DESIGN OF A SAND AND GRAVEL WASHING PLANT

BY

G. C. KUMBERA
EDWARD MUNDT

ARMOUR INSTITUTE OF TECHNOLOGY

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Kumbera, George C.
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DESIGN OF A SAND AND GRAVEL WASHING PLANT

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GEORGE C. KUMBERA AND EDWARD MUNDT

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The object of the writers, in this design, has been to make as theoretical, yet practical, a design of a Sand and Gravel Washing Plant as possible. There have been no works published, to the best knowledge of the writers, on this subject and the writers have had much difficulty in obtaining what little theory has been used in this design.

The writers wish to convey thanks to all who assisted in their undertaking. To Prof. R. I. Stevens, of the Armour Institute of Technology, the writers are indebted for the assistance rendered in the design of the bins. A. W. Burns, of the Smith Engineering Works, supplied information regarding the selection of the proper machinery. B. W. Huntington, of the Link Belt Company, gave us access to the theory underlying the analysis of screens and belt conveyors.
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DESIGN OF A SAND AND GRAVEL WASHING PLANT.

Present day concrete construction requires the use of materials which will give the highest attainable safe working strength. To obtain this point, it is necessary to properly proportion the ingredients which enter into the concrete mixture and remove any materials that may tend to weaken the concrete after its final setting. The only practical way yet found to meet the above conditions has been to wash the materials. The washing of sand and gravel being a comparatively new field, there is very little to be found on the theoretical design and economy of washing plants.

In our design, the object is to wash and grade the materials in such a manner that the materials can be proportioned to conform with the theoretical analysis of the materials entering into concretes giving the highest strengths.

Fullers Curve, which is the most practical, as well as theoretical, analysis of sands
we have to work with. The curve will give the reader a fair idea of an ideal composition of a sand. The curve is reproduced on another sheet for further reference. Curves for other sands are also reproduced on the same sheet.

It can be seen, from the curves, that ordinarily sands vary greatly from fuller's curve. It may also be reasoned that no two sands are alike and therefore each particular sand should perhaps be screened into different grades. But this would not be practical because sands vary in composition with their depth under the surface of the earth.

Fuller's curve, which is a combination of ellipse and straight line, is plotted with points obtained from an equation for which William B. Fuller is authority (See Taylor & Thompson's "Concrete, Plain & Reinforced", page 206). This curve is taken as the ideal which it is desired to approach by a combination of materials -- in this particular case, the "B" sand and the stone screenings.

It is evident that the percentages of either material passing any given sieve can be read for all three curves on any intersecting
ordinate. It is evident, also, that on such an ordinate, the percentages desirable to pass any given sieve can be determined from its intersection with Fuller's curve. Subtracting actual and ideal percentages then gives the variation of actual materials, from the ideal; and knowing this difference, the proportions of one needed to supply the lack of the other may be determined. With the results of this analysis it is possible to design screening machinery which would yield a washed sand of an ideal composition. The design of the screens will be considered, in great detail, later.
It is the object of the writers to design a plant to satisfy one certain set of conditions which will be enumerated later in this treatise. It is plainly seen that it would be impossible to design a plant which would satisfy all conditions.

In as much as there has never been any work published covering the design of this particular subject, the writers hope to incorporate such methods in the design of this plant, as have been justified by good engineering practice in other fields.

The writers do not undertake to design each and every separate machine used in the design. The machinery used in this design is well standardized in every detail and is found on the market of several different makes.

The capacity of the plant will be one thousand cubic yards per day. The writers feel that in choosing a capacity of one thousand cubic yards per day, the capacity and dimensions will
be that of the average modern plant. Plants of smaller capacities and all plants of larger capacities can be designed by using the same methods used in this design.

SIZES TO BE MARKETED.

Gravel and sands prepared for marketing vary greatly in their sizes depending upon the purpose they are to be used for. The greater part of the materials are used in concrete construction. A large amount of sand is used in the mixing of various kinds of plasters and a fairly large amount of pea size stone is used in the finish of hard surfaced roads.

Bank run gravel varies greatly in its sand content. From investigations conducted by the writers, some gravel pits have been found to have as much as sixty percent sand while others have been found to contain as little as twenty percent. Beside the varying sand contents that gravel banks may contain, layers of clay
and moulding sand are often uncovered. The clay layers are usually of small thicknesses, seldom exceeding four or five feet. While there is a market for clays of certain structures, the clays are seldom marketed on account of long hauls to points where they may be utilized.

Moulding sands are more easily marketed, but they require great care in preparation. Although this plant will not be designed to market moulding sands and various clays, the two materials are mentioned merely to enumerate the compositions of various gravel banks.

Generally, gravel sands have the composition as shown in Fuller's curve. In this plant, all stones that will not pass through a screen with two and one quarter \((2-1/4)\) inch perforations will be sent to a crusher and reduced to such size that will pass through the above mentioned screen. Any material passing through a two and one quarter inch screen but retained by an one and one half \((1-1/2)\) inch screen will be the largest size marketed.
The next size marketed will be that size which passes through a one and one half inch screen but is retained by a threequarter (3/4) inch screen. The three sizes screened out thus far are marketed as coarse aggregate used in concrete construction, although sometimes used in building hard surfaced roads. The next size screened out is that retained by a one quarter (1/4) inch screen. It is known commercially as pea size sand.

The remainder of the material is diverted to settling tanks in which the finer and lighter particles are held in suspension by water currents while the heavier and coarser particles settle to the bottom of the tank. The tank is constructed with a weir on one side from which the water containing the suspended material is drained off. The tank also has an opening at the bottom which dispenses with the heavier and coarser particles as they settle to the bottom of the tanks.
DESCRIPTION OF OPERATION OF PLANT.

An outline drawing of the plant is submitted on page 1 of the appendix.

