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Sinking and equipping inclined shafts of more than 60 degree dip

Wilford Stillman Wright

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SINKING AND EQUIPPING INCLINED SHAFTS OF MORE THAN 60 DEGREE DIP

by

Wilford Stillman Wright

A THESIS submitted to the faculty of the SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI in partial fulfillment of the work required for the DEGREE OF ENGINEER OF MINES Rolla, Mo. 1938

Approved by [Signature]
Professor of Mining.
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THE INCLINED SHAFT.

MERITS and DEMERITS.

The advisability of putting down an inclined shaft in preference to the vertical type should be carefully considered before a definite choice is made. One, of course, presupposes the existence of a dipping ore body that is to be prospected or developed for subsequent mining. Unless a vein has been previously developed there is no certainty that it maintains the same degree of pitch for any great distance below surface. If straight, the proposed inclined shaft may depart considerably from the downward course of the vein with the result, that, at least some of the anticipated advantages of the shaft have not been realized. On the other hand a shaft which changes its dip is apt to prove either very costly in construction or inefficient for hoisting purposes.

The nature of the vein and its walls as regards hardness and strength is a major item of consideration, because any disturbance due to subsidence or caving would be disastrous when mining operations are begun.
The hanging wall of an inclined shaft is, of course, more difficult to support in weak ground than the walls of a vertical shaft. Where vein material is soft and apt to cave, and the walls are strong, inclined shafts are usually put down in the footwall side on the vein. Shafts so placed have the advantage over vertical shafts of being closer to loading chutes thus permitting shorter hauls. If a shaft can be sunk in the ore, returns from the ore extracted will at least partially pay for the work as well as render valuable information as to its grade and composition. Frequently the vein material is softer than the walls, yet narrow enough to be within the short dimension of the shaft, thus permitting easier drilling and better progress in sinking.

Experience has shown that, in general, the maintenance of inclined shafts materially exceeds that of vertical shafts. The reason for this may be that the inclined shafts are more often put down in soft rock and pass through faulted zones, whereas, the vertical shafts are usually in the firm wall rock. However, in any well constructed shaft, where the walls are reasonably firm, shaft maintenance is a relatively small item of the mining expense and the lower first cost of the inclined shaft might easily offset the extra cost of shaft repair. The possible
conditions which warrant the selection of the inclined shaft are, therefore; the opportunity of marketing the material extracted from the shaft, soft vein material and firm walls permitting faster sinking, short crosscuts or no crosscuts at all from shaft to vein, and shorter haul to the shaft.

Inclined shafts of less than 60 degree dip are less common than those exceeding 60 degree dip, and often present special problems in sinking and equipping. They are apt to differ particularly in the timbering, laying of the rails, the type of skips employed and manner of loading and dumping. This discussion will, therefore, be confined to shafts having an inclination greater than 60 degrees to the horizontal.

LOCATION.

The location of the shaft is an important consideration from the standpoint of drainage, topography, position of surface equipment, waste disposal and transportation. The placing of a shaft in a gulch or below a considerable water shed is to be avoided since there is a chance of flooding the mine and endangering the lives of workmen. Seepage through soil and loose rocks is
certain to be less in a more elevated position. An attempt should be made to avoid faulted zones, water courses and weak strata in the path of the proposed shaft. An endless amount of trouble can be encountered due to an excess of water or bad ground, or both, because the cropping and surrounding rock was not studied sufficiently from a geological standpoint. Diamond drill tests are frequently made and even exploratory shafts are sunk as a measure of examining conditions below the surface. Time and labor spent in stripping covering and making trenches at the surface before investments in equipment are made is a wise procedure. This permits a geological study of the vein and a systematic sampling.

Due consideration should be given the location of a shaft with respect to the mill or mill site. It is desirable to have the shaft at a place which will afford transportation of the ore by gravity to the crushing plant. Mill tailings and mine waste must be disposed of and ample room and convenient location should be allowed for both.
SIZE AND SHAPE OF SHAFT.

