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Chapter 12

1265 San Juan Dr. - Merritt Island, FL 32952
Phone: 321-501-5601

Chapter 12

Mix Design: Concrete and Asphalt

Topics

1.0.0 Design of Concrete Mixtures

2.0.0 Bituminous Mix Design

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Overview

Chapter 8 of EA Basic discussed the properties that comprise a good quality concrete and introduces the use of concrete as a construction material. You learned about the different types of Portland cement, the methods used to identify cement, and the purpose and effect of various admixtures that are often used in the production of concrete. You also studied the physical requirements for water and aggregates used in concrete, and the various tests used to determine the suitability of water and aggregates as ingredients in a concrete mixture. The discussion of concrete in this chapter is directed towards the design of concrete mixtures. This discussion presupposes that you are well versed in the previous topics. If you are not, then it is strongly recommended that you review the aforementioned chapter before you begin the study of this chapter.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the design of concrete mixtures.
2. Describe the procedures for bituminous mix design.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

1.0.0 DESIGN OF CONCRETE MIXTURES

From your previous studies, you know that cement (usually Portland cement), water, and both fine and coarse aggregates are the basic ingredients used in the production of concrete. You also know that certain admixtures are used occasionally to meet special requirements. Designing a concrete mixture consists of determining the correct amount of each ingredient needed to produce a concrete that has both the necessary consistency or workability in the freshly mixed condition and the desired strength and durability characteristics in the hardened condition.

This chapter discusses two methods of proportioning concrete mixtures. One method, the ***trial batch method***, is based on an estimated weight of concrete per unit volume. The other method, based on calculations of the absolute volume occupied by the ingredients used in the concrete mixture, is called the ***absolute volume method***. Our discussion of these methods is intended to provide you with a basic understanding of mixture design. For a thorough discussion, you should refer to the most recent edition of *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, (ACI 211.1), published by the American Concrete Institute (ACI).

1.1.0 Mix Proportions

The end use of the concrete and the anticipated conditions at placement time determine the concrete mixture proportions for a particular application. The concrete mixture selection involves balancing reasonable economy and the job specification requirements for placeability, strength, durability, density, and appearance. Before proportioning a concrete mixture, you must have certain information about a job, such as the size and shape of structural members, the required strength, and the exposure conditions. Other important factors discussed in this chapter are the water-cement ratio, aggregate characteristics, amount of entrained air, and slump.

1.1.1 Water-Cement Ratio

Determine the water-cement ratio by analyzing the strength, durability, and watertightness requirements of the hardened concrete. The structural design engineer will usually specify the ratio, but you can arrive at tentative mix proportions from prior job knowledge. Always remember that a change in the water-cement ratio changes the characteristics of the hardened concrete. Use *Table 12-1* to select a suitable water-cement ratio for normal weight concrete that will meet anticipated exposure conditions. Note that the water-cement ratios in *Table 12-1* are based on concrete strength under certain exposure conditions. If possible, perform tests using job materials to determine the relationship between the water-cement ratio you select and the strength of the finished concrete. If you cannot obtain laboratory test data or experience records for the relationship, use *Table 12-2* as a guide. Enter *Table 12-2* at the desired f'_c (specified compressive strength of the concrete in pounds per square inch, psi) and read across to determine the maximum water-cement ratio. You can interpolate between the values. When both exposure conditions and strength must be considered, use the lower of the two indicated water-cement ratios. If flexural strength rather than compressive strength is the basis of design, such as for a pavement, perform tests to determine the relationship between the water-cement ratio and the flexural strength. An approximate relationship between flexural strength and compressive strength is as follows:

$$f'_c = \left(\frac{R}{k}\right)^2$$

where:

f_c' = compressive strength, psi

R = flexural strength, psi

k = a constant, usually between 8 and 10

Table 12-1– Maximum Permissible Water-Cement Ratios for Concrete in Severe Exposures.

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing*	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. cover over steel	0.45	0.40
All other structures	0.50	0.45

* Based on report of the durability of concrete in service.

* Concrete should also be air-entrained

Table 12-2 – Relationship between Water-Cement Ratio and Compressive Strength of Concrete.

Compressive strength At 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	--
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

* Values are estimated average strength for concrete containing not more than the percentage of air shown on *Table 12-4.*

1.1.2 Aggregate

Use fine aggregate to fill the spaces between the coarse aggregate particles and to increase the workability of a mix. In general, aggregate that does not have a large grading gap or an excess of any size, but gives a smooth grading curve, produces the best mix.

Use the largest practical size of coarse aggregate in the mix. The maximum size of coarse aggregate that produces concrete of maximum strength for a given cement content depends upon the aggregate source as well as the aggregate shape and grading. The larger the maximum size of the coarse aggregate, the less paste (water and cement) is required for a given concrete quality. The maximum size of aggregate should never exceed one-fifth of the narrowest dimension between side forms, one third of the depth of slabs, or three fourths of the distance between reinforcing bars.

1.1.3 Entrained Air

Use entrained air to improve workability in all concrete exposed to freezing and thawing, and sometimes under mild exposure conditions. Always use entrained air in paving concrete regardless of climatic conditions. *Table 12-3* gives recommended total air contents of air-entrained concretes. When mixing water remains constant, air entrainment increases slump. When cement content and slump remain constant, less mixing water is required. The resulting decrease in the water-cement ratio helps to offset possible strength decreases and improves other paste properties, such as permeability. The strength of air-entrained concrete may equal, or nearly equal, that of non-air-entrained concrete when cement contents and slump are the same. The upper half of *Table 12-3* gives the approximate percent of entrapped air in non-air-entrained concrete, and the lower half gives the recommended average total air content percentages for air-entrained concrete based on level of exposure.

Table 12-3 – Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregates.

Slump in.	Water, lb. per cu. yd. of concrete for indicated nominal maximum sizes of aggregate							
	3/8 in.*	½ in.*	¾ in.*	1 in.*	1-1/2 in.*	2 in.*	3 in. *	6 in.
Non-air-entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	--
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.25
Air-entrained concrete								
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	--
Recommended average total air content, percent for level of exposure:								
Mile exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Extreme exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

* These quantities of mixing water are for use in computing cement factors for trial batches. They are maxima for reasonably well shaped, angular coarse aggregates graded within limits of accepted specifications.

1.1.3.1 Mild Exposure

Mild exposure includes indoor or outdoor service in a climate that does not expose the concrete to freezing or deicing agents. When you want air entrainment for a reason other than durability, such as to improve workability or cohesion or to improve strength in low cement factor concrete, you can use air contents lower than those required for durability.

1.1.3.2 Moderate Exposure

Moderate exposure means service in a climate where freezing is expected but where the concrete is not continually exposed to moisture or free water for long periods before freezing or to deicing agents or other aggressive chemicals. Examples are exterior beams, columns, walls, girders, or slabs that do not contact wet soil or receive direct application of deicing salts.

1.1.3.3 Severe Exposure

Severe exposure means service where the concrete is exposed to deicing chemicals or other aggressive agents or where it continually contacts moisture or free water before freezing. Examples are pavements, bridge decks, curbs, gutters, sidewalks, or exterior water tanks or sumps.

1.1.4 Slump

The slump test measures the consistency of concrete. Do not use it to compare mixes having wholly different proportions or containing different sizes of aggregates. When testing different batches, note that changes in slump indicate changes in materials, mix proportions, or water content. *Table 12-4* gives recommended slump ranges for various types of construction.

Table 12-4 – Recommended slumps for various types of construction.

Types of construction	Slump, in.	
	Maximum*	Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

* May be increased 1 in. for methods of consolidation other than vibration.

