ADVANTAGES OF HYDRAULICS

FOR

M O V A B L E   B R I D G E S

PRESENTED AT

THE FIRST BIENNIAL

SYMPOSIUM AND EXHIBITION

ON

MOVABLE BRIDGE

DESIGN AND TECHNOLOGY

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AUTHORS: Gerd Schmitt
Dieter L. Wendt
Ricardo Mendolla

THE REXROTH CORPORATION
Industrial Hydraulics Division
P. O. Box 2407
Bethlehem, PA 18001

CE001-85USA

1. GENERAL

BRIDGES LINK, OVERCOME OBSTACLES, ESTABLISH CONNECTIONS. THEY EASE TRANSPORT AND TRAFFIC PROBLEMS AND, MOST IMPORTANTLY, BRING PEOPLE INTO CLOSER CONTACT WITH EACH OTHER.

LIFE WITHOUT BRIDGES WOULD BE UNTHINKABLE NOWADAYS.

WHATEVER THE TYPE OR LOCATION OF A BRIDGE, IT WILL ALWAYS BE ASSOCIATED WITH THE TERM "CONNECTION". TAKE AWAY THE BRIDGE AND YOU BREAK THE CONNECTION.

IT IS THEREFORE NOT SURPRISING THAT IN TIMES OF WAR, IT WAS THESE BRIDGES WHICH WERE SUCH STRATEGICALLY IMPORTANT TARGETS, TO BE PROTECTED OR DESTROYED, AS THE CASE MIGHT BE.

WHO IS NOT FAMILIAR WITH THE OLD DRAWBRIDGES FOUND ON CASTLES, WHICH TRAVERSED DEEP DITCHES OR MOATS. IN TIMES OF DANGER THESE CONNECTIONS WERE BROKEN, CAUSING FEAR AND ANXIETY AMONG THOSE AFFECTED, AND, INDEED IN MANY CASES, CAUSING EVEN DEATH.

SMALL WONDER, THEN, THAT BROKEN CONNECTIONS IMMEDIATELY RESULTED IN AN OUTBREAK OF EMOTIONS AMONG THOSE AFFECTED.

THIS IS STILL TRUE EVEN OF OUR MODERN MOVING BRIDGES TODAY.

NOWADAYS, THE SOLE PURPOSE OF MOVING BRIDGES IS TO ALTERNATELY CONNECT TWO DIFFERENT INTERSECTING TRAFFIC ROUTES IN A PRACTICAL MANNER. AND THERE WE HAVE THE REAL PROBLEM OF MOVING BRIDGES -- THEY CAN MAKE ONLY ONE CONNECTION AT A TIME. IN ORDER TO MAKE THE OTHER CONNECTION, IT IS NECESSARY TO BREAK THE FIRST CONNECTION.

YOU MAY BE ASKING YOURSELF WHAT THIS LONG, RAMBLING INTRODUCTION IS IN AID OF. WELL, IT IS HOPED THAT IT WILL AROUSE YOUR INTEREST IN THE ENORMOUS IMPORTANCE OF THE DRIVES FOR SUCH BRIDGES.

IN RECENT YEARS, THESE DRIVES HAVE ALL TOO OFTEN BEEN SO UNDER-DIMENSIONED THAT THEY HAVE BEEN SUBJECT TO CONSTANT FAILURES, AND INDEED HAVE COMPLETELY BROKEN DOWN AFTER ONLY A YEAR OR TWO.

IN THE CASE OF VERY BUSY TRAFFIC ROUTES THIS MEANT AN ENORMOUS AMOUNT OF TROUBLE FOR THE OPERATOR.

JUST HOW MUCH TROUBLE IS DESCRIBED IN PART IN THIS PAPER.

FIRST, HOWEVER, A LOOK AT PRESENT DAY BRIDGE SYSTEMS.

IF WE CLASSIFY MOVING BRIDGES PURELY ON THE BASIS OF PHYSICAL FEATURES, WE FIND THERE ARE THREE BASIC TYPES:

BASCULE BRIDGES -- SWING BRIDGES -- LIFTING BRIDGES

FOR EACH BASIC TYPE, VARIOUS DRIVE SYSTEMS ARE AVAILABLE, WHICH IN PART ARE DEPENDENT ON THE PARTICULAR TYPE OF BRIDGE IN QUESTION.

WE SHALL NOW LOOK AT THE IMPORT CHARACTERISTICS OF THE VARIOUS DESIGNS AND DRIVE SYSTEMS IN ORDER TO HIGHLIGHT THE DIFFERENCES.

2.1 BASCULE BRIDGES

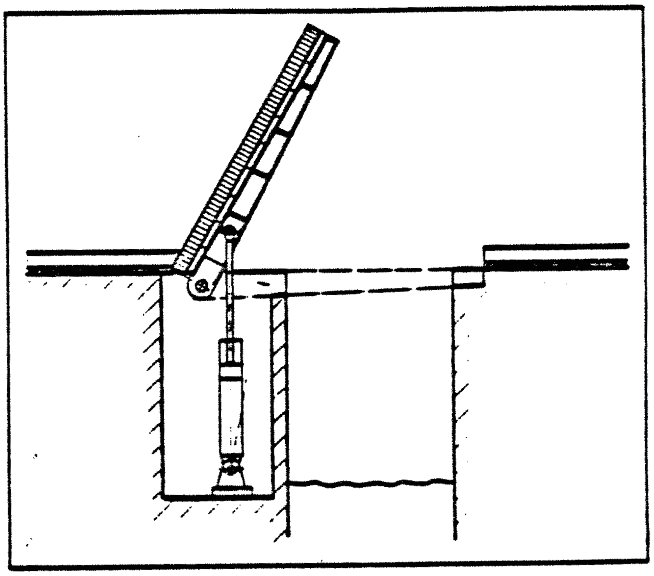


FIG. 2: BASCULE BRIDGE WITH FIXED PIVOT POINT

THIS SYSTEM IS NORMALLY USED FOR SMALL ROAD BRIDGES, IN WHICH THE CYLINDER OPERATES DIRECTLY ONTO THE BRIDGE ARM. THE DISADVANTAGE IS THE RELATIVELY HIGH DRIVE POWER AND THE HIGH SPACE REQUIRED FOR THE CYLINDER (S).

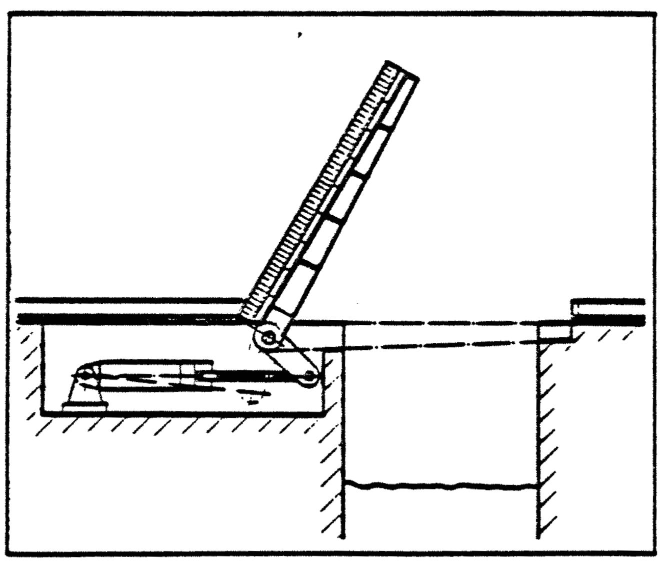


FIG.3: BASCULE BRIDGE WITH FIXED PIVOT POINT

THE CYLINDER OPERATES AGAINST A LEVER. THE BIG ADVANTAGE OF THIS ARRANGEMENT LIES IN THE DEPTH OF EXCAVATION NECESSARY. IN MANY CASES, THE CYLINDER OPERATES VIA A TORSION TUBE, WHICH IN TURN MAKES ACCESSIBILITY TO THE CYLINDER AND HYDRAULIC SYSTEM EVEN EASIER.