Most inclined shafts are rectangular in cross section and usually consist of two, three, four or more compartments arranged side by side on the line of the strike. Inclined shafts of three compartments are the most common, consisting of two hoisting compartments and one pipe and ladder compartment. The three compartment shafts are best suited for moderate production, because from 20 to 40% of the operating time is spent in handling men and supplies. However, if the two hoisting compartments are of size sufficient to accommodate skips of at least five ton capacity each, and fast winding hoists are provided, it is not out of the ordinary to hoist 1500 tons per day from an inclined depth of 1000 feet. The size of the compartments for hoisting depend upon the horizontal area of the skip or bucket, thickness of stringers and rails or skids, and clearance. This usually ranges from a 4' x 5' cross section for one ton skips to 5½' x 7' for ten ton skips. The compartment for ladders and piping should never be less than three feet in length, and if considerable water is apt to be encountered, a compartment of 5' or 6' in
length is advisable. The cross sectional dimensions inside of timbers are therefore determined by the size of the skips to be used in hoisting ore, and the number and size of pipes, conduits, etc., that will be installed in the ladder and pipe compartment.

The size of timbers required depends upon the load they are to bear. This is usually a rather indefinite factor in considering a new shaft, hence it is well to delay the installation of permanent timbers until some information concerning the tendency of the ground to stand or cave has been gained. When the size of timbers has been decided upon the full size of shaft outside of timbers is generally computed as the sum of compartments in the clear, plus the width of timbers, plus 4 inches outside of timbers in all sides.

EQUIPMENT.

Perhaps no branch of mining has received more careful attention than shaft sinking. The shaft is necessarily expensive to put down and equip, and upon completion it is the heart of the mine from an operating standpoint. For these reasons the best and most efficient equipment should be selected. In the long run good machinery, even

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at a higher price, will be an economy because the operation will be reasonably free from mechanical troubles. Furthermore dependable machinery is a good insurance against accidents. The kind and amount of equipment necessary depends largely upon the size and depth of the proposed shaft as well as the nature of the rock and amount of water encountered.

Shafts are put down under a variety of circumstances; some at properties which are already in the stage of production and both power and compressed air can be readily transmitted to the site of a new shaft; some in districts where central power plants exist and branch lines can be erected; and some in more isolated regions where power must be produced at the place of operation. The power question is greatly simplified in the first two instances. At the producing mine a power line and step down transformers are installed. The air is piped through not less than a three inch line to a receiver. In the second instance a motor driven air compressor must be installed.

In the more isolated regions all equipment including some type of engine must be purchased,
delivered to and installed at the place of operation. In the purchase of an engine the fuel consumption per horsepower and cost of the fuel are essential items of consideration. The Deisel type is perhaps the best suited for such work. When operated at full load this type will consume about .45 lbs. of oil per brake horsepower. Under variable load such as hoisting the consumption would no doubt be greater but by no means excessive. The simplest arrangement for power is an engine driven air compressor of sufficient size to provide air for both hoisting and drilling. The electric hoist, however, meets greater favor than the compressed air hoist because they are easier to control, have better mechanical efficiency and the electric motors have uniform torque. In the electric hoist arrangement there is the added cost of providing a generator either direct connected or belted to the engine, and the cost of motors to drive the separate units. The latter arrangement, while more expensive in first cost and installation, lends flexibility to the operation, in that small machines such as grinding wheels, blowers, etc., may be motor driven.
It is very important that the proper size and kind of engine, hoist and compressor be selected. The operator knowing the size of shaft he intends to put down will also know about how many rock drills will be operating at one time and he can perhaps make some kind of estimate of the amount of water to be pumped. He will know the approximate size of skip or bucket he intends to use and can calculate the necessary horsepower required for hoisting. If, for instance, he plans a shaft 17' x 9' outside dimensions in ground of medium hardness, four 50# jackhammers in use at one time should be sufficient. Of these it is doubtful if more than three would be drilling continuously. At a pressure of 90 lbs. per sq. inch the three machines will use about 285 cu. ft. of free air per minute. About 100 cu.ft. per minute should be allowed for the steel sharpener. Assuming the flow of water to be not more than 40 gal. per minute, a small compressed air driven sinker pump will lift this amount a height of 400 feet with an air consumption of 115 cu. ft. per minute.

The maximum demand for air would therefore be about 500 cu. ft. per minute. Allowing for losses due
to leakage and friction it would be safe to provide for a delivery of 520 cu. ft. at the compressor. At an altitude of 7000 ft., for instance, an increase of 26.7% in volume is necessary to give an efficiency equivalent to sea level, or approximately 660 cu. ft. in this case. To compress adiabatically 660 cu. ft. of free air at 7000 ft. altitude to 100 pounds pressure by two stage compression, allowing 15% for friction, requires about 100 horsepower. A single drum electric hoist, driven by a 25 hp. motor is sufficient for sinking a shaft of this size. About 15 hp. should be allowed for small equipment such as blowers, grinding wheels, etc., making the total of 140 hp. required. Allowing for altitude and electrical losses air engine with 175 hp. sea level rating should suffice.

