AGGREGATE PRODUCTION

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering

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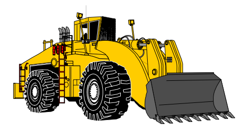

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PRODUCTION OF CRUSHED-STONE AGGREGATE

- The production of crushed-stone aggregate involves:
  - ✓Drilling
  - ✓Blasting
  - ✓Loading
  - ✓Transporting
  - ✓Crushing
  - ✓Screening
  - ✓Product handling and storage

PRODUCTION OF CRUSHED-STONE AGGREGATE

- In operating a quarry and crushing plant, the drilling pattern, the amount of explosives, the size shovel or loader used to load the stone, and the size of the primary crusher should be coordinated to assure that all stone from the quarry can be economically utilized.

RECOMMENDED MINIMUM SIZES OF PRIMARY CRUSHERS

Table 1

Recommended minimum sizes of primary crushers for use with shovel buckets of the indicated capacities

Capacity of bucket [cu yd (cu m)]		Jaw crusher [in. (mm)]†		Gyratory crusher, size of openings [in. (mm)]‡	
$\frac{3}{4}$	(0.575)	28 × 36	(712 × 913)	16	(406)
1	(0.765)	28 × 36	(712 × 913)	16	(406)
$1\frac{1}{2}$	(1.145)	36 × 42	(913 × 1,065)	20	(508)
$1\frac{3}{4}$	(1.340)	42 × 48	(1,065 × 1,200)	26	(660)
2	(1.530)	42 × 48	(1,065 × 1,200)	30	(760)
$2\frac{1}{2}$	(1.910)	48 × 60	(1,260 × 1,525)	36	(915)
3	(2.295)	48 × 60	(1,260 × 1,525)	42	(1,066)
$3\frac{1}{2}$	(2.668)	48 × 60	(1,260 × 1,525)	42	(1,066)
4	(3.060)	56 × 72	(1,420 × 1,830)	48	(1,220)
5	(3.820)	66 × 86	(1,675 × 2,182)	60	(1,520)

† The first two digits are the width of the opening at the top of the crusher, measured perpendicular to the jaw plates. The second two digits are the width of the opening, measured across the jaw plates.

‡ The recommended sizes are for gyratory crushers equipped with straight concaves.

TYPES OF CRUSHERS

- Crushers are classified according to the stage of crushing which they accomplish, such as:
  - ✓Primary
  - ✓Secondary
  - ✓Tertiary
- A primary crusher receives the stone directly from a quarry after blasting, and produces the first reduction in size.

TYPES OF CRUSHERS

- The output of the primary crusher is fed to a secondary crusher, which further reduces the stone size. Some of the stone may pass through four or more crushers before it is reduced to the desired size.
- The degree of breakage is spread over several stages as a means of closely controlling product size and limiting waste material.

TYPES OF CRUSHERS

- As stone passes through a crusher, the reduction in size may be expressed as *reduction ratio.*
- The reduction ratio is the ratio of crusher feed size to product size.
- The sizes are usually defined as the 80% passing size of the cumulative size distribution.
- For jaw crusher, the ratio can be estimated by the gape.

TYPES OF CRUSHERS

- The gape is the distance between the fixed and moving faces at the top, divided by the distance of the open-side setting at the bottom.
- The reduction ratio of a roller crusher can be estimated as the ratio of the dimension of the largest stone that can be nipped by the roller, divided by the setting of the rolls, which is the smallest distance between the faces of the rolls.

TYPES OF CRUSHERS

- Crushers are also classified by their method of mechanically transmitted fracturing energy to the rock.
- *Jaw, gyratory, and roll crushers* work by applying compressive force.
- Impact crushers such as single rotor and hammer mill apply high-speed impact force to accomplish fracturing
- Table 2 (T 14-2, Text) lists the major types of crushers.