The gravel is brought to the plant by means of a train operating between the plant and the gravel pit. The gravel is usually loaded on gravel cars by means of a steam shovel in large plants; in smaller plants, the use of a gravel train is dispensed with, and the gravel is brought to the plant directly from the pit by means of drag lines or grab buckets operating from a cable way. Some small plants have used drag hoes successfully.

When a gravel train reaches the plant, the gravel is unloaded into a hopper. Gravel cars are always provided with mechanical dumping devices. This hopper allows a constant stream of gravel to flow onto a conveyor belt which carries the gravel to a cylindrical screen above the crusher. This screen removes all the oversize; the oversize being lead to the crusher through a direct connected chute. The
material passing through the screen is diverted, through another chute, to the main conveyor which carries the material to the plant proper. The crushed material is conveyed from the bottom of the crusher to the oversize screen and all the material over two inches in diameter removed. Should any oversize pass through crusher, it would be retained by the oversize screen before reaching the conveyor running to the plant.

The main conveyor carries the material to the top of the plant. Here the material is divided into two equal streams. One stream passing through each of the two sets of conical screens. The material after being split into two sections, is conveyed through chutes to the screens. Dry material will generally not flow through chutes unless the inclination is great. A very large inclination of the chutes leading from screen to screen would mean a great waste of space and would diminish the capacity of the bins. The inclination of chutes is usually about twenty degrees; never any greater. This inclination is smaller than the angle of repose of the material and, theoretically,
the material will not flow at this angle.

At this point, a three inch water pipe is introduced and water is added to the material. In a thousand yard, duplex plant, about one hundred gallons of water per yard of material is added at this point. The material is carried through the chute, by the high velocity of the water into the one and one half inch conical screen. Some plants are equipped with scrubbers at this point. A scrubber is a cylinder equipped with baffle irons on the inside and has no perforations. The duty of the baffle irons is to toss the material around sufficiently so that the entire surface of the material will come in contact with water. Upon entering the screen, the water will carry all the material smaller in size than one and one half inches directly through the perforations in the screen. The larger sizes being retained by the screen. A one and one half inch water pipe enters the screen and water, at a high spouting velocity, is forced against the material retained by the screen. The nozzle on the pipe is so arranged that the water is spray-
ed over the material. This action of the water tends to completely wash the material retained by the screen. The material retained is then lead through chutes directly to receiving bins below. The material passing this process is separated, in a similar manner, in the three quarter inch screen. The material passing through the one quarter inch screen is diverted to the settling tanks. These tanks are provided with a weir. The material enters at one end of the tanks and the heavier particles settle to the bottom of the tanks. The material which remains in suspension passes off through the weir with the discharge water. The material which settles to the bottom of the tank is allowed to pass through an opening in the bottom of the tank into the bin; the settling tank being of hopper like construction and stationed directly above the sand bin.

The discharge water is lead through troughs to a storage reservoir near the plant. This reservoir is an excavated pit of such dimensions that the water can seep away through
its walls as fast as the water flows into it.

The bins are box-like in shape with chutes in their side walls. The chutes are placed high enough above the level of the railroad track so as to allow the material to flow freely from the bin into railroad cars; a loading track runs parallel and directly beside the bins. The material in the bins is kept sufficiently wet so that it flows freely through the chutes into the cars.

No switch engines are used on the loading track. The track is so graded that the cars can be coasted from their position on one side of the plant to the place where the loaded cars are stored.
DESIGN OF PLANT.

LOCATION AND RAILROAD CONNECTIONS:

The location of the plant depends on mainly on two things, namely, railroad connections and location of gravel bank. In choosing locations, the market must be one of the main considerations. A plant built some where out in the wilderness a long distance from the market would not be very economical, in that the cost of hauling would be too great. Also, the plant should be built on or near the main line of some railroad. The construction of a private railway to a plant will cost more than the cost of the entire plant if the railway was of very great length. The connections of the existing railway, if there is one, should be investigated as to the possible marketing area it would cover.

The location of the loading tracks depends mainly on the position of the plant. The only requirement being that it be built
parallel to the plant; so as to facilitate loading from the different bins. The part of the side track passing the plant should be inclined so that in the process of loading, the empty cars could be started downward, on a small grade, by hand by means of a car jack and controlled by means of the friction brakes on the cars. This effect will dispense with a switching engine. A thousand yard plant would be capable of loading about thirty carloads a day. The empty cars would be stationed on the upper end of the incline and would be coasted to the plant, singularly or in groups, for loading. After being loaded, the cars would be coasted to a place farther on the side track to be stored until removed by the railroad. A seven tenths percent grade has been employed successfully in practice for the coasting of railroad cars. The distance this incline should extend on each side of the plant would necessarily be equal to the length of thirty cars. This distance would be twelve hundred feet. The length of the side track would of course be sufficient to accommodate a storage of
empty cars greater than the number of cars used in any one day. In this particular design, the writers have decided to have a side track capable of accommodating at least sixty empty cars and as many full cars. This would call for a side track extending twenty four hundred feet on each side of the plant, which we will adopt.

**BINS:**

The capacity of the bins will be maintained small because of the fact that the material is loaded into cars almost as quickly as it is washed. The cost of bins for storage purposes is so great that it is found more economical to store the material in piles near the plant and load from these piles by means of a drag line. From this standpoint, the writers find the most economical size of bin to be one with a capacity of from to to three carloads. A sixteen foot square bin with a height of twenty five feet (the height being measured from the top of the loading spout) will give the desired capacity. The bins are built alto-
gether of wood with no super structure. While it may be argued that by building a super-
structure, a great deal of lumber may be saved, the writers find the most economical kind of
structure to be one built as a bin from the surface of the ground up, with no floor direc-
tly beneath the mouth of the loading spouts. Some may argue that the bin should be construc-
ted as a hopper, in view of the fact that the loading is performed by means of spouts placed into the sides of the bins, but the writers find that the material will act as a hopper by itself; the material acting along planes effected by its angle of repose, and the angles of repose may be controlled by the degree of wetness of the material.