1.2.0 Trial Batch Method

The following are some basic guidelines and an example to help you in performing the steps related to mix design by the trial batch method.

1.2.1 Basic Guidelines

In the trial batch method of mix design, use actual job materials to obtain mix proportions. The size of the trial batch depends upon the equipment you have and how many test specimens you make. Batches using 10 to 20 pounds of cement may be big enough, although larger batches produce more accurate data. Use machine mixing if possible, since it more nearly represents job conditions. Always use a machine to mix concrete containing entrained air. Be sure to use representative samples of aggregate, cement, water, and air-entraining admixture in the trial batch. Pre-wet the aggregate and allow it to dry to a saturated, surface-dry condition. Then place it in covered containers to maintain this condition until you use it. This simplifies calculations and eliminates errors caused by variations in aggregate moisture content. When the concrete quality is specified in terms of the water-cement ratio, the trial batch procedure consists basically of combining paste (water, cement, and usually entrained air) of the correct proportions with the proper amounts of fine and coarse aggregates to produce the required slump and workability. Then calculate the large quantities per sack or per cubic yard.

1.2.2 Example Using Trial Batch Method

Let's suppose that you are determining the mix proportions for a concrete retaining wall exposed to fresh water in a severe climate. The minimum wall thickness is 10 inches, with 2 inches of concrete covering the reinforcement. The required average 28-day compressive strength is 4,600 psi. Note that this average compressive strength is not the same as the design strength used for structural design but a higher figure expected to be produced on the average. For an in-depth discussion of determining how much the average strength should exceed the design strength, you should refer to *Recommended Practice for Evaluation of Strength Test Results of Concrete*, ACI 214.

The steps in proportioning a mix to satisfy the above requirements are as follows:

1. **Determine the water-cement ratio.** *Table 12-1* indicates that a maximum water-cement ratio of 0.50 by weight satisfies the exposure requirements and that the concrete should be air entrained. *Table 12-2* shows that a maximum water-cement ratio of approximately 0.42 by weight satisfies the strength requirements for Type IA (air-entraining) Portland cement with a compressive strength of 4,600 psi. As discussed previously, you will choose the lower of the two water-cement ratios, or 0.42, since both strength and exposure conditions are being considered.
2. **Determine the maximum size of coarse aggregate.** Since the maximum size of coarse aggregate must not exceed one-fifth of the minimum wall thickness or three fourths of the space between the reinforcement and the surfaces, the maximum size of coarse aggregate you should use is 1 1/2 inches.
3. **Determine the slump.** Assuming in this case that vibration will be used to consolidate the concrete, *Table 12-4* shows the recommended slump to be 1 to 3 inches.
4. **Determine the amount of mixing water and air content.** To determine the amount of mixing water per cubic yard of concrete, use *Table 12-3*. Using the

lower half of this table, you can see that for 1 1/2-inch aggregates and a 3-inch slump, the recommended amount of mixing water is 275 pounds. You also see that for extreme exposure, the recommended air content is 5.5 percent.

NOTE

It is not normal practice to buy air-entraining cement (Type IA) and then add an air-entraining admixture; however, if the only cement available is Type IA and it does not give the needed air content, addition of an air-entraining admixture would be necessary to achieve frost resistance.

5. **Determine the amount of cement required.** Using the amount of mixing water and the water-cement ratio (Steps 1 and 4 above), the required cement content per cubic yard of concrete is 275 ÷ 0.42 = 655 pounds.
6. **Determine the quantity of coarse aggregate.** Let's assume that the fineness modulus of sand is 2.6. Using *Table 12-5*, you find that for 1 1/2-inch aggregate and a fineness modulus of 2.6, you should use 0.73 cubic feet of coarse aggregate on a dry-rodded basis for each cubic foot of concrete. So, for 1 cubic yard of concrete, the volume needed is 27 x 0.73 =19.71 cubic feet. Now, assuming that you determined the dry-rodded weight of the coarse aggregate to be 104 pounds per cubic foot, the dry weight of the aggregate is 19.71 x 104 = 2,050 pounds.

Table 12-5 – Volume of Coarse Aggregate per Unit of Volume of Concrete.

Maximum size of aggregate in.	Volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of sand			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
½	0.59	0.57	0.55	0.53
¾	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 ½	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

7. **Determine the amount of fine aggregate.** *Table 12-6* shows that the weight of 1 cubic yard of air-entrained concrete having 1 1/2-inch maximum size aggregate should be 3,960 pounds. From this figure you simply subtract the weight of the water (275 pounds), cement (655 pounds), and coarse aggregate (2,050 pounds) to determine the weight of the fine aggregate needed for a cubic yard of the concrete. Doing that, you find that you need 980 pounds of fine aggregate (sand).

Now you know the weights of all the materials needed to produce 1 cubic yard of this air-entrained concrete. Since 1 cubic yard equals 27 cubic feet, to calculate how much is needed to make a 1-cubic-foot laboratory trial batch, simply divide the individual weights by 27. You find that you will need 24.2 pounds of cement, 10.2 pounds of water, 36.3 pounds of sand, and 75.9 pounds of coarse aggregate to make 1 cubic foot of concrete.

1.2.3 Adjusting for Slump and Air Content

Let's assume now that you have mixed the above trial batch and determined that the slump measures 1 inch. To adjust for slump, you should increase or decrease the amount of water per cubic yard by 10 pounds for each 1 inch of desired increase or decrease in stump. Then you maintain the same water-cement ratio by increasing or decreasing the amount of cement to maintain the same ratio as that with which you started. You can adjust for a 3-inch slump as follows:

Water	275 pounds + 20 pounds	= 295 pounds
Cement	295 pounds + 0.42	= 702 pounds
Fine aggregate		1,060 pounds
Coarse aggregate		2,050 pounds

If the desired air content was not achieved, recheck the admixture content for proper air content and reduce or increase the mixing water by 5 pounds per cubic yard of concrete for each 1 percent by which the air content is to be increased or decreased, and recalculate the cement to maintain the same water-cement ratio. To find the most economical proportions, make more trial batches, varying the percentage of fine aggregate. In each batch, keep the water-cement ratio, aggregate gradation, air content, and slump approximately the same.

1.3.0 Absolute Volume Method

You can proportion concrete mixtures using absolute volumes.

1.3.1 Basic Guidelines

For this procedure, select the water-cement ratio, slump, air content, and maximum aggregate size, and estimate the water requirement as you did in the trial batch method. Before making calculations, you must have certain other information, such as the specific gravities of the fine and coarse aggregate, the dry-rodded unit weight of the coarse aggregate, and the fineness modulus of the fine aggregate. If you know the maximum aggregate size and the fineness modulus of the fine aggregate, you can estimate the volume of dry-rodded coarse aggregate per cubic yard from *Table 12-5*. Now you can determine the dry-rodded unit weight of coarse aggregate and calculate the quantities per cubic yard of water, cement, coarse aggregate, and air. Finally, subtract the sum of the absolute volumes of these materials in cubic feet from 27 cubic feet per 1 cubic yard to give the specific volume of fine aggregate.