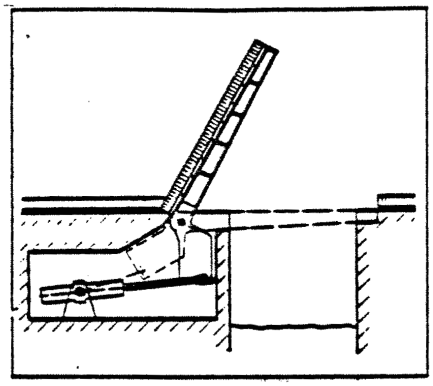


FIG. 4: BASCULE BRIDGE WITH FIXED PIVOT POINT & COUNTERWEIGHT

THIS IS A TRUE BASCULE BRIDGE WITH A COUNTERBALANCE AND MUST BE EMPLOYED WHEN BRIDGES EXCEED A CERTAIN SIZE, PARTICULARLY IN VIEW OF THE ENERGY COSTS. BRIDGE SYSTEMS USING A COUNTERWEIGHT CONSIDERABLY REDUCE THE DRIVE POWER, TOGETHER WITH THE SIZE OF THE CYLINDERS AND THE COSTS FOR THE HYDRAULIC AND ELECTRICAL COMPONENTS. PARTICULARLY IN RURAL AREAS, THE ELECTRICAL MAINS ARE NOT SUFFICIENTLY HEAVY FOR A DIRECTLY DRIVEN BRIDGE, AND THIS BECOMES YET ANOTHER POINT IN FAVOR OF USING A BRIDGE WITH A COUNTERBALANCE. WITH THE RISE OF ENERGY COSTS IN RECENT TIMES, BRIDGES WITHOUT COUNTERBALANCE WEIGHTS CAN SCARCELY BE CONSIDERED. THE BRIDGE SHOWN IN FIG. 4 HAS SUCH A COUNTERBALANCE WEIGHT, TO WHICH THE CYLINDER IS CONNECTED. THE CYLINDER IS THEREFORE WORKING IN COMPRESSION. THIS IS NORMALLY UNFAVORABLE, AS THIS TYPE OF BRIDGE IS NOT FULLY BALANCED. THE DISADVANTAGE IS MAINLY IN THE AREA OF THE UNDERGROUND CONSTRUCTION, WHICH REQUIRES ROOM FOR THE COUNTERBALANCE WEIGHT AND DRIVE CYLINDER.

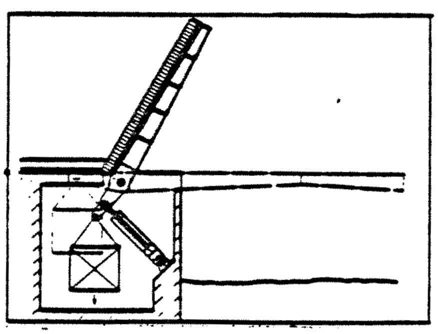


FIG. 5: BASCULE BRIDGE WITH FIXED PIVOT POINT & COUNTERWEIGHT

IN CONTRAST TO FIG. 4, THE BRIDGE SHOWN HERE HAS THE WEIGHT FREE TO SWING ON A BALANCE ARM. THIS ARRANGEMENT IS NOT PARTICULARLY GOOD BECAUSE OF THE LARGE VOLUME REQUIRED FOR THE COUNTERBALANCE. HOWEVER, THE CYLINDER IS IN TENSION WHEN THE GREATEST LOAD IS REQUIRED.

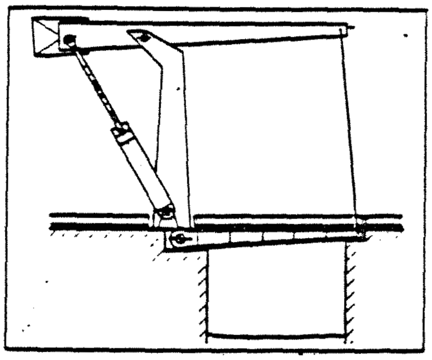


FIG. 6: BASCULE BRIDGE WITH COUNTERBALANCE BEAM

THIS SYSTEM IS VERY OLD, AS MAY BE SEEN FROM THE FAMOUS PAINTING BY VINCENT VAN GOGH, WHICH IS FAMILIAR TO PEOPLE FROM ALL WALKS OF LIFE.
THE ADVANTAGE IS CLEARLY THAT ALL MAJOR PARTS, PARTICULARLY THE COUNTERBALANCE ARM, LIE ABOVE GROUND. THIS SYSTEM IS GENERALLY USED FOR SMALL BRIDGES.

ONE FURTHER REMARK MUST BE MADE AT THIS POINT: ALL BRIDGES WITH A FIXED PIVOT POINT HAVE ONE THING IN COMMON, AND THIS IS THAT IF WATER TRAFFIC IS TO PASS THROUGH WITHOUT HINDRANCE, THE OPERATIONAL ANGLE MUST BE APPROXIMATELY 85°, OR THE BRIDGE ITSELF SO WIDE THAT A SMALLER ANGLE THAN 85° BECOMES UNIMPORTANT.

ON THE OTHER HAND, IN ORDER TO SAVE TIME TO ACHIEVE A SUFFICIENTLY WIDE OPENING, A SMALL TRICK IS PLAYED. INSTEAD OF A FIXED ROTATIONAL POINT, THIS POINT IS MADE TO MOVE. THE SYSTEM EMPLOYED IS THAT OF A ROLLING BASCULE BRIDGE (THE SCHERZER SYSTEM). AS THE NAME IMPLIES, THE BRIDGE DOES NOT ONLY SWING ABOUT A FIXED POINT, BUT ROLLS AT THE SAME TIME GIVING A WIDER OPENING FOR THE SAME ANGULAR MOVEMENT.

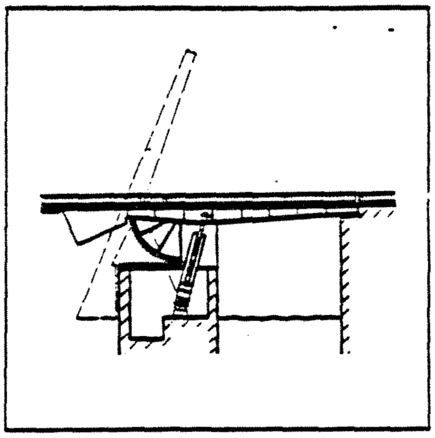


FIG. 7: ROLLING BASCULE BRIDGE WITH COUNTERBALANCE

SUCH A ROLLING BASCULE BRIDGE IS SHOWN IN FIG. 7, AND IT WILL BE APPRECIATED THAT RELATIVELY NARROW PIERS CAN BE USED TO ACHIEVE FULL OPENING TO WATER TRAFFIC.

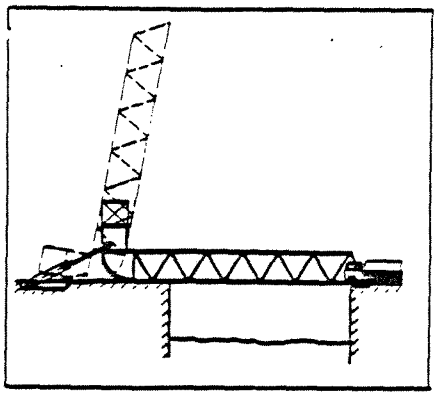


FIG. 8: ROLLING BASCULE BRIDGE WITH COUNTERBALANCE

THE BRIDGE SHOWN IN FIG. 8 IS PARTICULARLY ECONOMIC WITH REGARD TO THE EXCAVATIONS NECESSARY. THE ONLY DISADVANTAGE IS THE APPEARANCE OF THE BRIDGE. FOR THIS REASON, SUCH BRIDGES ARE MOSTLY FOUND IN INDUSTRIAL AND HARBOR AREAS.

THE SYSTEMS SHOWN IN FIG'S. 2 - 8 CAN ONLY SHOW THE BASIC DIFFERENCES. THERE ARE, OF COURSE, NUMEROUS VARIATIONS TO EACH SYSTEM, PARTICULARLY IN THE ARRANGEMENT OF THE DRIVE. FOR EXAMPLE, THESE MAY BE EITHER HYDRAULIC CYLINDERS, OIL HYDRAULIC MOTORS, OR RACK AND PINION SYSTEMS.

WHETHER THE HYDRAULIC DRIVE COMES FROM A CYLINDER OR A MOTOR, NEED NOT CONCERN US HERE.

ALL THESE BRIDGE SYSTEMS HAVE ONE THING IN COMMON: WHEN OPENING OR CLOSING, THE LOAD IS CONTINUALLY VARIABLE IN BOTH DIRECTION AND VALUE. THE REASON FOR THIS IS THE WIND FORCES.

WHEN LAYING OUT THE HYDRAULIC DRIVE, THIS CHANGE OF LOAD MUST BE GIVEN DUE CONSIDERATION.

A FURTHER POINT WHICH IS COMMON TO ALL SYSTEMS IS THAT THE MOVING MASSES ARE VERY LARGE, AND ARE MOVED RELATIVELY FAST.

THESE CRITERIA DETERMINE THE HYDRAULIC SYSTEM USED.

2.2. SWING BRIDGES

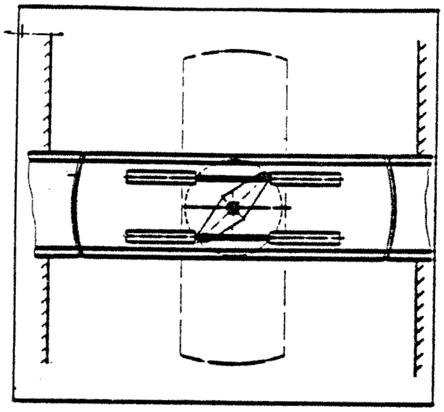


FIG. 9: SYMMETRICAL SWING BRIDGE

THE SWING BRIDGE SHOWN IN FIG. 9 IS A STEEL AND CONCRETE BRIDGE MOUNTED ON A KING-POST. THE DRIVE IS TRANSMITTED VIA FOUR SINGLE-ACTING CYLINDERS WORKING IN OPPOSED PAIRS.