In addition to the equipment mentioned above a forge, steel sharpener, fan, headframe, bin, ore buckets or skip, cars, drill steel, hose and a repair shop must be provided. For sinking to a depth of 400 or 500 feet a simple wooden headframe such as that shown in figure 1 is suitable. This headframe should be designed in such a way that it will not conflict with the
Fig. 1. Headframe and Ore Bin for Sinking.
erection of a permanent structure while the shaft sinking is still in progress. It must also be independent of any shaft timbers.

In the matter of hoisting the use of buckets is a simple and practical method for shallow depths. However, inasmuch as the shaft is apt to be equipped for skip hoisting eventually, particularly if the mine is to produce in excess of 100 tons per day, the skip and track installation may as well proceed with the sinking and timbering, thus avoiding double labor and extra material.

Buckets are applicable to small prospects where first costs are to be kept to a minimum. In such case it is common practice to use a half ton steel bucket with the bail fastened to ears at the rim and lugs attached below the center of gravity. This bucket can be dumped automatically by the method as shown in figures 2 to 6 inclusive. The bucket is pulled up or lowered on skids set at such an angle as to permit smooth movement. The lugs do not rest on the skids either ascending or descending until the point of dumping is reached, where the skids are channeled out on the inside. At this place the bucket sinks low enough to allow the lugs to rest on the
Various Positions of the Bucket in Dumping.
skids. Just above this the lugs drop in notches. The bucket is lowered to an overturning position and dumped, then pulled back up far enough to pass above the latches on the inside of the skids. When the bucket is lowered the lugs are prevented from entering the notches by the latches which overturn to a position in which the flared ends stop against the skids. The bucket again descends on down the shaft. The skids may be made of 6" x 6" or 8" x 8" timbers sawed diagonally or at an angle best suited to conform to the shape of the bucket.

In sinking the larger and deeper inclined shafts the skip is more generally used. In order to hasten the removal of muck two compartments are frequently equipped with a skip in each, and two single drum hoists are used. Such an arrangement will more than pay for the cost of the extra skip and hoist in saving of labor, if the shaft is to be deep. For sinking purposes it is advantageous to have the skip as shallow as possible for a given capacity, in order that the muck does not have to be lifted so high as to place unnecessary strain on the muckers. The back or side away from the wheels should be cut away at the top.
There are two general types of skips for inclined tracks, the more common type being those having the wheels on axles under the body, and the underslung type in which the wheels are on trunnions set in heavy plates bolted to the sides. In the latter type there is very little chance for derailment if the body of the skip extends below the rail heads. However, the former type performs satisfactorily under favorable conditions, and costs less than the other type. The skip is made of boiler plate and should be reinforced on the bottom and rear end. For dips exceeding 60 degree the bail should be attached slightly below the horizontal center line of the body and at a point about one-third of the length of the skip forward of the rear end. The front wheels are of standard tread while the rear wheels have treads of 5" or 6" width to suit the dumping arrangement. The skips are dumped by turning the main track to a horizontal position on which the front wheels follow, while the rear wheels continue on auxiliary tracks of the shaft inclination but set at wider gauge. (See figure 7).

The drilling equipment which is needed depends
Fig. 7. The Skip and Manner of Dumping.
somewhat on the hardness of the ground and whether the shaft will be dry for a considerable depth or wet throughout. In medium or soft ground, jackhammers of approximately 50 lbs. weight using 7/8 inch hexagon steel are found suitable. If the shaft is dry the drill should be of the wet type and the steel hollow. In hard ground a 90 pound drifter without the shell and equipped with handles, special backhead, and 1 inch hexagon chuck for steel of that size will permit of much faster drilling. The hardness of the ground will also control the amount of steel necessary and the gauge change of the bits. An average gauge change is 1/8 inch with changes of steel 1 ½ ft. in length. Using four lengths to the set namely; 2, 3 ½, 5 and 6 ¾ ft. with a starting gauge of 2 1/8 in. a hole can be bottomed at 6 ft. with 1 ¾ in. gauge finisher. This allows for the use of 1 1/8 in. powder.

