THE DESIGN AND CONSTRUCTION OF BULKHEADS TO WITHSTAND HIGH PRESSURE, IN CONNECTION WITH THE FLOODING OF PORTIONS OF TWO MINES.

by

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FIRES IN BUTTE MINES.

Butte as a vein mining camp originated in the 1870's, following exhaustion of the placer workings in the vinoinity. The hill has been mined continuously since that time. In the development of the mines up to the beginning of the present century, stopes were mined to the surface; and much open timbering, many filled stopes, and extensive waste dumps existed. Now it is the practice, wherever possible, to backfill abandoned workings and exhausted stopes with waste rock. Some hoisting and surface handling is eliminated, surface space is saved, the surface is not overloaded, and the mined out zones are braced and strengthened against shrinkage and ground movement.

Before the electrification of the mines animal haulage was the custom; and much stable refuse accumulated, both on the surface and underground. At some places manure was dumped into open workings. Much timber was always left in place in abandoned workings, and timber refuse also went into the gob to add to the total of combustible material underground.

The Butte mines are both hot and wet; in places there is much ground movement, causing splintering of timbers; and in general, conditions are very hard on timber. Some of the ore is of a strongly sulfide nature.

The original cause of fire in the Butte mines is not known; but there are several causes, any of which may have been the original one. One camp legend relates that fire from a barn spread down a manure filled opening, and caused the first underground fire. Spontaneous combustion in timber may have occurred. Carelessness and incendiarism are two other possible sources.

When other causes have been eliminated, spontaneous combustion is the old standby. Lamps are another cause; but as they are handled mostly in working places, such fires as they may start are usually quickly detected and stopped. No doubt exists that unprotected and untreated timber, left sufficiently long in the mines, with oxygen from the air available, has caused and will cause fire. Temperatures of over one hundred and ten degrees Fahrenheit have been recorded, even in some of the working places. Another source of fire is from electric conduits.

Malicious vandalism may have caused some fires. Early in this century there were intense struggles, and in some cases, open guerilla warfare between different mining factions in the camp. It is reported that fires were deliberately started as part of some of these campaigns. Since those days the camp has never been entirely free from underground fires, although usually they have been under restraint.

Similar to a fire working down from underground is one reaching or originating in an operating shaft. The majority of the Butte mines are now under one management, and the ventilation is one comprehensive system. The operating shafts are downcast, serving the workings with fresh air. Fires starting in working shafts can quickly spread into the mine, cutting off the stations and destroying the shaft. Due to the interconnected workings and many active shafts at Butte, even such a fire will not usually result fatally. There was such a fire in one of the Butte shafts a few years ago but although it wrecked the shaft, no lives were lost.

Fires which break out unexpectedly in a section of mining country often have fatal results because men may go into gas before they know of any danger.

Due to the gases generated and the danger of spreading, fire existing in any country must be isolated until it is extinguished. In Butte the task of extinguishing has been difficult. Fires outside of the Leonard mine district have always been successfully extinguished; but in the immediate vicinity of the Leonard, fire conditions have existed for the past quarter century, due largely to the extent of backfilled country, the rich sulfides and hot ore bodies, and the broken up condition of the ground, which facilitates access of air and transfer of heat.

COMBATTING FIRES.

The Butte Mines has a fire fighting organization which is a separate industrial group, under its own foreman. In passing it might be well to note that titles in Butte are misleading, even to one who is familiar with mining terminology. The actual head of any group is a foreman. The foreman of a mine is the man in direct charge, and he may have a thousand or twelve hundred men in his organization. Besides actual extinguishing, the fire fighting crew handles fire control and prevention, as well as fire inspection.

Local blazes can be put out by fire extinguishers and water from the mine system. In combatting larger fires the first necessity is to cut off the air, thus stopping the oxygen supply. A corollary task is the placing of barriers, so that fires and gas cannot spread along tunnels to other workings.

Previously constructed fire doors, consisting of concrete frames and steel plate doors, can check the advance of a fire. Partitions or brattices of various materials can cut off the main air supply, and are used to stop the spread of gas from a fire zone into the mine workings. Partitions, brattices and bulkheads are all of one class. The term "brattice" is borrowed from the coal mining industry. Locally it is applied to any partition which seals off air, gas or heat, but is not massive. Brattices may be built up to a maximum thickness of approximately one foot. In practice bratticing is principally for the purpose of restraint and control.

Another method of attacking fire areas is through the aid of diamond drill holes. An area in which an actual fire is known to exist, or in which fire is probable, may possibly be so situated that there is not good way of bringing water to it except by attacks from above. A stope which has not been holed through to an upper level is an example. Or it may not be advisable to approach the area by ordinary mining methods. In these circumstances diamond drill machines are set up, and holes are drilled to predetermined points. The drill holes are lined with pipe, for two reasons; (1) so that city water can be delivered to the end of the pipe without loss, and (2) because there is less possibility of losing the hole if it is lined. Through these holes water is turned into the fire area. This is a usual method; and the diamond drill crews are regularly and continuously employed.

The third method of fire fighting combines features of both the previously described methods. It is known as bulkheading and backfilling. The brattice form is employed, but it is heavier; as it must withstand water and material pressure. The backfilling material is water borne fines, and it serves several purposes. It furnishes water to quench the fire, and material to blank out the air in the zone. The material helps to seal cracks and crevices, preventing the ingress of more air. It increases the fire inertness of the area through its own noninflammability, low temperature, and the retarding and crowding out of air. It tends to pack and build up the zone as a solid mass, so that future mining may be undertaken with less unstable ground to be supported. After a zone has been mined for one system of ore deposits, another system, or part of the first-mined system, may remain unmined; and yet the condition of the ground and the timbering may preclude any further mining, due to excessive costs or actual inability to support the country.

PROJECT NUMBER FOUR.

The particular firefighting project, with which this thesis deals, is known to the company as Project Number Four. Three previous projects of like nature had been completed, so that the method of treatment was not new. As it involved the expenditure of a third of a million dollars of additional money at a time when many ordinary expenditures had been curtailed, the project must have been considered absolutely necessary to preserve the mining system in a territory which had been worked but which still contained an unknown quantity of ore, some of it known to be very high grade. Diamond drill attacks, bratticing, and sand bulkheads were being used on the zones when this project started.

The project was grouped as a single operation, although there are two separate regions undergoing treatment, one each in the Leonard and the Tramway mines. The regions actually treated were two irregular blocks of ground extending several hundred feet in each direction.

The preparatory paper work involved a detailed study of the scale maps of all workings in the zones. Bulkhead sites were located at the most advantageous points to cut off completely all openings into each zone. At the same time passages around the project had to be maintained. An additional problem was presented by the fact that the Tramway was operating at capacity, and operations could not be interrupted for this work. On the other hand the Leonard was completely closed except for the pumps. As the underground country is traversed by a mass of connected workings it was also possible to approach the area through two adjacent shafts: The East Colusa shaft, which was turned over to the firefighting foreman; and the Rarus shaft, which was shared with the mining operators.

