

FLUME CONSTRUCTION ON KING HILL
IRRIGATION PROJECT

A THESIS SUBMITTED TO THE FACULTY OF
THE SCHOOL OF ENGINEERING OF
THE UNIVERSITY OF KANSAS

FOR

THE DEGREE OF
CIVIL ENGINEER

BY

WALTER WARD

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PREFACE

The experience of the King Hill Irrigation Project of Idaho in constructing flumes of reinforced concrete under varied conditions is of much value and interest. An unusual opportunity was presented for making a comparative study of different types of flumes.

The author was Project Manager of the King Hill Irrigation Project and in that capacity had opportunity to study the physical and economic factors which influence the design of irrigation flumes.

King Hill, Idaho,

April, 1921.

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DESCRIPTION AND COMPARISON OF VARIOUS TYPES
OF CONCRETE AND GUNITE FLUMES AS BUILT BY THE UNITED STATES
RECLAMATION SERVICE ON THE KING HILL PROJECT - IDAHO

By Walter Ward, Project Manager.

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The King Hill Irrigation Project is located in south central Idaho in Gooding, Twin Falls, Owyhee and Elmore Counties. The Malad River, a spring fed stream and a tributary of the Snake River furnishes an unfailing water supply of 300 cubic feet per second.

The King Hill is a long narrow project with a main canal 52 miles in length. A large part of the canal system is located in the Snake River canyon and crosses numerous gulches, creeks and is four times siphoned across Snake River.

Where ever the topography and soil formation permit, the canal is an ordinary earth channel, but the long stretches of the canal located in the Snake River canyon are on side hill slopes so steep that the only type of structure feasible is a flume built on a bench excavated in the hill side. The Snake River and the deeper gulches and creeks are crossed by means of inverted siphons. There are 17 of these siphons on the main canal ranging from 48 inches to 100 inches in diameter. The 52 miles of the Main Canal consists of 37-1/2 miles of open earth channel, 5 miles of pipe line, and 9-1/2 miles of flume.

Historically, the project is a repetition of many other early ventures in irrigation in the western states. An Irrigation

Company formed under the Carey Act and tempted by the unfailing water supply and the potential wealth of the lands to be watered, initiated and built the project and opened it to settlement in 1908. The flumes built by this company were of fir lumber, rectangular in shape, resting on the ground supported only by mud sills. The siphons were built of fir and redwood staves supported by timber cradles resting on timber mud sills. It was well demonstrated by the experience of this company that timber structures which come in contact with the earth and which are alternately wet and dry, are short lived and unsafe. The flumes, even when new, leaked badly and the leakage cut away the earth foundations and allowed the flumes to settle. This settlement increased the leakage, caused more settlement and so on. Where ever earth came in contact with the flumes, the timber soon rotted and after only a few years were in such bad condition that failures were frequent increasing in number and extent during each succeeding year. As a result of these conditions, at the end of nine years, the timber flumes on the project were in a state of total collapse. The logical conclusion was that the settlers depending for their irrigation water upon a system of this kind were unable to raise crops and pay the construction charge. Bankruptcy of the original company followed and the project was sold to the State of Idaho at Sheriff's sale.

In order to prevent the project lands from reversion to desert, the Secretary of the Interior in 1917 entered into a

contract with the State of Idaho and the King Hill Irrigation District whereby the project would be reconstructed by the U.S.Reclamation Service. At the time the project was taken over, the engineers of the Reclamation Service after an examination of the wooden structures that were then in place, decided that some type of more permanent construction was absolutely necessary for the success of the project. Several types of flume were studied, the principal ones being semi-circular wood stave flume, metal flume, gunite flume, and concrete flume. The factors influencing the type of structure to be built were the first cost, the useful life, the ultimate cost and the service that each type could be expected to give. Estimates made in 1917 based upon the cost of both labor and material prevailing at that time indicated that a semi-circular wood stave flume with an estimated useful life of 20 years, would cost \$9.20 per linear ft. A 14 gauge galvanized metal flume with timber sub-structure resting on concrete sills would cost \$12.40 per linear foot, and would have a useful life of 20 years. A gunite flume with an estimated useful life of 50 years would cost \$12.50 per foot, and a concrete flume with an estimated useful life of 50 years would cost \$12.50 per linear foot. For purposes of comparison all estimates were based on a carrying capacity of 300 cubic feet per second. It was decided that the ultimate cost of the gunite and concrete flumes would be considerably less than either the wood stave or metal flume, due to the fact that /^{they} would have so many years greater useful life. These flumes also have the added advantage of being

more water tight which fact alone would tend to eliminate either of the other types, because much of the foundation is of such a character that it will erode and settle rapidly under a flume which has any considerable leakage.

This paper will deal only with the concrete and gunite flumes that were built on the project by the Reclamation Service, and which are as follows:

Concrete flume with Bell and Spigot joints.

Concrete flume without joints.

All Gunite Flume.

Combination Gunite and Concrete Flume.

Semi-Precast Concrete Flume.

These five types will be discussed in the order named.

CONCRETE FLUME WITH BELL AND SPIGOT JOINTS

A concrete flume with bell and spigot contraction joints was one of the first built. This type was adopted for the reason that a flume with contraction joints at frequent intervals requires such a small amount of temperature steel that it was assumed the cost would be materially reduced, and the fact that flumes built heretofore without contraction joints and with only a nominal amount of temperature steel had not been entirely satisfactory where there was a range of temperature similar to that of southern Idaho.

Figure No. 1 is a detail drawing of the bell and spigot type of flume with an 8' 7" base width and sidewalls 5'0" high. The

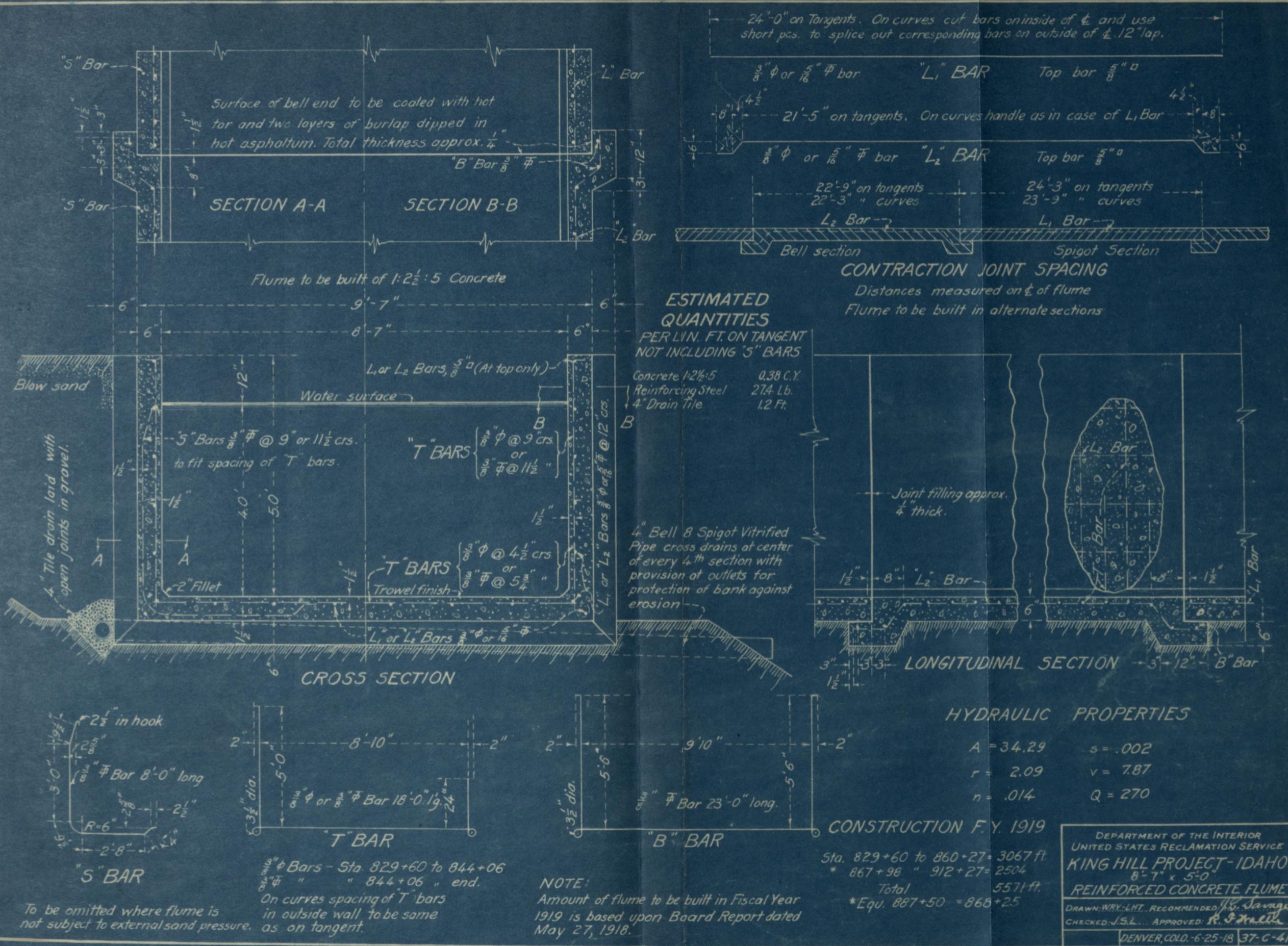


FIGURE No. 1.

floor and walls are 6 inches in thickness and the side walls are reinforced as cantilevers so that no cross ties are necessary. Although the flume will carry the required capacity with a free-board of one foot, the side walls are designed to withstand the load with flume running full. Additional reinforcing steel was placed in the bank wall where ever it was expected that sand would collect behind the flume and subject this wall to external pressure. A comparatively small amount (.00181%) of longitudinal steel was used as reinforcement against temperature changes and this has proven ample as some of this type of flume has been in service for three years and no temperature cracks have developed.

