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OPERATION AND MAINTENANCE OF HOISTING EQUIPMENT FOR FLOOD GATES FOR LOCKS AND DAMS

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INTRODUCTION

The unobstructed operation of the flood gates of any water project is of utmost importance. The choice of the type of gate and its operating mechanism is critical for that reason. For the low head flood gates (spillway gates) of navigation locks and dams, which are usually quite wide (100 ft. or more), the conventional choices include roller, tainter, vertical lift or hinged crest types for the gates, and chain, wire rope, screw stem or hydraulic types for the hoists. The operation and maintenance of each type is unique and each type presents certain advantages and disadvantages. The primary considerations for the selection of the gate type include gate size requirement, expected flows, efficiency of discharge, passage of floating debris, and initial cost;

the primary considerations for hoist selection include ease of operation, adjustability of hoisting capacity, ease of maintenance, initial cost, and operation and maintenance costs as compared to the initial cost.

Depending on the hoisting capacity requirement and the installation convenience, any hoist type may be used with any gate type. However, it is worth mentioning that the hydraulic type hoists, with the developments in recent years in the fluid power industry in U.S.A. and abroad, generally present the most flexibility in operation (speed variation, push/pull capability, hoisting capacity adjustability), are the easiest to maintain (long life of parts, ready availability of parts) and are generally more economical (due to industry developments leading to economical systems and competition between a vast number of manufacturers) in initial cost and in the operation and maintenance cost than the other types. This article describes the operation and maintenance details of each type of hoist, indicating comparative advantages and disadvantages including cost comparison.

TYPES OF GATES

The main gate types used for lock and dam flood control include:

1. Roller Gate
2. Tainter Gate
3. Vertical Lift Gate
4. Hinged Crest Gate

A roller gate which consists of a cylindrical plate steel roller approximately as large in diameter as the spillway opening height, and includes a heavy annular ring casting with peripheral teeth (to facilitate hoisting) at each end of the roller. A roller gate is more expensive to fabricate than a vertical lift, radial or a hinged crest gate. Also its hoisting arrangement which typically includes a heavy chain and a sloping rack (along which the gate moves, with the roller side teeth engaging the rack), is quite complicated and expensive. A roller gate can be conveniently lowered partially below the crest for passage of ice and debris; the cylindrical shape of the gate results in smooth flow above the gate and practically a vibration free gate. Because of the cost associated with them, hardly any roller gates have been installed in recent years. Fig. 1 shows a typical roller gate.

A *tainter gate*, also called a radial gate, is in the form of a cylindrical segment supported by structural columns, called gate arms, which in turn are supported by gate trunnions and trunnion support girders embedded in concrete piers. Figs. 2a to 2d show typical tainter gates. Tainter gates are generally simple in construction, reliable and efficient in the passage of the floods, especially large floods. They are also quite economical as compared to the other types, except when the height of the opening is small, say, less than 15 ft. In cases where the installation requires depression of the gate for passage of ice or debris, the gate skinplate is extended to form a suitable crest (Fig. 2e) or alternatively, the gate is equipped with a flap (Fig. 2f); both of these options considerably add to the cost of the gate, especially in proportion to the cost of the smaller gates. If skinplate modification or a flap is not provided, the gate must be raised above the upstream water level for passage of ice and debris, which can waste a lot of water; lowering a gate which does not have skinplate modification would cause negative pressures downstream of the gate and severe vibrations. Even a modified gate may not be vibration free in all cases and because of that uncertainty, the practice of depressing the gate is generally being discontinued for new installations; also some of the existing installations are being modified to conventional crest shapes. Since the tailwater level is relatively high for the lock and dam flood gates, tainter gates must be installed in such a way that the gate trunnion is above the tailwater level to guard against damage due to floating debris and ice; this causes an increase in the curved height of the gate for a given vertical opening, causing further increase in gate cost. Even with the added costs stated above, radial gates are frequently used because of their reliability and efficiency; also the overall cost including the added costs may be less than the overall cost of other types because other types also are affected by additions required to improve gate operation. Radial gates can be conveniently equipped with wire rope, chain or hydraulic hoist.

Vertical lift gates require a flatter crest than radial gates to avoid negative pressure downstream of the gate; the flatter crest has a lower coefficient of discharge and therefore for a given discharge, the size (width/height) of a vertical lift gate is generally larger than that of the radial and other type gates. The greater size of the gate and greater amount of concrete required for a flatter crest result in excessive cost for a vertical gate installation. To pass the ice and debris, vertical gate is usually provided in 2 sections, a smaller upper section and a larger lower section. Only the upper section is raised while passing the ice and debris. Lowering a vertical gate below the crest for passage of ice and debris from above the gate is not desirable, because a relatively large opening required in the crest for a vertical gate would cause substantial disruption of the flow. Passage of flow above the gate would cause severe vibrations of the gate. Large (specially very wide) vertical lift gates should preferably be equipped with wire rope hoists, because it is not easy to synchronize the two point lifting with hydraulic cylinders. Hydraulic proportional valves could be used to achieve the synchronization, but they are expensive and would generally result in excessive cost for the hoisting equipment. Vertical gates are preferable where the tailwater approaches the headwater level. Fig. 3 shows a typical vertical lift gate.

Hinged crest gates are preferable where the opening height is relatively small, say less than 15 ft. Figs 4a and 4b show typical hinged crest gate installations. Hinged crest gates can be fabricated in exceptionally long spans and can be hoisted at several points along their width. These gates are curved to form the shape of a crest and when fully lowered, can efficiently pass a large flood in a relatively short time. Unlike other type of gates, they do not have to be lowered below the crest to pass ice and debris. Their main drawbacks include presence of vibrations when the water is overflowing them in their partially open position and requirement of considerable hoisting force to raise them from the fully lowered position. In the fully lowered position of the gate, the full depth of water (and ice, when present) acts vertically on the full area of the gate; this drawback is the reason for their limited height. Vibrations can be minimized by provision of air intakes in the piers on either side of the gate. Where the tailwater aproaches the headwater, the hinges of the gates will remain submerged which is not particularly desirable, and therefore this type of gate is not preferable under that condition. Installation shown in Fig. 4a permits use of several hydraulic cylinders along the gate width, but requires an access gallery for repairs of the cylinders in case a problem occurs while the gate is fully lowered (external means, such as the use of a barge crane, to raise the gate for access to the hydraulic cylinders are not convenient because of very large hoisting capacity requirement). Installation shown in Fig. 4b provides ready access to the cylinders but 2 point hoisting requires an exceptionally rigid gate.

In many installations, the tainter and hinged crest gates are combined, with the use of hinged crest gates limited to one or two bays for the passage of debris. This arrangement is usually more economical than providing submersible tainter gates or providing flap gates on the tainter gates for passage of debris.

TYPE OF HOISTS

The main hoist types include:

1. Wire rope hoist
2. Chain hoist
3. Screw stem hoist
4. Hydraulic hoist

A typical wire rope hoist mainly includes two wire rope drums, one at each end of the gate width, an electric drive motor, a solenoid brake and the necessary reduction gearing. The drive motor and the solenoid brake (which is coupled to the drive motor) may be located at one end only (Fig 6) or equidistant from each drum on the top of a hoisting bridge (Fig. 5). The two drums are usually connected together (through necessary reduction gearing) by a line shaft spanning the distance between the drums or between the drive motor and each drum; in some cases, the line shaft is not used, a separate drive motor is provided for each side and the two sides are synchronized electrically. The drums may be either regular or spiral type. Regular drums permit the wire rope to wind in a single layer where as in the case of spiral type, the wire rope winds on the drum in multiple layers. Regular drums are provided with up to 2 wire ropes per drum whereas the spiral types can have several ropes, each rope winding separated from the next by plates bolted or welded to the drum. Figures 5 and 6 show arrangement of the regular and spiral type drum hoists provided for tainter type gates.

A chain hoist is identical to a wire rope hoist except that a chain is used instead of a rope and chain sprockets are used instead of wire rope drum. Since in most cases the chain cannot be easily connected to the gate like a wire rope, the chain is arranged in a loop. Figures 1 and 2a (and 2b) show arrangement of a chain hoist for a roller gate and a tainter gate respectively. Both wire rope and chain hoists are capable of pull action only.

A screw stem hoist mainly includes a threaded stem (square or acme thread, usually acme because of their ease of cutting) and a lifting nut mounted in a pedestal. The lifting nut is rotated by an electric motor through reduction gearing and thereby causes the up or down movement of the stem depending on direction of rotation of the nut. The screw stem hoists are capable of push or pull action. Stem guides are provided, as necessary, between the pedestal and the gate to minimize stem buckling during push action. Except for small hoisting capacities (say up to 20 tons), the screw stem hoists have limited applications for gate operation because even a minor misalignment between the lifting nut and the stem can cause rapid wear of the stem and the nut resulting in costly repair and/or replacement. For roller, tainter and hinged crest gates used for locks and dams, the angular movement of the gate would require a trunnion mounting of the hoist which is not convenient for a screw stem hoist. In view of the obvious difficulties with the screw stem hoists operating large capacity and angular movement gates, these hoists will not be addressed further in this article.

