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PRELIMINARY FIELD INVESTIGATION REPORT

Tailings Disposal Pipe Lines

of the

Climax Molybdenum Plant

Climax, Colorado

by

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PRELIMINARY FIELD INVESTIGATION REPORT

Tailings Disposal Pipe Lines

Authorization and Acknowledgements

The field trip to the Climax Molybdenum Company was made at the request of Mr. Robert A. Steele representing the Climax Company. Members of the engineering group making the trip from Fort Collins included S. S. Karaki and W. W. Sayre, of Colorado State University, and Dr. D. B. Simons, E. V. Richardson and W. L. Haushild of the U. S. Geological Survey stationed at Colorado State University, Fort Collins, Colorado.

INTRODUCTION

Nature and Purpose

The Climax Molybdenum Company has embarked on a multi-million dollar expansion program to increase the production of molybdenum. The plant expansion will require, among other things, an increase in the capacity of the tailings disposal system. It is the disposal system with which the field trip was concerned.

The tailings are presently conveyed hydraulically through two pipelines (used alternately) to a tailings pond about $2\frac{1}{2}$ miles away from the main plant. The company plans to continue with the hydraulic disposal of the wastes in the total expanded plant system. This will require an increase in size of the pipelines; the design of such line or lines will be dependent upon the hydraulic characteristics of the pipe, the fluid, and the transported particulate material. The principle information required for design is the relationship of head loss to velocity of a specific slurry flowing in a pipeline of given size and type.

Description of the Disposal System and Properties of the Tailings

The present average plant production necessitates disposal of about 33,000 tons per day (T.P.D.) of slurry at an average concentration of about 38% of solids by weight. Normally the flow varies little and the concentration may vary from 36 to 42 percent. During mill shut down periods the flow may decrease

to about 15,000 T.P.D. For short periods under abnormal loads the rate may increase to 40,000 T.P.D. It is expected that ultimately the expanded facility will require disposal of about 60,000 T.P.D. with increase in concentration to about 45 percent.

The tailings from the mill flows to a Tailings Distribution House where the flow to individual pipe lines is controlled. There are two pipelines from the distribution house, one along the west and the other along the east side of the valley. The flow in these lines is entirely by gravity. The existing pipelines are primarily 24 in. wood-stave pipe. Concrete pipe sections have been used to replace worn wood-stave sections. A portion of the pipelines on the west side of the valley also contains a paved corrugated metal pipe section 30 inches in diameter over the tailings pond dam.

The total length of the pipeline to the tailings dam on the west side is about 12,600 feet, and the total drop in elevation at present is about 275 feet. The pipeline slope varies from .010 to .001. There are 18 drops in the pipeline varying in height from 36.9 feet to 3.8 feet depending upon the topography of the mountain side. Some of the drops are 45 degree enclosed drops while others are vertical drops provided with an air vent. A typical drop of the latter type is shown in Fig. 1. Fig. 2 shows a general view of a typical reach of the west pipeline.

General comments are limited to the west side pipeline as it is expected that tests will be made only on certain reaches of this pipeline.

The solids transported as waste from the mill can be classified as fine sand having a specific gravity of about 2.68. The size distribution depends upon the "grind" in the mill. A 38-grind for instance refers to 38 percent of the material retained on a 100-mesh screen. A typical sieve analysis for a 38-grind would be:

Sieve Mesh size	Particle Size		Percent Retained
	in.	mm.	
48	.0104	.264	11.2
65	.0077	.195	24.4
100	.0050	.127	38.0
150	.0033	.084	48.4
200	.0025	.0635	56.2

BRIEF REVIEW OF LITERATURE

When flow in a pipeline is highly turbulent and the particle concentration in the cross-section of flow is relatively uniform, the mixture may be treated analytically as a homogeneous fluid with its mass density corrected for the presence of the suspended particles. The resistance equations for pipe flow may then be used, provided the head loss is corrected for the specific gravity of the mixture. The works of Durand (4) and Gregory (6), O'Brien and Folsom (10), Babbett and Caldwell (1), Mikumo (8), Durepaire (5), and others have confirmed the validity of its use.

As the intensity of turbulence, relative to the size of particles, decreases to some stage, the particles can no longer be transported in a homogeneous mixture. The resistance equation does not hold for this heterogeneous mixture because the effect of particle settling becomes important. From the early tests by Blatch (2), it was observed that the head-loss curves of a mixture deviated from that of a pure fluid at low velocity flows and high concentration of particles as shown in Fig. 8.

Increase in particle size causes the settling velocity to increase relative to the mean velocity of flow, hence developing a significant concentration gradient in the vertical cross section of the pipe and causing perhaps, deposition along the invert of the pipe.

If the sediment concentration gradient becomes pronounced and is combined with a range in size distribution of the transported particles, analysis of the flow system becomes difficult. Much research work has been done with uniform size materials. Typical is the work of Durand.

