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"Using Air Bags to Reposition A Rolling Lift", Fred Parkinson,
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USING AIRBAGS TO REPOSITION A DAMAGED ROLLING LIFT BASCULE

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INTRODUCTION

On the morning of March 27, 1989, a crane cable stabilizing the west leaf of the Lafayette Street Bridge snapped, causing the leaf to rotate backwards on its tracks into the counterweight pit. The leaf came to rest wedged between the live load uplift girder and the sides of the counterweight pit. This paper will examine the methods used to right the leaf using a system of airbags, hydraulic cylinders, and cranes.

The Lafayette Street Bridge is a double leaf Scherzer rolling lift bascule carrying state highway M-13/M-84 over the east branch of the Saginaw River in Bay City, Michigan. The bascule leaves each span 92'-6" from the centerline of the pinion to the center break, and consist of two girders with a floorbeam and stringer floor system supporting a half filled grating deck. The deck provides a 30'-0" roadway with two 5'-0" sidewalks. There are two multi-girder approach spans: a 96'-10" span to the west, and a 107'-8" span to the east.

At the time of the accident, the structural steel for the west leaf was nearly complete, and the majority of the counterweight installed. The leaf was counterweight-heavy, and would assume an "at-rest" position of approximately 68° from the vertical if left to its own devices. At night, the leaf was blocked in the fully open position for ship traffic. To lower the leaf, a crane on the approach span would slack off cables attached to the toe of the span until the leaf came to rest at about 68° . The crane would than release the toe cables, and lift cables attached to the back of the counterweight until the span rotated to the fully closed position. At this point a pin would be inserted into a frame mounted on the counterweight and approach span to lock the bridge in the down position for the work day.

Just prior to the pin placement on March 27, the crane cable attached to the back of the counterweight parted, allowing the leaf to start rotating backwards towards the open position. The leaf developed enough inertia to go beyond the equilibrium point and continue past the normal full-open position (70°). The leaf continued to rotate open until the bottom of the counterweight struck the back of the tail stop bumper blocks, which became the fulcrum to lever the entire leaf backwards. This movement tore off the rearmost pintle plates.

The rotation about the bottom of the counterweight continued until the top flange of the main bascule girders struck the live load uplift girder. This impact tore the web connections of the live load uplift girder and caused the tops of the supporting columns to rotate. The leaf then slid downward until the sidewalk stringers struck the top of the live load girder, wedging the leaf between the liveload girder and the concrete wall supporting the rolling girder tracks, at about an 84° angle, please refer to Figure 1.

The impact shock of the sudden stopping of the leaf broke the cables attaching a temporary counterweight of steel beams tied to the toe of the span. They slid down the roadway stringers and into the live load uplift girder, severely deforming it. These beams then continued down into the counterweight pit, further wedging the bridge into place.

After the leaf came to its final resting place, it was determined that all 1.3 million pounds of it would have to be moved toward the longitudinal centerline of the roadway, as well as vertically, and horizontally to return it to its as-designed maximum open position.

INITIAL RESPONSE

Shortly following the accident, the contractor braced the leaf against further movement by several methods. First, sections of steel H-piles were cut, fitted with base plates and placed between the top flange of the bascule girders and the backwall of the counterweight pit.

Four concrete pedestals were also cast under what was the back face (now the bottom) of the counterweight and the counterweight pit floor to support the deadweight of the leaf. Cables attached to the toe of the leaf were then anchored to a crane on the approach roadway. Portions of the damaged live load girder were then removed to relieve the stress in the sidewalk stringers that were partially supporting the leaf.

An initial damage assessment uncovered the following damage:

- The live load girder (W36 x 300) was distorted and torn beyond repair.
- The tops of the columns and double angle connections supporting the live load girder were severely twisted.
- The north rack girder was bowed out because the main bascule girder was resting against it.
- Several pedestals on the approach span bearings were spalled.

- The main bascule girders and floorbeams appeared to have sustained only minor damage.
- The counterweight appeared to have sustained only minor damage.
- Several roadway stringers were bent or kinked.
- Several sidewalk brackets and the plates were deformed when the rear sidewalk stringers struck the top of the live load girder.
- The rear ends of the sidewalk stringers were deformed and torn.
- Two pintle plates and pintles were destroyed.
- Several rolling track base plate anchor bolts were damaged or destroyed.
- The end of the rolling track base plate was deformed where the leaf and pintle plate came to rest on it.
- There was some cracking of the high-strength grout under the end of the rolling track base plate.
- There was some minor spalling of the counterweight pit walls.
- Some minor spalling to the approach span deck occurred.