Suitable material for backfilling was found in a tailings dump, situated about four thousand feet from the East Colusa shaft. This material was waste from a mill, and consisted of talc and table sands. The talc was very fine and quite readily floatable, the sands were of greater specific gravity and of larger sized particles. There were some well defined bodies of each in the dump, so that some control of the qualities of the backfilling was possible.

In backfilling, the material was shot down out of the dump, and set in motion by hydraulic giants. Two or three nozzles were employed, each throwing one hundred and twenty-five gallons of water per minute. The bank material contained about twenty percent of moisture. Tonnage moved was one item in the daily report. The material in transit was sampled, and the percentage of water determined. Tonnage was first determined by multiplying the weight of water put through the nozzles by the factor: Percent of Solids divided by Percent of Water. The water was metered. A total of one million seven hundred thousand tons of solids was moved into the project. Subzero weather, which is not unusual in Butte, slows down the operations and may cause a total shutdown of the hydraulicing. In the effort to get the project as near completion as possible before this kind of weather set in, provision was made to speed up the operation, as will be explained later. It was desirable to maintain a close check on the quantity of solids placed, so that the progress of the work and the percent completion might be known.

The formula first used did not give close results, due to the fact that there was on the average twenty-one percent of moisture in the solids in place. There was very little variation in this figure. As this twenty-one percent was part of the moisture in the analysis of samples the following formula was adopted:

$$\text{Weight of metered water} \quad X \quad \frac{S}{100 - \frac{S}{.79}}$$

in which "S" is percent of solids in pipe line by analysis.

The material, after being sluiced from the bank, was run through a tank containing a vertical shaft paddle wheel, driven by a motor, and then through a centrifugal pump driven by a 30 H.P. motor, thence through three thousand feet of six inch cast iron pipe, set on a two percent gradient, delivering four hundred gallons under this setup. This brought the material to the mine shaft where it was taken underground. The suction head developed in the pipe in the shaft was evidently part of the transporting force. In the shaft at intervals of 600 to 650 feet in vertical height, frictional pressure reducers were placed, to reduce the accumulated pressure head. From the shaft the line was carried to the two divisions of the project, with laterals to each point of delivery (practically each bulkhead).

Putting in a second pump in series with the first one served to increase the volume of delivery to five hundred and fifty gallons per minute. As this increased the velocity, the percent analysis of solids could be raised to sixty.

Pumping under pressure was new to this project, as previously the method had been to deliver by means of a flume, ten inches deep by twenty-two inches wide. The reasons for substituting pipe for flume were, that only low percentages of solids could be transported by the flume, also the solids would settle out and solids and ice would cut down the capacity by reducing crosssection. The time of several men had been consumed in ineffectually fighting these obstructions; therefore it was considered more efficient to install the pumps and pipe.

If sixty percent solids could be put through the line by the two pumps, over two hundred thousand tons of fines could be placed per month. In the first month of operation over fifty percent of solids was obtained with one pump. This is about one hundred thousand tons per month.

Pipes through the bulkheads permitted the backfilling to be placed immediately behind the bulkheads. It was at these points that the control of the characteristics of the materials was of advantage. The coarsest material was deposited against the bulkheads. When a condition of stability had been secured, ascertained by testing through the drainage pipes in the bulkhead, the water in the material was drained off. In badly faulted country much of the water escaped through the faulting. In tight country most of the draining was done through the bulkheads. The desire was to obtain clear water through the drain pipes, an indication that the solids had settled. As there were places where the bearing value of the rock in the contact areas of the abutments (hitches) was doubtful, it was important that heavier, inert material be placed there and become as solid as possible, to minimize the stresses on the abutment. It would seem apparent that the care and precautions just mentioned would eliminate the necessity for providing for heavy hydrostatic pressure, but the action of the material within the filling areas was very erratic and uncertain. Bulkheads which showed no water at one time might, within twenty-four hours, develop a head representing several hundred feet of liquid or the full head of the filled area.

The bulkheads themselves were more or less solid masses of gunite built within forms in place. Abutments, top, sides, and bottom, were cut into the rock. These are known as hitches. Usually one placing pipe and one drainage pipe, both valved, were placed through each bulkhead.

On this project the original estimate was for about two thousand four hundred cubic yards of gunite in bulkheads. The estimate was based upon the assumption that the cross-sections which had been used for eight foot by ten foot openings in other projects would be ample in this one. The assistant superintendent in charge of the Leonard and Tramway group of mines, who engineered the project, brought to the engineering office the problem of designing a better bulkhead, or of proving that the type previously used was the best. The improvements the writer made and the information he gained were the direct result of the superintendent's initiative and cooperation.

THE BULKHEADS

The bulkheads, used in previous projects were placed in openings, the greatest crosssection of which was not more than nine feet by ten feet. A "hitch" was cut into the walls of the opening, and completely encircling it, to a depth of 12 to 18 inches and of a width, parallel to the tunnel, of approximately 4 and one-half feet. The inside form was built and the front form started. The hitch bottom was baled out and the guniting started. The front form was carried up until it approached the roof or "back". A withdrawal hitch (a channel from the highest point of thehitch, sloped out ahead of the bulkhead) was then cut to permit the complete filling of the bulkhead with gunite. The withdrawal hitch was also formed over and filled with gunite. During the progress of the bulkheading the drainage and filling pipes were laid through the bulkhead.

Sometimes in the backfilling process, rock failure would develop and water or slime would flow from cracks or seams in the rock in front of the bulkhead. When the leaks occurred adjacent to the bulkhead, supplementary abutments of gunite were built against the side wall of rock and the bulkhead. These supplementary abutments probably had the following effects:

a. Since the bulkhead contained no reinforcement, the resistance must have been due to arch action. A total span of 11 feet by 10 feet or a net opening of 9 feet by 8 feet, with a 1 foot hitch around the whole perimeter, loaded with an hydraulic head of 500 feet, or 15 tons per square foot, would be safe for arch action and shear within the gunite. The bearing on the rock would be 32 tons per square foot, which is less than the load that good rock in that country should carry. However the shattering effect of cutting the hitch with perpendicular sides would lessen the usual strength of the rock; and failure would be caused by crushing of the rock. An abutment placed in the corner between the side wall and the bulkhead would receive at least part of this load, and transmit the forces to the back and the bottom by arch action.

b. The placing of these abutments reduced the net span of the arch in the bulkhead.

c. The abutment would also serve as a secondary arch at right angles to the arch described in (a) to transfer bursting and shearing out pressure from the weakened rock into the solid back and foot.

d. Placing of gunite would tend to seal the seams in the fractured rock, and cut off water flow.

The gunite composition was approximately three and one-half parts of sand to one part of cement. Water cement ratio cannot be controlled in the placing of gunite. The wetter the mix the greater is the reduction in the unpleasant dust fog. Hence the water content of the gunite was undoubtedly very high, especially since the application of the water cement ratio in concrete making was not in use in Butte at that time, and there would be no attempt made to keep the percentage of water at a minimum. Also at that time cement was not so finely ground. Compression tests on gunite samples showed failure at 1500 pounds per square inch for thirty days of age.

Despite all these factors the gunite crews must have produced to the very best of their ability, since no initial failure of gunite was noted.