1.3.2 Example Using Absolute Volume Method

Determine the mix proportions for a retaining wall, using the following specifications and conditions:

Required 28-day compressive strength (f'_c)	3,000 psi
Maximum size aggregate	3/4 in.
Exposure condition	Moderate freeze--thaw exposure--exposure to air
Fineness modulus of fine aggregate	2.70
Specific gravity of Portland cement	3.15
Specific gravity of fine aggregate	2.65
Specific gravity of coarse aggregate	2.60
Dry-rodded unit weight of coarse aggregate	102 lb/cu ft.
Dry-rodded unit weight of fine aggregate	100 lb/cu ft.
Slump	3 in.
Cement	Type IA

To determine the mix proportions, proceed as follows:

1. **Estimate the air content.** From *Table 12-3*, the air content should be 5 percent (3/4-inch aggregate, air-entrained concrete, moderate exposure).
2. **Estimate the mixing water content.** From *Table 12-3*, you should use 305 pounds of mixing water per cubic yard of concrete (3-inch slump, 3/4-inch aggregate, air-entrained concrete).
3. **Determine the water-cement ratio.** From *Table 12-2*, a water-cement ratio of 0.59 will satisfy the strength requirement for 3,000 psi concrete. From *Table 12-1*, you find that a water-cement ratio of 0.50 will satisfy the exposure conditions. Since 0.50 is the smaller of the ratios, that is what you should use.
4. **Calculate the cement content**. By using the weight of the mixing water content (Step 2) and the water-cement ratio (Step 3), you can determine the cement content as follows:
   - $$c = \frac{water\ lb / cu\ yard}{water - cement\ ratio}$$
   - $$c = \frac{305\ lb / cu\ yard}{0.50} = 610 lb$$
5. **Calculate the coarse aggregate content.** By using *Table 12-5* and interpolating between fineness moduli of 2.6 and 2.8, you find that for 3/4-inch aggregate having a fineness modulus of 2.7, the volume of dry-rodded aggregate per unit

volume of concrete is 0.63. Therefore, the volume of coarse aggregate needed for 1 cubic yard of concrete is 0.63 x 27 = 17.01 cubic feet. Since the dry-rodded weight of the coarse aggregate is 102 pounds per cubic foot, then the weight of the coarse aggregate for a cubic yard of the concrete is 17.01 x 102= 1,735 pounds.

6. **Calculate the absolute volumes.** For one cubic yard of air-entrained concrete, the volume of the air can be determined by simply multiplying the air content by 27. For this mixture, the air content from Step 1 above is 5 percent; therefore, the volume of air is 0.05 x 27 = 1.35 cubic feet.

For the cement, water, and coarse aggregate, the absolute volumes can be calculated using the following equation:

$$Absolute\,volume = \frac{W}{G \times 62.4}$$

where:

W = weight of the material

G = specific gravity of the material

62.4 = weight of water per cubic foot

By substitution into this formula, the absolute volumes of the cement, water, and coarse aggregate are calculated as follows:

- Volume of cement (W = 610 pounds and G = 3.15)

  = 610 ÷ (3.15 x 62.4) = 3.10 cubic feet
- Volume of water (W = 305 pounds and G = 1)

  = 305 ÷ (1 x 62.4) = 4.89 cubic feet
- Volume of coarse aggregate (W = 1,735 pounds and G = 2.60)

  = 1,735 ÷ (2.60 x 62.4) = 10.69 cubic feet

7. **Determine the fine aggregate content.** To determine the weight of the fine aggregate needed for a cubic yard of the concrete, you first need to add together the volumes obtained in Step 6 above. The resulting sum is then subtracted from 27 cubic feet to obtain the volume of the fine aggregate in a cubic yard of the concrete. This is shown as follows:

Cement	= 3.10 cubic feet
Water	= 4.89 cubic feet
Coarse aggregate	= 10.69 cubic feet
Air	= 1.35 cubic feet
	= 20.03 cubic feet
Absolute volume of fine aggregate	= 27 – 20.03
	= 6.97 cubic feet

Now, having calculated the volume of the fine aggregate and having been given its specific gravity, you can use the formula shown in Step 6 above to solve for the weight of the fine aggregate as follows:

Weight of fine aggregate = 6.97 x 2.65 x 62.4

= 1,152 pounds

8. Determine the quantities for the first trial batch. Let's assume that the size of our laboratory trial batch is 1 cubic yard. For a batch of this size, you need the following quantities of the ingredients:
    - Cement Type IA

      = 610 pounds 94 pounds per sack

      = 6.49 sacks
    - Water

      = 305 pounds 8.33 pounds per gallon

      = 36.6 gallons
    - Coarse aggregate = 1,735 pounds
    - Fine aggregate = 1,152 pounds
    - Air content = 5.0 percent

If needed, more trial batches should be mixed to obtain the desired slump and air content while you keep the water-cement ratio constant.

1.3.3 Variation in Mixtures

The proportions at which you arrive in determining mixtures will vary somewhat depending upon which method you use. The variation is the result of the empirical nature of the methods and does not necessarily imply that one method is better than another. You start each method by assuming certain needs or requirements and then proceed to determine the other variables. Since the methods begin differently and use different procedures, the final proportions vary slightly. This is to be expected and points out further the necessity of trial mixtures in determining the final mixture proportions.

1.3.4 Adjustments for Moisture in Aggregates

The initial mix design assumes that the aggregates are saturated, surface dry (***SSD***), that is, neither the fine aggregates nor the coarse aggregates have any free water on the surface that would be available as mixing water. This is a laboratory condition and seldom occurs in the field. The actual amount of water on the sand and gravel can be determined only from the material at the mixing site. Furthermore, the moisture content of the aggregates will change over a short period of time; therefore, their condition must be monitored and appropriate adjustments made as required. Coarse aggregates are free draining and rarely hold more than 2 percent (by weight) of free surface moisture (***FSM***) even after heavy rains. A good field test for estimating the FSM on fine aggregates is the squeeze test described below.

The squeeze test:

1. Take samples for the squeeze test from a depth of 6 to 8 inches below the surface of the piled sand. This negates the effect of evaporation at the surface of the pile.
2. Squeeze a sample of the sand in your hand. Then open your hand and observe the sample. The amount of FSM can be estimated using the following criteria:

   a. Damp sand (0- to 2-percent FSM). The sample will tend to fall apart (*Figure 12-1*). The damper the sand, the more it tends to cling together.

Figure 12-1 – Damp sand.

   b. Wet sand (2- to 4-percent FSM). The sample clings together without excess water (*Figure 12-2*).

Figure 12-2 – Wet sand.

c. Very wet sand (5- to 8-percent FSM). The sand will ball and glisten or sparkle with water (*Figure 12-3*). The hand will have moisture on it and may even drip.

Figure 12-3 – Very wet sand.

The procedure for adjusting the mixing water caused by free surface moisture is as follows:

- Determine the approximate FSM of the fine aggregate by the squeeze test.
- Estimate the FSM of the coarse aggregate by observation. Usually, 2-percent FSM is the maximum amount gravel will hold without actually dripping.
- Multiply the percentages of FSM on the aggregates by their respective weights per cubic yard. This will yield the weight of the FSM on the aggregates.
- Divide the total weight of the FSM by 8.33 pounds per gallon to determine the number of gallons of water. Subtract those gallons from the mixing water requirements in the original mix design.
- If you are batching your concrete mix by weight, you need to account for the weight contributed by the FSM by increasing the total weights of the aggregates per cubic yard by the weights of the FSM.

<u>Example Problem</u>: Using the final mix proportions as determined, adjust the design mix to account for 6-percent FSM on the fine aggregate (FM = 2.70) and 2-percent FSM on the coarse aggregate. Original mix design for a 1-cubic-yard trial batch was:

Cement: 6.49 sacks (Type IA)

Water: 36.6 gallons

Coarse aggregate: 1,735.0 pounds

Fine aggregate: 1,153.0 pounds

Air content: 5.0 percent

<u>Step 1</u>. Determine the amount of water (in gallons) on the coarse and fine aggregate.