Contraction joints of the bell and spigot type with an elastic filler were spaced on tangents at 22'9" intervals for bell sections and at 24'3" intervals for spigot sections. Both sections are 6" shorter on curves to permit of the economical use of the same length steel as used in the tangent sections. The extra length of the longitudinal bars on the inside of the curve were cut off and used to lengthen, with a 1 foot lap, the corresponding bar on the outside of the curve. Before adopting this contraction joint consideration was given to various types with distances between joints ranging from 10 to 100 feet. It was deemed necessary that this contraction joint fulfill the following conditions:

- (a) It should not weaken the flume section.
- (b) It should be provided with a filler of some elastic material that would prevent spalling of the concrete due to expansion.

(c) It should be easily and cheaply constructed.

(d) It should be water tight.

It was decided that the bell and spigot joint as shown in Fig. No. 1, with either burlap soaked in asphaltum or a wooden filler would most nearly meet all the above requirements.

The economical spacing of the contraction joints was a subject of considerable study. One contraction joint, regardless of distance between joints, was estimated to cost \$13.10. The cost per linear foot of flume due to the joints would therefore be inversely proportional to the distance between joints. On the other hand the amount of steel required for temperature reinforcement increases with the distance between joints. Computation based on these two factors were made which showed the economical spacing to be approximately 24 feet.

Experience demonstrated that the results of these computations were erroneous as they did not take into account the fact that all the work of building forms and placing concrete was retarded on account of these joints, therefore, the figure of \$13.10 used as the cost of a contraction joint is considerably too low. Later estimates giving proper weight to all these items showed the economical distance as being at least three times the distance used. In fact the amount of longitudinal steel required for temperature reinforcement in a section thus determined would approach so closely the amount needed in a flume without joints that the cost of the two types would be approximately the same

instead of being in favor of the contraction joint type as supposed.

There were two kinds of filler used in the contraction joint. The first was designed to allow the flume to be poured continuously and consisted of a 1" x 6" board to provide the elastic filler between two adjacent sections and an 8 inch strip of 22 gauge metal coated with asphalt to separate the bell from the spigot and provide the slip joint. It was expected that this board and metal strip could be held in position while the concrete was poured on each side simultaneously, completing the joint. It was found to be very difficult to hold this board and metal strip in place while the concrete was being spaded and they were frequently crowded out of position, to a large measure destroying the utility of the joint. This filler was therefore abandoned in favor of one made of burlap strips soaked in asphalt as shown in Figure No. 1, One objection to a filler of this kind is that it can not be placed until after the bells have been poured and the forms stripped, which necessitates the building of the flume in alternate sections requiring twice as many forms to accomplish the same amount of work daily as a flume that can be poured continuously. These fillers were at first made by dipping the burlap strips in hot asphalt and some difficulty was experienced in placing such fillers so that they would not wrinkle and form pockets at the joint. This was overcome by laying the burlap strips in a form of the required length and width and then filling

the form with the hot asphalt. A filler made in this manner is much more pleasant to handle, does not wrinkle, and makes a better and tighter joint. The slip joint was made by substituting a strip of the burlap and asphalt for the sheet iron.

The location survey was made to fit the existing bench as closely as possible, keeping the flume at all times on an undisturbed and solid foundation. The curves were made true arcs, and at first had center line radii of 50, 75, 100 and 200 feet. Later the use of the 75, 100 and 200 foot radii curves was discontinued and 50 foot radius curves only were used. The adoption of the sharper curve reduced the length of curved flume and simplified the form work. About 30% of this flume is on curves and as the form work on curves is more expensive than on tangent every effort was made in the location to reduce the curvature. It was estimated that the form work on curves cost 50¢ more per linear foot than on tangents and that this additional amount could be spent on excavation to eliminate curvature.

Teams and scrapers were used as far as possible in the excavation, altho considerable hand work was necessary on the hill side in opening it up before the stock could get a footing. After the teams had roughed out the bench some handwork was then necessary to finish the subgrade.

Approximately 450 feet of re-usable timber forms were needed for each crew building flume. These were made up in panels for both the inside and outside forms. It was neither practicable

nor economical to make sufficient forms to have exactly the proper panel length for all combinations of curves and tangents at the beginning and end of curves, therefore, a part of the panels were made of proper lengths to fit exactly the inside radius on the sharpest curve (which would be the shortest possible panel length) and the balance to fit exactly the section on the tangent (which would be the most common length used and also an average length on curves). Some combination of these panels would usually either fit exactly or lack only a few inches of closing at the mid point. Where ever this gap was less than 1 foot a 16 gauge sheet iron plate was tacked on the inside of form to close it. Where the gap was more than 1 foot, one or more short panel forms of 1 foot or 1'6" length were used with the sheet iron. A supply of templets either straight or cut to proper curvature was made and bolted to the back side of the panels as they were erected to hold the forms to proper alignment.

Braced frames or bents were used to stiffen and hold the forms plumb. This frame also supported the runway plank on which the concrete carts were operated. Care was taken to prevent the frame from resting on the top of the form panels and subject the concrete when partially set to the vibration incidental to wheeling the concrete carts over the runway.

Four hundred and fifty feet of forms in use two seasons with some repair work were worn out after being used to build 6000 feet of flume. If used continuously they would have lasted somewhat longer.

Snake River was the only source of water supply available for construction work. Triplex pumps with a capacity of 60 gallons per minute and driven by gas engines were installed at convenient points along the river, and water was pumped into temporarily constructed tanks located at points from sixty to two hundred feet in elevation above the flume bench, making the total lift ranging from 360 to 500 feet. This pumping plant provided sufficient water for all purposes, and was distributed by gravity from the tanks to camps, corrals, mixers and along the flume bench for sprinkling the concrete. It was necessary to bury all of the main lines that could not be readily drained to a depth of two feet, during the winter months, to protect against freezing.

Suitable sand and gravel was uncovered at various points along the work ranging in distance from one-half to three miles from the mixer sites, aggregate was screened at the pit and hauled to the mixer sites in horse-drawn 2-yard dump wagons or by 2-ton trucks equiped with dump bodies. The gravel was well graded and was screened to a maximum size of $2\frac{1}{2}$ inches. In some cases the most available gravel was found near the bed of the river in which case it was hoisted, by means of a steam hoist operating gravel cars on an industrial track, to the road above the flume bench and then distributed by wagons and trucks to the mixer sites.

Portland cement delivered to the nearest railway station was hauled to the mixer sites in 2-ton trucks, where it was stored until used.

Reinforcing steel was purchased in sizes and lengths that

would cut with minimum waste. This steel was hauled by truck to a central yard at the work where it was cut and bent to proper lengths and shapes. The bending of this steel was materially expedited by building a rigid bench on which templets of the proper dimensions were fixed and around which the steel was bent to required shapes. After some experience, two men could cut and bend from 350 to 400 transverse bars per day. In placing this steel in the forms crews were able to place two or three times as much steel by using the Bates tying tools and tie wire of proper lengths instead of ordinary pliers and straight wire.

As there was not sufficient room on the flume bench for a construction or operating road, it was necessary to build a construction road on the hillside above the flume. While the road was located as near the flume as possible it was in some cases a half mile distant requiring spur roads to be built to the mixer sites.

The location of the mixing plants and the transporting of the concrete from the mixers to the forms was controlled largely by local conditions but usually one of the three following described methods was employed.

First: Where the construction road was parallel to and only a short distance from the flume bench and where the flume bench was too narrow to operate a team and wagon, the mixer plants were located on the construction road at one-half mile intervals. Concrete from these plants was hauled along the road in one-horse

2/3 cubic yard carts to a point below which the flume building was then in progress. The concrete was then spouted from the road to a hopper on the flume bench and distributed from this hopper by hand-carts operated on runways laid on top of the flume forms. The chutes from the road to the flume bench were spaced at about 600 foot intervals requiring the concrete to be distributed by hand a maximum distance of 300 feet either side of the chute.

Second: Where the flume bench was wide enough to permit the operation of teams and wagon along side the flume the mixer plants were located at 1/2 mile intervals. A batch of concrete was spouted from the mixer into three one-man size concrete carts. These carts were pushed onto a flat top wagon and hauled along the flume bench to the forms and as the wagon bed had been built to approximately the same elevation as the flume forms the carts were easily pushed from the wagon onto the runway laid on the forms and the concrete deposited at any desired point. This method was the most economical as it was more flexible and did not require forms to be left in place to act only as a support for the runway as was often the case in the first and third method.

Third: Where the construction road could not be brought closely parallel to the flume bench nor operating roads be maintained thereon, mixer sites were located on the hillside above the flume at approximately 900 foot intervals and connected to the main road by spurs. The concrete was spouted directly from the mixer to a hopper on the forms from where it was distributed along the flume by hand-carts a maximum distance of 450 feet each way

from the hopper. Although in many cases this was the only practical method to follow, the cost was somewhat higher than either of the two methods described above.

Drainage was provided to prevent surface water or leakage from the flume collecting behind the flume and soaking into the foundation. This was accomplished by laying a 4 inch open joint vitrified tile parallel to the flume and located slightly below and on the same slope as the floor. Relief drains were provided every 100 feet by laying 4 inch bell and spigot tile from the drainage line at right angles and under the floor of the flume discharging over the side of the bench.

The procedure in building this flume after the grading was completed and the drainage system installed was as follows:

The outside forms were set up to line and grade, the reinforcing steel placed and then the inside forms were set up and all forms braced. Figure No. 2 shows the reinforcing steel and outside forms in place in the foreground and the completed forms in the background. The floor was poured first and allowed to get a partial set before the side walls were poured. Figure No. 3 shows a section of the completed flume.

In warm weather the forms were allowed to stay in place one day and in cold weather from two to three days before they were stripped and moved ahead. After the forms were stripped the concrete was sprinkled for ten days to cure it. During freezing weather the concrete was covered and protected from freezing with artificial heat.



FIGURE NO. 2.



FIGURE NO. 3.

The only advantage that the bell and spigot type of flume has over the other types is that it requires a less amount of temperature steel, which advantage at the present cost of steel and labor is off-set by the greater amount of labor required.

The disadvantages are as follows:

(1st) It is impossible at a reasonable cost to build expansions and contraction joints that are sufficiently water tight.