MAJOR TYPES OF CRUSHERS

Table 2

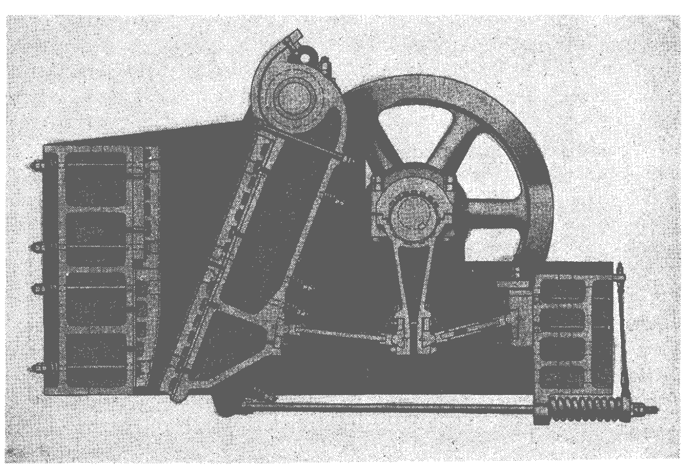
TABLE 17-2
The major types of crushers

Crusher type	Reduction ratio range
Jaw	
a. Double toggle	
(1) Blake	4:1–9:1
(2) Overhead pivot	4:1–9:1
b. Single toggle: Overhead eccentric	4:1–9:1
Gyratory	
a. True	3:1–10:1
b. Cone	
(1) Standard	4:1–6:1
(2) Attrition	2:1–5:1
Roll	
a. Compression	
(1) Single roll	Maximum 7:1
(2) Double roll	Maximum 3:1
Impact	
a. Single rotor	to 15:1
b. Double rotor	to 15:1
c. Hammer mill	to 20:1
Specialty crushers	
a. Rod mill	
b. Ball mill	

JAW CRUSHERS

- Jaw crushers operate by allowing stone to flow into the space between two jaws, one of which is stationary while the other is movable .
- The distance between the jaws diminishes as the stone travels downward under the effect of gravity and the motion of the movable jaw, until the stone ultimately passes through the lower opening.

JAW CRUSHERS



Blake-type jaw crusher. (*Fiat-Allis Construction Machinery, Inc.*)

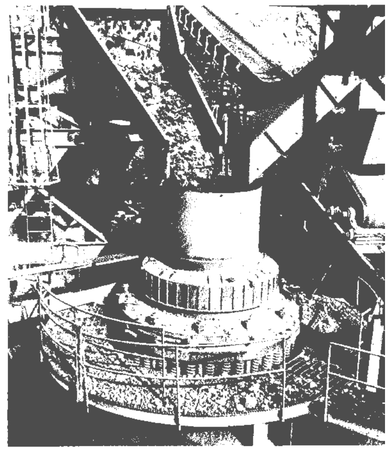
JAW CRUSHERS

- Jaw crushers are usually designed with the toggle as the weakest part. The toggle will break if the machine encounters an uncrushable object or is subjected to overload. This limits damage to the crusher.
- In selecting a jaw crusher, consideration must be given to the size of the feed stone.

GYRATORY CRUSHERS

- Gyratory crushers are characterized by a gyrating mantle mounted within a deep bowl.
- Gyratory crushers provide continuous crushing action and are used for both primary and secondary crushing of hard, tough, abrasive rock.

GYRATORY CRUSHERS



Gyrosphere crusher in an aggregate plant. (*Telesmith Division, Barber-Green Company.*)

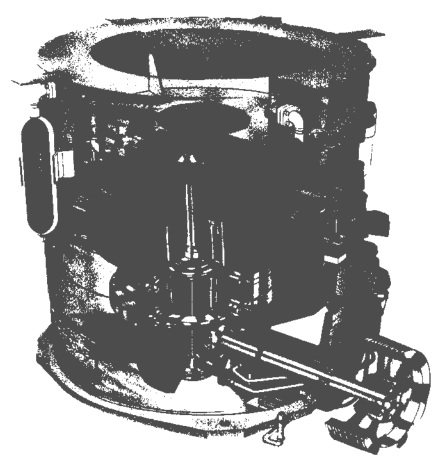
GYRATORY STANDARD CONE CRUSHER

- Cone crushers are used as secondary or tertiary crushers.
- Cone crushers are capable of producing large quantities of uniformly fine crushed stone.

GYRATORY STANDARD CONE CRUSHER

- A cone crusher differs from a true gyratory crusher in the following respects:
  1. It has a shorter cone.
  2. It has a smaller receiving opening.
  3. It rotates at a higher speed, about twice that of a true gyratory
  4. It produces a more uniformly sized stone.

