RECOMMENDED MODIFICATIONS
TO THE
COCHRANE-PLANT-WATER INTAKE PIPELINE

Prepared for

Stearns-Roger Corporation

by

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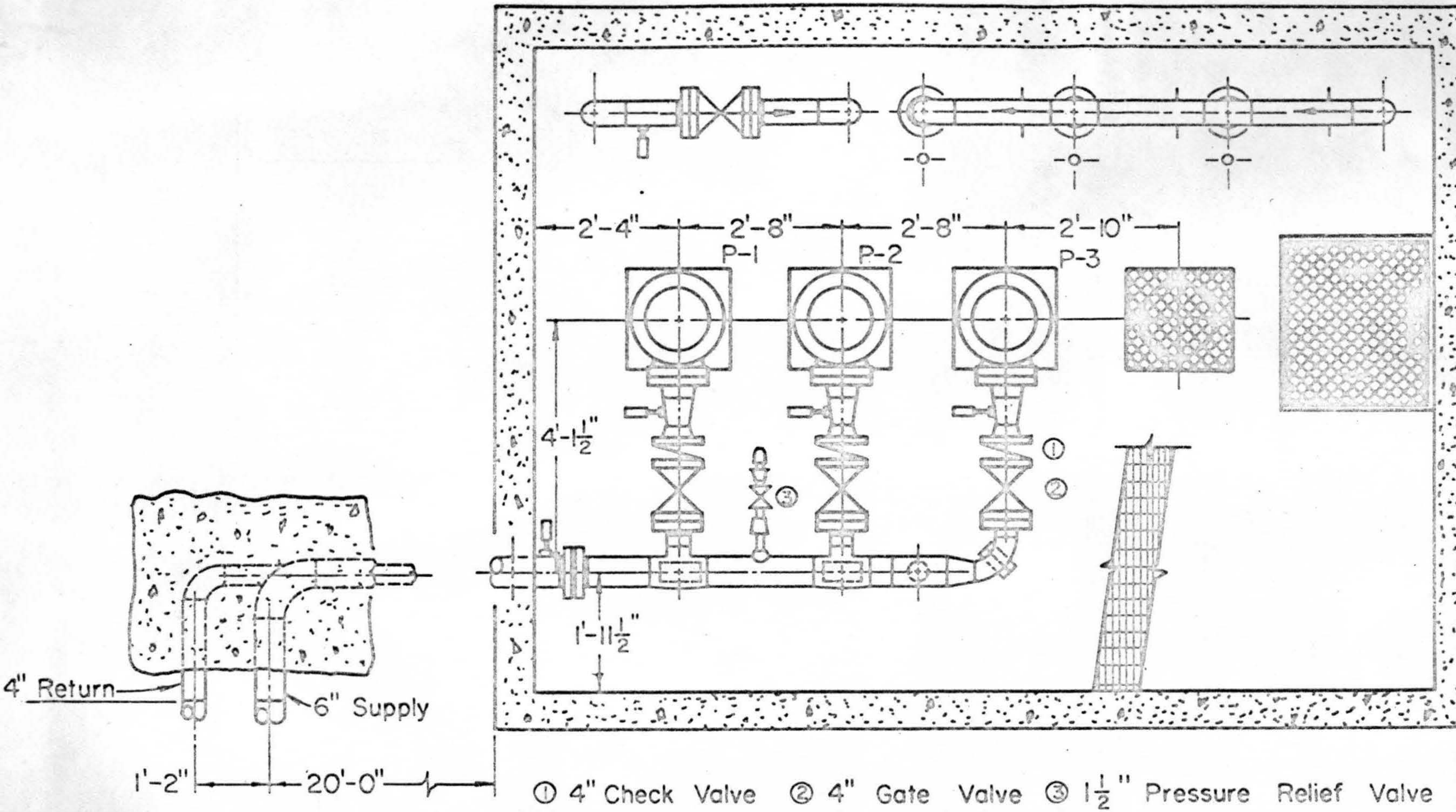
COCHRANE-PLANT-WATER INTAKE PIPELINE

INTRODUCTION

Description of System

The Cochrane-Plant-Water Intake Pipeline was constructed to supply cooling water for the Alberta Natural Gas Company at their Cochrane plant. The water is extracted from the Bow River and pumped into a raw water storage tank some 10,000 feet away. The installation consists of a pumping plant containing three 13-stage vertical turbine pumps which supply water through a 6-inch schedule 40 steel pipe to the raw water storage tank. The general features of the pumping plant are shown in Figs. 1 and 2. The pumps can be isolated by closing the 4-inch manually operated gate valves shown in Fig. 1. The 4-inch check valves, located between the gate valves and the pumps, control reverse flow. The 1½-inch pressure relief valve, connected to the 6-inch pipe between pumps one and two, is intended for controlling excessive positive pressures caused by transients. Provisions have been made at the pumping plant for installation of a fourth identical pump at a future date.

The 6-inch supply line and the 4-inch return line are buried in a 7-foot ditch which passes over a varied terrain. The pipeline profile is shown in Fig. 3. The pipelines are just over 10,000 feet in length and lift the water some 440 feet from the Bow River to the raw water storage tank at the Cochrane plant. The only valves in the pipeline are gate valves intended for operation either fully open or fully closed. Thus, no provision has been made for controlling the discharge from the pumps by regulating valves.


2'-4"
2'-8"
2'-8"
2'-10"
P-1
P-2
P-3
4'-1½"
1'-11½"
4" Return
6" Supply
1'-2"
20'-0"
① 4" Check Valve ② 4" Gate Valve ③ 1½" Pressure Relief Valve

