MAINTAINABILITY OF A MOVABLE BRIDGE

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Design for maintainability is a discipline which frequently resides on the bottom end of the priority totem pole. Most engineers concerned with bridge design are easily enticed to apply their talents and engineering effort to more exciting design features. Often, the results of this choice will not affect the original designer; instead, the next generation of engineers will determine the corrective actions required for earlier design decisions.

In discussing maintainability, a definition of the term, as it applies to movable bridges, is necessary. This author has not seen such a definition and offers, for the purposes of this paper, the following:

> Maintainability of movable bridges is defined as the adequacy of the design for applying cost-effective maintenance procedures which will minimize bridge malfunctions causing interruptions to marine and vehicular traffic flow.

Thus, a bridge may be considered "highly maintenable" if the owner can keep it in a functional condition, with minimum interruptions of traffic, by developing procedures which are reasonable in cost. If costs for carrying out maintenance procedures are high, maintainability may not be considered satisfactory, even with minimal traffic interruptions resulting because of malfunctions or routine maintenance activities.

Further, maintainability is determined by the design of the bascule bridge, and is an element of construction cost. Lack of maintainability is seen in increased cost of maintenance after construction is complete; these extra costs may be incurred in routine maintenance or through major rehabilitation projects necessitated because of inability to properly maintain the bridge. Improved maintainability, then, should be expected to result in reduced maintenance costs and fewer traffic interruptions.

The breadth encompassed by the above definition of maintainability will be appreciated from Figure 1, a photograph of Choctawhatchee Bay Bridge following impact by five barges pushed by a tug.

As the barges approached the span, the bridge tender raised the bascule; it is believed that unpredictability of cross-currents and wind were responsible for off-course vectoring of the barges toward the bridge fender system and the bascule pier. Eight approach spans were destroyed.

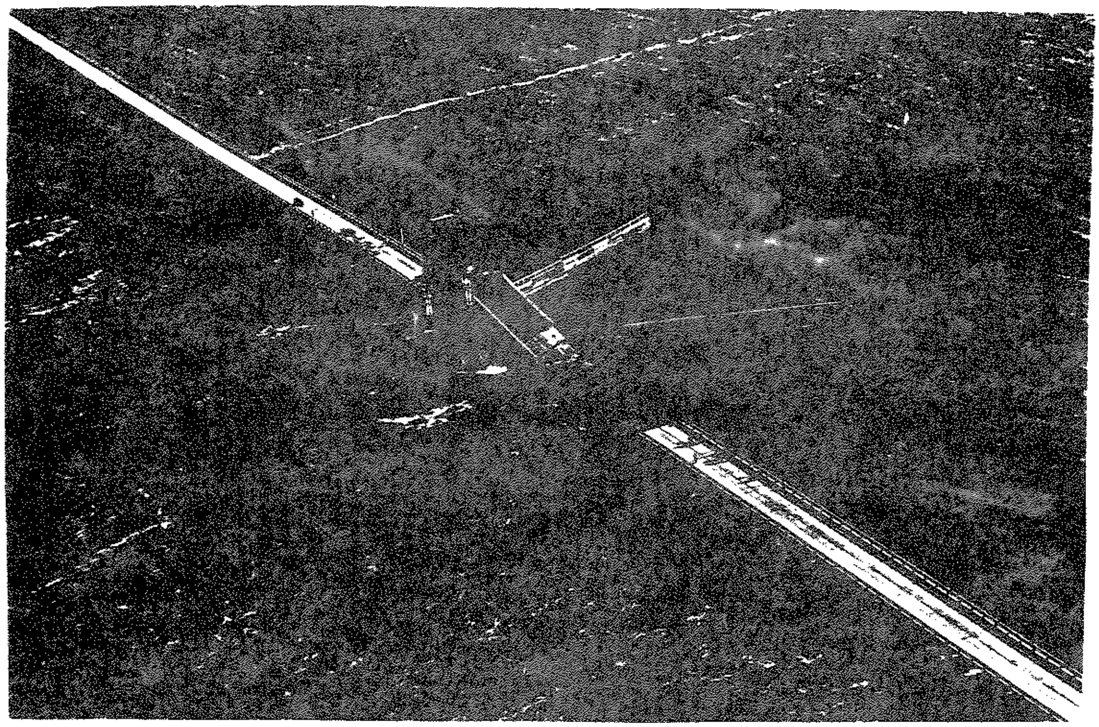


FIGURE 1

There were no cost-effective maintenance procedures which might have avoided this catastrophe. Marine and vehicular traffic were certainly interrupted! Considerations in design of this bridge, as it relates to the accident, involve impact capability, visibility factors, channel width evaluations, wind effects, hydrography, marine and vehicular traffic and operator safety.

This bridge, thus, is rated as "poor" from a maintainability standpoint. 27 impacts, with damage of various amounts, have occurred during a period of 12 years.

A detailed review of all factors relating to maintainability of the bridge is beyond the scope of this paper. It is apparent, nevertheless, that the history of repeated damage to the structure through impact substantiates the contention of need for complete evaluation of a wide variety of technical factors in establishing the overall bridge configuration.

The entire control house was swept from the structure and the bridge tender was killed in this accident. It is notable that the bascule configuration was such that the hand railing and bascule leaf, in the open position, prevented the bridge tender from escaping the control house before the barges impacted the pier.