The bins are built as water tight as is found practical in the process of construction. It is desired that they be water tight in that the angle of repose, and the flow, of the material both depend upon the degree of wetness of the material. The water system is construct-
ed in such a manner that any desired quantity of water may be diverted into the bins when it is found the material is not wet enough to cause sufficient flow from the bins.

In the design of the bins structure, the pressures at various depths in the bin, due to the material in the bins, have been taken into account as shown in the data on the following pages. The structure was designed according to the same methods used in the design of retaining walls. The writers have taken economy into consideration throughout the entire design.

The foundation has been designed to withstand a maximum loading, and also for dependable service. From investigations of plants now operating, made by the writers, it was found the lower parts of the bins are usually the places where the first failures of the plant structures occur. The lower parts of the bins, and also the foundations, were usually constructed too weak. The cause of the failures in the foundation was found to be lack of reinforcing steel in the concrete, or, as found in
some cases, the two sides of the foundations were not tied together. Without tie walls, bulging out of the foundation is certain to result. The writers have designed this foundation with an object of preventing any such failures. The foundations being of reinforced concrete with tie walls every sixteen feet; the walls of the bins being sixteen feet apart.

The screening machinery and motors rest directly upon the bin structure and the bins are designed with that end in view. The following page will give a demonstration of the method used in the design of the bins.
DESIGN OF BINS FOR GRAVEL.

The following is a typical design of members used in the construction of the bins.

Assumptions:

Angle of repose of material: 30°.

Weight of material: 120#/per cu. ft.

\( u_l = .40 \) for sand or gravel.

\( u = .57774 \).

Reference: Ketchum.

\[
\tan x = \frac{u + \sqrt{u^2 + u^2}}{u + u_l}
\]

\[
\tan x = .5774 \sqrt{\frac{.5774(1 + .333)}{.5774 + .40}}
\]

\[
\tan x = .5774 \sqrt{\frac{.77}{.9774}} = 1.4647.
\]

\[
P = \frac{Wh^2}{2\tan x} \times \frac{\tan x - u}{1 - uu_l + (u + u_l)\tan x}
\]

\( P \) = Total pressure on wall at depth desired.

\( h \) = Depth.

\( W \) = Weight of material.
P taken at a depth of 40' in this illustration.

\[ P = \frac{120 \times 403 \times 1600}{2 \times 92294} = 26,400\# \]

\( p = \) pressure at any particular point. 
\( p \) at 40' equals \( P \) at 40.5' less the \( P \) at 39.5'.

**DESIGN OF STUDING.**

Studding placed 28-0" c-c
Design of studs from 40' to 37'.

\[ M = \frac{(W_1 + W_2)L^2}{20} \text{ for end.} \]

\[ M = \frac{(W_1 + W_2)L^2}{24} \text{ for intermediate.} \]

\[ W_1 = 1250 + W_2 = 1,325. \]

\[ M = 26,900"\# \]

Assume 2"x8" studs.

\[ M = SI/C = 21.3333 S. \]

\[ S = 1,200\# \text{ which is within the allowed limits.} \]
DESIGN OF BRACING.

Horizontal bracing 37' from top.

\[ W_1 = 75 \quad W_2 = 1250. \]

\[ R_1 = \frac{(W_1L + W_2Lx3)}{6} \]

\[ R_1 = 1800\# \quad 37 - 34 \text{ feet.} \]

\[ R_1 = \frac{W_1L}{3} + \frac{W_2L}{2} \]

\[ R_1 = 1,913\# \text{ for } 40 - 37 \text{ feet.} \]

Total R is 3,713\# per linear foot.

Reaction for two foot interval is 7, 426\#

\[ M = 84,700\#'. \]

\[ M = SI/C \]

\[ S = 995\# \text{ which is within the allowed limit of stress.} \]

Use 1\"\# TIE rods spaced 4'-0" c-c.
CONVEYORS.

Where it is necessary to elevate the material handled, two methods may be employed: 1st, where space is limited, place a fixed dump at the end of the belt and install a bucket elevator; 2nd, run the belt on an inclined plane. The second method is approved where space permits. The angle of elevation is, however, limited — under the vary best conditions it must not exceed twenty five degrees and ordinarily from eighteen to twenty degrees is the limit. Large particles tend to roll back, and, if the feed is irregular, the tendency is for the whole load to land-slide. Therefore, a steady, well mixed load is advantageous.

Special consideration must be made where the belt runs along horizontally for a space and then starts on an incline. Here the belt tends to pull away from the idlers if the angle is too great. The allowable angle depends upon whether the belt is loaded or not, the nature of the load, the weight and tension of the belt, etc.
DESIGN OF BELT CONVEYORS.

Putting a belt over two pulleys, pulling and tightening until it is perfectly flat, and installing guide pulleys to "steer" it, does not by any means constitute the successful installation of a belt conveyor. On the contrary, there are a number of points, each small in itself, but which in the aggregate make or unmake a belt conveyor. Some of these points I will try to explain.

TROUGHING IDLERS:

The troughing idlers are often constructed more for the immediate convenience of their individual manipulation than with thoughtful consideration for the wear and tear of the belt. As this is first, last and always an item of the greatest importance, it ought to be considered first. Pulleys in line may have a tendency to act like a pair of shears and this is continuous and intensified when the loads are heavier than they ought to be, or when the carriers are spaced too wide apart, a condition that is a fruitful source of destruction to the belt.
belt. As a rule, in a belt conveyor of any appreciable length, the belt represents at least two thirds of the initial cost of installation, and it would hardly seem the part of wisdom to endanger the two thirds which is subject to constant wear to effect a saving in the one third which, owing to the nature of the material and the character of the work that it performs when under proper care and management should last almost indefinitely.

