7

Production of Aggregate, Concrete, and Asphalt Mixes

The production of high-quality concrete and asphalt mixes requires a supply of aggregate (gravel, sand, and mineral filler) meeting the specified gradation and other requirements. Most commonly, such aggregate is produced by crushing rock or gravel and blending it with sand and other minerals as required. Other construction operations which require crushed stone include highway and airfield base courses, drainage facilities, asphalt surface treatments, bedding for pipelines, and railroad ballast. The following sections describe the major steps in the production of aggregate, concrete mixes, and asphalt mixes.

7–1 PRODUCTION OF AGGREGATE

To produce quality aggregate, rock or gravel must be excavated, loaded, and transported to an aggregate processing plant (crushing plant) such as that shown in Figure 7–1. Here the raw material is washed if necessary, crushed, screened, sorted, and blended if necessary, and stored or loaded into haul units. Sands are not crushed but often require washing and dewatering before use.

Rock Crushers

Rock crushers such as the one shown in Figure 7–2 utilize mechanical action to reduce rock or gravel to a smaller size. The principal types of rock crushers and their characteristics are shown in Table 7–1 and include jaw crushers, impact crushers, cone or gyratory crushers, and roll crushers.

Jaw crushers (Figure 7–3a) utilize a fixed plate and a moving plate to crush stone between the two jaws. Jaw crushers are principally used as primary crushers. *Impact crushers* (Figure 7–3b) use breakers or hammers rotating at high speed to fracture the input stone. There are various types of impact crushers including impact breakers, horizontal and vertical shaft impactors, hammermills, and limemills. *Cone* or *gyratory crushers* (Figure 7–3c) use an eccentrically rotating head to crush stone between the rotating head and the crusher

Figure 7–1 Aggregate processing plant. (Courtesy of Cedarapids, Inc.)

body. *Roll crushers* (Figure 7–3d) produce fracturing of stone by passing the material between two or more closely spaced rollers. *Limemills* are similar to hammermills but are designed to produce a fine product from limestone.

The gradation of crusher output depends on crusher type and size, crusher setting, feed size, crusher speed, and other operating conditions. The best estimate of the gradation of a particular crusher output will be obtained from the crusher manufacturer's data or previous experience. However, Tables 7–2 and 7–3 present representative output gradations for jaw and roller crushers respectively. These tables will be used in the examples and problems which follow. Notice that a significant fraction of crusher output is larger than the selected crusher closed side setting.

The crusher which first receives raw stone is known as the *primary crusher.* If the product is passed to another crusher, this crusher is known as a *secondary crusher.* Similarly, if yet another stage of crushing is required, the third crusher in line is known as a *tertiary crusher.* Screens are used to sort crusher output and feed oversize material back for recrushing. If the material makes a single pass through the crusher and none is fed back to the crusher, this is classified as *open circuit* crushing. When some material is fed back to the crusher for recrushing, the crusher is operating in *closed circuit.*

Figure 7–2 Portable cone crusher. (Courtesy of Kolberg-Pioneer, Inc., and Johnson Crushers International)

Table 7–1 Principal types of rock crushers and their characteristics

Crusher Type	Maximum Feed Size	Reduction Ratio	Product Size	Crushing Stage
Jaw crusher	50 (1270 mm)	6 to 1	3″ –20″ (76–508 mm)	Primary
Impact breakers	60 (1524 mm)	20 to 1	2 –16 (51–406 mm)	Primary
Horizontal secondary impactor	16 (406 mm)	6–8 to 1	3/4 –4 (19–102 mm)	Secondary/ Tertiary
Standard head cone	14 (356 mm)	12 to 1	3/4 –4 (19–102 mm)	″
Hammermill	8 (203 mm)	20 to 1	#4–1½″ (4.8–38 mm)	″
Fine head cone	8 (203 mm)	4–6 to 1	1/4 –2 (6.4–51 mm)	″
Triple roll	8 (203 mm)	4–5 to 1	1/4 –2 (6.4–51 mm)	″
Dual roll	6 (152 mm)	2–2.5 to 1	1/4 –3 (6.4–76 mm)	″
Limemill	4 (101 mm)	20 to 1	#10–#4 (1.7–4.8 mm)	″
Vertical shaft impactor	3 (76 mm)	4–8 to 1	3/8″–1½″ (9.5–38 mm)	″

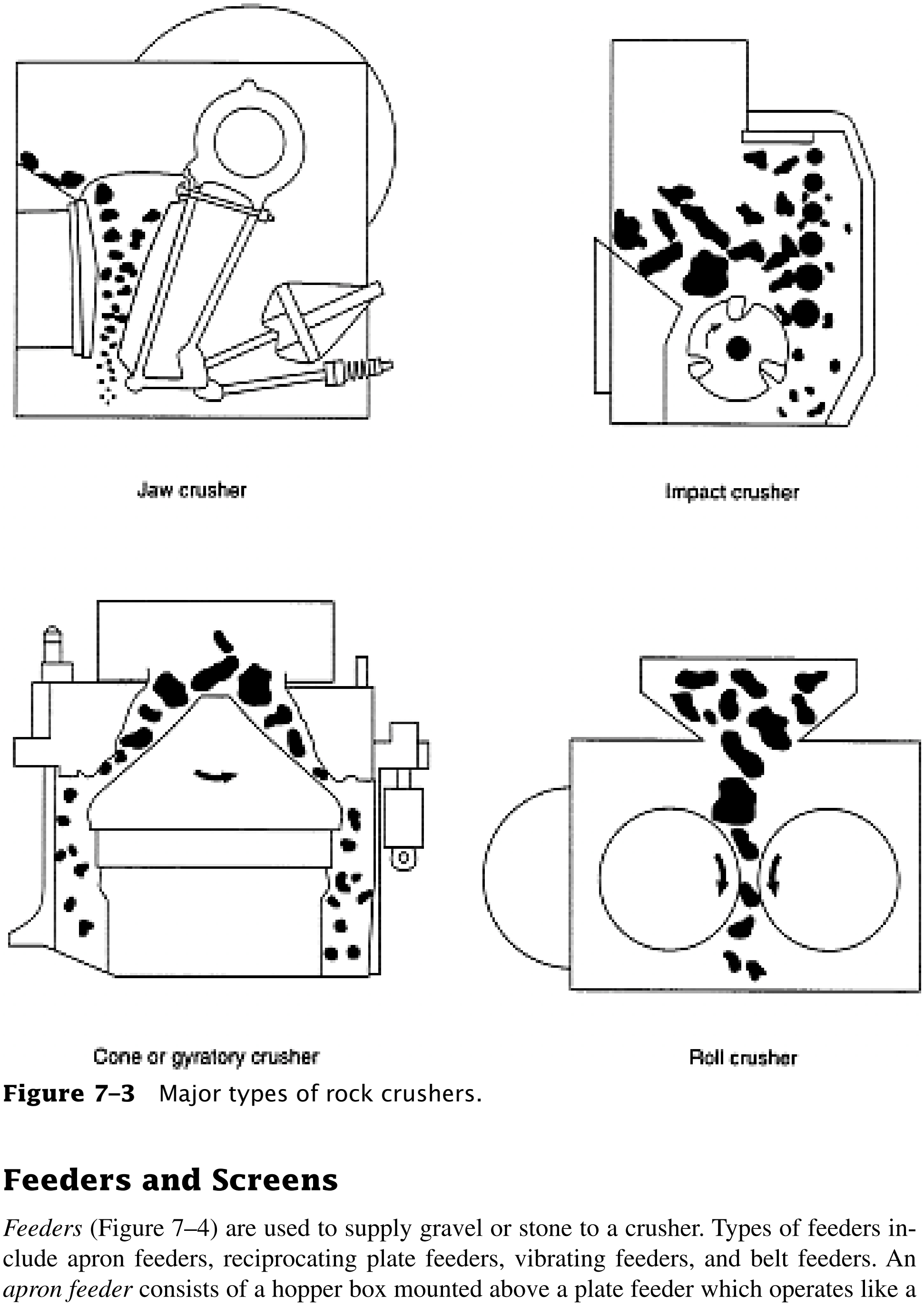


Figure 7–3 Major types of rock crushers.