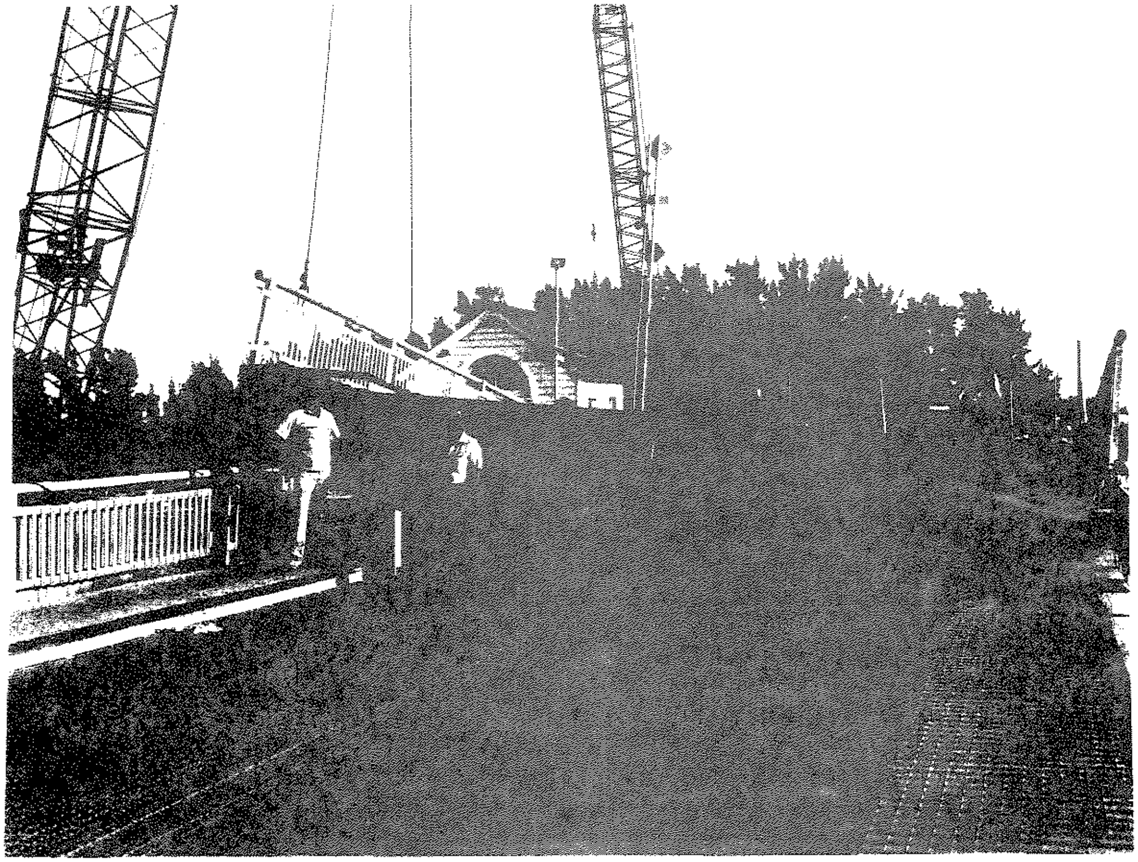


FIGURE 2

Figure 2 shows New Pass bridge following structural failure of the bascule girder. Failure resulted from sever corrosion in the region just forward of the counterweight. Following emergency repairs, the bridge was welded shut and now handles only vehicular traffic. A new bascule is nearing completion of construction.

This bridge provides an example of poor maintainability. The region between the bacule girder and the counterweight was inaccessible for routine maintenance and inspection. Moisture was retained in the region where corrosion was progressing.

This paper will review several case histories of maintainability problems encountered in Florida bascule bridges. From a pragmatic standpoint, problems have led to concepts for improving maintainability on existing bascule bridges; and these concepts will be discussed. Finally, a set of standards for maintainability of bascule bridges will be presented.

It cost the State of Florida at least a quarter of a million dollars because of improper design for maintainability of two bronze bushings on Sunny Isles Bridge. The emergency repair work resulting from the bearing failures delayed other important rehabilitation work on the bridge for approximately 6 months and disrupted local marine interests.

The quarter of a million dollar cost associated with improper design for maintainability in the previous paragraph is conservatively low, and represents the costs of bearing and trunnion repair and installing auxiliary structure to support the span during repair operations on the trunnions and bearings. A strong argument can be made that approximately $1 million in costs were incurred because of inadequate maintenability features which caused, in addition to the trunnion bearing failure, deterioration and failure of the bridge machinery.

Sunny Isles bridge is located in North Miami, was built in 1948 and has an average daily traffic of 35530. This bridge spanning the inland waterway services numerous marine interests and handles heavy beach-bound traffic.

About 2 years ago, one span became difficult to operate, and finally froze in position. When the failure occurred, the span was approximately 15 degrees open; the emergency measure taken to enable getting traffic moving again was to drive a Department of Transportation vehicle up onto the span to force the span to a closed position. Of course, potentially dangerous navigational problems immediately arose with only single span capability for handling marine traffic. Span openings during this period of single leaf operation averaged about 30 per day.

When the failure occurred, a machinery rehabilitation contract was already in progress; the additional potential of a failure of machinery still under rehabilitation on the operable leaf increased the urgency for reactivating the frozen bascule leaf.

Leaf failure was caused by a combination of factors which resulted in inadequate lubrication of trunnion bearings. First, the trunnion lubrication points were inaccessible; second, lubrication points were not visible; third, lubrication points were not marked; fourth, trunnion bearing caps were integral, and could not be removed for inspection; fifth, lubricant had congealed within lubrication passages; and, finally, service personnel were not instructed on corrective actions which should have been taken to assure proper lubrication.

It should be emphasized that the real causative factors in this failure were a result of poor design features; inadequate training of service personnel did not cause the failure. In fact, if adequate maintainability provisions had been made in the design, the likelihood of failure would have been considerably reduced.

What should have been a relatively quick and inexpensive corrective action became a major rehabilitation problem because the trunnion bearings had been designed with an integral housing, as shown in Figure 3. The only way to get into the trunnion bearings was to deactivate one leaf, jack the span and remove the trunnion bearings. Of course, there were no provisions in the design to enable span jacking, and this became a major element of the refurbishment cost.