GYRATORY STANDARD CONE CRUSHER

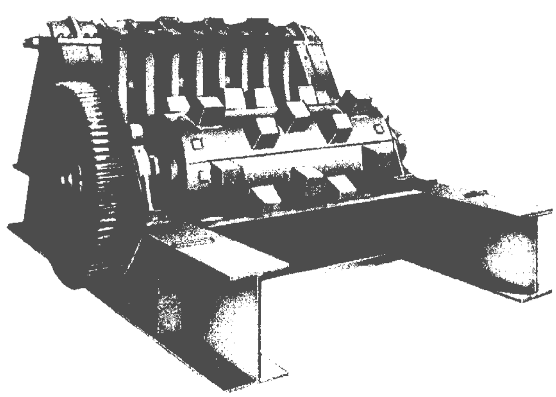


Rollercone crusher. (*Cedarapids Inc., A Raytheon Company.*)

ROLL CRUSHERS

- ***Roll crushers*** are used for producing additional reductions in the sizes of stone after the output of a quarry has been subjected to one or more stages of prior crushing.
- A roll crusher consists of a heavy cast-iron frame equipped with either one or more hard-steel rolls, each mounted on a separate horizontal shaft.

ROLL CRUSHERS



Cutaway of single roll crusher showing deep-ribbed pitman and segment-type rotor. Breaker plate with ribs provides concentrated crushing action between teeth and ribs and acts as a sizing anvil for close control of product size. (*Grundler Crusher & Pulverizer Company.*)

SIZES OF STONE PRODUCED BY JAW AND ROLLS CRUSHERS

- Even though the setting of the discharge opening of a crusher will determine the maximum-size stone produced, the aggregate sizes will range from slightly greater than the crusher setting to fine dust.
- For any given setting for jaw or roll crusher approximately *15%* of the total amount passing through the crusher will be larger than the setting.

SIZES OF STONE PRODUCED BY JAW AND ROLLS CRUSHERS

- If the opening of the screen which receives the output from such crusher are the same size as the crusher setting, 15% of the output <u>will not pass</u> through the screen.
- Figure 1 (Figure 14.4, Text) provides the percent of material passing or retained on screens having the size opening indicated.

Sizes of Stone Produced by Crushers

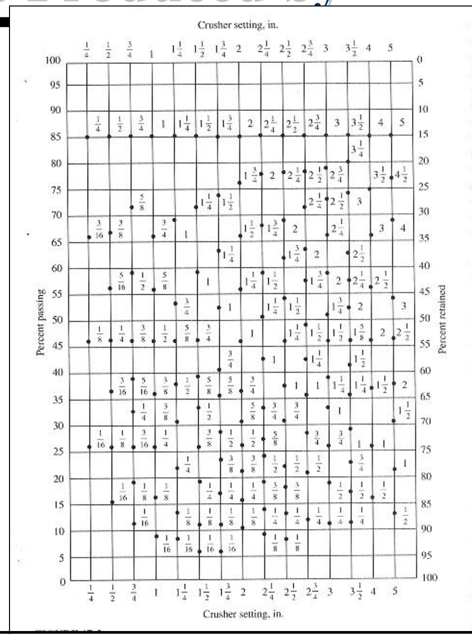


Figure 1 (Figure 14.4, Text)
Analysis of the Size of Aggregate Produced by Jaw and Roll Crushers

SIZES OF STONE PRODUCED BY JAW AND ROLLS CRUSHERS

- The chart can be applied to both jaw and roll-type crushers.
- To read the chart:
  - ✓ Select the vertical line corresponding to the crusher setting
  - ✓ Then go down this line to the number which indicates the size of screen opening
  - ✓ From the size of the screen opening proceed horizontally to the left to determine the percent of material passing through the screen or the right to determine the percent of material retained on the screen.

Example 1

- A jaw crusher with a closed setting of 3 in produces 50 tons per hour of crushed stone. Determine the amount of stone produced in tons per hour within the following size range: in excess of 2 in; between 2 and 1 in; between 1 and 1/4 in.