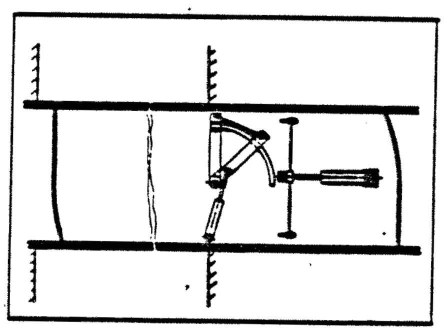


FIG. 10: ASYMMETRICAL SWING BRIDGE

THIS PARTICULAR BRIDGE IS SOMEWHAT SMALLER, BEING APPROXIMATELY 12 m WIDE. THE DRIVE IS VIA A DOUBLE-ACTING CYLINDER WORKING ON A TRIANGULAR LINKAGE.

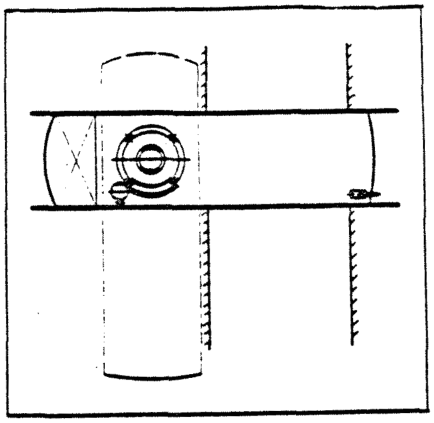


FIG. 11: ASYMMETRICAL SWING BRIDGE

THIS SWING BRIDGE OF APPROXIMATELY 40 m IN LENGTH IS ARRANGED AT ONE SIDE OF THE WATERWAY, AND IS MOUNTED ON A KINGPOST. IT IS FULLY COUNTERBALANCED. THE DRIVE IS VIA AN OIL HYDRAULIC MOTOR AND GEARBOX.

SWING BRIDGES HAVE THE SAME GENERAL CRITERIA WHICH MUST BE CONSIDERED:

A) REVERSING LOAD DIRECTION.

B) RELATIVELY LARGE MASSES AND SHORT OPERATIONAL TIMES.

C) BENDING UNDER THEIR OWN WEIGHT.

CRITERIA A) AND B) ARE IDENTICAL TO THOSE FOR BASCULE BRIDGES.

THERE IS NO SUCH THING AS AN ABSOLUTELY STIFF BRIDGE; ALL BRIDGES BEND SOMEWHAT DEPENDING ON THEIR DESIGN AND LENGTH. THIS MEANS THAT BEFORE BRIDGES CAN BE SWUNG OR LIFTED OUT OF THEIR REST POSITION, THEY MUST BE LIFTED SOMEWHAT. THERE ARE FURTHER SOLUTIONS AVAILABLE IN WHICH THE BRIDGES ARE ALLOWED TO SINK FROM THEIR ROAD USE POSITION.

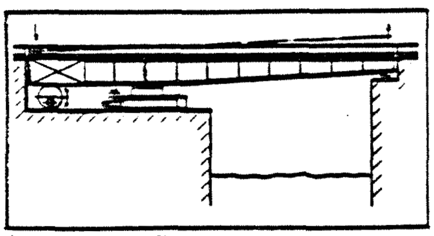


FIG. 12 SHOWS SIDE VIEW OF SWING BRIDGE ILLUSTRATED IN FIG.11

THE COUNTERBALANCE ARM IS ARRANGED ABOVE AN ECCENTRIC, ROTATION OF WHICH TIPS THE BRIDGE ABOUT THE KINGPOST. IN THIS CASE, THE COUNTERBALANCE WEIGHT WAS LARGER THAN THE WEIGHT OF THE BRIDGE ARM.

EVEN THIS OPERATION OF TIPPING THE BRIDGE MAY NOT BE CARRIED OUT SUDDENLY, DUE TO THE DANGER OF CAUSING THE BRIDGE TO OSCILLATE.

2.3. LIFTING BRIDGES

LIFTING BRIDGES - AND BY THIS WE MEAN PARALLEL LIFTING BRIDGES - HAVE THEIR OWN PARTICULAR PROBLEM IN THAT THE BRIDGE MUST LIFT LEVEL IN EACH DIRECTION. THIS PROBLEM IS GREATER: THE GREATER THE NUMBER OF CYLINDERS.

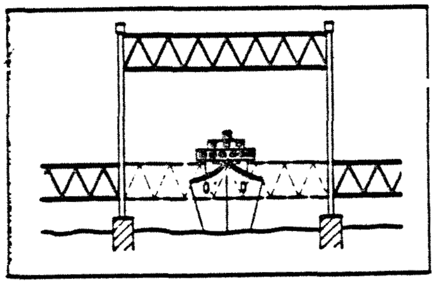


FIG. 13 LIFTING BRIDGE

THE PROBLEM HERE DOES NOT LIE WITH THE HYDRAULIC COMPONENTS, BUT WITH THE SYSTEM EMPLOYED FOR MEASURING MOVEMENT.

UP TO THE PRESENT TIME, PRACTICALLY ALL LIFTING BRIDGES WITH HYDRAULIC DRIVES HAVE A MECHANICALLY ENFORCED PARALLEL MOTION.

WITH MODERN COST, THIS BECOMES EXTREMELY EXPENSIVE. ON THE OTHER HAND, ELECTRICAL AND ELECTRONIC DEVICES ARE NOW AVAILABLE WHICH WILL MEASURE MOVEMENT EXTREMELY ACCURATELY AND AT THE SAME TIME WORK RELIABLY UNDER THE ROUGH CONDITIONS EXPERIENCED ON THIS TYPE OF INSTALLATION. THE CONVERSION OF THE SIGNALS GENERATED BY THESE MEASURING SYSTEMS IS ALSO EASILY OVERCOME USING MODERN TECHNIQUES.

OPERATIONAL RELIABILITY, HOWEVER, IS ANOTHER MATTER. WHILE ELECTRONIC CONTROLS REQUIRE HIGHLY SKILLED MAINTENANCE STAFF. NO COMPANY CAN HOLD SUCH STAFF IN READINESS. EITHER THE OPERATOR SOLVES THE PROBLEM HIMSELF, OR ALLOWS LONG DELAYS (AND INCURS HIGH COSTS) WAITING FOR THE RELEVANT SERVICE PERSON TO ARRIVE.

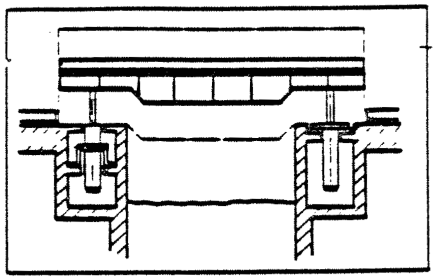


FIG. 14: LIFTING BRIDGE

ON LIFTING BRIDGES WITH MORE THAN 10 m STROKE, CYLINDER DRIVES ARE RULED OUT. ON THE LIFTING BRIDGE SHOWN IN FIG. 14, THE MAIN DRIVE WAS ELECTRO-MECHANICAL AND THE AUXILIARY DRIVES HYDRAULIC. THE MAIN DRIVE COULD ALSO BE CARRIED OUT HYDROSTATICALLY. THE ELECTROMECHANICAL DRIVE IS VERY EXPENSIVE BECAUSE THE ACCELERATION AND DECELERATION OF THE DRIVE MUST BE REGULATED DUE TO THE HIGH MASSES.

ON THE COAST, YET ANOTHER TYPE OF LIFTING BRIDGE IS TO BE FOUND, CONNECTING THE ROAD TO SHIPS OF VARIOUS TYPES. THESE ARE SO-CALLED "ROLL-ON/ROLL-OFF" BRIDGES.

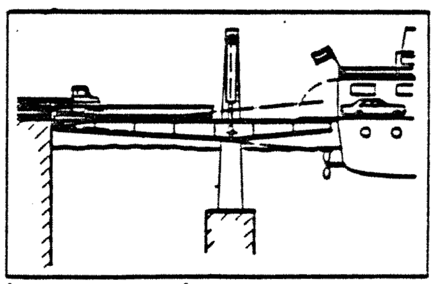


FIG. 15: ROLL-ON/ROLL-OFF BRIDGE

THESE MUST NOT ONLY CATER FOR THE DIFFERENCE IN THE LOADING OF THE VESSEL, BUT ALSO THE STATE OF THE TIDE.
IN THIS CASE, NOT ONLY MUST THE BRIDGE BE SET AT FIXED POSITIONS, BUT IT MUST BE ABLE TO HAVE ITS HEIGHT VARIED CONSTANTLY DURING LOADING AND UNLOADING. NORMALLY, THIS TYPE OF BRIDGE IS FITTED WITH A MOVING FLAP TO ALLOW VEHICLES TO PASS OVER MORE EASILY. LARGER FERRIES USUALLY HAVE THEIR OWN STERN FLAP WHICH CAN BE LAID ON THE ROLL-ON/ROLL-OFF BRIDGE.