Through dimensional and inspectional analysis, Durand was successful in consolidating his experimental data in the non-deposit flow regime with a single function expressed as:

$$\Psi \left(\frac{J-J_a}{J_e C_t}, \frac{V^2 \sqrt{C_D}}{gD(\rho_s - \rho)} \right) = 0$$

where: J = Energy gradient of mixture flow
 J_e = Energy gradient of pure fluid flow
 C_t = Mean concentration of sediment by volume
 V = Mean velocity of flow
 C_D = Drag coefficient of sediment particle
 g = Acceleration due to gravity
 D = Pipe diameter
 ρ_s = Mass density of the sediment
 ρ = Mass density of the fluid
 Ψ = "Function of"

The theoretical basis for this correlation may better be understood when compared to the theoretical equation of Newitt (9):

$$\gamma = \frac{J-J_e}{J_e C_t} = K_1 \left(\frac{s-l}{\rho} \right) \frac{gD}{v^2} \frac{w}{V}$$

where w = Terminal fall velocity of sediment particle,
or again with Vogt and White (12):

$$\frac{J-J_e}{J_e} = A \left(\frac{D}{d} \right)^2 \left(\frac{\rho}{s} \frac{\gamma}{R_e} \right)^{k_2}$$

where: A = constant

d = characteristic sediment diameter

γ = specific weight of fluid

k_2 = constant

R_e = Reynolds number

If the solids are large and the difference in mass density of the fluid and sediment is large, or if the mean velocity is small, there will exist a pronounced increase in concentration near the bottom of the pipe. Some observations on the vertical distribution of sediment concentration and local velocities have been reported by Howard (7) Durand and Chamberlain (3). Integral interpretation of these results, however, is difficult, even

though it is apparent that the existence of a mass density gradient has a profound effect on the magnitude of the deviation of the head loss curves.

In many industrial applications of sediment transport in pipes, a considerable size gradation of the particles exists. In spite of its practical importance, the effects of size distribution on the transport characteristics are only qualitatively understood.

Durand observed that an equivalent diameter of the mixture might be used if it is based on a weighted average. The mechanisms involved are not clarified, and it is unlikely that a simple relationship can adequately include all the effects. One of the more significant effects observed in the mixed-size transport is that the fine sediment seems to have an important role in reducing head loss.

Binary mixtures of sand and gravel with a diameter ratio of 1:40 were tested at the Imperial College in London and it was noted that there was a maximum carrying capacity of gravel with sand concentration of about 15 percent. This phenomenon may be of great significance in many industrial applications.

At Colorado State University comparisons of flow and transport characteristics of 12 inch Hel-Cor pipe, plain pipe and standard corrugated pipe were made to study the effects of artificial roughness on transport. The results showed that the

Hel-Cor pipe can usually deliver more sediment discharge with less head loss than the other two pipes tested. The U. S. Corps of Engineers (7) has long experimented in the design of rifling of pipe to increase sediment transport in circular pipes. These experiments indicate that rifling increases the efficiency of the line in cases where the material being transported would settle out in a plain pipe. The efficiency is decreased by rifling, however, if the velocity and turbulence are already great enough to keep the sediment in suspension.

In the foregoing brief discussion on the mechanics of transport in pipelines, it is evident that a unified theory is difficult to establish, hence a generalized design criteria is not readily possible. Lacking this design criteria, it appears that at present, the best method for designing large and important pipe-transport systems is to utilize all available analytical, and empirical knowledge that is applicable to the system, include benefits of past experience and to make special studies in laboratories or in the field pertinent to the proposed system.

THE FIELD STUDY

General Purpose

The purpose of the field study is to obtain data from the existing Climax Molybdenum Company pipe disposal system to develop sufficient background information for use in design of the enlarged system. It is understood at the writing of this report that the Company wishes to use concrete pipe in the new installation; hence the field data should be confined to the existing 24 inch concrete pipe.

Recommended Test Reaches

The recommended reaches for test are the concrete sections above and below Drop No. 3 in the west pipeline. These reaches have been selected on the basis of length, accessibility and adaptability for laboratory-type testing. According to the Company records on the profile of the system, the slope of the line upstream of Drop No. 3 is 0.00543 and the slope downstream from the drop is 0.00587. The drop is a 45 degree enclosed drop of 8.3 feet.

Equipment and Instrumentation

Discharge-measuring and hydraulic-gradient control section -

It is recommended that a ³⁰~~25~~-ft section of 24" I.D. steel pipe, (Fig. 3) equipped with an orifice plate for measuring the flow and a butterfly valve (Fig. 4) for controlling the flow be located

in the reach of wood-stave pipe immediately upstream from Drop No. 4 in the west tailings line. Location of the orifice plate approximately 50 ft upstream from the drop would be satisfactory.

A side-contracted segmental orifice plate is recommended, because it will not cause sediment deposit at the orifice which would affect the orifice coefficient.