(2nd) The leakage from imperfect joints, unless the flume is built on a very solid foundation, is apt to cause settlement which in turn increases the leakage and finally leads to failure of the flume.

(3rd) In climates where the foundation of the flume freezes during the winter months, the spigot sections are apt to heave, throwing such sections out of grade and opening the joints so that when the flume is refilled serious leakage occurs.

(4th) The continuity of the forms being broken at each joint it is difficult to hold the forms sufficiently rigid to maintain an even thickness of concrete in the side walls.

(5th) The progress of building a flume of this kind is greatly retarded on account of erecting the forms for the contraction joints, and double the length of forms are required in a type where the concrete is poured in alternate sections as in one which can be poured continuously.

(6th) The maintenance of this flume will be considerably higher than any of the other types.

Two and one-quarter miles of this type of flume have been built and it is believed that it will give good service for its expected useful life.

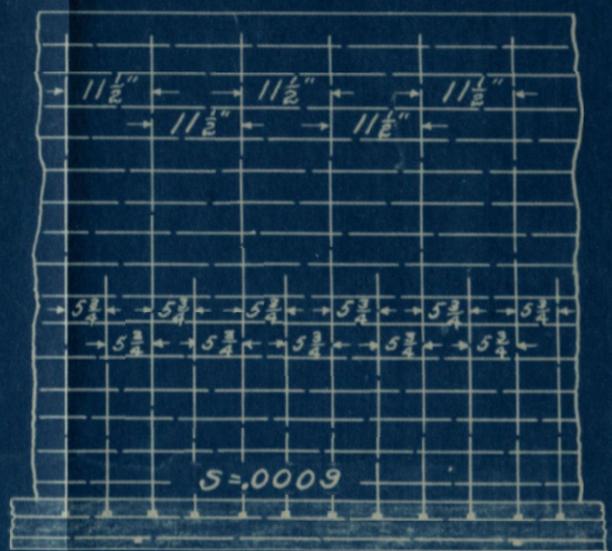
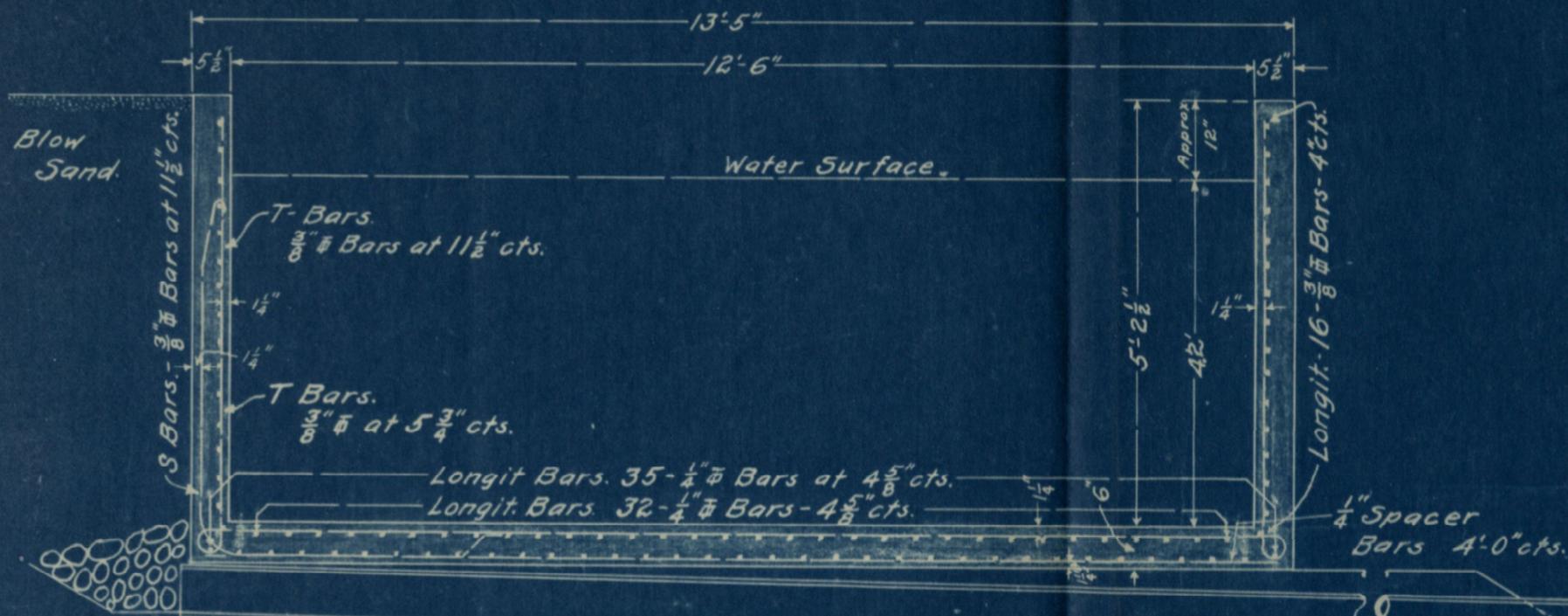
As the building of the various types of flume, hereinafter described, have many points in common such as grading, source of water supply, materials, etc. these features will not be discussed further.

CONCRETE FLUME WITHOUT JOINTS

As the contraction joints were directly responsible for all the objections arising in connection with the bell and spigot flume described above, the following described concrete flume without joints was designed.

Figure No. 4 shows a cross section of this type of flume, the reinforcing steel and the hydraulic properties. In order to build a flume without joints sufficient longitudinal reinforcement must be provided to prevent contraction cracks of sufficient size to permit water to escape. It was computed that with a temperature variation of 70 degrees and with sufficient reinforcing steel to force the concrete to crack at 72" intervals the cracks would be so small as not to be objectionable.

The temperature in southern Idaho ranges from about 20° F. below zero to 120° F. above, therefore, flumes constructed during the summer months would be subjected to a temperature variation of 140 degrees and would require a prohibitive amount of temperature steel unless some means could be found to take advantage



Transvers Tile Drains of suitable sizes as required. No Longit Drains.

TRANSVERSE SECTION

LONGITUDINAL SECTION

Protect from erosion as directed by the Engineer

HYDRAULIC PROPERTIES.

A = 52.50 r = 2.51 n = 0.14
 s = .0009 V = 5.93 Q = 311

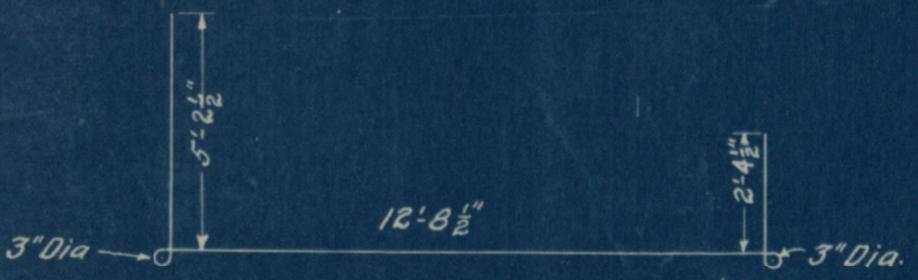
QUANTITIES PER LINEAR FOOT.

Per Lin. Ft. on Tangent. S Bars not included.

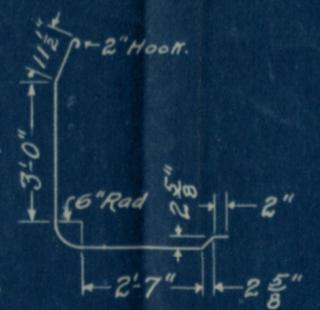
Concrete - 1:2 1/2:4 1/2 0.425 C.Y.
 Reinforcing Steel
 Transverse 22.638 Lbs.
 Longitudinal 31.028 Lbs.

SCALES.

General 1/2" = 1'-0"
 Steel 1/4" = 1'-0"



T-BARS.
 3/8" Bars - 22'-0" long.



S-BARS.
 3/8" Bars
 8'-0" Long

Use only where necessary.

Note:-
 During construction, when the temperature is higher than 50°F, joints 18" wide will be left across the flume. These joints will be poured when the temperature is between 40° and 50°F. All Longitudinal Bars will be lapped and unrestrained before the joint is poured. Joints on tangents and curves with central angles less than 30° will be spaced at 300 foot intervals. On curves with central angles greater than 30°, the distance from P.I. of curve to joint not more than 150 feet. Where the foundation is such that the coefficient of friction will be increased, the spacing of joints will be decreased in proportion.

Revised 2-17-21, E.T.G.

DEPARTMENT OF THE INTERIOR.
 UNITED STATES RECLAMATION SERVICE.
 KING HILL PROJECT - IDAHO.
 HEAD END FLUME - NO CONTR. JOINTS.
 MAIN CANAL - Sta. 70+20 to 96+20.

DRAWN: E.T.G. RECOMMENDED: *Haltiwanger*
 CHECKED: E.G.P. APPROVED: 8-3-20 R.F. Walters.

C-3043 KING HILL, IDAHO. JULY, 27, 1920

FIGURE No. 4.

of a lower temperature variation. This was accomplished by building the flume in sections 300 feet long whenever the temperature was above 50° F and leaving 18 inch joints between sections. The longitudinal steel from adjacent sections was allowed to extend unrestrained across the joint permitting the flume to move freely in each direction. During the fall months when the temperature dropped to between 40° and 50° F. these joints were poured bonding all the longitudinal steel together, this method had the same effect as pouring all of the flume at the lower temperature. It was estimated that the length of the sections that could be poured in the summer months would be the length of flume that the longitudinal steel could drag along its foundation without failure, assuming that the flume would be anchored at and pull an equal distance each side of the center point. In the case of curves with a large central angle the joints were placed not more than 150 feet each side of the curve.