ALL BRIDGE SYSTEMS SHOWN HERE SERVE ONLY AS A GENERAL GUIDE. VARIATIONS IN DESIGN AND DRIVE ARE NATURAL. THE SAME CRITERIA APPLIES TO THE GENERAL DESIGN OF THE HYDRAULIC SYSTEM.

3. HYDRAULIC DRIVES

WHEN DESIGNING AND SIZING A HYDRAULIC DRIVE, THE FOLLOWING CRITERIA IS USUALLY PREDOMINANT:

A) ABSOLUTE SAFETY OF LOADING OF THE DRIVE ACTUATORS IN ALL STATES OF OPERATION.
B) GENTLE ACCELERATION AND DECELERATION OF THE DRIVE IN ALL LOAD CONDITIONS
C) MONITORING OF THE DECELERATION PROCESS
D) HYDRAULIC UNLOADING OF THE DRIVE ACTUATORS IN THE STATIONARY POSITION
E) POSSIBLE SYNCHRONISING PROBLEMS, DEPENDING ON THE DESIGN OF THE BRIDGE

RE: A) ABSOLUTE SAFETY OF LOADING THE DRIVE ACTUATORS IN ALL STATES OF OPERATION

FIG. 16
FROM OUR EXPERIENCE, THIS FACTOR SHOULD BE STUDIED WITH THE GREATEST CARE BECAUSE THIS IS THE AREA IN WHICH LACK OF STUDY GIVES THE GREATEST PROBLEMS. INDEED, ONE COULD SAY THAT, IN ALL PROBABILITY, THIS WILL BE THE LIMITING FACTOR.

THE BASIS FOR THIS IS VERY SIMPLE: DEPENDING ON DESIGN, AND THIS APPLIES ABOVE ALL TO BASCULE BRIDGES, THE LOADING ON THE BRIDGE ARM ALTERS WITH ITS MOVEMENT.

IN ADDITION, CONSIDERABLE CHANGES IN LOAD MUST BE CONSIDERED WITH WIND LOADING. THIS ALSO APPLIES TO SWING BRIDGES. THIS WIND LOADING IN BOTH DIRECTIONS AND VALUE CANNOT BE ACCURATELY CALCULATED. IN ORDER TO ENSURE IMPECABLE OPERATION, THE CURRENT PRACTICE IS TO CALCULATE THE DRIVE POWER FOR MAXIMUM WIND LOADING UP TO HURRICANE STRENGTH.

HOWEVER, NOT ONLY THE WIND LOADING MUST BE TAKEN INTO CONSIDERATION FOR DRIVE POWER, BUT ALSO THE ROAD LOADING, TOGETHER WITH SNOW OR ICE LOADING. IN THE CASE OF A LARGE MOTORWAY BASCULE BRIDGE, IT WAS AT ONE TIME ASSUMED THAT THE SNOW COULD SLIDE OFF ON ITS OWN ACCORD AT 75 DEGREE OPENING. THIS WAS NOT ALWAYS THE CASE. FROM THIS, ONE CAN SEE THAT RELATIVELY LARGE, SUDDEN LOAD CHANGES CAN TAKE PLACE.

THEORETICALLY, ALL OF THE FOLLOWING FACTORS CAN OCCUR TOGETHER ON BASCULE BRIDGES:

1. LOAD REVERSAL FROM PULL TO PUSH, ORIGINATING IN THE DESIGN.
2. ADDITIONAL APPLIED WIND LOADING.
3. SLIDING SNOW OR FIRMLY FROZEN SNOW.
4. WORN ROAD SURFACE.

FOR THESE REASONS, THE DRIVE ACTUATOR - WHETHER LINEAR OR ROTARY - MUST BE APPLIED WELL WITHIN THEIR PERFORMANCE LIMITS.

SATISFACTORY PRELOADING OF THE HYDRAULIC ACTUATORS CAN TAKE TWO FORMS:

A) BY USING SO-CALLED BRAKING VALVES (MOTION CONTROL VALVES) IN OPEN CIRCUIT
   OR
B) BY APPLYING THE PUMP AND ACTUATOR IN CLOSED CIRCUIT.

FROM OUR POINT OF VIEW, THERE CAN BE NO DISCUSSION WHETHER TO GO FOR OPEN OR CLOSED LOOP CIRCUITS.

FIG. 17

WE SUGGEST QUITE CLEARLY GOING FOR OPEN CIRCUIT FOR THE FOLLOWING REASONS:

A) COST
B) PURELY PHYSICAL

IN ORDER TO ACHIEVE A 'THOROUGHBRED" CLOSED CIRCUT, CYLINDERS ARE REQUIRED WITH EQUAL AREAS EACH SIDE. AS THESE MUST ALSO HAVE STAINLESS STEEL RODS, THEY BECOME CONSIDERABLY MORE EXPENSIVE AND WHEN UNDERGROUND REQUIRE MORE SPACE WHICH CAN IN TURN LEAD TO A FURTHER INCREASE IN COSTS.

THESE ADVANTAGES COULD BE ACCEPTED IF CLOSED LOOP OPERATION WERE TO BRING IMPORTANT ADVANTAGES. FURTHER CONSIDERATION, HOWEVER, ONLY CONFIRMS THAT CLOSED CIRCUITS ONLY BRING DISADVANTAGES.

A POINT WHICH IS OVERLOOKED EVEN TODAY IS THE COMPRESSIBILITY OF THE HYDRAULIC FLUID. THERE ARE VARIOUS COMPLICATED METHODS OF CALCULATING THIS, WHICH ARE STILL INACCURATE, AS A VARIETY OF FACTORS MUST BE TAKEN INTO CONSIDERATION. FROM PRACTICAL EXPERIENCE, HOWEVER, WE KNOW THAT THE VOLUME CHANGE MUST BE CALCULATED AT APPROXIMATELY 1.5 PERCENT TO 2 PERCENT PER 100 BAR.

THE REAL DISADVANTAGE OF A CLOSED LOOP, HOWEVER, LIES IN THE DISTANCE BETWEEN PUMP AND DRIVE CYLINDER, WHICH IS OFTEN CONSIDERABLE. THIS IN TURN MEANS THAT THE VOLUME OF THE PIPING SYSTEM AND THE ELASTICITY IN THE PIPES AND HOSES MUST BE ADDED TOGETHER AND CONSIDERED AS A WHOLE.
WITH LOAD REVERSAL, THE PUMP BECOMES A MOTOR, WHICH MEANS THAT THE ELECTRIC MOTOR NO LONGER DRIVES THE PUMP, BUT MUST ACT AS A BRAKE.

IN ACHIEVING THIS, THE SPEED OF THE MOTOR ALTERS CONSIDERABLY - FOR EXAMPLE, FOR A MOTOR OF 20 KW CAPACITY AND NOMINAL SPEED OF 1500 RPM, THE LIMITING SPEED VALUES LIE BETWEEN 1460 RPM AND 1540 RPM, i.e. APPROXIMATELY 5 PERCENT SPEED CHANGE.

THESE THREE PHYSICAL CHARACTERISTICS, WHEN CONSIDERED IN CONJUNCTION WITH SHORT-TERM EXTREME LOAD VARIATIONS, LEAD TO VARYING DEGREES OF OSCILLATION OF THE WHOLE DRIVE SYSTEM.

IN OPEN CIRCUITS, THESE EFFECTS ARE TO A LARGE EXTENT ELIMINATED BY THE INSTALLATION OF BRAKING VALVES (OVER-CENTER VALVES) IMMEDIATELY ADJACENT TO THE DRIVE CYLINDER. AT NO POINT DOES THE PRESSURE DROP TO ZERO, BUT DEPENDENT ON THE DEVICE REMAINS AT A MINIMUM PRESSURE OF 20 TO 30 BAR.

RE: B) GENTLE ACCELERATION AND DECELERATION OF THE DRIVE IN ALL LOAD CONDITIONS

BECAUSE BASCULE BRIDGES AND SWING BRIDGES ARE NOT NORMALLY LIGHT-WEIGHT OBJECTS, THE ACCELERATION AND DECELERATION PROCESSES MUST BE GENTLE AND FREE OF SHOCK. IN SMALLER INSTALLATIONS, SAY UP TO MAX. 15 KW, THIS CAN BE ACHIEVED WITH FIXED PUMPS AND REGULATING DEVICES. FOR HIGHER POWERS, VARIABLE PUMPS ARE REQUIRED, IN ORDER TO AVOID UNNECESSARY LOSS OF ENERGY.

ONLY THOSE CONTROL DEVICES WHICH WORK INDEPENDENT OF LOAD MAY BE CONSIDERED. ALL AUTOMATIC REGULATING DEVICES ARE RULED OUT, BECAUSE THE OUTPUT FLOW OF THE PUMP ALTERS IN AN UNCONTROLLED MANNER.

NORMALLY, WE CONTROL THE PUMP OUTPUT BY MEANS OF GEAR MOTORS OR, FOR EXTREMELY SHORT CONTROL TIMES, BY PROPORTIONAL SOLENOIDS.

POWER LIMITING REGULATORS ARE NOT SUITABLE AS THESE AUTOMATICALLY REACT TO EVERY CHANGE IN LOAD.

