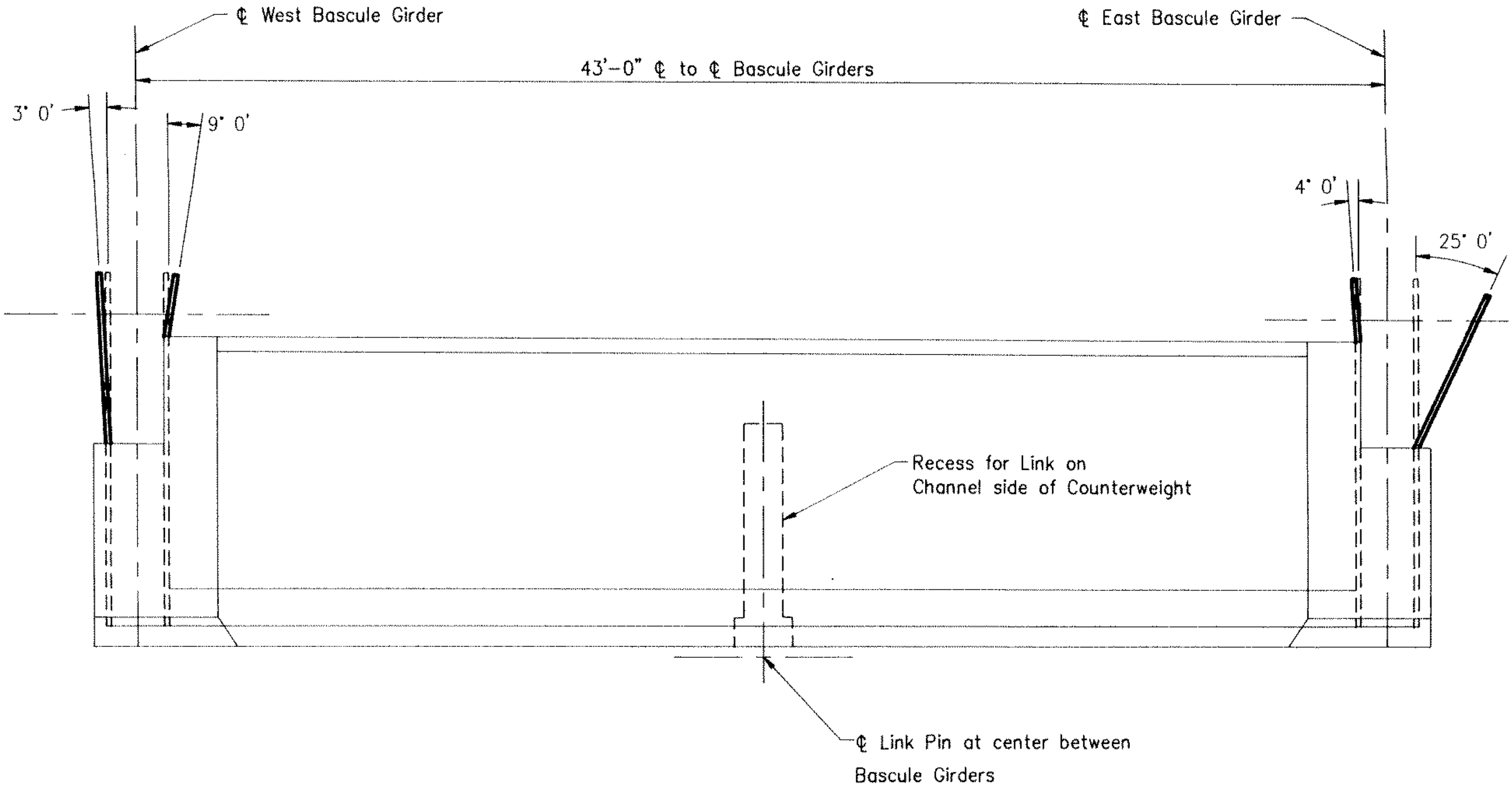
FIGURE 2



PLAN OF MACHINERY

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN

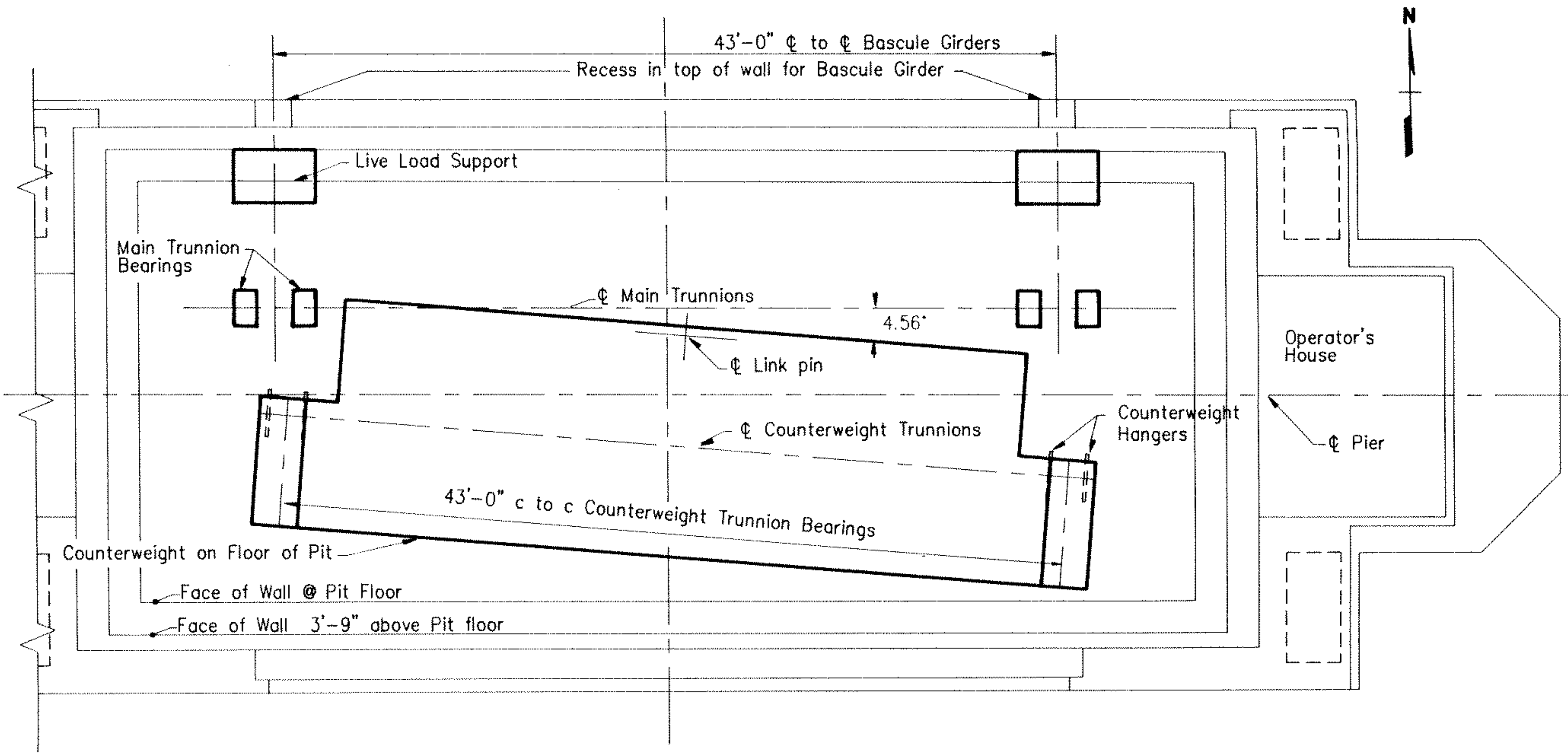
FIGURE 3



ELEVATION OF SOUTH COUNTERWEIGHT