- Coarse aggregate = 1,735 x 0.02 = 34.70 pounds
- Fine aggregate = 1,153 x 0.06 = 69.18 pounds
- Total weight of water = 103.88 pounds

- Converted to gallons = 12.47 gallons

Step 2. Adjust the original amount of mixing water by subtracting the amount of water contributed by the aggregates. The adjusted water requirement then is 24.13 gallons (36.6 - 12.47).

Step 3. Adjust the weights of the aggregates by the amount contributed by the water.

- Coarse aggregate = 1,735 + 34.7 = 1,770 pounds
- Fine aggregate = 1,153 + 69.18 = 1,222 pounds

Step 4. The adjusted mix design to account for the actual field conditions is now

Cement:	6.49	sacks (Type IA)
Water	24.13	gallons
Coarse aggregate	1,770.0	pounds
Fine Aggregate	1,122.0	pounds
Air content	5.0	percent

You should check the moisture content of the aggregates and make appropriate adjustments as conditions change (such as after rains, after periods of dryness, or after the arrival of new material). This quality control step assures that the desired concrete is produced throughout the construction phase.

1.3.5 Materials Estimation

After proportioning the mix, you must estimate the total amount of material needed for the job. Compute the total volume of concrete to be poured, adding a waste factor, and multiplying this volume times the amount of each component in the 1-cubic-yard mix design. The manner of doing this is described in the following example.

Example Problem: Using the mix design determined previously in this chapter, determine the total amount of materials needed to construct the 75-foot-long retaining wall shown in *Figure 12-4*. The 1-cubic-yard mix design is recapped below.

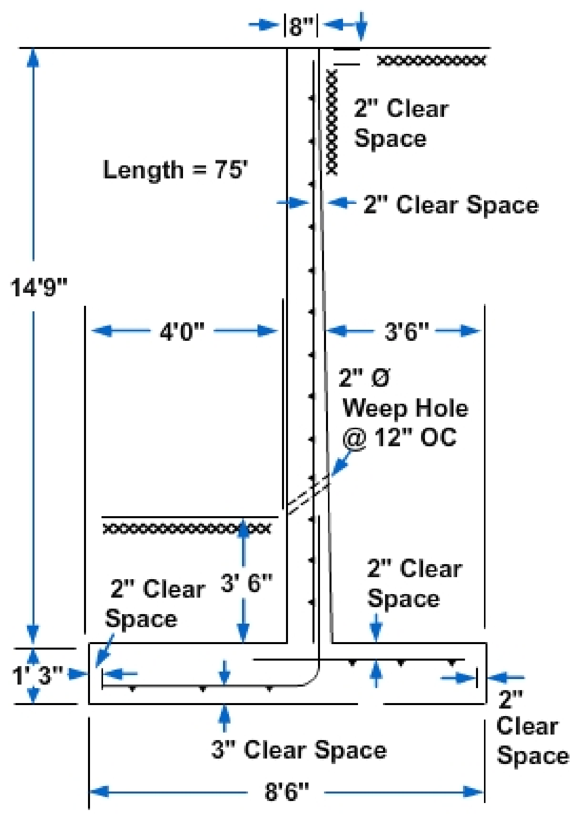


Figure 12-4 – Retaining wall

Cement:	6.49	Sacks (Type IA)
Water	36.6	gallons
Coarse aggregate:	1,735.0	pounds
Fine aggregate:	5.0	pounds
Air content:	1,153.0	percent

To determine the total quantity of each of the above ingredients needed for the retaining wall, you must first calculate the total volume of concrete required. Simply break the retaining wall into simple geometric shapes and then determine and accumulate the volumes of those shapes. Since you should know how to do this, we will simply say that the total volume of the retaining wall is 63.7 cubic yards. To this figure you add a 10-percent waste factor so that the adjusted amount of concrete needed for the project is 70.07 cubic yards. (Had the initial volume needed been greater than 200 cubic yards, you would have used a 5-percent waste factor.)

Now that you know the total amount of concrete needed, you can determine the total quantity of each of the concrete ingredients by simply multiplying the amount of each ingredient needed for 1 cubic yard by the total amount of concrete required for the retaining wall. As an example, you need 1,153 x 70.07 = 80,790.7 pounds, or 40.4 tons, of fine aggregate for the retaining wall. The other ingredients are computed in the same way. That being done, you find that the following quantities of ingredients are need for the project:

Cement:	455.0	sacks (Type IA)
Water:	2,567.0	gallons
Coarse aggregate:	60.8	tons
Fine aggregate:	40.4	tons

2.0.0 BITUMINOUS MIX DESIGN

Hot-mix bituminous concrete for pavements is a mixture of blended aggregate filled with bituminous cement binder. The materials are heated while being mixed to promote fluidity of the bitumen for thorough coverage of the aggregate particles. The design of a bituminous concrete mix consists of the determination of an economical blend and gradation of aggregates together with the necessary content of bituminous cement to produce a mixture that will be durable, have the stability to withstand traffic loads, and be workable for placement and compaction with the construction equipment available.

The procedures described in this section are performed during the design of a hot-mix bituminous concrete. They include testing, plotting the results on graphs, and checking the readings against values from the design tables. Testing of the ingredients and the mix is started before and continued throughout the paving operations.

2.1.0 General Procedures and Guidelines

The objective of hot-mix design is to determine the most economical blend of components that will produce a final product that meets specified requirements. The following is a list of general procedures:

1. Prepare a sieve analysis of each of the aggregates available.
2. Determine the aggregate blend that will achieve the specified gradation (*Paving and Surfacing Operations*, TM 5-337). Plot the selected blend proportions on a graph with the allowable limits to see that it conforms.
3. Determine the specific gravity of the components.
4. Using selected percentages of bitumen (TM 5-337), make trial mixes, and compute the design test properties of the mix.
5. Plot the test properties on individual graphs using the selected bitumen percentages. Draw smooth curves through the plotted points.
6. Select the optimum bitumen content (AC) for each test property from the curves of the Marshall test results.
7. Average the bitumen content values (from Step 6) and, from the graphs, read the test property value corresponding to this average.
8. Check these read values with the satisfactoriness of mix criteria.

The selection of the mix ratios of materials is tentative. The bitumen should be the same as the one to be used in construction. The aggregates and fillers must meet definite requirements. In general, several blends should be considered for laboratory mix-design tests. Gradation specifications are based on limits established by the U.S. Army Corps of Engineers as satisfactory. Within these limits, the following variables are considerations that will affect the final mix design:

1. Use of mix (surface course, binder course, or road mix)
2. Binder (asphalt, cement, or tar)
3. Loading (low tire pressure—100 psi and under, or high tire pressure—over 100 psi)
4. Maximum size of aggregate (in stockpile or based on thickness of the pavement course)

Once the gradation specifications have been selected, you should check the available materials to determine how to proportion the blend to meet these specifications. You should study sieve analyses of the available aggregates and compute a series of trial blends. You may have to make adjustment of the blend after testing the design and prepared mix. The considerations for establishing and adjusting the blend are explained in TM 5-337.

The determination of optimum bitumen content is based on a definite design and testing procedure known as the Marshall method.

The final step is the preparation of a job-mix formula to be furnished to the construction unit.

It is recognized that at times it will be necessary to shorten the design procedure as much as possible to expedite military construction. For additional information, refer to TM 5-337.

2.2.0 Example of Marshall Method of Hot-Mix Design

A typical mix design is illustrated by the calculations and graphs shown on *Figures 12-5* through *12-12*.

2.2.1 Aggregate Grading

Figure 12-5 (DD Form 1207) illustrates an aggregate grading chart depicting the gradation curves of the three aggregates available for the mix. You can make your calculations and record your data on standard sieve analysis data sheets before drawing the curves. You do not need a gradation curve for the mineral filler being used.