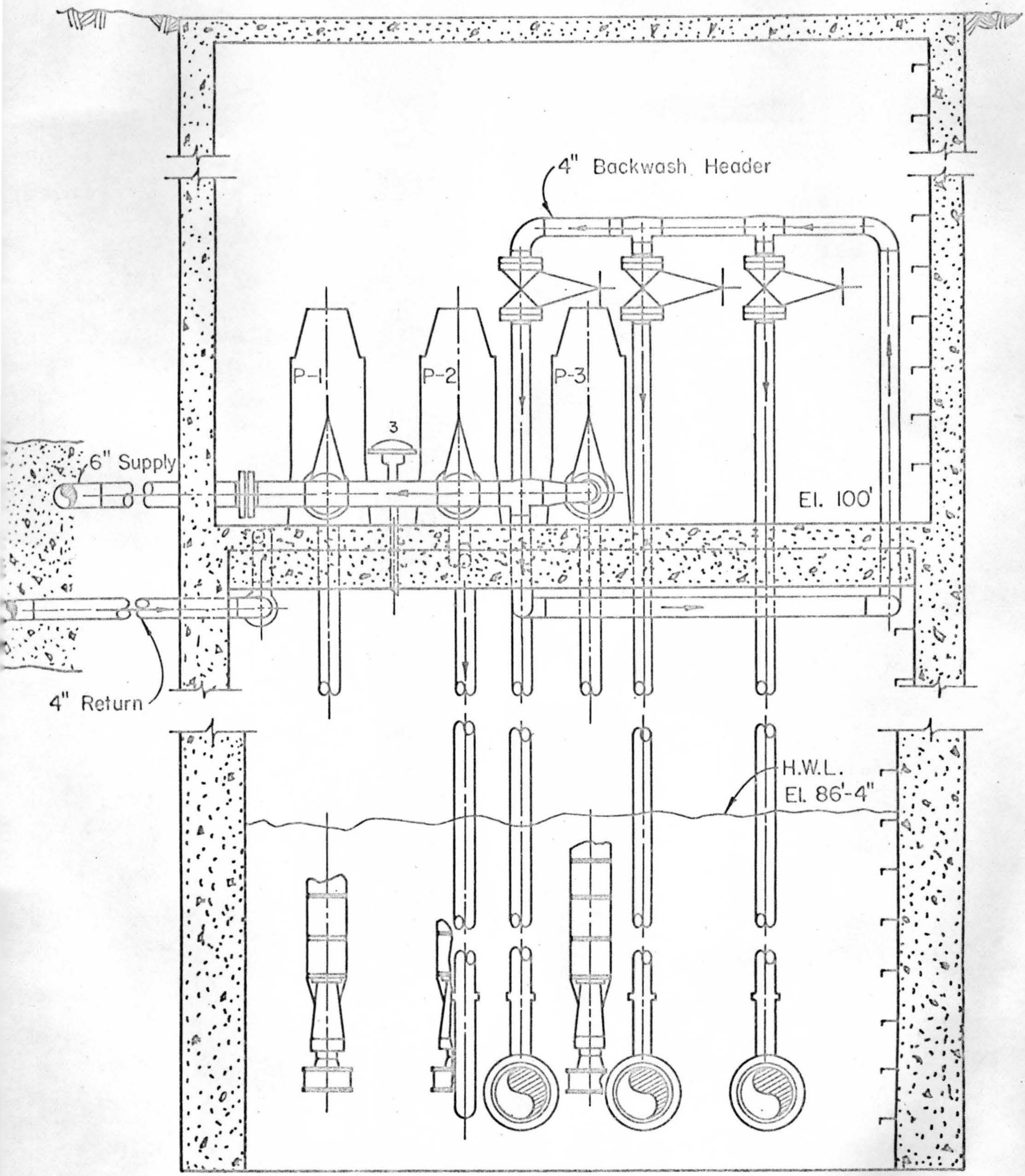


Figure 2. Section drawing of pumping plant.

The raw water storage tank at the Cochrane plant has a diameter of 45 feet 9 inches and a height of 24 feet. The bottom of the storage tank is at elevation 4138. A level control in the storage tank operates the pumps. Under normal conditions, one or two pumps will satisfy the discharge requirements to the tank. Only under unusual circumstances will more than two pumps be in operation. The normal discharge will vary between 290 gallons per minute with one pumps in operation to approximately 720 gallons per minute with four pumps on.

Scope of Report

The study was initiated by Stearns-Roger Corporation because of their concern over the possibility of transient problems in the pipeline. The two major items of concern were: 1) the possibility of water column separation due to accidental or intentional shutdown of the pumps and 2) the suitability of the pressure relief valve located at the pumping plant for controlling excessive positive pressures. The terrain over which the pipeline is laid has a number of hills, the highest of which is higher than the water surface in the raw water storage tank. This situation made it quite apparent that there is a potential problem of column separation.

Direction was given by Stearns-Roger to conduct the investigation in two phases. Phase 1 was to be a preliminary investigation of the system to determine the existence and the magnitude of problems associated with the possibility of column separation and the suitability of the pressure relief valve. If phase 1 indicated that serious problems do exist, the second phase would be carried out. The purpose of phase 2 was to perform a detailed analysis of the system and make recommended modification to eliminate any existing problems. The assignment for phase 2 included only providing general design criteria for any proposed modifications. The detail designs would be made by Stearns-Roger.

ANALYSIS OF EXISTING SYSTEM - PHASE I

Column Separation

Column separation may occur in a pipeline when something causes the pressure to be reduced at the upstream end. In this system such a pressure drop will occur when the pumps are shut down. Stopping the pumps causes a negative pressure wave to travel down the pipeline placing the fluid under tension. Normal fluids cannot sustain a tensile force, and if the pressure at any location in the pipe is reduced to the vapor pressure, a vapor cavity will form. The cavity normally forms at the high points in the pipeline where the static pressure is a minimum. Such cavities tend to stay in the downstream side of the hill due to the tendency of the water to drag them in the direction of flow. When the pressure in the pipeline becomes positive, the vapor pocket rapidly condenses and a very high pressure rise can occur when the two water columns meet.

An examination of the pipeline profile shown in Fig. 3 indicates that there are several locations where column separation may occur. The most vulnerable location is at the highest point in the system near Station 6+00. Other vulnerable spots would be near Station 80+70, which is near the crest of the hill just downstream of the pumping plant, and at the center of the pipeline near Station 50+00. The existence of column separation in the pipeline will depend upon the amount of downsurge created when the pumps are shut off.

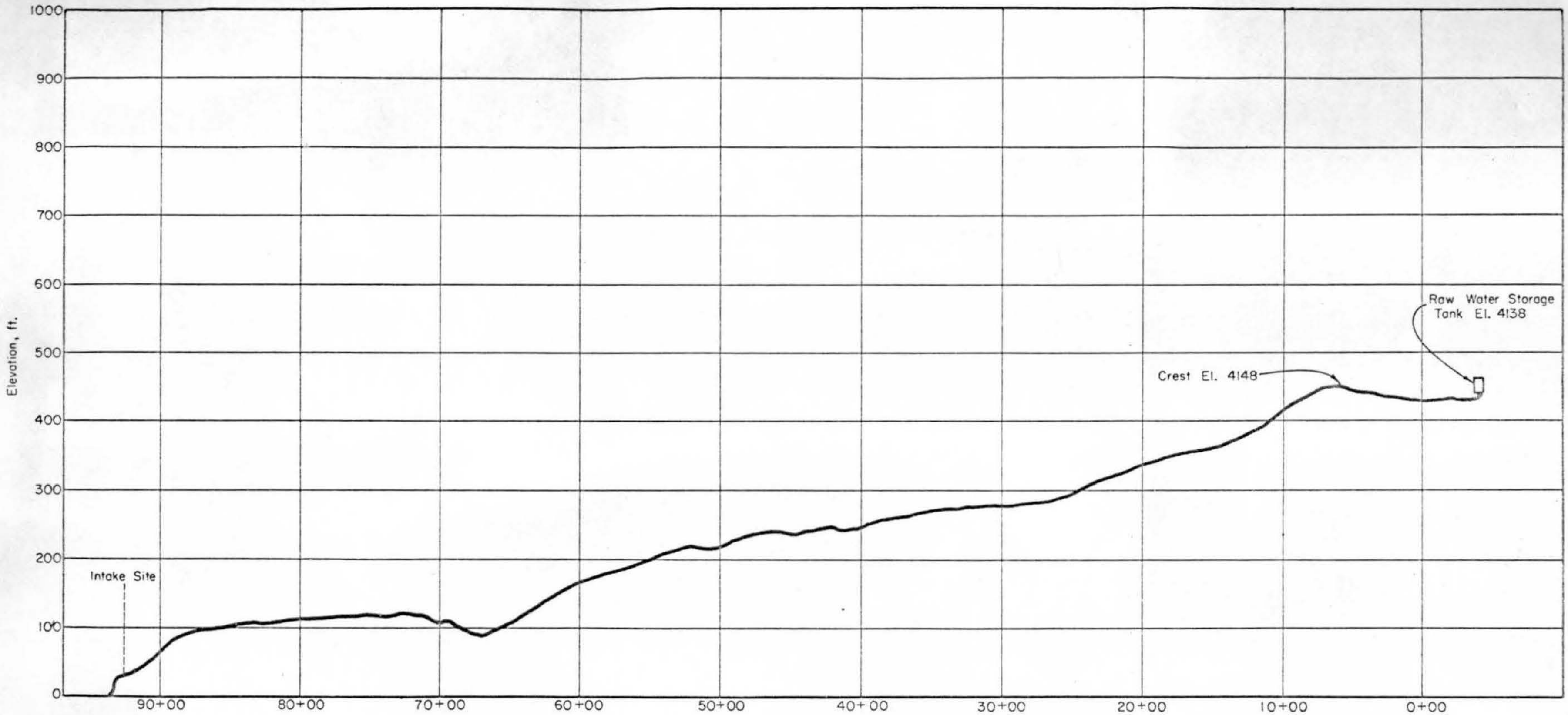


Figure 3. Pipeline profile.

