THE FIRST BIENNIAL
SYMPOSIUM AND EXHIBITION
ON
MOVABLE BRIDGE
DESIGN AND TECHNOLOGY

THE DEVELOPMENT OF THE HYDRAULIC SYSTEMS DESIGNED FROM 1965 TO THE STATE OF THE ART HYDRAULIC SYSTEMS OF TODAY

BY
JOHN A. SCHULTZ, JR.

DEDICATION

This Paper is dedicated to Mr. Rudolph Timmerman, our ingenious Chief Mechanical Engineer. Mr. Timmerman retired in 1980. His practical application of sound engineering principles led to the successful completion and operation of our first six hydraulically operated movable bridges. I am proud to have been associated with him and to be able to call him "My Friend".

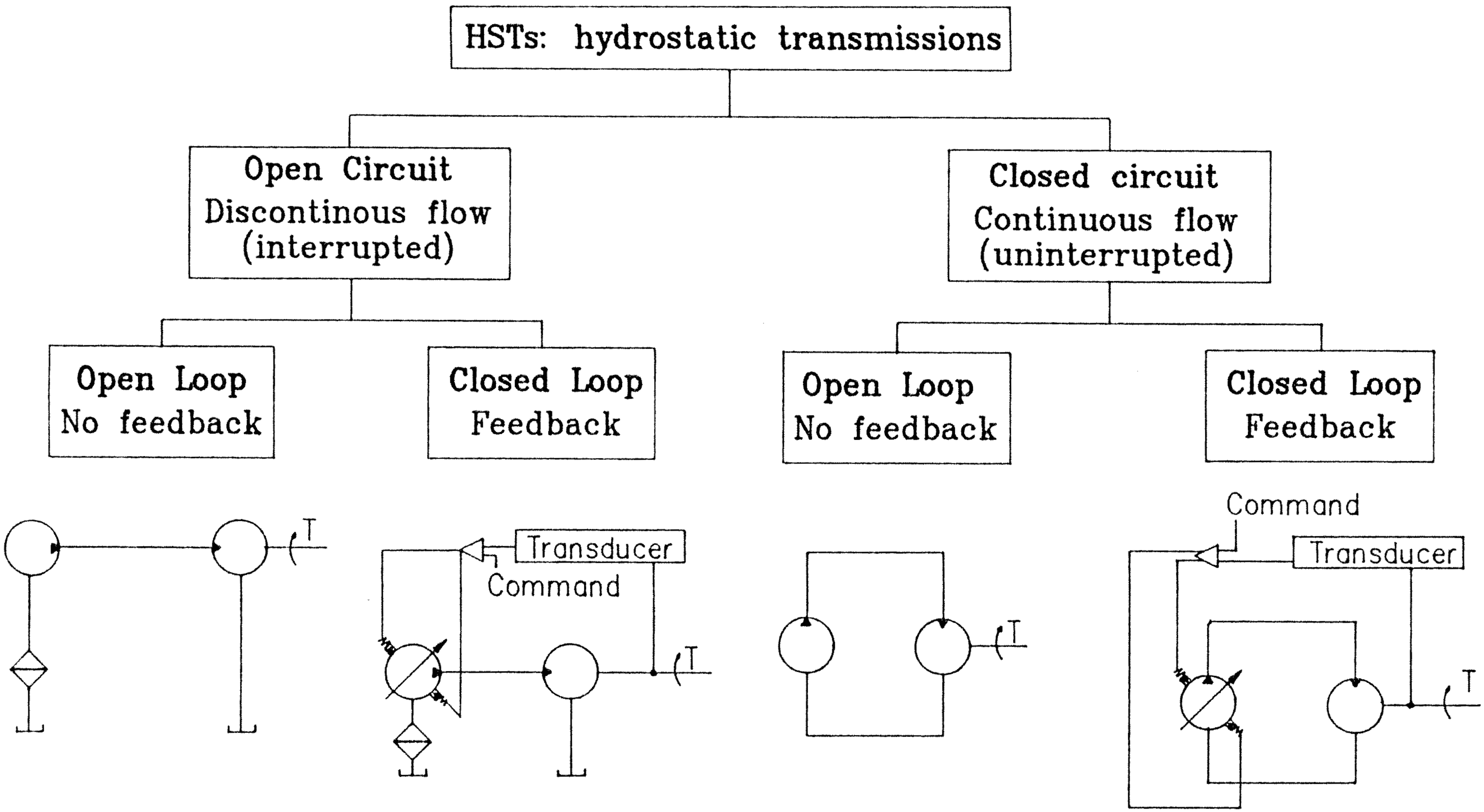
SUMMARY OF HYDRAULIC SYSTEMS DESIGNED

The types of hydraulic systems available are outlined on Page 2. All six of the hydraulically operated bridges currently in operation are listed on Page 14.

The first four bridges were open-circuit open-loop hydraulic systems, which required the operator to manually monitor the speed of the moving leaves and to control the acceleration and deceleration. The fifth and sixth bridges in St. Joseph and St. Clair, Michigan were closed-circuit open-loop hydraulic systems, which also required the operator to manually monitor the speed of the moving leaves and to control the acceleration and deceleration.

The three hydraulically operated bridges that have been designed in 1985 are listed on Page 27. They are closed-circuit closed-loop hydraulic systems. After the operator has manually lowered the traffic gates and cleared the bridge of pedestrians, they have pushbutton automatic operation. Pushbutton operation has been made practical by the application of state of the art equipment.

The shear locks used at the center of the span on the rolling lift bascule bridges have no moving parts. Therefore, they must be engaged before the moving leaves are fully closed and slide into place as both leaves simultaneously reach the fully closed position. Automatic operation requires that continuous precise indication of the location of each leaf must be Input to the Programmable Logic Controller (PLC). The PLC is programmed to make all necessary adjustments in its' Output to the moving leaves to bring them together at the fully closed position. The rear locks are then driven, the brakes are set and the traffic gates raised automatically. The operator must turn the control switch to OFF.



Four Basic HST Configurations

DEVELOPMENT OF THE HYDRAULIC SYSTEMS

The first two bridges were designed with no mention of hydraulic operation of movable bridges in either AASHTO Movable Bridge Specifications or in AREA Manual, Chapter 15, Part 6 Movable Bridges. The Joint Industrial Conference (JIC) Specifications were used as a guide along with much research and meetings with manufacturers.

In the 1970 Edition of AASHTO Movable Bridge Specifications included one paragraph on hydraulic pressure limits and rating of equipment. This Paragraph 2.5.18 "Power Hydraulic Systems" is copied hereinafter for your reference (see Page 4).

The next four bridges were designed after continued research and with the helpful manufacturers' representatives. The problems that came up becuase of the Contractor's lack of understanding of the application of the systems to movable bridges indicated that a comprehensive specifications for the design, fabrication and construction was needed.

As a member of AREA Committee 15, the author, stated at a meeting that we had four highway bridges and two railroad bridges in operation, but the word hydraulic was not even mentioned in Chapter 15 Specifications. You know the response, the author was asked to take on the task of writing the specification needed with the Movable Bridges subcommittee reviewing and developing the final draft for vote of approval by the full committee. After three years of continued research and the help of my associate, George N. Pavlakis, the specifications were approved and included in the 1984 Edition. A copy of Articles 6.4.8.1 "Allowable System Pressures" and 6.4.8.2 "Pressure Ratings for Hydraulic Components" are copied hereinafter for your reference. This is only a very small portion of the total specifications covering Hydraulic Systems (see Page 5).

During the development of the AREA specifications an in-house study was made to see how large a rolling lift bascule bridge could be economically operated by hydraulic cylinders. The longest single leaf rolling lift railroad bridge in the U.S. (shown on Page 7) would have taken tremendous cylinders that would make it completely out of the question. The author gave George N. Pavlakis the assignment of developing a system that could economically be used on any size bridge. As the results of his extensive research, a system was developed which would utilize the latest state of the art equipment used in industry but not yet applied to movable bridges. A layout of one-half of the hydraulic drive for one leaf is shown on Page 9. The system was presented to the Wisconsin Department of Transportation, their Green Bay District and the City Engineer of Manitowoc, Wisconsin, who all gave their approval to use it on the proposed US-10 (Southbound) bascule bridge in Manitowoc.

DEVELOPMENT OF THE HYDRAULIC SYSTEMS (Cont.)

The use of Programmable Logic Controllers (PLC) for the automatic control of the moving leaves also provided the capability for so much more at very little additional cost. A complete monitoring, self-diagnostic, and data acquisition system had also been included in the package that had been approved for the proposed bridge in Manitowoc. The hydraulic system parameters, that are monitored with diagnostic messages displayed and printed, is shown on Page 11. The Data Acquisition System (DAS) is outlined on Page 12. A Basic Closed-Circuit Closed-Loop Hydrostatic Drive is shown on Page 10.