A hydraulic hoist, which like the screw stem hoist is capable of both pull and push action, includes one or more hydraulic cylinders, a hydraulic power unit (including an electric motor, pump or pumps, a fluid reservoir, filters, necessary valves and piping) and piping interconnecting the hydraulic cylinder(s) with the power unit. The cylinder(s) can be conveniently trunnion mounted to suit the angular movement of the gates. Practically any hoisting capacity can be achieved by simply selecting a suitable cylinder bore size and/or pump pressure output. Fig. 2d, 4a and 4b show the typical arrangements of hydraulic hoists for a tainter gate and a hinged crest gate. Fig. 7 shows a typical hydraulic control schematic.

OPERATION AND MAINTENANCE OF WIRE ROPE AND CHAIN HOISTS

Wire rope hoists have been used for gate operation for scores of years and chain hoists have been around even longer. In recent years, with the development of wire rope technology, wire rope hoists have been used in many more applications than the chain hoists. Chain hoists are still used for larger hoisting capacities (say 200 tons or more) because it is not convenient to handle large size wire ropes (or too many wire ropes, in case several small size wire ropes are used). The following are the main advantages and disadvantages of the wire rope and chain hoists related to their operation.

Operation Advantages

1. Because they have been used for several years, many users are familiar with the technology of wire rope and chain hoists and feel more comfortable with them than with hydraulic hoists which require the understanding of hydraulic circuitry.

2. The connection between the hoisting drives is positive (line shaft). If wire wope or chain lengths at the two lifting points are equalized carefully, the handling of the gate is automatically synchronized.

3. It is convenient to provide a positive mechanical position indicator for the gate, by connecting the indicator to a convenient point in the hoist gearing assembly.

4. In the case of a tainter gate, the wire rope or chain hoists can be attached at the gate upstream face, resulting in greater moment arm about the gate trunnion and hence in lower hoisting force than a hydraulic hoist. Hydraulic hoist cylinders are usually attached on the downstream face for convenience of installation and also for protection against water and debris.

5. Wire rope and chain hoists can maintain the gate in any given position without fear of drift.

6. In the case of a roller gate, the circumferential movement of the gate makes the use of a chain hoist more convenient than a hydraulic hoist.

Operation Disadvantages

1. The chain, rope, axles, couplings and gearing are subject to wear and may have to be frequently replaced. This replacement can be very time consuming and expensive.

2. The stretching of wire ropes and chains can cause problems with the actuation of limit switches and with the position indication system causing operational difficulties.

3. A failure of a limit switch or of the solenoid brake can cause serious accidents.

4. Any flaw in the length adjustment of several wire ropes or chains on a gate can prove costly, as one side may carry more load than the other side and result in the gate getting stuck and in breaking of wire ropes or chains.

5. Closing the gate by gravity during electric power failure cannot be provided without providing expensive additional equipment such as a fan brake to absorb the energy of freely falling gate. Manual operation requires a separate load brake which adds to the cost.

6. All components, including wire ropes, chains, gears, sheaves, lifting lugs on the gate, etc. must be designed to withstand breakdown pull (stalled condition) of the hoisting motor which can be sometimes as large as 300% of the normal pull. This again adds to the cost.

7. Inspection must be frequent. Problems such as lack of lubrication on the gears, wire rope or chain, breaking of strands on a wire rope, stripping of screw threads on turnbuckles, improper winding of wire rope on the drums or improper storage of the chain, etc. must be found out as soon as possible otherwise serious accidents can occur resulting in costly repairs.

Inspection and Maintenance

The following is a typical recommended inspection and maintenance schedule for wire rope and chain hoists for the flood gates. It should be noted that flood gates are subject to more frequent operation than most other type of gates and therefore their hoisting mechanism is subject to greater wear and tear.

1. Before Every Operation.

   a. Check wire rope or chain condition.
   b. Check speed reducer for oil level and leakage.
   c. Check electrical system indicating lights.

2. Every 3 Months

a. Lubricate rope drum or sprocket bearings.
b. Lubricate sliding parts.
c. Check condition of sheaves for wire rope hoists.

3. Every 6 Months

a. Check electrical wiring and connections for deterioration.
b. Check calibration of position indicators.
c. Check condition of turnbuckles and U-bolts (gate to hoist connection).

4. Every 12 Months

a. Check wire ropes thoroughly for damage, deformation and uniform tension.
b. Check all couplings for alignment and coupling seals for damage.
c. Check brake linings and correct extension of the solenoid brake when the brake is applied.
d. Check for smooth operation of electric motors.
e. Check electrical equipment including functions of circuit breakers, selector switches, pushbuttons, etc.
f. Change oil required for lubrication of speed reducer. (except that after first 6 months of operation drain all oil and refill with new clean oil).

5. Every 5 years

a. Touch-up paint or repaint if necessary.
b. Check slack rope and overload settings.
c. Renew grease in electric motors (renew after 5000 hours of operation,if that occurs before 5 years).
d. Load Brake: check brake adjustment and lining.

OPERATION AND MAINTENANCE OF HYDRAULIC HOISTS

The use of hydraulic hoists for gate operation is relatively recent. Because of the versatility presented by them, they are being used more and more for operation of all type of gates. The advantages and disadvantages associated with their use and the type and frequency of their maintenance are as follows:

Operation Advantages

1. The inherent capability of the hydraulic hoists to apply pull as well as push force makes them very versatile for the operation of gates. Also the operating force can be widely varied simply by adjusting the operating pressure.

2. It is possible to adjust the speed of gate movement by adjusting the opening of a flow control valve. Also different speeds can be easily provided for opening and closing.

3. End-of-stroke cushioning can be readily provided to prevent damage to the gate.

4. Maximum hoisting force can be limited by the setting of the hydraulic system pressure relief valve.

5. Several gates (usually 2) can be powered by a single hydraulic power unit which can be a very economical arrangement.

6. The gate can be lowered without power by simply opening a manual shut-off valve. Also, accumulators can be provided in the system to raise the gate without power.(Because of large sizes of cylinders required for spillway gates, the usefulness of accumulators is limited unless they are very large in size, which is normally not practical).

7. There are very few moving parts compared to wire rope or chain hoists. Also the hydraulic fluid automatically lubricates the parts and therefore there is little wear.

8. The hydraulic system can easily accomodate one or more standby pumps to operate the gate, without loss of time, in case of the failure of the main pump or motor. For the wire rope or chain hoist, the power operation must wait until a spare motor can be installed.

9. The overall mechanical efficiency of the hydraulic hoist is higher (85-90%) compared to the wire rope or chain hoist (75-80%, much less if a worm gear reducer is used) and therefore for a given force required to operate the gate, the rated capacity (for a similar installation) can be smaller for a hydraulic hoist than for a wire rope or chain hoist.

10. Pilot operated check valves provide an excellent means for holding the gate still in a given position against the onslaught of the waves on the gate. It is nearly impossible to still the gates equipped with wire rope or chain hoists; gate movement would cause variation of flow under the gate and gate vibration.

Operation Disadvantages

1. In case of leakage through the hydraulic system, the oil spill can cause an environmental hazard. (Generally, unless a catastrophy happens, only minimal leakage is expected).

2. The system may be sluggish at cold temperatures (This can be overcome by the use of thin petroleum based fluids, such as MIL-H-5606-A which are quite suitable at temperatures down to -30°F. These fluids are 3-4 times more expensive than ordinary hydraulic fluids, but an unobstructed operation can more than compensate for the extra expense).

3. The gate may drift from a given position due to leakage across the cylinder piston or due to leakage at other points of the hydraulic system. (An inexpensive drift control circuit can readily overcome this problem).

4. The system must be maintained clean. Even a little contamination of the hydraulic fluid can cause severe problems; replacement of several components may be required, if the contamination is allowed to prolong.

5. Mechanically driven position indicators can be provided but require a rather elaborate arrangement. Electronic position indicators which can be conveniently provided are not as reliable as the mechanical position indicators; any movement of the gate without power would require readjustment of the electronic position indicator which can be time consuming.

6. Provision of 2 cylinders for a tainter gate and of 2 or more cylinders for a hinged crest gate (both these gates are externally guided in their movement, the tainter gate at their trunnions and the hinged crest gates at their hinges) can be readily provided, but equipping a wide vertical lift gate with 2 cylinders requires precise coordination between the two. To achieve the coordination, the hydraulic system needs expensive electronically set proportional valves.