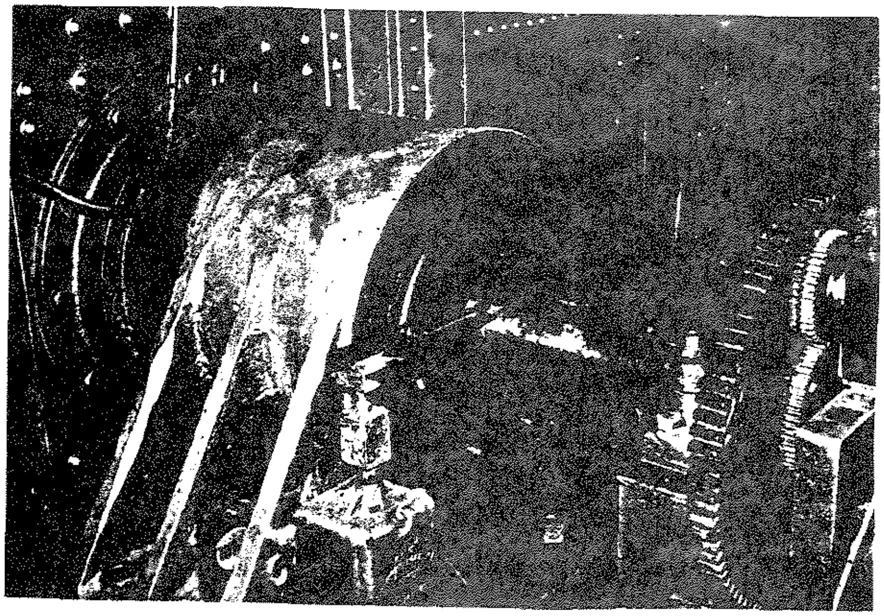


FIGURE 3

Poor maintainability of trunnion bearing lubrication results in deleterious effects such as complete stoppage of lubrication to bearing surfaces, as has been encountered in three Florida bridges. Charistically, if lubricant passages are infrequently purged by new lubricant, a hard, impervious material deposits inside the passage. Florida's experience has shown that complete closure of lubricant passages can occur within a period of as little as three months; in two of the three cases reported, the lubricant passages were inaccessible for proper maintenance.

Jewfish Creek Bridge, shown in Figure 4, is located in the Florida Keys, was built in 1944, has an average daily traffic of about 11300, and opens for marine traffic approximately 800 times per month.

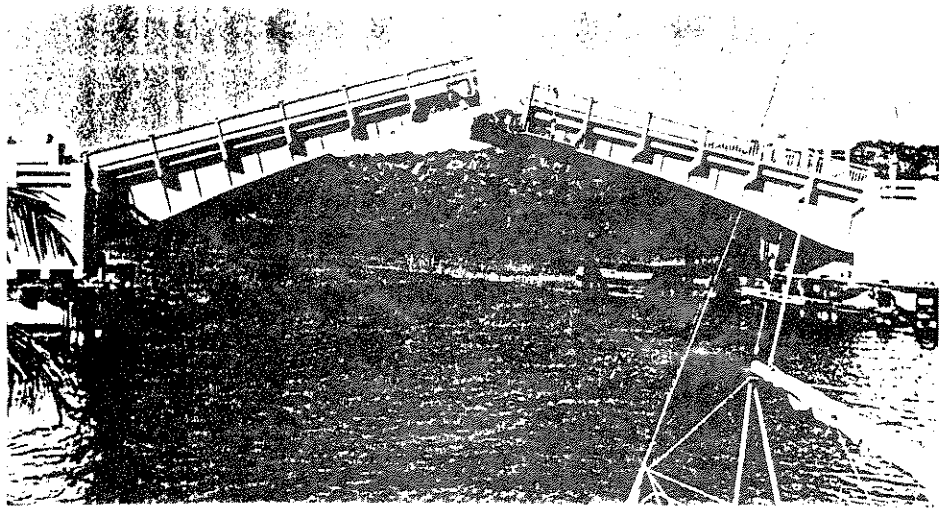


FIGURE 4

During routine inspection of the bridge, fractured bronze trunnion bushings were found; subsequent micrograph studies verified that the failure mechanism was fatigue.

Further inspection showed that the trunnions were considerabily misaligned, and inspection records indicated that the realignment had probably existed since the bridge was constructed.