Feeders and Screens

Feeders (Figure 7–4) are used to supply gravel or stone to a crusher. Types of feeders include apron feeders, reciprocating plate feeders, vibrating feeders, and belt feeders. An *apron feeder* consists of a hopper box mounted above a plate feeder which operates like a conveyor to feed stone into a crusher. Apron feeders often incorporate a grizzly to remove oversize stone from the crusher input. A *grizzly* is simply a set of widely spaced bars or rods which serve to remove oversized material which might jam the crusher. A *reciprocating*

Table 7–2 Gradation of jaw crusher output (percent passing—open circuit)

Screen Size		Crusher Closed Side Setting											
	in.	¾	1	1¼	1½	2	2½	3	4	5	6	7	8
in.	mm	19	25	32	38	51	64	76	102	127	152	178	203
10	254									100	97	87	84
8	203									96	88	81	73
7	178								100	90	82	74	65
6	152							100	94	83	69	64	55
5	127						100	98	86	75	63	55	47
4	102						97	90	75	62	51	43	36
3	76					100	86	78	58	47	37	32	27
2½	64			100	100	93	78	66	48	38	31	25	23
2	51		100	98	96	82	64	52	39	29	25	21	18
1½	38	100	96	90	84	65	47	39	29	22	20	17	14
1¼	32	99	91	83	74	55	40	33	25	20	17	15	12
1	25	94	79	68	58	43	31	26	19	16	14	11	10
¾	19	80	61	55	43	31	23	20	15	13	11	9	7
½	13	58	41	33	30	22	16	14	11	9	8	7	6
⅜	10	41	29	25	22	17	13	11	8	7	6	6	5
¼	6	27	20	18	16	12	9	8	6	5	5	4	3
#4	4.8	20	15	13	12	9	7	6	5	4	4	3	2
#8	2.4	10	8	8	7	6	4	4	3	2	2	2	1
#16	1.2	7	5	5	5	3	3	3	3	2	2	2	1
#30	0.6	4	3	3	3	2	2	1	1	1	0.8	0.6	0.6
#50	0.3	2	2	2	1	1	1	1	1	0.6	0.5	0.4	0.4
#100	0.2	1	1	1	1	1	0.5	0.5	0.4	0.3	0.3	0.2	0.2

Table 7–3 Gradation of roll crusher output (percent passing—open circuit)

Screen Size		Crusher Closed Side Setting											
		in.	¼	⅜	½	¾	1	1¼	1½	2	2½	3	4
in.	mm	mm	6	10	13	19	25	32	38	51	64	76	102
6	152											100	100
5	127										100	96	78
4	102									100	95	84	75
3	76								100	93	78	76	58
2½	64							100	96	82	72	64	48
2	51						100	95	87	77	63	52	37
1½	38						92	82	78	58	48	38	28
1¼	32					100	86	80	66	49	40	33	25
1	25				100	90	79	66	52	39	32	27	20
¾	19			100	92	80	60	49	38	29	25	21	16
½	13		100	90	81	58	41	32	27	22	18	16	12
⅜	10		97	82	62	41	29	25	21	16	14	12	9
¼	6		82	60	42	28	21	18	16	12	10	9	7
#4	4.8		59	43	31	21	16	14	12	10	8	7	5
#8	2.4		32	23	17	13	10	8	7	6	5	4	3
#16	1.2		16	13	9	7	6	5	4	3	2	2	2
#30	0.6		9	7	5	4	3	3	3	2	1	1	1
#50	0.3		6	4	3	3	2	2	2	1	0.8	0.7	0.6
#100	0.2		4	3	2	2	1	1	1	0.5	0.3	0.3	0.2

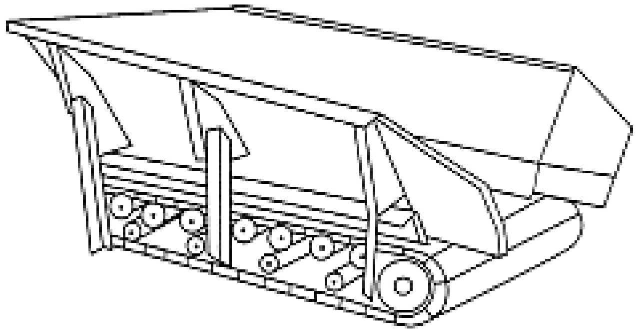


Figure 7–4 Apron feeder.

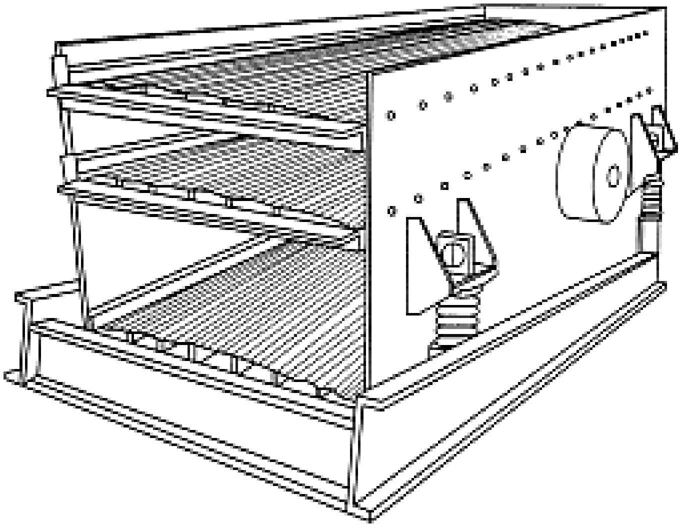
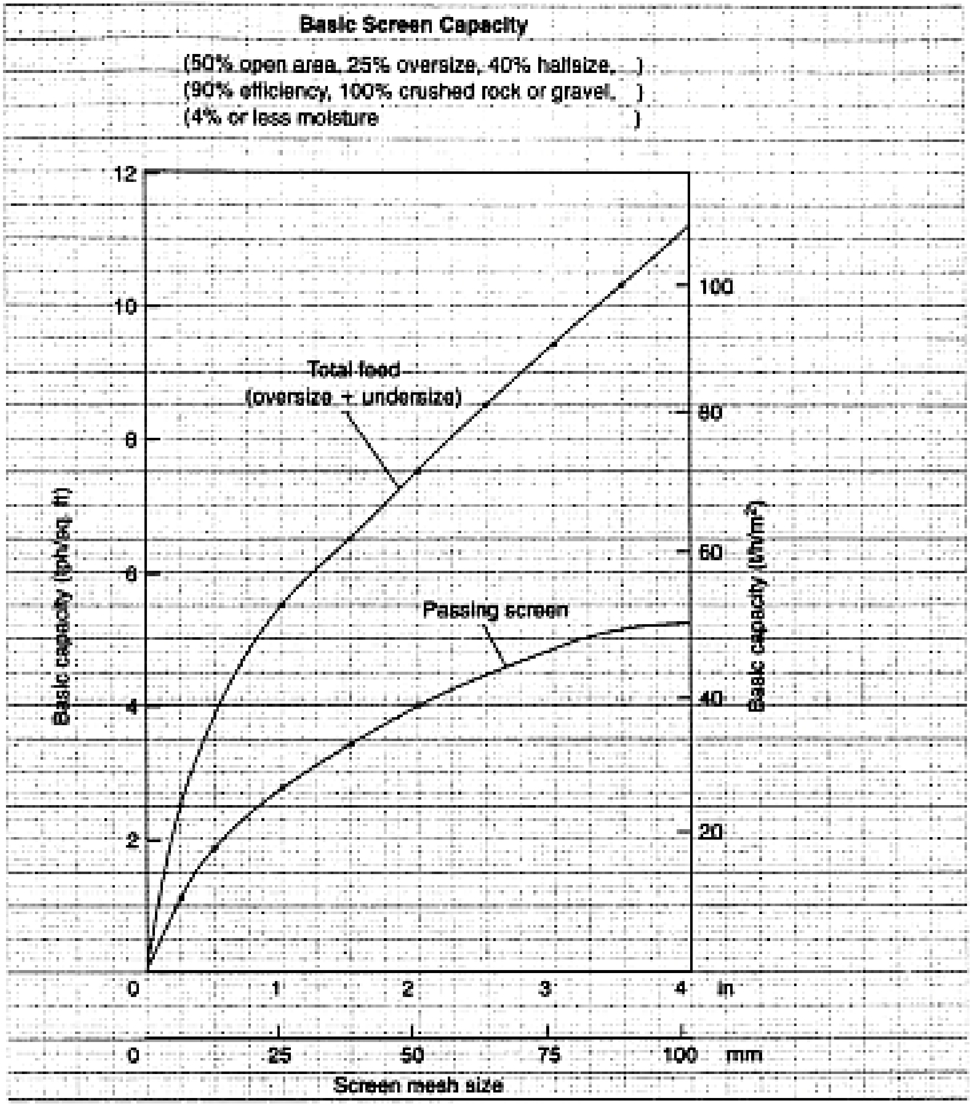


Figure 7–5 Three-deck vibrating screen.

plate feeder is somewhat similar to an apron feeder but is smaller and used mainly to feed secondary or tertiary crushers. A reciprocating motion rather than the conveyor action of the apron feeder is used to move material into the crusher. A *vibrating feeder* uses vibratory action to move material from the receiving hopper into the crusher. *Belt feeders* combine a receiving hopper with a conveyor belt to move material to the crusher.