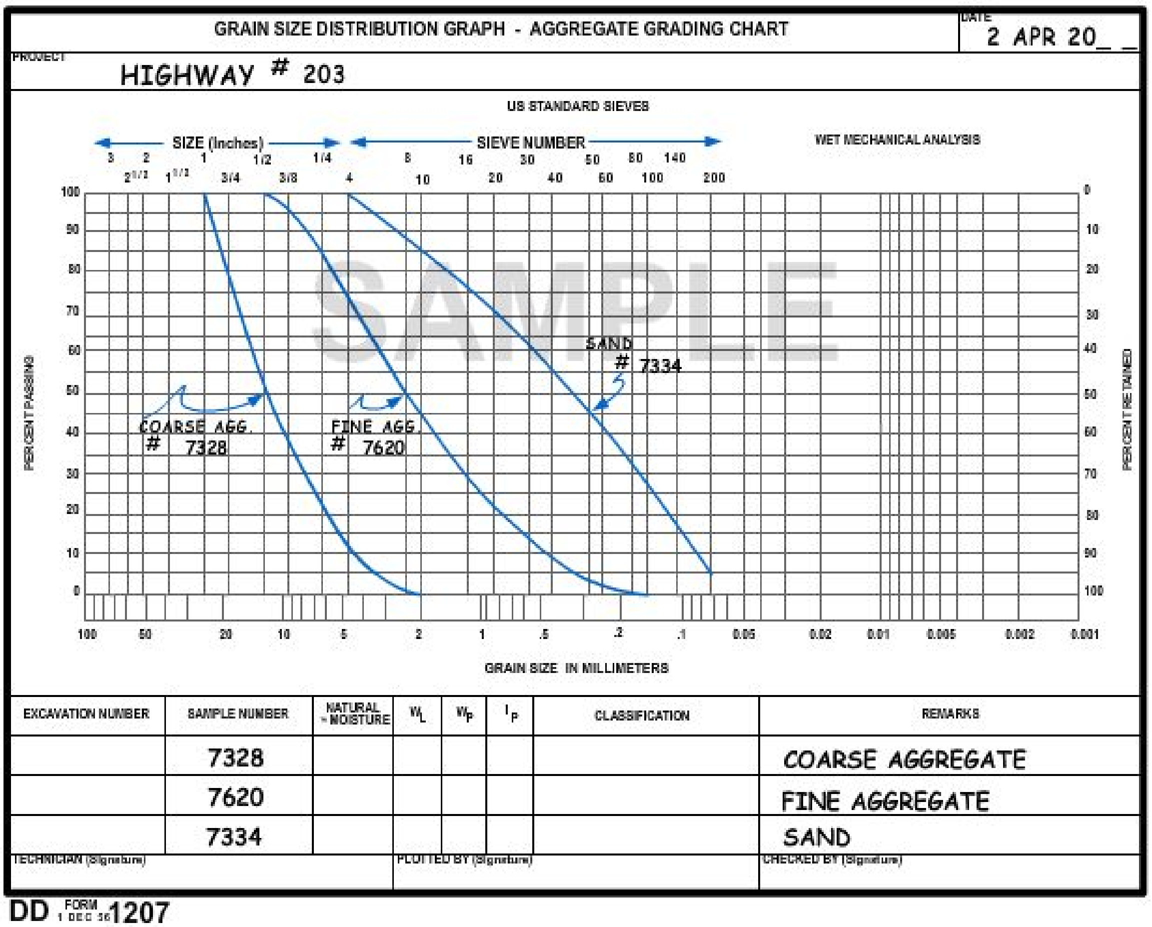


Figure 12-5 – Aggregate grading chart, stockpile materials.

2.2.2 Aggregate Blending

Figures 12-6 and *12-7* (DD Form 1217) show the front and back sides of a data and computation sheet for aggregate blending. Record the gradation of the available aggregates on the upper part (*Figure 12-6*) of the form. Use the form's lower part (*Figure 12-6*) for calculating the trial blend. You may require several attempts before successfully designing a blend meeting specifications. Set the cold feeds (quantities per batch) of aggregate to the asphalt plant according to the proportions obtained in the computation of the final trial blend.

BITUMINOUS MIX DESIGN - AGGREGATE BLENDING

DATE: 2 APR 20_ _

PROJECT: HIGHWAY # 203 | JOB: NO. 47236 | AGGREGATE GRADATION NUMBER: 2A

GRADATION OF MATERIAL

SIEVE SIZE (To be entered by Technician):	1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	#30	#50	# 100	# 200
MATERIAL USED	PERCENT PASSING										
COARSE AGGREGATE (CA)	100	72	46	33	12	2	0	0	0	0	0
FINE AGGREGATE (FA)	100	100	98	94	75	54	33	13	2	0	0
FINE RIVER BAR SAND (FRBS)	100	100	100	100	100	98	90	76	58	35	3
LIMESTONE DUST (LSD)	100	100	100	100	100	100	100	100	98	93	90
DESIRED:	100	80-95	68-86	60-77	45-60	34-49	26-40	19-30	14-23	8-16	3-7

COMBINED GRADATION FOR BLEND - TRIAL NUMBER FINAL

SIEVE SIZE (To be entered by Technician):		1"	3/4"	1/2"	3/8"	# 4	# 8	# 16	#30	#50	#100	# 200
MATERIAL USED	% USED	PERCENT PASSING										
CA	45	45.0	32.4	20.7	14.9	5.4	0.9	0	0	0	0	0
FA	30	30.0	30.0	24.4	28.2	22.3	16.2	9.9	3.9	0.6	0	0
FRBS	20	20.0	20.0	20.0	20.0	20.0	19.6	18.0	15.2	11.6	7.0	0.6
LSD	5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.8	4.5
BLEND:		100.0	87.4	75.1	68.1	52.9	41.7	32.9	24.1	17.1	11.8	5.1
DESIRED:		100.0	87.5	77.0	68.5	52.5	41.5	33.0	24.5	18.5	12.0	5.0

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ______

SIEVE SIZE (To be entered by Technician):												
MATERIAL USED	% USED	PERCENT PASSING										
BLEND:												
DESIRED:												

SAMPLE

DD FORM 1 DEC 36 1217 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 12-6 – Bituminous mix design, aggregate blending, data sheet

COMBINED GRADATION FOR BLEND TRIAL NUMBER													
SIEVE SIZE (To be entered by Technician): →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

COMBINED GRADATION FOR BLEND TRIAL NUMBER													
SIEVE SIZE (To be entered by Technician): →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

REMARKS		
TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)

SAMPLE

Figure 12-7 – Bituminous mix design, aggregate blending, data sheet (back).

2.2.3 Aggregate Blending Limits

Figure 12-8 is an aggregate grading chart (DD Form 1207) showing the specification limits for the mix and the gradation of the blend when mixed in the proportions shown in *Figure 12-6*, trial No. 1.

