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THE COLUMBUS DRIVE BASCULE BRIDGE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS SECOND BIENNIAL MOVABLE BRIDGE SYMPOSIUM

presented by
James J. Powers, Vice President
Envirodyne Engineers, Inc.

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1. INTRODUCTION

Columbus Drive Bridge, one of the largest movable bridges in the world, is the longest and widest bascule bridge in the City of Chicago. The following paragraphs describe the planning and design of this new giant, and culminates with some unique aspects of its construction.

2. PLANNING

The Columbus Drive Bridge over the Chicago River is the main link between the new Illinois Central Air Rights and Streeterville Developments located in the heart of Chicago. The I.C. Air Rights development is located on the former Illinois Central Railroad Yard and is an 83-acre city within a city just northeast of the famous Chicago elevated "Loop".

To service the I.C. Development a multi-level roadway network was conceived by Chicago planners to segregate various traffic functions. The upper level provides access for local traffic, the intermediate level is for through traffic, and the lower level is utilized for deliveries. Columbus Drive, which is parallel to and halfway between Michigan Avenue and Lake Shore Drive, is the major, new, north-south, through street in the development. The Columbus Drive Bascule Bridge carries the intermediate level of Columbus Drive across the Chicago River.

To alleviate traffic congestion it was evident that a new Chicago River bridge would be required at Columbus Drive. So the Columbus Drive Bridge was conceived and became the first bascule bridge at a new Chicago River location in over 40 years.

As part of the I.C. Development two 90-degree turns along Lake Shore Drive have been eliminated. The new Columbus Drive extension was designed to provide a detour for traffic during this construction.

Traffic projections indicated that a six lane roadway, with provision for a left turn storage lane at the south end, would be required at the new river crossing. The resultant structure width of 111 feet includes an 86 foot roadway, a 4 foot median and two 10'-6" sidewalks. The span length of 269 feet was dictated by the 201 foot channel width, and the requirement for a promenade under the bridge at the south dockwall to connect portions of a planned riverfront park.

For river traffic the structure provides 21 foot vertical clearance for a width of 177 feet when the bridge is closed and infinite clearance for a channel width of 180 feet when fully opened. Reference is made to Exhibit 1 for General Plan and Elevation.

With the bridge located near the lake front, Grant Park and major new commercial and residential developments, aesthetics was considered to be of utmost importance. The highly visible lines of the bridge superstructure, bridge house, railings and counterweight enclosures were analyzed to develop a silouette which would complement the architecture of the buildings planned for the immediate vicinity. Color schemes and the use of granite facade were selected in order to make the bridge area more attractive.

3. DESIGN

After the planning for the bridge was completed by Transportation Planners of the City of Chicago, the design of the structure was begun by the City's Bureau of Engineering, Department of Public Works with the assistance of Envirodyne Engineers as design consultants. The design conforms to the AASHTO Specifications for Movable Highway Bridges, and additional specifications established by the City of Chicago for movable bridges.

In the following sections, various aspects of the design will be discussed, including substructure, superstructure, operating machinery, electrical systems, bridge house and enclosures, and the provision for strain and accelerometer gage instrumentation.

3.1 Substructure

The fixed portions of the bridge are supported by 46 caissons, 23 for each side, ranging in size from 4 foot to 7 foot in diameter. Belled caissons, founded on hardpan, were utilized at lightly loaded areas, such as under the counterweight pit enclosure walls. With the heavy loads from the trunnion support columns, and the possibility of settlement due to soil displacement caused by future adjacent construction, the counterweight pits are supported by caissons extended two feet into sound bedrock. For the general arrangement of the south pit refer to Exhibit 2.

The pits provide space for the counterweight when the bridge is in the raised position. The bottom of the pit floor is located 28 feet below grade and pit walls and floor are designed for a full hydrostatic head of water. Consequently the pits are massive concrete structures.

The pit river wall is seven feet thick at the base and its counterfort is 13 feet thick. The pit slab is 4'-6" thick. More than 11,600 cubic yards of concrete and 1.7 million pounds of reinforcement steel were used in the construction of the pits and caissons.