7. The control panel for the hydraulic system is more elaborate because the performance of several components such as filters, pressure switches, pumps and acculmulators must be monitored.

8. Familiarity with fluid power principles and with the hydraulic system of the gate being operated is essential.

Inspection and Maintenance

The following is a typical recommended inspection and maintenance schedule for the hydraulic hoists:

1. Before Every Operation

   a. All filters: check clogging indicators at the beginning and end of each operation.

   b. All valves and hose couplings: check for leakage (visually).

   c. Oil tank: check fluid level.

   d. Check electrical system indicating lights.

2. Every 6 Months

   a. Accumulators (if used): Check charging pressure, clean all parts, inspect all components for signs of damage and wear.

   b. All Valves: Visually check for leakage and clean the outside of the valves. Manually actuate several times in order to prevent sticking of the spool and gumming of the oil.

   c. All accessible piping and hoses: Inspect and clean from outside. Check visually for leaks at connections. Check for damage caused by flaking of hoses.

   d. Hydraulic Oil: Check for aging by taking a drop of oil from the circuit and putting it on a piece of white filter paper. If a yellow spot appears in the center, the oil is still good. If a dark spot appears, replace the oil in the system. In case of doubt, send a sample to the oil manufacturer for examination (change oil every 2 years).

e. Check electrical wiring and connections for deterioration.

f. Hydraulic cylinders: Visually inspect for external leakage.

g. Check calibration of position indicators.

3. Every 12 Months.

a. Hydraulic Pumps: Check for smooth operation and leakage.

b. Oil Tank: Check all accessories including cleanliness of the oil filler and level switch (remove level switch to check).

c. Electric Motors: Check for smooth operation.

d. Hydraulic Cylinder Piston Rod: Inspect for foreign particles and clean. (Also inspect for damage to the chrome plating).

e. Check electrical equipment including function of circuit breakers, selector switches, pushbuttons, etc.

f. Check with operator for frequent excessive drift and for sluggish operation and correct the problem areas.

4. Every 5 Years

a. Electric Motors: Renew grease (renew after 5000 hours of operation if that occurs before 5 years).

b. Hydraulic Pumps: Disassemble ends, check for worn parts and clean.

c. Oil Tank: Drain and clean.

d. Check working and setting of limit switches, timers, presure switches, etc.

5. <u>Special Note about Filtration</u>

a. After first 100 hours of operation, drain the oil tank and refill with oil filtered to 10 microns, clean the suction filters and replace cartridges in pressure and return filters.

b. Repeat the above every 2000 hours of operation.

SELECTION OF HOIST

As discussed above, each type of hoist has its advantages and disadvantages. However, most of the disadvantages presented by the hydraulic hoists can be readily overcome. This fact coupled with the versatility of the hydraulic hoists, their reliability due to recent advances made by the fluid power industry, and the initial cost and maintenance cost economics presented by them should make them a natural choice in most applications. The main drawback to their selection is that the operators must be educated in their operation and maintenance procedures and with the hydraulic control schematic; if this is not done and the maintenance is relaxed, serious problems could occur.

Wire rope hoists are no doubt simpler to operate than the hydraulic hoists (no air in the system to worry about, no checking of fluid level, no leakage, filtration or contamination problems) but wear and tear of parts (specially for the frequently operated flood gates) can prove costly in the long run in terms of downtime as well as money.

The writers recommend selection of hydraulic hoists as a normal rule unless site conditions (ready availability of hydraulic fluid, layout of the spillway structure, etc.) and lack of personnel trained in hydraulic systems dictate otherwise. For hinged crest gates which are usually exceptionally wide and which thus should preferably be provided with several hoisting points, there is practically no alternative to the hydraulic type hoist. Provision of a rigid gate structure will eliminate the need for external means (such as proportional valves) to coordinate movement of several hydraulic cylinders.

COST COMPARISON

TABLE I compares the estimated initial costs of hydraulic hoists versus wire rope and chain hoists (mechanical hoists) for radial gates of several sizes. In comparing the costs it is assumed that the hydraulic hoist is attached to the downstream side of the gate (which is usually the case). The mechanical hoist estimated cost is indicated both for upstream and downstream installations. The estimates are based on bid prices received from various manufacturers in recent years. It should be noted that the costs or the cost comparison shown in Table I are not absolute because the variables such as the installation layout and the civil structural costs associated with each type of hoist directly affect the overall cost. The comparison is made to merely give an idea of the cost effect of selecting a particular type.

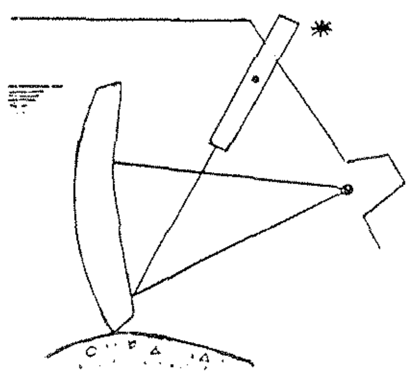
The maintenance cost is much higher for a mechanical hoist than for a hydraulic type. If filters are regularly checked and replaced, the hydraulic system maintenance cost is not expected to be much more than the cost of filters. It is not possible to estimate monetary value of the maintenance cost because several variables such as the location of project and frequency of inspection are determining factors.

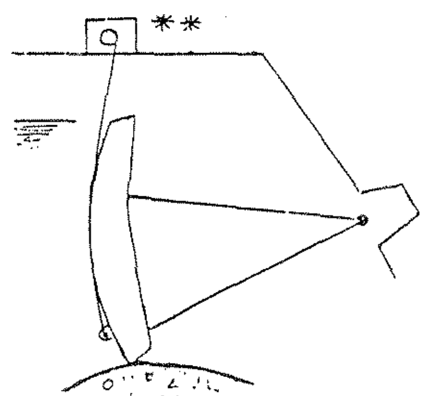
REFERENCES

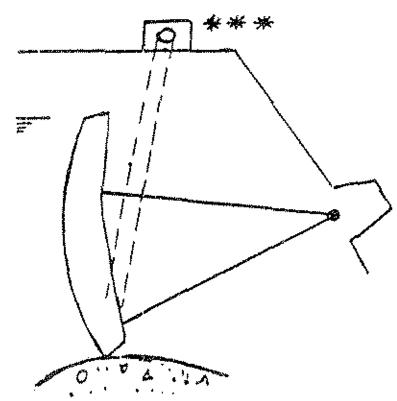
1. Handbook of Applied Hydraulics by Davis and Sorensen, Third Edition, McGraw Hill.
2. American Civil Engineering Practice, Volume II, by Robert W. Abbett, John Wiley and Sons.
3. Harza files relating to several projects.
4. Manitoba Hydro, Vertical Lift Gate Installation.