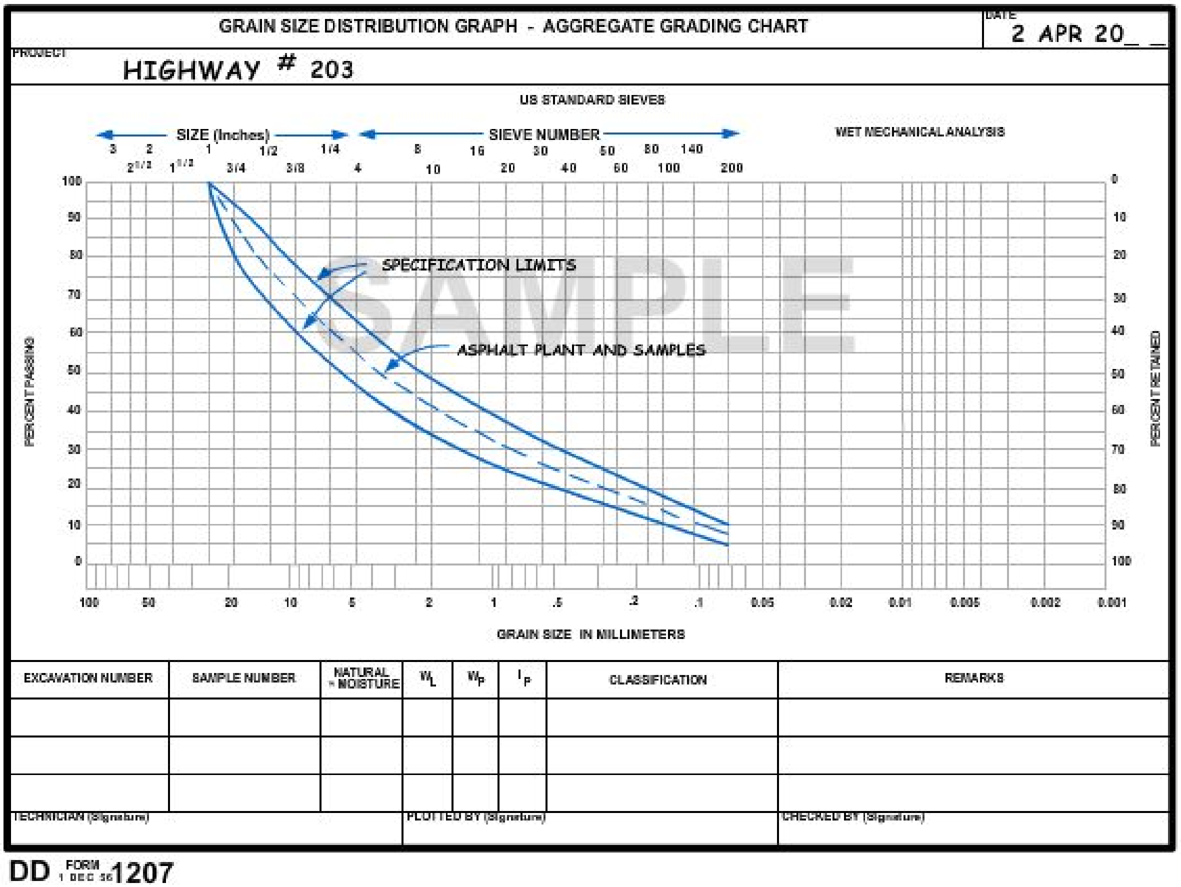


Figure 12-8 – Aggregate grading chart, specification limits and gradation of blended aggregate.

2.2.4 Specific Gravity of Bituminous Mix Components

Figure 12-9 (DD Form 1216) shows a specific gravity data sheet. Use this form for computing the specific gravity of all the bituminous mix components. If more aggregate fractions are used than are provided for on the form, use additional forms. Procedures for performing these tests are discussed in Chapter 10.

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS	DATE 2 APR 20_ _			
PROJECT HIGHWAY # 203	JOB NO. 47236			
COARSE AGGREGATE	UNITS (Grams)			
MATERIAL PASSING 1" SIEVE AND RETAINED ON 16 SIEVE				
SAMPLE NUMBER	CA			
1. WEIGHT OF OVEN - DRY AGGREGATE	378.3			
2. WEIGHT OF SATURATED AGGREGATE IN WATER	241.0			
3. DIFFERENCE (Line 1 minus 2)	137.3			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 1)}{(Line\ 3)}$	$\frac{378.3}{137.3}$ = 2.755			
FINE AGGREGATE	UNITS (Grams)			
MATERIAL PASSING NUMBER 3/8" SIEVE				
SAMPLE NUMBER	FRBS			
4. WEIGHT OF OVEN - DRY MATERIAL	478.8			
5. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	678.6			
6. SUM (Line 4 + 5)	1157.4			
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C	977.4			
8. DIFFERENCE (Line 6 minus 7)	180.0			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 4)}{(Line\ 8)}$	$\frac{478.8}{180.0}$ = 2.660			
FILLER	UNITS (Grams)			
SAMPLE NUMBER	LSD			
9. WEIGHT OF OVEN - DRY MATERIAL	466.5			
10. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	676.1			
11. SUM (Line 9 + 10)	1142.6			
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C	973.8			
13. DIFFERENCE (Line 11 minus 12)	168.8			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 9)}{(Line\ 13)}$	$\frac{466.5}{168.8}$ = 2.762			
BINDER	UNITS (Grams)			
SAMPLE NUMBER	6873			
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	61.9595			
15. WEIGHT OF EMPTY PYCNOMETER	37.9215			
16. WEIGHT OF WATER (Line 14 minus 15)	24.0380			
17. WEIGHT OF PYCNOMETER + BINDER	47.8617			
18. WEIGHT OF BINDER (Line 17 minus 15)	9.9402			
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	62.1568			
20. WEIGHT OF WATER TO FILL PYCNOMETER (Line 19 minus 17)	14.2951			
21. WEIGHT OF WATER DISPLACED BY BINDER (Line 16 minus 20)	9.7429			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 18)}{(Line\ 21)}$	$\frac{9.9402}{9.7429}$ = 1.020			
TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)		

DD FORM 1 DEC 56 1216 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 12-9 – Specific gravity of bituminous mix components, data sheet.

2.2.5 Marshall Stability Computations

Figures 12-10 and *2-11* show DD Form 1218, a data and computation sheet used in the Marshall stability test. Compute the fractional weights and prepare the test specimens using the specific gravity values of the aggregates and the aggregate fraction percentages from the trial blending. Record the measurements made on the test specimens in the upper right-hand corner of the form. Determine, as described in Chapter 10, the stability, flow, unit weight of total mix, and percentage of voids filled with binder to complete the form.

MARSHALL METHOD COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES — DATE OF COMPUTATION: 2 APR 20_ _

JOB NUMBER: 47236 — PROJECT: HIGHWAY # 203 — DESCRIPTION OF BLEND: SURFACE COURSE 45/30/20/5 AGG BLEND

SPECIMEN NUMBER	ASPHALT CEMENT (Percent)	THICK-NESS (Inches)	WEIGHT (Grams)		VOLUME CC	SPECIFIC GRAVITY		AC BY VOLUME (Percent)	VOIDS (Percent)		UNIT WEIGHT TOTAL MIX (Lb./Cu.Ft.)	STABILITY (Pounds)		FLOW UNITS OF 1/100 IN.
			IN AIR	IN WATER		ACTUAL	THEO-RIZED		TOTAL MIX	FILLED		MEASURED	CON-VERTED	
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
					(d - e)	(d)/(f)		(b x g)/(Sp.Gr. of AC)	(100 - 100(g)/(h))	(i)/(i+j)	(g x 62.4)		*	
A-1	3,5		1228,3	716,3	512,0	2,339						2020	2020	11
A-2	3,5		1219,5	712,2	507,3	2,404						1862	1936	10
A-3	3,5		1205,5	705,3	500,2	2,410						1821	1894	8
A-4	3,5		1206,2	708,4	497,8	2,423						1892	1868	8
AVG	3,5		—	—	—	2,409	2,579	8,3	6,6	55,7	150,3	—	1955	9
B-1	4,0		1276,9	747,3	529,6	2,411						2110	2026	10
B-2	4,0		1252,6	733,3	519,3	2,412						2025	2025	9
B-3	4,0		1243,5	730,7	512,8	2,425						1995	1995	9
B-4	4,0		1230,4	722,8	507,6	2,424						2080	2101	9
AVG	4,0		—	—	—	2,418	2,550	9,5	5,5	66,3	150,9	—	2037	9
C-1	4,5		1254,4	738,2	516,2	2,430						2050	2050	12
C-2	4,5		1238,3	726,8	511,5	2,421						2095	2095	9
C-3	4,5		1239,0	724,9	514,1	2,410						2110	2110	10
C-4	4,5		1273,5	752,0	521,5	2,442						2045	2045	10
AVG	4,5		—	—	—	2,426	2,539	10,7	4,5	70,4	151,4	—	2075	10

* From conversion table — COMPUTED BY — CHECKED BY

SAMPLE

DD FORM 1 DEC 56 1218 — PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 12-10 – Test results, Marshall stability test (front).