Example 1 (cont'd)

- From Figure 1, the amount retained on a 2-in screen is 42% of 50, which is 21 tons per hr.
- Similarly, the amount in each of the size range is determined as shown in the following Table 3:

Example 1 (cont'd)

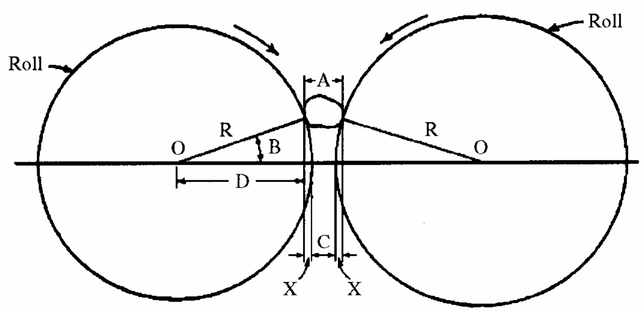
Table 3

Size Range (in)	% Passing Screen	Percent in Size Range	Total Output of Crusher (ton/hr)	Amount Produced in Size Range (ton/hr)
Over 2	100 – 58	42	50	21.0
2 – 1	58 – 33	25	50	12.5
1 – 1/4	33 – 11	22	50	11.0
¼ - 0	11 - 0	11	50	5.5
Total		**100 %**		**50.0 tph**

FEED SIZE

- The maximum size of material that may be fed to a roll crusher is <u>directly proportional to the diameter of the rolls.</u>
- If the feed contains stones that are too large, the rolls will not grip the material and pull it through the crusher.
- The angle of nip, *B*, in the following figure (Figure 2) has been found to be 16.76^0.

FEED SIZE

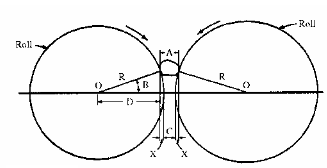


Crushing rock between two rolls.

Figure 2

FEED SIZE

- The maximum-size particles that can be crushed is determined as follows:



Crushing rock between two rolls.

Let

R = radius of rolls

B = angle of nip

$D = R \cos B = R \cos(16.76) = 0.9575\,R$

A = maximum-size feed

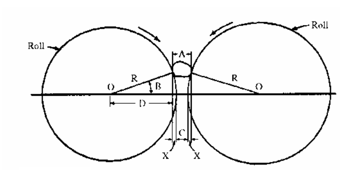
C = roll setting = size of finished product

FEED SIZE

$$X = R - D = R - 0.9575R = 0.0425R$$

$$A = 2X + C = 2(0.0425R) + C = 0.085R + C$$

$$\boxed{\therefore \text{Maximum - size Feed } (A) = 0.085R + C} \qquad (1)$$



Crushing rock between two rolls.

Example 2

Determine the maximum-size stone that may be fed to a smooth-roll crusher whose rolls are 40 in. in diameter when the roller setting (size of finished product) is 1 in.

$$\text{Maximum - size Feed } (A) = 0.085R + C$$

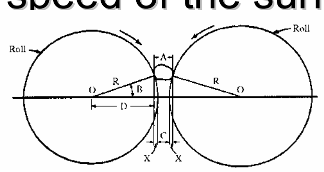
$$A = 0.085(20) + 1 = \underline{\underline{2.7 \text{ in}}}$$

CAPACITY OF ROLL CRUSHER

- The capacity of a roll crusher will vary with:
  - ✓The kind of stone
  - ✓The size of feed
  - ✓The size of the finished product
  - ✓The width of rolls
  - ✓The speed at which the rolls rotate
  - ✓The extent to which the stone is fed uniformly into the crusher.

CAPACITY OF ROLL CRUSHER

- Referring to Figure 1, the theoretical volume of a solid ribbon of material passing between the rolls in 1 min will be the product of the width of the opening times the width of the rolls times the speed of the surface of the rolls



Crushing rock between two rolls.

CAPACITY OF ROLL CRUSHER

- The volume may be expressed in cubic inches per minute or in cubic feet per minute (cfm).
- In actual practice, the ribbon of crushed stone will never be solid.
- A more realistic volume should approximate one-fourth to one-third the theoretical volume.