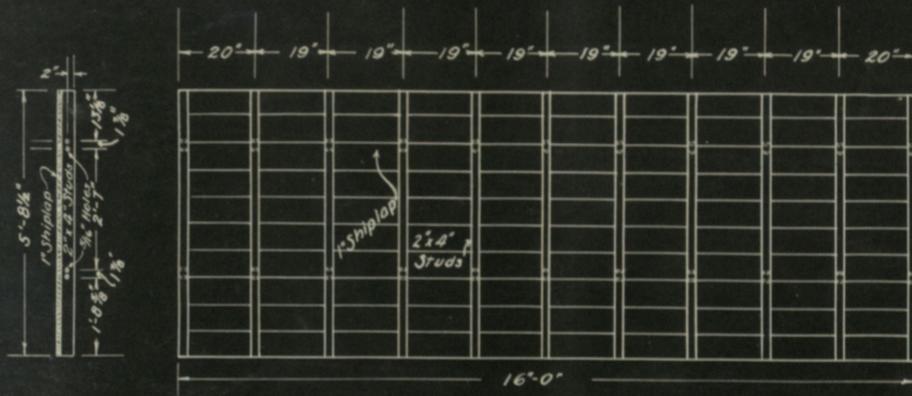
Computations showed, using $3/8$ inch square twisted steel bars with an elastic limit of 55000 lbs. per square inch, that .65 percent of steel was necessary to force the concrete to crack at 72" intervals and when the temperature variation was 70 degrees the cracks would be .0327 inches in width, however, the cracks would only be .013 inches in width at the lowest temperature at which water would be carried in the flume. Using $1/4$ inch square twisted steel bars in the floor, .43 percent of steel was required to force cracks at the same intervals with the same range of temperature. The side walls were designed as vertical cantilevers

and required no cross ties.

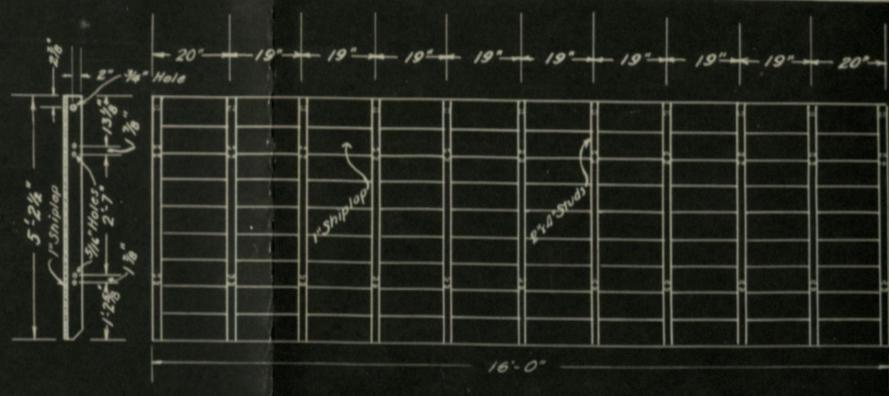
By reference to Figure No. 4, it will be noted that the side wall forms a right angle at the point it joins the floor; while Figure No. 1, which is a drawing of the Bell and Spigot type of flume, shows a fillet at this point. This fillet used in the original design as an extra factor of safety can be safely omitted as the flume is amply strong without it and it adds a decidedly objectionable complication in the forms, particularly on curves.

This flume is for all practicable purposes water tight, and the tile drainage system described in connection with the Bell and Spigot flume is not required. Cross drains under the flume of 12" tile or 12" square concrete boxes were provided at frequent intervals to carry off storm water.

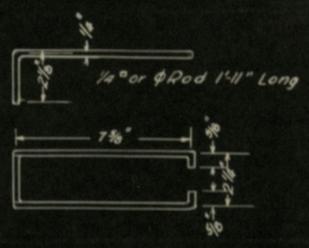
Previous experience showed plainly that the progress and cost of the concrete in this class of work depended largely on the forms. Therefore, a new type of form was developed using a minimum amount of material and offering possibilities of rapid erection. The re-usable forms used to build this flume are shown in Figure No. 5. They consist of inside and outside panels 16' long with templets, posts and braces for obtaining the alignment. On account of the leakage caused by form wires and the time and trouble required in placing them, this method of tying the forms together was abandoned in favor of the use of steel pins which could be removed from the concrete when the forms were taken down. The holes resulting from the use of these pins were plugged with grout as soon as the pins were removed. These forms were designed with an



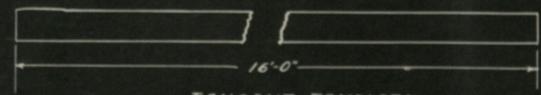
OUTSIDE FORM PANEL
Make 40



INSIDE FORM PANEL
Make 40



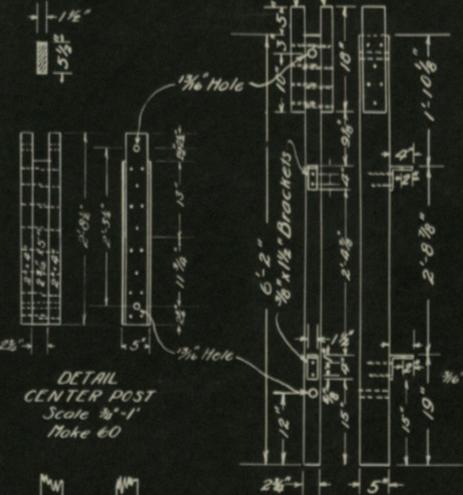
DETAIL TEMPLET LATCH
1/4" SIZE
Make 100



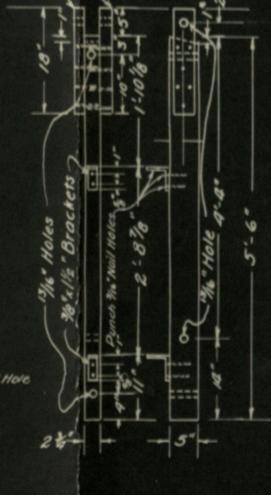
TANGENT TEMPLETS
Scale 1/4" = 1'
Make 160



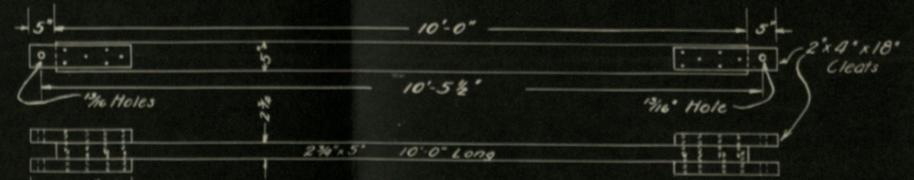
CURVE TEMPLETS
Scale 1/4" = 1'
Make 80 10'-0" Long R-43'-6"
Make 40 6'-0" Long R-43'-6"
Make 80 10'-0" Long R-56'-6"
Make 40 6'-0" Long R-56'-6"



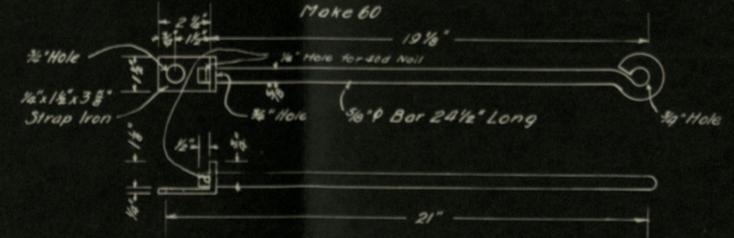
DETAIL OUTSIDE POST
Scale 1/4" = 1'
Make 120



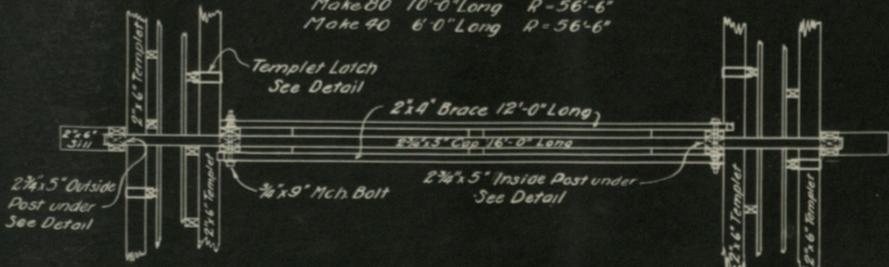
DETAIL INSIDE POST
Scale 1/4" = 1'
Make 120



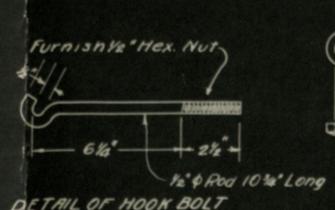
DETAIL OF STRUT
Scale 1/4" = 1'
Make 60



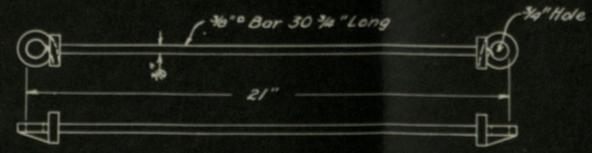
DETAIL OF COUPLING PIN
1/4" SIZE
Make 120