MARSHALL METHOD COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES													DATE OF COMPUTATION 2 APR 20_ _	
JOB NUMBER			PROJECT					DESCRIPTION OF BLEND						
SPECIMEN NUMBER	ASPHALT CEMENT (Percent)	THICK-NESS (Inches)	WEIGHT (Grams)		VOLUME CC	SPECIFIC GRAVITY		AC BY VOLUME (Percent)	VOIDS (Percent)		UNIT WEIGHT TOTAL MIX (Lb./Cu.Ft.)	STABILITY (Pounds)		FLOW UNITS OF 1/100 IN.
			IN AIR	IN WATER		ACTUAL	THEO-RIZED		TOTAL MIX	FILLED		MEASURED	CON-VERTED	
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
					(d - e)	$\frac{(d)}{(f)}$		$\frac{(b \times g)}{(Sp.Gr. of AC)}$	$(100 - 100\frac{(g)}{(h)})$	$\frac{(i)}{(i+j)}$	(g x 62.4)		*	
D-1	5,0		1237,9	727,0	510,9	2,423						1875	1875	14
D-2	5,0		1300,0	763,6	536,3	2,424						2130	1981	10
D-3	5,0		1273,6	746,9	526,7	2,418						1900	1824	12
D-4	5,0		1247,9	731,8	516,1	2,418						1855	1855	12
AVG	5,0		—	—	—	2,421	2,519	11,9	3,9	75,3	151,5	—	1884	12
E-1	5,5		1237,3	724,1	513,2	2,411						1450	1450	12
E-2	5,5		1264,0	740,6	523,4	2,415						1530	1469	14
E-3	5,5		1286,4	752,4	534,0	2,409						1615	1550	13
E-4	5,5		1253,4	733,8	519,7	2,412						1505	1505	16
AVG	5,5		—	—	—	2,412	2,560	13,0	3,6	78,3	150,5	—	1494	14
* From conversion table			COMPUTED BY						CHECKED BY					

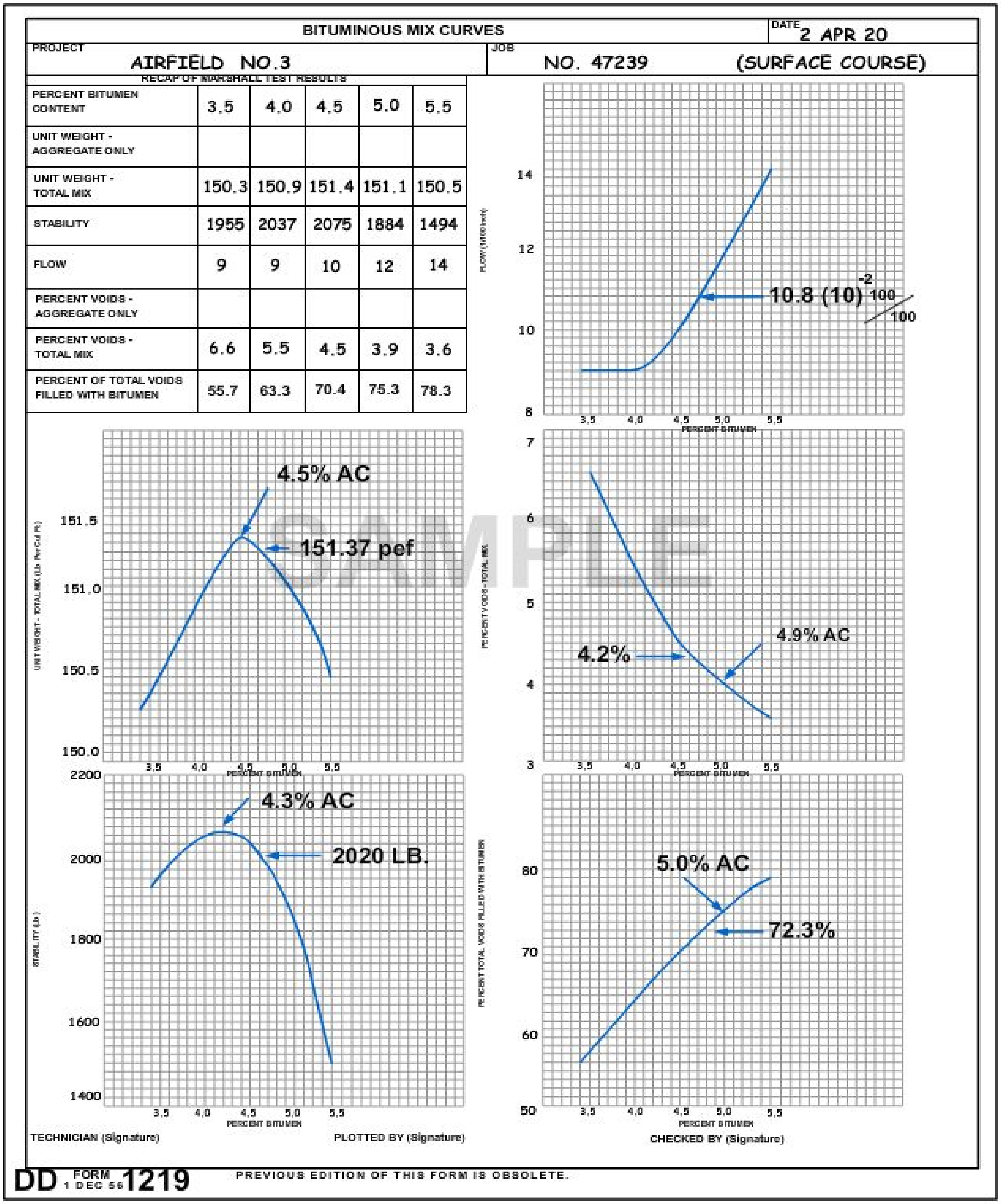
SAMPLE

DD FORM 1 DEC 56 1218 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 12-11 – Test results, Marshall stability test (back).

2.2.6 Marshall Method Computations

Transfer each binder content computation value from DD Form 1218 (*Figures 2-10* and *12-11*) to DD Form 1219 (*Figure 12-12*). Each graph on the form represents a different test property. Plot the values for each property on their respective graph using the binder contents as ordinates. Draw a smooth curve through the plotted points.