LOOKING NORTH FROM APPROACH SIDE
SHOWING BENT HANGER PLATE ASSEMBLIES

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN
FIGURE

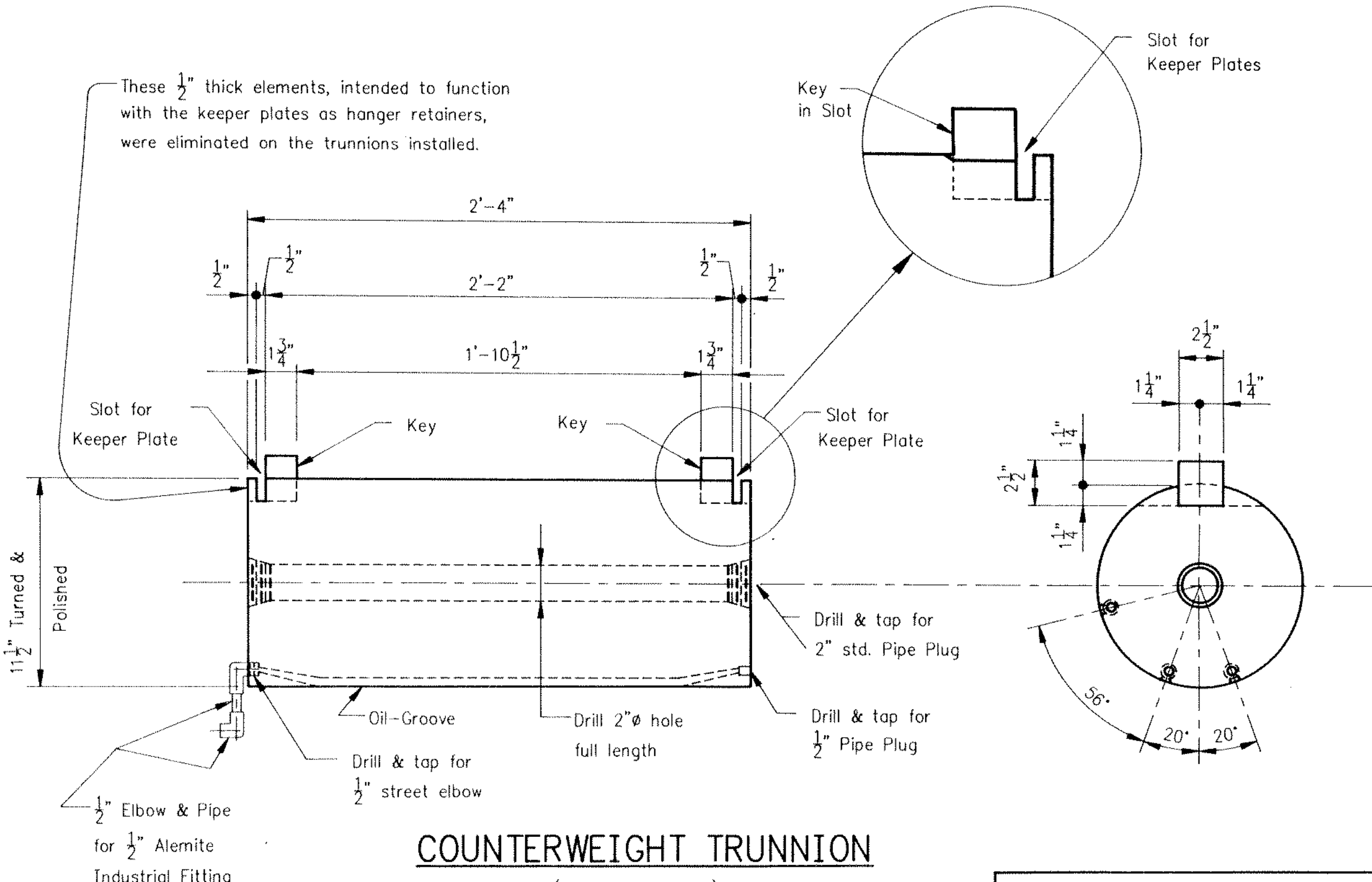


PLAN SOUTH BASCULE PIER