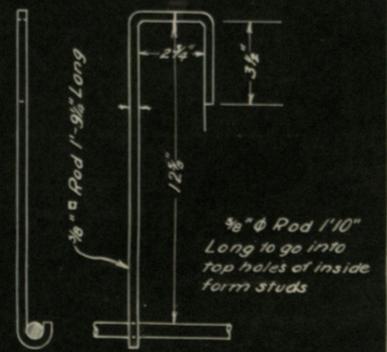
PLAN
Runway Removed



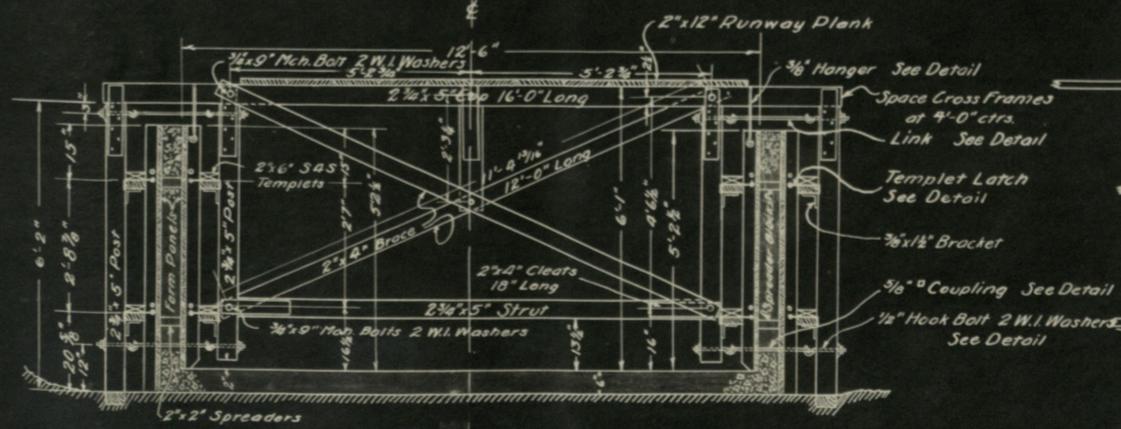
DETAIL OF HOOK BOLT
1/4" SIZE
Make 480



DETAIL OF LINK
1/4" SIZE
Make 120



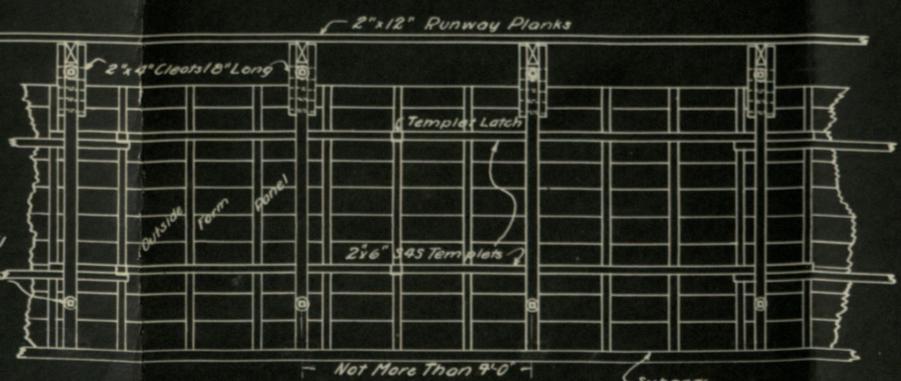
DETAIL OF HANGER
1/4" SIZE
Make 120



SECTION

See Details for Posts & Struts

Scale 1/2" = 1'



SIDE ELEVATION

NOTE - Odd dimensioned timbers obtained from old wood staves

DEPARTMENT OF THE INTERIOR.
UNITED STATES RECLAMATION SERVICE.
KING HILL PROJECT-IDAHO
FORMS FOR
HEAD END FLUME

Revised Jan 15, 1921 L.S.H.

DRAWN, E.C.P.-L.S.H. RECOMMENDED.
CHECKED, O.U.S. APPROVED, Hattie Hardy

A-1030 King Hill, Ida. Sept. 9, 1920

FIGURE NO 5

idea of eliminating as much work as possible and at the same time having a set of forms when in place would not spread. With this in mind, bolts, coupling pins and other labor saving mechanical devices were used where ever possible. These forms proved to be entirely satisfactory and by their use the form costs were reduced 40 percent.

Following the installation of the cross drainage, two 3x6 plank, one on either side and parallel to the center line, were placed at such distances from the center line that they would come directly under the outside of the forms. These planks were placed to exact grade of the foundation and a straight edge was then used with its ends resting on them to level off the subgrade. The procedure in the erection of the forms and the placing of the steel was as follows:

The outside panels together with the posts and templets were set up and held together with the top cross braces. The steel was placed and the inside panels and posts were suspended from the top cross beams. The inside templets were placed on the brackets and all securely held in place by the inside struts and braces. Figure No. 6 shows the forms and reinforcing steel in position.

Concrete (proportioned $1:2\frac{1}{2}:4\frac{1}{2}$) was mixed at a central mixing plant and hauled each way from the mixer about 1/4 mile. The method employed in distributing the concrete was to spout it from the mixer into one-man push carts which in turn were hauled on flat top wagons to their destination as described in a previous chapter. No difficulty was experienced in the separation of the aggregate on



FIGURE NO. 6.

this long haul, care, however, was exercised in securing the correct water content in the batch, it being found that a comparatively dry mix showed less tendency to separate than one containing more water.

There being no expansion joints in this flume, it could be poured continuously. After the forms were set up it was only necessary to put a bulk head in the forms at the end of each day's run. The usual method in this connection being to run as much floor with 4" of the side walls as could be poured in the forenoon. The bulk heads were then placed across the flume at this point and in the afternoon the side walls were poured, experience showing that this about evenly divided the day's work.

As previously stated this flume was poured in 300 feet sections and an 18 inch joint was left between such sections it being the idea that these joints would be poured later when the temperature was between 40° and 50° F. It was found when these joints were poured that there was enough variation in the temperature during the time that it took the concrete to set to cause a movement of the steel in the joints tending to break the bond between the steel and the concrete. To overcome this an Oxo-Acetylene welding outfit was used to weld the reinforcing bars in the joints before the concrete was poured, thus making the reinforcement continuous and preventing any movement due to contraction.

During the warmer weather forms could be removed from the concrete the following day after pouring but as the weather grew colder it was necessary to leave these forms on for a longer

period. The concrete was protected from freezing by covering the structure with burlap and by keeping fires on the inside of the flume. The most efficient kind of stove and the most easily fired was a 15" corrugated pipe 10 feet long. One of these stoves would accommodate long sticks of wood which saved labor and at the same time produced as much heat as several ordinary sheet iron stoves.

An average day's work was about 125 linear ft. of this size flume, containing .425 cubic yards per linear foot.

There have been approximately two miles of this type of flume built and it has proven entirely satisfactory. It has overcome all the objectionable features mentioned in connection with the bell and spigot type, and to-date has developed no weak point. Figure No. 7 is a view of the Snake River canyon with a section of this completed flume and the construction road on the hillside above.

ALL GUNITE FLUME

As the name indicates this type of flume was built entirely of gunite. As shown in Figure No. 8 it is rectangular in section, 6 feet wide and 3 feet 8 inches in depth with side walls and floor 2-1/4 inches in thickness, and has a capacity of 116 cubic feet per second. The flume is built without joints and is designed with sufficient longitudinal temperature steel to force the gunite to crack at 24" intervals. It was observed after this flume had been built for some time that instead of cracking



FIGURE NO. 7.

at 24" intervals, a very fine hair crack appeared every ten inches, at the point the transverse steel reduced the gunite section. The walls of the flume are designed as simple vertical beams and the load from the water pressure is transmitted from these walls to the floor and to a coping or rail which was built on top of each wall, and which was reinforced as a continuous beam. Tie bars across the top of the flume at 8 foot intervals connected the copings. The flume was built on a 6 inch gravel foundation which provided ample drainage for any possible leakage from the flume and also the ordinary surface drainage, except at the crossing of small draws where additional tile drains were installed to carry off surface water.

The aggregate used in the gunite was one part cement and four parts sand. It was found that when this mix was shot onto the forms there was a rebound amounting to about 25% of the sand; the amount of the rebound depending largely upon how well the sand was graded and more particularly upon the percentage of small particles. This rebound was found to contain practically no cement.

The hydraulic properties of a gunite flume are the same as those for other flumes of like section except for the value of n in Kutters coefficient. It was assumed that for the side walls, which were formed on the inside, the value of n would be .014 which is the same value as for concrete with a like finish, but that for the bottom of the flume which was untrowled gunite, the value of n would be .018, giving approximately an average value for the

flume of n equal to .016. An attempt was made to reduce the friction loss in the floor by troweling the surface, but this was abandoned as it was found that this trowling was injurious to the gunite to the extent of reducing it to the density of concrete.

The principle equipment used in the building of this gunite flume was two air compressors, two cement guns of the N-2 type and the necessary forms. The compressors had a capacity of 240 cu. ft. of air at 50 lbs. pressure. They were portable and driven by direct connected internal combustion fuel oil burning engines, and were located along the flume at 700 ft. intervals. The air was conducted from the compressors about 350 ft. in both directions. The forms were re-usable, built of shiplap in panel lengths of 14 feet and were held in place with a system of cross bracing. The bracing and form panels were designed for rapid erection and removal. Figure No. 9 shows the alignment which consisted of a series of tangents connected by curves of 50, 75, 100 and 200 ft. radii. Templates cut to the required radii were bolted to the studding on the back side of the form panels to make the forms fit the curves.

Sand was secured from nearby pits and hauled to the flume bench with teams where it was screened by hand over a 1/4 inch mesh. The sand and cement were mixed dry by hand in proper proportion before it could be used in the cement guns. The cement gun does not mix the aggregate, it is merely a convenient way of placing after it is mixed.

Following the preparation of the subgrade, the reinforcing steel which had previously been cut and bent to proper lengths



FIGURE NO. 9.

and shapes in a central yard, was placed in position. The inside wall form panels, which were the only forms needed in gunite work, were next erected. These were securely braced and to them were tied the reinforcing steel where it was held to proper shape and grade. The cement guns were at all times kept close to the work, it being our experience that better and faster work could be done with material hose lines not exceeding 50 feet in length. The side walls were built first, in two layers of from 1 to $1\frac{1}{2}$ inches in thickness. Next and on the same day the floor was placed and finally, after removing the wall forms and allowing the gunite time to set, the forms for the coping were placed and the coping poured using the rebound mixed with cement in a proportion of 1 part cement to 4 parts sand. Considerable trouble was experienced in obtaining a good job in the floor as the rebound having no avenue of escape would tend to collect in piles which if covered with gunite would leave weak spots in the floor. It was, therefore, necessary to shut down the machines at frequent intervals and clear away the rebound, which added materially to the cost. The forms were left in place until they could be removed without injury to the gunite, in warm weather this requires only five or six hours, but during cold weather from one to two days. This flume was built during the early spring when strong winds prevailed, and was covered with burlap on which water was sprinkled for ten days to prevent the gunite from drying out too rapidly. An average day's run with two machines after the men became familiar with the operation of the cement guns consisted of 160 lin. ft. of

completed flume, which is equivalent to 15 cubic yards of gunite per day of eight hours for two machines.