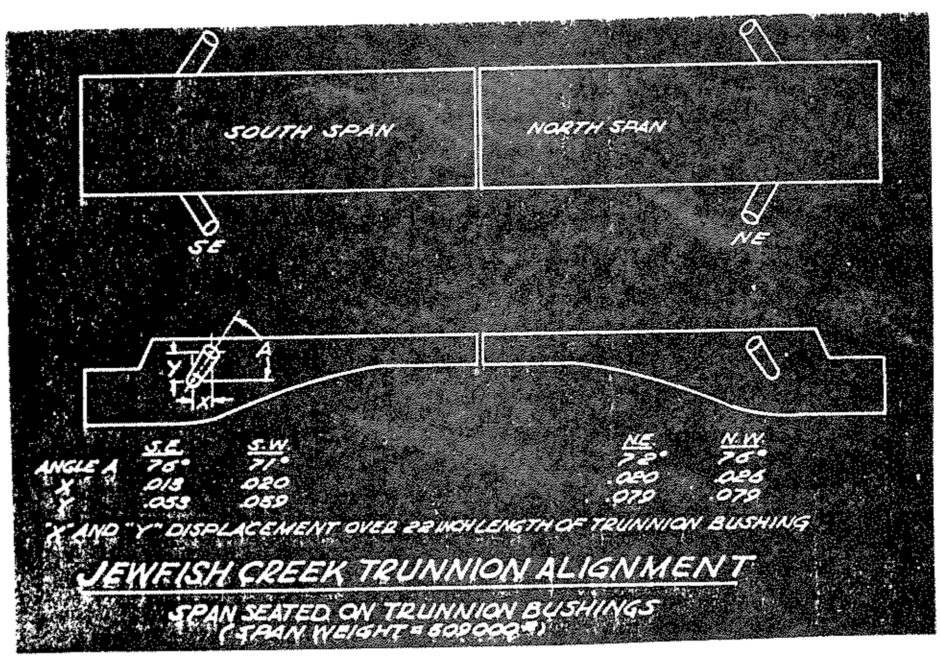


FIGURE 5

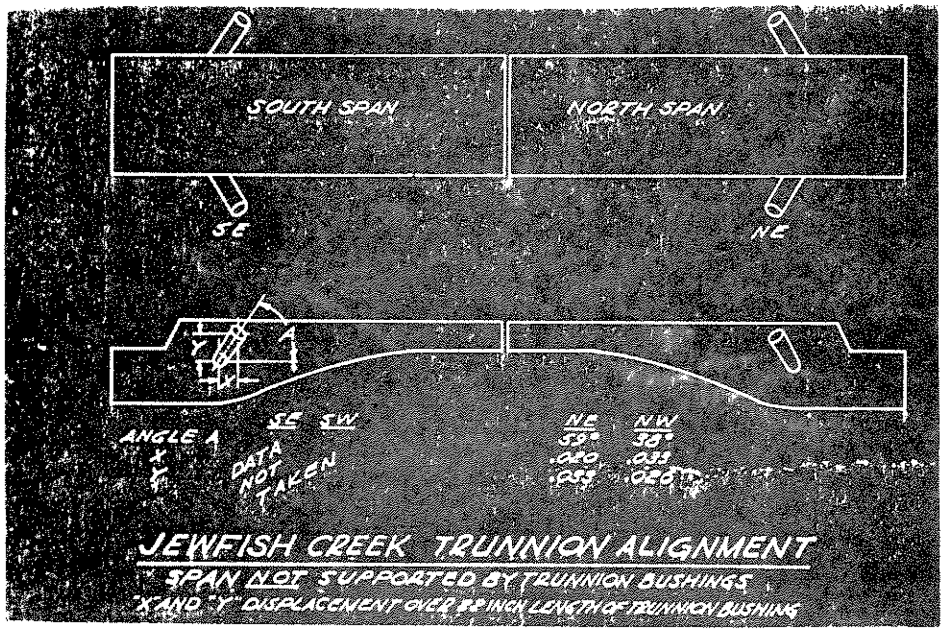


FIGURE 6

Trunnions were found to be heavily corroded and pitted on the upper section of the journal. (See Figure 7). Large particles of corrosion products from the trunnion journal rotated into the load bearing portion of the trunnion, machining grooves into the lower half of the trunnion bushing.

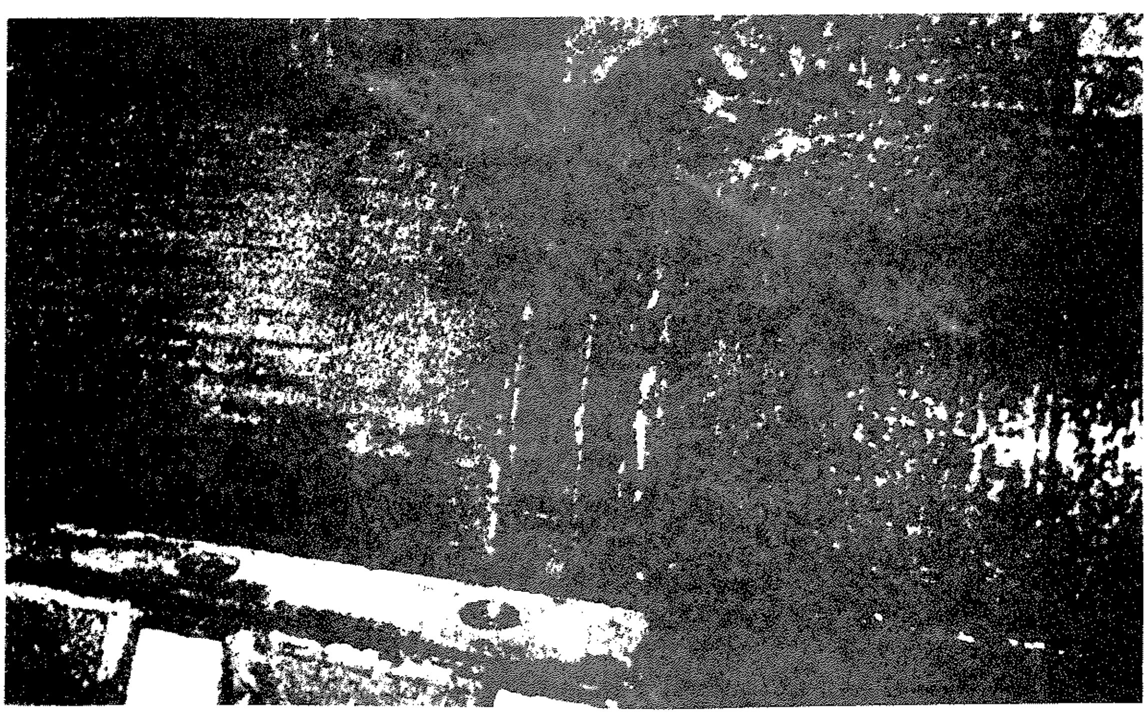


FIGURE 7

The cause of journal corrosion was determined to have resulted from inadequate protection of the trunnion journals from salt water products regularly washing through the upper half to the trunnion bearing, removing whatever lubricant might have protected the surfaces.

A clear determination of the cause of trunnion bearing failure is clouded by two defects, either of which may have caused or jointly contributed to the fatigue failure; (a) trunnion misalignment, and (b) scaling of corrosion products into the load bearing region between trunnion journal and bronze bushing.

Completion of the rehabilitation on this bascule bridge thus involved jacking the span so that trunnion bearings and trunnions could be removed, while still maintaining traffic on the bridge. Significantly, features which would permit jacking a span to repair or replace trunnions or bushings will improve the maintenability of Florida's bascule bridges.

Another maintainability requirement learned through experience with Jewfish Creek bascule bridge is that protection from water drainage in trunnion bearing locations must be provided. (See Figures 8 and 9).