SHOWING LOCATION OF COUNTERWEIGHT IN PIT

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN

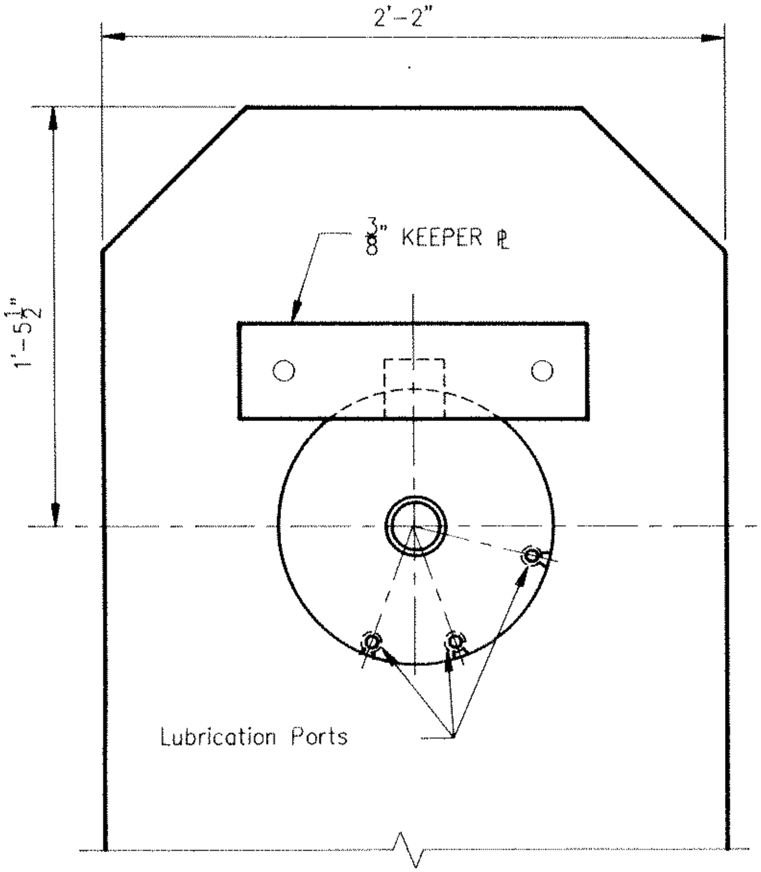
FIGURE 5



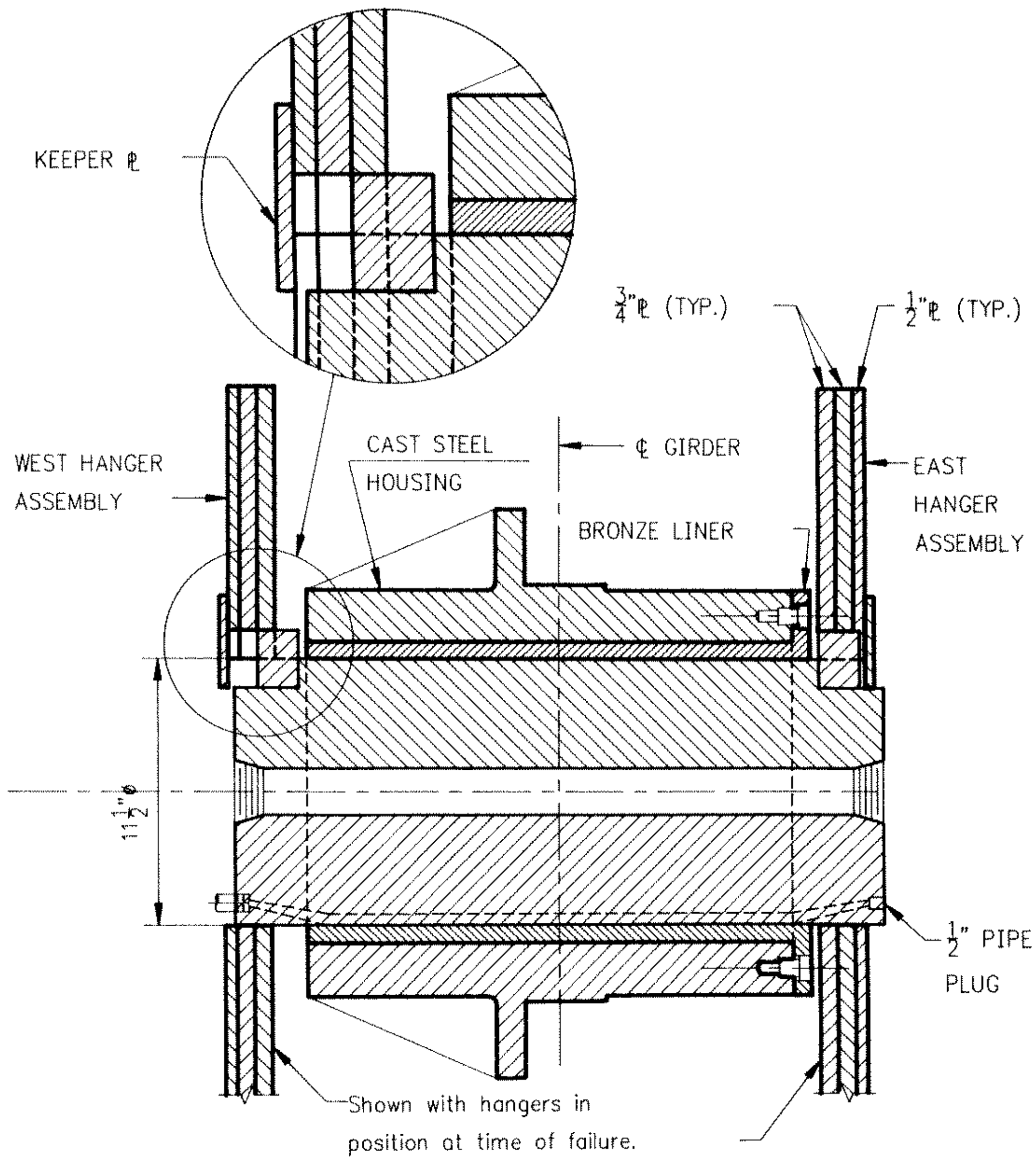
COUNTERWEIGHT TRUNNION

(AS DETAILED)

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN
FIGURE



ELEVATION



SECTION

COUNTERWEIGHT TRUNNION
(AS BUILT)

TAYCO STREET BASCULE BRIDGE
OVER
U.S. CANAL
MENASHA, WISCONSIN

FIGURE 7