CAPACITY OF ROLL CRUSHER

- An equation which may be used as a guide in estimating the capacity is derived as follows:

Let

C = distance between rolls, in.
W = width of rolls, in.
S = peripheral speed of rolls, in. per min
N = speed of rolls, rpm
R = radius of rolls, in.
V_1 = theoretical volume, cu in. or cfm
V_2 = actual volume, cu in. or cfm
Q = probable capacity, tons per hour

CAPACITY OF ROLL CRUSHER

Then

$$V_1 = CWS$$

$$\text{Assume } V_2 = \frac{1}{3}V_1$$

$$\therefore V_2 = \frac{CWS}{3}, \quad \text{in ft}^3 \text{ per min}$$

$$\text{Dividing by } 1{,}728 \text{ in}^3 \text{per ft}^3$$

$$V_2 = \frac{CWS}{3(1728)} = \frac{CWS}{5{,}184}, \text{ in cfm}$$

CAPACITY OF ROLL CRUSHER

Assume the crushed stone has a unit weight of 100 lb per cubic ft, then

$$Q = \frac{100 \times 60(V_2)}{2{,}000} = 3V_2 = 3\frac{CWS}{5184} = \frac{CWS}{1728}, \text{ in tons per hour}$$

$$S = 2\pi RN$$

$$\text{Substituting for } S \text{, hence}$$

$$\boxed{Q = \frac{CW\pi RN}{864}} \qquad (2)$$

CAPACITY OF ROLL CRUSHER

- Table 4 (Table 14-6, Text) gives representative capacities for smooth-roll crushers, expressed in tons of stone per hour for material having a unit weight of 100 lb per cu ft when crushed
- The capacities should be used as a guide only in estimating the probable output of a crusher
- The actual capacity may be more or less than the given values

CAPACITY OF ROLL CRUSHER

Table 4. (Table 14-6, Text) Representative Capacities of Smooth-Roll Crushers, in Ton/hr of Stone

Representative capacities of smooth-roll crushers, in ton/hr (metric ton/hr) of stone*

Size of crusher [in. (mm)]†	Speed (rpm)	Power required [hp (kW)]	Width of opening between rolls [in. (mm)]						
			$\frac{1}{4}$ (6.3)	$\frac{1}{2}$ (12.7)	$\frac{3}{4}$ (19.1)	1 (25.4)	$1\frac{1}{2}$ (38.1)	2 (50.8)	$2\frac{1}{2}$ (63.5)
16 × 16 (414 × 416)	120	15–30 (11–22)	15.0 (13.6)	30.0 (27.2)	40.0 (36.2)	55.0 (49.7)	85.0 (77.0)	115.0 (104.0)	140.0 (127.0)
24 × 16 (610 × 416)	80	20–35 (15–26)	15.0 (13.6)	30.0 (27.2)	40.0 (36.2)	55.0 (49.7)	85.0 (77.0)	115.0 (104.0)	140.0 (127.0)
30 × 18 (763 × 456)	60	50–70 (37–52)	15.0 (13.6)	30.0 (27.2)	45.0 (40.7)	65.0 (59.0)	95.0 (86.0)	125.0 (113.1)	155.0 (140.0)
30 × 22 (763 × 558)	60	60–100 (45–75)	20.0 (18.1)	40.0 (36.2)	55.0 (49.7)	75.0 (67.9)	115.0 (104.0)	155.0 (140.0)	190.0 (172.0)
40 × 20 (1,016 × 508)	50	60–100 (45–75)	20.0 (18.1)	35.0 (31.7)	50.0 (45.2)	70.0 (63.4)	105.0 (95.0)	135.0 (122.0)	175.0 (158.5)
40 × 24 (1,016 × 610)	50	60–100 (45–75)	20.0 (18.1)	40.0 (36.2)	60.0 (54.3)	85.0 (77.0)	125.0 (113.1)	165.0 (149.5)	210.0 (190.0)
54 × 24 (1,374 × 610)	41	125–150 (93–112)	24.0 (21.7)	48.0 (43.5)	71.0 (64.3)	95.0 (86.0)	144.0 (130.0)	192.0 (173.8)	240.0 (217.5)

Courtesy Iowa Manufacturing Company.

*Based on stone weighing 100 lb per cu ft when crushed.

†The first number indicates the diameter of the rolls, and the second indicates the width of the rolls.