The air line should not be smaller than 2 inches in diameter and never advanced closer than 50 ft. of the bottom of the shaft. A very convenient method of transporting air to the drills is by the use of a
manifold (see figure 14) attached to a 35 ft. length of hose having the same inside diameter as the main air line to which it is connected. A number of 50' lengths of \( \frac{1}{4} \) inch air hose convey the air from the drills. Each line from the manifold is equipped with a line oiler and plug valve. A smaller manifold for water should be provided. The manifold can be suspended from the bottom of the skip and lowered into, or raised out of the shaft. The \( \frac{1}{4} \) inch air hoses can be coiled inside the skip and the large air hose is pulled up and tied to the shaft timbers when the round is blasted. This arrangement decreases the chance of fittings and connections being lost, a condition which so frequently proves a time waster in many mines.

Pumping is usually done by air driven Cameron pumps, the smaller size being preferred because they are easier to handle. Two No.7 or No.8 pumps are more practical than one No.10 if the pumping requirement does not exceed 100 gal. per minute. Heavy rubber hose is used in the discharge line between the pump and water column to prevent injury to the pipe connections, due to vibration of the pumps. These
pumps can be used to relay the water but for deep shaft work it is more practical to cut stations at certain intervals and install electrically driven multistage centrifugal pumps or plunger pumps. It is well to provide at the pumping station a series of tanks connected together near the top in order to settle out as much of the sand and grit as possible. There are centrifugal pumps on the market which employ the use of rubber impellers and rubber shell liners, thus greatly reducing the maintenance cost due to abrasion.

The quick removal of powder smoke, and gases from a shaft is not an easy matter. While fans or blowers are usually installed, the compressed air is introduced one way or another in most cases. Suction fans call for the use of metal tubing which ordinarily does not withstand the destructive effect of concussion due to blasting. Electric blasting, which is generally used in shaft sinking, is particularly disastrous to pipe rolled from light sheets. For blowing air into the shaft, flexible canvas or jute tubing, which can be lowered from the collar of the shaft by a windlass, is more practical. The end of the tubing may be
attached to the bail of the bucket or skip and the two lowered at the same rate to prevent the tubing from hanging on the shaft timbers. A spray arrangement in which a jet of compressed air meets a jet of water under pressure is very effective, because of the fact that, a number of poisonous gases from exploded or burned powder are partially soluble in water. After the blast the spray is turned on for about five minutes, producing a dense fog and settling the smoke and dust.

For safe and efficient work some lighting arrangement should be provided. The circuit should be a two-wire lead covered cable of \#14 wire ending in a socket about 75 feet from the bottom into which an extension cable from the light is plugged. The permanent cable is fastened to the shaft timbers and the extension with lamp and reflector is removed before each blast. The lamp should be 300 watt capacity provided with metallic reflector and hood.

If the steel sharpener is to be solely in conjunction with shaft sinking work one of the smaller sizes, such as the No.34 Ingersoll-Rand or Class C Sullivan Machinery designed for sharpening jackhammer steel, will be adequate. Dollies, dolly springs,
holding dies, guaging blocks, and formers must be supplied according to needs. The shop must be provided with a small furnace for forging and tempering. Oil fed by gravity from a tank at a head of six feet and atomized by compressed air is a commonly used fuel.

No better time saver can be adapted than a good repair shop close to the shaft. This shop should be provided with a work bench, vise, extra rock drill parts, hose fittings and menders, pipe fittings, stock and dies for bolt and pipe threading, chain and rope blocks, timber jack, wrenches, hammers, saws, axes, files and a number of lesser items. As work progresses such a shop becomes indispensable.

**THE COLLAR.**

It is best to start a shaft where solid rock outcrops, but if this is not possible, a pit, of size large enough to permit the building of a solid concrete wall around the proposed shaft, should be dug to bedrock. The inside dimensions of the structure should be great enough to permit the placing of regular shaft sets in perfect alignment with those below. These