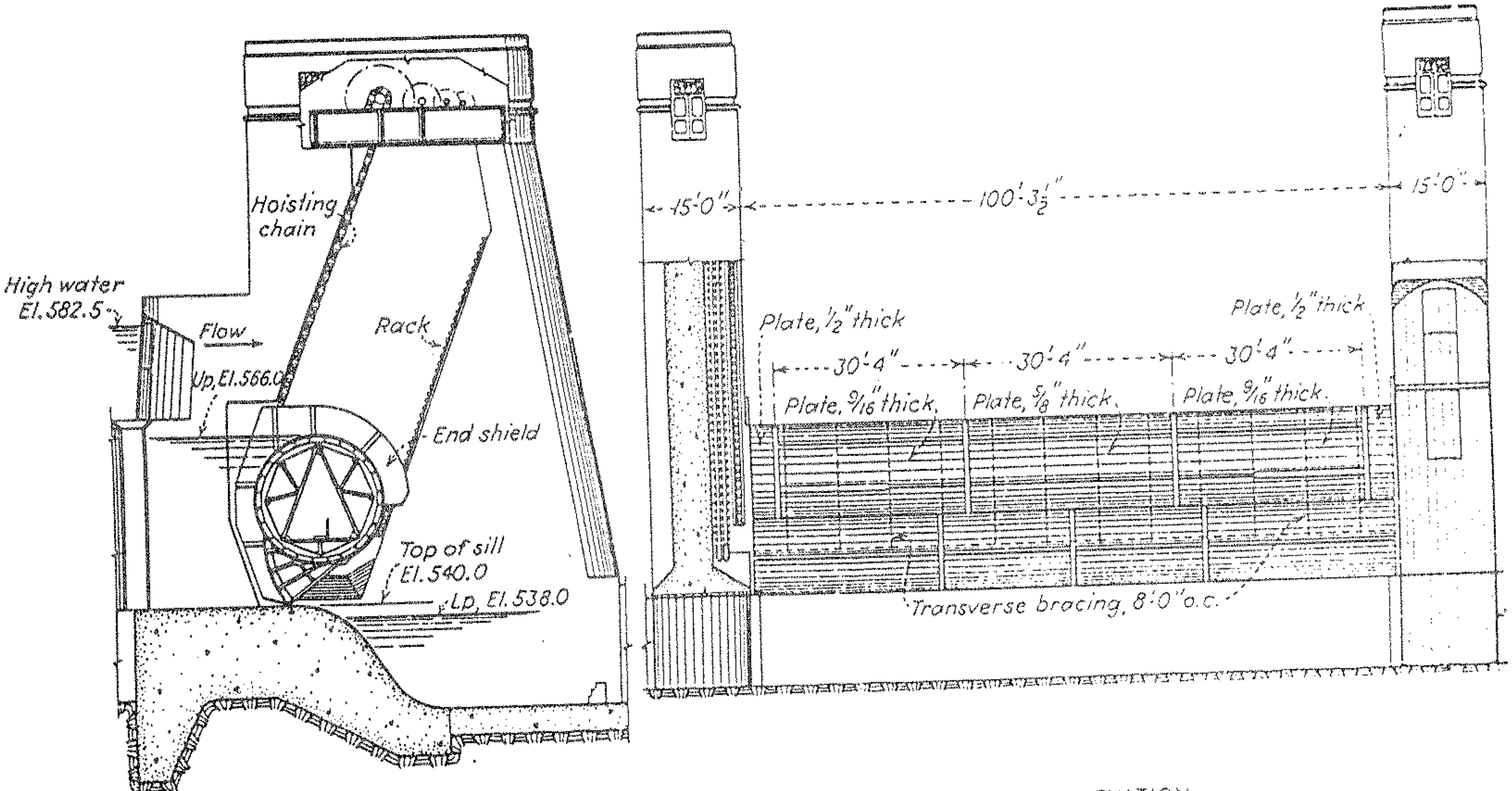
TABLE 1
COMPARATIVE ESTIMATED INSTALLED COSTS OF HYDRAULIC HOISTS
VERSUS WIRE ROPE/CHAIN HOISTS FOR TAINTER GATES

TAINTER GATE SIZE	HYDRAULIC HOIST		WIRE ROPE/CHAIN HOIST			
	HOIST CONNECTED ON D/S SIDE		HOIST CONNECTED ON U/S SIDE		HOIST CONNECTED ON D/S SIDE	
	ESTIMATED* HOISTING CAPACITY	ESTIMATED COST	ESTIMATED** HOISTING CAPACITY	ESTIMATED COST	ESTIMATED*** HOISTING CAPACITY	ESTIMATED COST
20' X 20'	70t	$ 45,000	16t	$ 25,000	20t	$ 35,000
30' X 30'	110t	$ 80,000	32t	$ 55,000	45t	$ 70,000
40' x 40'	180t	$140,000	65t	$115,000	90t	$140,000
50' x 50'	280t	$200,000	110t	$200,000	150t	$240,000
60' xx 60'	400t	$300,000	170t	$300,000	250t	$360,000
80' x 20'	200t	$100,000	80t	$120,000	100t	$125,000
100' x 20'	250t	$120,000	100t	$150,000	125t	$165,000









SECTIONAL ELEVATION

UPSTREAM ELEVATION

Rolling gate at Lock and Dam No. 1, Kanawha River. (*U.S. Corps of Engineers.*)

Fig. 1: Roller Gate, Chain Hoist (Ref. 1)

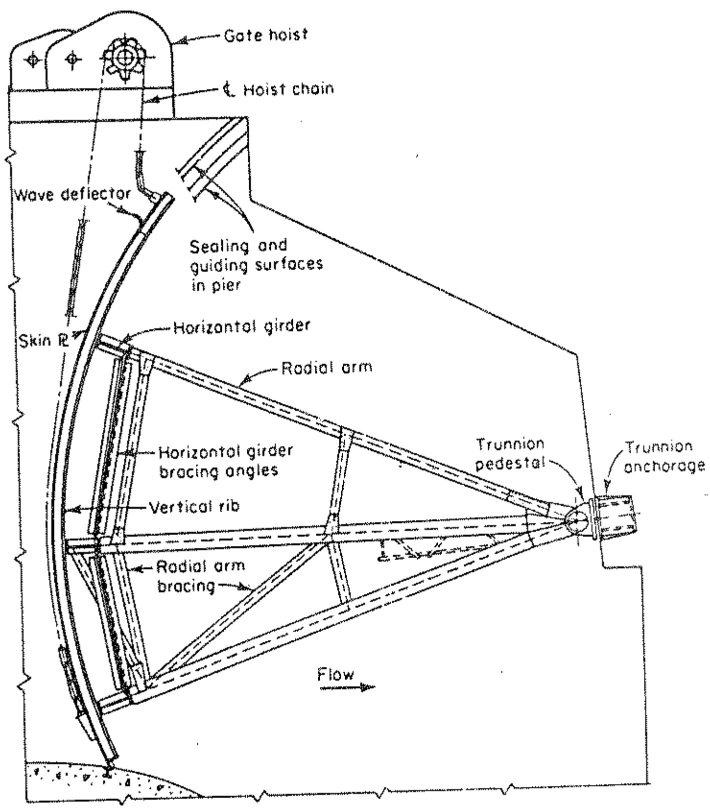


Fig. 2a: Tainter Gate, Chain Hoist Attached on the Upstream Face (Ref. 1)

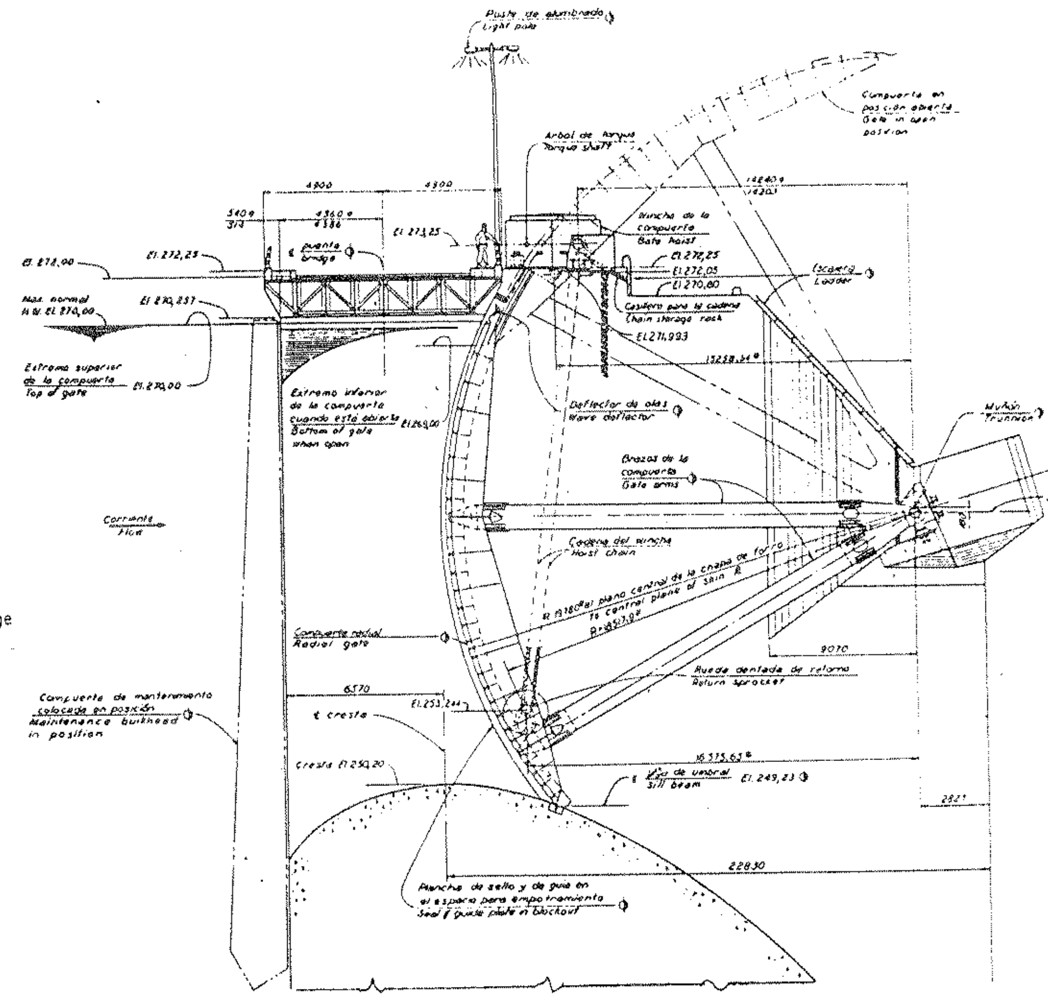


Fig. 2b: Tainter Gate, Chain Hoist Attached on the Downstream Face (Ref. 3)