Overall, the span appeared to be in fairly good shape, considering what it had been through. Once the leaf was stabilized, the removal of debris and temporary counterweight beam wedged in the pit began.

CALCULATIONS AND OFFICE WORK

As the original bridge designer, the state brought us in to assist in the restoration process. The state also asked the contractor to retain a consulting engineer to assist the contractor in preparing a restoration scheme. The contractor proposed using a system of airbags under the counterweight to lift the span, stabilized by hydraulic cylinders, struts, and crane cables. In evaluating the contractor's proposal, several key criteria were used:

- The track record of the airbag system.
- Methods for determining and maintaining the stability and control of the leaf during the operation.
- Minimizing further damage to the bridge.
- Speed of restoration.

During our review of the airbag system, we were unable to find any similar applications of these airbags to lift as large a structure. The airbags had been used in the past to lift houses and heavy machinery successfully, but this application to a bridge would be a first. Manufacturer's data indicated that the bags were tested to a pressure 4 times the 120 psi proposed for this application.

The airbags themselves were about 3 foot square with a deflated height of about 1" Constructed of butyl rubber and stainless steel mesh, each bag could lift up to 40 tons at an internal working pressure of 150 psi and 9 to 15 inch extension. Each bag was connected to an individual pressure gage, relief valve, and pressure controls that enabled the bags to be controlled individually or in groups.

The behavior of the airbags under load was an added complication. Unlike conventional hydraulic cylinder jacks with fixed piston areas, the airbag capacity was dependant on the stroke as well as the internal pressure. The airbag is constructed like a large pillow; as the internal pressure increases, the bag inflates and the portion of the airbag skin in contact with the load decreases. The manufacturer supplied calibration curves that enabled the contractor to estimate the maximum load lifted for a given stroke, a sample of which is shown in Figure 2.

The center of effort of a group of airbags was difficult to predict, due to their stroke dependant capacity. Consequently, the contractor proposed several possible airbag arrangements to allow for repositioning the bags during the jacking process. In addition to the vertical movement of the leaf, the airbags would also have to assist, or at least tolerate, rotation and translation of the leaf.

Because of their easily deformable shape, the contractor did not think this to be a problem. The bags could easily conform to the tapered shape necessary for rotation, and the contractor proposed placing tapered shims to minimize the distortion in the bag. The manufacturer also stated that the bag could withstand some rotation, which would allow the counterweight to move horizontally. The maximum allowable amount of rotation was limited to that point when the horizontal seam of bag rolled forward and touched the ground. Thus, a lightly loaded bag (one with a large stroke) could rotate or roll further than a heavily loaded bag (one with a small stroke).

The proposed initial arrangement of the airbags provided seven in the first row near the front of the counterweight and seven in the second row near the back of the counterweight. These would be supplemented by two additional bags behind the front pedestals as jacking progressed. The jacks would be followed up by plywood shims on the pedestals to minimize any drop in the event of a bag failure.

Since groups of bags were connected to common manifolds, the loss of one bag or hose would result in several sudden deflations, and may have resulted in overloading of the remaining bags. To minimize the consequences of this action, the contractor used the aforementioned shims and placed safety blow-off valves on the bags to release over-pressures in a controlled fashion.

The front row of bags carried the majority of the leaf weight, and their stroke limited the jacking operation. Once maximum pressure had been reached, the shims on top of the temporary concrete pedestals would be brought up tight under the counterweight and the bags deflated. Plywood shims would then be placed to bring the deflated airbag back up into contact with the underside of the counterweight. This process would be repeated until the span was restored to its correct position.

During the time that the bridge was supported on the airbags, it needed bracing to assure its stability. These stabilizing forces were hard to properly estimate, as there were several complications. First, the true position of the center of gravity of the leaf was hard to determine. Several different C.G.'s could be determined depending on whether one started from the contract plans or the shop drawings. In addition, the number of lead blocks in the counterweight was uncertain.