To examine the possibility of column separation, a simplified computer program was written using the method of characteristics to solve the basic water hammer equations. A number of different operating conditions were investigated with this program: the number of pumps in operation, the number of pumps shut down, the time for the water column to come to rest, and the boundary condition at the storage tank were all varied so that a wide range of normal operating conditions would be analyzed. Even though the simplified boundary condition at the pumps was not an accurate representation of the operation of the pump under power failure, the results of the program clearly indicated that column separation would be a severe problem under virtually all operating conditions. With one, two, three, or four pumps in operation and all the pumps shut down simultaneously, water column separation will occur.

Figure 4 shows the steady-state and the minimum hydraulic grade lines based on the simplified computer program for three pumps in operation and all three stopped simultaneously in 8 seconds. The negative pressure agenerated near the crest of the hill are below vapor pressure.

The system was also studied under the conditions of several pumps in operation with one or two of the pumps shut down. The only condition investigated for which column separation did not occur was with four pumps in operation and the one pump turned off with the stopping time of 6 seconds. For this condition, the stopping time of 6 seconds was greater than would be expected for the pump to come to rest. Consequently, it is very possible that even for that condition column separation may occur at Station 6+00.

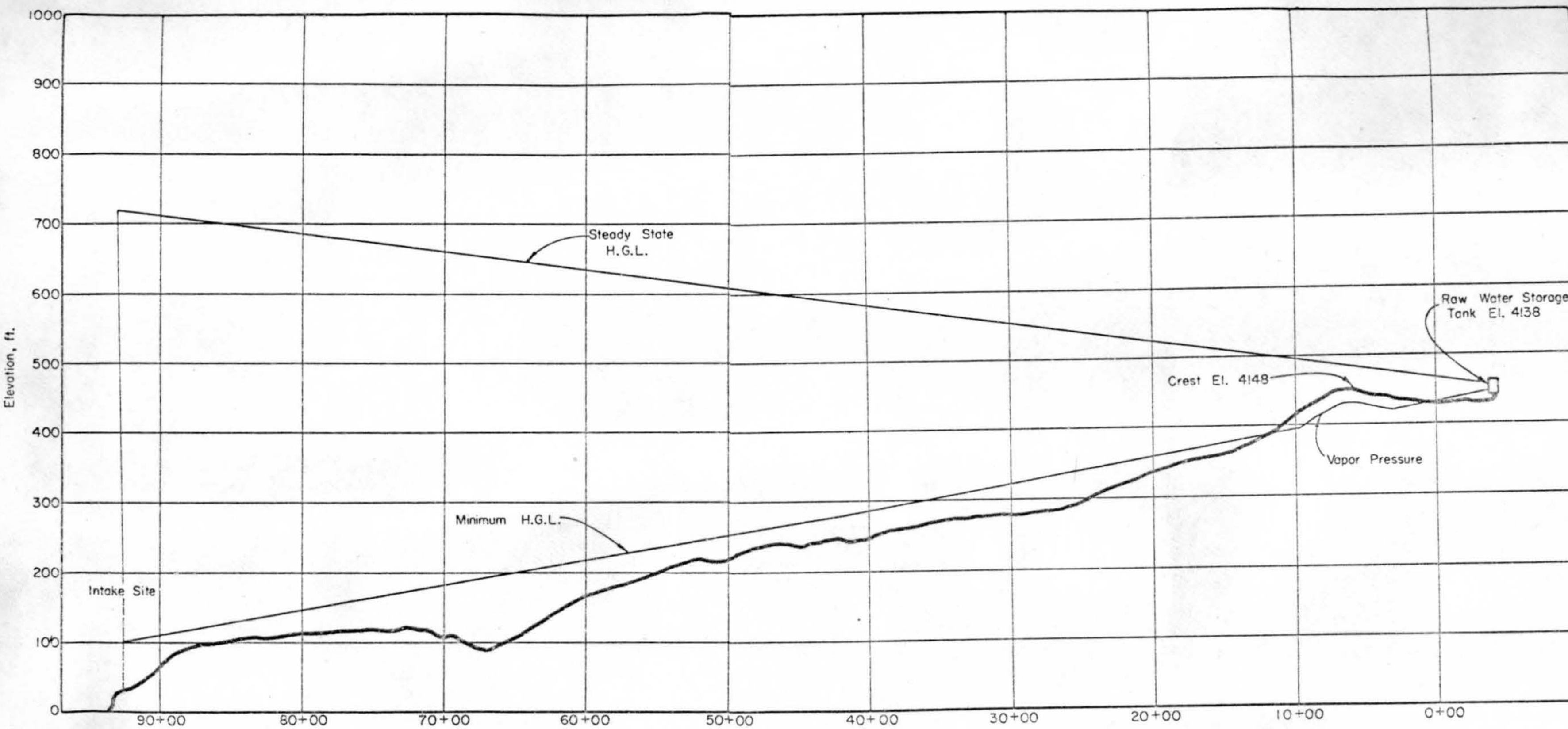


Figure 4. Transient conditions estimated by the simplified computer program for three pumps in operation and all three stopped in 8 seconds.

Pressure Relief Valve

A proper evaluation of the effectiveness of the pressure relief valve was not possible during this initial phase. Since under virtually all conditions column separation occurred, the program became invalid for subsequent cycles of the pressure wave. It was therefore necessary to defer any decision on the effectiveness and need for this relief valve until the system and the computer program was modified so that column separation cannot occur.

ANALYSIS OF THE SYSTEM - PHASE II

The findings of the initial phase of the investigation were relayed to Stearns-Roger. With the existence of the column separation problem clearly identified, direction was given to proceed with a detailed analysis of the system and with recommended modifications to eliminate the existing problems.

Column Separation Analysis (Simplified Computer Program)

Before any additional analysis of the system could be undertaken, it was necessary to make adequate modifications to eliminate the possibility of column separation at Station 6+00. The first solutions considered were: 1) installation of a vacuum breaking valve which would allow air to be drawn into the line when the pressure became negative, or 2) the installation of a one-way surge tank which would allow water to be introduced into the pipeline in the event of negative pressures. Neither of these solutions appeared to be suitable for this particular situation.

Vacuum valve - The vacuum valve was considered to be unsatisfactory for this application for two reasons. First, the admittance of air into the pipeline to avoid the possibility of cavity formation creates additional problems since large quantities of air in a pipeline can result in additional transients being generated. Second, under certain normal operating conditions the pressure at the top of the hill is negative because of the elevation of the pipeline. Under this condition it is possible that the vacuum valve would be actuated and air admitted into the pipeline under steady-state conditions. This would, of course, create serious operating problems.

One-way surge tank - The one-way surge tank concept for location 6+00 was eliminated as a possibility for much the same reason as was the facuum breaking valve concept. Under normal operating conditions with the pressure negative at the top of the hill, it would be necessary to have the surge tank control system designed such that water would not be discharged from the tank into the pipeline. However, when the negative pressure approached vapor pressure, it would be necessary that the tank release water into the system to avoid the formation of a vapor cavity. It is considered that it would be expensive and risky to design a system which would be able to distinguish between the steady-state negative pressure conditions and the transient negative pressure conditions sufficient to cause column separation.

If the maintaining of a positive pressure near Station 6+00 is not adequate to eliminate all column separation problems, a one-way surge tank might be required at some other location in the system.

Interim tank - To correct the problem of column separation at Station 6+00, it is suggested that a tank (hereafter referred to as the interim tank) be installed near that location to maintain a positive pressure on the pipe at all times. The interim tank should be located near Station 6+00 at the highest point in the terrain. If the top of the hill in that location is fairly level, it is suggested that the tank be located towards the crest of the hill nearest the pumping plant.