IF, THEREFORE, THE POWER MUST BE LIMITED, THEN THE OPERATIONAL TIME MUST BE EXTENDED. IT IS CLEARLY SELDOM THE CASE THAT ALL LOAD INFLUENCES OCCUR CONTINUOUSLY AND SIMULTANEOUSLY. IN ADDITION, A DOUBLING OF THE OPERATIONAL TIME - E.G. FROM 2 TO 4 MINUTES - HAS LITTLE EFFECT ON THE TRAFFIC FOR MANY BRIDGES. IT SHOULD THEREFORE BE GENERALLY CONSIDERED WHETHER SHORT OPERATIONAL TIMES ARE ACTUALLY REQUIRED BECAUSE IT CAN BE BROADLY STATED THAT FOR HYDRAULICS.

OIL VOLUME (Q) COSTS MONEY
PRESSURE (p) IS FREE (ALMOST).

RE: C) MONITORING OF THE DECELERATION PROCESS

MUCH MORE CRITICAL THAN ACCELERATION IS DECELERATION.

THE BASIS FOR THIS IS CLEAR AND ARISES FROM THE DANGER THAT THE PUMPS, DUE TO SOME FAILURE, DO NOT SWIVEL TO ZERO. THIS MEANS THAT RELATIVELY LARGE MASSES COULD THEN DRIVE COMPLETELY UNBRAKED AGAINST FIXED STOPS.

WHAT CAN THEN OCCUR NEEDS NO FURTHER EXPLANATION.

WE SOLVE THIS PROBLEM BY FITTING LIMIT SWITCHES DIRECTLY ON TO THE SWIVELLING PORTION OF THE PUMP, TO MONITOR THE SWIVEL TOWARDS ZERO. SHOULD THE PUMP AT A CERTAIN TIME "X" NOT HAVE SWIVELLED BACK TOWARDS ZERO, AN EMERGENCY STOP IS IMMEDIATELY CARRIED OUT. DURING SUCH AN EMERGENCY STOP, OR SHOULD THE MAIN POWER FAIL, CONSIDERABLE PRESSURE PEAKS OCCUR. FOR THIS REASON, INSTALLATION OF SECONDARY PRESSURE RELIEF VALVES IS ALWAYS NECESSARY.

THESE PRESSURE VALVES ARE OFTEN INCORRECTLY SELECTED FOR PRESSURE WHICH CAN OCCUR IN NORMAL OPERATION. THIS, HOWEVER, LEADS TO UNCONTROLLED RUNAWAY OF THE DRIVE.

<u>THESE VALVES MUST BE SET ABOVE THE MAXIMUM PRESSURES OCCURRING (APPROXIMATELY 10 PERCENT SO THAT THEY ONLY COME INTO FUNCTION ON EMERGENCIES)</u>.

FIG. 18

A FURTHER SOLUTION IS THE INSTALLATION OF MECHANICALLY OPERATED DECELERATION VALVES FOR EMERGENCIES.

THESE DECELERATION VALVES ARE SET APPROX. 2 - 5 PERCENT HIGHER THAN THEIR BRAKING CHARACTERISTICS WOULD BE FOR NORMAL OPERATION. THE MAXIMUM POSSIBLE FLOW IS SET AT THE DEVICE, AND THE DECELERATION PHASE ITSELF IS DETERMINED TO GIVE A LINEAR DECELERATION.

SHOULD THE PUMP NOT SWIVEL BACK TO ZERO, THE BRIDGE WILL BE DECELERATED IN SPITE OF THIS, BUT WITH A 2 - 5 PERCENT HIGHER RATE OF DECELERATION.

IN THIS WAY, IT IS ENSURED THAT THE BRIDGE ALWAYS DECELERATES IN AN ORDERLY MANNER, NO MATTER WHAT ELECTRICAL FAILURE OCCURS.

THE PRESSURE OIL SUPPLY IS VIA THE AXIAL PISTON PUMP SETS. THE PUMP OUTPUTS ARE CONTROLLED ELECTRICALLY, AND ARE SO DESIGNED THAT, SHOULD ONE PUMP SET FAIL, THE BRIDGE MAY BE DRIVEN AT HALF SPEED. THE SAME IS TRUE FOR THE CYLINDERS, AS THESE ARE SIZED SUCH THAT ONE CYLINDER MAY DRIVE THE BRIDGE IN AN EMERGENCY. IN THIS CASE, A TWO-STAGE PRESSURE RELIEF VALVE IS INSTALLED IN THE POWER UNIT FOR PRESSURE RELIEF.

THE MOST IMPORTANT PART OF THE CONTROL IS ONCE MORE THE SAFETY DEVICES WHICH ARE INSTALLED TO PREVENT DAMAGE TO THE BRIDGE.

IN A SIMILAR MANNER TO OUR BASCULE BRIDGE DRIVES, WE HAVE ALSO INCORPORATED A MONITOR ON THE PUMP RETURN SWIVEL. IF THE MAXIMUM SETTING OF THE PUMP IS NOT REDUCED AFTER A SET TIME "X" AFTER THE INTRODUCTION OF THE DECELERATION PHASE, AN EMERGENCY STOP IS NOT ENGAGED IN THIS CASE, BUT THE CONTROL IS SWITCHED TO HAND OPERATION AND THE DRIVE SWITCHED OFF. THE BRIDGE STOPS, IN FACT, AS IF IN AN EMERGENCY BUT CAN, HOWEVER, ONLY BE DRIVEN INTO ITS END POSITION BY HAND CONTROL. ONLY AFTER CORRECTING THE FAILURE CAN THE SYSTEM ONCE MORE BE SWITCHED TO AUTOMATIC. OVERALL SAFETY IS THEREFORE BUILT IN.

WHEN OVERRIDING,THE END POSITION IS BROUGHT ABOUT BY THE FAILURE OF THE ELECTRICS, HYDRAULICALLY OPERATED DIRECTIONAL VALVES ARE OPERATED, WHICH EFFECTIVELY ACHIEVE THE REVERSAL OF THE MAIN CONTROL VALVE AND REVERSE THE DIRECTION OF THE DRIVE CYLINDERS.

IN THIS CASE, THE SECONDARY RELIEF VALVES OPERATE UNTIL THE AVAILABLE ENERGY IS DISSIPATED AND THE CONTROL THEN REVERTS TO THE LOCKED POSITION.

FIG. 19

RE: D) UNLOADING IN THE STATIONARY POSITION

PARTICULARLY WITH BASCULE BRIDGES HAVING WIDE SPANS, OSCILLATIONS OCCUR DUE TO THE PASSAGE OF VEHICLES. BECAUSE THE DRIVE CYLINDERS ARE NORMALLY CONNECTED DIRECTLY UNDER THE BASCULES, THESE OSCILLATIONS ARE CARRIED THROUGH TO THE CYLINDERS, WHICH IN TURN ACT AS PISTON PUMPS. IN ORDER TO PREVENT THIS HAVING AN ADVERSE EFFECT, SUITABLE SHORT CIRCUITS AND ANTI-CAVITATION VALVES MUST BE INSTALLED.

RE: E) SYNCHRONIZATION PROBLEMS

WITH BRIDGES OF KNOWN CONSTRUCTION, EITHER BASCULE OR SWING TYPE, SYNCHRONIZATION IS MECHANICALLY ENFORCED.

THIS MEANS THAT FOR THE HYDRAULIC ENGINEER NO OTHER FORM OF DEVICE IS REQUIRED IN ORDER TO ENFORCE HYDRAULIC SYNCHRONIZATION, WHICH WOULD OTHERWISE LEAD TO AN INCREASED WEAR OF THE MECHANICAL DRIVE ELEMENTS.

IT IS THEREFORE SENSIBLE TO ENSURE THAT THE OIL VOLUMES ARE UNHINDERED IN THEIR EQUAL DIVISION TO THE DRIVE CYLINDERS.

WITH ROTARY BRIDGES, THERE ARE FURTHER CHARACTERISTICS WHICH MUST BE TAKEN INTO CONSIDERATION.

BECAUSE ALL BRIDGES BEND TO A GREATER OR LESSER EXTENT UNDER THEIR OWN WEIGHT, THEY MUST - BEFORE THE SWIVELLING OR SLEWING TAKES PLACE - BE LIFTED OUT OF OR LOWERED FROM THEIR REST POSITION.

THIS IS CARRIED OUT IN A NUMBER OF WAYS, WITH EXCENTERS, TAPER LOCKS, ETC. EVEN HERE, IT IS ADVISABLE TO REGULATE THIS OPERATION IN ORDER TO PREVENT OSCILLATIONS OF THE BRIDGE. WHEN USING EXCENTERS, THERE IS THE DANGER OF LOAD REVERSAL, AND TENSIONING OF THE DRIVE CYLINDER IS ADVISABLE. A FULL EXPLANATION OF THE HYDRAULIC DRIVES FOR THESE OPERATIONS, AND ALSO FOR THE MULTIPLICITY OF LOCKING SYSTEMS WILL BE AVOIDED HERE AS THE SUBJECT IS TOO BROAD.