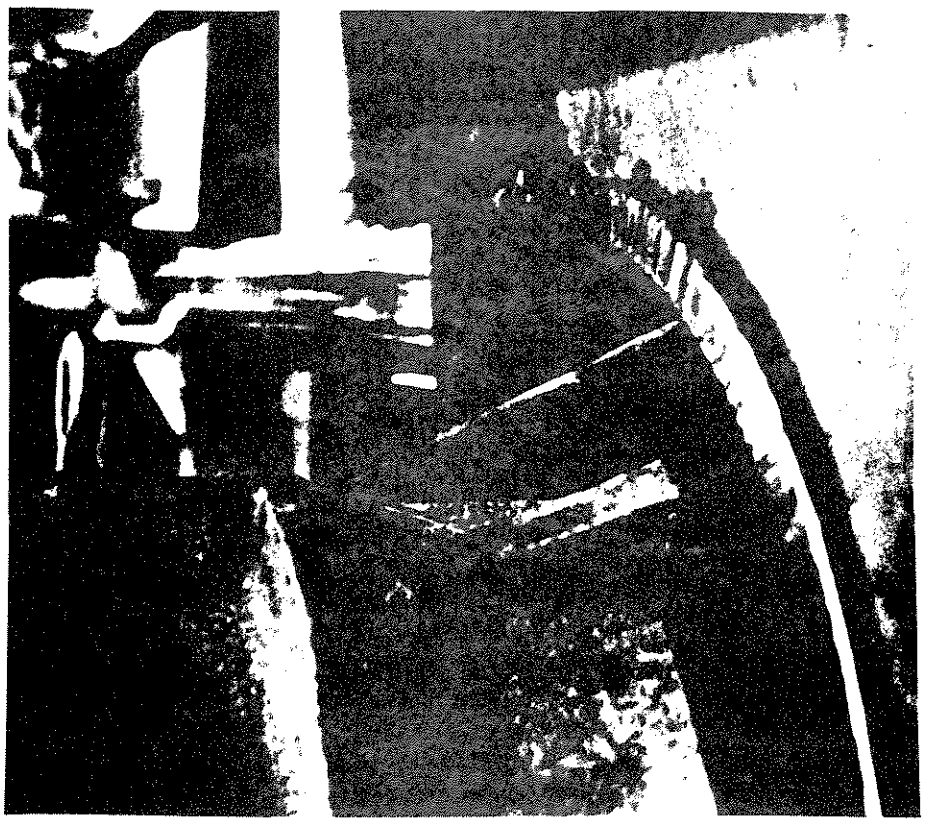


FIGURE 8

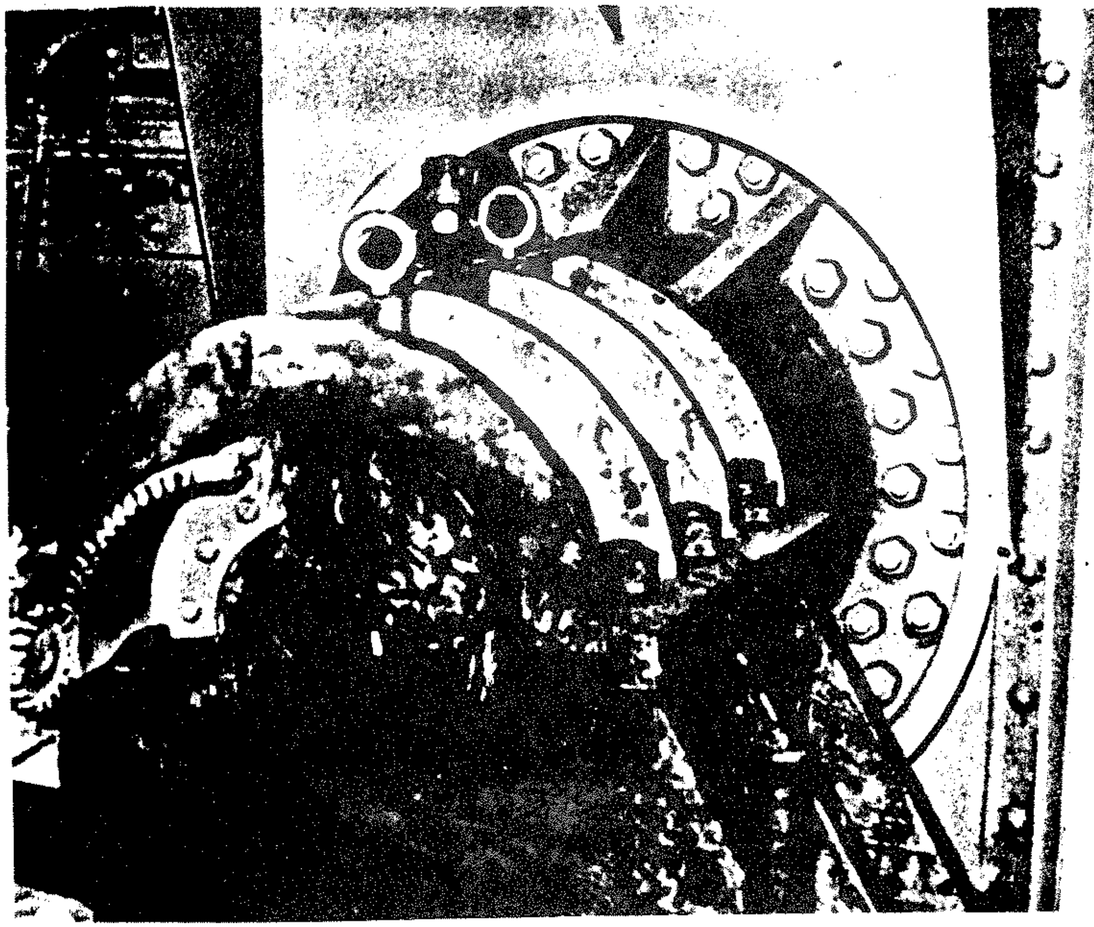


FIGURE 9

The examples discussed above represent some of the types of maintainability problems encountered on Florida's bascule bridges and have placed emphasis on establishing design policies for maintainability requirements. The importance of establishing a design policy becomes apparent with the visualization of the scope of Florida's rehabilitation program, which encompasses 39 bridges over the period of the next 2 and one-half years.

The following summarizes the Florida Department of Transportation's design policy for maintainability of bascule bridges.

> The technical policy of the Department is to incorporate provisions in the design of bascule bridges consistent with application of sound engineering principles and reasonable application of engineering judgment in trade-offs between initial construction costs and maintenance expenditures during the life of the bascule bridge.

Here in Florida, this policy is being implemented through the following Design Guide for Maintenability of Bascule Bridges. The policy is applicable to both new bridges and rehabilitation plans for existing bridges on which construction has not been initiated.

A copy of the Design Guide is appended to this paper. Detailed discussions of each element of the Guide will be omitted where the information is self-explanatory, or where previous paragraphs in this paper have provided information supporting the Design Guide.

Item 1 relates to design of trunnion bearings so that greater ease in replacement may be achieved. Specific requirements are: (a) capability for replacement with span jacked 1/2 inch, (b) incorporation of jacking holes or puller grooves to permit extraction, anc (c) split bearing housings with upper half removable without span jacking or removal of other components.

Item 2 establishes requirements for designing suitable jacking points into the structure for temporary support of the bascule span during special maintenance and inspection operations. Figure 12 describes the elements of the jacking system. These requirements result in capability for raising the span without installation of additional structure. The only additional hardware need to permit span jacking is hydraulic jacks.

Trunnion alignment (Item 3) requires a through hole for inspection. Work platforms will be installed to permit trunnion adjustment, and special tooling for trunnion alignment will be permanently stored at the bridge site for maintenance personnel.

Still another maintenability problem found on a number of Florida bridges relates to span locking provision. Three bridges currently under rehabilitation contracts are Whitehair bridge, located near Deland, Wilson Pigott, located near Fort Myers, and Jupiter Beach bridge. These bridges have employed cylindrical locking bars, as shown in Figures 10 and 11.