A sketch of the tank showing the pertinent design features is included as Fig. 5. It consists of a 3-foot diameter tank, 20 feet high, mounted on a concrete base. The top of the tank is closed with an air-relief, vacuum-breaking valve installed at the top. The 6-inch inflow pipe from the pumping station enters the tank at the bottom. The 6-inch outflow line leading to the raw water storage tank is connected on the side of the tank approximately 13 feet from the bottom.

If there are any humps in the outflow line between the interim tank and the storage tank, suitable air-relief valves should be installed at the high points in the pipeline. The half-inch drain line connecting the inflow and outflow lines could provide a means of draining the storage tank. This line would remove all water from the tank and minimize the possibility of freezing. For this "anti-freezing" system to work, it will be necessary to make an accurate determination of the elevation of the maximum water level in the storage tank compared with the elevation of the drain line. The data available for this report were not sufficiently defined to accurately determine these elevations. If the maximum water level in the storage tanks is above the crest of the hill, the interim tank will have water in it and suitable heating will be required.

The operation of the tank would be as follows: 1) For low discharges and low water surface elevations in the raw water storage tank, the air-release valve will be open with atmospheric pressure above the water surface. Under this condition the gravity head between the interim tank

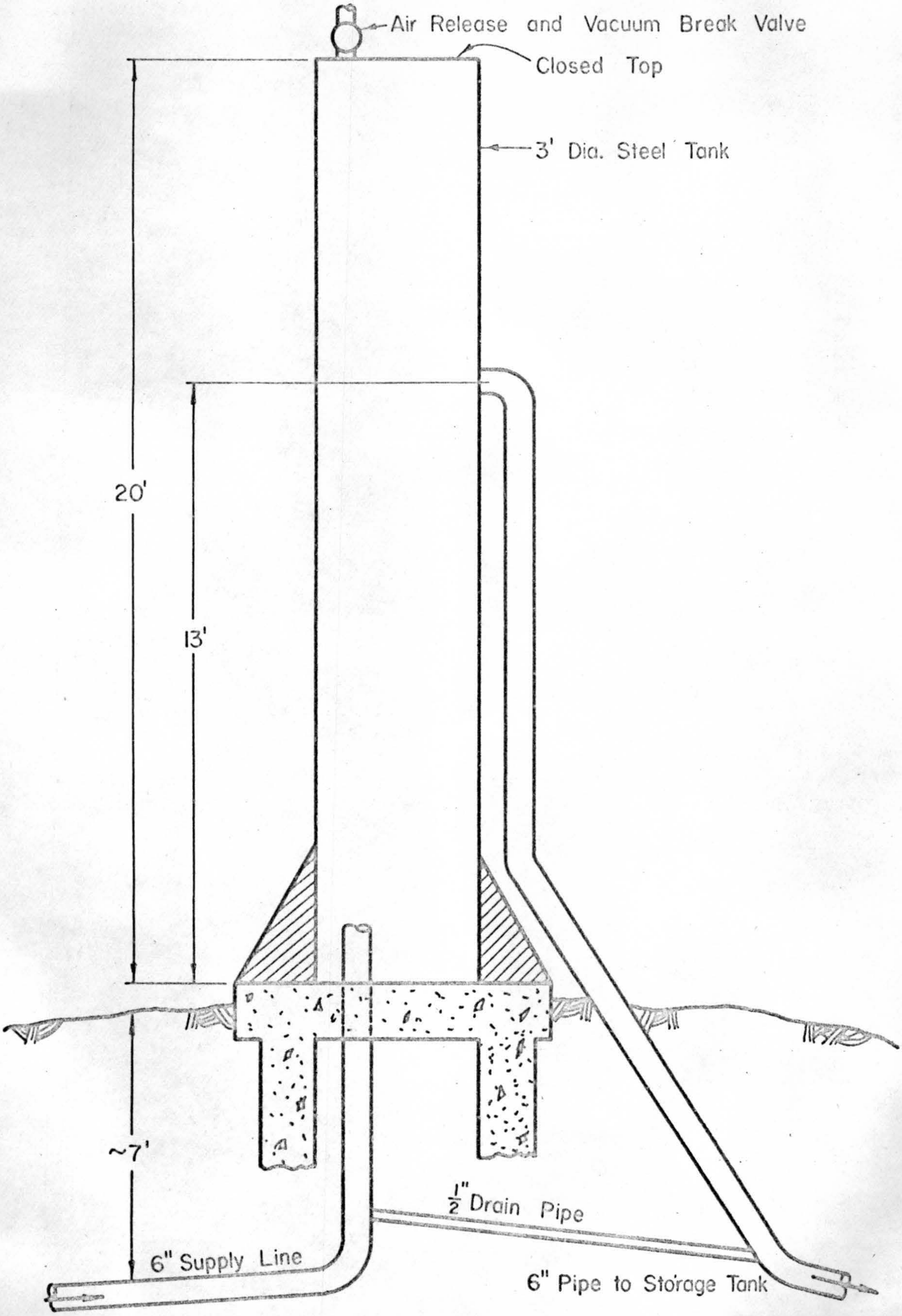


Figure 5. Interim tank located near Station 6+00.

and the storage tank will be sufficient to supply the required water.
2) For high discharges or high water surface levels in the storage tank, the interim tank will fill and the air-release valve close. This will pressurize the interim tank and will give the additional driving force required to satisfy the discharge requirements to the storage tank.

Upon shutdown of the pumps or power failure, the pressure in the interim tank will drop to atmospheric pressure, the vacuum breaker will open and allow the water surface to drop to the bottom elevation of the discharge pipe. The water surface will then remain at an elevation 13 feet above the bottom of the tank, giving approximately 20 feet of positive head to the discharge pipe. With the addition of the interim tank, the possibility of column separation near the crest of the hill is eliminated and the analysis of the rest of the system could be complete.

With other humps in the pipeline, there is still some concern about the possibility of column separation elsewhere in the system. The simplified computer program proved to be inadequate for determining the existence or non-existence of column separation with the interim tank in operation. It did, however, indicate that there is a possibility of additional column separation. Figure 6 shows the transient conditions estimated by the simplified computer program for three pumps running and all three stopped in 6 and 8 seconds. For 8 seconds stopping time no column separation occurs. For 6 seconds stopping time column separation occurs between Stations 3 and 9. However, the simplified program gives a non-conservative estimate of the minimum pressures. The hydraulic grade lines shown on Fig. 6 are almost straight. In reality they would be concave at minimum pressure conditions; and hence, more of the pipeline could be under negative pressure.