Plans for two rolling lift bascule bridges in the City of East Chicago, Indiana, for the Indiana State Highway Commission had been completed several years earlier. A proposal was made to update the operation of these two bridges to the State of the Art Hydraulic Systems of Today, and was accepted. The Plans for US-12 and 20 were completed several months ago and the Plans for SR912 are now being updated.

AASHTO STANDARD SPECIFICATIONS FOR MOVABLE HIGHWAY BRIDGES - 1978

2.5.18.- Power Hydraulic Systems

The working pressure of hydraulic systems shall preferable be limited to 1,000 psi (6,895MPa), with relief valves set at 100 psi (.690MPa) above the working pressure. All piping, valves, cylinders, and other equipment shall be designed for 2,000 psi (13,790MPa) service at 100±F (37.8±C). The pump shall have a continuous pressure rating of 120 percent of the specified working pressure with sufficient volume to open the span in the required time, including acceleration and deceleration.

6.4.8 - Hydraulic Systems and Components

6.4.8.1 Allowable System Pressures

(a) The hydraulic system shall be designed and hydraulic components proportioned such that the maximum allowable system pressures shall not exceed the following, except as otherwise permitted by prior written approval of the Company.

Normal operation.	1000 psi
Operation against maximum specified loads.	2000 psi
Holding against maximum specified wind loads.	3000 psi

(b) Normal operation shall be defined as operation against Condition A loads specified in Art. 6.3.6. Operation against maximum specified loads shall be defined as operation against Condition B & C loads specified in Art. 6.3.6. Holding against maximum specified wind loads shall be defined as holding the movable span in the fully open position, static condition, against the loads specified in Art. 6.3.6(e).

6.4.8.2 Pressure Ratings for Hydraulic Components

(a) Minimum working pressure ratings for hydraulic components shall be as follows, except as otherwise permitted by prior written approval of the Company.

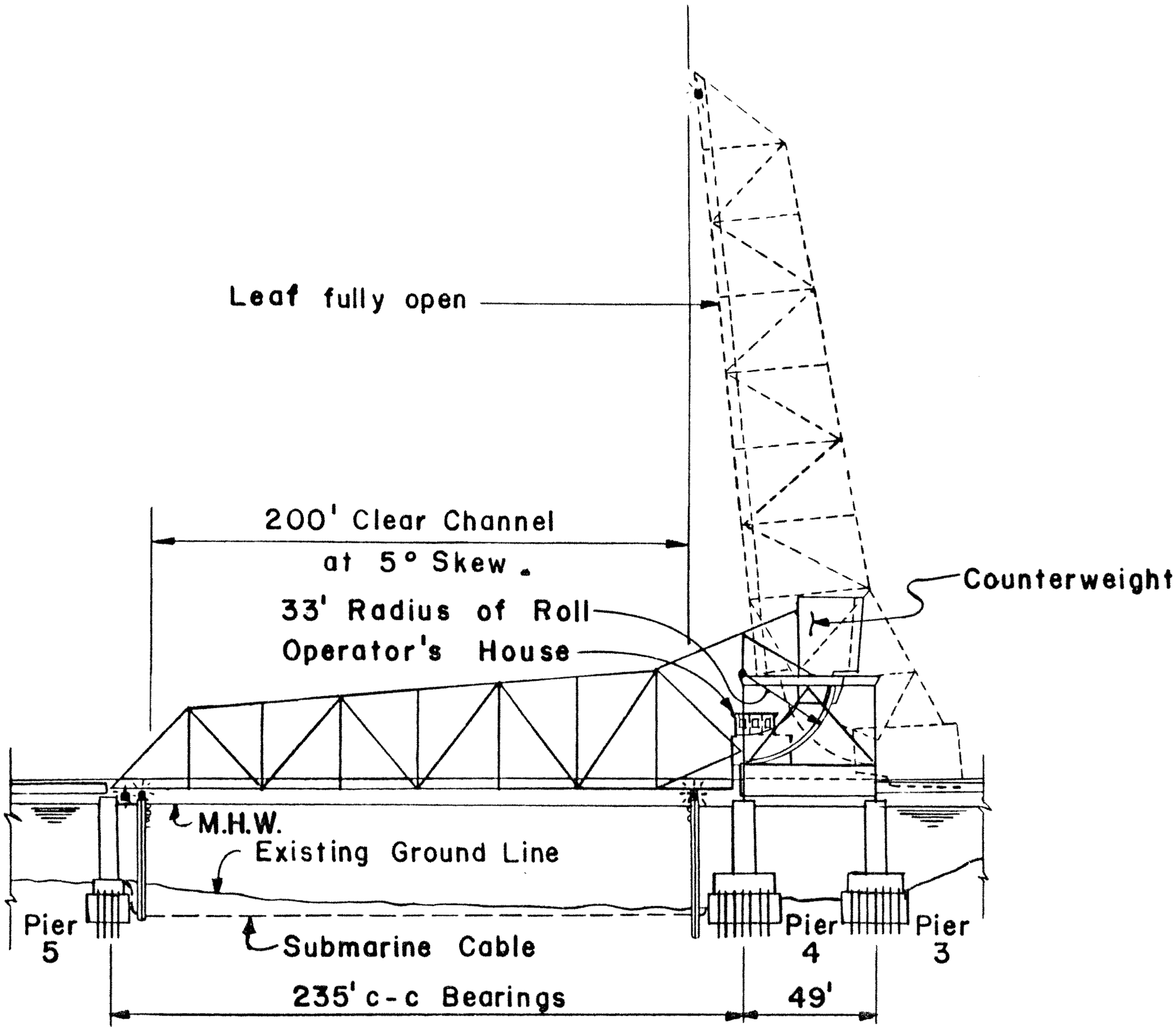
Pipe, tubing and their fittings:	3000 psi
Flexible hose and hose fittings:	
For pressure lines	5000 psi
For drain lines	2000 psi
Cylinder, pumps, valves and all other components:	3000 psi

(b) Working pressure rating shall be defined as the maximum continuous operating pressure for the component. For pipe, tubing, flexible hose and fitting the working pressure ratings are equal to the burst pressure rating divided by a minimum factor of safety of 4. For cylinders the working pressure rating shall be equal to the NFPA theoretical static failure pressure rating as required by Art. 6.5.37.11 divided by a minimum factor of safety of 3.33. For pumps, valves and other components the working pressure rating is equal to the maximum allowable peak (intermittent) pressure rating divided by a minimum factor of safety of 1.5.

(c) The minimum factors of safety designated in paragraph (b) apply to systems having light to moderate operating shock loads during operation resulting in short duration peak system pressures no greater than two times the allowable maximum operating pressure against Conditions B or C loads, whichever is greater. For systems having higher shock load pressures, the factors of safety shall be increased proportionally.

DRIVE COMPARISON

FEATURE	DC ELECTRIC	AC ELECTRIC	LSHT HYDRAULIC
CONTROL TYPE	SOLID STATE RECTIFIER	SOLID STATE INVERTER	SOLID STATE SERVO
CONTROL RELIABILITY	EXCELLENT	GOOD	EXCELLENT
SPEED REGULATION	EXCELLENT	GOOD	GOOD
RESPONSE TIME (TORQUE/INERTIA RATIO)	FAIR	FAIR	EXCELLENT
SPEED RANGE	EXCELLENT. TO 0 RPM	GOOD. 20 TO 1	EXCELLENT. TO 0 RPM
DYNAMIC BRAKING	OPT.	OPT.	STD.
REGENERATIVE BRAKING	OPT.	OPT.	STD.
INSTALLATION FLEXIBILITY	POOR	POOR	GOOD
SPEED REDUCER	YES	YES	NOT REQUIRED
ENVIRONMENTAL	FAIR	GOOD	EXCELLENT
ELECTRIC MOTOR COST	HIGH	LOW	LOW
ELECTRIC MOTOR MAINTENANCE	MODERATE	LOW	LOW
SYSTEM FIRST COST (HARDWARE ONLY)	\$190,000	\$170,000	\$150,000