This flume after being in operation for three years has demonstrated its merit as a type to be built on a foundation which will not stand up under any leakage from the flume. Although the floor and sides are only 2-1/4 inches in thickness, the flume is for all practical purposes, water tight, and has required no maintenance since its construction. There were, however, some disadvantages developed. The coping wall, which had to be poured after the gunite was placed, materially reduced the rate at which this flume could be built. Also the cross ties retarded and increased the cost of the form work. Another disadvantage of this type of flume is the increased water area required for a given slope, necessitated by the rough gunite floor. To overcome these objectional features a type of flume, hereinafter described, was designed having a concrete floor poured in place and side walls of gunite reinforced as cantilevers.

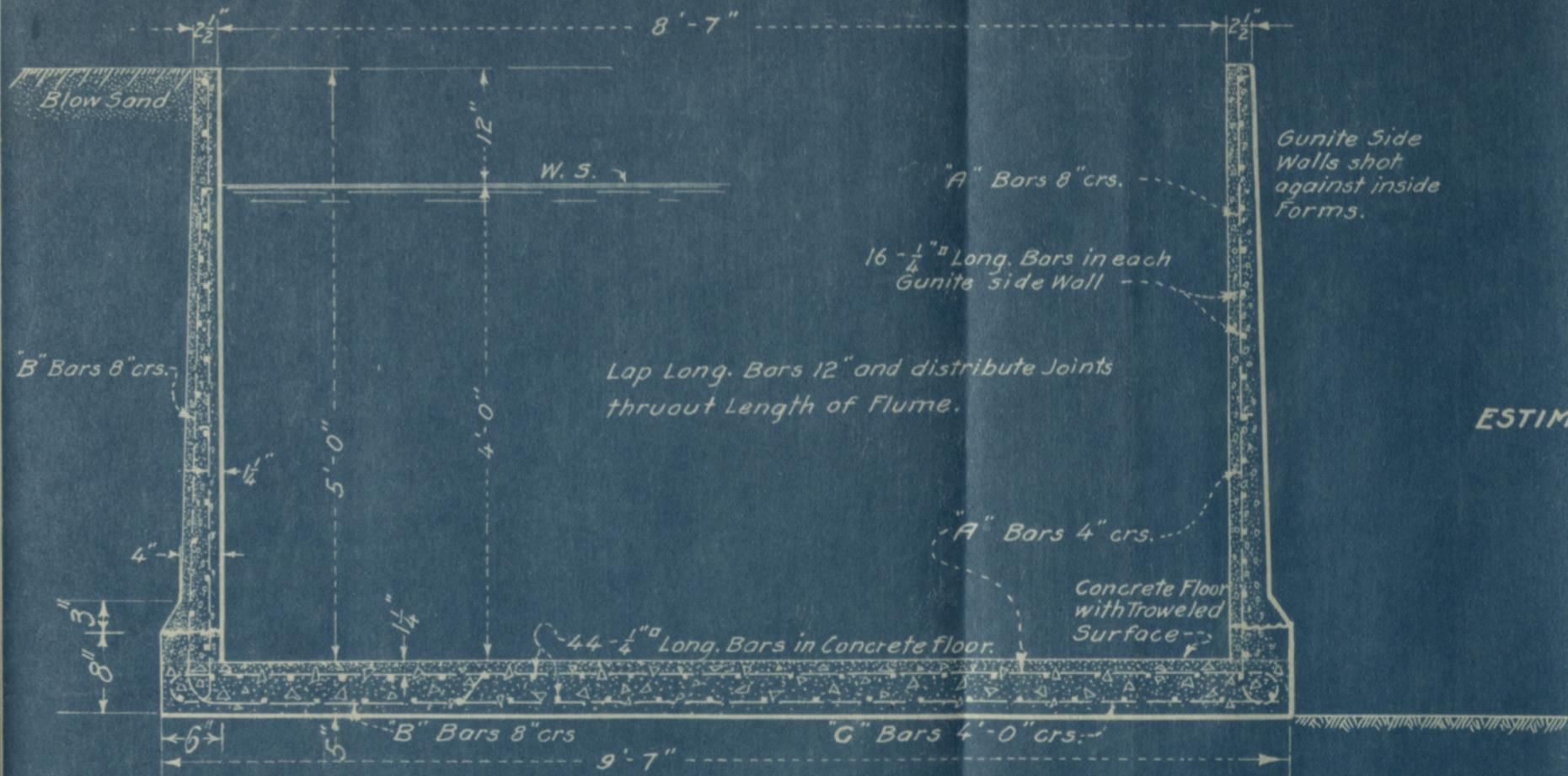
COMBINATION CONCRETE AND GUNITE FLUME

The combination concrete and gunite flume has a concrete floor and gunite side walls. The floor has a uniform thickness of 5 inches while the side walls vary in thickness from 2½ inches at the top to 4 inches at the bottom. The inside dimensions of this flume are 8'7" by 5'0" and has a capacity of 268 cu. ft. per second with a freeboard of one foot. The concrete is in the proportion of 1 part cement, 2½ parts sand and 5 parts of gravel. The gunite

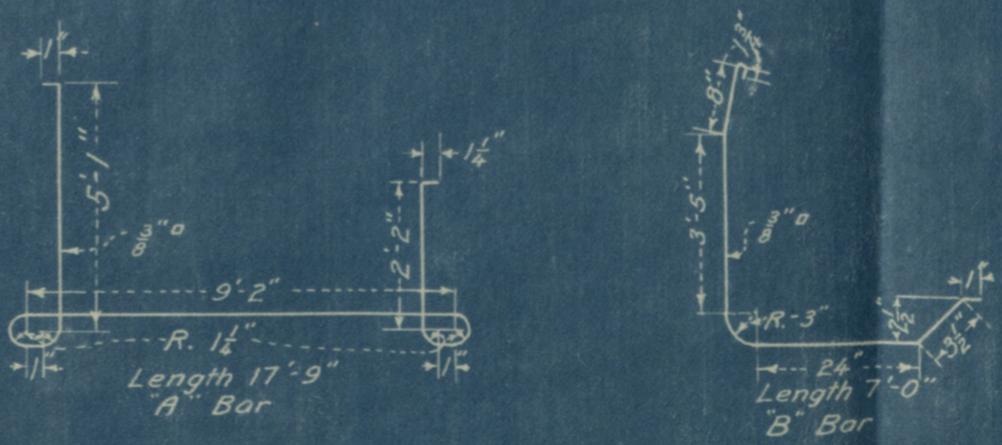
was mixed in the proportion of 1 part cement to five parts sand, but as 20% of the sand was lost in the rebound, the gunite in place is in the proportion of 1 to 4, there being very little cement lost in the rebound.

Figure No. 10 shows a cross section of this flume, the reinforcing steel and the hydraulic data. As may be noted the floor has a double row of longitudinal or temperature reinforcing steel. This double row of steel is to permit of a wider spacing of the bars, otherwise they would be so close together it would be difficult to properly place and tamp the concrete. The transverse bars in the floor bend at right angles and extend through the side walls which are reinforced as vertical cantilevers. Additional reinforcing steel was used in the bank wall to make it safe against external pressure caused by blow sand accumulating behind the flume. The higher compressive strength of gunite over ordinary concrete permits of the reduction in section of the side walls at the base from 5 to 4 inches. This reduced thickness of side wall has the advantage of reducing the amount of longitudinal or temperature steel required as the amount of this steel is based on a percent of the total area of gunite.

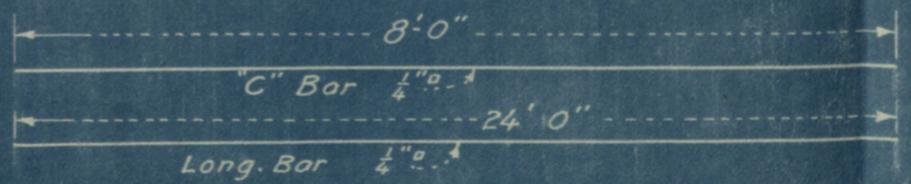
This flume is designed with sufficient temperature steel to force it to crack at 6 foot intervals. In arriving at the percentage of temperature steel required, it was assumed that as this flume would be built in the late fall it would be subjected to a range of temperature of 70 degrees from which it was computed that 1/2 of 1 percent would be required when 1/4 inch square twisted bars



SECTION OF FLUME



DETAILS OF REINFORCING BARS



HYDDRAULIC PROPERTIES

| | |
|--------------|----------|
| Area = 34.33 | n = .014 |
| r = 2.06 | v = 7.79 |
| s = .002 | Q = 268 |

ESTIMATED QUANTITIES PER LIN FOOT

| | |
|--------------|------------|
| Gunite | 0.106 c.y. |
| Concrete | 0.148 " |
| Reinf. Steel | 47.7 lbs. |

Revised Feb. 25 '21.

DEPARTMENT OF THE INTERIOR,
 UNITED STATES RECLAMATION SERVICE,
 KING HILL PROJECT-IDAHO
 FOUR MILE FLUME
 COMBINATION CONCRETE AND
 GUNITE SECTION

DRAWN: W.H.N.-L.H.T. RECOMMENDED: *[Signature]*
 CHECKED: J.H. APPROVED: *[Signature]*

Denver, Colo. 8-5-19. 37-8-71

FIGURE N^o10.

were used with an elastic limit of 55000 lbs. per sq. inch. It was observed after this flume had been built for some time that fine hair cracks appeared at more frequent intervals than 6 feet and usually at 18" intervals and at the point where the gunite area was reduced and weakened by the vertical transverse bars.

Attention is called to the fact that the lower 3 inches of the side walls were built of concrete and poured in conjunction with the floor, forming a curbing against which the forms for the gunite side walls could be placed and held in exact line and grade. By using a concrete floor, with a steel trowled surface in place of a rough gunite, the value of n in Kutters coefficient was reduced from .018 to .014 for the floor. This reduction permits the building of a flume 8'7" wide which will have the same carrying capacity as one 9'6" wide where the floor is untroweled gunite.

A 4 inch tile drainage system was provided similar to the one described in connection with the bell and spigot flume.