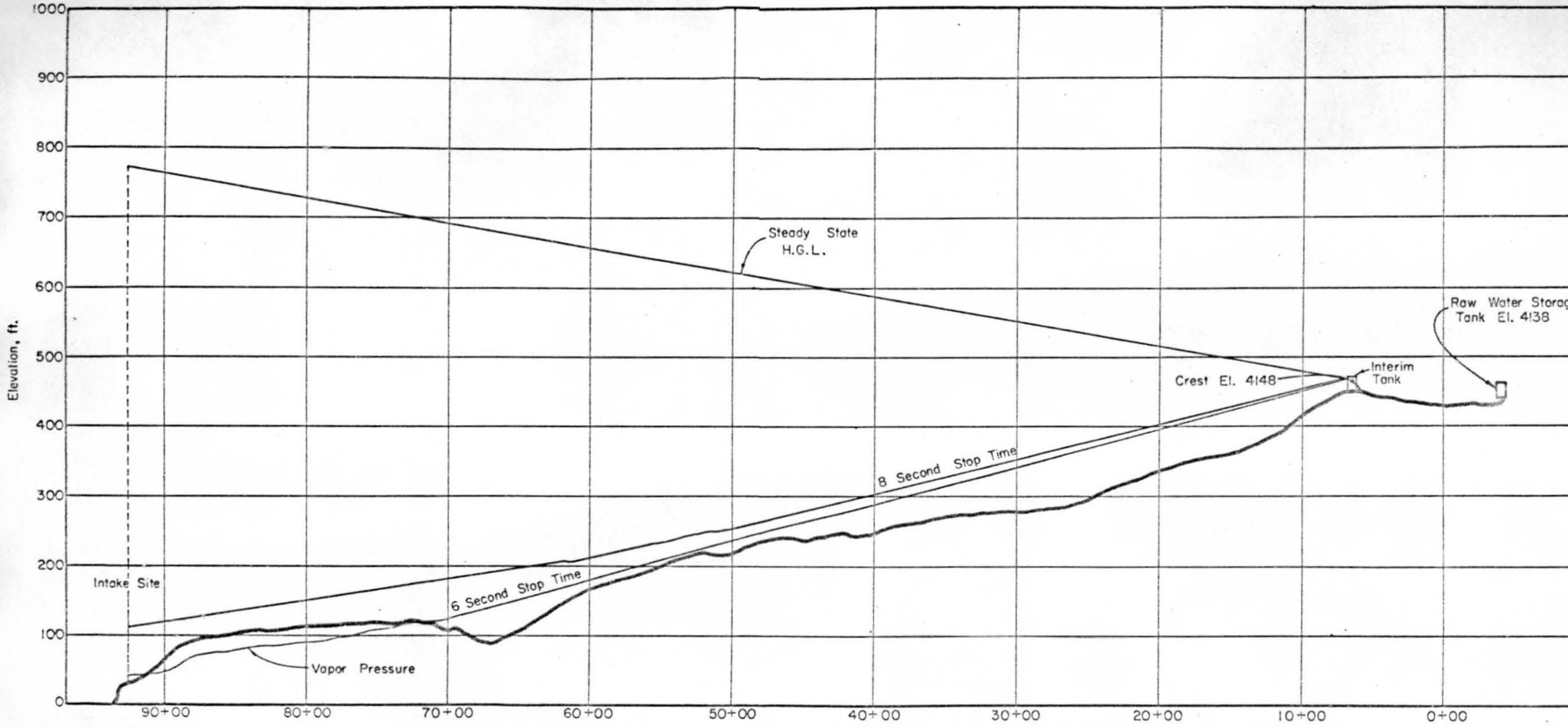


Figure 6. Minimum hydraulic grade lines estimated by the simplified computer program for three pumps and the interim tank in operation.

The time for the water column to come to rest, neglecting the inertia of the pumps, was estimated to be between 6 and 8 seconds. It was therefore necessary to make more exact calculations. To evaluate the problem more closely, a second program was written which encorporated the complete pump characteristics as furnished by Stearns-Roger.

Column Separation Analysis (Complete Computer Program)

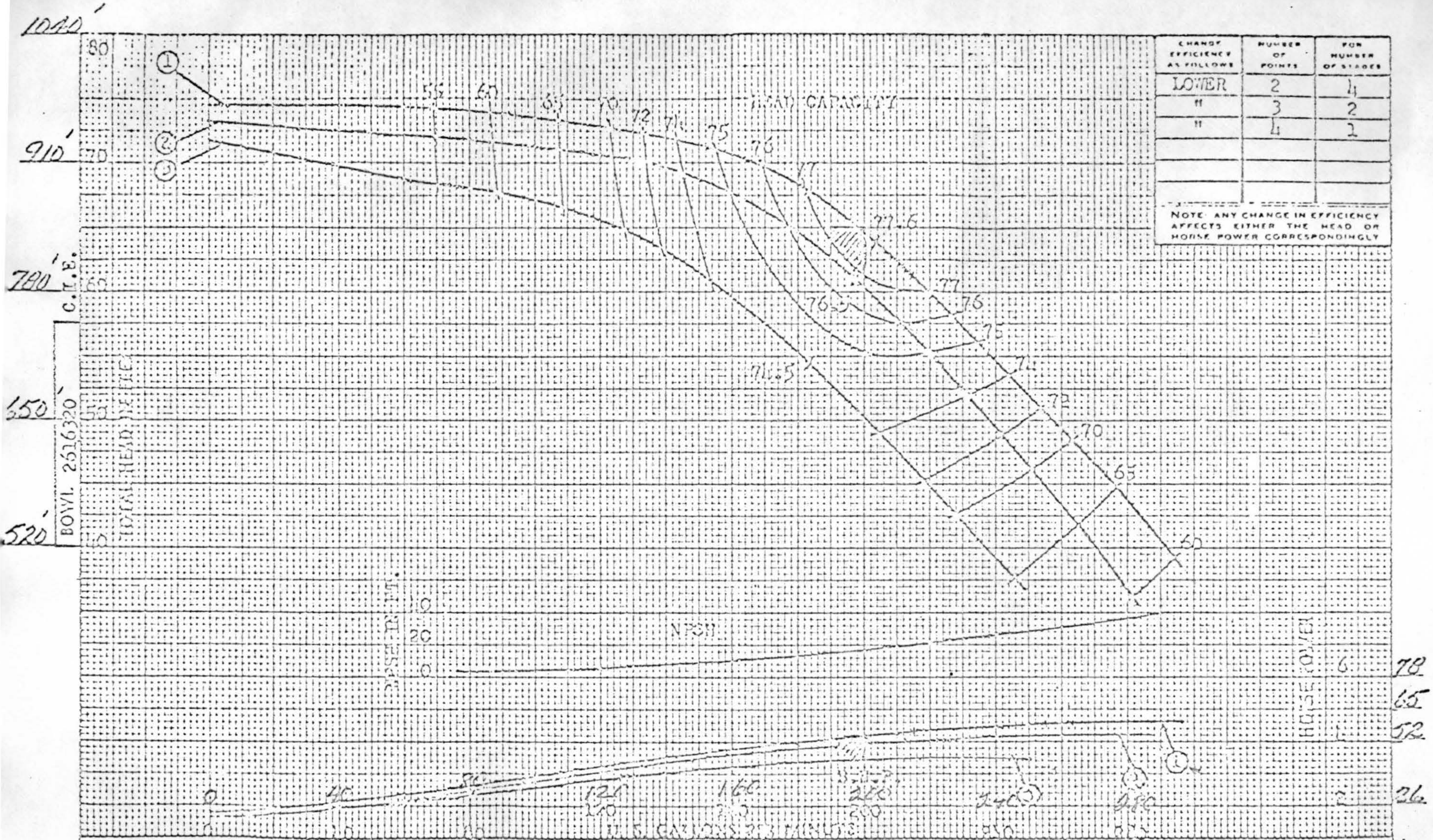
Figure 7 shows the pump characteristics adjusted for the 13 stages. The WR^2 for the pumps and motors were obtained from the manufacturers as 5.8 $lb\text{-}in^2$ per stage and 4.0 $lb\text{-}ft^2$, respectively. These data were utilized as input to the new computer program. The very samll moment of inertia of the rotating parts added greatly to the severity of the column separation problem.

Figure 8 shows the minimum hydraulic grade lines for the system with the interim tank located at Station 6+00. Even with a positive head of about 20 feet at the tank, column separation will occur any time all pumps are stopped. Additional protective measures will therefore be required.

The interim tank suggested for installation near Station 6+00 would not be located on property owned by the client. It was requested by the client that, if possible, all corrective devices be located on company owned property. Additional solutions were therefore required.