Single Track RailRoad Bridge

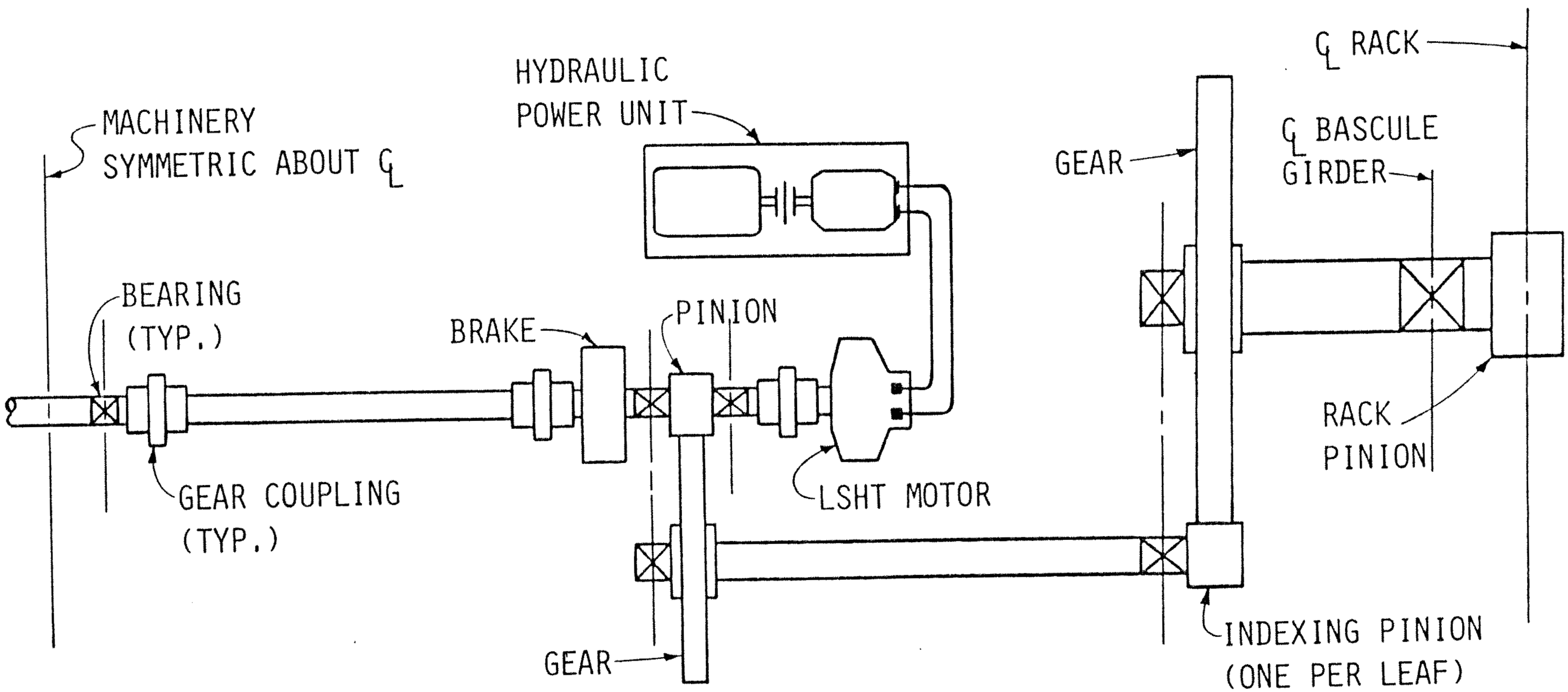
SEABOARD COAST LINE BRIDGE
OVER NORTH EAST CAPE FEAR RIVER
AT WILMINGTON, NORTH CAROLINA

SUMMARY OF HYDRAULIC PARAMETERS FOR HIGHWAY BASCULE BRIDGES

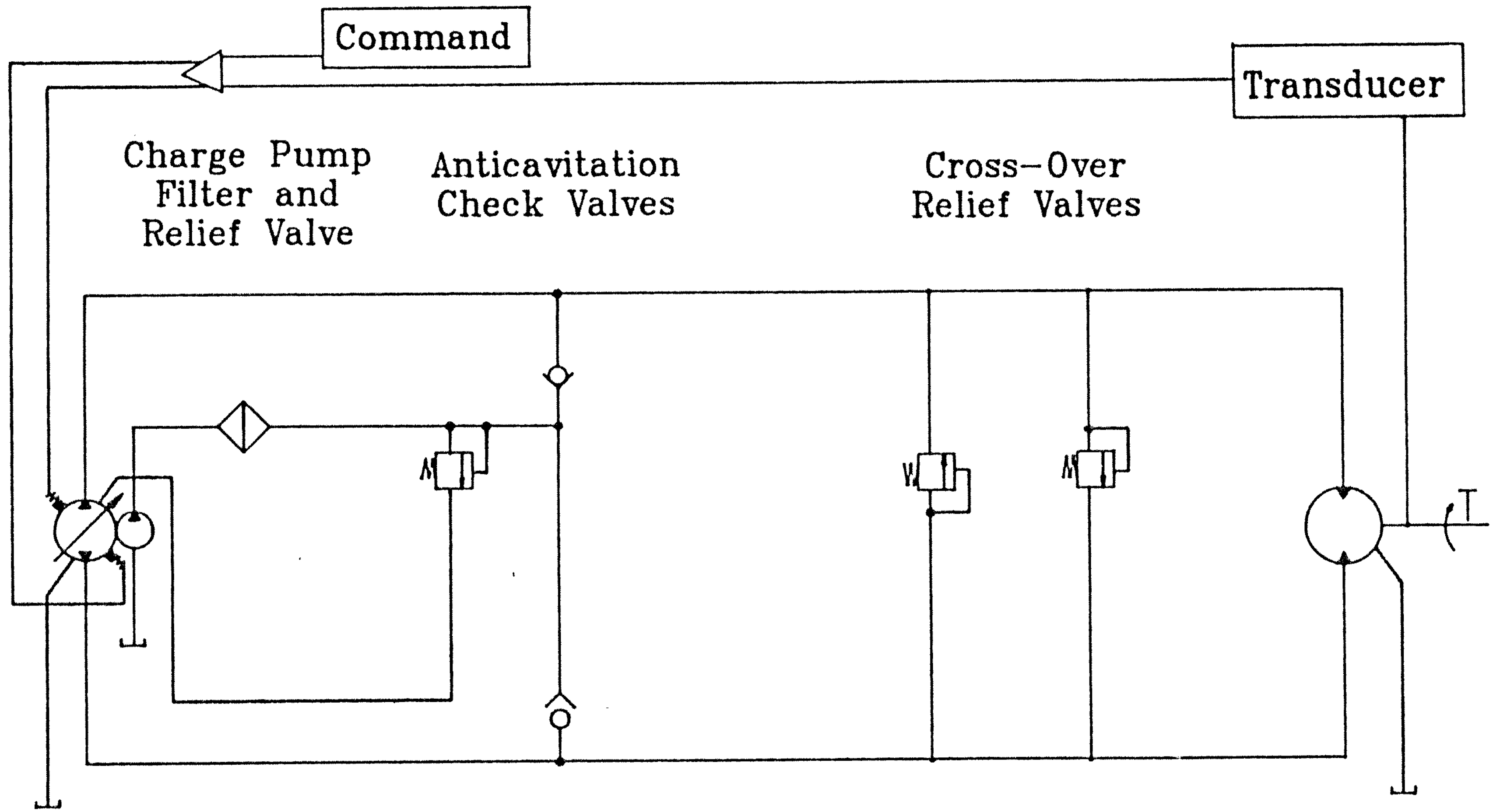
YEAR	BRIDGE	ACTUATOR	PUMP	FLOW GPM	PRESSURE PSI	VELOCITY FPS
		Cylinder:				
1965	South Haven, Michigan	8" ø Bore 60" Stroke	Variable, Manual	30	750 Oper. 1200 Hold	12
1971	Oshkosh, Wisconsin	12" ø Bore 87" Stroke	Fixed	38	1450 Oper. 2000 Hold	9
1974	St. Joseph, Michigan	12" ø Bore 124"Stroke	Variable, Servo	53	1200 Oper. 1650 Hold	8
1975	St. Clair, Michigan	12" ø Bore 64" Stroke	Variable, Servo	32	1000 Oper. 1350 Hold	10

Development of AREA Hydraulic Specifications

YEAR	BRIDGE	ACTUATOR	PUMP	FLOW GPM	PRESSURE PSI	VELOCITY FPS
		LSHT Motor:				
1985	Manitowoc, Wisconsin	244 CIPR	Variable, Servo	48	1800 Oper. 0 Hold	15
1985	East Chicago, Indiana (Ind. Blvd.)	146 CIPR	Variable, Servo	18	2100 Oper. 0 Hold	15
1985	East Chicago, Indiana (Dickey Pl.)	244 CIPR	Variable, Servo	51	1900 Oper. 0 Hold	15



LSHT HYDRAULIC DRIVE



Basic Closed-Circuit
Closed-Loop Hydrostatic Drive

HYDRAULIC SYSTEM PARAMETERS THAT ARE MONITORED WITH DIAGNOSTIC MESSAGE DISPLAYED AND PRINTED

PRINTED MESSAGE	INTERLOCKED WITH BYPASS AVAILABLE
LOW HYDRAULIC FLUID LEVEL AT __ BRIDGE DRIVE POWER UNIT	YES
LOW CHARGE PRESSURE AT __ BRIDGE DRIVE POWER UNIT	YES
LOW FLUID TEMPERATURE AT __ BRIDGE DRIVE POWER UNIT	YES
SERVO CONTROL MALFUNCTION AT __ BRIDGE DRIVE PUMP	YES
HIGH DIFFERENTIAL PRESSURE AT __ SUCTION FILTER, REPLACE FILTER	YES
HIGH DIFFERENTAIL PRESSURE AT MAIN LINE FILTER, REPLACE FILTER	NO
HIGH FLIUD TEMPERATURE AT __ BRIDGE DRIVE POWER UNIT	NO
_____ PSI (SYSTEM PRESSURE AT __ EVERY 5' WITH PEAKS BETWEEN)	NO

NOTE: ITEMS NOT INTERLOCKED ARE ADVISORY ONLY. VARITION OF SYSTEM PRESSURES WILL BE USED TO BALANCE THE MOVING LEAVES.