The behavior of the bridge while supported on the airbags was also difficult to predict. As long as the bags were not too heavily loaded and the C.G. of the leaf passed between the two rows of airbags, the system would tend to be self righting. If one row of bags were loaded beyond their capacity, such as through wind loading, or if the C.G. of the leaf passed beyond the centerline of one of the lines of airbags, the system could become unstable.

The contractor developed a system of complimentary restraints to address these concerns. Cables were attached to the toe of the span and lead back to two forty ton cranes 250' from the end of the approach span of the bridge. The cable tension could be controlled by taking up or releasing cable from the crane drum. The short sections of H-pile strutting the top flange of the bascule girders to the pit backwall were left in place, and occasionally repositioned as the leaf was lifted. These, along with the original damaged bumper blocks at the front edge of the counterweight, provided reaction points for the crane cables to work against.

Four dywidag bars (one on each side of both girders) were connected between a hydraulic jack mounted on the top flange of the girder and an anchorage plate on the front wall of the pit. Tensioning these rods, along with using higher pressures in the rear row of jacks, would rotate and translate the bridge horizontally. By using the cable/strut and hydraulic jack/dywidag rod system, the leaf could be kept under positive control at all times. Figure 3 and 4 show the general arrangement of the restraints.

Additional small hydraulic jacks and porta-powers would be used to push the leaf away from the pit walls transverse to the centerline of the bridge. The airbag arrangement was much wider transverse to the centerline of the roadway than along it (the ratio was about 3:1), and the bascule girders were closely confined by the rack girders and the pit walls. In addition, only minor rotation of the leaf was required about an axis parallel to the centerline of the roadway, so no cables were used to stabilize the leaf in this direction.

Even with the stabilizing systems described above, there was some concern about the controlability of the leaf in windy conditions. To respond to this the contractor proposed suspending all operations when the wind speed exceeded 30 mph, and securely blocking the leaf on the concrete pedestals and tensioning the cables at night.

The effect of the jacking operation on the leaf was thoroughly investigated. Shear in the counterweight during jacking and while at rest on the pedestals was checked, with an allowance for 100% impact in the event that jack failure occurred. The stresses in the lower lateral counterweight bracing was checked to see if it could transfer jacking loads. Foundation loads were checked for the temporary as well as the final position of the leaf. The backwall of the pit was checked for strut loads. The cable, strut, and jacking points on the bascule girders were considered adequate by inspection.

The airbags and shimming under the counterweight effectively distributed the load over the strongest member of leaf, and obviated the need for jacking or lifting brackets on the fracture-critical bascule girders. Lifting the bridge from the bottom also resulted in smooth stress transitions in the girders as they were rotated back into normal position.

The contractor was able to rent all the needed airbags and fittings from the manufacturer and rented a compressor locally. The contractor went ahead and also ordered replacement components for some of the damaged steel, to shorten the repair time-frame. The contractor was able to find the remainder of the hydraulic cylinders, rods, cables, plywood, and timber blocking locally or in his stock.

The contractor and his engineer's fast work and speedy submissions, coupled with timely reviews by us and the state, resulted in the contractor having his jacking scheme in place and ready to go just over eight weeks from the accident.

LIFTING THE BRIDGE

Prior to the June 1, 1989 start of lifting, the contractor had removed all remaining debris from the counterweight pit, leveled the pit floor with packed sand and plywood, installed the airbags and shimming, stockpiled plywood and timber shims in various thicknesses, installed all of the bracing and stabilization systems, welded temporary keeper rods to the damaged pintle plates to prevent their falling and hooked up all of the hoses and gages.

At about 3:30 pm, the airbags were inflated as a group to 120 psi. The vertical movement of the heavily loaded front edge of the counterweight was a disappointing 3/8". The pressure was raised to 150 psi, and leaf movement increased to 1-1/2". The dywidag rods and hydraulic cylinders were used to snug the bridge up against the timber tail stop blocks at the front of the counterweight, and the crane cables tensioned. Shims were placed on the concrete pedestals under the counterweight and the bags were deflated, shimmed, and reset for the next morning. At all times the leaf remained easy to control, with no unusual sounds or movements.

June 2, 1989, was the first full day of "production" jacking. The timber tail stop blocks, having already been damaged in the accident, were supplemented with additional timbers and hydraulic jacks for more precise control. A 10-ton porta-power was placed against the north bascule girder flange to push the leaf away from the north pit wall, against which the bridge rested.