When troughing idlers were first built they were designed for an angle of troughing of 45, 30, 25, and 20 degrees, and finally the five pulley idler in contradistinction to the three pulley idler, was made with the differentiation in the pulleys of 15 degrees. The reason for this is self evident. The latter type more nearly conforms to the circular, eliminating angular bending and being a compromise, although a bad one because not necessary.

ABRASION OF BELT:

The abrasion of belt is controlled by so many factors that we will necessarily have
to take them up individually.

First: A conveyor belt should never be called upon to do any other work than transfer the material from point to point. But often it is called upon to stop the velocity of the material, producing abrasion that is illegitimate and ought to be taken care of in the design of transfer or feeding chutes, but which unfortunately is not usually the case. There are two methods of making transfers: One using gravity, which is always preferable when conditions make it possible, and the other, in cases of absolute necessity, utilizing velocity.

Second: Much depends upon the correct design of the transfer chutes. Too often we see skirt boards used, running parallel with the travel of the belt, to control the spill of the material due primarily to the inability of the belt to conform to the outline of the troughing idler, which in many cases is running almost flat, and in these cases the material catching under the edge of the skirt boards has to drag and wear and abrade until it has reached the end of
these retaining devices. This is wrong and should be avoided. If the transfer is properly designed, with the center sufficiently contracted and the noses or leads given the necessary freeing angle, skirt boards can be entirely eliminated, and the belt relieved of this wear and tear.

Third: Installing elevating belts at too steep an angle or running them too fast produces slip and scour. There is a relation between the speed and angle of elevating which must not be overlooked.

THE DRIVER or HEAD PULLEY:

In order to conform to false economic ideas and to reduce first cost, the hear or drawing pulley is often made too small, increasing the necessary tension inorder to obtain traction, whereas the true common-sense of conveyor belt driving is to have the traction without tension. In dynamo driving, as well as in conveyor driving, tension must be eliminated if you wish to get the best results in longevity of your belting. This is sometimes overcome, or attempted to be, by the use of lagged pulleys, but too frequently this is only the excuse for decreasing their diameter rather than decreasing the
tension. In no part of the design of belt conveyors is more damage done than in this one particular feature, for it is true that the usual type of conveyor belt requires absolutely this excessive tension in order to make it tract or approximately run true.

CLEANING A CONVEYOR BELT:

The method that is commonly used is that of employing a brush to clean the conveyor belt and often using it on a tripper between the two pulleys to prevent the material on the working side being imbedded in the cover of the belt by the pressure of the snub pulley. This is a very poor method. Both pulleys on a tripper are crown pulleys, which prevent the brush from having a level or flat surface to operate against. If the material is wet, as is usually the case, it clings and cannot be removed except with the use of so much pressure by the brush on the belt as to do serious damage to the cover, as well as rapidly wearing out the brushes, necessitating an almost constant adjustment. A preferable method of clean-
ing a belt is to have a driven shaft with loose auxiliary shafts pivoted together and thrown out by centrifugal force, which strike the belt with a continuous and incessant series of blows, jarring the material loose and necessitating no adjustment. This method is equally efficient and divested of all the disabilities inherent in the use of the complicated mechanism required to operate the brushes.

**IMPROPER HANDLING:**

In operating belt conveyors in series, especially if any of the sections are elevating, as is the case in this design, there should be a gradual stepping up of speed from the initial receiving conveyor to the ultimate distributing conveyor, if it is desired to prevent breakage. If the item of breakage does not enter into the problem, the speeds can be uniform. To produce breakage, choke a thin rapid stream with a thick slow one by incorporating a large slow-moving conveyor into a series of conveyors with faster speeds, and this object will be accomplished.
When starting, the conveyor should be at full speed before any material is fed onto the belt; and when stopping, the conveyor should be run at full speed at least five or ten minutes after the feed has been stopped, in order to have delivered the laggards or those pieces which may have a tendency of all other material, to roll back.

**SNUB PULLEYS:**

It is preferable, where it is possible to eliminate snub pulleys to do so, rather increasing the diameter of the hear or tail pulley and making a long lead to the first return idler; as the tendency of all snub pulleys is to bring the working surface of the belt with the material clinging to it against this snub pulley embedding the material, which cuts its way into the body of the belt and thereby does serious damage.

**FEEDS:**

Correct feed is often the most essential adjunct of a belt conveyor, for its successful operation, and needs careful thought and consider-
ation. The general principle involved is that the material should reach the belt moving in the same direction and at approximately the belt's speed of travel. This can be done in most cases, and always, if sufficient thought is given to the proposition in time. The feeding chute should be arranged to deliver the bulk of the load to the center of the belt, having the wings or leads sufficiently opened up or at an angle, so as to make the belt free itself and let the load distribute and come to a state of rest.

DEEP TROUGHING:

Originally belts were designed to have a deep trough. This gives the greatest capacity, cleanest carrying, it is the easiest to feed on and to design the feeding chute for, and has only been modified to conform to the weakness developed in the belting which broke at the bending points, where the horizontal and angle pulleys met and sheered and destroyed the belt. To any longer suffer under the prejudice of this modified and unmechanical condition and construction is not necessary.

DECKING:

One of the most important features of a
conveyor system, and the one too frequently overlooked, is the necessity for protecting the lower returning belt from any material dropping on it; and this is practically true when the feed is very close to the end pulley, as is usually the case. This is very close to the end pulley and the material goes between the inner and unprotected surface of the belt and the pulley, and is embedded, destroying the thin film of protective cover, baring the fabric and allowing absorption of moisture and grit, producing rapid destruction and disintegration of the belt.