In some instances bulkheads failed to such an extent that abutments could not save the bulkhead; and an additional bulkhead, placed some distance in front of the first one, had to be built. This was called a retreat bulkhead. Abutments cost about the same as bulkhead. A retreat bulkhead with abutments would make the total cost at a location three times the original cost.

The problem originally given to the engineering office was to design one bulkhead, to close an eight by nine opening and to withstand an hydraulic head of five hundred feet. Design principles were to be coordinated with construction conditions. An important factor was saving of cost. A single bulkhead, built over a year previous to that time, was quite massive and showed very little regard for economy. The arch theory was applied to the conditions, and a different but satisfactory section was developed. When later it was learned that the project included many bulkheads of varying size, and in its entirety involved the expenditure of a third of a million dollars in cash outlay, the subject received the following treatment.

Factors given: A. Any useable design produced by the engineering office would be adhered to in construction.

b. Results, which involved full cooperation and expedition, were the principal object.

c. A specified volume of ground was to be blocked off by means of bulkheads. The volume was such that a maximum hydrostatic head of 575 feet of water might be developed on the lowest levels.

d. Local sands were to be used if possible, since cost was an important factor.

e. As this was the fourth project for aggressive firefighting, there was some data available from previous projects, the outstanding item being the ultimate compressive strength of gunite at the age of thirty days. This was given as thirteen hundred to fifteen hundred pounds per square inch. On previous work our office had used fifty pounds per square inch as the working value for shear in gunite.

Conditions existing. The basic design followed by the writer (the single bulkhead he designed) was laid out with these values per square inch: Shear value sixty pounds, compressive strength one thousand pounds, and shear in steel twenty-four thousand pounds. He was the object of considerable criticism when it was learned that he had used seventy percent of the minimum ultimate strength as determined by the old tests for the working strength value. His only contention was, that gunite of much greater ultimate strength than that shown by the tests could be economically produced, and that the mix should be 1:3. Consultation with the district engineer of the Portland Cement Association and through him and the Three Forks Portland Cement Company, with the headquarters of the Portland Cement Association in Chicago, resulted in the receipt of the following information and opinion: 1:3 gunite of approved materials should produce an ultimate compressive strength of five thousand pounds per square inch with working strengths of one thousand pounds per square inch in compression and three hundred pounds per square inch in shear.

They condemned the sand previously used in the bulkheads, as well as all other local sands (cost of which ranged from $.70 to $1.20 per yard) and recommended a washed, sized sand from another locality, which would cost $2.40 a yard. The local sands were unwashed bank run, and consisted of decomposed feldspar. The sand in use in the gunite (which cost $.70 per yard) was so irregular and dirty that the engineering department had discontinued using it in structures above ground and had developed a better pit, in which the sand although unwashed, was uniform and fairly clean. The idea of using the sand recommended by the Portland Cement Association was vetoed - due to the higher cost. A screen and color analysis of the two local sands under consideration - see Table I - showed the better sand to be of sufficiently good quality to permit its consideration for use in the work.

Consultation with cement mill officers at Three Forks produced the information that their cement was ground much finer than cement association specifications called for, and that its tensile strength was about four hundred pounds per square inch. Taking all factors into consideration (gradually applied and static conditions of load, close supervision of construction, recommendations of the Cement Association, and authorization to take samples of gunite and make compression tests, it was thought best to use working stresses of fifteen hundred pounds for compression, one hundred and fifty pounds for punching shear, and shear in steel twenty-four thousand pounds.

With these most important questions decided thirty-five tons per square foot was estimated to be the maximum safe bearing value for rock as encountered in local conditions under ground. A "contact area" of six to seven feet per hitch, or haunch, was adopted. The contact area unit of measure is the length of the contact line between the gunite and the rock; and its value is for sealing off the flow of liquid between the bulkhead and the rock. Its value is derived from both adhesion and pressure. The remaining conditions assumed were that an arch would exist within the gunite and that another arch, at right angles to the first one, would exist whenever the loads were such that the assumed stresses were exceeded in the first arch. Since the sections were wholly enclosed, the condition actually existing might more properly have been considered a dome, rather than two arches within the same material; but the double arch theory was employed for two reasons. First, while in some cases the compressive strength was needed, in others the theory of the second arch was needed to develop the shear resistance of all faces. The idea used was that shear resistance would develop along the plane area passing through the toe of the arch and the corresponding line on the back of the bulkhead, which, theoretically, would be a plane perpendicular to the pressure face of the bulkhead. Second, in actual construction it was sometimes found that the straight line of the drift, or crosscut, was not maintained in construction; and the shear area, instead of being of a surface similar to a cylinder, was one similar to a truncated cone. The generating line would not follow a regular path but an irregular one - due likewise to the rock irregularities.

A triangular recess in the rock had been adopted in place of the previously used rectangular one, for several reasons. The triangular section furnished a base in the rock more nearly perpendicular to the line of pressure of the arch; it gave more shear area; it was easier to construct; and it would result in less injury to the rock base of the arch. The actual cutting of the triangular section was accomplished by placing the drill holes parallel to the base plane and at a distance of approximately one foot, in front of the face of the desired excavation. After the shots had been fired, all loose rock was picked or barred down by hand. In good ground this procedure produced the desired cross section.

In some places where crossed tunnels were adjacent, it was necessary to consider arches as existing in the rock itself; for there was not other way to transfer the pressure which the rock base received into the oblivion of larger cross sections. While steel rails were placed in the bulkheads at intervals of eighteen inches, their value was computed for shear only, and not as a tie for arching. Construction made advisable a minimum thickness of two feet in the center of the bulkheads.

In various construction work at Butte, punching shear in concrete occasionally arose, as in the bulkhead mentioned, where a value of fifty pounds per square inch for gunite was used. A few years previously it had been the determining factor in the base of a column carrying a million pound load. Here the 0.06 fc, had been used as given by the A.S.M.E. Committee, for punching shear in reinforced concrete. The Joint Committee also stated that where there was no web reinforcement the maximum value of punching shear should be 0.02 fc. The Cement Association had evidently been using the factor 0.06 fc when they recommended three hundred as a safe working shear value on 5000 gunite.

Hool and Johnson in "Concrete Engineers Handbook" state, "It is very difficult, however, to make experimental determinations of pure shearing strength, because most methods and devices which may be used to make shearing tests, involve either a cutting action, bearing pressures or beam stresses." They cite a series of tests by R. Feret on grouts of various proportions in which the punching shear varied, for mixtures of 1:3 to 1:4, from 60% to 68% of the respective compressive strengths. They cite tests by Prof. C. M. Spofford at Massachusetts Institute of Technology and Prof. A. N. Talbot at University of Illinois on Concrete Mixtures. M.I.T. tests showed 63% for 1:2:4 concrete, and the Illinois tests ranged from 49% to 139% of the compressive strengths on 1:2:4 and 1:3:6 concretes.

In view of former practice, and until some new data could be developed, it was felt that 150 pounds per square inch working stress was the greatest shear value that could be used for the gunite.

THE SOLUTION

The actual solution was based upon the solution of an arch by simple graphics.