Once the leaf was supported on the airbags and away from the north wall, it proved surprisingly easy to move and control. Progress was so good that the damaged south pintle plate, formerly trapped under the rolling girder, was removed before noon. Two additional bags were added behind the front pedestal to speed the work. Several lifting cycles were completed and, by the end of the day, the leaf had been brought back into line with longitudinal centerline of roadway and the leaf lifted 7" vertically and 13 1/2" horizontally in relation to the benchmark on the top of the south rack girder.

June 3, 1989 passed in much the same fashion. The north pintle plate was still wedged under the girder, and only a half day of work was done, it being Saturday. No work was performed on Sunday, June 4.

Monday, June 5, 1989 was the final and most critical day of the jacking operation. Early in the day, the north pintle plate was finally freed and the leaf approached its final position. The leaf had rotated far enough that the center of gravity of the leaf was in danger of passing outside of the center of effort of the front row of airbags. The position of the C.G. was checked with a plumb bob, and the operation proceeded carefully until the rolling portion of the bascule girder, along with its pintle plate, was resting on the rolling track sole plate, please see Figure 4. The dywidag bars and hydraulic jacks were then used to slide the leaf along the greased sole plate.

At 2:50 pm on June 5, 1989, the leaf slid into its final as-designed full-open position. The entire jacking operation had taken about 5 calendar days and 3 days of actual jacking, well under the 2 weeks that had been projected. By the end of the day on June 6, 1989, the contractor had cleared the pit of all of the lifting equipment, and the repair process could begin.

CONCLUSION

The airbag system proved to be a versatile and effective means to reposition the fallen span. The system of airbags, cables, and struts reacted as predicted and enabled the contractor to reposition the leaf with no additional damage to the structure in a timely fashion.

After the span was restored to its as-designed open position, the contractor began restoration operations. Damage was generally to minor components on the span, with the exception of the live load girder and columns. The bascule girders were designed for HS-25 loading with over 2,000,000 fatigue cycles, and escaped major damage. After the replacements and repairs were completed, the contractor finished the bridge. It was opened to traffic in late 1989.