The butterfly valve is required for the purposes of:

- (1) maintaining flow under pressure past the orifice plate, and
- (2) providing full flow in the second test reach.

Pressure-tap installations - Pressure taps (Fig. 5) should be installed at regular intervals along the two test sections. There should be no less than four sets of taps along each test section. The 60° angle from the vertical angle of orientation for the taps shown in Fig. 5 is somewhat arbitrary. However, it is advisable that the taps be located at some angle less than 90° from the vertical, the water-surface level under free-flow conditions permitting.

Manometers - The sketch of the inverted u-tube differential manometer for the orifice plate on Fig. 6 is self-explanatory with the possible exception of the settling bottles, the function of which is to prevent sediment grains from being entrained in the manometer tubes. Heavy-wall glass bottles, tight-fitting rubber stoppers, and thin-wall brass tubing can be used to make the settling bottles. The manometer tubes should be filled with

clear water from the top in order to avoid problems which would arise from not being able to determine precisely the specific gravity of the unstable fine-sediment suspension in the manometer column.

From the point of view of portability and ease of handling it may be advisable to break the portable manometer into separate water and mercury manometer units rather than to combine them into a single unit as indicated in Fig. 6. At least two sets of manometer units should be constructed so as to permit simultaneous observation of the hydraulic-gradient level at the opposite ends of a test section during establishment of equilibrium flow and sediment-transport conditions. Since manometers are comparatively cheap to build, and since only two test reaches containing a total of eight sets of pressure taps are contemplated, it may be well to provide eight non-portable monometers, one for each set of taps, in view of the time and trouble it would save when taking measurements.

When operating the manometers, care should be taken to ensure that all air bubbles are removed from the pressure-tap lines.

Sediment concentration - It is recommended that sediment samples for concentration determinations be obtained with a U. S. DH-48, depth-integrating sampler or equivalent. The sample should be obtained from at least three verticals across

the rectangular section in the distribution house. A desirable location would be where the flow passes over a sill extending across the width of the channel.

Sonic depth sounder - Access parts for the sonic depth sounder (Fig. 7) should be provided in each test section in which it is suspected that appreciable amounts of sediment are being transported as bed load. Access parts should be located at about the middle of the test reaches. Since sharp bends at the base of vertical drops are commonly considered to create the conditions most favorable to deposition, it might also be advisable to provide access parts immediately downstream from vertical drops.

Recommended Procedure

Collection of data - After changing or adjusting flow conditions (Q_m or J) in a test reach, sufficient time must be allowed for equilibrium conditions of hydraulic gradient and sediment transport rate to be re-established. Particularly in cases involving free-surface flow and deposition on the pipe invert, more than an hour may be required. Statistical stability of the difference between manometer readings at the respective ends of the test section indicating a stable hydraulic gradient may be regarded as a criterion that equilibrium conditions have been established. When sediment is being transported as bed load along the invert of the pipe, statistical constancy of deposition depth as indicated by the depth sounder would be another equilibrium criterion.

After equilibrium conditions have been established, measurements should be obtained within as short a time span as possible since uncontrolled variables (e.g. temperature) are capable of causing regime changes.

The measurements which should be obtained and their sequence is:

1. Discharge - measure before and after obtaining hydraulic gradient measurements.
2. Fluid temperature - before and after as with discharge.
3. Hydraulic gradient measurement.
4. Depth sounding measurements - when some of the sediment is being transported as bed load, the depth sounder should be allowed to operate and record continuously while hydraulic gradient measurements are being obtained.
5. Concentration - samples from the distribution house should be obtained before and after each run.

It is also recommended that viscosity and specific gravity measurements be made of mixtures containing several different concentrations of tailings, after having allowed initial settling (say $\frac{1}{2}$ hour). Curves showing fluid properties as a function of concentration may then be constructed.

It would be desirable to run tests for flow under pressure and free-surface flow simultaneously, with the free-surface flow in Reach 1 and the flow under pressure in Reach 2 if proper adjustment of the butterfly valve above Drop No. 4 permits this combination of conditions. If it is possible to maintain approximately uniform flow in Reach 1 by controlling the water level in Drop No. 3 with the valve, this would also be desirable when obtaining data in Reach 1 for free-surface flow conditions. This may not prove feasible, however.

Range of variables - It is recommended that data be obtained for flow conditions involving four concentrations at each of three different discharges as indicated in the table below. It should be possible to obtain these conditions by (1) diverting part of the flow into the East Tailings Line and (2) regulating the flow of clear water into the system.

In addition, it would be very desirable to conduct at least one run with clear water in order to establish definitely the roughness characteristics of the pipe.