575 feet head of water = 250 pounds per square inch or 17.5 tons per square foot

400 feet head of water = 174 pounds per square inch or 12.5 tons per square foot

500 feet head of water = 217 pounds per square inch Or 15.2 tons per square foot

Shear in gunite at 150 pounds per square inch = 10.8 tons per square foot

Compression at 1500 pounds per square inch = 108 tons per square foot.

Fig. A. Plate I is a horizontal cross section of an 8 foot high by 9 foot wide bulkhead for 400 foot head. In this case an arch 9 inches thick at the crown and 12 inches at the base will transfer the load to the rock, and still remain within the outline of the minimum construction dimensions. The bulkhead is 2 feet thick for a distance of 4 feet at the center. A thickness of 4 feet at the rock face is the minimum for construction purposes. This gives a contact area of the minimum 6 feet, and extends into the rock $2\frac{1}{4}$ feet. This horizontal arch is sufficient to take the full thrust. The shear actually developed in this direction is $\frac{9}{2} \times \frac{12.5}{4} = 14$ tons.

As this is 3.2 tons more than the strength set up here, either one of two theories is applicable to the design.

The transverse arch may be figured to carry the excess shear to the floor and the back; or the shearing value of the rails placed in the concrete may be used. As the rails have a shearing value of 20 tons per foot of bulkhead section, and the additional shear needed is $\frac{9}{2} \times 3.2 = 14.4$ tons, the latter value will suffice, and no more computations are necessary. The direct bearing on the rock is $4.5 \times 12.5 = 56.25$ tons, which divided by 2 feet = 28 tons per foot, a value less than the 35 tons optimum.

For a head of 500 feet with the same opening, the computations are along the same line. The load which the horizontal arch will take is limited by the shear, which is 20 tons $+ 4 \times 10.8 = 63$ tons. As this is less than 2×35, the rock pressure is safe. For shear, $\frac{63}{9-2} = 14$ tons of load, which means that $(15.2 - 14)$ tons of load must be carried by a transverse arch. Actually in all these cases the theory of least work will apply, and the stresses will be equal in all directions. The computations showing what the transverse arch takes are for the purpose of making sure that the stresses in that direction are within the limits assumed.

For 575 foot head the same method is employed, with the exception that the secondary arch carries so much load that it is necessary to develop this arch graphically, to make sure it falls within the confines of the structure.

17.5 tons - 14 tons (the maximum because of shear that the horizontal arch will carry) = 3.5. It is evident that the arch, which is made heavy and flat for the transverse lay-outs where the abutement is not thickened at the wall, is still sufficient for the remainder of the load.

Some of the bulkheads were so located that secondary arch action could not exist, for either of two reasons: (1st) because the main resistance was a vertical arch, due to the fact that the plan of the bulkhead showed a section in which a horizontal arch could not form (one of the first bulkheads built was built around a bratticed-off air shaft and made a right angle with the pressure from the inside of the right angle), or (2nd) because the horizontal or transverse section was so long that an arch would be so flat as to be of no value.

So many varieties of openings were finally encountered that a set of sections was developed applicable to many cases. For example, one simple computation is as follows: 575 foot head, 12 foot span, long or irregular in other direction so that arch exists in one direction only. Shear per linear foot is one-half the load or $\frac{12}{2} \times 17.5$ tons = 105. tons. Compute shear as follows: Deduct 20 tons on account of rails, = 85 tons. Divide by 10.8 = 7.9 feet thick at shear section. Compute bearing as follows: 105 tons - 35 tons = 3 foot depth of hitch in rock.

Actual ly before any such section was encountered the punching tests on concrete had shown that the ultimate punching strength was far beyond the figure demanded by a working stress of 150 pounds per square inch. However, as the tests were so few and not made under laboratory conditions, it was thought best not to exceed 230 pounds per square inch working stress in shear. 230 pounds per square inch is 16.5 tons per square foot. 16.5 tons per square foot, with a problem like the preceding one, with the exception of an arch span of 14 feet, would show the following results: shear $= \frac{14}{2} \times 17.5 =$ 122.5 tons. Deduct 20 tons (rail) $=$ 120.5 tons. Divide by $16.5 = 6.37$ feet thick at haunch, which was the thickest section designed.

The accompanying photostat from the Anaconda Copper Mining Company shows some of the final sections.

CONSTRUCTION AND ITS PROBLEMS.

The regular details of the construction are somewhat as follows: Sand and cement are delivered to the two sites, and the correct amount of each for the mix to be used is measured out, after which they are mixed dry. The capacity of a mine car is approximately 12 cubic feet, and that is used as the unit of mix, which requires 4 sacks of cement for a 1:3 mix and 3 sacks for 1:4. The mine cars are then loaded and sent to the proper place in the mine. Frozen masses and anything visible is thrown out of the sand by hand at mixing. Two styles of mixers are used, a gravity cascade mixer and a regular concrete batch mixer.

In loading a cement gun the mix is screened through a No. 4 screen and the oversize rejected. City water is used in the gunite. The gunner directs the nozzle downward, holding it about 18 inches from the mass. There is no rebound.

The gunite after deposition is disturbed only by the gunner's walking on it. There is usually a little free water on the top of the gunite, which is pushed ahead as the mass is built up. The gunite is deposited uniformly over the whole area inside the forms, and is thus built up uniformly. It is the aim of the construction force to make the guniting continuous until a bulkhead is completed. If the work is interrupted, the last surface is cleaned and washed down, and a little neat cement is placed for a bond. The guniting is usually carried on in two shifts, so that there may be an interval of six hours during which the surface is exposed without any fresh deposits. For that job the two shift system is held to be continuous, but the assistant foreman usually sees the surfaces before the day crews start on their guniting.

Vertical arches present greater problems of constructionm on account of the sloping of the forms in the front face. The gunner has to work first in a converging and lastly in a widening area, which is wider at the retreat. At one place where a vertical arch was employed the main haulage was passed along against the bulkhead. The place to be bulkheaded was already sealed off, furnishing an inside form; but the bulkhead was practically plastered onto the rook at that place. Its length was about thirty-five feet. Hitches could be cut into the rock at the ends and the floor but not in the back. In the construction, an abutment was actually carried across the back and landed on the wall opposite the one where the bulkhead was built. As the country there was badly shattered, this place was expected to be one of the worst in the matter of leakage, as it was on the bottom level, and it was predicted that there would be much trouble with water when the backfilling started. Probably, because of the deposition of well graded fines, and possibly because of extra precautions in constructing a special structure there, the resulting leakage was a minimum.

The stresses and sections used could be improved upon theoretically, and if it becomes necessary to build another project the designs might be revamped, but unless further tests are made in sufficient quantity to establish definitely that certain strengths can be consistently produced, it is doubtful that any refinement will be of advantage. During the first three months $30,000 was saved on construction, which could be credited to nothing other than design: and another $30,000 would be saved in maintenance on the same account later. Bulkheads could not be built too skimpily, as rock pressure might change, and it was felt that some factor of safety should be used on that account; especially since a serious failure might cause the loss of the $200,000 pumping station serving those levels.

The 1:3 mix is used for the 500 and 575 foot heads and the 1:4 mix is employed for the levels where a lesser head - 400 feet or less - might be encountered.

The biggest problem of construction is to have the responsible heads understand both the theory and the application of the solution, and apply the correct bulkhead section to suit the condition existing.