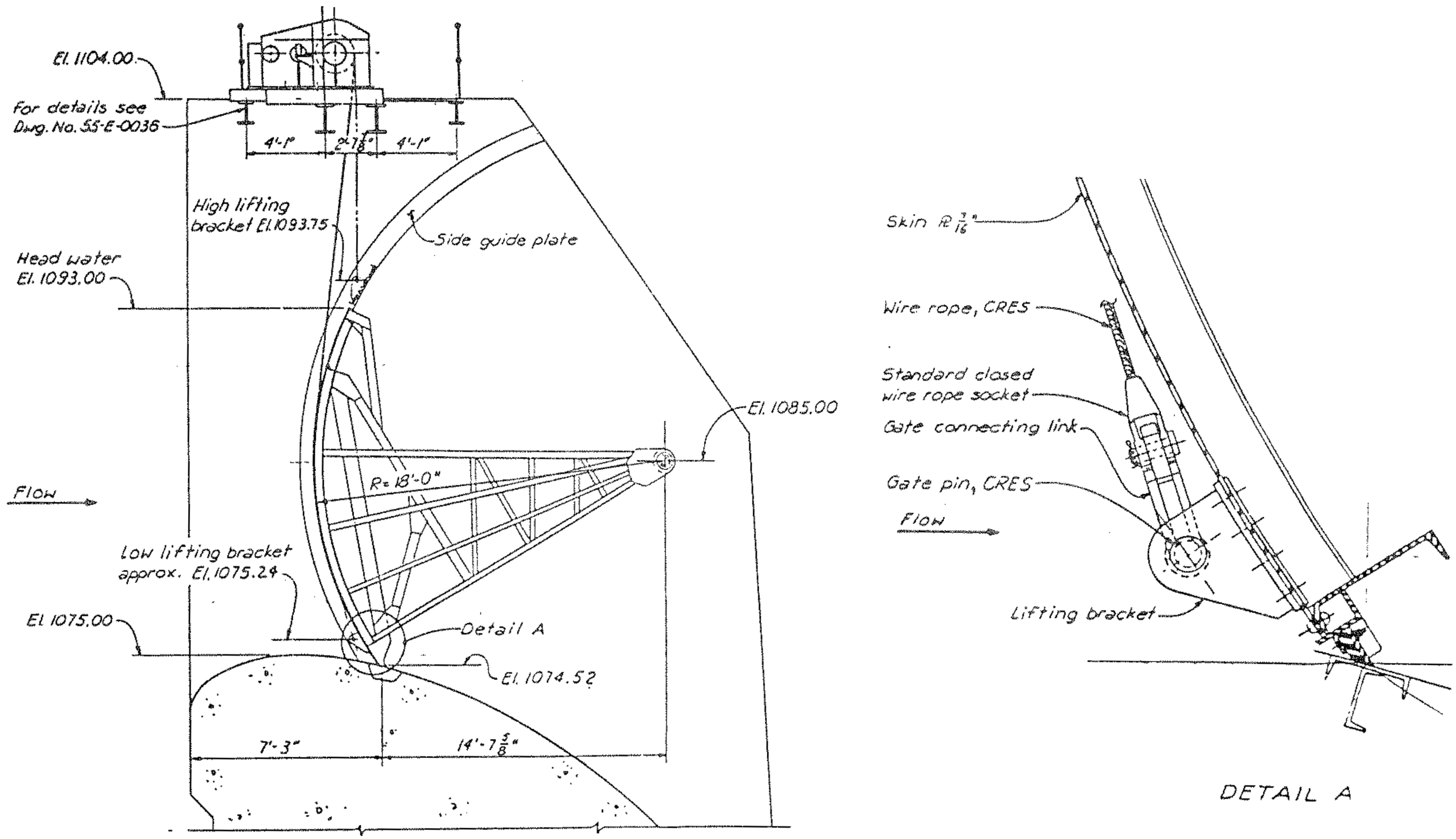


Fig. 2c: Tainter Gate, Wire Rope Hoist Attached on the Upstream Face (Ref. 3)

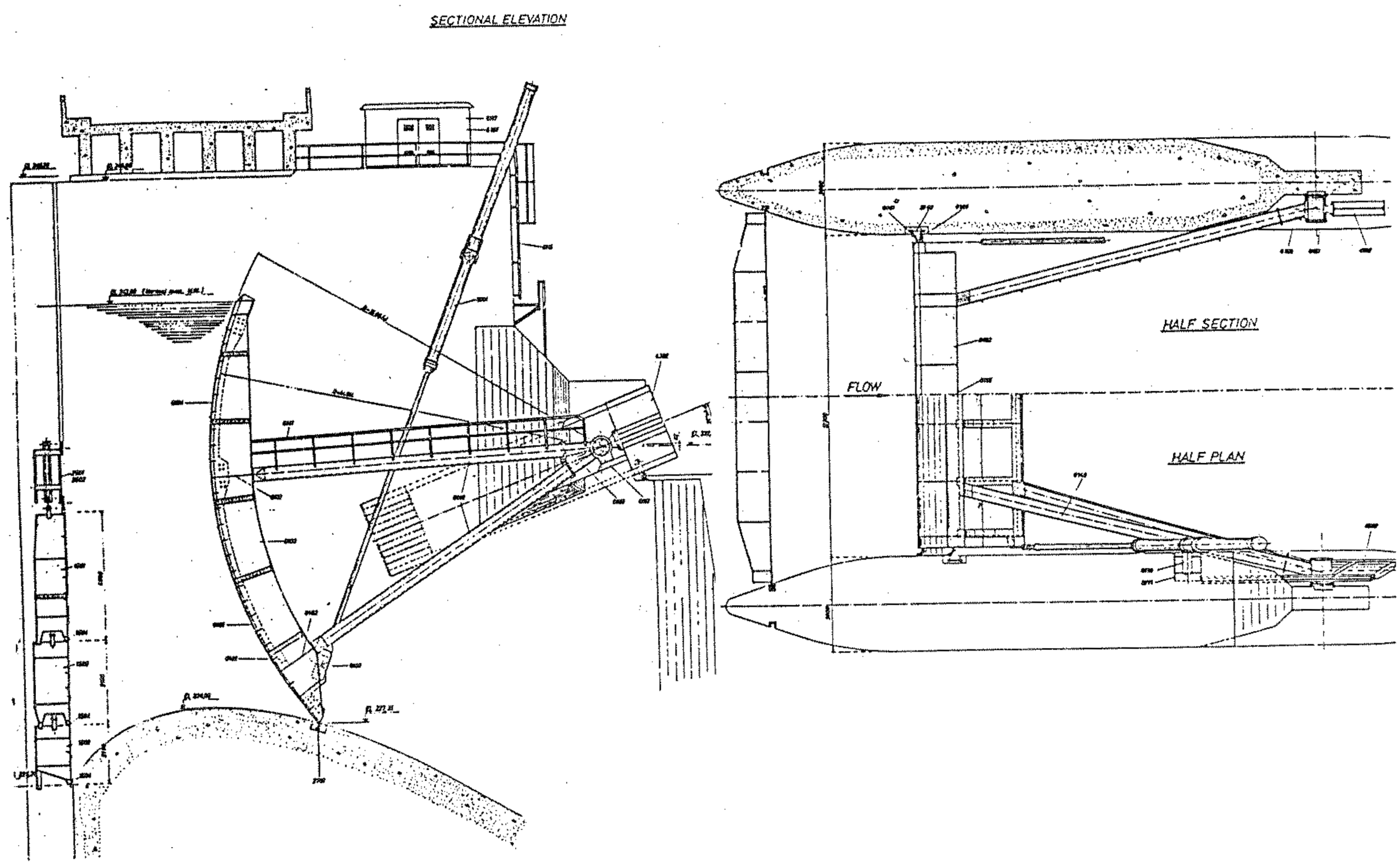


Fig. 2d: Tainter Gate, Hydraulic Hoist (Ref. 3)

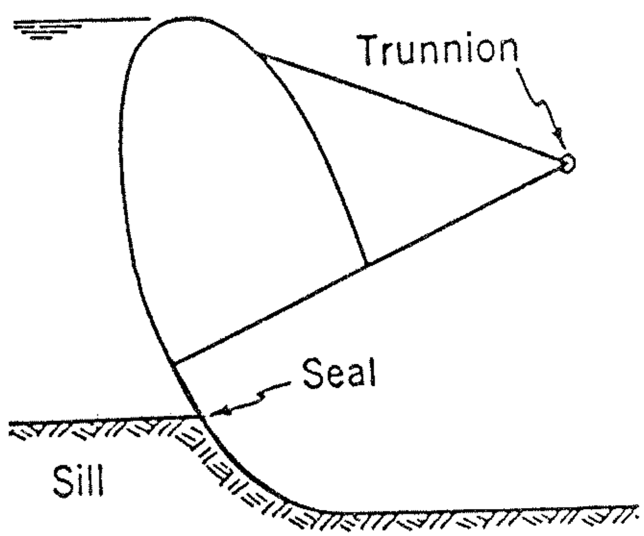


Fig. 2e: Tainter Gate, Modified Skinplate For Submersible Gate (Ref. 2)