Table of Recommended Range of Variables

Q_m cfs	C_w %	C_v %	Q_s tons/day	Q_w cfs
15	0.30	0.138	15,000	12.9
15	0.35	0.167	18,100	12.5
15	0.40	0.199	21,600	12.0
15	0.45	0.234	25,400	11.5
20	0.30	0.138	20,000	17.2
20	0.35	0.167	24,200	16.7
20	0.40	0.199	28,800	16.0
20	0.45	0.234	33,800	15.3
25	0.30	0.138	25,000	21.6
25	0.35	0.167	30,200	20.8
25	0.40	0.199	36,000	20.0
25	0.45	0.234	42,300	19.1

In the above table:

Q_m is the discharge of the water-sediment mixture

C_w is the concentration by weight of sediment
in the mixture

C_v is the concentration by volume of sediment
in the mixture

Q_s is the sediment discharge

Q_w is the water discharge

The equations relating these quantities are:

$$C_w = \frac{G C_v}{C_v (G-1) + 1}$$

$$C_v = \frac{C_w}{C_w + G(1-C_w)}$$

$$Q_s = 43.2 C_v Q_m G \gamma_w = 7230 C_v Q_m \text{ tons/day}$$

$$Q_w = (1 - C_v) Q_m$$

In the above equations:

G is the specific gravity of the sediment (2.68)

γ_w is the specific weight of water (62.4 lb/ft³)

ANALYSIS OF DATA

The flow discharges and concentrations recommended in the table of variables were arrived at by (1) considering present operating conditions in the West Tailings Line, and (2) a rough analysis similar to the one performed by Parmakian (11), the results of which are shown on Fig. 8.

The clear-water head-loss curve on Fig. 8 was obtained by using the Darcy-Weisbach formula, f having been determined from the Moody diagram, assuming $T = 50^{\circ} F$ and pipe roughness $\epsilon = 0.005$ ft. The curves of constant C_v were obtained by applying a variation of the Durand formula

$$\frac{J - J_e}{J_e C_v} = k \left(\frac{V^2}{gD} \frac{C_p}{s} \right)^{-1.5}$$

to Wilson's data (13) in the manner outlined by Parmakian.

In the above equation:

J is the hydraulic gradient of the water-sediment mixture

J_e is the hydraulic gradient for clear water flowing at the same velocity

k is a constant of proportionality

V is the velocity of flow of the water-sediment mixture ($V = Q_m/A$)

g is the acceleration of gravity (32.2 ft/sec^2)

D is the diameter of the pipe

C_D is a dimensionless drag coefficient for the
sediment particles (absorbed into k in this
case since only one sediment is considered)

ρ_s is the mass density of the sediment particles
(5.20 slugs/ft³)

ρ is the mass density of water (1.94 slugs/ft³)

It is recommended that the experimental data be plotted in the manner suggested by Fig. 8, or as a similar family of curves, in order to check the validity of the analysis. If the predicted trends prevail, even though the position of the curves be shifted somewhat, it is our opinion that the information derived from the experiments would provide an adequate basis for the design of the future pipeline, at least for the case of the pipe flowing under pressure. For the case of free-surface flow, however, where hydraulic gradients in the experiments will be limited to the existing gradient of the pipeline, supplementary laboratory experiments in which pipe gradient could be varied would be desirable.

In analyzing the data, it should be remembered that manometer readings should be corrected for the difference in specific gravity between clear water (or other manometer fluid) and the water-sediment mixture flowing in the pipe. The observed manometer readings may be corrected to obtain the piezometric head of the water-sediment mixture by use of the relationship

$$H_m = \frac{\gamma_f H_f}{\gamma_m}$$

in which

H_m is the corrected piezometric head

H_f is the observed piezometric head

γ_f is the specific weight of the manometer fluid

γ_m is the specific weight of the water-sediment

mixture flowing in the pipe $\gamma_m = \gamma_w [1 + C_v(G-1)]$

If the interface between the manometer and pipe fluid is not maintained at the same elevation as the pressure taps, an additional correction should be made.

Referring to Fig. 8 it is interesting to note the location of the point indicating a transport rate of 33,000 T.P.D. of tailings at a concentration by weight of 0.38. If the analysis is anywhere near correct, the flow velocity is well above that (indicated by the low points on the C_w curves) required to maintain the tailings in suspension.