3.1. LIFTING BRIDGES

LIFTING BRIDGES WITH HYDRAULIC DRIVES ARE AN EXCEPTION. THE BASIS FOR THIS IS THE PROBLEM OF SYNCHRONIZATION. THIS PROBLEM BECOMES GREATER, THE GREATER THE NUMBER OF CYLINDERS EMPLOYED. THE PROBLEM LIES NOT SO MUCH IN THE HYDRAULIC PARTS, BUT IN THE DISTANCE MEASURING SYSTEM.

WE HAVE THEREFORE DEVELOPED A SYNCHRONIZATION CONTROL WHICH GUARANTEES AN EXTREMELY HIGH DEGREE OF SYNCHRONIZATIONAL ACCURACY, WITHOUT RESORTING TO ELECTRONICS. WE HAVE ALREADY EQUIPPED A NUMBER OF DIFFERENT INSTALLATIONS, E.G. LIFTING AND SWINGING GATES WITH THIS SYSTEM.

IN A VARIATION OF THIS SYSTEM FOR A LIFTING BRIDGE, A TOTAL OF SIX HYDRAULIC CYLINDERS IS INSTALLED, IN WHICH THE SYNCHRONIZATION OF THREE CYLINDERS IS CONTROLLED. THE SYNCHRONIZATION OF THE TWO CYLINDER GROUPS, LEFT AND RIGHT, IS ELECTRICALLY MONITORED, AND DEPENDENT UPON THE DEGREE OF ERROR, THE RELEVANT PUMP GROUP IS REGULATED.

FIG. 20: CIRCUIT DIAGRAM FOR A LIFTING BRIDGE
IN ORDER TO GUARANTEE SYNCHRONIZATION OF THE CYLINDERS, EACH OF THE THREE CYLINDERS IS RELATED TO A MOTOR/PUMP GROUP. THE PUMPS ARE SWIVELLED ON A COMMON PUMP CONTROL ROD.

A SMALL QUANTITY OF OIL IS METERED OUT FROM THE PRESSURE LINE OF THE OUTER CYLINDERS. THIS MEANS THAT THE CENTER CYLINDER IS ALWAYS FORCED TO MOVE SLIGHTLY IN ADVANCE. THE MOVEMENT OF THE CYLINDERS IS TRANSMITTED TO A ROTARY TRANSMITTER VIA A CHAIN AND COUNTERWEIGHT. THE VALUE TAKEN FROM THIS IS COMPARED IN A DIFFERENTIAL RECEIVER.

WHEN A DIFFERENCE OCCURS BETWEEN THE TWO OUTER CYLINDERS AND THE CENTER LEADING CYLINDER, THE DIFFERENTIAL RECEIVER TURNS A VALVE, WHICH ALLOWS THE OIL VOLUME TO BE MADE UP BY MEANS OF A SECONDARY FEED PUMP. SHOULD A CYLINDER ADVANCE TOO FAR, THE EXTRA VOLUME IS METERED OUT TO TANK.

WHEN LIFTING, THE OIL BEING RETURNED FROM THE CYLINDER ANNULUS IS FED DIRECT TO THE PUMP, AND THE EXTRA OIL REQUIRED (THE ROD VOLUME) IS SUCKED FROM THE TANK.

WHEN LOWERING, THE PUMP IS SWIVELLED IN THE OPPOSITE DIRECTION, AND THE BRIDGE IS SUPPORTED BY THE ELECTRIC MOTOR DURING THE LOWERING OPERATION. THE ANNULUS VOLUME IS LIGHTLY PRE-LOADED TO ENSURE COMPLETE FILLING, AND THE EXCESS OIL (ROD VOLUME) IS FED BACK TO TANK.

FOR SAFETY, PILOT OPERATED CHECK VALVES ARE FLANGED DIRECTLY ONTO THE CYLINDERS. THESE VALVES ARE, IN FACT, ARRANGED AS TWINNED PAIRS, MONITORED BY LIMIT SWITCHES TO ALLOW FOR REDUNDANCY. FOR SAFETY DURING AN EMERGENCY SITUATION, EACH CYLINDER IS EQUIPPED WITH AN OVERRIDE PRESSURE RELIEF VALVE.

TO GIVE SYNCHRONIZATION OF THE TWO ENDS OF THE BRIDGE, THE PUMP CONTROL CYLINDER IS CONTROLLED BY A PROPORTIONAL VALVE.

THE POSITION OF THE TWO CONTROL CYLINDERS, AND WITH IT THE SWIVEL ANGLE AND OUTPUT FLOW OF THE PUMP, IS FED BACK INTO AN ELECTRONIC SYNCHRONIZATION LOOP, THUS ENSURING THAT THE PUMPS ON THE TWO ENDS OF THE BRIDGE HAVE PRACTICALLY THE SAME OUTPUT FLOWS.

IN CONTRAST TO BASCULE AND SWING BRIDGES, NO CHANGE OF LOAD IS POSSIBLE WITH LIFTING BRIDGES. HYDRAULIC TENSIONING IS THEREFORE UNNECESSARY.