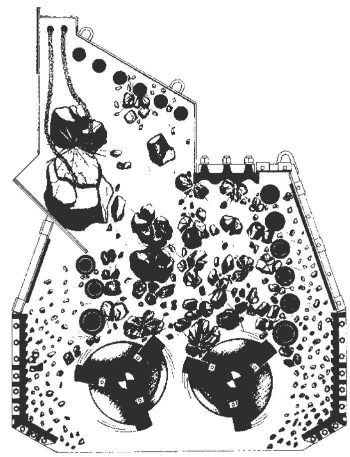
IMPACT CRUSHERS

- In impact crusher stones are broken by the application of high-speed impact forces.
  - ✓**Single rotor.** The single rotor-type impact crusher breaks the stone both by the impact action of the impellers striking the feed material and by the impact which results when the impeller-driven material strikes against the aprons within the crusher unit.

IMPACT CRUSHERS

- ✓**Double rotor.** These units are similar to the single rotor models and accomplish aggregate-size reduction by the same mechanical mechanisms. They will produce a somewhat higher proportion of fines. With both single and double rotor crushers, the impacted material flows freely to the bottom of the units without any further size reduction.

IMPACT CRUSHERS



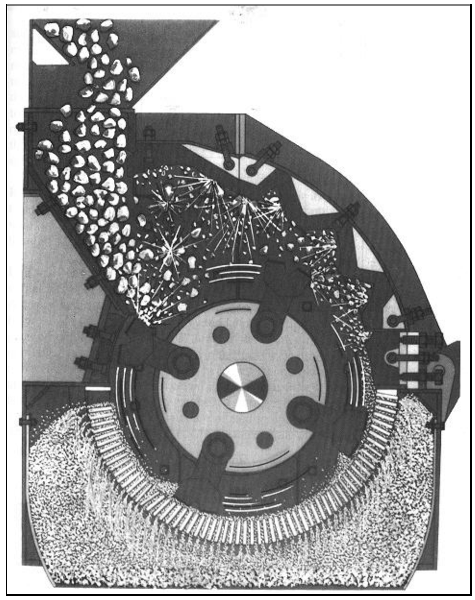
Cutaway showing double rotor impact breaker. (*Iowa Manufacturing Company.*)

IMPACT CRUSHERS

- ✓**Hammer mills.** The hammer mill, which is the most widely used impact crusher, may be used for primary or secondary crushing. The basic parts of a unit include a housing frame, a horizontal shaft extending through the housing, a number of arms and hammers attached to a spool which is mounted on the shaft, one or more manganese-steel or other hard-steel breaker plates, and a series of grate bars whose spacing may be adjusted to regulate the width of openings through which the crushed stone flows.

IMPACT CRUSHERS

Cutaway of Hammer Mill Rock Crusher Showing Breaking Action



HAMMER MILL ROCK CRUSHER

Table 5. Representative Capacities for Hammer Mills

Representative capacities for hammer mills, in ton/hr (metric ton/hr) of stone†

Size feed opening [in. (mm)]	Size feed [in. (mm)]	Power required [hp (kW)]	Width of openings between grate bars [in. (mm)]						
			$\frac{1}{8}$ (3.2)	$\frac{3}{16}$ (4.7)	$\frac{1}{4}$ (6.4)	$\frac{3}{8}$ (9.5)	$\frac{1}{2}$ (12.7)	1 (25.4)	$1\frac{1}{4}$ (31.8)
$6\frac{1}{4} \times 9$ (159 × 229)	3 (76.2)	15–20 (11–15)	2.5 (2.3)	3.5 (3.2)	5.0 (4.5)	8.0 (7.2)	10.0 (9.1)		
12 × 15 (304 × 380)	3 (76.2)	50–60 (37–45)	9.0 (8.2)	13.0 (11.8)	17.0 (15.4)	23.0 (20.8)	29.0 (26.2)	36.0 (32.6)	39.0 (35.2)
15 × 25 (380 × 635)	6 (152.4)	100–125 (75–93)	18.0 (16.4)	25.0 (22.6)	31.0 (28.1)	40.0 (36.3)	47.0 (42.6)	65.0 (59.0)	70.0 (63.5)
15 × 37 (380 × 940)	6 (152.4)	150–200 (112–149)	27.0 (24.5)	37.0 (33.6)	47.0 (42.6)	60.0 (54.5)	71.0 (64.4)	97.0 (88.0)	105.0 (95.4)
15 × 49 (380 × 1, 245)	6 (152.4)	200–250 (149–187)	36.0 (32.6)	50.0 (45.4)	63.0 (57.0)	80.0 (72.5)	95.0 (85.9)	130.0 (117.5)	140.0 (126.8)

†Based on stone weighing 100 lb per cu ft when crushed.