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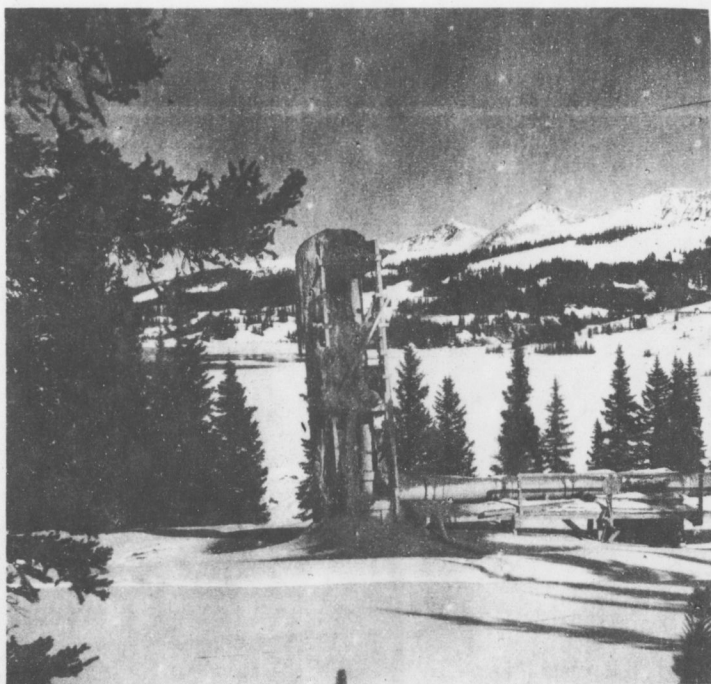
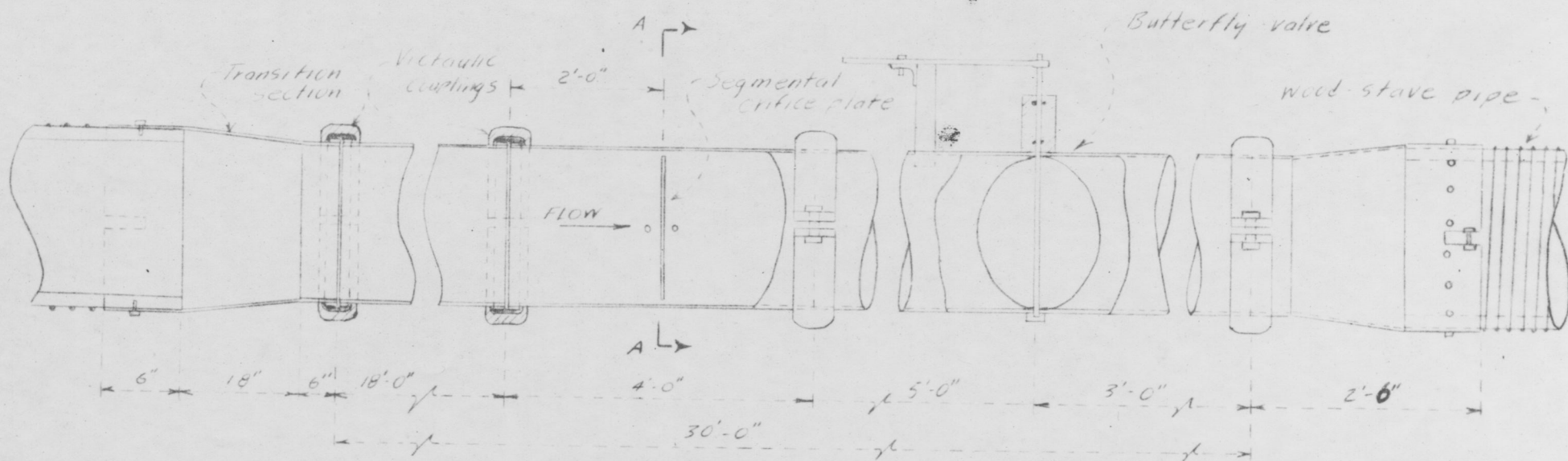


Fig. 1. Vertical Drop in Pipeline.
Climax Molybdenum Tailings
Disposal System.

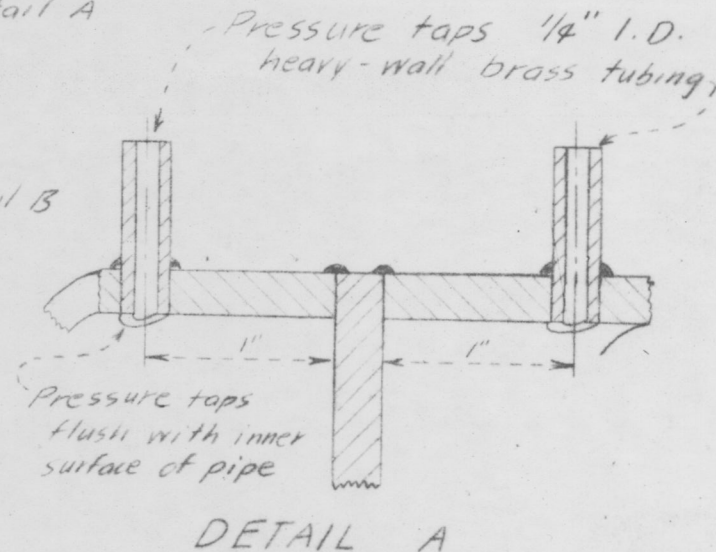
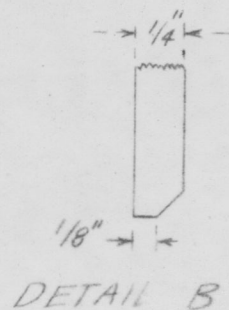
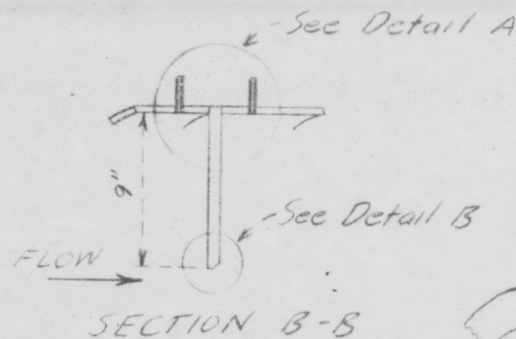
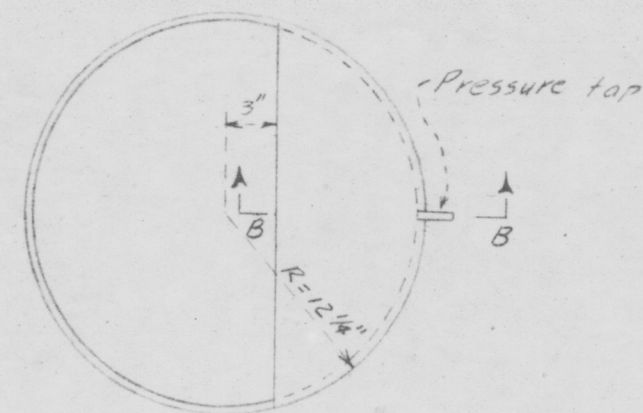