Pressure control valve - With the pumps and motors having so little inertia, undesirable negative pressures occur when the pumps are stopped. Even with the one interim tank installed and one pump on line, column separation will occur as indicated by Fig. 8.

Another method of correcting this trouble would be to offset the negative wave transmitted downstream from the pumps by a positive wave



HYDRAULIC PERFORMANCE	CURVE NO.	IMPELLER NO.	IMPELLER DIA.	TAKEN FROM
GUARANTEED AT THE DESIGNATED POINT ONLY AND IS CONTINGENT ON WELL PROPERLY FURNISHING PUMP WITH NON-AERATED OR NON-GASEOUS WATER FREE FROM ABRASIVES. PUMP BOWLS MUST BE PROPERLY ADJUSTED FOR THE HEAD AT WHICH THEY OPERATE AND MUST BE SUBMERGED.	1	2616318	4-15/32	34385
	2	2616318	4-5/16 x 4-15/32	37221
	3	2616318	4-1/64 x 4-15/32	37324

PEERLESS PUMP
HYDRODYNAMICS DIVISION

PERFORMANCE PER STAGE
6 LB — DEEP WELL TURBINE PUMP
3460 — R. P. M.
SHEET NO. 2831811

PRINTED IN U. S. A.

Figure 7. Pump characteristics.

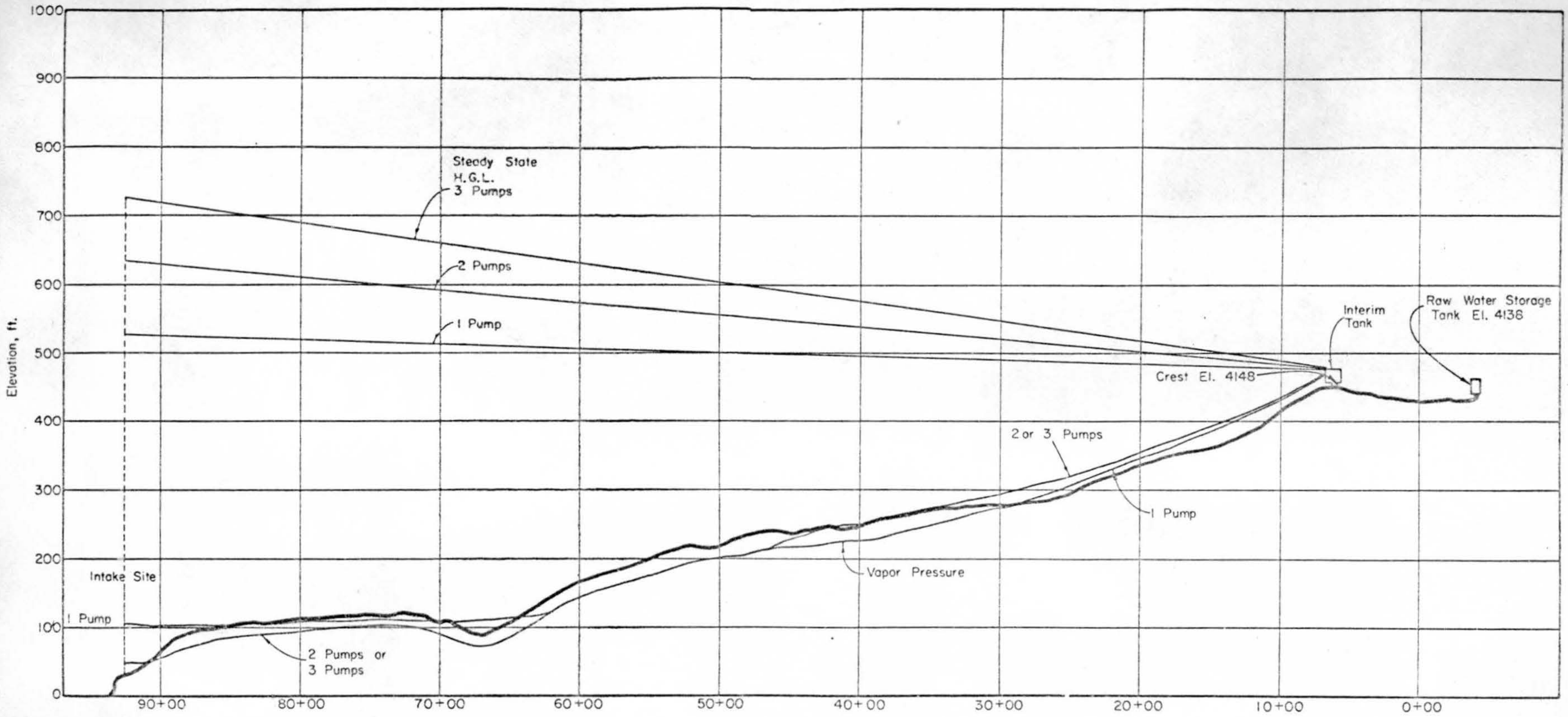


Figure 8. Minimum hydraulic grade line caused by pump failure for one, two, or three pumps and the interim tank in operation at Station 6+00.

traveling upstream from the storage tank. The two waves would add and keep the pressure everywhere positive. Such a positive wave could be generated by the closing action of a valve. The valve would have to be automatically actuated so that it would close each time the pumps were stopped either intentionally or by a power failure. The closing time for the valve should be about equal to the time it takes for the pressure wave to make one round trip through the pipeline.

Figure 9 shows the hydraulic grade line with increasing time after power failure to three pumps. Four hydraulic grade lines are shown on the figure. At time equals zero, the steady-state hydraulic grade line is a straight line between the storage tank and the pumping plant. At time equals 0.52 seconds, a negative wave has traveled approximately 1,000 feet downstream and a positive wave approximately 1,000 feet upstream. At time equals 1.05 seconds, the negative and positive wave have traveled approximately 3,000 feet. At time 2.89 seconds, the waves have crossed and are beginning to add. The maximum positive surge at the pressure regulating valve is approximately 500 feet (gage). Minimum surge at the intake site is about 50 feet (gage). For one or two pumps in operation, the characteristics of the curve were similar to that shown in Fig. 9 for the three pumps; the only major difference being that the positive increase in pressure at the pressure regulating valve is less for fewer pumps. The one condition for which negative pressure was observed was at about 2.6 seconds after power is interrupted for three or four pumps. The negative pressures occurred at the first hill just downstream of the intake site. The maximum negative pressure calculated was approximately -12 feet of water.