SPACING OF IDLERS:

When it is considered that the belt usually represents two thirds of the cost of installation, the machinery one third, and the troughing idlers often the least proportion of the one third, it would seem the part of wisdom not to space them too far apart, producing an unnecessary sag in the belt and causing a flexing that does no good and often much harm. A little closer spacing is much to be desired and no additional power
is required, as more power is saved by the elimination of the sag than is required to operate the additional pulleys. A belt conveyor should embody maximum capacity, minimum expense, deep troughing and a clean carry, minimum tension and a perfect alignment, and absence of edge wear and corner system to secure the desirable features mentioned and eliminate the objectionable ones.

BELTING:

The ultimate strength of the average rubber belt is about 360 pounds per inch width of ply; the safe working tension (using a factor of safety of 12) is about 30 pounds per inch width of each ply. The pull required to move a belt over its carriers upon the level, is approximately 20% of the weight of the belt plus 10% of the weight of the load upon the belt. The proper flexibility for troughing idler belts is one ply for each four or five inches of belt width, with 12 inch 3 ply as a minimum, and 48 inches 8 ply as a maximum.
PULLEYS:

It has been found to be good practice to make the diameter of all drive pulleys five times the number of plies of the belt, and all other pulleys four times the number of plies. Bend or Snub pulleys of a three or four ply belt should be ordinarily about eight inches in diameter; for five ply belts, twelve inches and for six ply or over, sixteen inches in diameter.

Rubber lagged pulleys increase the tractive effort of the plain driving pulley of a belt from ten to twenty percent, where contact between the pulley and the belt is clean or where the dust from the materials is damp. However in dry and very dusty conditions of clays and similar materials which are smooth, the tractive effort may be decreased by using rubber lagged pulleys.

Snub pulleys are recommended at each end pulley in ordinary practice, to relieve the strain on the end return idlers where the belt bends to encircle the pulleys.
DRIVES:

When greater tractive force than usual is required a greater length of belt is brought in contact with the driving pulley by means of a snub pulley. The arc of contact may be increased from 180 degrees to 240 degrees, which increases the horsepower pull 20% and makes it possible to use a belt with one fifth as many plies. This extra tractive pull may also be used to extend the maximum length of the loaded belt 20% if the shafting and gears are increased in proportion. The average diameter of a plain snub shaft is about one and fifteen sixteenths inches.

A yet greater tractive pull may be secured with 240 degrees contact if the driving and first snub pulley are of the same diameter and are connected by gears as shown in the drawing of this plant, thus making the contact on the geared snub available for doing a part of the driving. This is known as a multiple drive. With 240 degrees around the geared snub and 180 degrees around the driving pulley, the tractive effort is increased 40% instead of 20% as given by a plain snub, thereby permitting a proportional
decrease in belt plies within proper troughing and service limits oer permitting an extension of the conveyor with heavier drive.

The disadvantage of the snub in any form is that the reverse action of the belt over the snub causes some internal wear between the plies of the belt, while any reduction of plies below the number required for proper flexibility tends to crease the belt longitudinally and make the belt of not sufficient durability for handling abrasive materials.
DISTRIBUTION AND INSTALLATION OF POWER.

The first consideration, is necessarily, the horsepower required. In this design, three power units will be employed.

The first unit will supply the power necessary to operate the screens and the belt conveyor. From experience and experimental data, obtained by the writers upon the investigation of numerous plants near Chicago, it has been found that the power necessary for the operation of screens of the dimensions and capacity used in our design was approximately five horsepower per screen. The power necessary to operate a carrier belt of the capacity and dimensions used in our design was found to be approximately five horsepower per twenty foot length of belt, or thirty horsepower for the entire belt; the belt carrying maximum load. The conveyor belt and two sets of "three screens on a singleshaft are the only machines driven by this power unit. The overall horsepower necessary will be sixty horsepower for the first unit.
The second unit supplies the necessary power to operate the necessary water supply system. The horsepower needed in this unit will depend upon the amount of water used and the height it is to be lifted. From the calculations made for the water supply, and the efficiency of the pump as given elsewhere in this thesis, a 16 horsepower motor will be required to operate the water system.

The third unit will operate the crushing plant and the preliminary screens. The motor must be of sufficient size to operate the crusher at maximum capacity. The power required to operate the crusher in this design will be fifteen horsepower. Beside the crusher, this motor operates a twenty four foot belt conveyor consuming eight horsepower when carrying a maximum load. In as much as motors have even rateing only, a twenty five horsepower motor will be required.

In choosing the kind of motive power to be used, the factor of economy must be considered.
Many plants have steam power plants and all the machinery is driven by belt from the central unit. This power system is not only inefficient but has a very high rate of maintenance. It is not as dependable as electrical power. It is a well known fact that small steam plants cannot compare in efficiency with electrical power.

In this work, we will use electrical power only. There is usually a transmission line in, or near, the vicinity of the plant. Although the common voltage used in transmission lines is far too great for use in driving motors, the amount of power used by this plant is sufficient to warrant the installation of a transformer station. The line leading to the plant, and the transformer station are always installed by the power company; so there is no need of our dwelling on that subject.

The transformer station being at the plant, it is not necessary to operate the motors at high voltages. In this plant two hundred and twenty volt (220) motors will be used. The plant
will also be wired for lighting on the two twenty volt circuit. Two twenty volt circuits are just as dependable as one ten volt circuits when used for lighting. The only disadvantage being that of the cost of appliances for two twenty volt circuits; the appliances cost a little more.

Considering the two twenty volt circuit from the motor stand point, the two twenty circuit has an advantage in that a small sized wire can be used; the current consumption of two twenty volt motors being less than that of the one ten volt motors.

Five hundred and fifty volt motors may also be used. This voltage, although it might increase the power efficiency of the entire system (transformers included) has its disadvantage in that it would have to be stepped down for the light circuit. The danger of common labor around five fifty volts is also to be considered. Although an ordinary mechanic may be able to make repairs on a two twenty or one ten volt circuit, it would be a dangerous undertaking for him to
attempt working with five fifty volts around
a plant which is wet all over, if he was not
an electrician. The insulation for a five
fifty volt circuit would also have to be great
and the cost of the entire circuit would be
much greater.