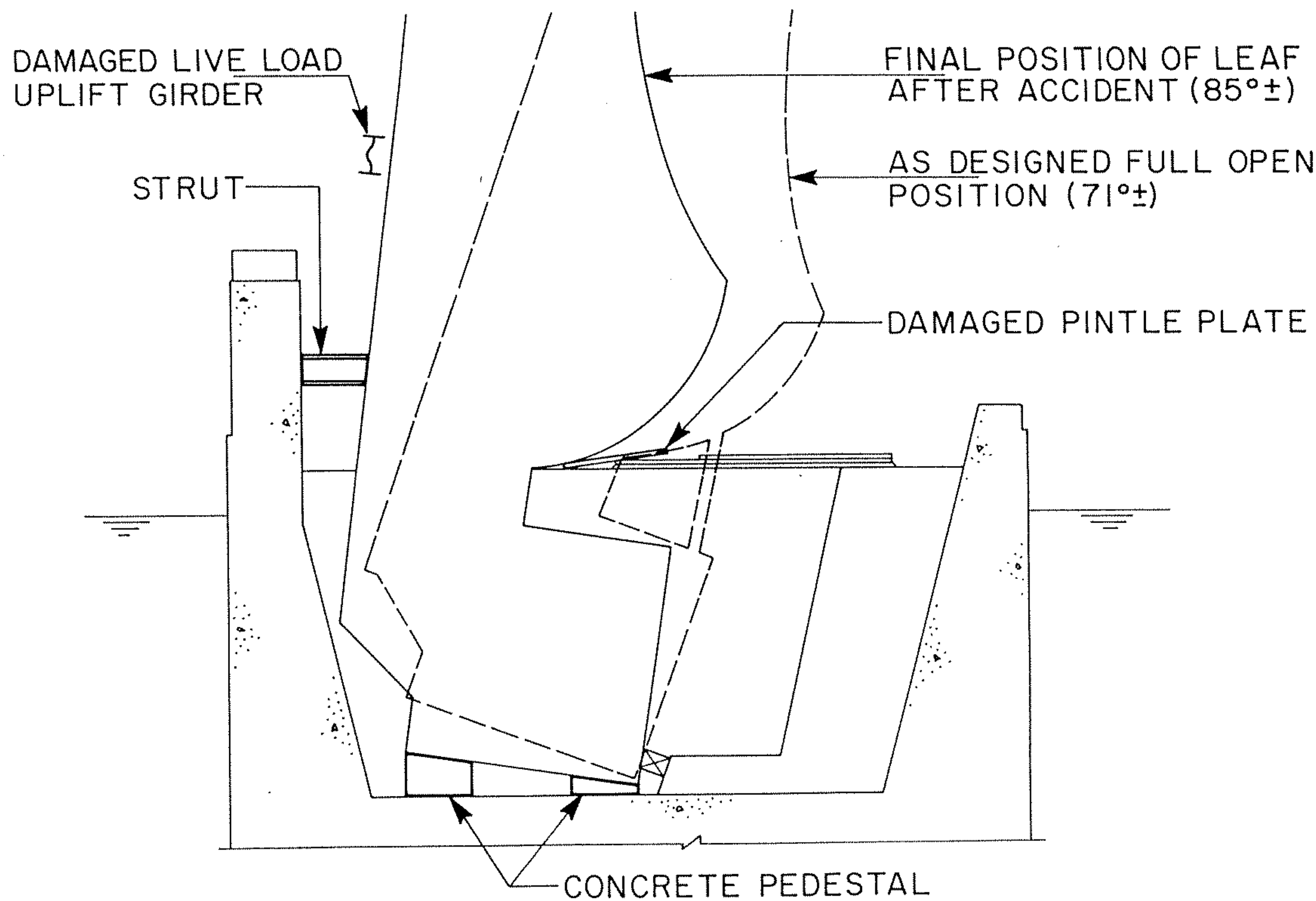
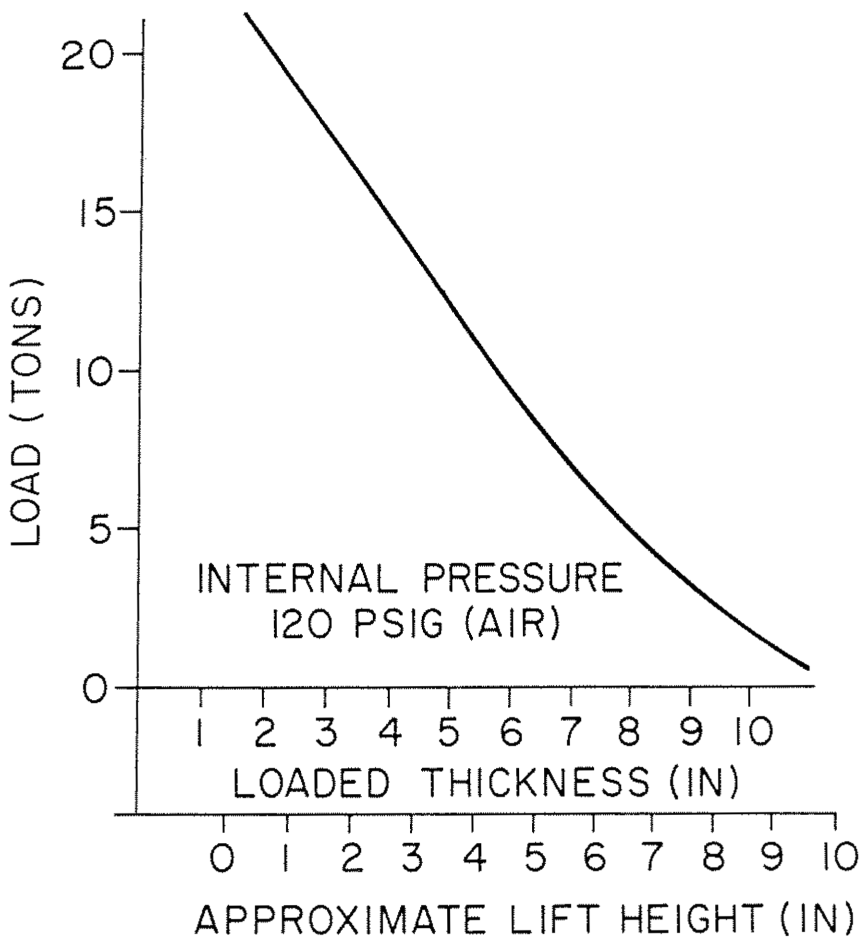