3.2 Superstructure

The movable part superstructure is composed of four welded box girders per leaf. The roadway deck is a five inch open steel grating system supported by stringers and floorbeams, which span between the box girders. To reduce the weight of the structure and to insure a minimum of differential deflection between adjacent box girders, the floorbeams are deep Vierendeel trusses. The sidewalk is a two inch, concrete filled grating supported by stringers and brackets cantilevered from the outside of the exterior box girders.

The fixed part superstructure is a reinforced concrete deck and stringer system supported on steel frames.

Comparing the Columbus Drive Bridge to other bascule bridges in the City of Chicago, one of the most notable features is the use of welded, deck-type, box girders rather than the more traditional through truss members.

During the early design phase, various truss and girder types were evaluated for the main movable support members. Due to the structural depth limitations created by the required channel height, it was found that use of two main girders or trusses was not feasible, since the 111 foot bridge width would require excessively deep floorbeams.

A comparison of the use of three or four main support members indicated that using three main members would reduce the fabrication and erection costs; however, the long floorbeams required would increase the total weight of structural steel. A cost analysis indicated that the increase in fabrication and erection costs of a four main member system is approximately equal to the cost of the additional steel required for a three member system.

An added advantage of a four main member structure is that additional trunnion girder columns can be located between the interior trusses or girders. With this arrangement the counterweight sections between the exterior and interior main support members could be full depth and only the center section of counterweight would have to be cut short to eliminate interference with the trunnion girder columns. To provide an effective counterweight in a three main member structure would require added cost in either supporting the trunnion bearings or modifying the counterweight to notch around interior trunnion columns. For these reasons a four main support member structure was selected.

Various truss and girder types were considered for the main support members. Pratt and Warren trusses have been used extensively for bascule bridges and have proven to be economical. However, due to the structural depth limitations created by the channel height, a through truss design with the upper chords penetrating the deck would be required. This would create a safety hazard to traffic, reduce sight distance, especially for turning vehicles, and detract from the appearance of the structure. Therefore, to design an aesthetically pleasing structure with adequate clearance for river traffic under the bridge, but without the hazardous trusses projecting above the deck, it was decided that four box girders located completely under the deck would be utilized to support each leaf.

To minimize field erection operations and to provide an aesthetically pleasing structure, each box girder is divided into two segments, the river arm and the anchor arm. These segments are bolted together at one field splice connection with is located at the live load bearing and completely hidden from view by the fixed bridge enclosure. This connection required 484 1-1/4 inch diameter A490 and 74 7/8 inch diameter A325 high strength bolts. Because of the size of the bridge and uniqueness of the design, an investigation was made to determine the feasibility of constructing such a structure. The outcome of the investigation was the Steel Erection Sequence shown in Exhibit 3. Modern shop fabrication methods combined with closer than normal quality control requirements made this single connection girder design possible.

The river arm segments cantilever 121 feet over the river and provide support for the movable roadway and sidewalks. The river arms are 2'-6" wide and vary in depth from four feet at the center break to 22 feet at the live load bearing. The flange plates are from 1-1/2 to 3 inches in thickness and the web plates vary from one to two inches. Each river arm weights 92 tons.

Located at the center of each anchor arm is the 24 inch diameter trunnion or central pivoting point about which the leaf rotates. The anchor arm segments also support the counterweight boxes and the rack gears which are used to drive the bridge.

Because the anchor arm assembly is actually a rigid frame, there was concern that residual stresses would be induced by welding, especially if full penetration welds were required. A study of the residual stresses was made and it was determined that partial penetration welds would be advantageous for certain portions of the box girder. The use of partial penetration welds not only reduced the fabrication costs by also resulted in a reduction of total stress, particularly in some of the critical members of the anchor arm. Plate thickness in the anchor arm vary from one to four inches and each anchor arm segment weighs 97 tons.

Design of the fixed part of the superstructure included studies of alternative methods of supporting the main trunnion bearings and the approach spans from project limits to the rear break of the movable leaves.