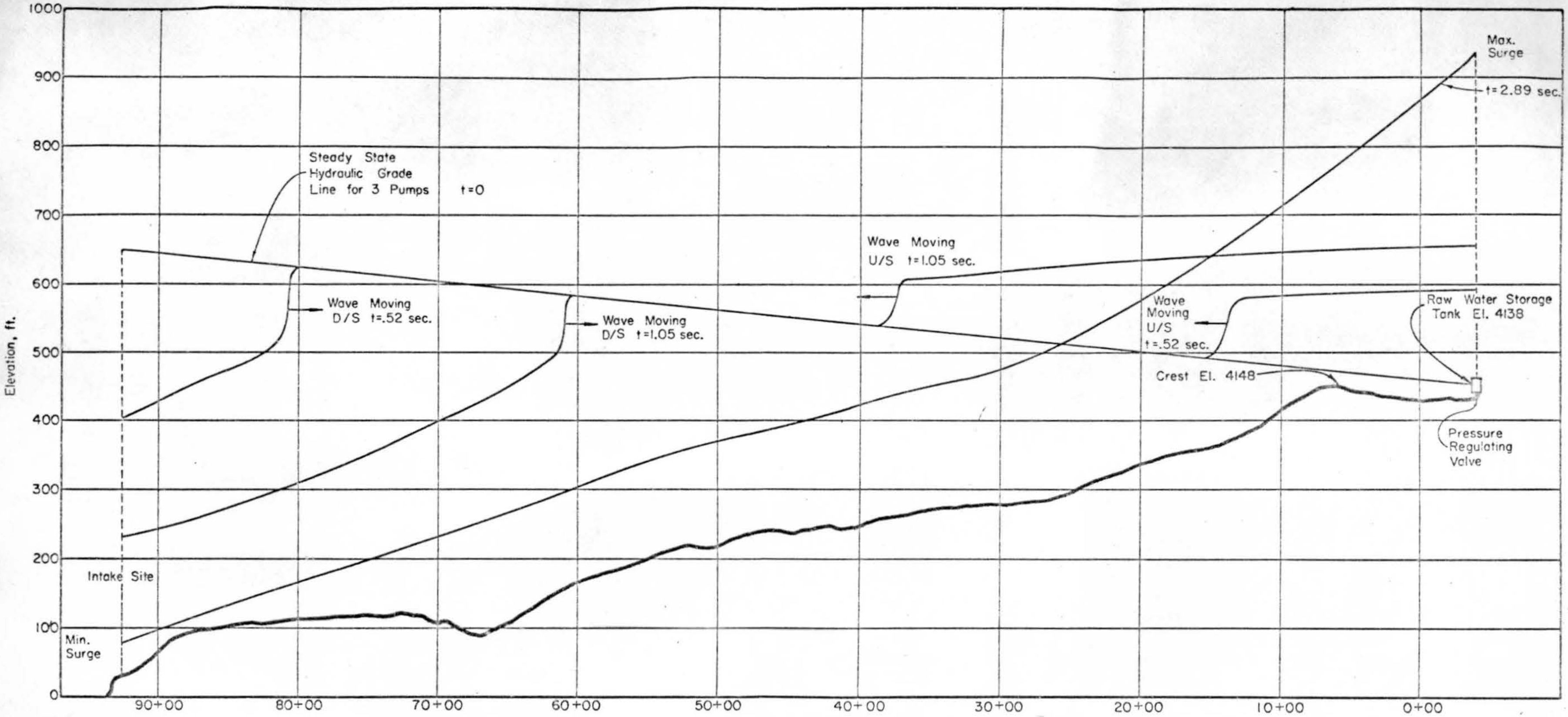


Figure 9. Pressure conditions for three pumps stopped with a pressure regulating valve at the storage tank.

The closing time of the pressure regulating valve was set at 6 seconds. By slightly decreasing this closing time, the negative pressures near the intake site could probably be eliminated. When the computer program was run with four pumps, the positive surge at the pressure regulating valve was over 700 feet. Also, there was more of the pipeline subjected to negative pressure near the intake site. Because of the severity of the problem, it is recommended that if the pressure regulating valve is used, the fourth pump not be installed since it would add to the existing major difficulties.

The advisability of using a pressure regulating valve for controlling the column separation problem is primarly dependent upon being able to obtain a reliable valve, operator and suitable control equipment.

As far as the author is aware, this type of system has not yet been used for controlling column separation problems. Before recommending it as a solution, it was felt advisable to inquire regarding the reliability of valve systems available for this type of service. It was the feeling of those contacted that such a system, which requires an accuracy in responses of about ±0.5 sec, is not commercially available. Since such a system has not been used and if it may not be possible to obtain a control system with adequate reliability, this solution should not be considered the preferred recommendation.

Multiple surge tanks - Another solution considered for solving the column separation problem is the use of surge tanks located at critical points in the system. Two different solutions were considered. First, was with the interim tank located at Station 6+00 and a one-way surge tank located approximately at the midpoint of the pipeline. The second solution investigated was with a 66-foot standpipe installed at the

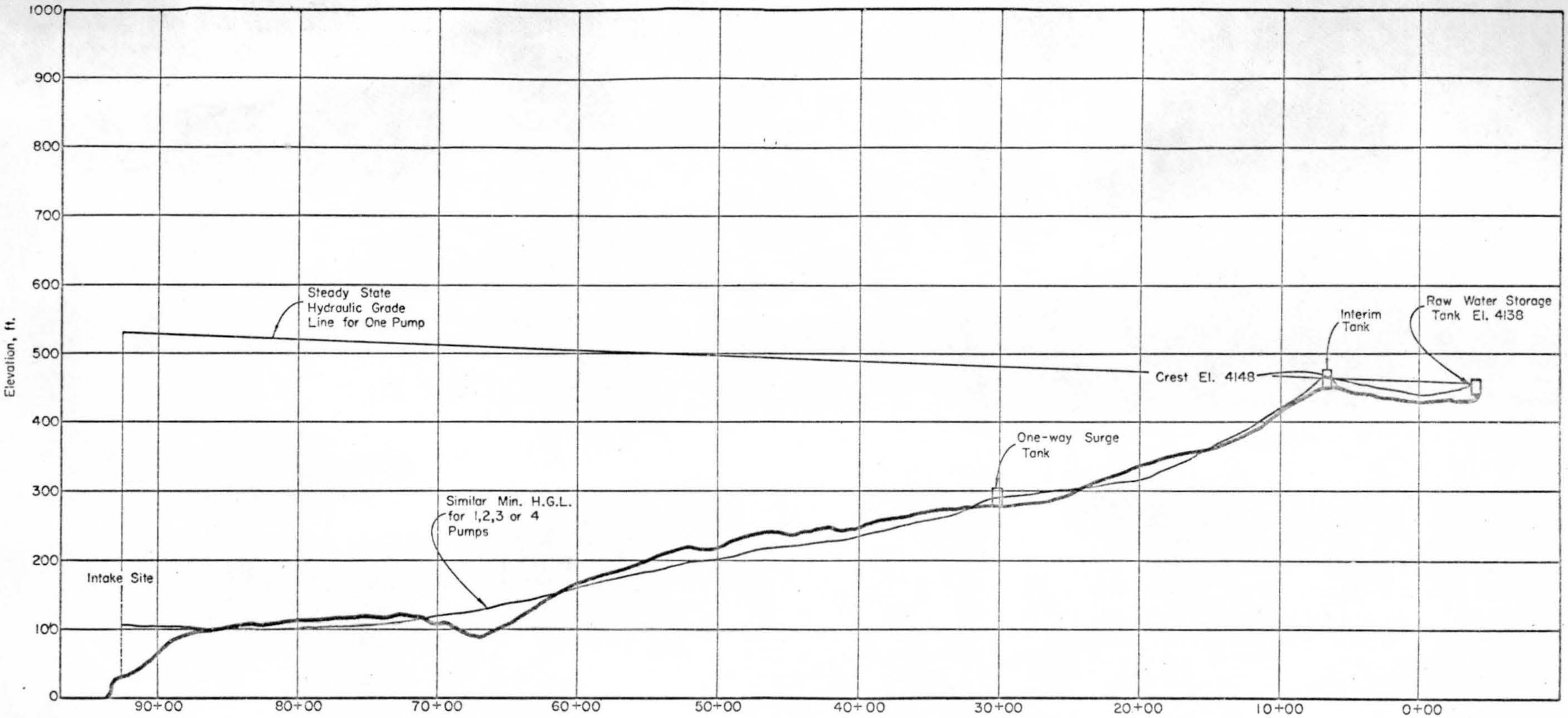


Figure 10. Column separation with the interim tank and a one-way surge tank.