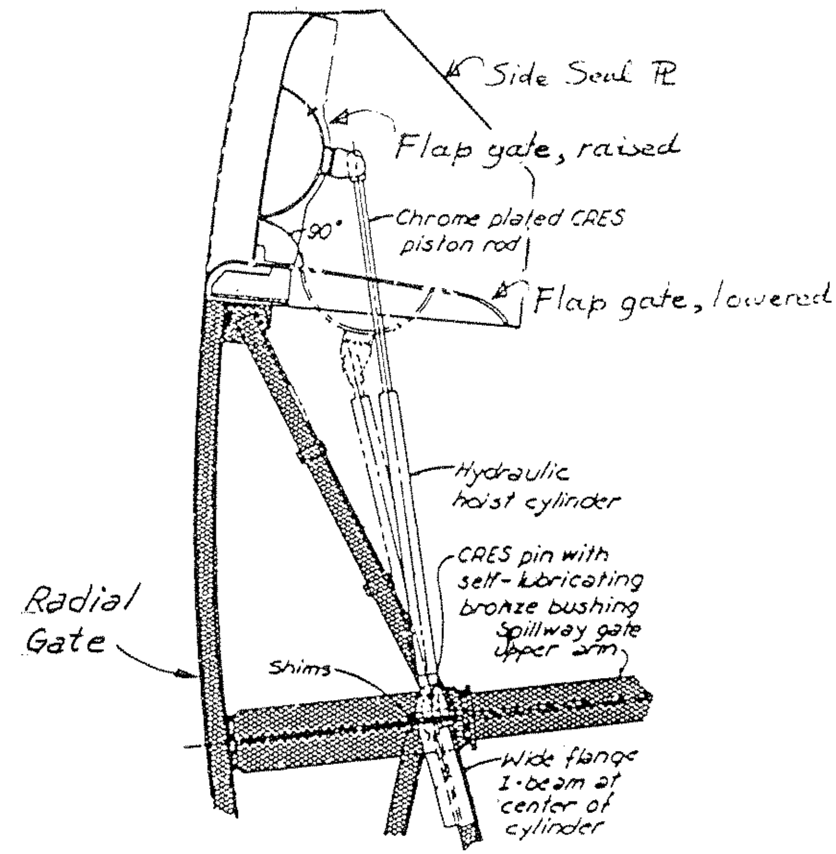


Fig. 2f: Tainter Gate, Equipped with a Flap Gate (Ref. 3)

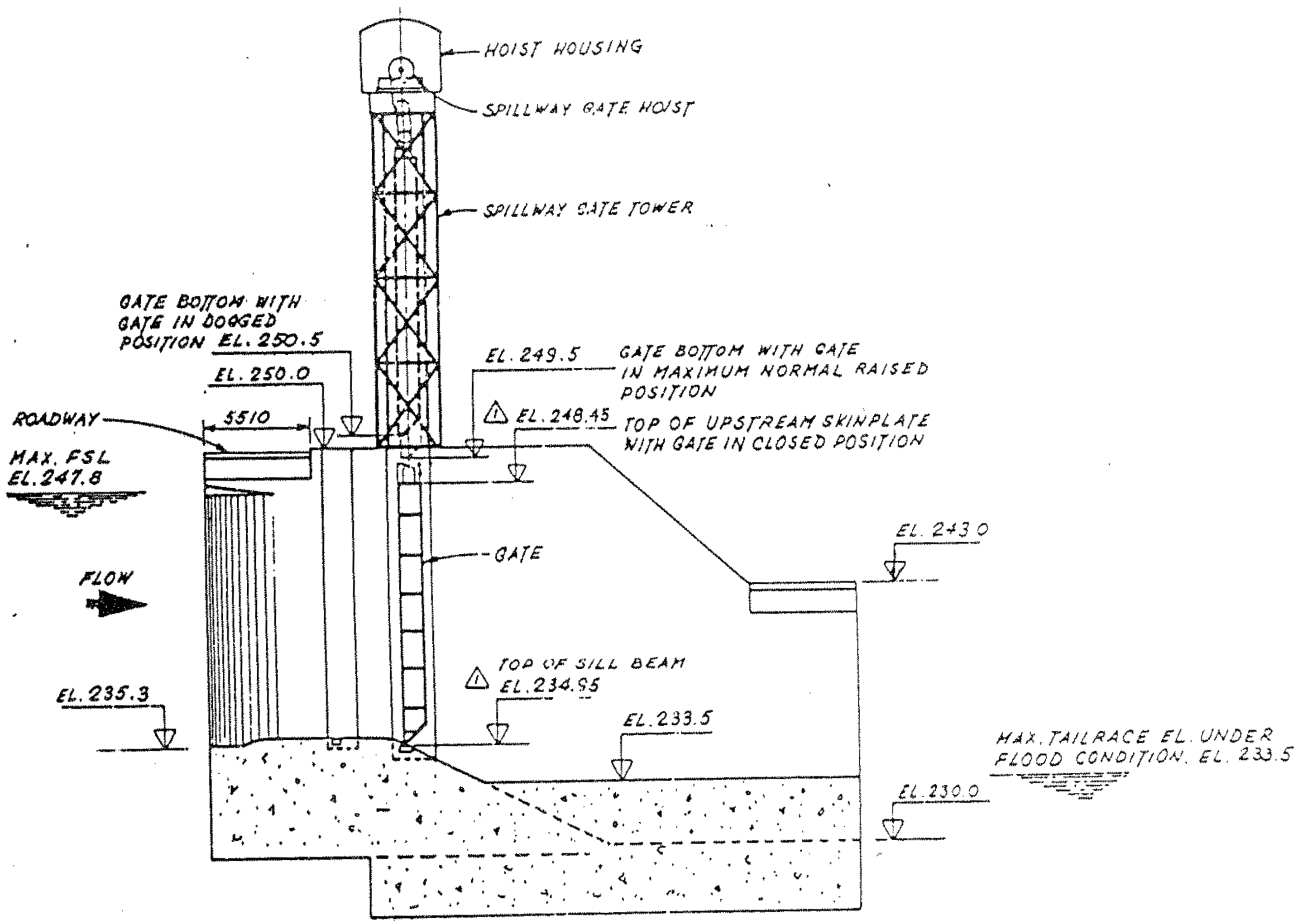


Fig. 3: Vertical Lift Gate, Wire Rope Hoist (Ref. 4)

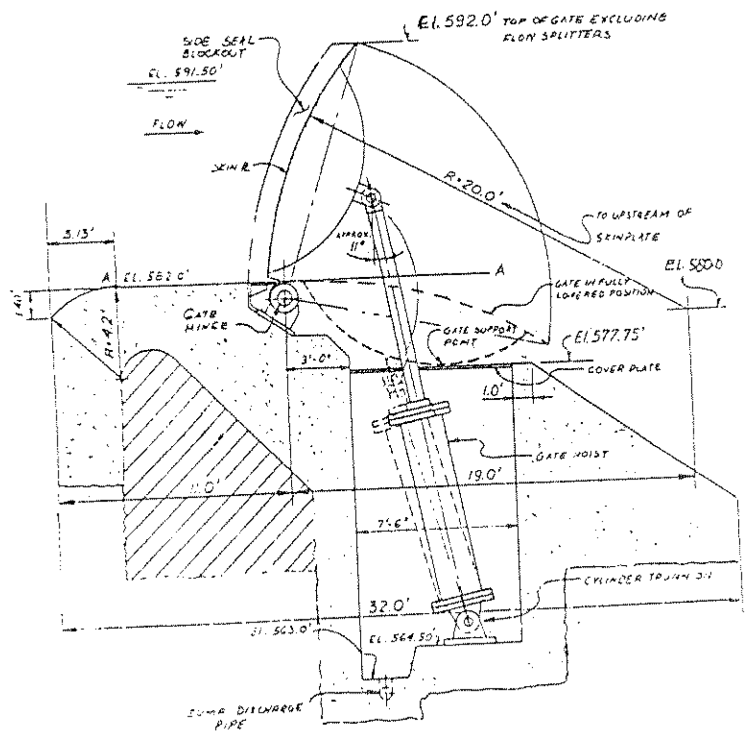


Fig. 4a: Hinged Crest Gate, Hydraulic Hoist Attached at Bottom (Ref. 3)