Courtesy Fiat-Allis Construction Machinery, Inc.

SPECIAL AGGREGATE PROCESSING UNITS

- To produce fine aggregate, such as sand, from stone that has been crushed to suitable sizes by other crushing equipment, rod or ball mills are frequently used.
- It is not uncommon for concrete specifications to require the use of a homogeneous aggregate regardless of size.
- If crushed stone is used for coarse aggregate, sand manufactured from the same stone can satisfy the specifications.

Rod Mill

- *A rod mill* is a circular steel shell that is lined on the inside with a hard wearing surface.
- Rod mill is equipped with a suitable support or trunnion arrangement at each end and a driving gear at one end. It is operated with its axis in a horizontal position. The rod mill is charged with steel rods, whose lengths are slightly less than the length of the mill.

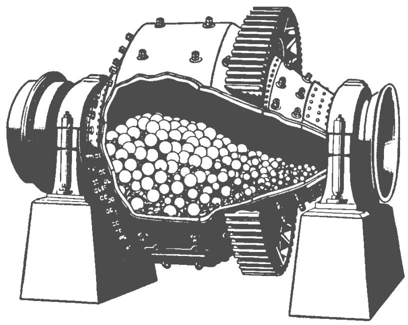
Rod Mill

- Crushed stone, which is fed through the trunnion at one end of the mill, flows to the discharge at the other end. As the mill rotates slowly, the stone is constantly subjected to the impact of the tumbling rods, which produce the desired grinding. A mill may be operated wet or dry, with or without water added.

Ball Mill

- A ***ball mill*** is similar to a rod mill but it uses steel balls instead of rods to supply the impact necessary to grind the stone.
- ***Ball mills*** will produce fine material with smaller grain sizes than those produced by a rod mill.

Ball Mill



Section through a conical ball mill.

CRASHING EQUIPMENT SELECTION

- In selecting crushing and screening equipment, it is essential that certain information be known prior to making the selection.

CRASHING EQUIPMENT SELECTION

- The information needed should include, but will not necessarily be limited to, the following items:
  1. The kind of stone to be crushed.
  2. The maximum individual size of the feed stones and perhaps the size ranges of the feed to the plant.
  3. The method of feeding the crushers.
  4. The required capacity of the plant.
  5. The percent of material failing within specified size ranges.

SCREENING AGGREGATE

- Screening of crushed stone is necessary in order to separate the aggregate by size ranges.
- Most specifications covering the use of aggregate stipulate that the different sizes shall be combined to produce a blend having a given size distribution.

SCREENING AGGREGATE

- Persons who are responsible for preparing the specifications for the use of aggregate realize that crushing and screening cannot be done with complete precision, and accordingly they allow some tolerance in the size distribution.

SCREENING AGGREGATE

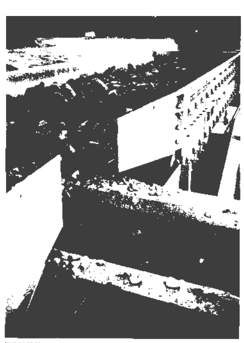
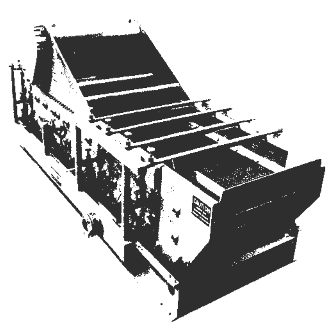
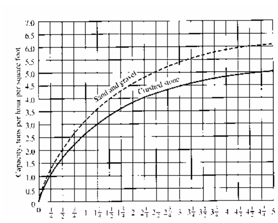


FIGURE 17-20



Triple-deck screen with bars for washing aggregate. *(Iowa Manufacturing Company.)*



Screen capacity chart.