THE TESTS

As before stated, previous tests had been made on gunite, both the gunite and the tests being made by the Anaconda Company. Due to the disparity between those results and that claimed as possible by the Cement Association, and also to check on the work to obtain uniform results, it was decided to make tests, both for information and for control of Project Number Four.

Molds for cylinders six inches in diameter by twelve inches in length were used for compression. The tests were made on an Olsen testing machine of 100,000 pounds capacity, which belonged to the Montana State School of Mines at Butte, Montana. The machine had no adjustable head.

Because most of the cylinders and cakes which were tested had unsatisfactory heads, it was necessary to face most of them on one face or end with plaster of paris set on glass. Then the test was placed in the machine, faced surface on lower head of the machine, and the upper head of the machine was set with wet plaster of paris on the upper surface of the test. All of this consumed a great deal of time, and it was learned that by putting a little initial compression on the test as soon as the plaster was applied, a practically complete head, could be obtained and the time of settimg of the plaster could also be lessened.

At the time the tests were first agreed upon, compression due to the arch action was assumed to be the most important stress. But as the investigation of bulkhead sites progressed and more study was given to the problem, it developed that punching shear was as important as compression. Therefore tests were made for punching shear.

The bulkheads were laterally restrained on all sides. Given sufficient head against them, the exposed areas of the bulkheads would be forced out of the concrete masses as corks are pushed out of popguns. Such a stress of pure punching shear is unusual in engineering structures.

An attempt was made to reproduce in miniature, the actual conditions in the experiments on punching shear. The flat discs of gunite, used for punching shear tests, were molded in two, three and four inch lengths of ten and twelve inch pipes. A few of these pipe ring molds were finished on the inside with a slight taper, so that the "cake" could be removed from the mold after the gunite had set. The removal when made, was twenty-four hours after pouring.

In placing gunite in the cylinder mold, it was first attempted to shoot it in directly from the nozzle of the gun. This resulted in a very poor cylinder, and that method of procedure was abandoned. The next attempt was to shoot it into a box or bucket; but this did not give uniform gunite, as there was no chance to adjust the nozzle and control and average the mixture. Finally the gunite was shoveled out of the bulkhead, either in front of or behind the regular gunner. While the amount of water is controlled at the nozzle the supply of sand and aggregate is not uniform to the extent that a certain setting of the water valve will produce a certain result. The gunner must manipulate his valve to suit conditions, which he judges by the feel and appearance of the freshly deposited gunite.

In the final method of sampling, batches about three inches deep were deposited in the cylinder molds; and as each batch was deposited it was tamped down with a wooden mine wedge, with the cylinder standing on a fairly flat timber or piece of lagging. In the rings the base was the same, and the gunite was patted lightly into place. All were screeded off on top. Attempts to cast cylinders on glass plates and on parafined paper on glass showed no improvement in testing over the cruder method. Cylinders were stripped after twenty-four to forty-eight hours, and the cylinders were allowed to stand in the mine without wetting or protection of any kind. Only a few of the rings were removed from cakes. The air of mines was at a temperature ranging from 70° F. to 90° F. and the air was about 80% saturated. The specimens received only the benefit of the moist warm air.

At the end of seven days the specimens were removed from the mines and taken as soon as possible to the testing floor.

The appliance used with the testing machine for punching shear was as follows: Two steel plates, the lower $\frac{3}{4}$ inch thick and the upper $\frac{1}{2}$ inch thick, had holes of equal size bored through their centers. For the set of two plates cylindrical punch of steel was provided, one sixteenth inch less in diameter than the bored holes. The lower plate had four studs in it which passed through four holes in the upper plate, so arranged that one bored hole was directly over the other.

The test specimen was placed on a fresh bed of plaster of paris on the lower plate, and the plate and specimen were set into the machine. The upper plate was then placed over, but not touching, the specimen. The steel cylinder was then passed through the upper plate and seated on a pat of fresh plaster; and then the head of the machine was brought down to bear against the upper end of the cylinder.

Three steel cylindrical punches of $1\frac{1}{2}$, $3\frac{1}{2}$, and $5\frac{1}{2}$ inches in diameter with corresponding sets of plates were made and used in the tests.

For straight punching shear the cylinder or punch and the two plate holes were all of the same diameter. To simulate some of the conditions where a smaller exposed face had a larger periphery on the face of the bulkhead, a larger diameter lower hole was used, with a smaller diameter upper hole, and the punch for the upper hole. The use of the upper plate was solely as a guide for the punch, except in one or two trials, where the two plates were clamped tightly together, for restraint, on cakes from which the steel ring had been removed.

As the tests were run at approximately seven days of age, the twenty-eight day strength was computed from the formula

$$S_{28} = S_7 + 30\sqrt{S_7}$$ taken from "Design and Control of Concrete Mixtures" published by the Portland Cement Association.

Typical tests of the sand used are given in TABLE ONE.

Results of compression tests on cylinders are given in TABLE TWO.

Results of straight punching shear are given in TABLE THREE.

Results of conical punching shear are given in TABLE FOUR.

Plate III is a curve

OBSERVATIONS.

A study of the tables suggests the following conclusions.

First, there was not a sufficient number of tests under the different conditions to form anything more than a guide for further study; but the results so group themselves that they point to definite conclusions, although the exact percentages and strengths may be modified by the results of further tests.

Second, for working conditions in the Butte Mines careful supervision will produce gunite of 1:3 proportions, with an ultimate compressive strength of 2800 pounds per square inch in seven days, 4500 pounds per square inch in twenty-eight days.

Third, for 1:4 gunite the corresponding figures are 2300 and 3700.

Fourth, direct cylindrical punching shear is over 50% of compressive strength where gunite is restrained laterally and over 25% where not restrained.

Fifth, for conical punching shear the percentage of the punching shear is a function of the angle between the axis of the cone and the generating line of the surface of the shear cone. Where there is restraint around the periphery of the concrete, an empirical equation which approximately fits the results obtained, is as follows:

Percentage of compressive strength equals

$$55 - 281 \times (\tan \text{angle})^{\frac{5}{2}}.$$

Sixth, a larger series of tests may show that to reproduce field and not laboratory conditions, these practices in taking samples give sufficient accuracy. They are close enough to check conditions such as exist in Butte Mines. A few samples taken according to the methods of the American society for Testing Materials gave disappointing results.

Seventh, fractures of gunite show many small pockets. "Bumping" the freshly poured cylinders brought much air to the surface but did not produce cylinders without voids, and seemed to cause a stratification in the cylinders. The voids in that case were possibly made by entrained water.

Under the actual conditions the compression used in the later designs, i. e., 1500 pounds per square inch for 1:3 gunite, and 1000 pounds per square inch for 1:4 gunite, appear a justifiable limit; but a punching shear 50% greater than the 230 pounds for 1:3 mix and 150 for 1:4 mix, which we used, may safely be used in good rock with only cylindrical punching shear. Where conical punching shear exists, but the rock is sound and tight, and the cone angle is not greater than 20°, the stresses used are the limit. Where the cone angle is greater than 20° the design should also be considered for tension.