The equipment used in building the gunite portion of this flume was the same as described under "Gunite Flume". The compressors instead of being spaced at intervals along the flume bench and moved as the work progressed were set up permanently on the bluff above the flume at a central point and the air was conducted through pipe lines leading to the cement guns. When the guns were operating at the maximum distance from the compressors these air conduits were 2200 ft. long. The transmission loss through this length of pipe was high and should be avoided if possible, but in this case it was not practicable, due to the narrow flume bench, to set up the

compressors and move them along as the work progressed, neither was it feasible to move the compressor along the bluff above the flume. On account of the narrow flume bench, a construction road along the flume over which materials and equipment could be hauled with teams was not practicable, and as the bench, due to its location on the steep hill side, was accessible only from each end, a 36" gauge industrial railroad was laid along the bench paralleling the flume over which all materials and equipment were transported.

The railroad extended to a central mixing plant which was located at the upper end of the work where a pit with an unlimited amount of sand and gravel was uncovered with a small amount of stripping. At the mixing plant two mixers were installed, one to mix concrete and the second to mix dry sand and cement ready for use in the cement guns.

The forms needed for the walls as may be noted in Figure No. 11 were inside panels built of shiplap with a system of cross bracing to hold them in alignment. As only one side of the walls was formed and no pressure exerted by the gunite, these forms were comparatively simple and were easily and rapidly set up and removed. A top templet only was needed to force these panels to conform to the alignment, the bottom being held tight against the concrete curbing by means of spreaders between the panels. After the forms were placed and securely braced a one inch board which was straight for the tangent and cut to the proper radius for the curves was, at first, nailed along the top to act as a form for the top of the wall, but this was later omitted as it was found that pockets of



FIGURE NO. 11.

rebound would collect against this board and, when the forms were removed, would brush off and leave a bad looking top. Instead of shooting the gunite against this top board it was shot directly against the vertical wall and struck off level with a steel trowl which left the top of the wall sound and smooth.

Following the preparation of the subgrade and the installation of the drainage system, the reinforcing steel, which had previously been cut and bent in a central yard, was placed. Figure No. 12 shows the reinforcing steel assembled, and suspended from a frame work used to hold it to line and grade, and the curbing forms set ready to receive the concrete. The concrete from the central plant was hauled over the track to its location in the flume in 1-cubic yard side dump cars and discharged from the cars onto the floor by gravity. The bottom of the inside curb forms served as a gauge for the top of the floor.

After the concrete floor had been allowed to set, sufficiently to permit workmen to walk on it without injuring its surface, the frame work shown in Figure No. 12 was moved ahead and the gunite forms shown in Figure No. 11 erected. The gunite aggregate mixed dry in a concrete mixer at the central plant was sacked in batch quantities and hauled on flat cars to the cement guns. The guns were mounted on a flat car and were moved along the industrial track, at all times keeping them within 50 feet of the work. The guns were kept together, a nozzleman working on each side of the flume and one crew feeding both machines; thus the entire operation was under the supervision of one foreman and



FIGURE NO. 12.

fewer laborers were required.

In building the vertical side walls, application of the gunite began at the bottom and was carried upward. This allows the rebound to escape with less danger of any of it being buried in the wall. Gunite having a tendency to build up upon whatever it strikes, could not be shot at right angles against the wall until the space between the steel and the forms had first been filled by shooting at an angle. Square twisted steel bars proved decidedly objectionable in this connection as they present a flat surface close to the forms and it is almost impossible to completely fill in the space between these bars and the forms and insure that the bars are entirely embedded. Round bars of small diameter should be used when gunite is applied from only one side. If too much water was mixed with the gunite or too great a thickness applied at one time on a vertical wall, the gunite had a tendency to sag and slough off leaving cracks along the horizontal bars. Experience demonstrated that the walls should be built in layers of about $1\frac{1}{2}$ to 2 inches with a moderate moisture content and each coat allowed to set somewhat before the next was applied. To insure a proper thickness of wall a gauge marking the finish lines of the wall was hung from the top of the forms and was kept close up to the nozzleman as the finish coat was applied.

As most of this flume was built during the winter months it was necessary to heat the steel and forms ahead of the nozzleman and protect the green gunite from frost. The former was

accomplished by attaching the water hose to a steam line and playing live steam on the steel and forms, and the latter by covering the entire flume with a burlap or other covering and keeping stoves in the flume from two to five days. During extreme cold weather sacks filled with hay were piled against the outside walls of the flume. Gunite will set up sufficiently to resist frost action in about half the time required by concrete. Figure No. 13 is a view of the country through which this flume was built with a section of the completed flume in the foreground and the compressor plant on top of the bluff.

The sand first used in this gunite work was a well graded concrete sand obtained at the central mixing plant. It was observed that the rebound was unusually high amounting to at least 30% of the total aggregate, and consisted mostly of the coarser particles. With this in mind a series of experiments were conducted to determine which of the sands available would be most economical, and what effect would be produced by the addition of hydrated lime to the sand and cement mix. Although these experiments were not by any means exhaustive, they did bring out some interesting and valuable information, as follows:

(a) The rebound can be decreased by the addition of hydrated lime and the decrease is proportional to the amount of lime used, up to a proportion of one part of lime by weight to ten parts of cement.

(b) The rebound decreases in proportion to the decrease



FIGURE NO. 13.

in sand particles rejected on a 1/8 inch screen. Especially is this true where the reinforcing steel is closely spaced and of large diameter.

(c) These experiments showed, with the grades of sand used, that the smaller the sand particles the less the rebound. As an example:- Using a sand 100% of which passed a 1/8 inch screen, 92% a number 10, 90% a number 20; 80% a number 30; 68% a number 40 and 50% a number 50, the rebound was 20% as compared to 30% rebound for sand of which 100% passed a 1/4" screen, 92% a 1/8" screen; 82% a number 10; 75% a number 20; 56% a number 30; 30% a number 40; and 19% a number 50 screen.

(d) The density of the gunite in which the fine sand was used was also 8 to 10% greater than the gunite made of the coarser sand.

A total of 3300 lineal feet of this combination type of flume was built and has been in operation for one year. It has all the advantages of the all gunite flume, with the disadvantages eliminated.

This flume was built on a foundation that was extremely treacherous but after being in operation one year, at the time of writing, no settlement or disturbance of the foundation has occurred, and as the flume is water tight no settlement or erosion of the foundation is expected. This flume has fulfilled all expectations and is a type well adopted for an insecure foundation. No maintenance or repair work has been done on it nor is any now needed and it

should last its expected useful life with a very low maintenance charge.

SEMI - PRECAST CONCRETE FLUME

The construction program for the fall of 1919, and spring of 1920 contemplated the building of over two miles of concrete flume. The construction season was limited to the non-irrigation season, and to accomplish this amount of work in the allowable time, it was either necessary to purchase additional equipment and increase the organization sufficiently to push this work thru in the short construction season, or provide some means of doing a portion of the work during the summer months. Considerable doubt existed as to whether or not it would be possible to secure the required number of men to hurry the work as at that time there was an extreme shortage of labor, and further, it was not considered economical to purchase the required amount of additional equipment as it would not be needed for subsequent work, therefore, the idea of doing all of the work during the non-irrigation season was abandoned. Included in the contemplated work was a stretch of 4500 linear feet where the foundation was mainly lava rock and advantage could be taken of this condition to design a flume from which a small amount of leakage would not be serious.

To meet all of the above conditions a semi-precast concrete flume was designed and built. The side walls of the flume were cast during the summer months, were set up during the winter months and the floor and joints were poured in the spring, completing

the flume.

Figure No. 14 shows a cross section, side elevation and a detail of the joints of this flume. The shaded section indicates the portion that was precast and the balance the part that was poured in place.

The precast side walls, except on the inside curves, were built in 12'2" lengths, 3" wide on top, and 5" wide at the base. A short section of the floor was poured in conjunction with the side walls giving the slab an I shape with one leg 5'6" long and the short leg 8" in length. The wall slabs were designed to act as vertical cantilevers when placed in the flume section. The lower 6 inches of the slab properly a part of the floor was embedded in concrete when the floor was poured. The transverse bars from the wall slab, bent as shown in the plan, extended thru the short leg of the slab and into the concrete floor poured in place, 21 inches and laping the floor transverse bars 15 inches. There was some question as to whether there would be sufficient bond developed between the old and new concrete to resist shear and to overcome any weakness from this source, the corner bars (marked C) were added. The hook bars in the fillet, marked H, were added as an additional factor of safety against overturning. The concrete floor which was poured in place extends under and six inches up the outside of the wall, this is to prevent any possible leakage following around the joint between the old and new concrete, and also to furnish a solid footing for the side walls. Additional steel was placed in the slabs on the bank side where ever it was anticipated that there would be

any external pressure caused by the accumulation of blow sand. A nominal amount only of temperature or longitudinal steel was required as each 12 foot section was free to move at either end. Concrete sills 4" thick and 10" wide with a 6" vertical leg at each end were placed across the subgrade at the required intervals to support the wall slabs. These sills were built to exact line and grade and the inside of the vertical legs marked the exact position of slabs while the top of sill established the grade.

The joints between the precast slabs were closed with a pilaster poured in place connecting with the sills and filling the wedge shaped space between two adjacent slabs. These pilasters with the sills formed a collar around the flume at the joint and provided a slip joint for the wall slabs.

Expansion and contraction joints were provided by painting each end of the precast slabs and both ends of alternate floor sections with a mixture of asbestos cement and sarco in a proportion of one to three. This same mixture was used to paint the top of the sill and outside of the walls, between the wall and pilaster, to form the slip joint.

As most of this flume was built on a lava rock foundation the only drainage necessary was an occasional cross drain built to take care of storm water, however, at the short stretches built on a clay foundation, a 4 inch open joint tile drain was placed with relief drains every 100 feet.