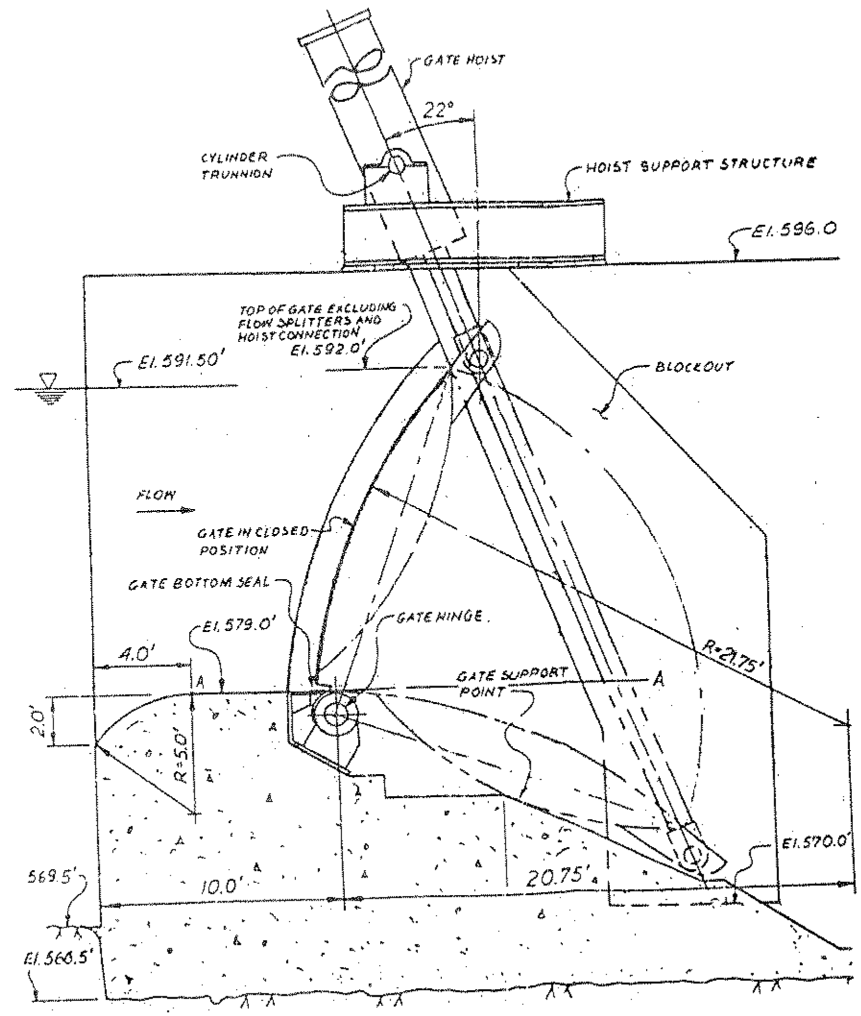


Fig. 4b: Hinged Crest Gate, Hydraulic Hoist Attached at top (Ref. 3)

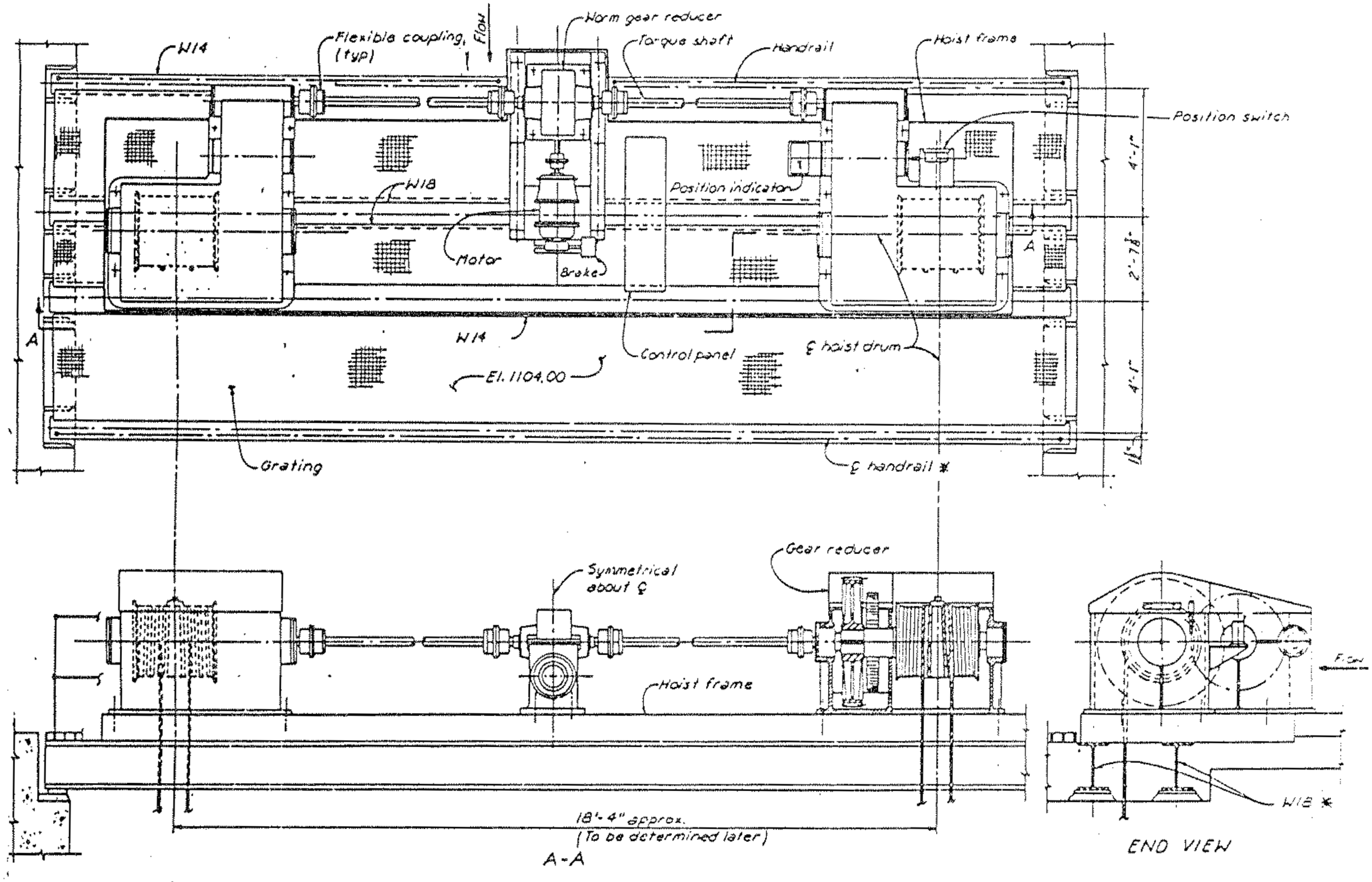


Fig. 5: Wire Rope Hoist, Regular Drum, Drive Motor in the Center (Ref. 3)