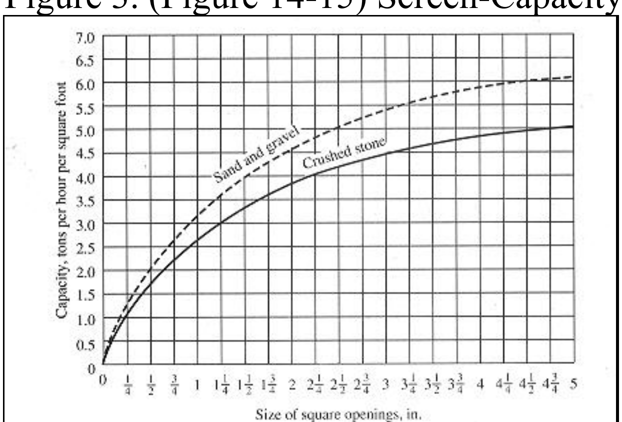
DETERMINATION OF REQUIRED SCREEN SIZE

- Figure 3 gives the theoretical capacity of a screen in tons per hour per square foot based on material weighing 100 lb per cu ft when crushed
- The corrected capacity of a screen is given by the following equation

$$\boxed{Q = ACEDG} \qquad (3)$$

DETERMINATION OF REQUIRED SCREEN SIZE

Figure 3. (Figure 14-15) Screen-Capacity Chart



DETERMINATION OF REQUIRED SCREEN SIZE

Where

- Q = capacity of screen, tons per hour
- A = area of screen, sq ft
- C = theoretical capacity of screen, tons per hour per sq ft
- E = efficiency factor
- D = deck factor
- G = aggregate factor

DETERMINATION OF REQUIRED SCREEN SIZE

The minimum area of a screen to provide a given capacity is determined from the following expression:

$$\boxed{A = \frac{Q}{CEDG}} \qquad (4)$$

Tables 6, 7, and 8 give the efficiency, deck, and aggregate-size factors for use in Eqs. 3 and 4

DETERMINATION OF REQUIRED SCREEN SIZE

Table 6. Efficiency Factors for Aggregate Screening

Permissible Screen Efficiency (%)	Efficiency Factor
95	1.00
90	1.25
85	1.50
80	1.75
75	2.00

Table 7. Deck Factors for Aggregate Screening

For Deck Number	Deck Factor
1	1.00
2	0.90
3	0.75
4	0.60

DETERMINATION OF REQUIRED SCREEN SIZE

Table 8. Aggregate-size Factors for Screening

Percent of Aggregate less than ½ the Size of Screen Opening	Aggregate-size Factor
10	0.55
20	0.70
30	0.80
40	1.00
50	1.20
60	1.40
70	1.80
80	2.20
90	3.00

Example 3

Determine the minimum-size single-deck screen, having 1.5-in-sq openings, for screening 120 tons per hour of dry crushed stone, weighing 100 lb per cu ft when crushed. A screening efficiency of 90% is satisfactory. An analysis of the aggregate indicates that approximately 30% of it will be less than 0.75 in. in size.

Example 3 (cont'd)

The values of the factors to be used in Eq. 4 are as follows:

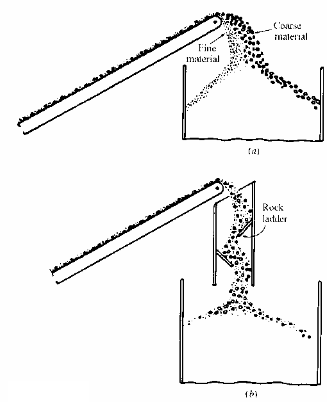
Q = 120 ton/hr	
C = 3.3 ton/hr per sq ft	(Figure 3)
E = 1.25	(Table 6)
D = 1.0	(Table 7)
G = 0.8	(Table 8)

Substituting these values in Eq. 4, we get

$$A = \frac{Q}{CEDG} = \frac{120}{3.3(1.25)(1.0)(0.8)} = \underline{36.4 \text{ sq ft}}$$

HANDLING CRASHED-STONE AGGREGATE

- After stone is crushed and screened to provide the desired size ranges, it is necessary to handle the stone carefully or the large and small particles may separate, thereby destroying the blend in sizes which is essential to meeting graduation requirements. If aggregate is permitted to flow freely off the end of a belt conveyor, especially at some height above the storage pile, the material will be segregated by sizes.



Method of preventing the segregation of aggregate discharge from a conveyor belt.