In choosing the motors, it is necessary to know the voltage and the frequency of the
main line. The common frequencies in this coun-
try are twenty five and sixty cycles, but the
voltage varies over a large range. Standard motors
are usually built for 110, 220 and 550 volts.

So far we have only considered alternating current as our electrical power. Direct
current may also be used, but direct current is
seldom available. The efficiency of transmission
lines depends upon the copper losses in the lines,
which in turn depends upon the voltage of trans-
mission. It is possible to generate direct curr-
ent at high voltages, but the disadvantage is
that the direct current voltages cannot be trans-
formed to a lower value in the manner alternating
current voltages can. There are not many appliances
which are able to operate on the high voltages used in the transmission of power, and as a result, the direct current is seldom used in power transmission. Electric railways are the greatest users of direct current. They operate the car motors on five fifty and seven fifty volts. About the only time direct current could be considered in sand and gravel washing plants is when an electrical generating plant is to be installed at the washing plant.

Direct current motors have an advantage over the alternating current motors in that they have a very wide speed range. That advantage is offset by their cost. The cost of a direct current motor, per horsepower, is usually so much greater that that of alternating current motors that some manufacturers have found it economy to install converters and convert direct current to alternating current so as to be able to use alternating current motors. Alternating current motors are much simpler in construction. Alternating current Squirrel Cage Induction Motors are of very simple and very rugged construction. They are the cheapest kind of motor and their efficiency
ranges with that of the best motors. The speed of Induction Motors depends on the number of poles of the motor and the frequency of the alternating current. The range of speed for the motors is very small. They have a constant speed. Where peak loads are to be encountered, it is desirable to have a fly wheel when using Induction Motors. An Induction Motor, when loaded, has a certain percent of slip, that is, with a certain frequency, the speed of the motor should be a certain number of revolutions per minute, but this is the case. The motor does not attain the theoretical speed. The speed is usually ten or twenty revolutions less. This amount is called the slip. It tends to lessen the efficiency of the motor. This factor should be taken into consideration in selecting a motor. It is desirable to have as low a slip as possible.

The one disadvantage an Induction Motor has, compared to other motors, is that the Induction Motor has no accelerating torque. The motor requires the use of some kind of a starting device. The starting devices used should also be
taken into consideration in the selection of a motor. Many kinds of devices are being built by the various motor manufacturers. They are all good devices as long as the can serve the purpose intended for. The same style of devices may be used for several different conditions, but it must be built to take care of each separate set of conditions. In selecting a motor, the conditions to be met with must be specified for the maker. Makers guarantee their motors to carry a certain load for a certain length of time with a certain rise in temperature during the time of the run. Motors are built to carry heavy overloads for short intervals of time. A ten horsepower motor would be capable of carrying a fifteen horsepower load for a short length of time. Therefore, in selecting a motor, the motor need only be large enough to carry the average load.
THE INCLINED OR GRAVITY SCREEN.

A screen in its simplest form is the inclined plane or gravity screen. The main difficulty with this type of screen is that the material after traveling a few feet accelerates to such a velocity that the holes in the screen are passed over by particles which should pass through. The length of the effective travel is very short and the results obtained are very unsatisfactory.

Engineers might say, why not make the shape of the screen or curvature of the path such that the velocity is constant or uniform and without acceleration? Fig. 1, on page 46 is referred to as a possible curve for such a screen. Let A-B represent the curve and our problem is to find the shape of the curve or its equation.

The acceleration of a particle passing downward on an inclined plane without friction is $gs\sin \theta$ where $\theta$ is the angle of the inclination with the horizontal. The retardation due to friction or negative acceleration is $gf\cos \theta$ when $f = \text{coeff-}$
icient of friction. Therefore, the acceleration of the particle passing down the plane at any instant is:

\[ g(\sin \theta - f \cos \theta) \]

Now since we desire maintaining a uniform velocity without acceleration:

\[ g(\sin \theta - f \cos \theta) = 0 \]

\[ \sin \theta = f \cos \theta \]

\[ \frac{\sin \theta}{\cos \theta} = f = \tan \theta \]

The result shows that the curve resolves itself into a straight line the tangent of which is equal to the coefficient of friction. In other words, if the screen is set at the angle of friction the particle will slide down the screen at the same speed at which it started. Unfortunately, we have quite a variation in the coefficient of friction, for some particles will slide down while others will roll down. Therefore, by setting the screen for the former will result in giving the later considerable acceleration. Another difficulty with this type of screen is that particles will lodge in the holes of the screen and
block the screen unless removed by some means.

THE CYLINDER SCREEN.

The cylinder screen is the oldest type of revolving screen in use. They are set at slightly downward slope to cause the material to travel through the screen. The path of the particles on the screen surface is a helix. In order to determine the pitch of the helical path of the particle in a cylinder screen we will assume a certain angle "a" as the inclination of the screen with the horizontal. Every element of the screen surface parallel to the axis will have this angle with the horizontal, assuming that these angles are taken in vertical planes.

First assume a horizontal plane with the line A-O in that plane. (See Fig. 2, page 46). Assume that the vertical plane through A-O is rotated about A-O through an angle of 90° or into the horizontal plane. Now draw C-A-O equal to angle "a"; the C-A line represents an element of the cylinder. Next draw C-B-A equal to:

\[ \theta = \tan^{-1} \frac{CO}{OB} \]

angle of friction.
We know that the particle will travel in some direction in the normal plane which has an instantaneous angle of $\theta$ with the horizontal plane. Rotating BCA back again into the vertical plane about BOA as an axis, we will determine the intersection of the normal plane with the horizontal plane and rotate the normal plane about the line of intersection into a horizontal, and determine the true angle which the path makes with the cylinder element. Rotating OB about vertical axis, O making the arc BD, and draw AD tangent to the arc, Ad is the line of intersection of the normal plane and the horizontal plane.