Studies of systems for supporting the main trunnions included longitudinal S-girders for each interior trunnion bearing and a common cross girder supporting all trunnion bearings. The S-girder, which derives its names from its general shape in elevation, would support the trunnion by spanning from front to back of the counterweight pits. With a movable leaf consisting of four main trusses or girders, six S-girders would be required for each leaf. The outer trunnions would be supported on braced columns. Due to the span requirement of 47 feet from front to back of the counterweight pits, the S-girder support systems proved to be uneconomical.

The cross girder trunnion support system, which was selected, supports the main trunnion bearing directly on box girders, which pass through the main support members of the movable leaves. The trunnion girders are supported by two columns located between the two interior girders and another two columns embedded in the side walls of the counterweight pit. Sub-piers are located under each column to transmit the load directly to bedrock.

The common practice in bascule bridge design is to leave an open joint at the center and rear breaks in the roadway and sidewalks. However, the Columbus Drive Bridge uses an innovative method of sealing the rear breaks, prohibiting water and deicing salts from corroding the steel framework and pit substructure. At the center break, a unique hinged and spring loaded transition plate spans the opening and provides positive contact to the adjoining leaf in the closed position. These designs eliminated the open gap at the center and rear breaks.

All structural elements were fabricated from ASTM A588 steel because of its high strength and weathering characteristics. A total of more than 12.6 million pounds of steel is incorporated into the movable parts. The bascule leaves are counter-balanced by 3,000 tons of heavyweight concrete and 700 tons of steel and cast iron blocks.

As an added corrosion deterant, all structural steel received one shop coat and two field coats of an acrylic latex emulsion paint. The final coat is dark bronze.

3.3 Operating Machinery

The design of the operating machinery included evaluation of various types of drive systems, racks, bearings, and center locks.

The drive systems considered were conventional open spur gear trains and helical or herringbone gear speed reducers. An open spur gear train with two parallel shafts between the rack pinion shaft and the motor shaft along with the large gears requires a large amount of space within the counterweight pit enclosure and an extensive maintenance program. On the other hand speed reducers operate in a totally enclosed oil bath resulting in higher efficiency, better reliability and less maintenance. The drive system was, therefore, designed with a speed reducer.

The feasibility of using an exterior circular rack on the bottom chord rather than an interior circular rack was investigated. The exterior location would protect the rack and pinion from damage due to objects becoming lodged in the teeth; however, the main drive machinery would have to be placed at a lower elevation thus subjecting the machinery to a greater risk of flood damage. Therefore, an interior rack location was selected.

Both journal and anti-friction types of trunnion bearings were considered. Conventional journal trunnion bearings have proven most satisfactory in the past with normal maintenance. Anti-friction trunnion bearings provide smaller friction forces; however, the friction forces are relatively unimportant in that the main motor design is determined principally by wind forces. Therefore, the additional cost of anti-friction bearings was not considered justified, and journal type trunnion bearings were utilized.

Various types of center locks were evaluated including jaw type and bolt type. The bolt type centerlock was selected because of the larger bearing area to carry the unbalanced forces and the fact that there are fewer moving parts to maintain.

3.4 Electrical Power and Control

One of the main considerations in the design of the electrical systems, was reliability of bridge operation. Possible sources of normal and standby service on the south side of the river and an alternate service on the north side were investigated. The electric utility company agreed to provide two sources of 12KV AC power and 750 KVA transforming equipment on the south side of the river. These sources serve as the main 480 V normal and standby services for the north and south leaf power centers. Because of the advantage of locating the bridge controls near the main power sources, the single bridgehouse was located on the south side of the river. To provide power and control for the north half of the structure, the leaves are electrically connected by submarine power and control cables buried under the river bottom. A single 350KVA, 480V power service was provided on the north side as an emergency interlocked power source for driving the bridge's auxiliary AC motors, which were installed on both the north and south leaves.

In view of the availability of three power sources engine-generator auxiliary power equipment was not provided.