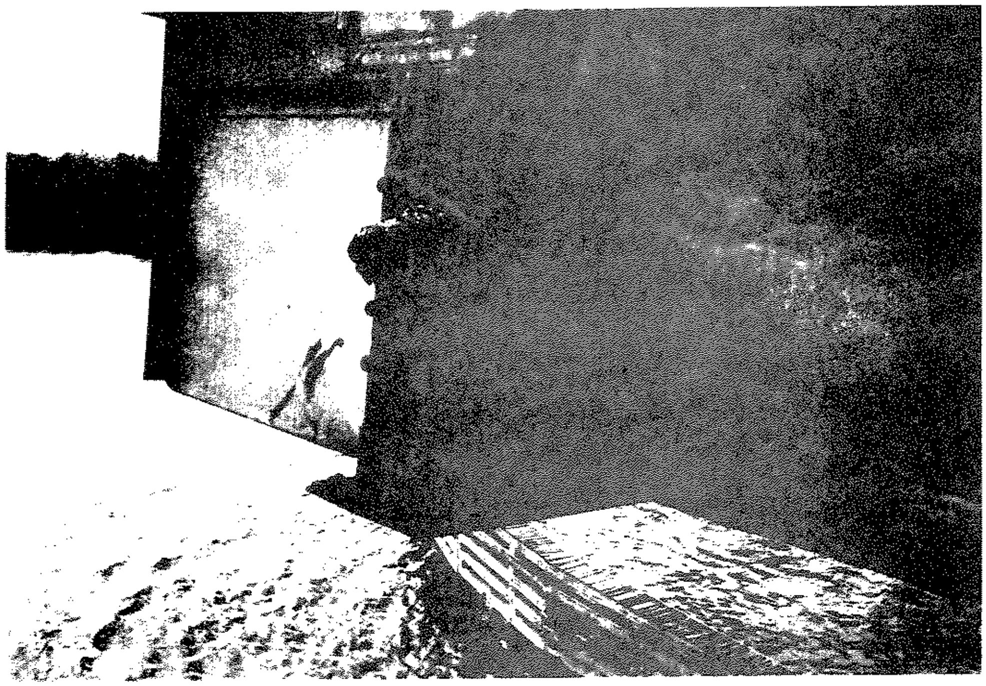


FIGURE 1[illegible]

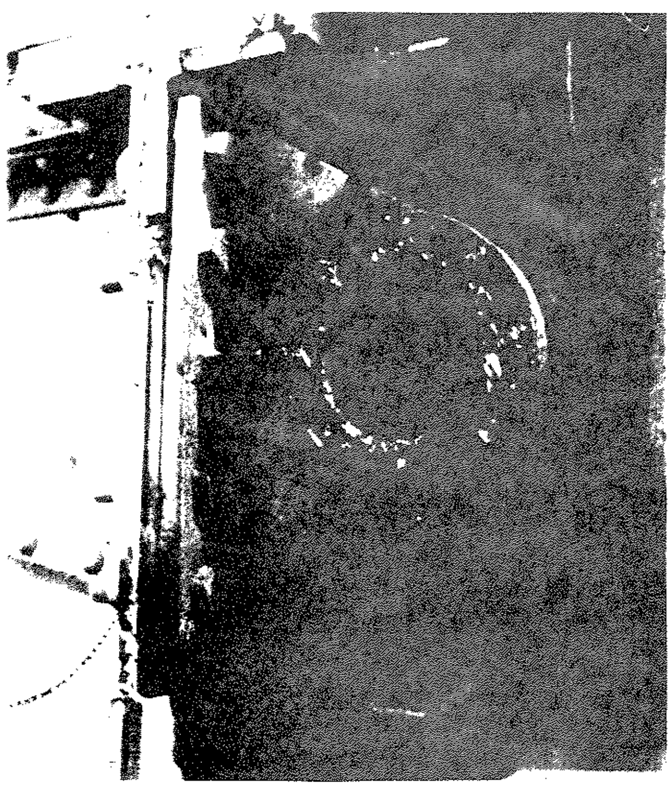


FIGURE 11

With long term wear, lock integrity deteriorates because of lack of provisions for adjustment to compensate for wear. Of course, the current state of the art will permit application of lockbar systems having rectangular sections, for which satisfactory wear adjustment can be accomplished by the owner's maintenance forces.

Item 4 of the Maintainability Design Guide describes features to be included in lock system designs. The requirements include: accessibility; work platforms for maintenance; capability of operating a single lock (in multiple lock systems) with the remaining lock disabled; operating clearances to be adjustable for wear compensation.

Lubrication Systems (Item 6) has been partially discussed in prior paragraphs. Additionally, consideration has been given to requirements for automated lubrication systems and self lubricating bushings.

Item 8, providing "on-off" capability for maintenance operations, has been found to improve ease of maintenance and assures greater safety for maintenance personnel. Note that a Florida maintenance worker's life was lost several years ago through lack of local switching capability; and, in another case, a worker lost an arm in an accident which could have been avoided with local switching capability.

Florida is introducing digital controls on new bridges and some existing bridges which are under the rehabilitation program, making possible the application of diagnostic instrumentation, system fault displays and automated data recording. (Item 13).

Introduction of digital systems has placed emphasis on training of personnel in operating and servicing these systems. Operaional training models have been designed and will be constructed in support of the training program.

Finally, maintainability can be enhanced by improvement of the conditions under which maintenance must be accomplished.

DESIGN GUIDE --- BASCULE BRIDGE MAINTAINABILITY

1. Trunnion Bearings

Trunnion bearings shall be designed so that replacement of bushings can be accomplished with the span jacked 1/2 inch and in a horizontal position. Suitable jacking holes or puller grooves are to be provided in bushings to permit extraction; jacking holes shall utilize standard bolts driving against the housing which supports the bushing.

Trunnion bushings and housings shall be of a split configuration; the bearing cap and upper half bushing (if an upper half bushing is required) shall be removable without span jacking or removal of other components.