In order to get the true angle with the cylinder element it is necessary to lay out the angle $\theta$ as ODE and rotate the normal plane into the horizontal plane about AD as axis, which gives us APD of $\phi$ as the true angle which the path of the particle makes with the cylinder element.

To reduce this analytically in terms of the given angle, we have:

$$\frac{CA}{AF} = \frac{\cos \alpha}{\sin \alpha}$$
CB = DF = \frac{CO}{\sin a}

\cos \phi = \frac{-df}{AF} = \frac{-CB}{UA} = \frac{\frac{CO}{\sin \theta}}{\sin a} = \frac{-\sin a}{\sin \theta}

\phi = \cos^{-1} \frac{\sin a}{\sin \theta}

In order to compute the length of the helix we will develop the surface of the screen and indicate the path of the particle. (See Fig. 3, page 46). The pitch \( P \) of each turn of the spiral is:

\[ P = \frac{\pi \tan \phi}{\sin \phi} = \frac{\pi D \cos \phi}{\sin \phi} \]

The length of each turn of spiral is:

\[ L = \frac{P}{\cos \phi} = \frac{\frac{\pi D \cos \phi}{\sin \phi}}{\cos \phi} = \frac{\pi D}{\sin \phi} \]

The number of turns is:

\[ N = \frac{L}{P} = \frac{\pi D \cos \phi}{\sin \phi} = \frac{L \sin \phi}{\pi D \cos \phi} \]
The total length of spiral is equal to the length of a turn multiplied by the number of turns:

\[
\text{Total Length} = \frac{D}{\sin \phi} \times \frac{L \sin \phi}{D \cos \phi} = \frac{L}{\cos \phi}
\]

But

\[
\cos \phi = \frac{\sin \alpha}{\sin \phi}
\]

Total length of spiral = \(\frac{L \sin \phi}{\sin \alpha}\)

Assume \(\theta = 45^\circ\) and \(\alpha = 7^\circ\)

And we have \(0.707L/1.219 = 5.8L\) for length of spiral.

It therefore follows that the length of travel in a cylinder screen is independent of the screen diameter, but simply depends on the length of the screen and the inclination of its axis. This fact no doubt will be a great surprise to many, including screen manufacturers, for screens of large diameter are usually given considerably higher rateing than they should have. The length of travel of a particle in a screen
36 inches in diameter and 12 feet long is identical to the path of a particle in a screen 72 inches in diameter and 12 feet long, if both screens are set at the same inclination. This path is about 70 feet long. The advantage of the large screen, however, is that the distance between the coils of the helix is greater, which allows the material to spread out more and make a wider helix. (See Fig. 4 page 46).

THE OVERHUNG CONICAL SCREEN.

We will next take up a type of screen used a few years ago quite extensively in gravel washing plants. It is known as the overhung conical type. Figure 5 illustrates the screen and the manner in which they were used.

To determine the angle of advance of the spiral, we will assume line AB, Fig. 6, as the intersection of the normal plane drawn tangent to the screen and forming angle of friction with a horizontal plane. Draw AC equal to MO of Fig. 5, then draw CD, making angle CDA equal to \( \alpha \), the angle
of advance. Draw DE parallel to AB, making length AE equal to MN in fig. 5. Then EAB, Fig. 6, as equal to angle of advance of the helix. This is evident by assuming that the normal plane is rotated into the horizontal plane. The element AE and the axis are then in a vertical plane through AE and the perpendiculars to AB and AE give the angle of advance and by geometry would be equal to angle EAB.

To trace the path of travel it is necessary to develop the surface of the screen cone. The path then takes the curve of the logarithmic spiral as shown by Fig. 7, and when drawn in on the cone takes the form as shown by Fig. 5,

The Length of the spiral is:

where R is the length of the cone element AE from the apex to the large diameter of the cone and r the cone element from apex to small diameter of cone and $\phi$ the angle of advance of the spiral just found.
Assuming the same slope for the screen as taken for the cylinder screen, we find that the angle of advance is approximately $10^0$ and $R = 18.18 \text{ ft.}$, $r = 12.1 \text{ ft}$ and $\cos 80^0 = .1736$, and the length of spiral is $34.7 \text{ ft}$ for a cone screen 72 inch long and 1-1/2 inches per foot slope. This is practically the same length of travel for a cone screen as cylinder screen 72 inches long. This would naturally be expected since we found that the diameter of the cylinder screen did not affect the length of the path of the travel of the particle.

The form of the logarithmic spiral formula is $r = ae^{m\theta}$ and by use of hyperbolic logarithms the curves of Fig. 7 are plotted.

**INCLINED CONICAL SCREEN.**

The screen which we will next discuss is the well known inclined conical screen, which is mounted on the same shaft as shown in Fig. 8. The material in this screen travels ahead while
the screen shown by Fig. 5, has a backward flow. These screens have an entirely different taper than the other style and are designed to give the best pitch of the spiral and minimum pitch for the flume, from screen to screen. These two angles, together with the given diameter of the large end of the screen, determine the shape of the cone.

A different diagram is necessary to determine the angle of advance of the helix as well as the path of the particle.

Assume line OA as the intersection of a vertical plane through the screen or cone axis and a horizontal plane through the apex O. Draw OB, making angle of friction with line OD, which is at right angles to OA. We next locate E, knowing that it is equal to MP, Fig. 8, from Bo and a distance PH from DO. Now drop a perpendicular EH to BO and rotate HO into OD. We know have the screen element in the horizontal plane and can lay off element MN, as DJ or as HK before rotation about OA. The axis of the screen is in the vertical plane through OL. Rotate the vertical plane about OA in figure to the right in
diagram and we have OL as the axis and KO as the projected co-ordinate of the element. Assume a point as M and draw MN perpendicular to OL or cut the element with a perpendicular plane, which gives us the true angle of advance of the helix or \( \phi \).