AC motors were selected for the bridge's two 150 hp drive motors on each leaf because of the availability of reliable solid state AC variable speed drives of the Thyristor type. This gives the wound rotor motors speed control characteristics similar to that obtained with DC drives, without the DC drives high resistor power losses and maintenance costs. In addition, the 150 hp Ac wound rotor drives were easily interfaced with a conventional step controller for manual operation of the motors in the event of Thyristor control failure. Two 40 hp AC manually controlled motors were provided on each leaf as back-up in the event of failure of the main 150 hp motors or control system.

The bridge is operated by one bridgetender from a control console in the south bridge house. The bridgetender can operate the 150 hp main motors automatically and has the ability to manually operate the bridge, should the automatic controls fail. In the event that the 150 hp motors or their controllers fail, the bridgetender can then operate the bridge with the two 40 hp auxiliary motors and controllers provided on each leaf. If control of the north leaf is lost at the main south leaf control console, an emergency control panel has been provided in the north leaf sidewalk deckhouse for the operation of the leaf by a second operator.

After the bridge was constructed final adjustments to the thyristor control system were made by Dr. Loren F. Stringer of Stringer Power Electronics Corporation to provide synchronous operation of the two motors that drive each leaf.

3.5 Bridge House and Enclosures

Studies of the bridge enclosures included consideration of the number of bridge houses along with construction details dictated by space requirements. Aesthetics and durability for both the bridge house and counterweight pit enclosures were the prime factors in the final choice of materials and details.

The possibility of a bridgehouse on both sides of the river was evaluated. Due to the highly sophisticated bridge control system only one bridge house was required from an operations standpoint, whereas aesthetics tended to prefer the two bridge house design. With form following function, the single bridge house alternate was selected.

The bridgehouse was located on the south side of the river, since this is where the main electrical power sources are provided. For access to the north counterweight pit from street level, a small stairway enclosure was included.

The counterweight pit enclosures contain the power load center rooms, an electrical transformer vault, operating machinery areas as well as a garage and work storage areas. Various stairways and entrances were provided for access to locations such as the machinery, trunnion girders and bearings, transformer vault and channel lights.

3.6 Strain and Accelerometer Gage Instrumentation

One of the unique features incorporated into this bridge is the provision for the installation of a system of strain and accelerometer gages. Bending and axial gages can be positioned along the box girders to determine the actual stress in these members under various loading conditions. In addition, the pinion shafts can have torque gages mounted on them. These gages would provide an indication of the bridge's state of balance and aid in the balancing of the structure.

The accelerometer gages, which would be mounted at the ends and near the live load bearings of each box girder, could determine lateral distribution of counterweight balancing blocks and ascertain a change in stiffness or strength of the box girders which may result from deterioration or from a collision with a ship. Accelerometer readings are taken by raising the bridge a few inches and allowing it to drop onto the live load bearings. The acceleration of this first mode vibratory motion would be recorded and analyzed. Differences in readings between box girders and from earlier recordings would indicate a change in balance or stiffness of a member.

To determine to total stress in a member, the dead load and fabrication stresses had to be measured independently, since the strain gages would not be installed until after the bridge was erected. This was accomplished by measuring the dead load strain in each member with a mechanical strain gage positioned at pilot holes drilled in the sides of the unloaded members. These measurements could be added to the electrical strain gage readings, to arrive at the total stress in a member.

4. CONSTRUCTION

Construction commenced in the summer of 1980 with Paschen Contractors, Inc. as the general contractor.

Acting as subcontractor, the American Bridge Division of U.S. Steel Corporation fabricated and erected all structural steel required on the project. The steel was fabricated at their plant in Ambridge, Pennsylvania and loaded on barges for delivery to Chicago.

Earle Gear and Machine Company located in Philadelphia, Pennsylvania was selected as subcontractors for the machinery fabrication.

4.1 Substructure

Most bascule bridge pits are constructed within the confines of a watertight cofferdam. Because of the setback from the dockwall created by the pedestrian promenade, the existing watertight dockwall was utilized as a cofferdam, resulting in considerable cost savings.

4.2 Superstructure

The anchor and river arm sections were erected by a 150 ton capacity derrick, mounted on twin barges. In order to control the final fitting of the members, tethers constructed with block and tackle were employed.