Screens (Figure 7–5) are used at a number of points in the aggregate processing cycle to separate aggregate by size for storage, blending, or recrushing. There are a number of types of screens including horizontal and inclined vibrating screens and rotating screens. Screens are often placed into a *deck* consisting of two or more screens placed one above the other. A *scalping screen* is simply a screen used to remove oversized particles from the aggregate stream.

The capacity of a screen is determined by a number of factors including screen size and screen opening size; slope of the screen; position in the deck; amount of oversize and half-size material; and material condition, shape, and weight factors. Due to the complexity of the problem of estimating screen capacity, the methods used are largely empirical. One method for estimating both permissible total feed (oversize plus undersize) to the screen and the passing capacity of the screen is presented in Figure 7–6 and illustrated in Example 7–1.



Modifying Factors

Deck factor		Halfsize factor		Oversize factor		
					Factor	
Position	Factor	% Feed less than halfsize	Factor	% Feed larger than opening	Passing screen	Total feed
Top	1.0	0	0.4	0	1.05	0.95
Second	0.9	20	0.6	20	1.02	0.97
Third	0.8	40	1.0	40	0.95	1.10
Fourth	0.7	60	1.4	60	0.85	1.30
		80	1.8	80	0.70	2.00

Weight Factor

$$W = \frac{\text{Weight (lb/cu ft)}}{100}$$

$$\left[W = \frac{\text{Weight (kg/m}^3\text{)}}{1600} \right]$$

Figure 7–6 Estimating screen capacity.

EXAMPLE 7–1

A jaw crusher is producing 250 tons/h (227 t/h) of crushed gravel and discharging it onto a 3-screen deck. The top screen in the deck is a 1½ in. (38-mm) screen. The gradation of crusher output shows 100% passing 3 in. (76 mm), 92% passing 1½ in. (38 mm), and 80% passing ¾ in. (19 mm). Material weight is 115 lb/cu ft (1842 kg/m^3). Find the minimum size of the 1½ in. (38-mm) screen to be used. Check both total screen load and screen passing capacity.

SOLUTION

Basic capacity (Figure 7–6):

Total feed = 6.5 tons/h/sq ft (62 t/h/m^2)

Passing screen = 3.5 tons/h/sq ft (34 t/h/m^2)

Deck position factor (top) = 1.0
Halfsize factor (80%) = 1.8
Oversize factor (8%):

Total feed = 0.96 Passing screen = 1.04

$$\text{Weight factor} = \frac{115}{100} = 1.15$$

$$\left[= \frac{1842}{1600} = 1.15 \right]$$

Total feed = 250 tons/h (227 t/h)
Passing screen = 250 × 0.92 = 230 tons/h (209 t/h)
Total feed capacity = 6.5 × 1.0 × 1.8 × 0.96 × 1.15 = 12.9 tons/h/sq ft

$$[= 62 \times 1.0 \times 1.8 \times 0.96 \times 1.15 = 123 \text{ t/h/m}^2]$$

$$\text{Required screen area for total feed} = \frac{250}{12.9} = 19.4 \text{ sq ft}$$

$$\left[= \frac{227}{123} = 1.85 \text{ m}^2 \right]$$

Passing capacity = 3.5 × 1.0 × 1.8 × 1.04 × 1.15 = 7.5 tons/h/sq ft

$$[= 34 \times 1.0 \times 1.8 \times 1.04 \times 1.15 = 73 \text{ h/t/m}^2]$$

$$\text{Required screen area for passing} = \frac{230}{7.5} = 30.7 \text{ sq ft}$$

$$\left[= \frac{209}{73} = 2.9 \text{ m}^2 \right]$$

Therefore, the minimum screen area required for this screen is determined by the screen passing capacity and is equal to 30.7 sq ft (2.9 m^2).

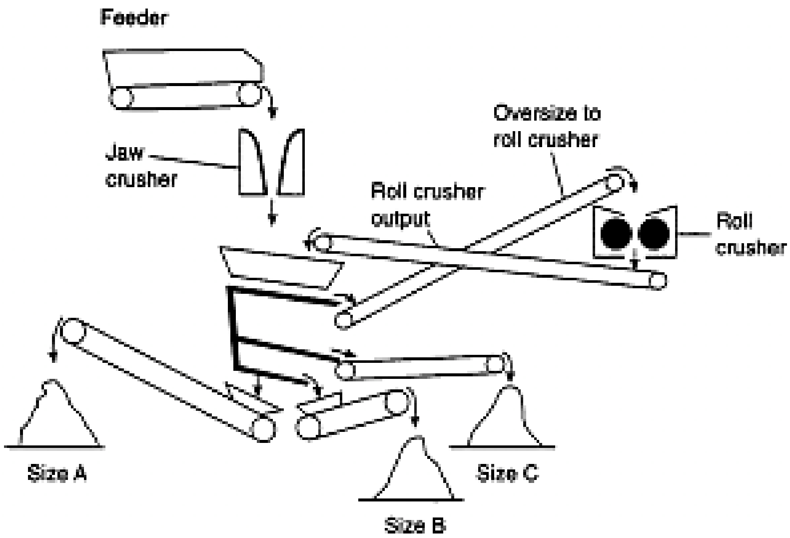


Figure 7–7 Aggregate flow through crushers.

The Crushing Cycle

A typical flow of stone through a primary jaw crusher and a secondary roll crusher is illustrated in Figure 7–7. Notice that the output of the primary crusher is separated by screening and the larger stone is sent to the roll crusher. The output of both crushers is further screened to divide the stone into the desired size ranges.

Estimating the production of an aggregate plant for a specific output is complex since it depends on many factors. Estimates are usually based on manufacturer's data and previous experience. However, computer programs, such as that presented in reference 5, have been developed to assist in making production estimates.

EXAMPLE 7–2

A primary jaw crusher with a closed setting of 4 in. (102 mm) is producing 200 tons/h (181 t/h). The crusher output is to be screened into the following sizes: 2 in. (51 mm) and over, 1¼ in. (32 mm) to 2 in. (51 mm), ½ in. (13 mm) to 1¼ in. (32 mm), and under ½ in. (13 mm). A three-deck vibrating screen will be used to separate the stone. Jaw crusher output which does not pass the 2-in. (51-mm) screen will go to a roll crusher set at 2 in. (51 mm). The output from the roll crusher will be fed back over the 2-in. (51-mm) screen. Determine the output of this plant in tons per hour (t/h) for each of the following sizes:

1¼ to 2 in. (32–51 mm)

½ to 1¼ in. (13–32 mm)

under ½ in. (<13 mm)

SOLUTION

Distribution of primary crusher output (Table 7–2):

Size		Output
inches	*mm*	*tons per hour[t/h]*
> 2	> 51	(100–0.39) × 200 = 122.0 [111.0] to roll
1¼ to 2	32–51	(0.39–0.25) × 200 = 28.0 [25.0]
½ to 1¼	13–32	(0.25–0.11) × 200 = 28.0 [25.0]
< ½	< 13	(0.11) × 200 = 22.0 [20.0]

Distribution of roll crusher output (Table 7–3):

Crusher load required to yield 122 tons/h (111 t/h) passing 2-in. (51-mm) screen $= \dfrac{122}{0.77} = 158.4\ \text{tons/h}\ (143.7\ \text{t/h})$

Size		Output
inches	*mm*	*tons per hour[t/h]*
> 2	> 51	(1.00–0.77) × 158.4 = 36.4 [33.1] recycle
1¼ to 2	32–51	(0.77–0.49) × 158.4 = 44.4 [40.2]
½ to 1¼	13–32	(0.49–0.22) × 158.4 = 42.8 [38.8]
< ½	< 13	(0.22) × 158.4 = 34.8 [31.6]

Combined output:

Size		Output
inches	*mm*	*tons per hour[t/h]*
> 2	> 51	0
1¼ to 2	32–51	28.0 + 44.4 = 72.4 [65.7]
½ to 1¼	13–32	28.0 + 42.8 = 70.8 [64.2]
< ½	< 13	22.0 + 34.8 = 56.8 [51.5]
		Total = 200.0 [181.4]

Notice that the total feed to the roll crusher is the sum of the jaw crusher output larger than 2 in. (51 mm) plus the oversized stone from the roll crusher which is fed back to the roll crusher. Thus, the total roll crusher feed is 122.0 tons/h (111.0 t/h) plus 36.4 tons/h (33.1 t/h) or 158.4 tons/h (144.1 t/h). Initially the plant output will be somewhat less than 200 tons/h (181.4 t/h) but will soon reach a steady-state output of 200 tons/h (181.4 t/h).