Finally it seems that, judging by the variety of conditions encountered and handled in Project Number Four, a suitable set of crosssections can be developed, similar to the ones described herewith, which can be used for all conditions arising in such a project and that such a set would have a value far beyond the cost of their production.

TABLE ONE

SAND	"A"		"B"	
	1 %	2 %	1 %	2 %
Retained on 3/8" screen	.67	2.34	2.76	1.91
#4 screen	9.17	12.66	18.06	11.94
#16 screen	42.38	49.97	51.78	48.40
#50 screen	34.97	27.93	21.78	28.97
#100 screen	9.44	5.32	4.52	7.12
Pass #100	3.37	1.78	1.10	1.66

A.S.T.M.
C-40-27

Organic Impurities All less than 250 Ppm.

A.S.T.M.
D-136-28
Decantation Test

	"A"	"B"
Silt, clay, and loam	2.64	1.53

TABLE TWO.

NO.	MIX	PRESSURE ON TOP	BEAM AT FAILURE	7-DAY STRENGTH LB./SQ. IN.	COMPUTED 28-DAY STRENGTH LB./SQ. IN.
1.	1:3	19,000	61,700	2180	3580
2.	"	6,000	88,500	3130	4800
3.	"	2,500	88,150	3115	4790
4.	"	16,000	66,250	2350	3500
5.	"	6,500	87,600	3100	4770
6.	"	9,2000	81,600	2890	4500
7.	"	10,500	71,700	2540	4050
8.	"	3,600	79,900	2820	4410
9.	"	7,000	94,450	3340	5070
10.	"	18,500	67,300	2380	3840
11.	1:4	6,800	69,350	2450	3935
12.	"	7,300	53250	1880	3180
13.	"	13,000	67,630	2340	3790
14.	"	7,500	61,790	2180	3580
15.	"	7,100	74,720	2640	4180
16.	"	2,500	61,350	2170	3570
17.	1:3	7,000	92,400	3260	4970
18.	"	4,000	83,010	2930	4550
19.	"	12.000	79,460	2810	4400
20.	1:3	3,000	45,000	1590	2790
21.	"	12,000	80,750	2850	4450
22.	"	6,100	74,200	2630	4170
23.	"	15,700	86,700	3070	4730
24.	"	11,750	90,700	3210	4910
25.	"	16,400	40,500	1430	2560
26.	"	4,300	48,4000	1710	2950
Average #1-10, and #17,18,19				2830	4420
Average #11-16				2280	3710

TABLE THREE

NO.	MIX	THICKNESS	PUNCH	DIE	SET	FAILURE	UNIT STRESS	% OF COMPRESSION	REMARKS
1	1:3	2-7/32"	3½"	3½"	xx	43,750	1790	63	Top Plate Bolted Down
2	"	2-1/8"	"	"	4,700	17,100	730	25	NO BAND.
3	"	3-1/16"	"	"	5,500	99,750	2960	104	NO FAILURE.
4	"	2-3/16"	3½"	3½"	10,000	46,600	1940	68.5	
5	"	2-9/64"	"	"	12,000	27,400	1170	41	"A" Sand. NO BAND.
6	"	2-3/16"	5½"	5½"	7,100	71,500	1910	67.5	
7	"	2-1/4"	"	"	5,500	56,000	1435	50.5	Slight taper in cake
8	"	3-1/16"	"	"	11,600	90,700	1700	60	
9	1:4	3-15/16"	3½"	3½"	8,350	66,310	1535	67	From wet sample
10	Same	Specimen	5½"	5½"	3,550	99500	1465	64	
11	1:4	2-1/4"	5½"	5½"	5,400	41,250	1055	46	
12	"	2-1/8"	3½"	3½"	1,300	13,610	583	25.5	NO Band. Top Plate Bolted Down.
13	1:4	3"	5½"	5½"	1,870	71,650	1380	60.5	
14	Same	Specimen	3½"	3½"	xxx	60,330	1830	80	15 days
15	#11	Specimen	"	"	xxx	22,560	1000	44	15 days
16	1:4	3-15/16"	5½"	5½"	3,900	68,800	1010	44	Slight taper in cake
17	Same	Specimen	3½"	3½"	xxx	51,040	1180	51.5	
18	1:4	3"	5½"	5½"		71,100	1370	60	
19	Same	Specimen	3½"	3½"		49,800	1510	66	
20	1:4	2-1/8"	5½"	5½"	3,100	21,270	578	39.5	NO Band. NO Pl.
21	"	2-3/16"	"	"	2,800	28,200	745	30.5	
22	Same	Specimen	3½"	3½"	xxx	26,650	1110	48.5	14 days
23	1:4	2-1/16"	"	"	9,800	25,130	1110	48.5	From wet sample
24	Same	Specimen	5½"	5½"	1,750	42,800	1200	52.5	14 days
25	1:4	2-1/8"	3½"	3½"	2,150	30,790	1315	57.5	
26	Same	Specimen	5½"	5½"	3,900	49,800	1350	59	14 days
27	1:4	3-7/32"	"	"	15,250	56,170	1005	62	Low strength mix
28	"	2-1/8"	3½"	3½"	2,000	11,270	480	29.5	Do. NOBand.

Note: At seven days these specimens were removed to a dry room of about 60 degrees F. No more moisture reached them. The average increase in strenght after seven days was about 2% per day.