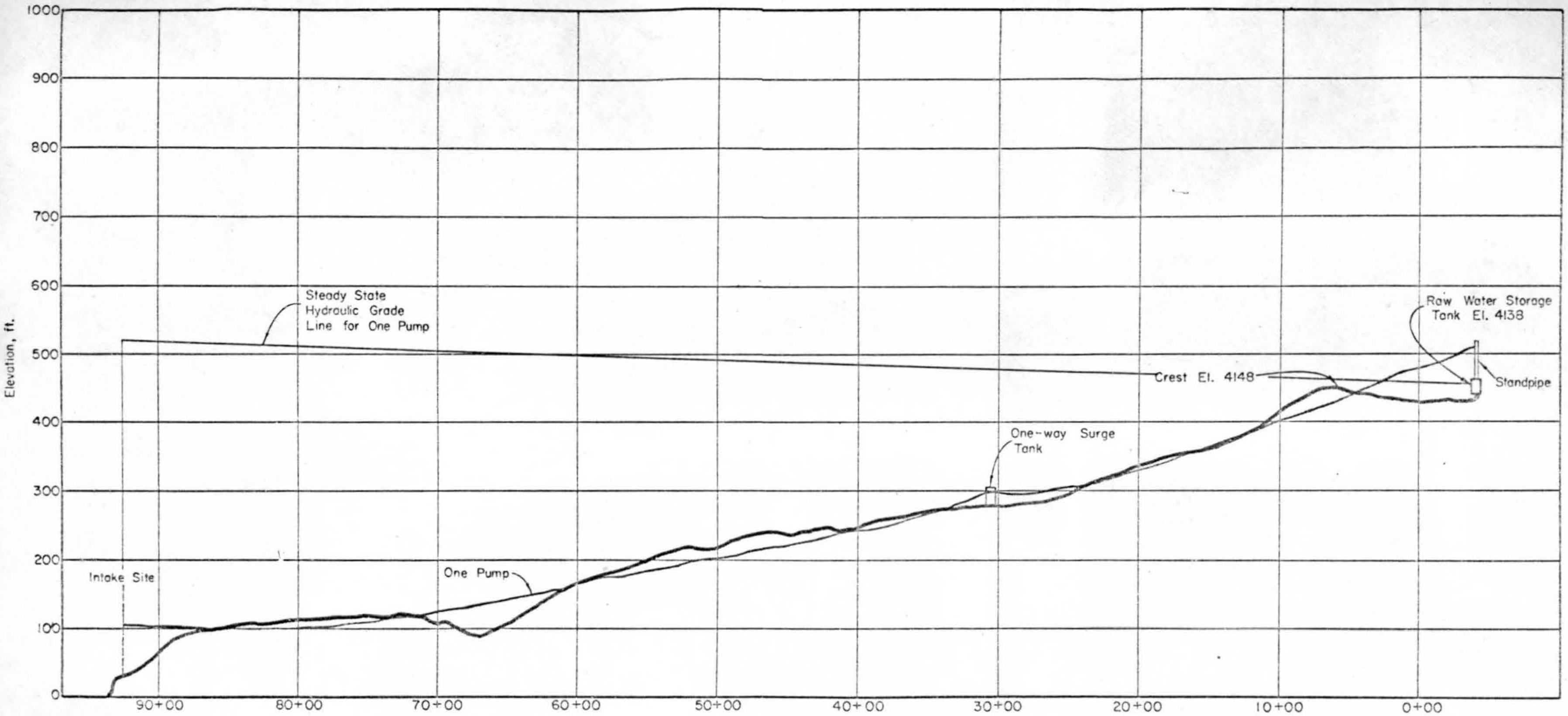


Figure 11. Column separation with a 66-foot standpipe at the storage tank and a one-way surge tank.

raw water storage tank and the one-way surge tank installed at approximately the midpoint of the pipeline. The minimum hydraulic grade lines for these two situations are shown in Figs. 10 and 11, respectively. It is evident from the figures that even with the two tanks installed, much of the pipeline is subjected to negative pressure when any of the pumps are shut down. The heads in surge tanks were only about 20 feet. Higher heads in the tanks would improve the situation but probably not completely eliminate the problem.

There are four factors which intensify the column separation problem for this installation. These are 1) the small moment of inertia of the rotating part of the pumps and motor, 2) the high gravity heads against which the pumps are operating, 3) the length of the pipeline, and 4) the fact that the profile of the pipeline almost parallels the hydraulic grade line under minimum pressure conditions. Consequently, if the pressure anywhere in the system tends to go negative, essentially the complete pipe is subjected to negative pressure. These four problems, and particularly number 4, make it necessary to install a number of surge tanks at critical points in the pipeline to ensure that negative pressures do not occur. Such a solution would be very expensive.

Air chamber - Column separation problems have been successfully solved for certain installations using an air pressurized surge tank located near the pumping plant. In brief, the system works as follows: A tank is directly connected to the discharge line. Water is supplied to the tank by pressure in the pipeline. The proper air pressure and volume is supplied and adjusted by an air compressor and suitable control devices. The chamber is passive under steady-state operating conditions. If the pressure in the pipe changes, water flows either into or out of the chamber through differential orifices. When the pumps stop, sufficient energy is available from the compressed air to bring the water column slowly to rest in a safe time. Adequate air and water volume in the tank would be needed to bring the column to rest in approximately 30 seconds.

With this system a standpipe at the raw water storage tank would be needed. Running the standpipe to the top of the tank would place it at elevation 4162 feet which is 14 feet above the crest of the hill near Station 6+00. This height should be sufficient to eliminate the possibility of column separation if the air chamber is used.

For details regarding the design of the air chamber, it is recommended that contact be made with:

Pulsations Control Corporation
126 West Santa Barbara Street
Santa Paula, California 93060.

Pressure relief valve - The analysis of the transients created in the Cochrane pipeline did not indicate, for the conditions investigated, that the pressure at the pumps would rise sufficiently to require a pressure relief valve at that location. However, if the pressure regulating valve at the raw water storage tank is installed to control the column separation problem, it is recommended that the pressure relief valve be retained since it is possible that the regulating valve could close while the pumps are on, sending a positive pressure which would exceed that calculated for the case of pump failure. It is recommended that the valve be set to open when the pressure reaches about 450 psi. This pressure is in excess of any pressures observed during normal transient conditions.

If the air chamber is used, the pressure relief valve would not be required.

CONCLUSIONS AND RECOMMENDATIONS

It is obvious that there is a potential for severe water column separation problems with the Cochrane intake pipeline. With one or more pumps in operation and all pumps stopped simultaneously, most of the pipeline becomes subjected to negative pressures sufficient to cause column separation. The problem is intensified by the low moment of inertia of the rotating parts of the pumps and motor, by the high gravity head, the length of pipeline, and by the profile of the pipeline being almost parallel to the minimum hydraulic grade line. The result is that most of the pipeline is subjected to negative pressures when the pumps are shut down.

Recommendations

A. The recommended solution to the existing problem of column separation is the installation of an air chamber at the intake site and a 24-foot standpipe in the raw water storage tank.

   1. Properly designed, the tank should control separation for all four pumps in operation, or for any combination of pumps.
   2. The tank should be designed to bring the water column to rest in about 30 seconds, based on four pumps.
   3. Adequate heating will, of course, be required.
   4. The pressure relief valve at the pumping plant would not be required.

B. An alternate solution is the installation of a pressure regulating valve at the raw water storage tank. The valve would be controlled such that it automatically closed in approximately 6 seconds each time the pumps were turned off either accidentally or intentionally.

With the time of closing properly selected, no negative pressures should occur anywhere in the pipeline.

1. It is recommended that the fourth pump at the intake site not be installed. With the fourth pump in operation, the positive surge at the pressure relief valve appears to be excessive and the possibility of negative pressures near the intake structure is increased.

2. It is recommended that the 1½-inch pressure relief valve located at the intake site be retained and that the opening pressure be set at 450 psi.

C. The system should not be operated before adequate corrective measures are completed. If, for some reason, it is necessary to use the system sooner the following procedure would help to minimize the chance of damage:

1. Use only one pump.

2. Throttle the flow to almost zero flow before stopping the pump.

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