As is the case with all concrete work where the structure consists entirely of thin walls, the form work is one of the principal items of cost and it is therefore necessary that the forms be as simple as possible and admit of easy and rapid erection. For the precast slabs the forms consisted of flat panels made up of shiplap nailed to 2 x 4 studdings similar to the panels used in the other types of flume construction. These panels were laid flat on a frame consisting of three longitudinal timbers, rigidly cross braced, forming a stiff supporting and tilling frame. A board cut to the dimensions of the cross section of the slab was nailed across each end of the panel to form the ends. In building straight slabs the form panels were wired down to the horizontal frame but for curved sections the panels were lashed to curved templets which were bolted to the frame work. Figure No. 15 shows two of these curved forms in place filled with concrete. The slabs were 12'2" long on tangents and the outside of the curves. The slabs on the inside of the curve were reduced in length the necessary amount to keep the joints on radial lines. These shorter slabs were molded in the same forms by simply inserting the end pieces in the form at the proper location.

Extra ordinary care was taken in the field location of this flume and numerous points were referenced in order that the location might be accurately re-established at any point. After the location had been completed and checked the entire length of the flume was divided into 12'2" sections and each slab assigned a number.



FIGURE NO. 15.

With this information a chart was prepared showing the exact dimensions and shape of each slab and its location in the completed flume. A map was then made of the casting yard showing the number of each slab and its location. The yard layout was such that the slabs could be most readily loaded and hauled to the point of erection in the flume with a minimum amount of moving of the loading equipment.

After the slab forms had been set in position the reinforcing steel was placed in them in the form of a mat. The concrete, which was mixed at a central plant in the proportion of one part cement to $2\frac{1}{2}$ parts sand to 5 parts gravel, was hauled from the mixer to the casting yard in $\frac{2}{3}$ yard hoppers mounted on wagons. The concrete was discharged from these hoppers into the forms by gravity where it was tamped and spaded into place. The exposed surface of the concrete which was the inside face of the flume wall was rodded off to exact thickness and section by a straight edge guided on the ends of the panel forms. In the case of the curve sections the straight edge or screed board was cut to the required curvature.

As these slabs must be allowed to set for two days in summer weather before it is safe to up end them and recover the forms, an average day's run with a total of 60 forms was twenty slabs, however, when forms were available it was easily possible to fill forty of these forms in eight hours. There were 706 slabs manufactured.

The slabs were up ended (see Figure No. 16) by a homemade portable derrick and held in a vertical position by a



FIGURE NO. 16.

simple system of frame work.

After the flume bench was graded a 36 inch gauge industrial track was laid parallel to and 8 feet/^{distance} from the center line of the flume. This railroad was used to transport the slabs and all other materials and equipment used in the building of the flume. A tramway laid up the face of the bluff was used to connect the railway with the casting yard, which was located on the top of the bluff 1000 feet from the nearest end, and 200 feet above the flume bench. Using the portable derrick shown in Figure No. 16, the slabs were loaded two on a car and lowered down the incline by the use of a steam hoist, as shown in Figure No. 17. The slab cars at the foot of the incline were coupled to a 3 ton locomotive and run out on the track opposite their position in the flume where they were unloaded and set in position by a stiff leg derrick as is shown in Figure No. 18. The mast and one leg of the derrick was mounted on two flat cars placed on the track with the second leg resting on a dolly which rolled on a portable track made up of short length 6 x 12 timbers. It was necessary to start setting these slabs at the end nearest the slab yard and working away in order to operate the derrick on the track and not have it in the way of the incoming slabs. When the slabs had been set in their exact position on the fills they were held in place by a cleat joining them to a slab previously placed and by an occasional cross frame as is shown in Figure No. 19.

When the slabs had been set in position the concrete floor was poured in sections of the same length as the slabs and



FIGURE NO. 17.

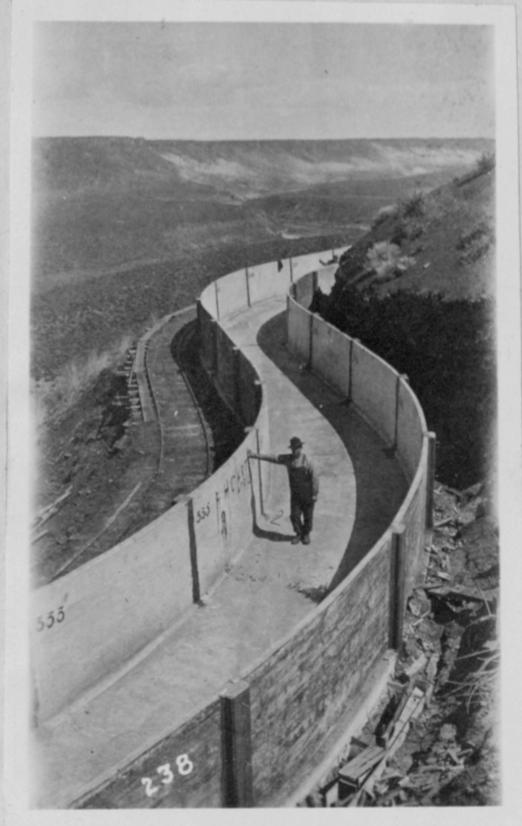


FIGURE NO. 18.



FIGURE NO. 19

FIGURE NO. 20



as it was necessary to place an elastic filler between two adjacent sections, the floor was poured in alternate sections.

Concrete for the floor was mixed at the central mixing plant located at the junction of the railroad and the tramway. For the purpose of conveying concrete to the flume and spouting it over the side of the wall two specially constructed hopper cars were used. The hoppers on these cars could be raised and lowered in 6 x 6 timber guides by means of a hand crab. The hoppers were kept in a lowered position when moving. Following the pouring of the floor the pilasters were poured completing the flume.

This flume, 4500 feet in length, has been in operation one year and although it was expected that this flume might leak somewhat at the joints, it has proven to be, for all practicable purposes, water tight, there being very much less leakage through these joints than thru the bell and spigot joints described in connection with the flume of that type. The precast concrete was of an extra good quality, it being possible to thoroughly tamp and spade it into the forms making it unusually dense. Figure No. 20 is a picture of the completed flume.

COSTS AND CONCLUSION

The costs of the above described flumes as taken from actual cost reports are not comparable as the flumes were of different sizes and the construction work was spread over a period of three years with fluctuating labor and material costs. The difference in

the length of haul of materials, local conditions and the season of year in which the construction work was done had a decided effect on the costs.

There is given below a cost per lineal foot for each type of flume with conditions adjusted so as to make the costs comparable. These costs are based on a flume with a carrying capacity of 270 cu. ft. per second on a slope of 2 feet per 1000 feet. This requires the inside dimensions to be 8'7" x 5'0" including a 12" freeboard for all types of flumes except the all gunite. The width of the all gunite, had to be increased 11 inches to provide for the same capacity.

The costs follow:

| | |
|--|---------------------|
| Bell and Spigot concrete flume - - - - | \$12.22 per lin.ft. |
| Concrete flume without joints - - - - | 11.83 " " " |
| All gunite flume - - - - - - - - - - | 12.40 " " " |
| Combination gunite and concrete - - - | 12.10 " " " |
| Semi-Precast concrete - - - - - - - - | 11.58 " " " |

The above are field costs exclusive of excavation and based on, winter construction, ten mile haul for materials from railroad to job, two mile haul for sand and gravel, common labor costing 50¢ per hour and skilled labor in proportion, cement \$4.00 per bbl. at job, steel 5¢ per lb. and lumber \$70.00 per M.

These costs are abnormally high due to the fact that labor was scarce, inefficient and the cost of both labor and materials high on account of war conditions.

The fact that most of the flumes were built during the winter months was a factor greatly increasing the costs. Records show that a reduction of 25% would have been made if the work had been done during favorable construction weather.

From experience gained in the construction and from observation of the various types in operation the following general conclusions are drawn.

1. The cost per linear foot is approximately the same but is slightly in favor of the semi-precast and concrete flume without joints.
2. Although some types have marked advantages under certain conditions all types have proven sufficiently satisfactory to justify their erection.
3. All of the above described types of flume from a stand point of safety would be satisfactory on a rock or similar foundation in which case the flume to be selected might be left entirely to the first cost, the maintenance and the estimated useful life. The flume without joints either concrete or gunite will have a lower maintenance charge than the flume with joints.
4. Foundations of clay, and loam which might become saturated with water and freeze during the winter months or which might settle under the flume during operation are not safe for flumes with joints. On such foundations the continuous flume, either concrete or gunite should be built as there is considerably less chance of heaving and very little if any chance of the foundation being eroded by leakage from the flume.

5. The Bell and Spigot flume should probably be considered an obsolete type for the reason that it has the highest first cost, probably the shortest useful life and the following disadvantages which do not obtain in any of the other types. It has an excessive amount of leakage through the joints and unless located on a rock or other foundation not affected by water the leakage will erode the foundation, cause settlement and ultimately lead to failure of the flume. In climates where the foundation freezes, the sections may heave throwing such sections out of grade which increases the leakage and decreasing the carrying capacity of the flume.

6. The Semi-precast type has a marked advantage when it is desired to build a considerable amount of flume during the short construction period between two irrigation seasons providing it has a suitable foundation.

7. A gunitite flume would not prove economical unless a considerable volume of work is undertaken for the reason that it requires a larger amount of special equipment for its installation than a concrete flume, and also requires skilled labor to operate such equipment.

8. Until the useful life is known no choice can be made between the concrete flume without joints and the combination gunitite and concrete types, and the selection of the type to be used is a matter to be considered in connection with local conditions and first cost. The experiences on this project indicates that the concrete flume without joints is slightly cheaper, however, with

the development of reliable portable compressors, suited to gunite construction, it is probable that the first cost of the gunite flume might be reduced considerably.

9. The all gunite flume when built is equal to the other types of flumes without joints except it offers one disadvantage in operation: the cross ties present a barrier against which weeds and other debris floating down the flume lodge and form obstructions.

10. In conclusion it might be said that any of these types of flume may be built and operated successfully on a rock or other good foundation but the flume without joints is preferable when there is any doubt about the foundation.

The above described construction work was all done by Government forces and was carried on under the supervision of A. P. Davis, Director U.S. Reclamation Service; F. E. Weymouth, Chief Engineer; Walter Ward, Project Manager; A. M. Rawn and E. C. Panton, engineers.