2. Span Jacking

NOTE: the following definitions describe elements of the span jacking system shown on the attached sketch, Figure A:

a) Span jacking surface -- an area on the bottom surface of the bascule girder.

b) Span stabilizing connector point (forward) -- an area adjacent to the live load shoe point of impact on the bottom surface of the bascule girder.

c) Span stabilizing connector point (aft) -- an area at the rear end of the counterweight on the lower surface of the counterweight girder. (Note: for bascule bridges having tail locks, the span stabilizing connector point may be located on the bottom surface of the lockbar receiver located in the counterweight.)

d) Stationary jacking surfaces -- these surfaces are located on the bascule pier under the span jacking surfaces. The stationary jacking surfaces provide an area against which to jack for lifting the span.

e) Stationary stabilizing connector points are located on the bascule pier. These points provide a stationary support for stabilizing the span, by connection to the span stabilizing connector points.

One set of span jacking surfaces shall be located under the trunnions (normally, this will be on the bottom surface of the bascule girder); a second set shall be located on the lower surface at the rear end of the counterweight, as shown on the attached sketch, Figure A.

Span stabilizing connector points shall be located on the bascule girder forward and aft of the span jacking surfaces, as shown on the attached sketch, Figure A. Stationary stabilizing connector points shall be located on the bascule pier below the span stabilizing connector points. Connector points shall be designed to attach stabilizing structural steel components. (Note: Stationary jacking surfaces, located under the span jacking surfaces, shall be positioned at an elevation as high as practical so that standard hydraulic jacks can be installed. The maximum elevation of the stationary jacking surfaces shall be determined based upon required operating clearance between the fully opened span and stationary jacking surface.

3. Trunnion alignment features

Center holes shall be installed in trunnion shafting to measure and inspect trunnion alignment; span structural components shall not interfere with complete visibility through the trunnion center hole. Trunnions shall be individually adjustable for alignment.

A permanent walkway or ladder with work platform shall be installed to permit trunnion adjustment. Special tooling, such as trunnion adjust wrenches, shall be permanently stored for accessibility to maintenance personnel.

4. Lock systems

Center locks are to be accessible from the bridge sidewalk through a suitable hatch or access door. Under the deck, and in the region around the centerlocks, a work platform suitable for servicing of the lockbars shall be provided.

Lock systems shall be designed so that an individual lock may be disabled for maintenance or replacement without interfering with operation of other lockbars on the bascule leaf.

Tail locks shall be designed so that the lockbar mechanism is accessible for repair without raising the leaf. The lockbar drive mechanism shall be accessible from a permanently installed platform within the bridge structure. The lockbar mechanism shall drive in a direction parallel to the trunnion axis.

Lockbar clearances shall be adjustable for wear compensation.

5. Machinery drive systems

All machinery drive assemblies shall be individually removable from the drive system without removal of other major components of the drive system. For example, a speed reducer assembly shall be removable by breaking flexible couplings at the power input and output ends of the speed reducer.

6. Lubrication provisions

Bridge system components requiring lubrication shall be accessible without use of temporary ladders or platforms. Permanent walkways and stairwells will be installed to permit free access to regions requiring lubrication.

Lubrication fittings shall be visible, clearly marked and easily reached by maintenance personnel.

If specified by the Department, automatic lubrication systems shall be provided for bearings and gears. Designs for automatic lubrication systems shall provide for storage of not less than 3 months supply of lubricant without refilling. Refill will be accomplished within a period of 15 minutes through a vandal-proof connection box located on the bridge sidewalk clear of the roadway; blockage of one traffic lane during this period is permitted.

If specified by the Department, self-lubricating bushings will be incorporated in bridge designs.

7. Drive system bushings

All bearing housings and bushings in open machinery drive and lock systems shall utilize split bearing housings and bushings and shall be individually removable and replaceable without affecting adjacent assemblies.

8. Local Switching

"Hand-Off-Automatic" switching capability shall be provided for maintenance operations on traffic gate controllers and brakes and motors for center and tail lock systems.

"On-Off" switching capability shall be provided for maintenance operations on span motor and machinery brakes, motor controller panels and span motors.

Remote switches shall be lockable for security against vandalism.

9. Service Accessibility

A service area not less than 30 inches wide shall be provided around system drive components.

10. Service Lighting

Machinery and electrical rooms will be lighted as necessary to to assure adequate lighting for maintenance of equipment. Switching shall be provided so that personnel may obtain adequate lighting without leaving the work area for switching; master switching shall be provided from the control tower.

Each work area shall be provided with receptacles for supplementary lighting and power tools such as drills, soldering and welding equipment.

11. Communications

Permanent communications equipment shall be provided between the control tower and areas requiring routine maintenance (machinery drive areas, power and control panels locations).

12. Wiring Diagrams

Wiring diagrams shall be provided for each electrical panel inside the panel door. Diagrams shall be enclosed in glass or plastic of optical quality.

13. Diagnostic Reference Guide for Maintenance

Diagnostic instrumentation and system fault displays will be installed for mechanical and electrical systems. Malfunction information will be presented on control system monitors located in the bridge control house. Data will be automatically recorded. System descriptive information, such as ladder diagrams and wiring data, will be available on the system memory to enable corrective actions on system malfunctions and to identify areas requiring preventative maintenance.

14. Training models

The Bureau of Structures has prepared plans for operational models of movable bridges; an important application of the bridge models will be that of training both district maintenance personnel (electricians, bridge crews and bridge tenders) on span operations with new types of control systems.

Training models will be made available to consultants, upon request.