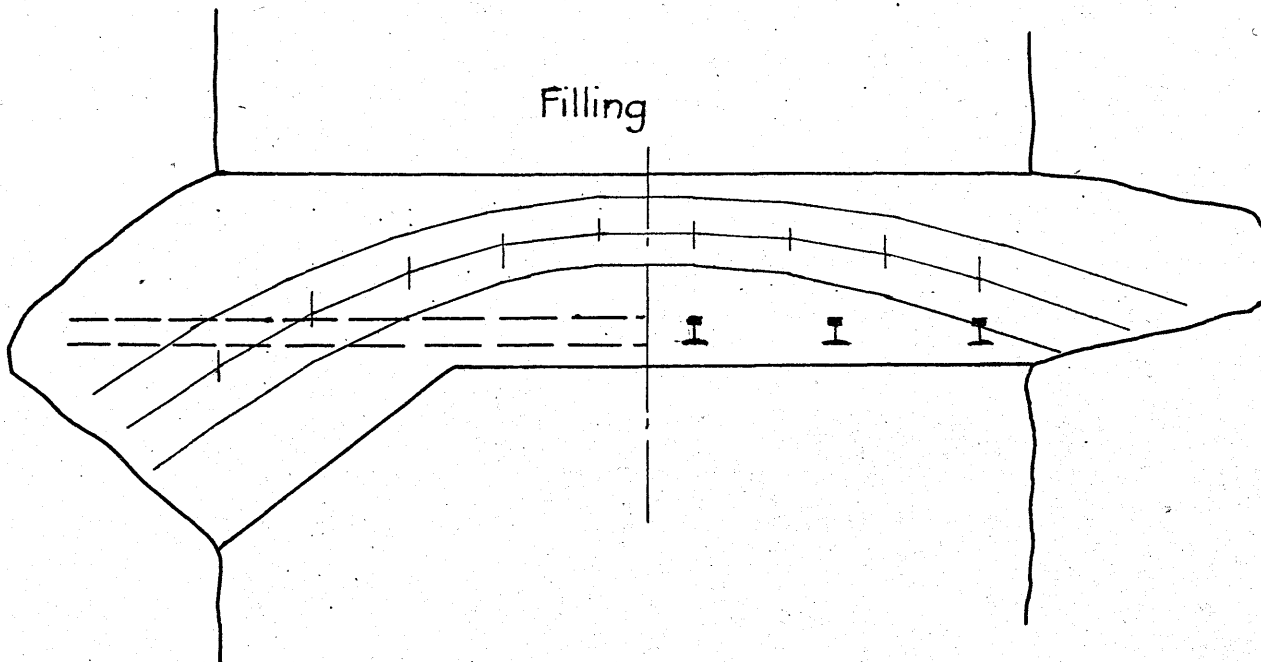
TABLE FOUR

NO.	MIX	THICKNESS	PUNCH	DIE	CONE AREA SQ.IN.	COMPUTED ANGLE OF SIDE	FAILURE POUNDS	UNIT STRESS	% OF COMPRESSION	REMARKS
1	1:3	3-1/16"	3½"	5½"	45.6	18°05'	52,000	1140	40	No3, Table 3.
2	"	4-1/8"	"	"	60.	13°37'	100,200	1670	59	NO Failure
3	Same	Specimen	1-29/32"	5½"	52,5	23°32'	45,800	870	31	Radial cracks in bottom.
4	1:3	4-3/16"	"	5½"	52.5	23°13'	37,600	715	25	
5	"	2"	3½"	"	26.2	26°	7,000	268	9.5	NO BAND Tension=820# or 0.29 compression
6	1:3	2-3/16"	3½"	5½"	34.	24°34'	9,300	338	12	NO BAND
7	"	4-1/8"	1-29/32"	5½"	35.7	11°46'	59,960	1670	59	14 days
8	1;3	3-3/32"	3½"	5½"	46.	17°55'	60,000	1300	46	14 days
9	1:4	3-1/8"	1-29/32"	3½"	27.2	15°23"	15,980	587	39	NO BAND. Top plate bolted down.
10	1:4	3-15/16"	3½"	5½"	57.5	14°15"	36,100	625	36.5	From wet sample.
11	1:4	2"	1-29/32"	5½"	x	xx	2,040			Failed by fracture. NO BAND. Tension 385# or 0.24 compression.

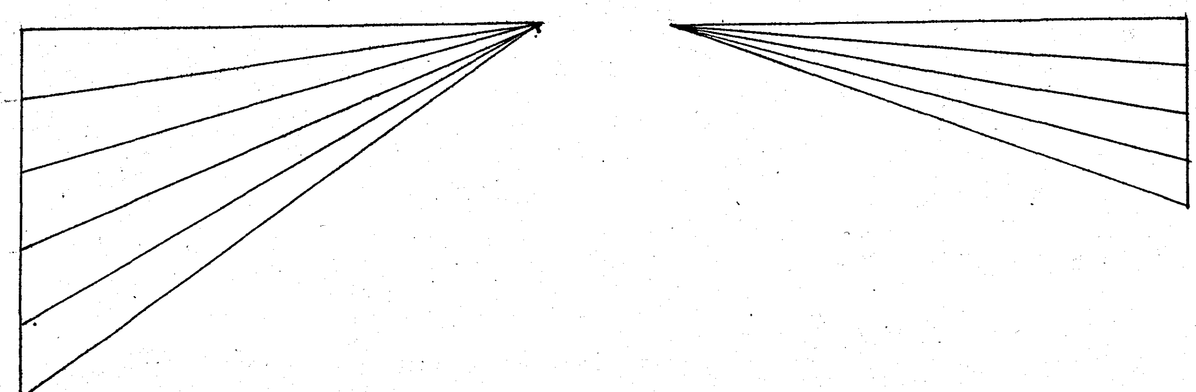
PHOTOGRAPH OF APPARATUS AND SPECIMENS.

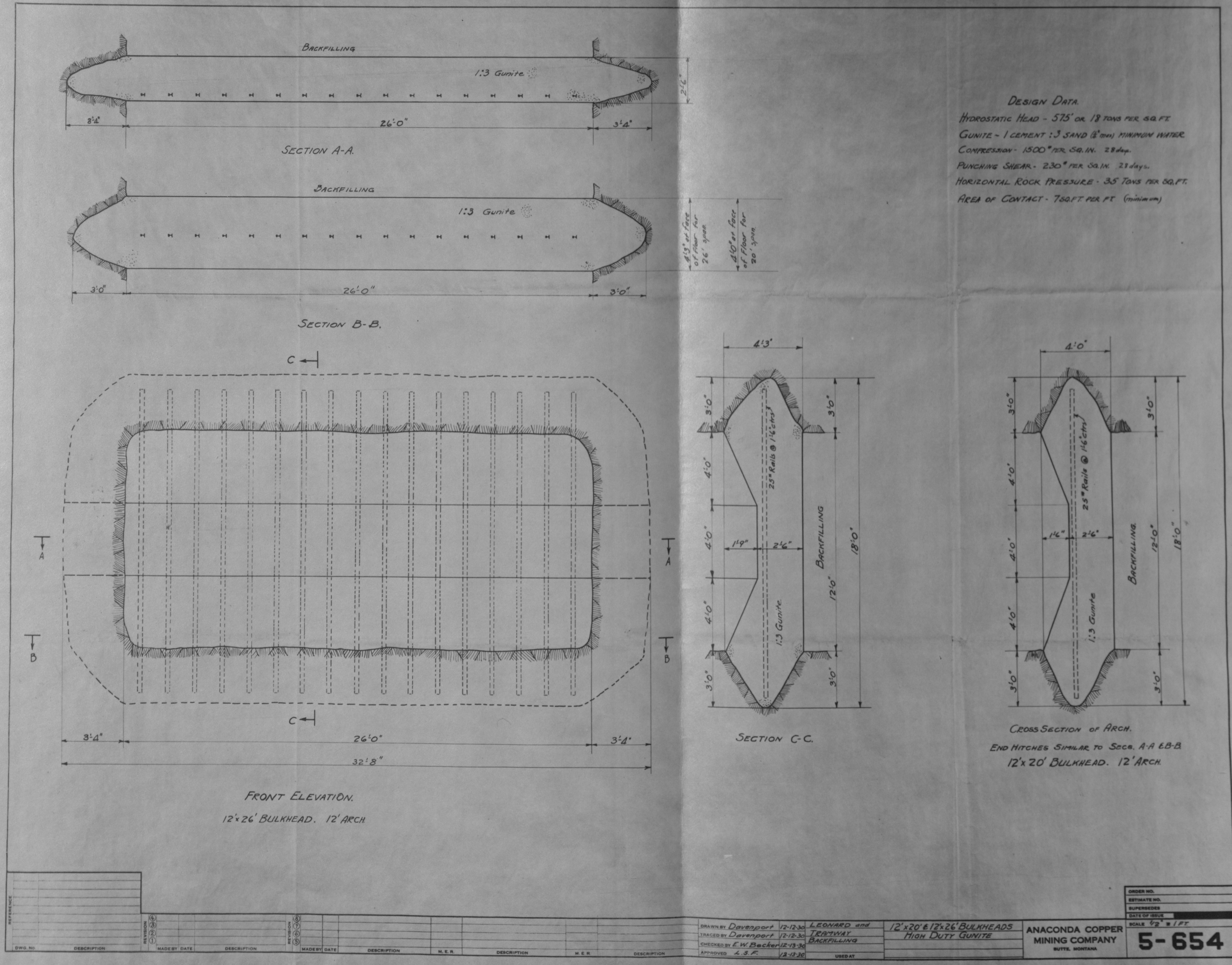
In the background is the Olsen machine and to the right , a tested cylinder, showing typical fracture with slope of fractured surfaces making angles of from 6° to 26° with direction of pressure. In front are three cakes with the truncated cores punched from the respective cakes. The rule against the center cake is twelve inches in length. To the right of the cakes is the base of one of the punching devices, showing bored hole and studs. This plate formed the base for the middle test - a 1½" punch and the 3½" plate as shown. The type of conical plug punched out is clearly shown on all three specimens.