Fig. 2. Typical Pipeline on West Side.



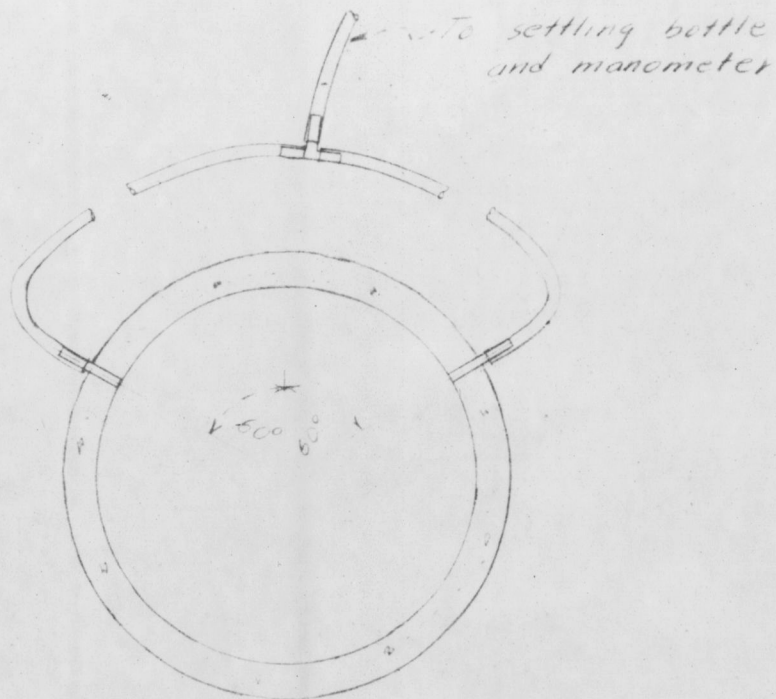
NOTE - Pipe and transition sections of $\frac{1}{4}$ " steel.

LONGITUDINAL SECTION

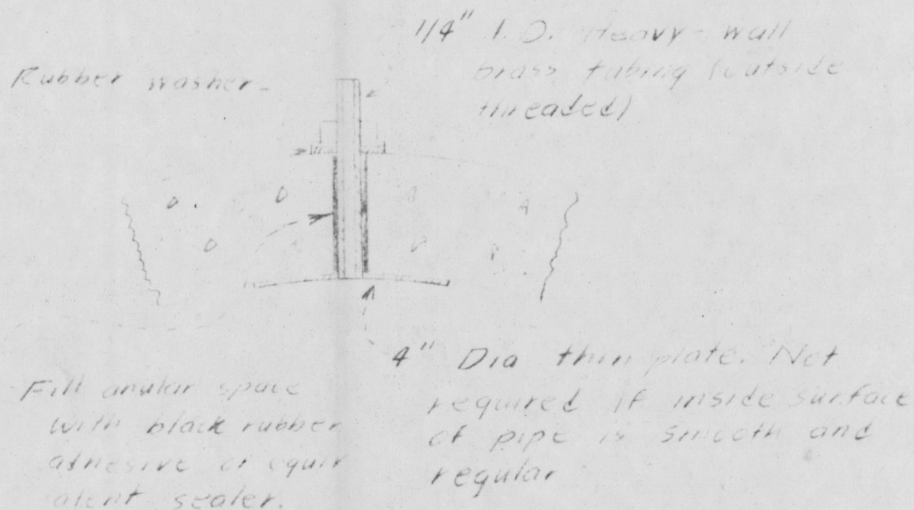


NOTE - Orifice plate inserted thru slot in pipe and welded into place.