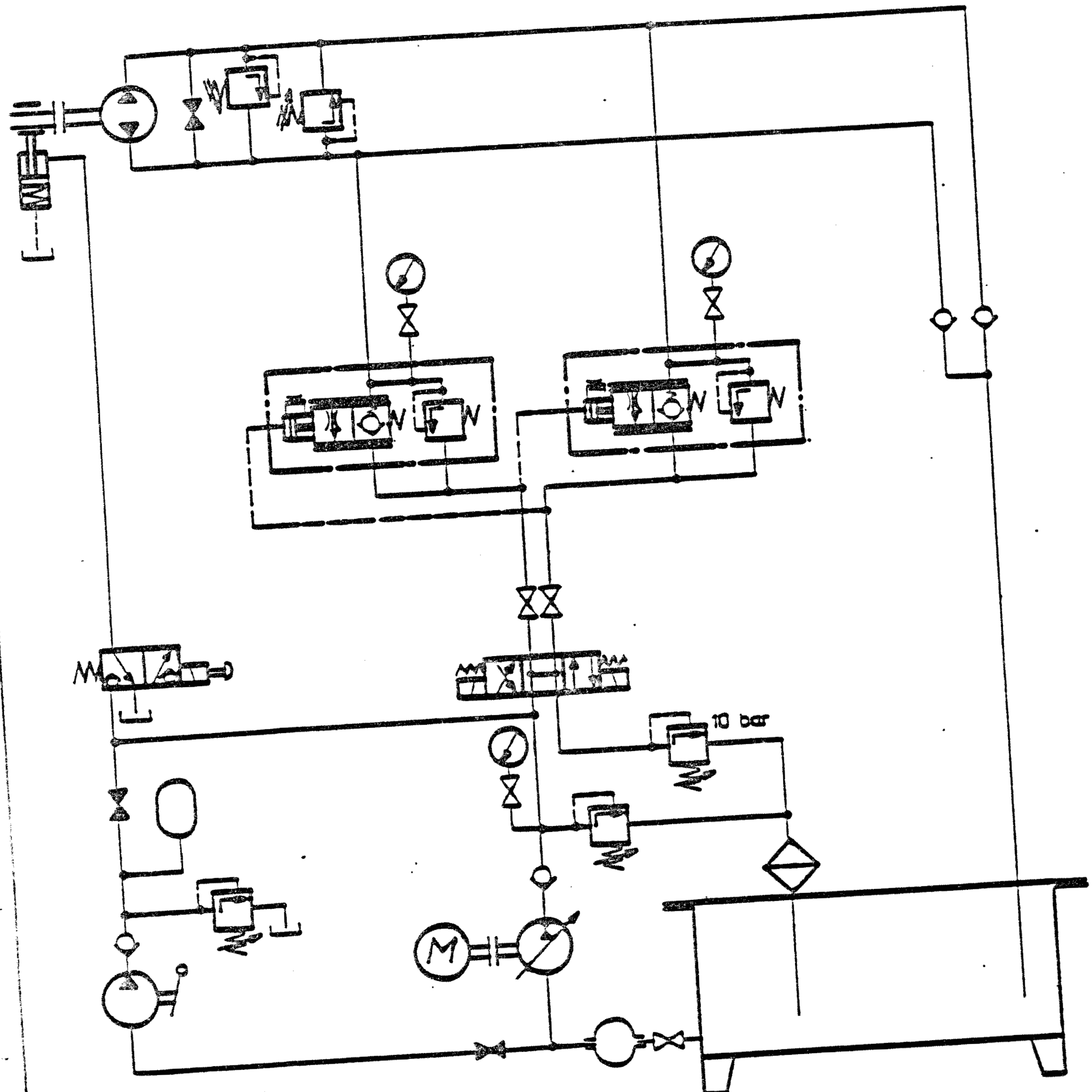

10 bar

Fig. 17

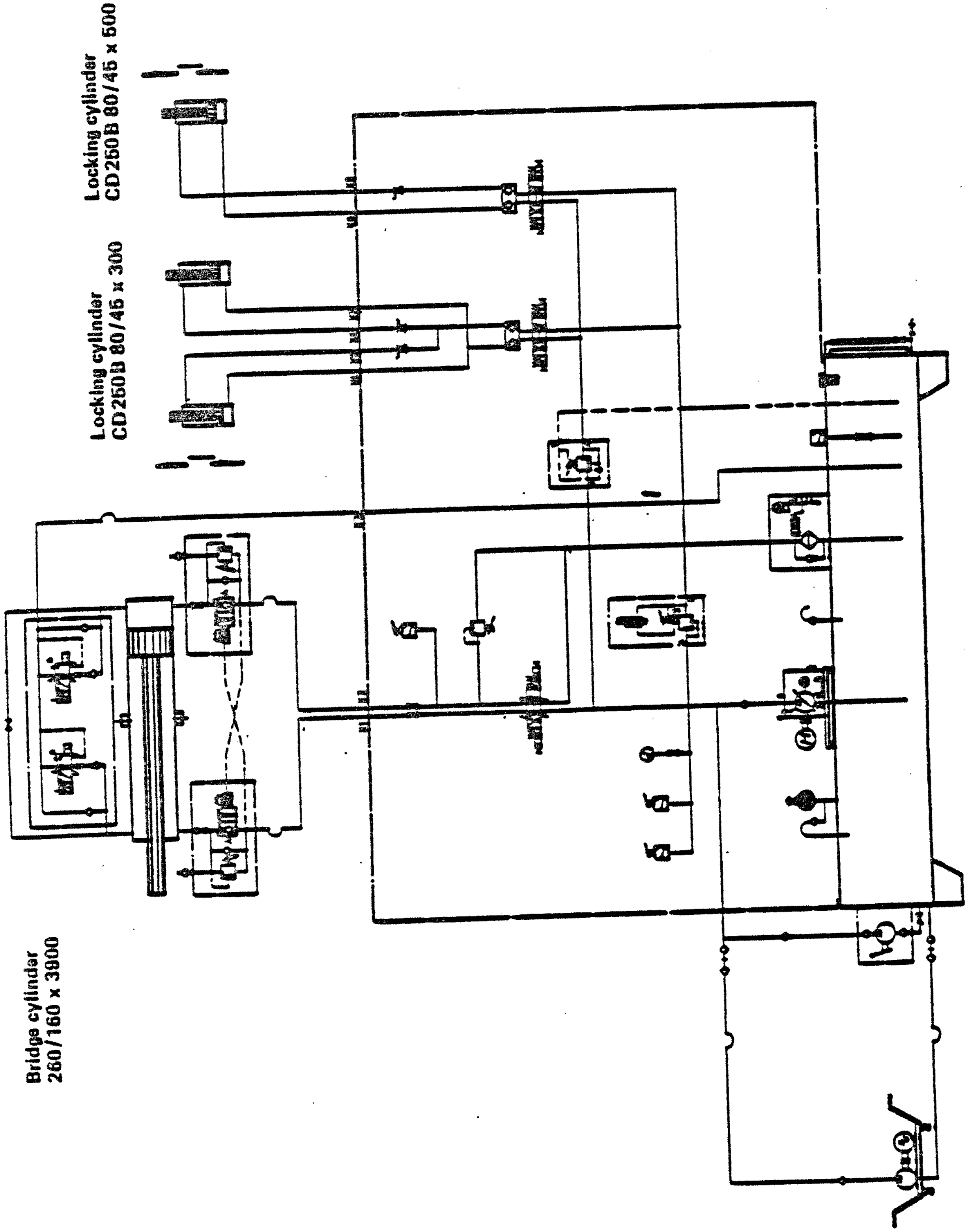

Locking cylinder
CD250B 80/45 x 500
Locking cylinder
CD250B 80/45 x 300
Bridge cylinder
260/160 x 3800