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inside dimensions are measured in a plane normal to the dip of the shaft and the inside forms for the foot and hanging wall conform to the proposed dip. The concrete should be set deep enough into the rock to prevent seepage of surface water into the shaft. It should also be set back far enough to furnish a foundation for the headframe. The wall should extend above ground surface at least the thickness of the wall plates, two notches being left in each end wall to provide for the placing of the hanging wall and footwall plates in their proper position. When the wall has sufficiently set, the first two timber sets are placed, the upper set resting horizontally as in a vertical shaft. The wall plates extend beyond the concrete wall, and the footwall plate is beveled at the angle of the shaft where the two stringers are to rest. The framing having been previously done, the end plates are placed and the set is wedged securely into its permanent position. The second set is placed normal to the dip as shown in figure 1.
The heavier items of expense such as labor, power for compressing air, steel sharpening and upkeep of the drill machines combine to make the drilling the most costly part of the operation, in the majority of cases. It is, therefore, imperative that the holes for each round be accurately spaced and pointed to secure the maximum breakage in the proper place. The holes should be loaded with the right amount of powder to obtain efficient breaking. By varying the number of sticks per hole used in the first two or three rounds the correct amount for the kind of ground being broken can be pretty well determined. Experimenting of this kind is costly and should be avoided if any reliable data can be obtained, but, on the other hand, it is apt to effect a considerable saving of powder in sinking a large shaft. The necessity for proper rotation in firing the holes is so obvious that the matter is frequently given little thought, but, if one or two charges in a round are fired out of order the work of an entire shift is apt to be wasted as a result.
To avoid lost time on the part of the drillers all equipment should be looked over between drilling shifts to see that it is in good working condition before being lowered into the shaft. The bottom of the shaft should be thoroughly cleaned of broken material where the drilling is to start and all ladders and piping advanced the necessary distance.

Pipe lines are supported by clamps with long bearing arms resting on stulls or dividers and end plates.

The most typical round for shaft sinking is that making use of the V cut, as shown in figure 8. The round is blasted with instantaneous and delay electric blasting caps in the order indicated in the diagram. It is sometimes customary, where the ground is hard and tight, to shoot only the cut holes and the first line of relief holes with instantaneous caps and shovel out the muck before the remaining holes are loaded. The removal of the muck affords a free face for the remaining relief holes to break to, resulting in a saving of explosives and a cleaner break.
Fig. 8. A Shaft Round with V Cut.

Fig. 9. A Shaft Round with V Cut for Two-Stage Breaking.
In large shafts the cut is sometimes put near one end to provide for breaking out of about half of the round first. This is mucked out, sheets of boiler plate are laid down in the bottom and the other half of the round blasted on top of it. This provides for much faster mucking. The round is shown in figure 9.

Figure 10 shows a round which has been used successfully at various mines in the United States and elsewhere. Four central holes are drilled in a line and spaced about 3 inches apart, center to center. These holes are not loaded but form a channel to which the next two holes break. Holes No. 0 going first, break to the channel forming an open cavity, to which all other holes break in the order shown. It is essential that all holes be parallel and all holes should be the same depth. Advances of eleven feet per round have been made by this method.

Electric detonators should always be used in shaft work. A sufficient number of the various delays required for the customary round should be kept
Fig. 10. A Shaft Round with Channel Cut.
in a dry place away from other explosives. If the shaft is particularly wet water-proof detonators are used.

Only series connections are recommended where blasting machines are used. (See figure 11). In a series connection the electric current should have a volume of 1.5 amperes. Therefore, using Ohm's law, the voltage required for any given series circuit can be found by calculating the resistance of the circuit and multiplying by 1.5.

Manufacturers do not recommend the connection of more than fifty detonators in series. If more than this number are used they should be connected in a parallel-series circuit, and charged from a power circuit. The wiring arrangement for 24 holes is shown in figure 13. As an illustration, suppose we have 60 caps connected in 10 parallel series, 6 caps to the series. The required current is 10 x 1.5 amps, or 15 amps. Assuming the caps have 12 foot wires the resistance of each series is 6 x 1.608 or 9.65 Ohms. Total cap resistance is 9.65 divided by 10 which equals .965 Ohms. No.20 connecting wire, which is the size generally employed.
Fig. 11. Series Connection for Four Rows of Electric Blasting Caps.

Fig. 12. Parallel Connection for Four Rows of E.B.C.

Fig. 13. Parallel-Series Connection for Four Rows of E.B.C.
in shaft work, has a resistance of 10.15 Ohms per 1000 feet. Assuming 150 ft. of this is sufficient the resistance is that of half its length or 75 \times 0.001010 = 0.76\text{ Ohms}. If there are 1000 ft. of No. 14 leading wire its resistance is 2.525\text{ Ohms}. Total resistance of the circuit equals 3.566\text{ Ohms}. The voltage required equals 3.566 \times 15 or 53.5\text{ volts}.

If the leading wires are connected to a power circuit some precaution should be taken against any possibility of current being thrown into the line at any time except when blasting. The best means of preventing such an accident is to keep the switches connecting the two circuits locked open, the blaster keeping the key in his pocket. Another is to keep the fuses locked in a locker separate from the switch.