Fig. 3 & 4 - Discharge measuring and control section

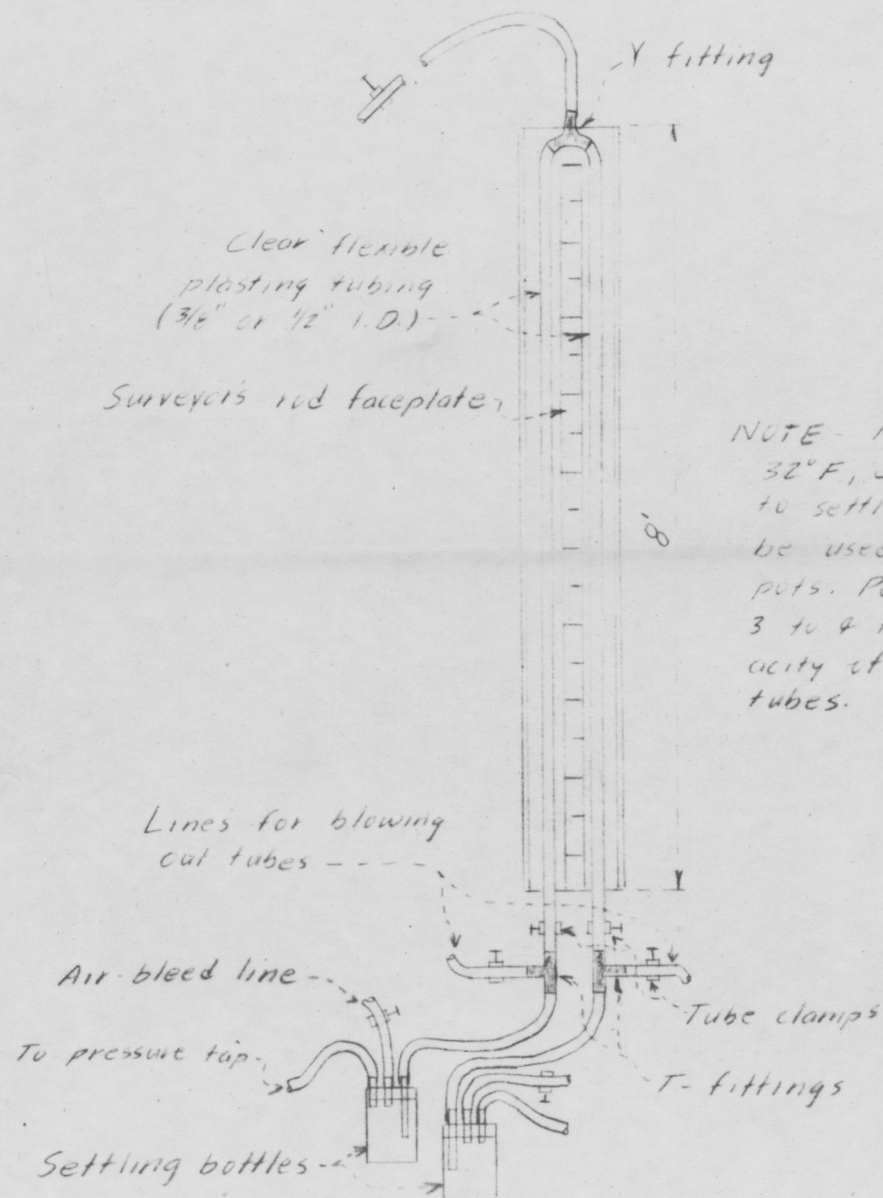


LOCATION OF PRESSURE TAPS



INSTALLATION DETAIL

Fig 5- Pressure tap installations for hydraulic gradient measurements



NOTE - For work below 32°F, devices similar to settling bottles may be used as alcohol pots. Pots should have 3 to 4 times total capacity of manometer tubes.