Washers and Other Equipment

Aggregates often require washing to remove silt, clay, or organic material prior to processing and sorting. Common types of washing equipment include scrubber drums, wet screens, log washers, sand dehydrators, and classifying tanks. *Scrubber drums* consist of an inclined revolving drum equipped with agitator fins and water spray nozzles. Undesirable material is removed as the aggregate is mixed with water and agitated while moving down the drum. *Wet screens* are essentially vibrating screens equipped with water spray bars to remove undesirable material as the aggregate is screened. *Log washers* utilize revolving auger paddles immersed in a tub of water to wash off undesirable material as the aggregate is moved through the tub by the auger blades. *Sand dehydrators* consist of rotating auger screws mounted in an inclined trough. Water and material to be cleaned are piped into the bottom of the trough. As the aggregate is moved up through the trough by the screw conveyors, the lighter undesirable material overflows into a flume and is drained off. *Classifying tanks* are essentially settling tanks which float off undesirable material while allowing clean aggregate to settle to the tank bottom where it can be removed.

The other major piece of aggregate processing equipment is the *belt conveyor.* Portable or stationary belt conveyors are used to move aggregate between crushers, screens, washers, and stockpiles, and to load the processed material into haul units. A *radial stacker* is a form of belt conveyor which pivots about a base point so that the conveyor discharges its output to form a semicircular stockpile.

7–2 PRODUCTION OF CONCRETE

Concrete is produced by mixing portland cement, aggregate, and water. In addition, a fourth component, an additive, may be added to improve the workability or other properties of the concrete mix. The construction operations involved in the production of concrete include batching, mixing, transporting, placing, consolidating, finishing, and curing. The production and transporting of plastic concrete are described in this section. The placing, consolidating, finishing, and curing operations are described in Chapter 8 for pavements and in Chapter 12 for building construction.

To meet design requirements while facilitating construction, it is important that concrete possess certain properties. Hardened concrete must meet design strength requirements and be uniform, watertight, durable, and wear-resistant. Desirable properties of plastic concrete include workability and economy. All of these properties are influenced by the concrete components and mix design used as well as by the construction techniques employed.

Types of Concrete

Concrete is classified into several categories according to its application and density. *Normal-weight concrete* usually weighs from 140 to 160 lb/cu ft (2243 to 2563 kg/m^3), depending on the mix design and type of aggregate used. A unit weight of 150 lb/cu ft

(2403 kg/m^3) is usually assumed for design purposes. Typical 28-d compressive strength ranges from 2000 to 4000 psi (13 790 to 27 580 kPa). *Structural lightweight concrete* has a unit weight less than 120 lb/cu ft (1922 kg/m^3) with a 28-d compressive strength greater than 2500 lb/sq in. (17 237 kPa). Its light weight is obtained by using lightweight aggregates such as expanded shale, clay, slate, and slag. *Lightweight insulating concrete* may weigh from 15 to 90 lb/cu ft (240 to 1442 kg/m^3) and have a 28-d compressive strength from about 100 to 1000 lb/sq in. (690 to 6895 kPa). As the name implies, such concrete is primarily utilized for its thermal insulating properties. Aggregates frequently used for such concrete include perlite and vermiculite. In some cases, air voids introduced into the concrete mix in foam replace some or all of the aggregate particles.

Mass concrete is concrete used in a structure such as a dam in which the weight of the concrete provides most of the strength of the structure. Thus little or no reinforcing steel is used. Its unit weight is usually similar to that of regular concrete. *Heavyweight* is concrete made with heavy aggregates such as barite, magnetite, and steel punchings; it is used primarily for nuclear radiation shielding. Unit weights may range from 180 to about 400 lb/cu ft (2884 to 6408 kg/m^3). *No-slump concrete* is concrete having a slump of 1 in. (2.5 cm) or less. Slump is a measure of concrete consistency obtained by placing concrete into a test cone following a standard test procedure (ASTM C143) and measuring the decrease in height (slump) of the sample when the cone is removed. Applications of no-slump concrete include bedding for pipelines and concrete placed on inclined surfaces.

Refractory concrete is concrete that is suitable for high-temperature applications such as boilers and furnaces. The maximum allowable temperature for refractory concrete depends on the type of refractory aggregate used. *Precast concrete* is concrete that has been cast into the desired shape prior to placement in a structure. *Architectural concrete* is concrete that will be exposed to view and therefore utilizes special shapes, designs, or surface finishes to achieve the desired architectural effect. White or colored cement may be used in these applications. Surface textures may include exposed aggregates, raised patterns produced by form liners, sandblasted surfaces, and hammered surfaces. Architectural concrete panels are often precast and used for curtain walls and screens.

Concrete Components

The essential components of concrete are portland cement, aggregate, and water. Another component, an admixture or additive, is often added to impart certain desirable properties to the concrete mix. The characteristics and effects of each of these components on the concrete are discussed in the following paragraphs.

Cement

There are five principal types of portland cement, classified by the American Society for Testing and Materials (ASTM) as Types I to V, used in construction. Type I (normal) portland cement is a general-purpose cement suitable for all normal applications. Type II (modified) portland cement provides better resistance to alkali attack and produces less heat of hydration than does Type I cement. It is suitable for use in structures such as large piers and drainage systems, where groundwater contains a moderate level of sulfate. Type III (high early strength) cement provides 190% of Type I strength after 1 day of curing. It also produces about 150% of the heat of hydration of normal cement during the first 7 d. It is used to permit early removal of forms and in cold-weather concreting. Type IV (low heat) cement produces only 40 to 60% of the heat produced by Type I cement during the first 7 d. However, its strength is only 55% of that of normal cement after 7 d. It is produced for use in massive structures such as dams. Type V (sulfate-resistant) cement provides maximum resistance to alkali attack. However, its 7-d strength is only 75% of normal cement. It should be used where the concrete will be in contact with soil or water that contains a high sulfate concentration.

In addition to these five major types of cement, ASTM has established standards for a number of special cement types. Types IA, IIA, and IIIA are the same as Types I, II, and III, with the addition of an air-entraining agent. Type IS is similar to Type I except that it is produced from a mixture of blast-furnace slag and portland cement. Type IS-A contains an air-entraining agent. Types IP, IP-A, P, and P-A contain a pozzolan in addition to portland cement. Because of their reduced heat of hydration, pozzolan cements are often used in large hydraulic structures such as dams. Types IP-A and P-A cements also contain an air-entraining agent. White portland cement (ASTM C150 and C175) is also available and is used primarily for architectural purposes.

Aggregates

Aggregate is used in concrete to reduce the cost of the mix and to reduce shrinkage. Because aggregates make up 60 to 80% of concrete volume, their properties strongly influence the properties of the finished concrete. To produce quality concrete, each aggregate particle must be completely coated with cement paste and paste must fill all void spaces between aggregate particles. The quantity of cement paste required is reduced if the aggregate particle sizes are well distributed and the aggregate particles are rounded or cubical. Aggregates must be strong, resistant to freezing and thawing, chemically stable, and free of fine material that would affect the bonding of the cement paste to the aggregate.