River traffic was maintained during construction by erecting the box girders in the open position. The girders remained in the open position until auxiliary drive motors were operational. A daily routine was then developed that consisted of lowering one leaf in the morning, erecting floor system members while the concrete counterweight was placed and then raising the leaf in the evening. THis procedure continued until the bridge was completed.

4.3 Construction Sequence

The introduction of a field splice in the lower chord member of the anchor arm frame slightly modified the originally planned construction sequence.

The original plan was to mount the anchor arm sections onto the pit floor and then thread the trunnion cross girders through the anchor arm frames.

By providing a field spliced member into the frame, the anchor arms could be slipped around the trunnion cross girders.

4.4 Construction Tolerances

Because the box girders could be adjusted only at the single connection between the river and anchor arms, special construction tolerances were specified.

A constant check of alignment between the two bridge leaves resulted in a near perfect fit when both leaves were lowered for the first time.

5. CONCLUSION

The Columbus Drive Bridge was dedicated on October 18, 1982 to the memory of Chicago Police Officer William T. Fahey, who died as the result of a gunshot wound received in the line of duty.

The new bridge was officially opened to traffic on October 31, 1982, 5 months ahead of schedule. The cost of the bridge was $33,000,000, which was paid by a grant from the Federal Highway Administration with a local share from the State of Illinois.