DAMAGED LIVE LOAD UPLIFT GIRDER
STRUT
FINAL POSITION OF LEAF AFTER ACCIDENT (85°±)
AS DESIGNED FULL OPEN POSITION (71°±)
DAMAGED PINTLE PLATE
CONCRETE PEDESTAL

FIGURE 1



LOAD vs LOADED THICKNESS

FIGURE 2

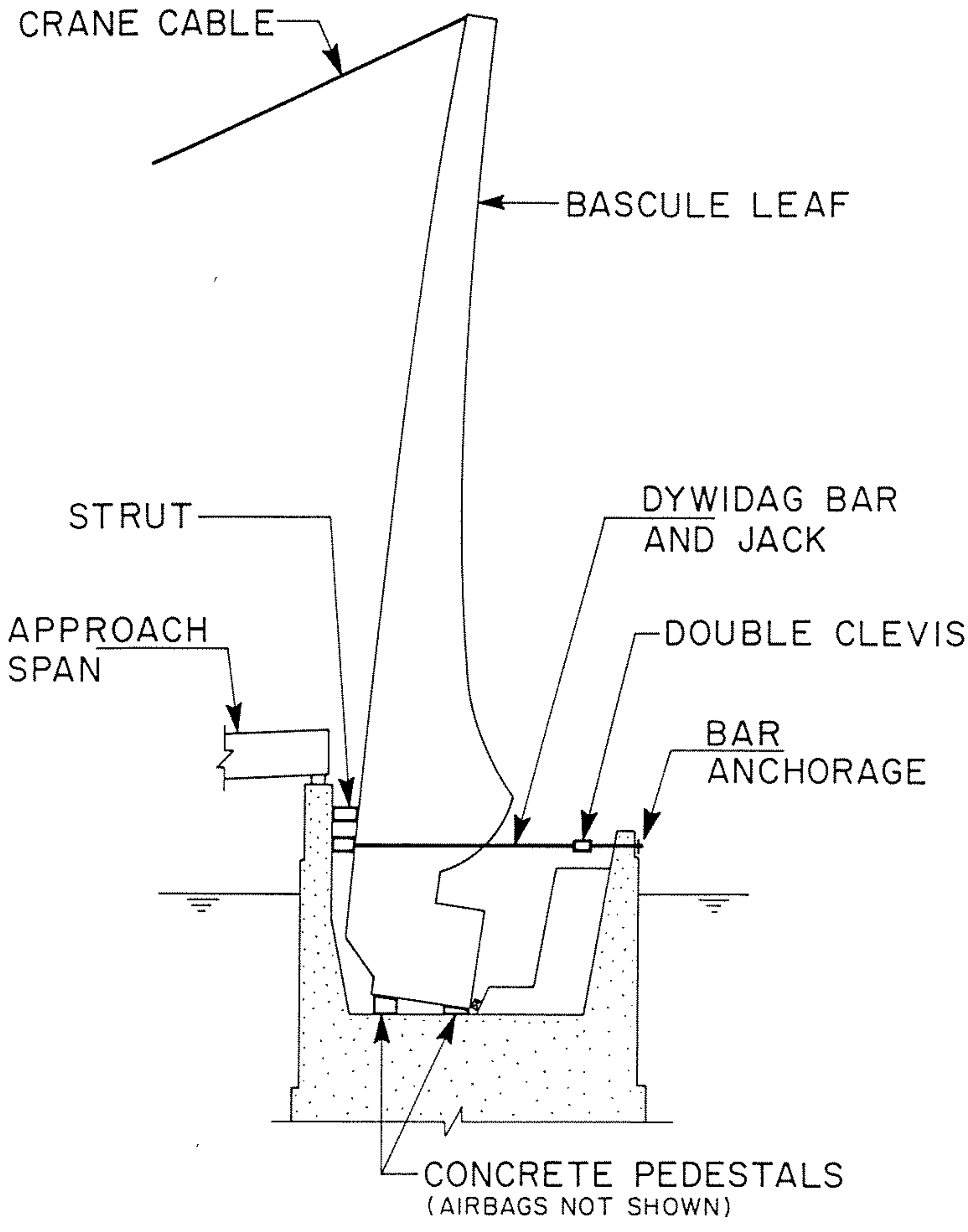

CRANE CABLE
BASCULE LEAF
STRUT
DYWIDAG BAR
AND JACK
APPROACH
SPAN
DOUBLE CLEVIS
BAR
ANCHORAGE
CONCRETE PEDESTALS
(AIRBAGS NOT SHOWN)