Fig. 18

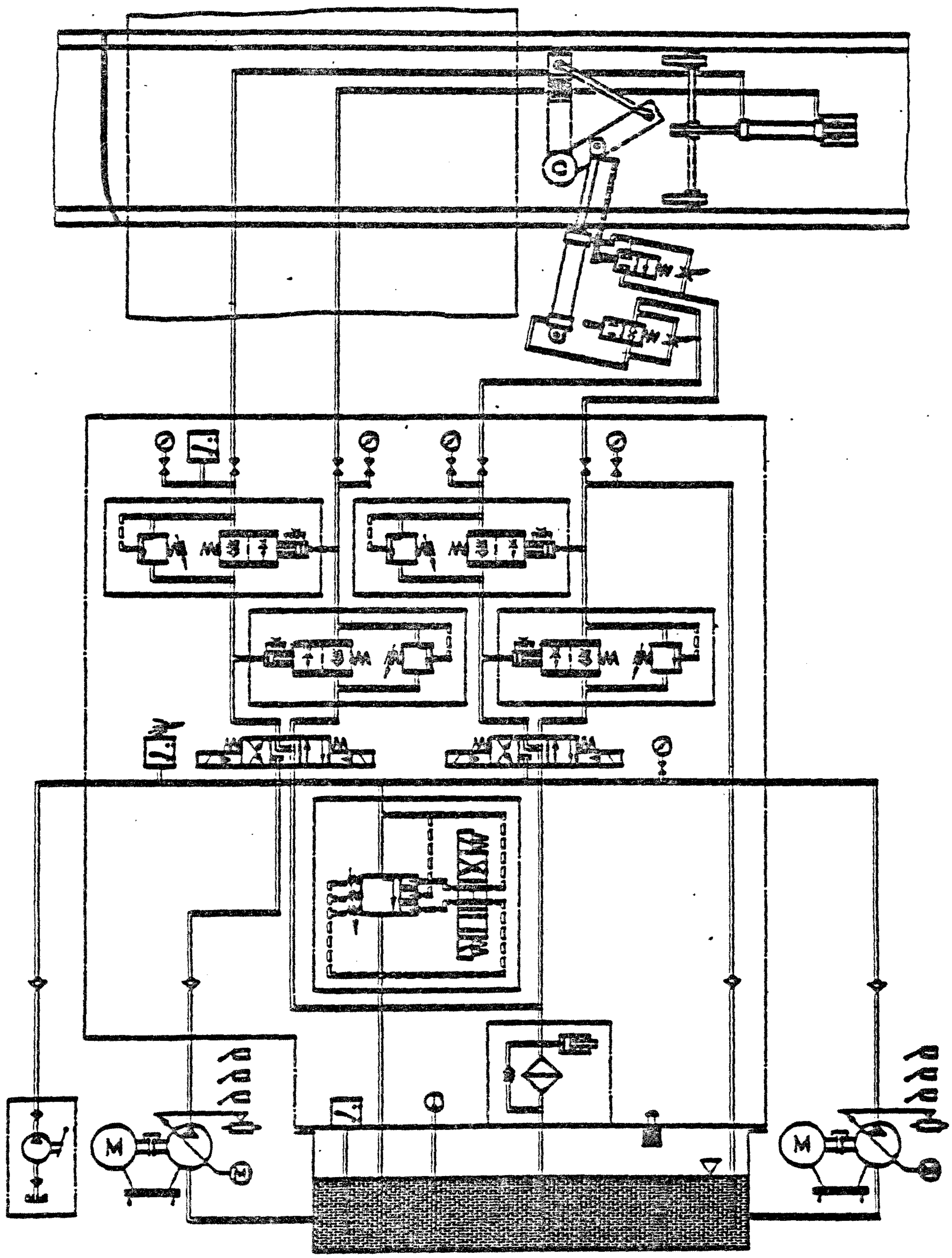


Fig. 13

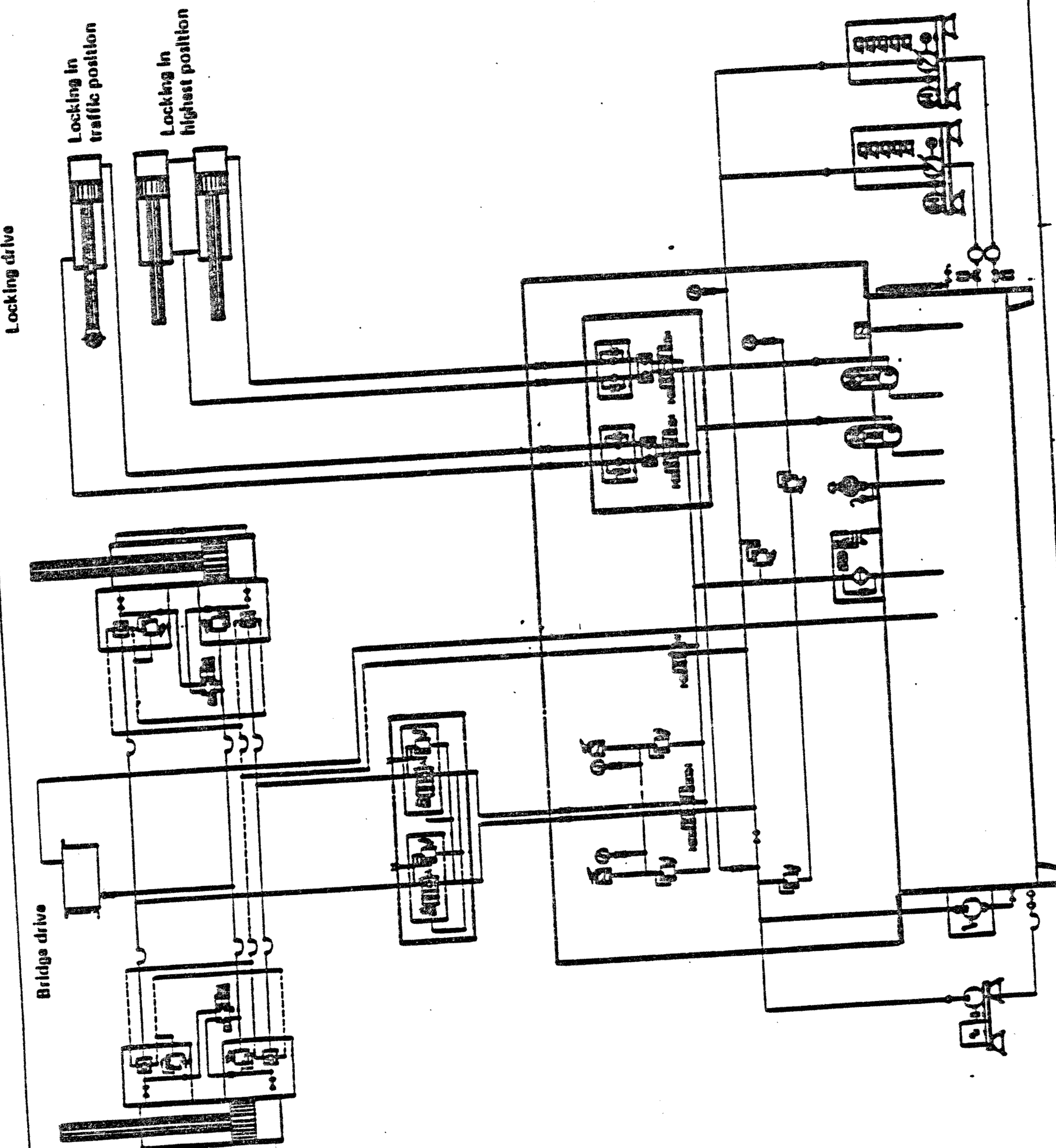

Locking drive
Locking in traffic position
Locking in highest position
Bridge drive

Fig. 20

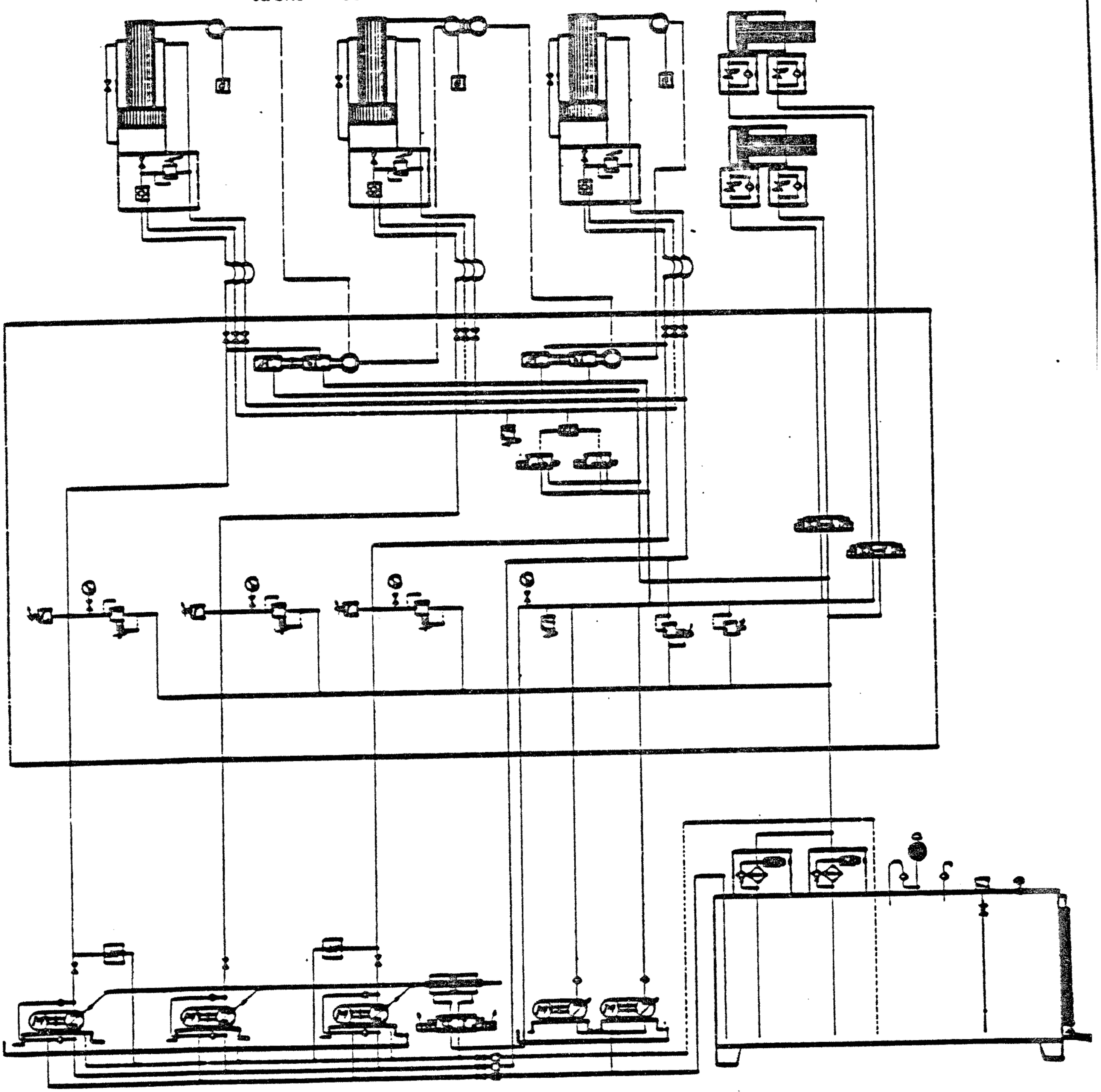
Cylinder dimensions

piston dia. 320
rod dia. 200
stroke 3500

Lefthand Side of Bridge

Cylinder dimensions

piston dia. 80
rod dia. 56
stroke 500



P = 162 bar
Q = 374 L/min (306 L/min)
n = 1450 rpm
N = 110 kW (90 kW)

P = 170 bar
Q = 25 L/min
n = 14[illegible] rpm
N = 7.5 kW

S U M M A R Y

THE PRECEDING PAPER DID IN NO WAY COVER ALL THE VARIABLES WHICH MUST BE CONSIDERED IN THE PROPER DESIGN AND APPLICATION OF HYDRAULICS IN MOVABLE BRIDGES.

BUT HYDRAULIC DRIVES OFFER THE FOLLOWING ADVANTAGES:

1. EXCELLENT POWER TO WEIGHT RATIO OF PRIME MOVER
2. EXCELLENT WAYS OF DRIVE POWER CONSERVATION
3. EXCELLENT MEANS OF COMBINING EFFECTIVE CONTROL DEVICES FOR OPERATION AND SAFETY PURPOSE
4. EFFICIENT APPLICATIONS OF REDUNDANCY
5. PROVISIONS OF A HYDRAULICALLY "STIFF SYSTEM", YET EXCELLENT SUITABLE TO PROVIDE "FLEXIBILITY" TO MINIMIZE MECHANICAL WEAR AND DAMAGE.
6. EASY INTERFACE OF PUMP OR VALVE CONTROLS WITH P.C. UNITS
7. ECONOMICAL IN ORIGINAL EQUIPMENT SUPPLY AND MAINTAINABILITY

TO ACHIEVE THE DESIRED RESULTS IN TROUBLE-FREE HYDRAULIC BRIDGE OPERATIONS, THE HYDRAULIC SYSTEM EQUIPMENT SUPPLIER MUST BE INVOLVED AT THE ONSET OF THE ENGINEERING AND DESIGN STATE TO CONTRIBUTE HIS EXPERTISE NOT ONLY FROM A COMPONENT VIEW ON PUMPS-VALVES-ACTUATORS, BUT MORE SO ON THE OVERALL WORKING AND OPERATION RELATION OF A WHOLE BRIDGE SYSTEM.

THE HYDRAULIC SYSTEM SUPPLIER, WITH HIS KNOWLEDGE AS A SYSTEMS ENGINEER, MUST BE REGARDED A PROFESSIONAL, SHARING HIS KNOW-HOW WITH THE PROFESSIONS REPRESENTED AT OWNER AND OPERATORS, ENGINEERING AND CONSULTING COMPANIES, GENERAL CONTRACTORS, AS WELL AS AGENCIES INVOLVED IN PREPARATIONS OF SPECIFICATIONS.

WE WISH TO PARTICIPATE IN THE RESPONSIBILITY AND THE SUCCESS OF HYDRAULICALLY OPERATED MOVABLE BRIDGES.