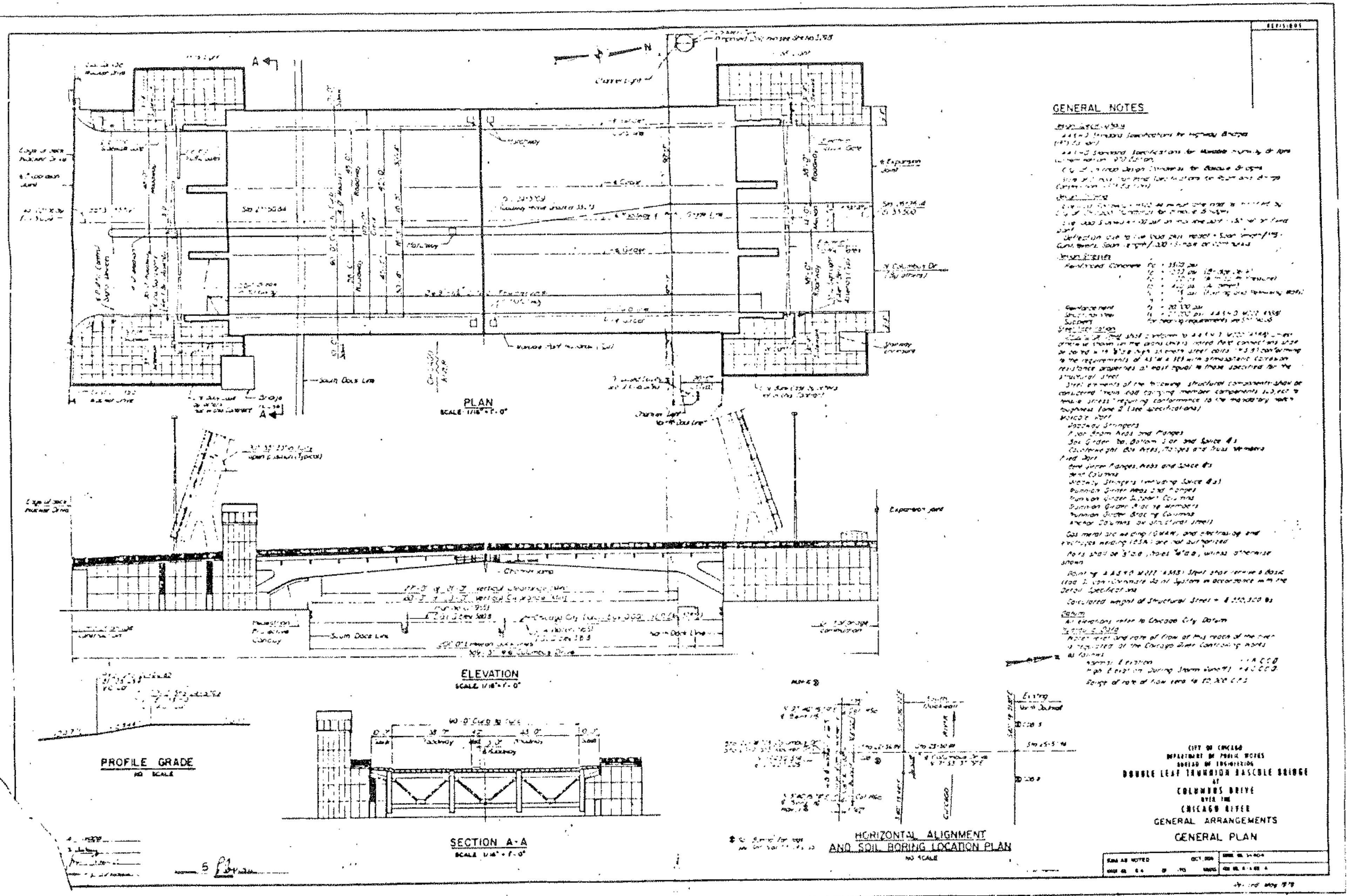
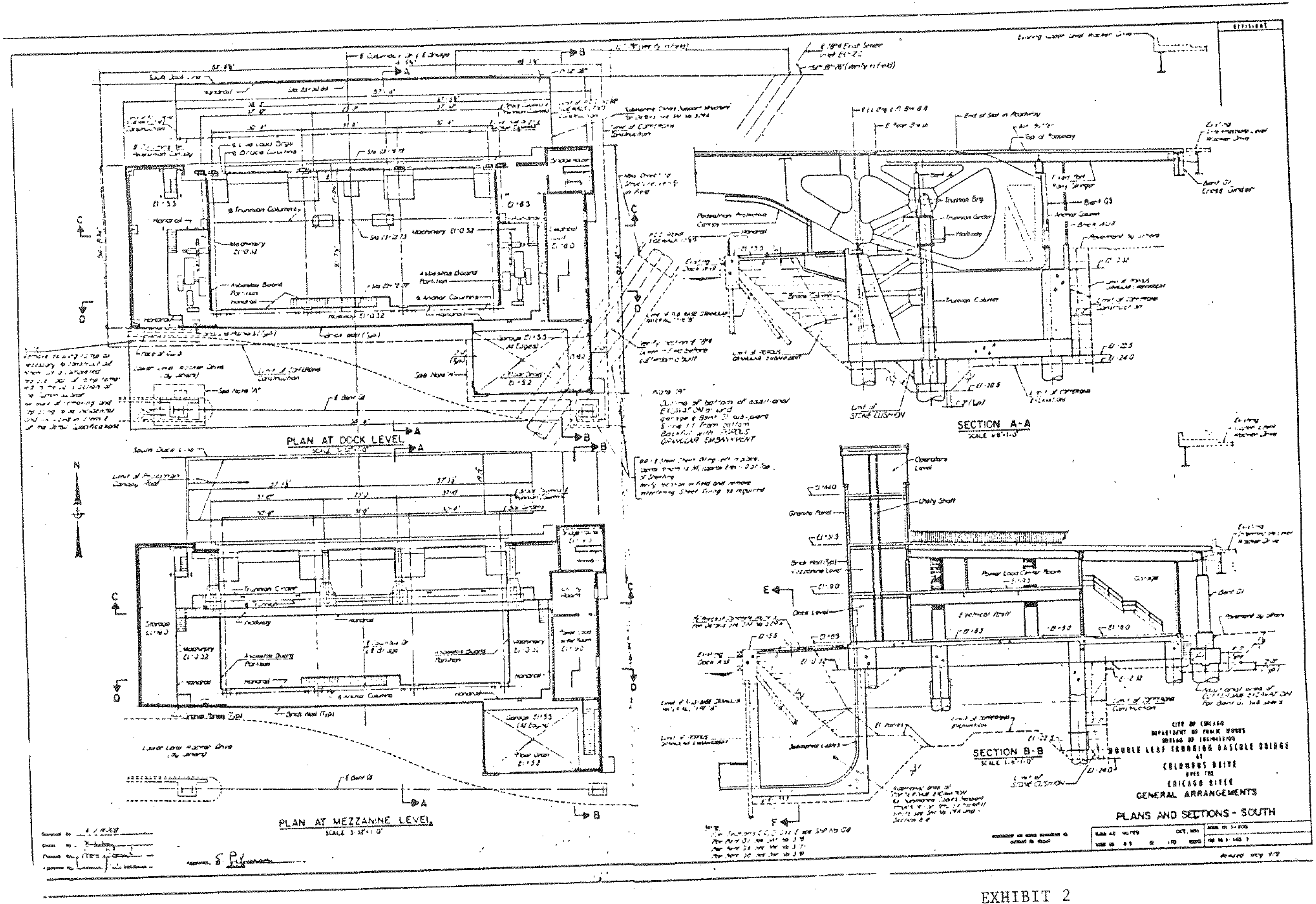