DATA ACQUISITION SYSTEM (DAS)

A bridge monitoring and recording system, usually referred to as a data acquisition system (DAS) is provided to monitor the bridge drive and electrical systems.

The DAS automatically activates when the CONTROL CIRCUIT selector switch is turned to AUTOMATIC or MONITOR positions and either PLC NO. 1 or PLC NO. 2 is operational. DAS will also activate when CONTROL CIRCUIT switch is at EMERGENCY position if at least one PLC is functioning properly and the PLC SELECTOR switch is turned to that PLC. This permits monitoring of bridge hydraulic, electrical and mechanical systems and operating procedure during an Emergency Operation test. The following items are monitored and printed:

- Time and date of Power On & Bridge Opening
- Operating Mode (PLC1, PLC2 or Emergency)
- Operational status of PLC's
- Status of electrical system bypasses
- Circuit breaker trips
- Traffic warning system and traffic gate operation
- Traffic gate electric eye operation
- Rear lock operation
- Brake operation
- Hydraulic system parameters (see Page 11)
- Main motor electric currents
- Electrical system power consumption
- Rack pinion shaft strain and stress on all four shafts
- Operating horsepower
- Angle of opening for each leaf
- Limit switch malfunction
- Machinery maintenance intervals
- Normal or standby power connected

DAS automatically deactivates when the CONTROL CIRCUIT switch is turned to OFF position. Printer may continue to print data for a short period of time.

PROPOSED HYDRAULIC SYSTEM RETROFIT OF EXISTING BRIDGES

Each bridge to be reconditioned could be retrofitted with four hydraulic drives - one drive to operate each rack pinion. Each hydraulic drive would be a combination hydraulic-mechanical system consisting of a hydraulic power unit, low speed high torque (LSHT) fluid motor and a hydraulically operated brake. The LSHT motor would be coupled to one of the pinions of the existing open gear train, providing that the existing gearing is in good enough condition to justify reuse. Otherwise, suitable new gearing would have to be provided. At some bridges a speed reducer may have to also be provided if the existing open gearing does not have the required amount of gear reduction. If speed reducers are required either LSHT motors or conventional fluid motors could be used.

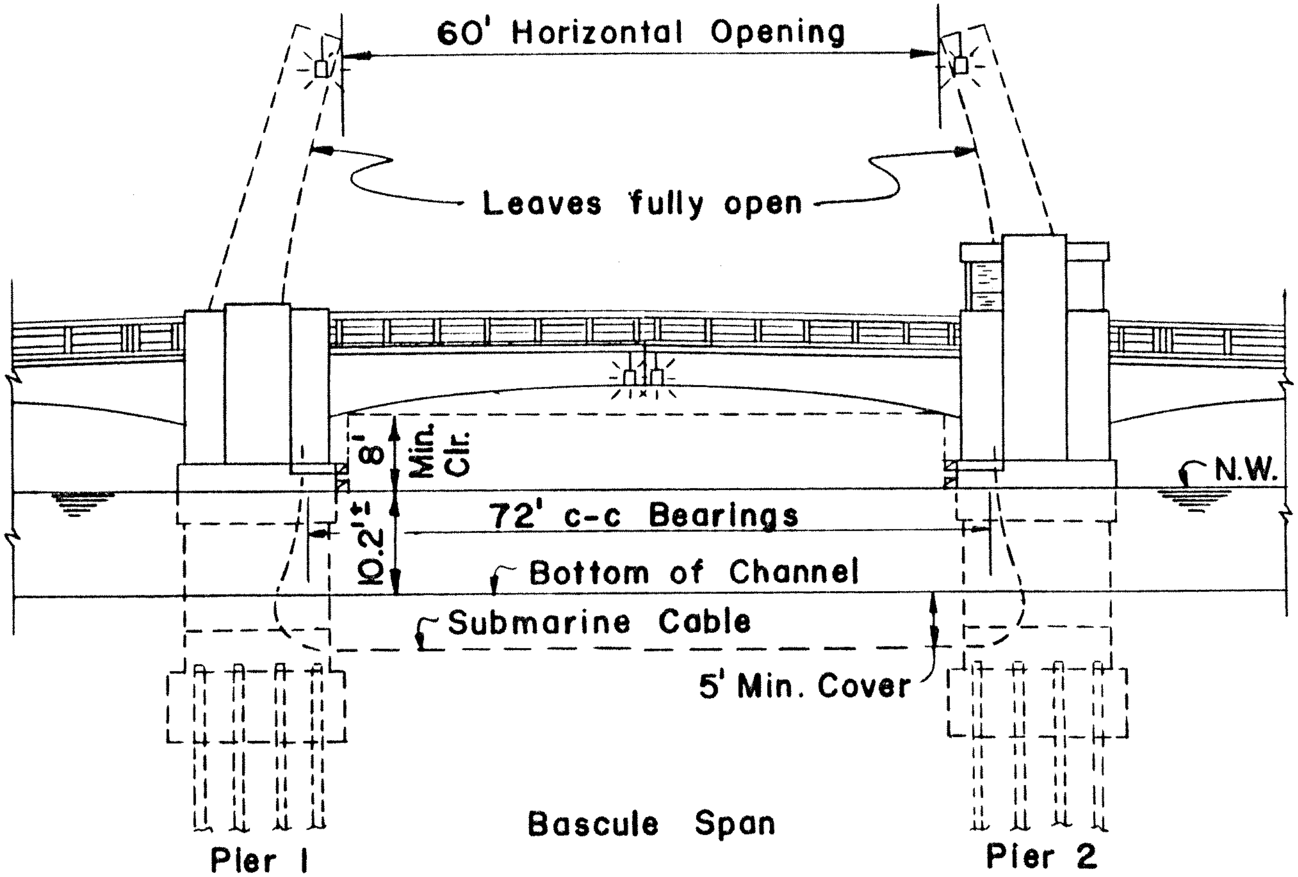
Two LSHT motors would normally drive each bridge leaf but one LSHT motor could drive each leaf if necessary. Two hydraulically operated brakes would be provided as parking (machinery) brakes for each leaf. Motor brakes would not be needed because each hydraulic drive would provide dynamic-regenerative braking action during leaf deceleration. The parking brakes would be set after the bridge comes to rest to assist in holding against maximum wind loads or can be used as emergency stopping brakes, if necessary, to bring the bridge to a stop faster than dynamic-regenerative braking action can provide. The result would be much lower shock loads on the machinery and structure during normal operation and the problem of adjusting brake time delays for sequenced brake setting would be eliminated.

Controls for the hydraulic system would be solid-state proportional electro-hydraulic servo valve type control. The controls would provide pre-set acceleration and deceleration of the bridge leaves. The rate of acceleration and/or deceleration can be adjusted to suit bridge conditions. Either automatic pushbuttons and/or manual joysticks could be provided at the operator's console. The existing operator's console at each bridge would require minor modifications, which could most likely be done in place at the bridge, to accommodate the hydraulic control systems. Motor controls would have to be modified or replaced, depending on their type and condition, to operate the electric motors which drive the pumps of the hydraulic power units. The new or revised motor controls would be simpler than the existinng arrangements because the electric motors would be NEMA B Squirrel Cage type AC motors requiring only one direction of rotation. The hydraulic circuitry would provide the necessary fluid flow direction to open or close the bridge leaves.

The cost to retrofit a bridge with hydraulic drives would be approximately $350,000 per bridge. This cost is an average amount which would vary depending on the amount of work which may be required at the bridge.