Water

Water is required in the concrete mix for several purposes. Principal among these is to provide the moisture required for hydration of the cement to take place. Hydration is the chemical reaction between cement and water which produces hardened cement. The heat that is produced by this reaction is referred to as *heat of hydration.* If aggregates are not in a saturated, surface-dry (SSD) condition when added to a concrete mix, they will either add or subtract water from the mix. Methods for correcting the amount of water added to a concrete batch to compensate for aggregate moisture are covered in this chapter. The amount of water in a mix also affects the plasticity or workability of the plastic concrete.

It has been found that the strength,watertightness, durability, and wear resistance of concrete are related to the water/cement ratio of the concrete mix. The lower the water/cement ratio, the higher the concrete strength and durability, provided that the mix has adequate workability. Thus the water/cement ratio is selected by the mix designer to meet the requirements of the hardened concrete. Water/cement ratios normally used range from about 0.40 to 0.70 by weight. In terms of water quality, almost any water suitable for drinking will be satisfactory as mix water. However, organic material in mix water tends to prevent the cement paste from bonding properly to aggregate surfaces. Alkalies or acids in mix water may react with the cement and interfere with hydration. Seawater may be used for mixing concrete, but its use will usually result in concrete compressive strengths 10 to 20% lower than normal. The use of a lower water/cement ratio can compensate for this strength reduction. However, seawater should not be used for prestressed concrete where the prestressing steel will be in contact with the concrete. When water quality is in doubt, it is recommended that trial mixes be tested for setting time and 28-d strength.

Additives

A number of types of additives or admixtures are used in concrete. Some of the principal types of additives used are air-entraining agents, water-reducing agents, retarders, accelerators, pozzolans, and workability agents. *Air-entrained concrete* has significantly increased resistance to freezing and thawing as well as to scaling caused by the use of deicing chemicals. Entrained air also increases the workability of plastic concrete and the watertightness of hardened concrete. For these reasons, air-entrained concrete is widely used for pavements and other structures exposed to freezing and thawing.

Water-reducing agents increase the slump or workability of a concrete mix. Thus with a water-reducing agent the amount of water in the mix may be reduced without changing the concrete's consistency. However, note that some water-reducing agents also act as retarders. *Retarders* slow the rate of hardening of concrete. Retarders are often used to offset the effect of high temperatures on setting time. They are also used to delay the setting of concrete when pumping concrete over long distances. The use of retarders to produce exposed-aggregate surfaces is discussed in Section 12–1. *Accelerators* act in the opposite manner to retarders. That is, they decrease setting time and increase the early strength of concrete. Since the most common accelerator, calcium chloride, is corrosive to metal, it should not be used in concrete with embedded prestressing steel, aluminum, or galvanized steel.

Pozzolans are finely divided materials, such as fly ash, diatomaceous earth, volcanic ash, and calcined shale, which are used to replace some of the cement in a concrete mix. Pozzolans are used to reduce the heat of hydration, increase the workability, and reduce the segregation of a mix. *Workability agents* or plasticizers increase the workability of a mix. However, air-entraining agents, water-reducing agents, pozzolans, and retarders will also increase the workability of a mix.

Mix Design

The concrete mix designer is faced with the problem of selecting the most economical concrete mix that meets the requirements of the hardened concrete while providing acceptable workability. The most economical mix will usually be the mix that uses the highest ratio of aggregate to cement while providing acceptable workability at the required water/cement ratio.

Table 7–4 Maximum water-cementitious material ratios and minimum design strengths for various exposure conditions (Courtesy of Portland Cement Association)

Exposure condition	Maximum water-cementitious material ratio by mass for concrete	Minimum design compressive strength f'_c, MPa (psi)
Concrete protected from exposure to freezing and thawing, application of deicing chemicals, or aggressive substances	Select water-cementitious material ratio on basis of strength, workability, and finishing needs	Select strength based on structural requirements
Concrete intended to have low permeability when exposed to water	0.50	28 (4000)
Concrete exposed to freezing and thawing in a moist condition or deicers	0.45	31 (4500)
For corrosion protection for reinforced concrete exposed to chlorides from deicing salts, salt water, brackish water, seawater, or spray from these sources	0.40	35 (5000)

Adapted from ACI 318 (1999).

Table 7–5 Recommended slumps for various types of construction (Courtesy of Portland Cement Association)

Concrete construction	Slump, mm (in.)	
	Maximum*	Minimum
Reinforced foundation walls and footings	75 (3)	25 (1)
Plain footings, caissons, and substructure walls	75 (3)	25 (1)
Beams and reinforced walls	100 (4)	25 (1)
Building columns	100 (4)	25 (1)
Pavements and slabs	75 (3)	25 (1)
Mass concrete	75 (3)	25 (1)

*Many be increased 25 mm (1 in.) for consolidation by hand methods, such as rodding and spading. Plasticizers can safely provide higher slumps.
Adapted from ACI 211.1

A suggested mix design procedure is to first select a water/cement ratio that satisfies requirements for concrete strength, durability, and watertightness. (Table 7–4 gives maximum water/cement ratios recommended by the American Concrete Institute for various applications.) Next, select the workability or slump required (see Table 7–5). The third step is to mix a trial batch using a convenient quantity of cement at the selected water/cement ratio. Quantities of saturated, surface-dry fine, and coarse aggregate are then added until the desired slump is obtained. After weighing each trial mix component, the yield of the mix and the amount of each component required for a full-scale batch may be calculated by the method to be described.

Batching and Mixing

The process of proportioning cement, water, aggregates, and additives prior to mixing concrete is called *batching.* Since concrete specifications commonly require a batching accuracy of 1 to 3%, depending on the mix component, materials should be carefully proportioned by weight. Central batching plants that consist of separate aggregate and cement batching units are often used for servicing truck mixers and for feeding central mixing plants. In such batching plants cement is usually handled in bulk. The addition of water to the mix may be controlled by the batching plant or it may be accomplished by the mixer operator. Batching for small construction mixers is accomplished by loading the required quantity of cement and aggregate directly into the skip (hopper) of the mixer. Water is added by the mixer operator. Cement for such mixers is usually measured by the sack (94 lb or 42.6 kg).

A standard classification system consisting of a number followed by a letter is used in the United States to identify mixer type and capacity. In this system, the number indicates the rated capacity of the mixer in cubic feet (0.028 m^3) of plastic concrete. Satisfactory mixing should be obtained as long as the volume of the mix does not exceed the mixer's rated capacity by more than 10%. The letter in the rating symbol indicates the mixer type: S is a construction mixer, E is a paving mixer, and M is a mortar mixer. Thus the symbol "34E" indicates a 34-cu ft (0.96-m^3) paving mixer, "16S" indicates a 16-cu ft (0.45-m^3) construction mixer, and so on.

Construction mixers are available as wheel-mounted units, trailer-mounted units, portable plants, and stationary plants. Mixer drums may be single or double, tilting or nontilting. Mixer capacities range from 3½ cu ft (0.1 m^3) to over 12 cu yd (9.2 m^3). The wheel-mounted 16–cu ft (type 16S) construction mixer is often used on small construction projects where ready-mixed concrete is not available. Large central mix plants are used to supply concrete for projects such as dams, which require large quantities of concrete.

Truck mixers or *transit mix* trucks (Figure 7–8) are truck-mounted concrete mixers capable of mixing and transporting concrete. The product they deliver is referred to as *ready-mixed concrete.* The usual procedure is to charge the truck mixer with aggregate, additives, and cement at a central batch plant, then add water to the mix when ready to begin mixing. Truck mixers are also capable of operating as *agitator trucks* for transporting plastic concrete from a central mix plant. A truck mixer used as an agitator truck can haul a larger quantity of concrete than it is capable of mixing. While a unit's capacity when used as an agitator truck is established by the equipment manufacturer, agitating capacity is generally about one-third greater than mixer capacity. Standard truck mixer capacity ranges from 6 cu yd (4.6 m^3) to over 15 cu yd (11.5 m^3).

Paving mixers are self-propelled concrete mixers especially designed for concrete paving operations. They are equipped with a boom and bucket which enable them to place

Figure 7–8 Truck mixer. (Courtesy of Kenworth Truck Company)

concrete at any desired point within the roadway. With the increasing use of slipform pavers, paving mixers are now most often used to supply slipform pavers or to operate as stationary mixers. Dual-drum paving mixer production is almost double that of a single-drum mixer. When operated as a stationary plant, a type 34E dual-drum paving mixer is capable of producing about 100 cu yd (76.5 m^3) of concrete per hour.