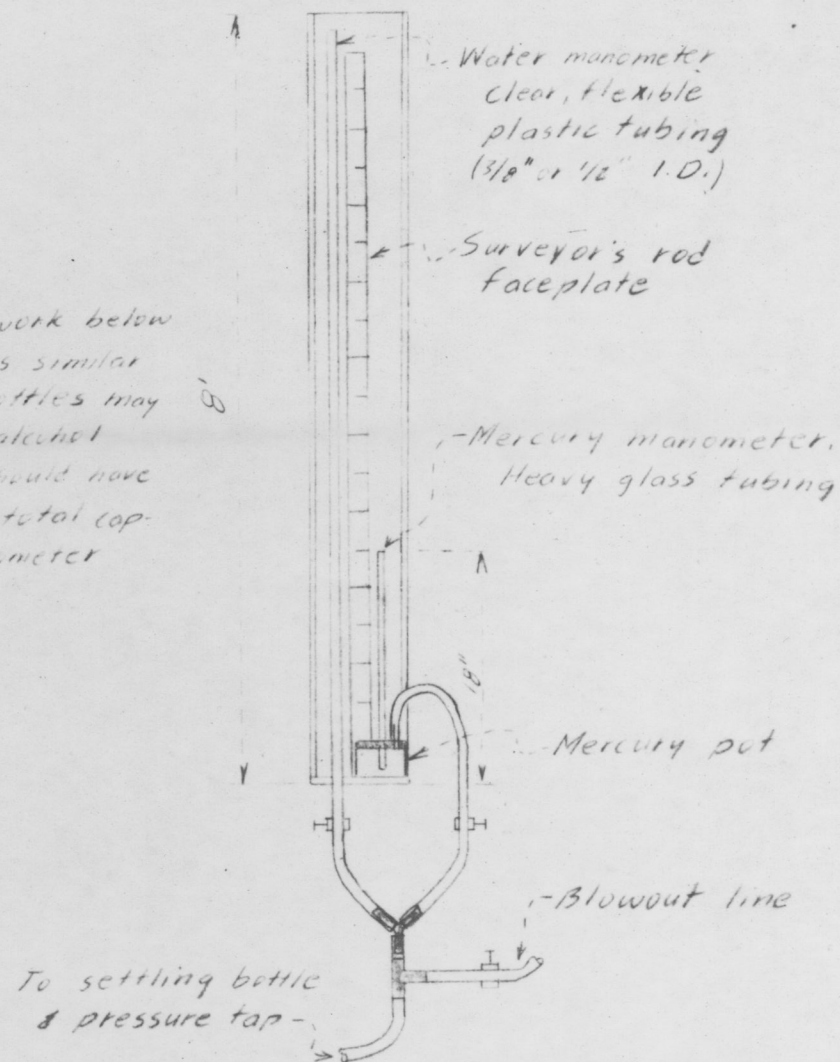
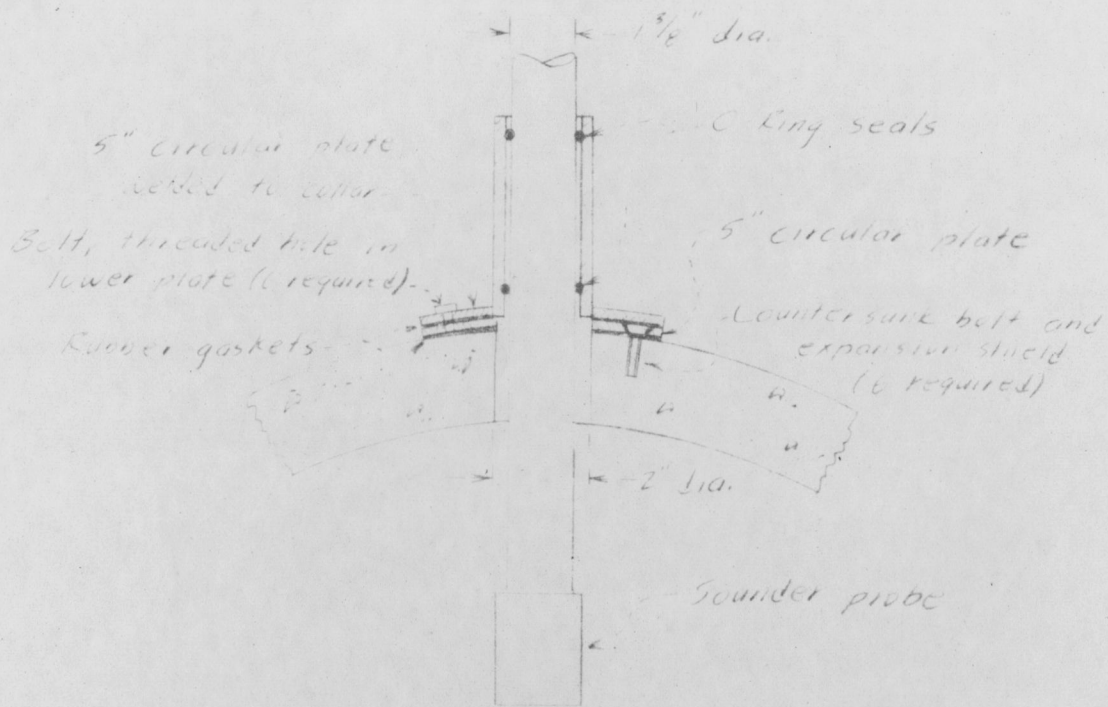


Fig. 6 - MANOMETER FOR ORIFICE PLATE

MANOMETER FOR HYDRAULIC GRADIENTS



INSTALLATION DETAIL

NOTE: Provide blank plate that is interchangeable with collar plate for sealing access port when sounding probe is not in use.

Fig. 7- Installation detail for depth-sounding probe