HYDRAULICALLY OPERATED MOVABLE BRIDGES IN OPERATION

DESIGNED	LOCATION OF BRIDGE
1965	M–43 OVER THE BLACK RIVER IN THE CITY OF SOUTH HAVEN, MICHIGAN
1966	SEABOARD SYSTEMS R.R. (FORMERLY L&N R.R. OVER ST. LOUIS BAY BETWEEN BAY ST. LOUIS AND HENDERSON POINT, MISSISSIPPI
1971	MAIN STREET OVER THE FOX RIVER IN THE CITY OF OSHKOSH, WISCONSIN
1974	SEABOARD SYSTEMS R.R. (FORMERLY L&N R.R. OVER BILOXI BAY BETWEEN BILOXI AND OCEAN SPRINGS, MISSISSIPPI
1974	I–94BL OVER THE ST. JOSEPH RIVER BETWEEN THE CITIES OF ST. JOSEPH AND BENTON HARBOR, MICHIGAN
1975	M–29 OVER THE PINE RIVER IN THE CITY OF ST. CLAIR, MICHIGAN



26' Roadway and 2-4' Sidewalks

M-43 OVER THE BLACK RIVER
IN SOUTH HAVEN, MICHIGAN

M-43 OVER THE BLACK RIVER
IN THE
CITY OF SOUTH HAVEN, MICHIGAN

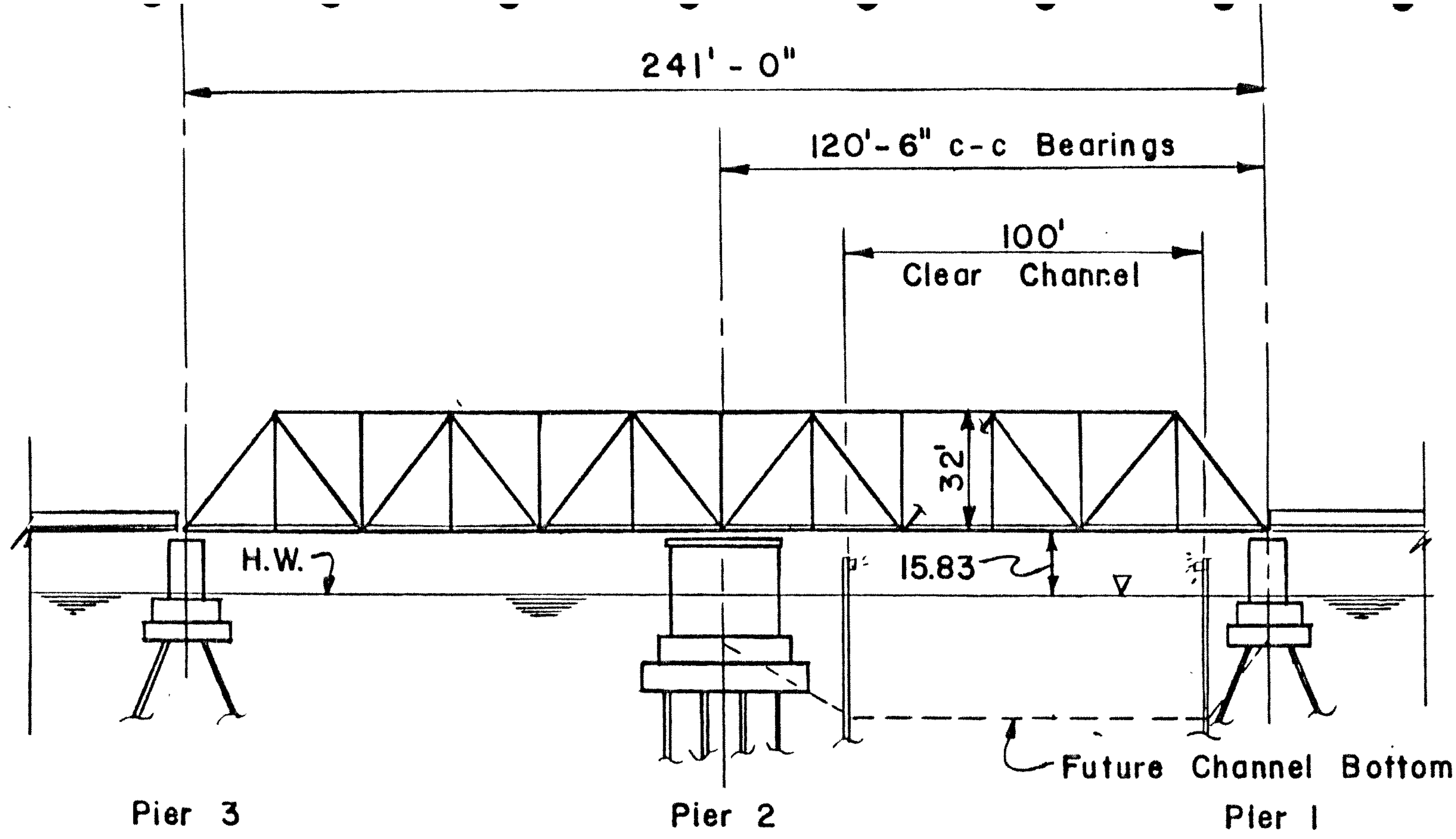
Double Leaf Rolling Lift Bascule Bridge Providing 60± Clear Channel at 0± Skew.

Operating System Designed By: Rudolph Timmerman
Chief Mechanical Engineer
Checked by: John A. Schultz, Jr.
Project Engineer

The design is an open-circuit open-loop hydraulic system. Power for each leaf is provided by a 15 HP squirrel cage induction motor driving a variable displacement pump, which delivers a maximum of 30 GPM. The flow of oil (maximum velocity of 12.5 fps) from the varible displacement pump is manually controlled by a pilot cylinder. The operator controls the movement of the pilot cylinder which in turn controls the movement of the bridge.

Each leaf is operated by two 8" diameter hydraulic cylinders having a 12" stop tube and utilizing a 60" stroke. The maximum operating (dynamic) pressure is 750 psi while the maximun holding pressure (static) is 1200 psi.

The same pumps are used to operate the rear locks by means of a 2" diameter cylinder. Power is simultaneously applied to the main bridge cylinders in the "lower" direction to lift the rear end of the moving leaf off of the rear locks and allow them to be pulled out.



Single Track Swing Bridge

LOUISVILLE AND NASHVILLE RAILROAD BRIDGE
OVER ST. LOUIS BAY
AT ST. LOUIS, MISSISSIPPI

SEABOARD SYSTEMS RR (FORMERLY L&N RR)
OVER
ST. LOUIS BAY BETWEEN BAY ST. LOUIS AND HENDERSON POINT MISSISSIPPI

Single Track Railroad Swing Bridge Providing 100 Ft. Clear channel at 0± Skew.

Operating System Designed by: Rudolph Timmerman
Chief Mechanical Engineer
Checked by: A. L. R. Sanders
Chief Engineer & Partner

The design is an open-circuit open-loop hydraulic system.

This center pivot swing bridge with balance wheels is operated by two Staffa Mark 5 Hydraulic Motors, each with seven cylinders. The starting torque at 1500 psi equals 3,250 ft. lbs. while the running torque at 750 psi and 37 RPM equals 2,170 ft. lbs. The design rack force equals 45,000 lbs. acting on a circular rack with a 13' - 1-9/16 Pitch Radius.

Two mechanical brakes are used to control the span. They are Stearns style 46,000, Series 1,000 ft. lb. torque Disc Brakes, manufactured by Stearns Electric Corporation in Milwaukee, Wisconsin. The brakes are mounted for manual release.

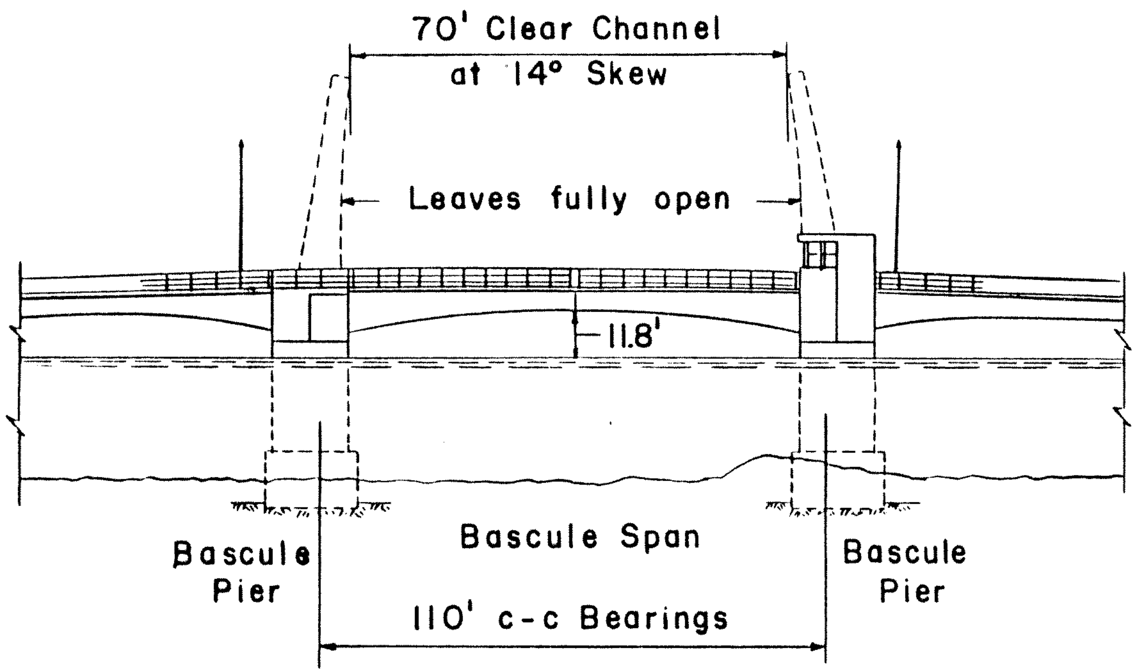
Miller Fluid Power Hydraulic Cylinders, Model H84, with stainless steel rods, cushion both ends, with Style 2 rod ends and having Miller Rod Clevis, eye brackets and pins were used to operate the following:

2 Center Wedges
4 End Wedges
2 sets of Lift Rails and End Locks.

The two Center Wedges are operated by one 6" diameter hydraulic cylinder having an 18" stroke and 2" stop tube.