A minimum mixing time of 1 min plus ¼ min for each cubic yard (0.76 m^3) over 1 cu yd (0.76 m^3) is often specified for concrete mixers. However, the time required for a complete mixer cycle has been found to average 2 to 3 min. A mixing procedure that has been found to help clean the mixer drum and provide uniform mixing is to add 10% of the mix water before charging the drum, 80% during charging, and the remaining 10% when charging is completed. Timing of the mixing cycle should not begin until all solid materials are placed into the drum. All water should be added before one-fourth of the mixing time has passed. Standards of the Truck Mixer Manufacturers Bureau require truck mixers to mix concrete for 70 to 100 revolutions at mixing speed after all ingredients, including water, have been added. Any additional rotation must be at agitating speed. Concrete in truck mixers should be discharged within 1½ h after the start of mixing and before the drum has revolved 300 times.

Estimating Mixer Production

After a concrete mix design has been established, the volume of plastic concrete produced by the mix may be calculated by the *absolute-volume method.* In this method the volume of one batch is calculated by summing up the absolute volume of all mix components. The absolute volume of each component may be found as follows:

$$\text{Volume (cu ft)} = \frac{\text{Weight (lb)}}{62.4 \times \text{specific gravity}} \tag{7–1A}$$

$$\text{Volume (m}^3\text{)} = \frac{\text{Weight (kg)}}{1000 \times \text{specific gravity}} \tag{7–1B}$$

When calculating the absolute volume of aggregate using Equation 7–1, aggregate weight must be based on the saturated, surface-dry (SSD) condition. Such aggregate will neither add nor subtract water from the mix. If aggregate contains free water, a correction must be made in the quantity of water to be added to the mix. Example 7–3 illustrates these procedures.

EXAMPLE 7–3

(a) Calculate the volume of plastic concrete that will be produced by the mix design given in the table.

		Quantity	
Component	**Specific Gravity**	***lb***	***kg***
Cement	3.15	340	154
Sand (SSD)	2.65	940	426
Gravel (SSD)	2.66	1210	549
Water	1.00	210	95

(b) Determine the actual weight of each component to be added if the sand contains 5% excess moisture and the gravel contains 2% excess moisture.

(c) Determine the weight of each component required to make a three-bag mix and the mix volume.

SOLUTION

(a) $\text{Cement volume} = \dfrac{340}{3.15 \times 62.4} = 1.7 \text{ cu ft}$

$$\left[= \frac{154}{3.15 \times 1000} = 0.05 \text{ m}^3\right]$$

$$\text{Sand volume} = \frac{940}{2.65 \times 62.4} = 5.7 \text{ cu ft}$$

$$\left[= \frac{426}{2.65 \times 1000}\ 0.16 \text{ m}^3 \right]$$

$$\text{Gravel volume} = \frac{1210}{2.66 \times 62.4} = 7.3$$

$$\left[= \frac{549}{2.66 \times 1000} = 0.21 \text{ m}^3 \right]$$

$$\text{Water volume} = \frac{210}{1.00 \times 62.4} = 3.4 \text{ cu ft}$$

$$\left[= \frac{95}{1.00 \times 1000} = 0.09 \text{ m}^3 \right]$$

$$\text{Mix volume} = 1.7 + 5.7 + 7.3 + 3.4 = 18.1 \text{ cu ft}$$

$$[= 0.05 + 0.16 + 0.21 + 0.09 = 0.51 \text{ m}^3]$$

(b) Excess water in sand = 940 × 0.05 = 47 lb

[= 426 × 0.05 = 21 kg]

Excess water in gravel = 1210 × 0.02 = 24 lb

[= 549 × 0.02 = 11 kg]

Total excess water = 47 + 24 = 71 lb

[= 21 + 11 = 32 kg]

Field mix quantities:

Water = 210 − 71 = 139 lb

[= 95 − 32 = 63 kg]

Sand = 940 + 47 = 987 lb

[= 426 + 21 = 447 kg]

Gravel = 1210 + 24 = 1234 lb

[= 549 + 11 = 560 kg]

(c) Adjusting to a three-bag mix:

Cement = 3 × 94 = 282 lb

[= 3 × 42.6 = 127.8 kg]

$$\text{Sand} = \frac{282}{340} \times 987 = 819 \text{ lb}$$

$$\left[= \frac{127.8}{154} \times 447 = 370 \text{ kg} \right]$$

$$\text{Gravel} = \frac{282}{340} \times 1234 = 1023 \text{ lb}$$

$$\left[= \frac{127.8}{154} \times 560 = 464 \text{ kg} \right]$$

$$\text{Water} = \frac{282}{340} \times 139 = 115 \text{ lb}$$

$$\left[= \frac{127.8}{154} \times 63 = 52 \text{ kg} \right]$$

$$\text{Mix volume} = \frac{282}{340} \times 18.1 = 15.0 \text{ cu ft}$$

$$\left[= \frac{127.8}{154} \times 0.51 = 0.42 \text{ m}^3 \right]$$

After the batch volume has been calculated, mixer production may be estimated as follows:

$$\text{Mixer production (cu yd/h)} = \frac{2.22 \times V \times E}{T} \qquad \textbf{(7–2}\boldsymbol{A}\textbf{)}$$

$$\text{Mixer production (m}^3\text{/h)} = \frac{60 \times V \times E}{T} \qquad \textbf{(7–2}\boldsymbol{B}\textbf{)}$$

where V = batch volume (cu ft or m^3)
T = cycle time (min)
E = job efficiency

Transporting and Handling Concrete

A number of different items of equipment are available for transporting concrete from the mixer to its place of use. Some equipment commonly used includes transit mixer trucks, agitator trucks, dump trucks, conveyors, pumps, and cranes with concrete buckets. Special rail cars designed for transporting plastic concrete are also available, but seldom used except on mass concrete projects such as concrete dams.

Regardless of the equipment used, care must be taken to avoid segregation when handling plastic concrete. The height of any free fall should be limited to 5 ft (1.5 m) unless downpipes or ladders are used. Downpipes having a length of at least 2 ft (0.6 m) should be used at the end of concrete conveyors. When using nonagitator trucks for hauling concrete, specifications may limit the truck speed and maximum haul distance that may be used. Temperature, road condition, truck body type, and mix design are the major factors that influence the maximum safe hauling distance that may be used. Other considerations in transporting and handling plastic concrete are described in Section 12–2.

7–3 PRODUCTION OF ASPHALT MIXES

Asphalt and Other Bituminous Materials

Bituminous materials include both asphalt and tar. Although asphalt is the type of bituminous material most frequently used in surfacing roads and airfields, road tars are sometimes used. Most properties of asphalt and tar are similar, except that tars are not soluble in petroleum products. As a result, tar surface treatments and tar seal coats are often used when the pavement is likely to be subjected to spills of petroleum fuels—for example, on airfield aprons and taxiways and in gasoline stations. A major disadvantage of tar is its tendency to change consistency with small variations in temperature. Tar also has a different coefficient of expansion than does asphalt. Thus, when a tar seal coat is applied to protect an asphalt pavement from petroleum spills, the difference in their coefficients of expansion can result in severe cracking of the seal coat within a few years. Such cracking will allow fuel spills to penetrate into the asphalt pavement, with resulting damage to the asphalt pavement. However, there are also fuel-resistant asphalts available as described next. Since asphalt predominates in construction, the words bituminous and asphalt are often used interchangeably in construction practice.

Bituminous surfaces (pavements and surface treatments) are used to provide a roadway wearing surface and to protect the underlying material from moisture. Because of their plastic nature, bituminous surfaces are often referred to as flexible pavements, in contrast to concrete pavements, which are identified as rigid pavements. Bituminous surfaces are produced by mixing solid particles (aggregates) and a bituminous material. Since the bituminous material serves to bond the aggregate particles together, it is referred to as *binder.*

The aggregate in a bituminous surface actually provides the load-carrying ability of the surface. The aggregate also resists the abrasion of traffic and provides skid resistance to the travel surface. In addition to the coarse aggregate (gravel) and fine aggregate (sand) used in concrete mixes, asphalt mixes often contain a third size of aggregate called *fines.* Fines, also called *mineral filler* or mineral dust, consist of any inert, nonplastic material passing the No. 200 sieve. Material used as fines includes rock dust, portland cement, and hydrated lime. Aggregates used in asphalt mixes should be angular, hard, durable, well graded, clean, and dry, in order to provide the required strength to the mix and to bond with the binder.