GENERAL NOTES
PLAN
SCALE 1/16" = 1'-0"
ELEVATION
SCALE 1/16" = 1'-0"
SECTION A-A
SCALE 1/16" = 1'-0"
PROFILE GRADE
NO SCALE
HORIZONTAL ALIGNMENT AND SOIL BORING LOCATION PLAN
NO SCALE
South Dock Line
North Dock Line
Channel Light
Expansion Joint
Roadway
Chicago City Datum
All elevations refer to Chicago City Datum
CITY OF CHICAGO
DEPARTMENT OF PUBLIC WORKS
BUREAU OF ENGINEERING
DOUBLE LEAF TRUNNION BASCULE BRIDGE
AT
COLUMBUS DRIVE
OVER THE
CHICAGO RIVER
GENERAL ARRANGEMENTS
GENERAL PLAN
SCALE AS NOTED

EXHIBIT 1



CITY OF CHICAGO
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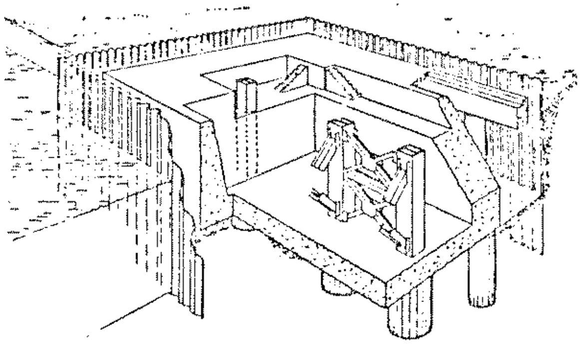
BUREAU OF ENGINEERING
DOUBLE LEAF TRUNNION BASCULE BRIDGE
AT
COLUMBUS DRIVE
OVER THE
CHICAGO RIVER
GENERAL ARRANGEMENTS