The helix can then be drawn as shown by Fig. 10, in same manner as before except in the reverse order. We find that the length of this helix is the same, but usually the pitch is a little less and the path a little longer.

We now come to the most interesting analysis of these paths.

The cylinder screen has a spiral which has uniform distances between the coils, When a quantity of material is introduced into the screen it can spread, depending on the distance between the spirals. The greater the diameter the greater the spread. Now as the material travels through the screen and the amount gets less and less since the greater portion goes through, we must overcrowd the screen at the start or we are not using
the full width between the coils at the lower end.

The screens illustrated in Fig. 5 have the helical paths close together at small end and the discharge between the corresponding points on the helix, or pitch of spiral increases toward the large end of the screen. The material is delivered to the small end of the screen where the material can spread the least amount, yet this is the point of maximum quantity of material in the screen.

It is, therefore, necessary to crowd the small ends of these screens to make use of the wider path at the large end of the screen. In other words, the increased pitch of the helix is in the wrong direction. The piling up of the material at the small end interferes with the pebbles passing through the openings and a large percent of the screen area is lost.

The screens shown in Fig. 8, have the wide helical path at the large end where the material is received. The paths get nearer together as the material travels along. The quantity also becomes less and less. In this screen the spirals are in
the right direction and the efficiency is much higher.

The cost of screens is proportional to the area of screening surface. Another consideration in comparing screens is the correct speed for screens. It is known, from results found by experiments, that a surface speed of from 175 to 200 feet per minute is the most efficient; if slower than this the capacity is cut down and if faster the screening efficiency is lowered because the pebbles do not have sufficient time to go through. With the cone screens the speed should be computed for the large end, for if speeded according to small end the speed of large end would be excessive.

This results in a further cut of efficiency in screen, Fig 8, because the bulk of the material is at the small end where the screen speed is greatly reduced, while with the screen of Fig. 8, the correct speed is at the large end where the greatest quantity of material is received while the decreased speed of the small diameter does not cut down capacity much because the quantity of
material is then so small.

The screens used in this design conform with the theory set forth in the preceding pages. They were built by the Smith Engineering Works, of Milwaukee, Wisconsin and are illustrated on page 30, Catalog 254, published by the Smith Engineering Works.

The description of the screen is as follows:

Diameter of screens:
small end --------------- 36 inches
large end --------------- 54 inches

Length --------------- 84 inches
Average peripheral speed ------ 140 feet/Min
Capacity of screens --------- 125 cu. yds/hr.

The screening is performed by three screens; each screen having different size perforations. In this design, the three screens have perforations of 1-1/2", 3/4" and 1/4" in diameter.
BRIEF.

Foundation:

Reinforced concrete.

Depth below surface of ground: - 2'-0"

Length .......................... 66'-6"

Width ............................ 18'-6"

Thickness ........................ 2'-0"

Three Tie Walls  } Same dimensions.
Two End Walls  } Same dimensions.

Bins:

Number of bins .................... 4

Length (Overall) .................. 64'-0" c-c

Length (Bins) ..................... 16'-0" c-c

Structure ......................... Yellow Pine.

Stress (Working) .................. 1300#'

Studdings ......................... 2"x8" 2'-0" c-c

Sheeting .......................... 2"x8"

Corner Posts ....................... 6"x8" and 8"-8" 16'-0" c-c

Whalers ........................... 6"x8"

Tie rods ........ 18'-6" long 1" diameter.

See drawings for Detail.
Super-structure:

Material - yellow pine
Posts 6"x6" and 6"x8"
Bracing 2"x8".

Conveyor:

Belt - Duck with rubber covering.
Length - 120'-02"
24"-100ton Conveyor Complete as manufactured by the Smith Engineering Works, of Milwaukee Wisconsin; their type No. 3-A, Five pulley troughing idlers spaced 4'-0''.
Maximum size of lump material: 8 inches.

One conveyor, same as above, 30 feet long.

Motors:

Manufactured by the General Electric Company of Schenectady, N.Y.
One 25 Horsepower 220- Volt Squirrel Cage Induction Motor; Makers type 16 - 4.
One 15 Horsepower 220 Volt Squirrel Cage Induction Motor type 16 - 6.
One 60 Horsepower 220 Volt Squirrel Cage Induction Motor type 14B.
Drive Pulleys and Gears:

Two - 12" - 60 Horsepower Pulleys.
Two - 36" - 60 " "
Two - 8" - 30 " "
Three 18" - 30 " "
Four 8" - 30 b 45 degree beveled gears.

Screens:

Six Telsmith Conical Gilbert screens as manufactured by the Smith Engineering Works.
Diameter - Small end - 36"
" Large end - 54"
Length ................. 84"
Total capacity: 250 cubic yards per hour.

Screen Troughing:

Eight 1/4" sheet iron, 3'-10" semi-circular troughs as detailed on drawing.

Settling Tanks:

Two 60" Conical sand separators as manufactured by the Smith Engineering Works.
Water Supply:

Main line: 4" piper
Branches: 1 - 1/2" (One and one half) pipe.

Pump:

Capacity: 500 gallons per minute.
Lift - 60' above surface of ground.
Manufactured by Allis Chalmers Company of Milwaukee, Wisconsin.
Makers No. Typer 11-Ka.

Car Loading Gates and Chutes:

Four 12"x14"x6'-0" cast iron car loading gates and chutes as manufactured by Smith Engineering Works.

Receiving Hopper for Main Conveyor:

Top dimensions 8'-0"x14'-0".
Depth: 6'-0".
One side vertical.
Structured supported on 8"x8" corner posts fabricated with 2"x8" yellow pine with sheet iron lining.
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