Asphalt cement, the solid form of asphalt, must be heated to a liquid state for use in bituminous mixes. Asphalt cements have traditionally been viscosity-graded based on their absolute viscosity measured at 60˚C and 135˚C and range from AC-2.5 (soft) to AC-40 (hard). A grading system based on a penetration test is also sometimes used. In this system, the penetration (in hundredths of a centimeter) which occurs in 5 s is measured for a standard needle under a 100-g load with the asphalt temperature at 25˚C. Penetration grades range from soft (penetration numbers 200 to 300) to hard (penetration numbers 40 to 50). More recently, in order to implement the *Superpave*™ asphalt pavement design and construction system described in Section 8–2, a *Performance Graded Asphalt Binder* classification system has been developed. Under this classification system, asphalt binder Performance Grades range from PG 46-46 to PG 82-34. Note that this is classified as an "asphalt binder" specification since it is intended to apply to both modified and unmodified asphalts. In this system, the first two digits indicate the average 7-d maximum pavement design temperature (in degrees Celsius), and the last two digits indicate the minimum pavement design temperature (in minus degrees

Celsius). Some of the laboratory tests and procedures which are required to classify asphalt binder under the Performance Graded (PG) system include the following:

The Rotational Viscometer, which indicates asphalt binder handling and pumping properties at high temperatures.

The Dynamic Shear Rheometer, which provides a measure of the permanent deformation and fatigue cracking of asphalt binder at high and intermediate temperatures.

The Bending Beam Rheometer and the Direct Tension Tester, which provide a measure of low temperature asphalt binder cracking.

The Rolling Thin Film Oven and the Pressure Aging Vessel, which measure asphalt binder aging and hardening characteristics.

Fuel-resistant asphalt, often based on a polymer modified asphalt (PMA), is available and has demonstrated high resistance to rutting and cracking as well as to petroleum fuels. Some such asphalts can sustain less than 1% material loss after 24 h of immersion in jet fuel.

An asphalt *cutback,* which is liquid at room temperature, is created when petroleum distillates are mixed with asphalt cement. Asphalt cutbacks are classified as medium-curing (MC) or rapid-curing (RC), depending on the type of solvent used in their production. Road oils or slow-curing (SC) asphalt may be residual asphalt oils or may be produced by blending asphalt cement with residual oils. The classification symbol used for cutbacks and road oils includes a number that indicates the viscosity of the mixture. Viscosity grades range from 30 (viscosity similar to water) to 3000 (barely deforms under its own weight).

Asphalt *emulsions* contain particles of asphalt dispersed in water by means of emulsifying agents. Asphalt emulsions have several important advantages: they can be applied to wet aggregates and they are not flammable or toxic. Asphalt emulsions are classified as rapid setting (RS), medium setting (MS), or slow setting (SS).

Road tars are designated by the symbol RT plus a number indicating viscosity. Twelve grades are available, ranging from RT-1 (low viscosity) to RT-12 (solid at room temperature). Two tar cutback grades, RTCB-5 and RTCB-6, are also available.

Handling Bituminous Materials

When cutbacks are heated for mixing or spraying, they are usually above their flash point. The *flash point* of a liquid is the temperature at which it produces sufficient vapor to ignite in the presence of air and an open flame. Since the flash point is reached at a temperature below that at which the liquid would normally burn, extreme care must be taken when heating cutbacks or when handling the heated material. No open flame or spark-producing equipment should be allowed near the hot liquid. Use only equipment specifically designed for the purpose when heating, storing, mixing, or spraying cutbacks. Adequate fire-extinguishing equipment must be readily available together with personnel properly trained in its use. Proper precautions must also be taken to prevent burns when working with hot materials. Hot surfaces must be conspicuously marked or guarded to protect workers against contacting them. Gloves and other protective clothing must be used by workers handling hot equipment.

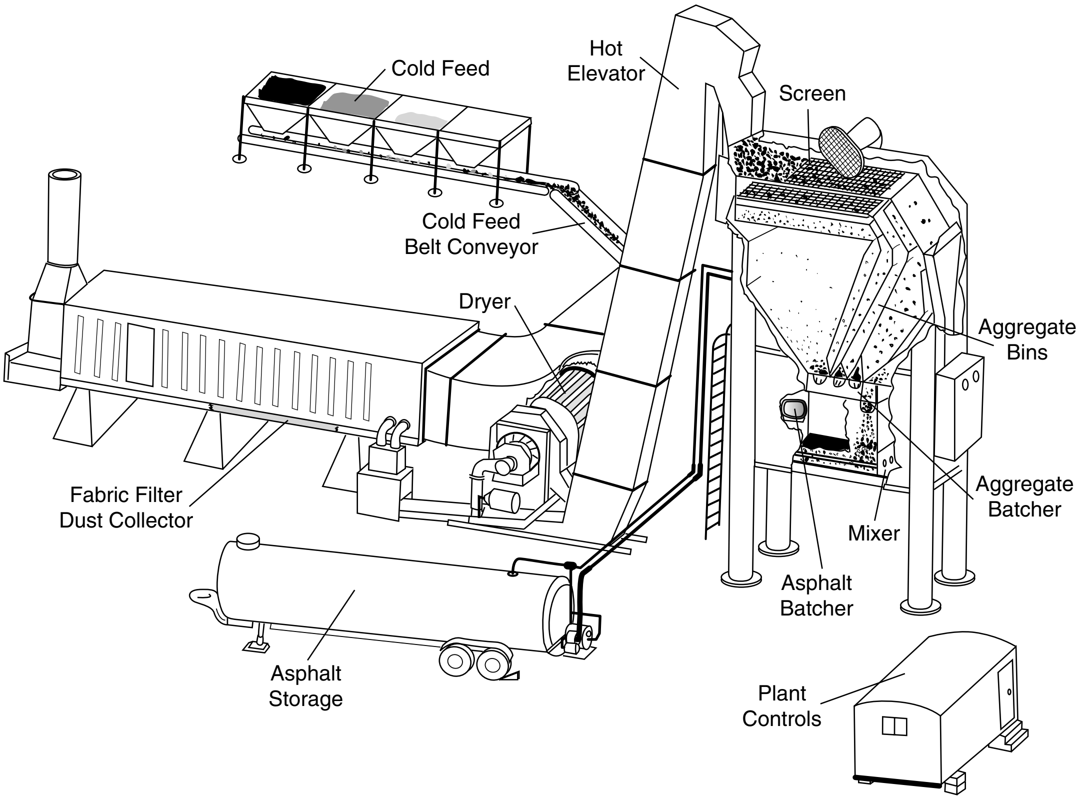


Figure 7–9 Asphalt batch plant.

Asphalt Plants

While cold asphalt mixes may be produced using asphalt cutbacks or emulsions, asphalt plants are primarily used to produce *hot-mix asphalt* (HMA) from asphalt cement. The principal types of asphalt plants are batch plants and drum-mix plants. The *batch plant* illustrated in Figure 7–9 uses a cold feed hopper and cold feed belt conveyor to feed aggregate into the dryer. From the dryer, hot aggregate is moved by a hot elevator into an aggregate batcher. Here the hot aggregate is separated by screening and placed into bins by size. Calibrated feeders provide a supply of aggregate and mineral filler in the required quantities to the pugmill (mixer). Asphalt is injected into the pugmill and the mixture is mixed for the required time. The batch of hot-mix asphalt is then deposited into a haul unit.

In recent years the *drum-mix plant* illustrated in Figure 7–10 has become quite popular and has largely replaced the older continuous-flow plant. As you see, both drying and mixing take place in the drum. The process eliminates the separate aggregate batcher, hot elevator, and pugmill of the batch plant. The dust emitted by the dryer is also less than that emitted by the batch plant dryer because the liquid asphalt tends to trap fines inside the drum.