15. Automatic Lamp Changers (Navigation Lights)

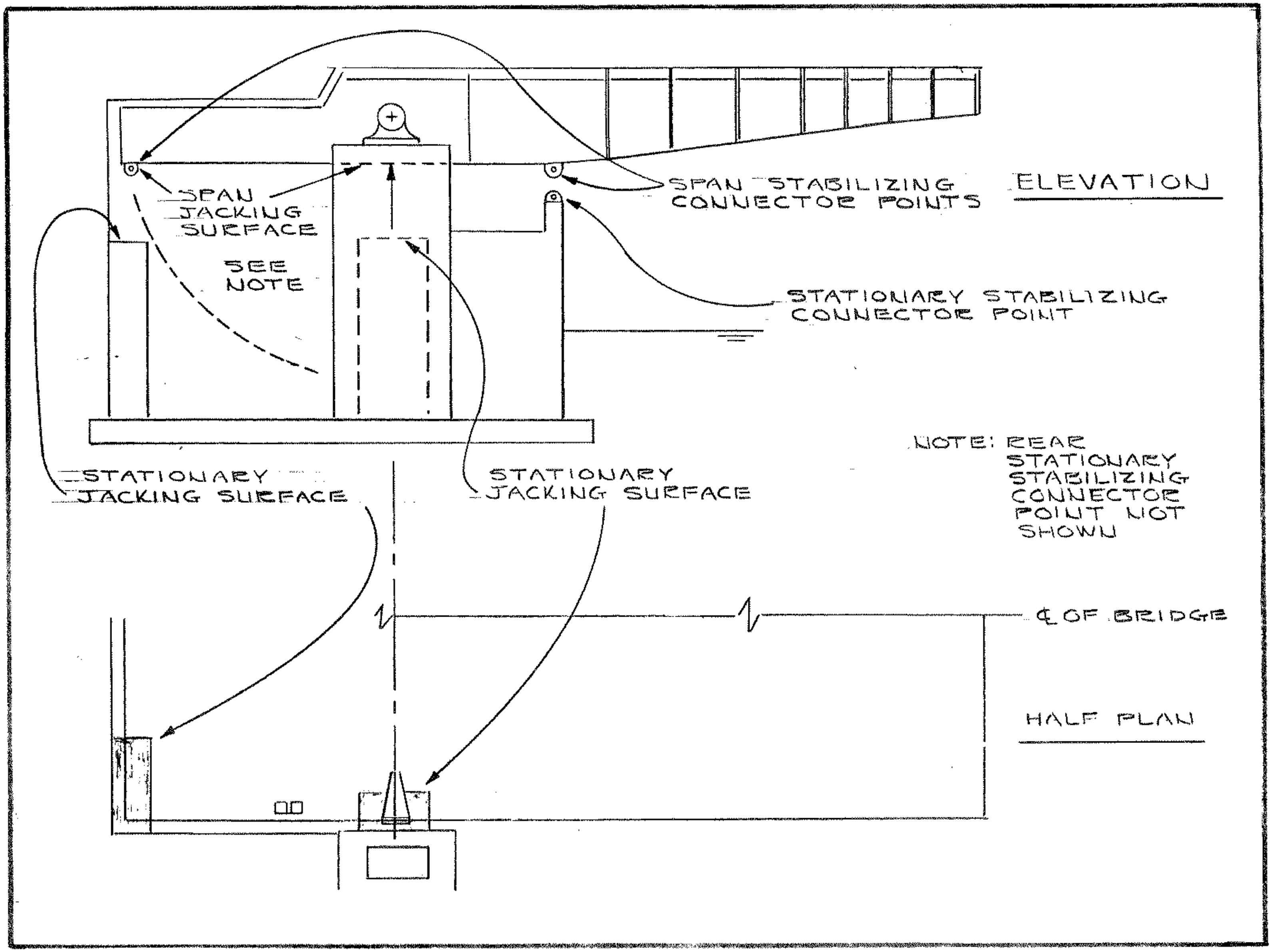
(Note: automatic lamp changers are already being installed for navigation lighting. This is a relatively recent development, and represents a good maintainability feature. For a rough approximation, a 4-lamp changer cuts maintenance to about 25%, while a 6-lamp changer drops to about 17%.)

Automatic lamp changers will be installed on fenders and center of channel positions to reduce effort required for maintenance of navigation lights.

16. Working Conditions for Improved Maintainability

(Note: Bascule bridge are often dirty and hot places for Department crews to perform their maintenance work. Machinery areas are covered with grease and bird droppings; roaches, mosquitoes and other insects abound; --also rats. An environment of this kind is not conducive to maintaining equipment. There are two alternatives: (a) clean up what's there, and keep it clean, or (b) install equipment enclosures and provide air conditioning. Air conditioning not only improves the comfort level; it will promote improved performance in required maintenance work.)

When specified by the Department, new and rehabilitated bascule bridge designs will call for enclosed machinery and electrical equipment areas. Enclosed areas will be air conditioned.



SPAN JACKING

FIGURE A

DOT PRESENTATION

"WORK ORDER SYSTEM"

1. IMC History of Computer Program

   - Production Cost Distribution (%)

   - Indexed Relative Cost Graph

2. Elements of Effective Maintenance Program

   - Maintenance Organization

   - Equipment Records

   - Work Order System

   - Lubrication Program

   - Preventive Maintenance Program

   - Job Planning

   - Effective Scheduling

   - Adequate Spare Parts

   - Work Measurement

   - Equipment History

   - Management Reporting

3. Maintenance Elements Unorganized

4. Maintenance Work Order System

5. Equipment Records

   - Numbering System
   - Equipment Descriptions
   - Sub-Assemblies
   - Specifications
   - Spare Parts Cross-Reference

6. Sources of Work Orders

   - Operator Complaints
   - PM Mechanic Check Sheets
   - Vibration Technician Reports
   - Outside Consultant's Vibration Reports
   - Oil Analysis Reports
   - Periodic PM Inspection Reports
   - Component Predictive Maintenance Program
   - Equipment Breakdown
   - Modification

7. Work Order Elements

   - Unique Number

7. Work Order Elements (con't)

- Equipment Number
  - Location
  - Equipment Class or Type
  - Equipment Number
  - Sub-Assembly
- Name of Requester
- Date of Request
- Time of Request
- Date Needed
- Crew to do Work
- Class of Work
  - Normal Repair
  - Preventive Maintenance
  - Moving and Alteration
  - Breakdown
  - Safety
  - Lubrication
- Priority
  - Normal Repair
  - Emergency
  - Turn-around
  - Urgent

7. Work Order Elements (con't)

   . Work Requested

   . Estimate

      .. Labor

      .. Material

      .. Outside Services

      .. Total

   . Approval Based on Estimated Cost

   . Work Done - Completion Date

8. Planning

   . Use of Parts Cross-Referencing

   . Pre-planned Jobs

   . Detailed Estimating

   . Manpower Requirements

   . Outside Services Requirements

9. Approval Procedure

   . Approval Level Depends on Estimate

   . All On-Line

10. Scheduling

11. Work Performance

12. Equipment History

    . Description of Work Done

    . Labor Detail

    . Material Detail

    . Outside Services

    . Total Cost

13. Management Reports

    . Labor Distribution

        .. By Work Order

        .. By Crew

        .. By Operating Location

        .. By Class of Work

    . Cost by Area

    . Cost by Equipment

    . Major Repair Cost

    . Productivity - Manhours per Unit