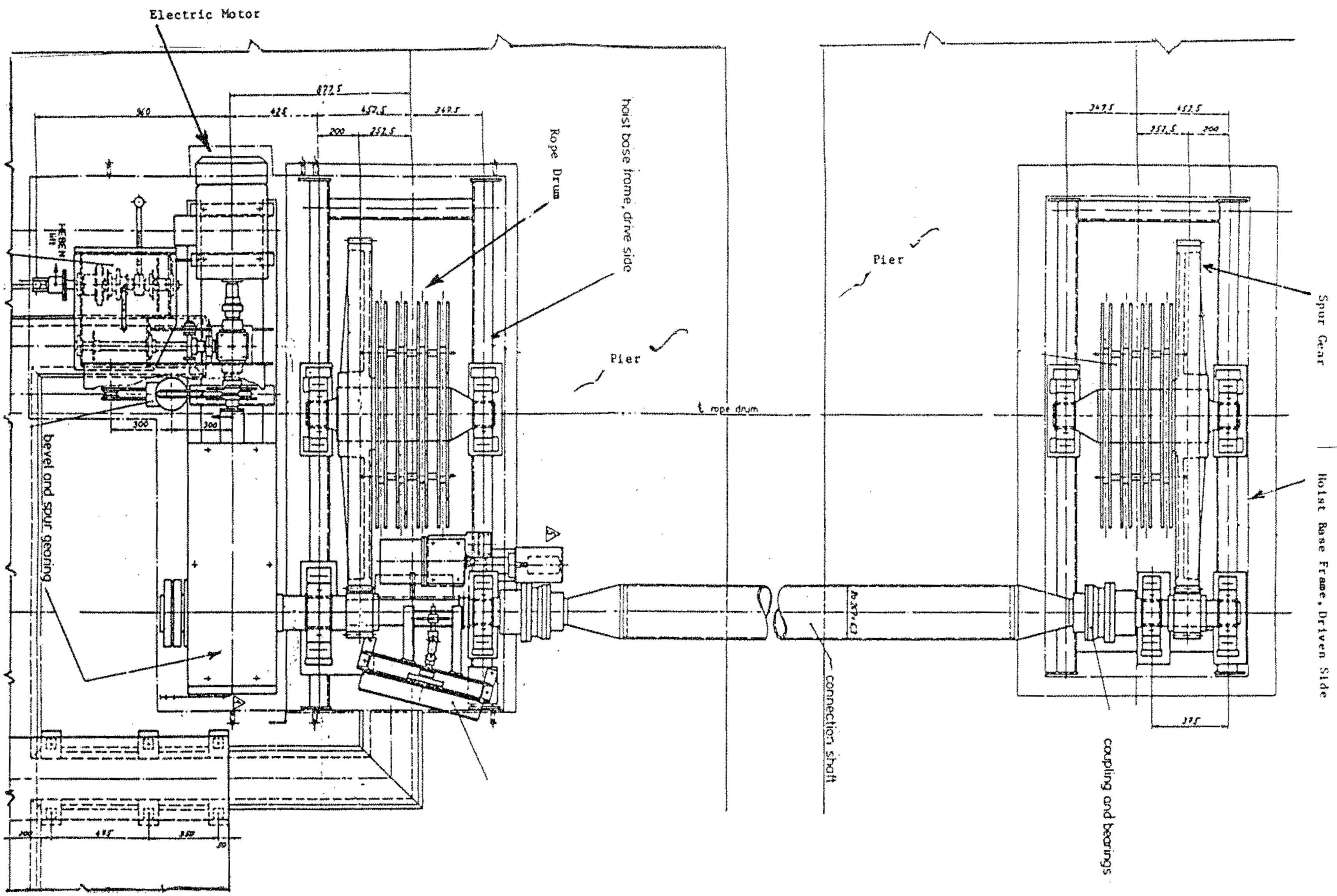
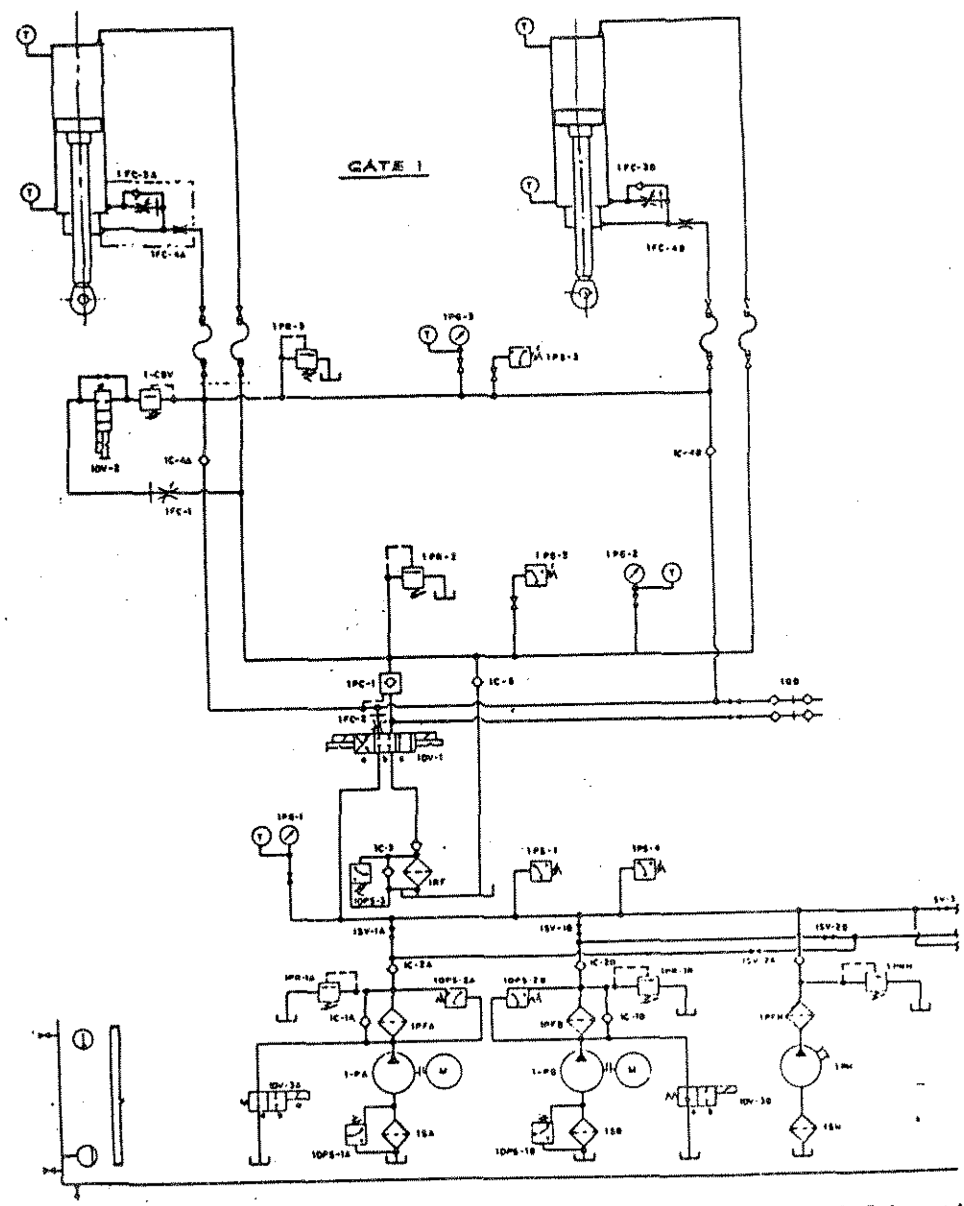


Fig. 6: Wire Rope Hoist, Spiral Drum, Drive Motor at One End (Ref. 3)



Note on Hydraulic Schematic

The schematic shown is half of the complete schematic for 2 gates (2 cylinders per gate) served by one power unit. Component designation Prefix 1 denotes components serving gate 1. The functions of various key components of each gate are as follows (prefix not shown below):

PA, PB: Pumps A and B of each gate. Each acts as standby for the other.

SA, SB: Suction filters for pumps A and B

PFA, PFB: Pressure filters for pumps A and B

RF: Return filter

PR-1A, PR-1B: Pressure relief valves for pumps A and B

PS-1, PS-4: Pressure switches to automatically shut off the malfunctioning pump and automatically start the stand-by pump in case of a malfunction in one of the pumps. PS-4 acts as a back-up for PS-1

PR-2: Pressure relief valve for cylinders A and B upper chamber to safeguard against pressure rise due to temperature or otherwise.

PS-2: To signal pressure rise beyond the setting of PR-2

PR-3: Pressure relief valve for cylinder A and B lower chamber to safeguard against pressure rise due to temperature or otherwise.

PS-3: To signal pressure rise beyond the setting of PR-3

DV-1: Main directional control valve actuated in suitable direction to raise and lower the gate.

DV-2: Directional control valve that connects the upper and lower chamber of the cylinder, actuated only while lowering the gate.

CBV: Counterbalance valve

FC-1: Flow control valve to set gate lowering speed

FC-2: Flow control valve to set gate raising speed

FC-3A, B: Cushioning valve for cylinders A and B

FC-4A, B: Speed limit valve for cylinders A and B in case of hose rupture

QD: Quick disconnects for attachment of portable power unit

DPS-1A, 1B, 2A, 2B and 3: Differential pressure switches to indicate clogging of filters

PG-1, 2, 3: Pressure gages

C-1A, C-1B: Check valves in the circuits of pumps A and B to permit flow if pressure filters are clogged.

C-2A, C-2B: Check valves to prevent backflow to pump A and B

C-4A, C-4B: Check valves to prevent return of flow from cylinders lower chambers to sump during lowering of the gate

C-5: Check valve to assure one way flow from sump to the cylinders upper chambers

PC-5: Pilot check valve to hold the gate steady against waves acting on the gate. This check valve will connect the cylinder upper chamber with the sump during raising of the gate.

SV-1A, SV-1B: Shut-off valves to be closed to isolate pump A or B so that both pumps could be used separately for operating each gate if both pumps of one gate fail.

SV-2A, SV-2B: Shut-off valves to be opened to operate one gate with pump A or B of the second gate.

SV-3: Shut-off valve to be opened only during simultaneous operation of both gates with one set of pumps

DV-3: Two-way directional control valve for pump start-up (timer actuated)

Fig. 7: Hydraulic Control Schematic (Ref. 3)