FIGURE 3

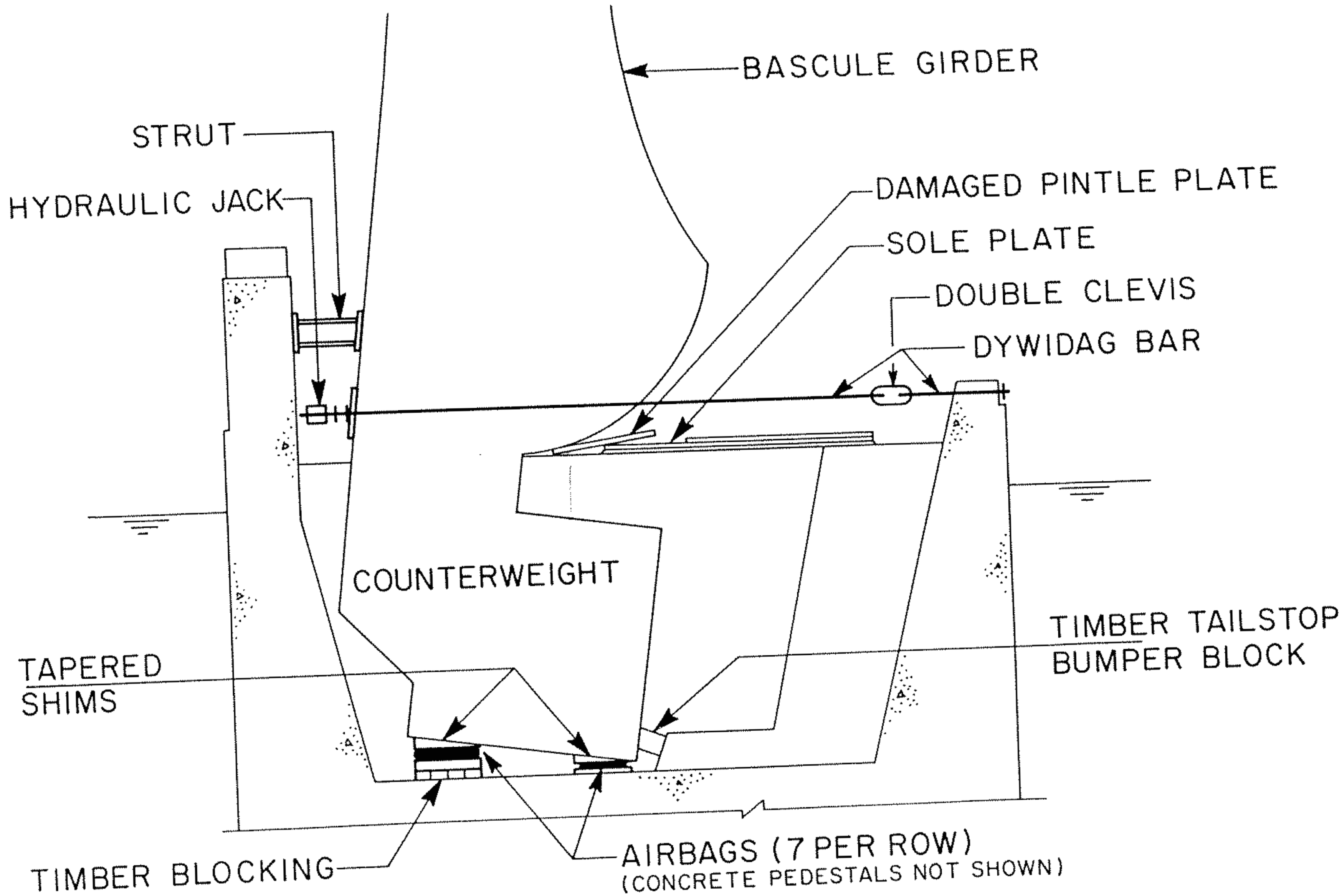

BASCULE GIRDER
STRUT
HYDRAULIC JACK
DAMAGED PINTLE PLATE
SOLE PLATE
DOUBLE CLEVIS
DYWIDAG BAR
COUNTERWEIGHT
TIMBER TAILSTOP
BUMPER BLOCK
TAPERED
SHIMS
TIMBER BLOCKING
AIRBAGS (7 PER ROW)
(CONCRETE PEDESTALS NOT SHOWN)