The four end Wedges are each operated by one 6" diameter hydraulic cylinder, having a 28" stroke and 2" stop tube.

The Rails and vertical End Locks at the ends of the swing span are each lifted by one 4" diameter hydraulic cylinder having a 16" stroke and 1" stop tube.



48' Roadway and 2 - 5' Sidewalks

<u>MAIN ST. OVER FOX RIVER</u>
<u>IN OSHKOSH, WISCONSIN</u>

MAIN STREET
OVER THE
FOX RIVER IN THE CITY OF OSHKOSH, WISCONSIN

Double Leaf Rolling Lift Bascule Bridge Providing 70 Ft. Clear Channel at 14± Skew.

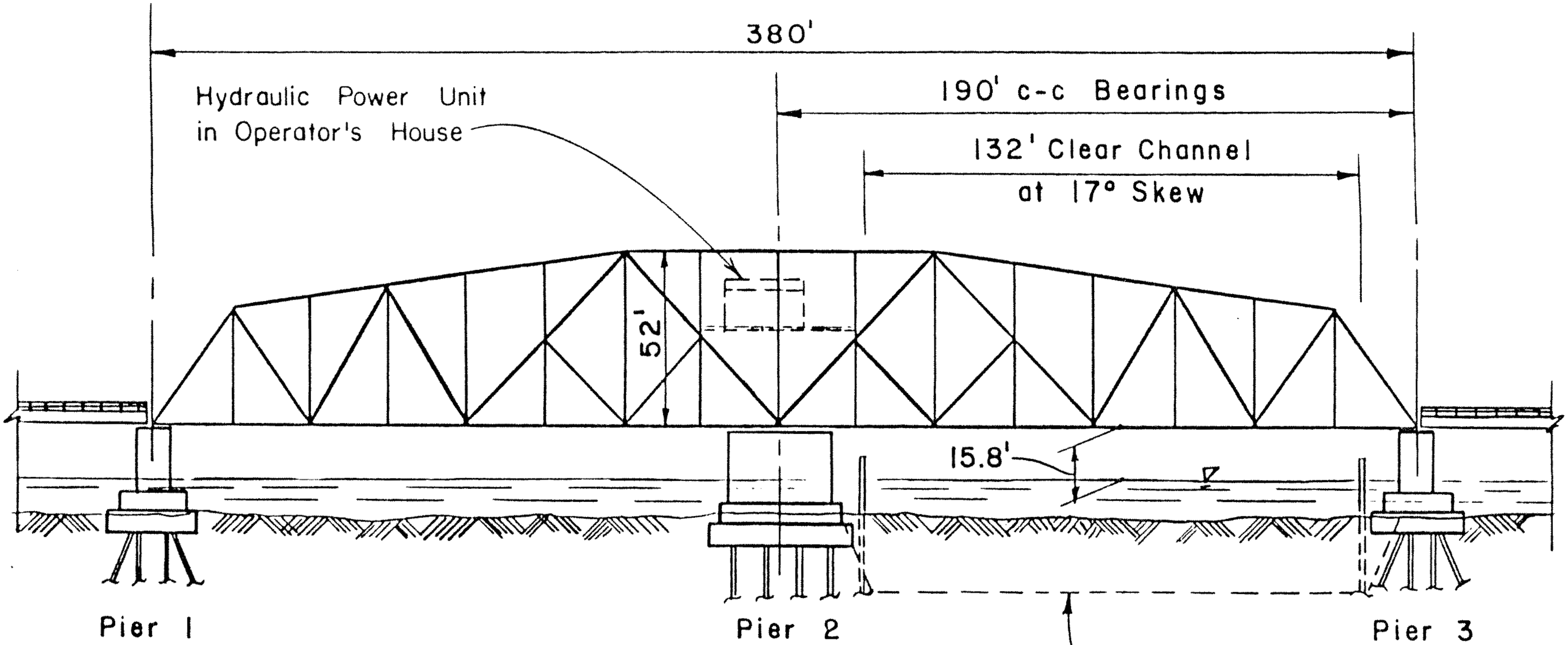
Operating System Designed By: Rudolph Timmerman
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Project Engineer

The design is an open-circuit open-loop hydraulic system. Power for each leaf is provided by two 30 HP squirrel cage motors, each driving a fixed displacement gear pump, which delivers 38 GPM. The direction of oil flow to the head end or rod end of the cylinders is determined by two pilot operated check valves controlled by the operator. The volume of oil flow (maximum velocity 9 fps) is controlled by three pilot operated check valves in the return lines from both the head end and rod end depending on the direction of the cylinder.

The speed of each leaf is manually controlled and monitored by the operator using a selector switch, which provides three speeds in each direction. The switch electrically controls three solenoid operated two position valves in the pilot lines to the check valves. When pressure is applied in the pilot line, the check valve is opened allowing system oil to return to the tank. The flow is regulated by having a pressure compensated adjustable flow control valve in the return line. The pumped oil not used by the system is returned to the tank through a pressure relief valve.

Each leaf is operated by two 12" diameter hydraulic cylinders with a 5-1/2" diameter stainless steel rod utilizing an 87" stroke. The maximum operating (dynamic) pressure is 1450 psi while the maximum holding pressure (static) is 2000 psi.

The same pumps are used to operate the rear locks by means of 2" diameter cylinders, same as the M-43 Bridge over the Black River.



Hydraulic Cylinders operate Rail Joints, Lock Bars, Center Wedges and End Wedges. Hydraulic Motors drive Pinions on 360° Rack. (One motor in each quadrant).

Single Track Swing Bridge
(Center Pivot with Balance Wheels)

LOUISVILLE AND NASHVILLE RAILROAD BRIDGE
OVER BILOXI BAY
AT BILOXI, MISSISSIPPI

PRIZE BRIDGE 1982/MOVABLE SPAN

SEABOARD SYSTEMS RR (FORMERLY L&N RR)
OVER
BILOXI BAY BETWEEN BILOXI AND OCEAN SPRINGS, MISSISSIPPI

Single Track Railroad Swing Bridge Providing 132 Ft. Clear Channel at 17± Skew.

Operating System Design By: Rudolph Timmerman
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design is an open-circuit open-loop hydraulic system.

This center pivot swing bridge with balance wheels is operated by four Gerotor MH-39 Fluid Motors. Each motor drives a right angle speed reducer thru a Falk Type G10 Size 10G Gear Coupling and a Stearns Disc Brake, Series 87,700 with a 50 ft. lb. torque setting. The brakes were modified for manual operation only with spring return handles. The right angle speed reducer was a Falk Type YBX3, Unit Size 2090 with a reduction ratio of 105.9:1.

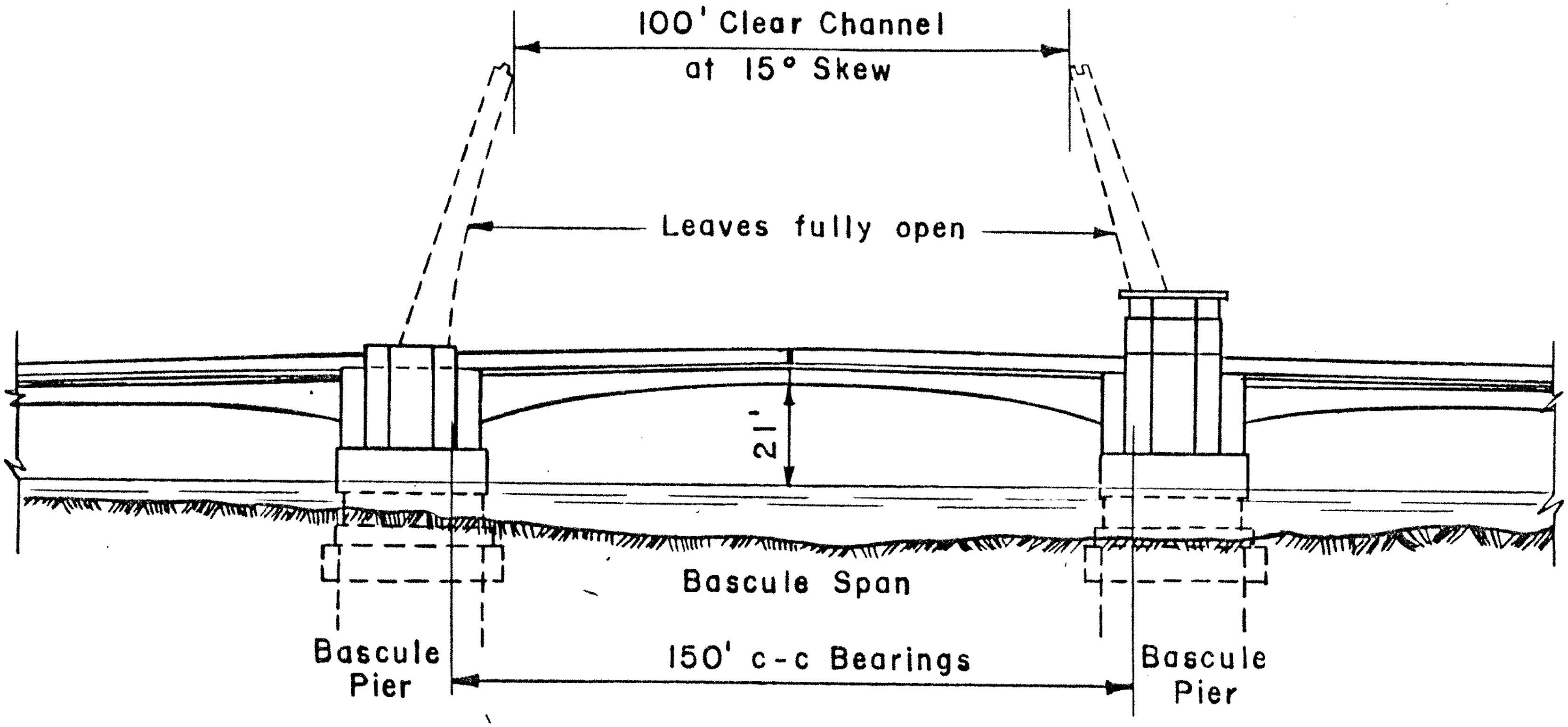
Miller Fluid Power Hydraulic Cylinders, Model H84 with stainless steel rods, cushion both ends, with Style 2 rod ends having Miller rod clevis, eye brackets and pins were used to operate the following:

2 Center Wedges
4 End Wedges
2 sets of Lift Rails and End Locks

The 2 Center Wedges are operated by two 5" diameter hydraulic cylinders having a 14" stroke and 1" stop tubes.

The four End Wedges are each operated by one 6" diameter hydraulic cylinder with a 2-1/2" rod, having a 38" stroke and 6" stope tube.

The Rails and vertical End Locks at the ends of the swing span are each lifted by one 4" diameter hydraulic cylinder having a 16" stroke and 1" stop tube.



2-28' Roadways with 4' Median and 2-5' Sidewalks

I-94 CONNECTOR ROAD OVER ST. JOSEPH RIVER
IN ST. JOSEPH, MICHIGAN

I-94BL OVER THE ST. JOSEPH RIVER
BETWEEN THE
CITIES OF ST. JOSEPH AND BENTON HARBOR, MICHIGAN

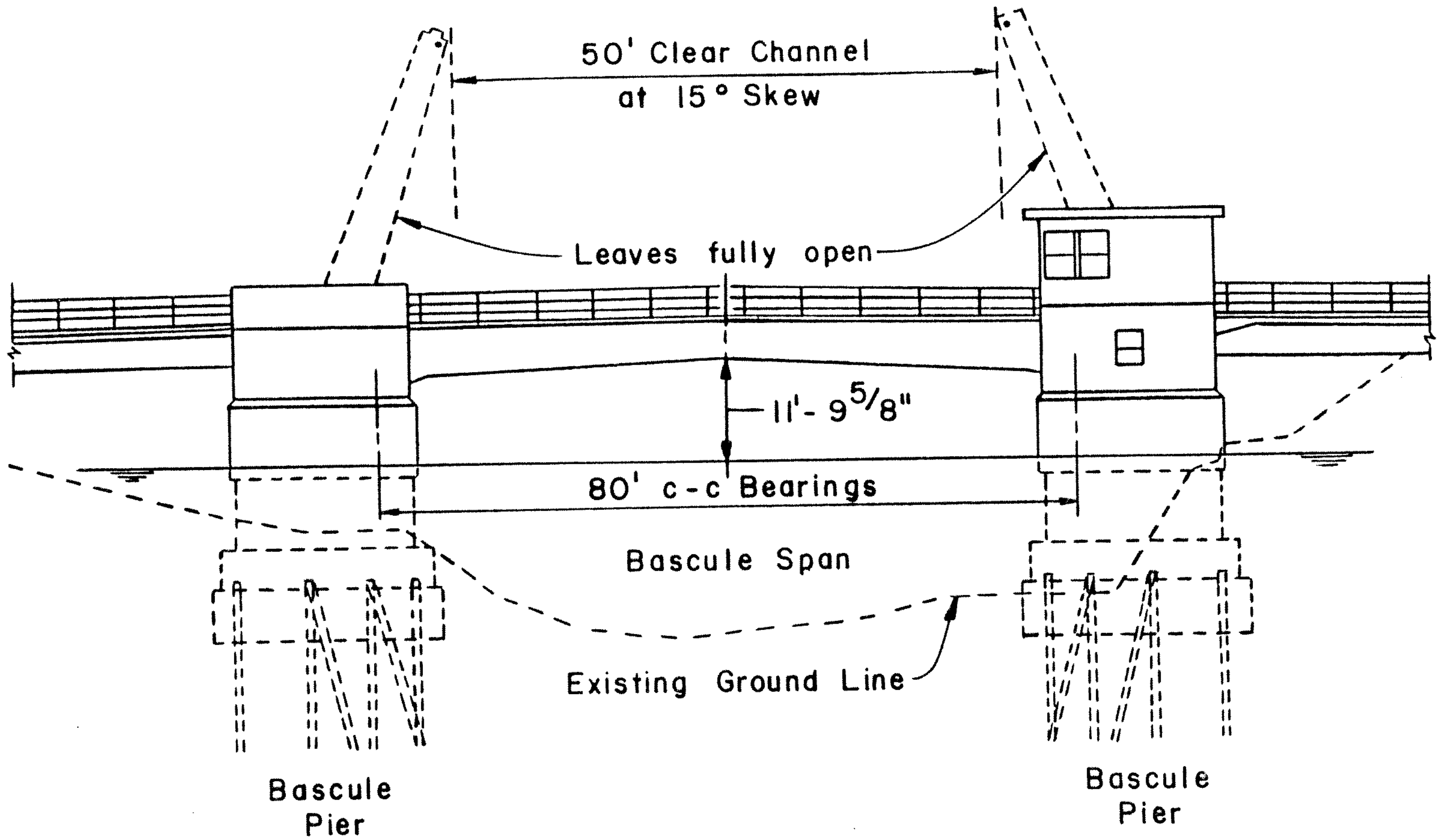
Twin Double Leaf Rolling Lift Bascule Bridge Providing 100 Ft. Clear Channel at 15± Skew.

Operating System Designed By: Rudolph Timmerman
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design is a closed-circuit open-loop hydraulic system. Power for each leaf is provided by two 15 HP squirrel cage, induction motors each driving a variable displacement pump which deliver a maximum of 53 GPM. The flow of oil (maximum velocity of 8 fps) from the variable displacement pumps is regulated by a servo valve electrically controlled by the operator.

Each of the four leaves are operated by two 12" diameter hydraulic cylinders with a 7" diameter stainless steel rod and a 25" stop tube, utilizing a 124" stroke. The maximum operating (dynamic) pressure is 1200 psi while the maximum holding (static) pressure is 1650 psi.

The same pumps are used to operate the rear locks by means of 2" diameter cylinders, same as the M-43 Bridge over the Black River.



52' Roadway and 2 - 6' Sidewalks

M-29 OVER THE PINE RIVER
IN ST. CLAIR, MICHIGAN

M-29 OVER THE PINE RIVER
IN THE
CITY OF ST. CLAIR, MICHIGAN

Double Leaf Rolling Lift Bascule Bridge Providing 50 Ft. Clear Channel at 10± Skew.

Operating System Designed By: Rudolph Timmerman
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design is a closed-circuit open-loop hydraulic system. Power for each leaf is provided by two 10 HP squirrel cage induction motors, each driving a variable displacement pump which delivers a maximum of 32 GPM. The flow of oil (maximum velocity of 10 fps) from the variable displacement pumps is regulated by a servo valve electrically controlled by the operator.