It is necessary to make some provision for the protection of the shaft timbers when blasting. A mat made of old hoisting cable woven together and suspended from the second to the last set of timbers by a chain or cable is quite serviceable. Short lengths of cable suitable for the area to be protected
can be cut with a torch, the ends having been previously tied with wire to prevent unraveling. The lengths are then laid in a convenient manner for cross weaving. After the mat is formed each cross is tied with small wire to make it secure.

If cable is not available green saplings or sheets of boiler plate may be hung in the shaft. In case the mat or boiler plate is used it is best to provide two of such type that they can be easily and quickly hoisted out of the shaft by fastening them to a ring on the bottom of the skip or bucket.

**MUCKING.**

Shoveling in a shaft bottom is difficult and requires about 50% of the shaft sinking time. The writer knows of no mechanical device to be used in an inclined shaft which will compete with hand shoveling. It is, therefore, imperative that the best muckers be obtained, and that every reasonable provision be made to alleviate their labor and hasten the completion of their task. In shaft bottoms,
Fig. 14. A Drilling Manifold.

Fig. 15. Inverted Extension Rail Clamped to Track Rail.
where the two ends are blasted alternately, mucking is greatly facilitated by laying steel plates to receive the broken rock. If buckets are used for hoisting, an empty bucket should always be ready at the bottom to avoid delay. If the shaft is large and the rock is hoisted in skips, it is economical to provide two hoists and skips for two compartments. In either arrangement provision must be made for lowering the skip or bucket the last twenty feet or so beyond the last timber set.

Track for the skip may be extended very satisfactorily by clamping two inverted rails to the main rails as shown in figure 15. The base of inverted rails should be forged flat at the upper ends so that they do not appreciably obstruct the passage of the skip wheels. The rails should be kept from spreading by means of clamp rods which can be adjusted as needed. The two rails are independent of each other and can be moved upward or downward along the bottom of the shaft.

If skids and bucket are used an inverted ladder with 4" x 4" sides is frequently used. The sides
are spaced so that the ladder can be pulled up just inside the skids when blasting.

**TIMBERING.**

The matter of selecting the kind of timber to be used depends largely upon the strength of the walls and the anticipated useful life of the shaft. Douglas spruce is usually conceded to be the best mine timber for general purposes. If the shaft is wet timbers will last indefinitely, but, if damp, the timbers should be seasoned from two to four months and treated in a bath of creosote and 6% zinc chloride. The preservative is heated from about 90 degrees to 212 degrees F., and allowed to cool approximately 6 hours for maximum penetration.

The size of the shaft, the weight of the ground and the service which the shaft is to render determine the size of the timbers. In small shafts, where the ground is firm, round stulls 8 or 10 inches in diameter, set in hitches in foot and hanging walls and supporting 8" x 8" cross ties or footwall plates, will suffice. The stulls are placed normal to the dip.
of the shaft and tightly wedged. They are dapped if necessary, to allow the cross ties to rest level longitudinally, with the inside faces in perfect alignment, conforming to the dip of the shaft. For light service 6" x 8" stringers are laid end to end parallel to the shaft and bolted to the cross ties for rail support. These stringers are held in position by 6" x 6" spacers and tie rods placed approximately 8 feet apart to prevent movement of rails. The spacers are sawed the proper length to allow for the exact gauge of the track with the rails being exactly centered on the stringers. The rails are next lowered on a timber truck and placed in position for the proper gauge and securely spiked. To prevent slippage the flanges of the rails are notched three or four places on each side for the spikes. Regardless of skip size nothing lighter than 30 lb. rail should be used because it is subjected to considerable jar and might easily become bent.

Azimuth and dip of the shaft are first determined by transit, the telescope and target being offset fixed
distances from stulls and cross ties. After the first two sets of stulls and wall plates have been placed the azimuth and dip can be maintained by means of a chalk line. Tacks are driven in the two wall plates on the center line as established by transit. A chalk line held tightly and just touching these two tacks will, when extended, determine the center line for the next set of stulls and wall plate. To determine dip, a triangular straight edge, with top side horizontal when the bearing edge is at the required inclination, is most serviceable. The bearing edge must span three sets. This straight edge should be held in a line parallel to the center line and as far away from the center line on both sides of the shaft as is convenient, so that no possible twist in shaft will develop.

In heavy ground inclined shafts are timbered similar to vertical shafts, the sets being placed normal to the dip. The hanging wall plates are often of deeper section than the footwall plates to withstand the greater strain. In shafts of greater dip that 75 degrees the studdles are often omitted and the wall plates are allowed to extend beyond the
end plates which are framed with V tenons, as figure 16 indicates. If studdles are used, however, the end plates are framed with square tenons.