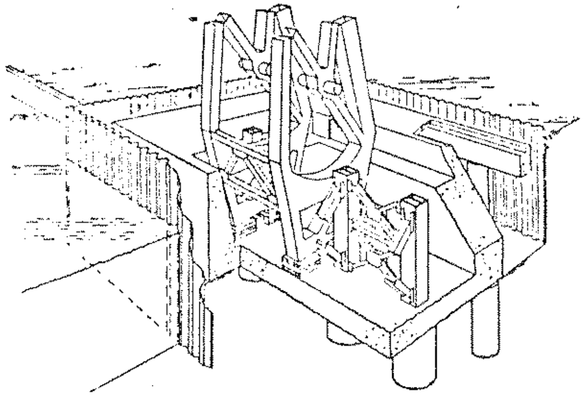
PLANS AND SECTIONS - SOUTH

EXHIBIT 2



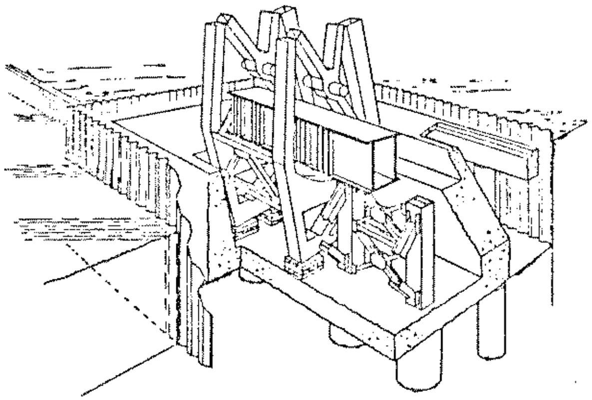
STAGE 1

CONSTRUCT FOUNDATIONS
AND PLACE COLUMNS



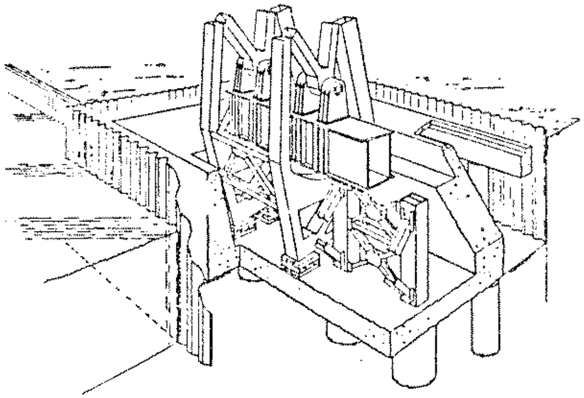
STAGE 2

PLACE ANCHOR ARMS
AND ADJUSTABLE SUPPORTS



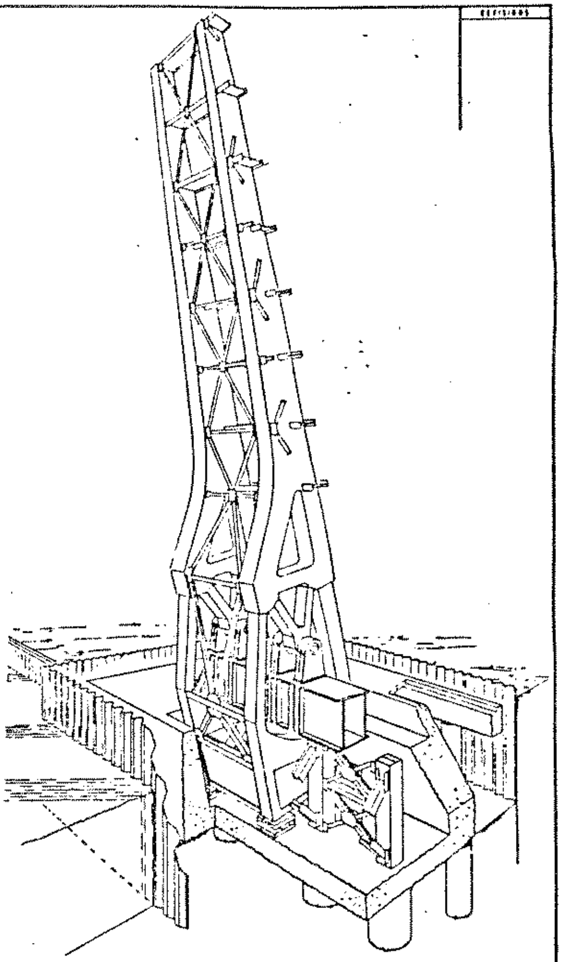
STAGE 3

INSTALL TRUNNION GIRDER
THROUGH ANCHOR ARMS



STAGE 4

POSITION TRUNNION BEARINGS
AND SEAT TRUNNIONS



STAGE 5

CONSTRUCT COUNTERWEIGHT
AND ERECT RIVER ARM

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DOUBLE LEAF TRUNNION BASCULE BRIDGE
AT
COLUMBUS DRIVE
OVER THE
CHICAGO RIVER

STEEL ERECTION SEQUENCE

Designed by
Drawn by RCT
Checked by AJH
Approved by JJP

Approved

EXHIBIT 3