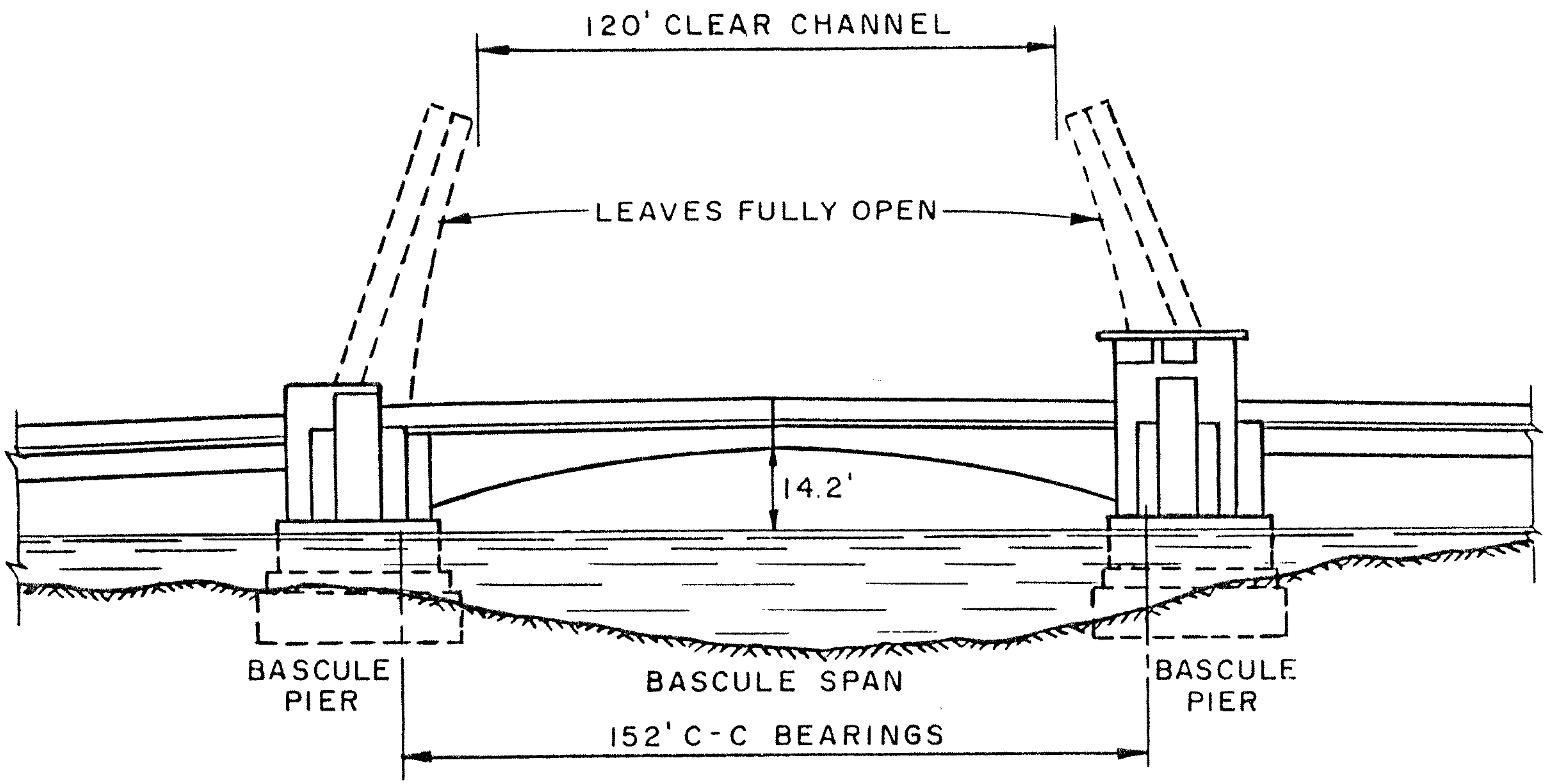
Each leaf is operated by two 12" diameter hydraulic cylinders with a 5-1/2" stainless steel rod and a 14" stop tube, utilizing a 64" stroke. The maximum operating (dynamic) pressure is 1000 psi while the maximum holding (static) pressure is 1350 psi.

The same pumps are used to operate the rear locks by means of 2" diameter cylinders, same as the M-43 bridge over the Black River.

HYDRAULICALLY OPERATED MOVABLE BRIDGES DESIGNED USING STATE OF THE ART HYDRAULIC SYSTEMS OF TODAY

DESIGNED	LOCATION OF BRIDGE
1985	U.S.10 OVER THE MANITOWOC RIVER IN THE CITY OF MANITOWOC, WISCONSIN
1985	U.S.12 AND 20 OVER THE INDIANA HARBOR CANAL IN THE CITY OF EAST CHICAGO, INDIANA
1985	S.R.912 OVER THE INDIANA HARBOR CANAL IN THE CITY OF EAST CHICAGO, INDIANA

NOTE: THE ABOVE BRIDGE DESIGNS ARE CLOSED-CIRCUIT CLOSED-LOOP HYDRAULIC SYSTEMS SQUIRREL CAGE INDUCTION MOTORS DRIVE VARIABLE PISTON PUMPS WHICH CONTROL THE SPEED OF LOW SPEED HIGH TORQUE (LSHT) FLUID MOTORS. THE OUTPUT SHAFT OF THE LSHT MOTORS ARE EACH CARRIED THRU TWO OPEN GEAR TRAINS TO THE RACK PINIONS. A SEPARTELY MOUNTED HYDRAULICALLY OPERATED DISC BRAKE IS LOCATED ON THE SAME SHAFT AS EACH LSHT MOTOR FOR HOLDING AND EMERGENCY STOPPING ONLY. HYDRAULIC CIRCUIT AND SERVO CONTROLS PROVIDE DYNAMIC BRAKING DURING NORMAL OPERATION.



44' ROADWAY AND TWO 9' SIDEWALKS

U.S. 10 OVER MANITOWOC RIVER
IN MANITOWOC, WISCONSIN

U.S. 10 (EASTBOUND) OVER THE MANITOWOC RIVER
IN THE
CITY OF MANITOWOC, WISCONSIN

Double Leaf Rolling Lift Bascule Bridge Providing 120 Ft. Clear Channel at 0± Skew.

Operating System Designed By: George N. Pavlakis
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design is a closed-circuit closed-loop hydraulic system.

Each leaf is operated by two independent hydraulic power units each driving a low speed high torque (LSHT) fluid motor coupled to a drive pinion and a hydraulically operated disc brake. This pinion is part of two sets of open gear train and delivers the power to the rack pinion. All of the above equipment is on the moving leaf. The two systems are coupled together and are symmetrical about the centerline of the leaf. If a problem developes in one of the systems it automatically shuts itself down and the leaf is operated by the functioning system. The LSHT motor of the disabled system is placed in a drift mode and turns with the shaft.

Each Hydraulic Power Unit consists of an L shaped reservoir on a base that supports a 30 HP Squirrel cage induction motor driving a variable displacement, overcenter for reversing flow, piston type pump with an integral charge pump and an electrically actuated pump servo controller mounted on the pump. The power unit also includes the flexible coupling with guard, manifold(s), valves, piping between power unit components, filters and all other required accessories.

U.S.12 & 20 OVER THE INDIANA HARBOR CANAL
IN THE
CITY OF EAST CHICAGO, INDIANA

Double Leaf Rolling Lift Bascule Bridge Providing 68 Ft. Clear Channel at 0° Skew.

Operating System Design By: George N. Pavlakis
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design of the hydraulic system is basically the same as the U.S. 10 Bridge over the Manitowoc River except for the size and capacity of the equipment.

STATE ROUTE 912 OVER THE INDIANA HARBOR CANAL
IN THE
CITY OF EAST CHICAGO, INDIANA

Double Leaf Rolling Lift Bascule Bridge Providing 118.5' Clear Channel at 3±-30' Skew.

Operating System Designed By: George N. Pavlakis
Chief Mechanical Engineer
Checked By: John A. Schultz, Jr.
Movable Bridge Design Manager

The design of the hydraulic system is basically the same as the U.S. 10 Bridge over the Manitowoc River except for the size and capacity of the equipment.

BIOGRAPHICAL SKETCH OF AUTHOR

John A. Schultz, Jr., P.E.
Movable Bridge Design Manager
HAZELET + ERDAL, INC.
547 WEST JACKSON BLVD.
CHICAGO, ILLINOIS 60606
PHONE (312) 461-0267

EDUCATION	BS Civil Engineering, Northwestern University, 1947
SERVICE	U.S. Navy 1943 to 1946, NROTC at Northwestern University, Electronics officer at Bremerton Navy Yard and on Destroyer Tender Dixie, AD14, in Pacific. Took part in Atomic Bomb Test at Bikini Atoll in 1946.
PROFESSIONAL	Structural Engineer: Illinois
AFFILIATIONS	American Society of Civil Engineers, Fellow American Railway Engineering Association
MOVABLE BRIDGES	Mr. Schultz has over 38 years of experience in structural, mechanical, hydraulic, and electrical design and project management aspects of movable bridge projects including successful completion of over 20 movable bridge designs. As project manager, has supervised bascule, swing, and vertical lift design projects, including the longest rolling lift railroad span in the U.S.; the The Cape Fear Bridge for the Seaboard System Railroad. Recent projects have also included the rehabilitation of three bascule bridges along the Gulf Coast of Mississippi and a vertical lift bridge at the Philadelphia Naval Shipyard. Mr. Schultz is a recognized expert in movable bridge design and has a particularly strong background in rolling lift bascule bridges. The most noteworth bascule bridge that he has inspected and prepared rehabilitation plans for was the Arlington Memorial Bridge across the Potomac River, in Washington, D.C.
BACKGROUND	Mr. Schultz's background includes activities in several professional societies. As chairman of an AREA Committee 15 task force, he prepared standard specifications for hydraulic operation of railroad movable bridges. These specifications were adopted by the AREA in 1984. He has designed and supervised the design of all aspects of movable bridges including structural, mechanical, hydraulic and electrical elements.