The placing of timbers in an inclined shaft is attended with more difficulty than in a vertical shaft because there is always considerable lifting to be done. First a temporary staging must be built for the timber crew to stand upon. Three stulls, resting in hitches and tightly wedged, with 2" inch planks laid across them, serve satisfactorily. It is then necessary to see that the walls will be in the clear of the outside of the set all around. The footwall plate is lowered to the platform, preferably on a timber car. It is placed in position with due regard for alignment with the footwall plates above and it must be perfectly level. The procedure for alignment is similar to that described above except that the line is a given distance away from the edge of the framing for the end plates. A point on the new wall plate measured a like distance from the edge of the framing is placed approximately in line with the string, and then shifted into exact
Fig. 16. Timber Framing for Three Compartment Shaft in Which Posts Are Omitted.
alignment by means of wedges. When the footwall plate has been wedged at both end and made secure the hanging bolts are put in, the posts, if used, set in their respective daps and the bolts screwed up. The hanging wall plate, posts, end plates and dividers are next lowered to the platform. The hanging wall plate is lifted and the posts and end plates are held in position while the hanging bolts are quickly adjusted and screwed tightly. The set is wedged temporarily, aligned in the same manner as the footwall plate and then wedged permanently. Placing of the dividers completes the set.

Lagging is necessary in ground that has a tendency to spall off along the walls. Two inch planks cut in lengths to span two or more sets are nailed in position behind hanging wall and end plates. If lagging is nailed to the footwall plates the work should not be done until after the stringers for the rails have been bolted down.

To avoid disarrangement or even collapse of the structure, bearers, or heavy timbers extending
Fig. 17. Shaft Timbering in Running Ground.
across the ends of the shaft, resting their ends in hitches are introduced at about 50 foot intervals. The ends of the wall plates rest upon the bearers, the end plates being placed in the usual manner.

In swelling ground provision must be made for cutting away ground along the shaft and easing the timbers. Under such conditions the shaft is made large enough to allow a space of 2½ or 3 feet outside the shaft timbers. The main set is placed in the usual manner except that the wall plates do not extend beyond the end plates, and are held away from the wall with timbers, blocks and wedges. The timbers or bridges are placed around the entire set with lagging inserted between the bridge and wall plates. The lagging is driven ahead of excavation into the soft ground and kept pointed outward by means of blocks above the bridges as shown in figure 17. Timbering in bad ground is carried on close to the bottom.

The work of timbering can proceed while drilling is being done, after the staging has been
erected to provide against falling objects in the bottom of the shaft. A trap door should be provided at the collar of the shaft and kept closed except during periods of hoisting. Timber bulkheads should be built in the shaft with openings just large enough for passage of the bucket or skip. These, however, must be at least 75 feet above the bottom to avoid being torn out by concussion of the blast.

Ladderways should be maintained as near the working face as possible without being torn out by blast. Below this point wire rope or wooden extension ladders should be used to reach the bottom.

A good hoisting signal must be maintained. A galvanized guy strand of about 3/16 " diameter and mine gong are serviceable for a depth of 400 or 500 feet. Beyond this electric signalling is advisable. As a matter of safety the bucket or skip should be stopped 15 feet above the bottom until rung down by a workman.
The cutting of stations and ore pockets is usually done in connection with shaft sinking. The shaft is usually sunk to a depth 40 or 50 feet below the point where it is decided to establish a level and an inclined raise is started about 10 feet above bottom on not less than a 50 degree slope on the hanging wall side. As soon as a pocket of ample size to accommodate production from the level has been stoped out around the raise, strong chutes are built to provide for the loading of muck directly into the skip. The type of chute depends upon the amount and size of rock to be handled. For coarse material steel plates, sliding vertically in guides bolted to posts, and operated by direct acting air cylinders, are fairly dependable. For small tonnage and moderately fine ore hand operated arc gates are frequently used. Gates must be provided for both the storage pocket and the measuring pocket, the latter being, if possible, just large enough to hold one skip load of ore. Space must be allowed on
Fig 18. Shaft Station and Loading Pocket.
either side of the chutes for convenience of the chute operator.

The stations should be out at least 12 feet high and 25 feet wide to provide ample room for unloading pipe and long timbers. The ore pocket is usually provided with a grizzly made of heavy rail. A chain block hung from an eye-bolt wedged in the roof of the station near one of the hoisting compartments, proves very serviceable for unloading heavy equipment. Figure 18 illustrates the station and ore pocket construction.