PLATE I



HALF HORIZONTAL SECTION ~ HALF VERTICAL SECTION.





Backfilling
1:3 Gunite
2'-6"
3'-4"
26'-0"
3'-4"
Section A-A.
Backfilling
1:3 Gunite
4'-3" at face of floor for 26' span
4'-0" at face of floor for 20' span
3'-0"
26'-0"
3'-0"
Section B-B.
Design Data.
Hydrostatic Head - 575' or 18 tons per sq. ft.
Gunite - 1 cement : 3 sand (¼" max) minimum water
Compression - 1500# per sq. in. 28 days.
Punching Shear - 230# per sq. in. 28 days.
Horizontal Rock Pressure - 35 tons per sq. ft.
Area of Contact - 7 sq. ft. per ft. (minimum)
C
A
B
3'-4"
26'-0"
3'-4"
32'-8"
Front Elevation.
12'x26' Bulkhead. 12' Arch.
4'-3"
3'-0"
4'-0"
4'-0"
4'-0"
3'-0"
1'-9"
2'-6"
25# Rails @ 1'-6" ctrs.
1:3 Gunite
Backfilling
12'-0"
18'-0"
Section C-C.
4'-0"
1'-6"
2'-6"
25# Rails @ 1'-6" ctrs.
1:3 Gunite
Backfilling
12'-0"
18'-0"
Cross Section of Arch.
End Hitches Similar to Secs. A-A & B-B.
12'x20' Bulkhead. 12' Arch.
Drawn by Davenport 12-12-30
Traced by Davenport 12-12-30
Checked by E. W. Becker 12-13-30
Approved L. S. F. 12-13-30
Leonard and Tramway Backfilling
Used at
12'x20' & 12'x26' Bulkheads
High Duty Gunite
Anaconda Copper Mining Company
Butte, Montana
Order No.
Estimate No.
Supersedes
Date of Issue
Scale ½" = 1 ft.
5-654

PLATE II

MECHANICAL ENGINEERING DEPARTMENT

ANACONDA COPPER MINING CO. Butte, Montana, Jan. 5, 1931

Sketch of CURVE FOR ANGULAR PUNCHING SHEAR

Designed for LATERAL RESTRAINT. Drawn by DAVENPORT Sketch No. 5-661

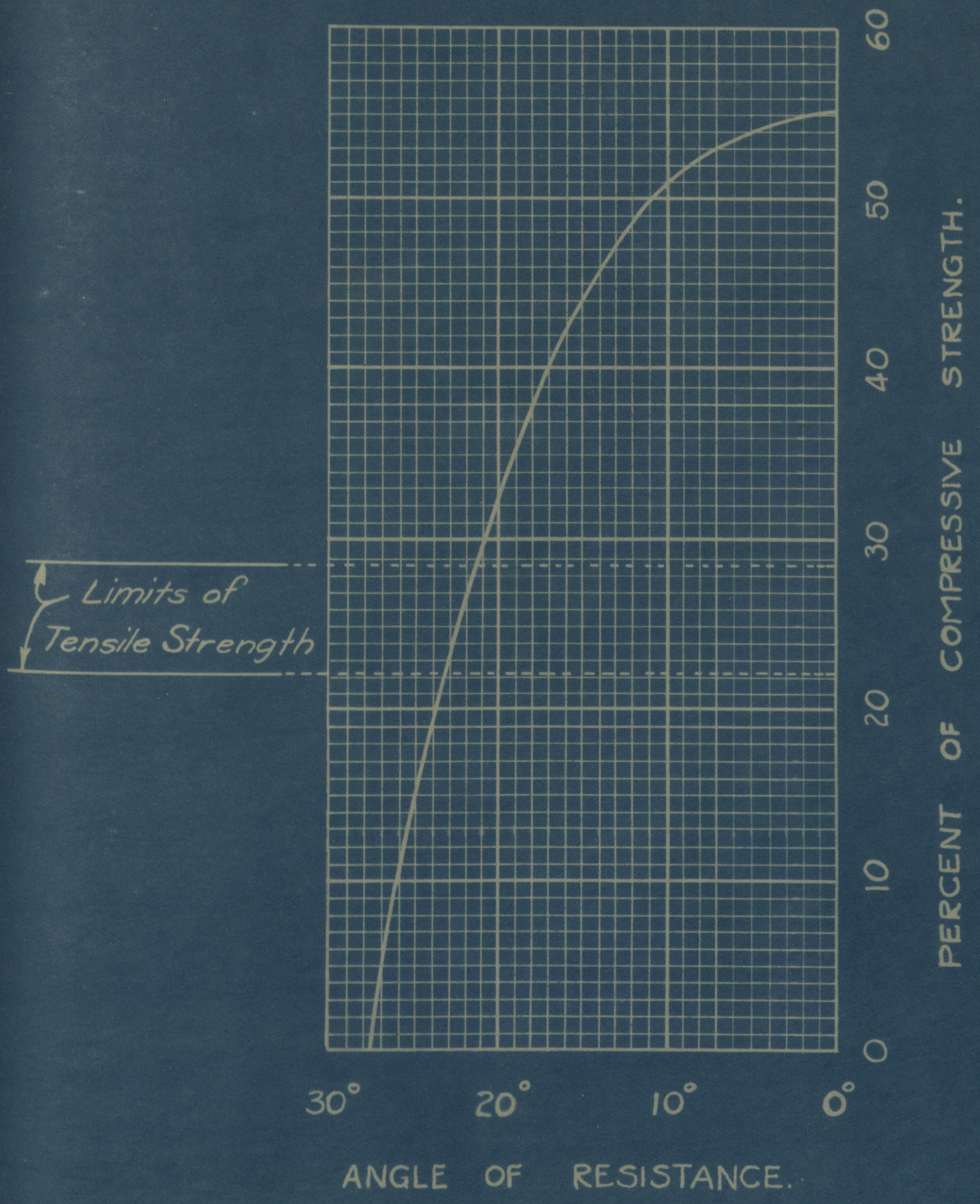


PLATE III.