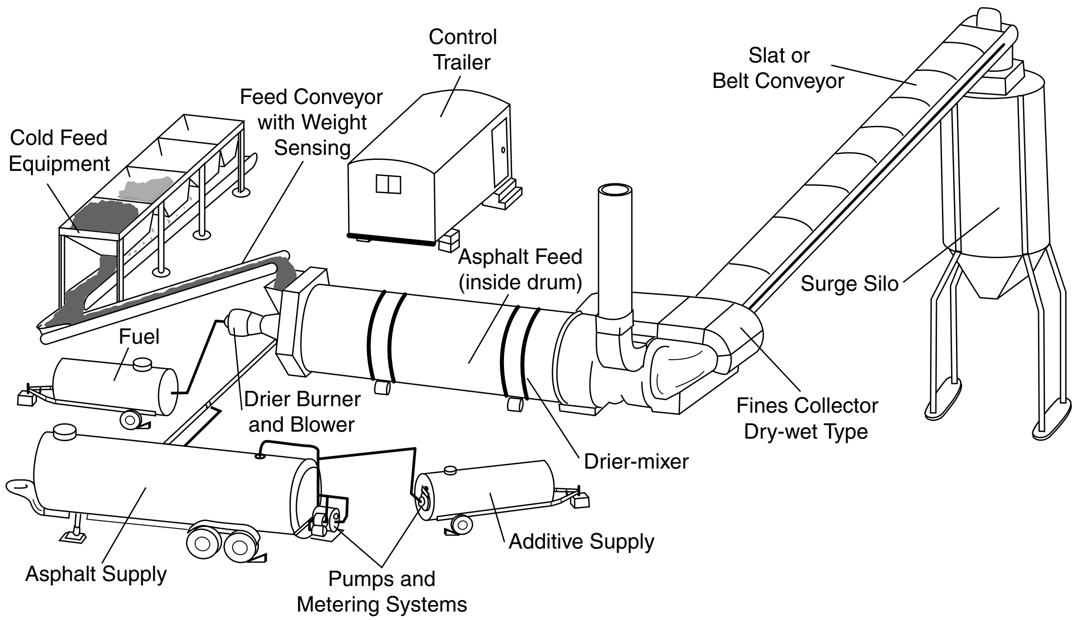


Figure 7–10 Components of a drum-mix asphalt plant.

This reduces the amount of pollution control equipment needed. Some recent innovations such as dual-drum mixers and counterflow air systems have further increased these plants' efficiencies. The high production capability, efficiency, economy, and portability of these plants make them attractive to asphalt producers.

Frequent sampling and testing of asphalt plant mixes is required to ensure adequate quality control. Insulated storage bins such as that shown in Figure 7–11 are available to store plant output when hauling capacity is limited or uncertain. Loading and hauling must be carefully conducted to prevent degradation of the mix. Trucks should be clean and dry before loading. Insulated or heated trucks may be required to ensure that the mix is delivered to the job site at the specified temperature.

Estimating Asphalt Plant Production

An asphalt mix is composed of asphalt, coarse aggregate (gravel), fine aggregate (sand), and mineral filler (or fines). The amount of asphalt in a mix is expressed as a percentage of total mix weight. Aggregate is heated in the dryer to permit bonding with the hot asphalt. Since fines are largely lost as the aggregate passes through the dryer, mineral filler is usually added directly to the pugmill along with the asphalt and hot aggregate.

Dryer capacity, which depends on aggregate moisture content, is normally the controlling factor in asphalt plant capacity. Thus, the maximum hourly plant capacity may be calculated from the dryer capacity and the percentage of asphalt and fines in the mix. The procedure is illustrated in Example 7–4. Notice that the calculations are based on dry

Figure 7–11 Insulated hot-mix asphalt storage bin with skip hoist. (Courtesy of Terex Road Building)

aggregate weights. The weight of coarse aggregate and sand must be corrected for moisture to obtain the actual field weight of these materials required to feed the dryer. Additional information on asphalt plant calibration is contained in reference 2.

EXAMPLE 7–4

(a) Calculate the maximum hourly production of an asphalt plant based on the data in the following list.

(b) Find the required feed rate (ton/h) for each mix component to achieve this production.

Mix composition:

Asphalt = 6%
Aggregate composition:
  Coarse A = 42%
  Coarse B = 35%
  Sand = 18%
  Mineral filler = 5%
Aggregate moisture = 8%
Dryer capacity at 8% moisture removal = 110 ton/h

SOLUTION

(a) $$\text{Plant capacity} = \frac{\text{Dryer capacity} \times 10^4}{(100 - \text{asphalt }\%)(100 - \text{fines }\%)}$$

$$= \frac{110 \times 10^4}{(100 - 6)(100 - 5)} = 123 \text{ ton/h} \qquad \textbf{(7–3)}$$

(b) Feed rate (ton/h):

Component	Fraction	Total	Rate
Asphalt	0.06	123.0	7.4
Aggregate (dry)	0.94	123.0	115.6
	1.00	123.0	123.0
Aggregate components (dry weight)			
Coarse A	0.42	115.6	48.5
Coarse B	0.35	115.6	40.5
Sand	0.18	115.6	20.8
Mineral filler	0.05	115.6	5.8
	1.00	115.6	115.6

PROBLEMS

1. What are the characteristics of a Performance Grade PG 58-10 asphalt binder?
2. Determine the actual field weight (lb or kg) required to charge a 34E mixer with a 10% overload using the mix proportions given here. The field excess moisture content of the sand is 6% and that of the gravel is 2%.

Component	Weight lb (kg)	Specific Gravity
Cement	94 (42.6)	3.15
Gravel	415 (188.2)	2.66
Sand	235 (106.6)	2.65
Water	54 (24.5)	1.00

3. Calculate the cold feed rate in tons per hour (tons/h) for a drum-mix asphalt plant under the following conditions.

Asphalt content = 6%
Aggregate composition:
  Coarse A = 50%
  Coarse B = 20%
  Sand = 24%
  Mineral filler = 6%
Field moisture content of gravel and sand = 6%
Drum capacity at required moisture removal = 140 tons/h (127 t/h)

4. Calculate the hot feed required per batch for an asphalt batch plant producing 3 tons (2.7 t) per batch under the following conditions:

Asphalt content	= 5%
Aggregate composition:	
Coarse A	= 45%
Coarse B	= 35%
Sand	= 15%
Mineral filler	= 5%

5. Develop a computer program to calculate the feed rate for an asphalt plant. For drum-mix plants, output the cold feed rate in tons per hour (t/h) of coarse and fine aggregate, mineral filler, and asphalt cement. For batch plants, output the dry weight in tons (t) per batch for aggregates, mineral filler, and asphalt cement. Input should include the type of plant, the aggregate composition, asphalt content, field aggregate moisture, and drum capacity at the required moisture removal. Solve Problem 4 using your program.
6. a. Determine the water-cement ratio of the mix of Problem 9.
   b. What difficulties might result from lowering the water-cement ratio of the mix and how might these be overcome?
7. Select the crusher settings for a primary jaw crusher and a secondary roll crusher to produce 150 tons/h (136 t/h) of aggregate meeting the following specifications. Indicate the output in tons per hour (t/h) and in percentage for each of the specified size ranges.

Screen Size in. (mm)	Percent Passing
2½ (6.4)	100
1 (25)	50–60
¼ (6)	15–30

8. The output from a closed-circuit jaw crusher is shown below. A three deck horizontal vibrating screen is to be used to separate the aggregate output. The stone weighs 100 lb/cu ft (1602 kg/m^3). If 25% of the feed to the ½ (13 mm) screen is smaller than ¼ in. (6 mm), determine the minimum size required for the ½-in (13-mm) screen.

Screen Size in. (mm)	Screen Load tons/h (t/h)	Passing tons/h (t/h)
2½ (64)	83.0 (75.3)	56.4 (51.2)
1½ (38)	56.4 (51.2)	37.3 (33.8)
½ (13)	37.3 (33.8)	16.1 (14.6)

9. A one-sack trial mix that meets specification requirements has the proportions shown here. Determine the quantity of each ingredient by weight required to batch a 16S

mixer with no overload using an integer number of sacks of cement. Assume that the aggregate is saturated, surface-dry, and allow a 10% overload.

Component	Weight		Specific Gravity
	lb	*kg*	
Cement	94	42.6	3.15
Gravel	395	179.2	2.66
Sand	215	97.5	2.65
Water	50	22.7	1.00

10. Develop a computer program to calculate the field batch weight of each component for a specified concrete mix and mixer capacity. Input should include the rated mixer capacity, percent overload to be used, and mix proportions. For each mix component, input the SSD weight for the component, the specific gravity, and the field excess moisture. Solve problem 2 using your computer program.

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