**ORGANIZATION.**

Organization of the crew is governed by conditions such as type and amount of labor available, efficiency and dependability of equipment, size of shaft, nature of ground and the matter as to whether low cost or speed of operation are of prime importance. There are two general systems of organizing the underground work of sinking. One provides for machine men to do the drilling and blasting, and lower priced men, working with them on opposite shifts, to do the mucking.
This system demands close supervision, a strict schedule and very dependable equipment.

The other system provides for all labor to be used indiscriminately to drill, muck and timber, each shift taking up the work where the other left off. This system makes for greater speed but theoretically it is more costly.

A combination of the two systems wherein the same men do the mucking and drilling, and a different crew do all timbering, can be established providing a regular schedule is followed. Some such schedule as the following is quite satisfactory where the round is blasted in two relays: six hours in which to drill the entire round; two hours for removing equipment blowing holes and blasting the first relay; one and one-half hours for blowing out smoke; eight hours for mucking out the first relay; one-half hour for blasting the second relay and six hours for mucking the second relay. Timbering is done within the six hours of drilling.
The surface crew will consist of one hoistman, one top trammer for each mucking shift, one steel sharpener and one general repairman.

COSTS.

The cost of equipment for a sinking plant varies so greatly according to size and depth of shaft, amount of water encountered and hardness of the ground that no general set of figures would be of much value from an estimating standpoint for a specific project. However, some contractors provide themselves with equipment for sinking shafts to certain depths and for handling a definite maximum of water. The following is an estimate of cost of new equipment necessary for sinking a three compartment shaft a depth of 500 feet, assuming the water flow does not exceed 40 gallons per minute.

1 - 175 h.p. Diesel Engine ..... $10,000
    Direct connected to
    Generator with exciter,
    switch board, starting unit
    and circulation pump.
1 - 660 cu. ft. cap. 2 stage air compressor... 3980.00
belted to 100 h.p. induction motor.

1 - motor-driven single drum hoist 35 h.p. ... 1140.00
600 feet 3/4" hoisting rope and attachments... 180.00
1 - 3/4 ton skip .................. 275.00
1 - wooden headframe and sheave. ......... 500.00
1 - drill sharpener, furnace & accessories ... 2000.00
4 - 50# jackhammers. .................. 900.00
40 - sets of drill steel .................. 300.00
Air and water pipe ................. 290.00
5 - each air and water hoses ......... 140.00
1 - sinking pump, suction hoses & foot valves.. 750.00
2 - 16 cu. ft. dump cars and rail. .......... 355.00
Ventilating fan and tubing .......... 250.00
Buildings. ......................... 800.00
Tools and sundry items ............. 1000.00

**TOTAL** ................ $22860.00

These figures do not include cost of transportation and erection of machinery. Cost of installation of the above may be estimated at $2500. For a shaft of large cross section, having at least two hoisting
compartments, the use of two independent hoists and two skips is an economical procedure.

No informative figures on cost of the sinking operation can be given due to the wide variation of conditions encountered in different localities. The cost per foot advanced is only of value for shafts of the same cross section, and cost per cubic foot of shaft volume would not be of comparative value because the cost would not vary in direct ratio to volume for different sized shafts. However, it is of some value to know the cost of shafts which have been put down in the past. Taking the average cost of four each of 2-compartment, 3-compartment and 4-compartment shafts, which were sunk in various years ranging from 1910 to 1935, and under varying conditions, we arrive at the following costs:

<table>
<thead>
<tr>
<th>Type</th>
<th>Av. Cost per ft.</th>
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<tbody>
<tr>
<td>2-compartment</td>
<td>$27.51</td>
</tr>
<tr>
<td>3-compartment</td>
<td>49.83</td>
</tr>
<tr>
<td>4-compartment</td>
<td>77.16</td>
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</tbody>
</table>

Present labor and supply costs would probably average 25% more.
SPEED.

The number of feet advanced per drill shift does not vary so greatly according to the cross sectional area as does the cost per foot. In a large shaft a proportionally greater number of drillers and muckers can be employed, hence, other conditions being equal, the rate of advance should be nearly the same for a large or small shaft. However, the amount of water to be pumped, hardness of ground and strength of walls are factors which have a very important bearing on the length of time required to complete a shaft of a certain depth. The average advance per 8 hour shift for the twelve shifts mentioned above was 1.67 ft. Good records in shaft sinking require careful planning and preparation, serviceable and efficient equipment on surface and underground, a loyal and experienced crew, a practical working schedule and close supervision.
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