FIGURE 4

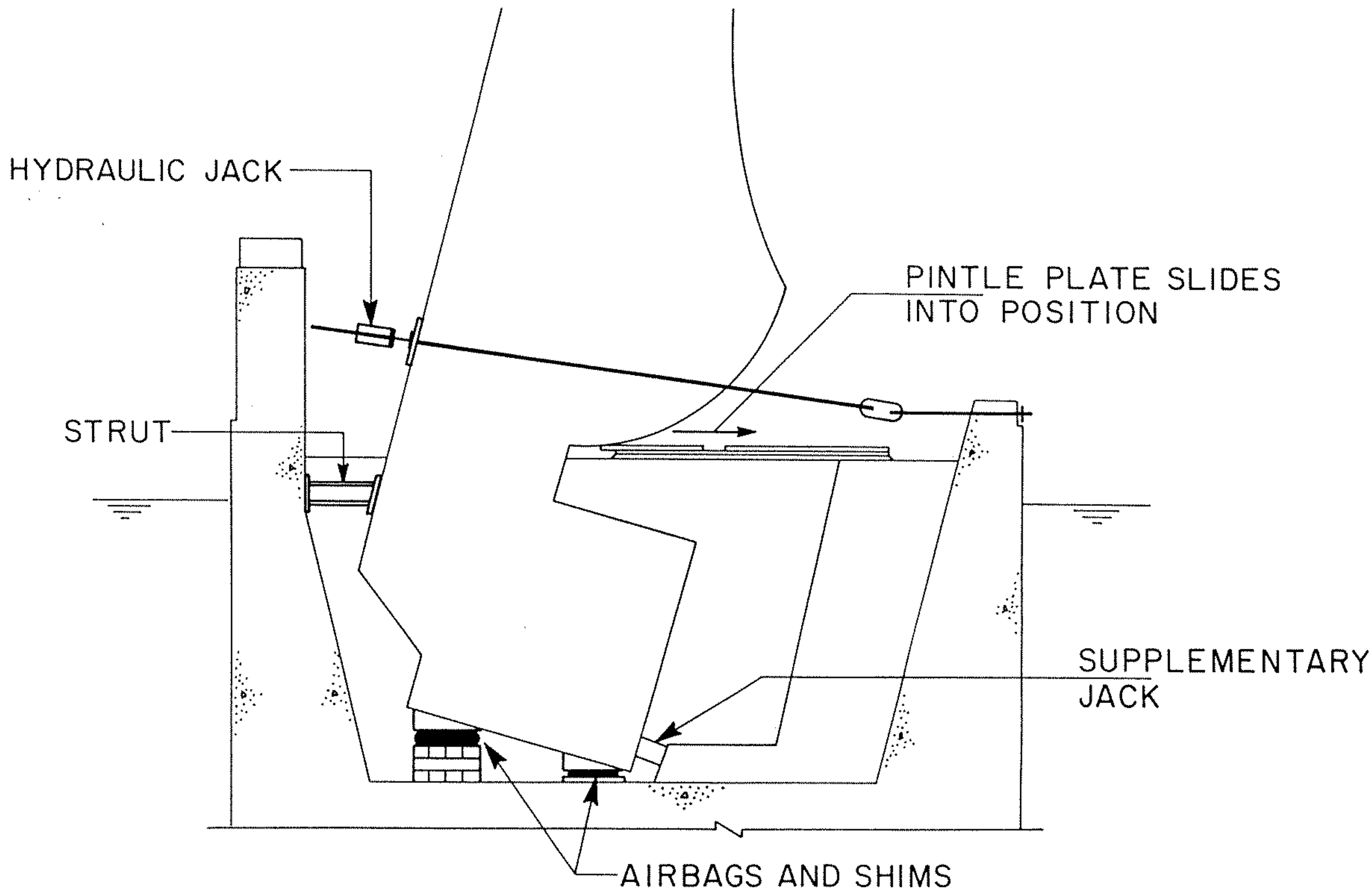

HYDRAULIC JACK
STRUT
PINTLE PLATE SLIDES
INTO POSITION
SUPPLEMENTARY
JACK
AIRBAGS AND SHIMS

FIGURE 5