BITUMINOUS MIX CURVES

DATE 2 APR 20

PROJECT AIRFIELD NO.3

JOB NO. 47239 (SURFACE COURSE)

RECAP OF MARSHALL TEST RESULTS

PERCENT BITUMEN CONTENT	3.5	4.0	4.5	5.0	5.5
UNIT WEIGHT - AGGREGATE ONLY					
UNIT WEIGHT - TOTAL MIX	150.3	150.9	151.4	151.1	150.5
STABILITY	1955	2037	2075	1884	1494
FLOW	9	9	10	12	14
PERCENT VOIDS - AGGREGATE ONLY					
PERCENT VOIDS - TOTAL MIX	6.6	5.5	4.5	3.9	3.6
PERCENT OF TOTAL VOIDS FILLED WITH BITUMEN	55.7	63.3	70.4	75.3	78.3

Figure 12-12 – Asphalt mix curves, Marshall Test properties.

2.2.7 Marshall Test Criteria

Table 12-7 lists the criteria for determining optimum asphalt content (***OAC***). For each test property, you should consider the type of mix to be used and the expected load. The optimum bitumen content for each property is designated as a definite point on the curve for that property. The bitumen content percentages (one for each property) are averaged, and the average is used to read the corresponding value of each test property.

The value, as determined, should be referred to the criteria portion of *Table 12-7* to see if it is within the permissible limits so that the mix will perform satisfactorily.

2.2.8 Test Variation for Aggregates with 10 Percent or More Larger Than 1-Inch Maximum Size

The procedure described in the Marshall method and the examples given in the preceding paragraphs are applicable to hot-mix design where the amount of aggregate larger than the 1-inch sieve is less than 10 percent of the total. When the larger than (plus) 1-inch material exceeds 10 percent of the total, the following variations are made in the procedure:

1. Mix bitumen at the selected content with the entire aggregate, including the plus 1-inch portion.
2. Pass the mixed hot batch through a 1-inch sieve. Discard the plus 1-inch portion.
3. Make compacted specimens from the portion that passes the 1-inch sieve and perform the Marshall test, except do not calculate the voids of the compacted specimens at this time.
4. Determine the bulk specific gravity of the plus 1-inch aggregate, and, with the specific gravity of the compacted specimens, compute the adjusted specific gravity (G_A) as follows:

$$G_A = \frac{100}{\frac{A}{C} + \frac{B}{D} \times f}$$

where:

A = weight of dry material retained on 1 inch sieve, expressed as percent of total batch

B = portion of total batch remaining after the dry, plus 1-inch portion is removed (100%-A%)

C = bulk specific gravity of plus 1-inch aggregate

D = actual specific gravity of compacted specimen

f = empirical factor = 0.995

G_A = adjusted bulk specific gravity of specimen

Table 12-7 – Marshall Test Specifications and Determination of Optimum Asphalt Content.

(1) Property	(2) Course	(3) Criteria		(4) Determination of OAC	
		(75 Blows) ***High Press	(50 Blows) Low Press	High Press	Low Press
Aggregate blends showing water absorption up to 2 ½ % (used with ASTM apparent specific gravity)					
Stability	Surface	1,800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Surface	--	--	Peak of curve	Peak of curve
Flow	Surface	16 or less	20 or less	Not used	Not used
% Voids total mix	Surface	3%-5%	3%-5%	4% -	4%
% Voids filled w/AC	Surface	70% - 80%	75% - 85%	75%	80%
Stability	Binder	1,800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Binder	--	--	Peak of curve	Peak of curve
Flow	Binder	16 or less	20 or less	Not used	Not used
% Voids total mix	Binder	5% - 7%	4% - 6%	6%	5%
% Voids filled w/AC	Binder	50% - 70%	65% - 75%	60%	70%
Stability	Sand asphalt	**	500 or higher	**	Peak of curve
Unit wt	Sand asphalt	--	--	**	Peak of curve
Flow	Sand asphalt	**	20 or less	Not used	Not used
% Voids total mix	Sand asphalt	**	5% - 7%	**	6%
% Voids filled w/AC	Sand asphalt	**	65% - 75%	**	70%
Aggregate blends showing water absorption greater than 2 ½ % (used with bulk-impregnated specific gravity)					
Stability	Surface	1,800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Surface	--	--	Peak of curve	Peak of curve
Flow	Surface	16 or less	20 or less	Not used	Not used
% Voids total mix	Surface	2%-4%	2%-4%	3%	3%
% Voids filled w/AC	Surface	75% - 85%	80% - 90%	80%	85%
Stability	Binder	1,800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Binder	--	--	Peak of curve	Peak of curve
Flow	Binder	16 or less	20 or less	Not used	Not used
% Voids total mix	Binder	4% - 6%	3% - 5%	5%	4%
% Voids filled w/AC	Binder	55% - 75%	70% - 80%	65%	75%
Stability	Sand asphalt	**	500 or higher	**	Peak of curve
Unit wt	Sand asphalt	--	--	**	Peak of curve
Flow	Sand asphalt	**	20 or less	Not used	Not used
% Voids total mix	Sand asphalt	**	4% - 6%	**	5%
% Voids filled w/AC	Sand asphalt	**	70% - 80%	**	75%

* If the inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen should be adjusted so that the voids total mix are within limits

** Criteria for sand asphalt to be used in designing pavement for high pressure tires have not been established

*** High pressure tires are those above 100 psi. Low pressure tires are those with 100 psi or under.

5. Calculate the voids by using the adjusted specific gravity, and apply the design criteria for this value.
6. Use stability and flow values as measured on the compacted specimens.

2.3.0 Job-Mix Formula (AC Mixes)

When you have found the mix satisfactory, the percentages by weight of the aggregate and the averaged optimum bitumen content should be combined to establish the job-mix formula. *Figure 12-6* lists the final percentages of the aggregate for a given job mix. By plotting the test results (*Figures 12-10* and *12-11*) on DD Form 1219 (*Figure 12-12*) and applying the Marshall test criteria for determining optimum bitumen content, you make the determination that the mix requires 4.7 percent of asphalt cement. Accordingly, the aggregates must be 95.3 percent of the total mix. The selected blend contained 45 percent coarse aggregate (CA), 30 percent fine aggregate (FA), 20 percent fine river bar sand (FRBS), and a 5 percent limestone dust (LSD) mineral filler. The job-mix formula is computed as follows:

CA	= 95.3 X .45	=	42.9%
FA	= 95.3 X .30	=	28.6%
FRBS	= 95.3 X .20	=	19.0%
Mineral filler	= 95.3 X .05	=	4.8%
		=	95.3%
Asphalt cement	=		4.7%
Total	=		100.0%

2.4.0 Modified Test for Cold-Mix Pavements

Use a modified version of the Marshall method as an aid in determining the asphalt content for cold-mix design of light-duty pavement. Use it where asphalt cutbacks will be the binder. The procedures follow those used for hot-mix design (Marshall method), in general, with the following modifications:

- Aggregates: Aggregates should be dried to a moisture content expected during construction (up to a maximum of 2 percent, by weight).
- Asphalt: Mix selected bitumen with the aggregates, but at the temperature recommended for field application. The aggregates remain at room temperature.
- Curing:. Before compaction, cure the mixture for at least 12 hours in an oven set at 140°F (± 5°).
- Compaction: After curing, the mixture is compacted at 140°F using 50 blows of the hammer at each end of the specimen.
- Cooling: After molding, cool the specimens to room temperature in the molds. You must take care to remove the specimens, undisturbed and undamaged, from the molds.
- Testing: Heat the specimens in an oven to 100°F (±2°) and test them in the Marshall machine. Heating will normally take about 2 hours.

- Selection of the design amount of asphalt: The asphalt contents at maximum density and maximum stability, after averaging, are used as the design amount.

2.5.0 Surface Area Method of Mix Design

When laboratory equipment, except for sieve analysis, is not available, the following formulas may be used in place of laboratory procedures to determine the necessary asphalt content:

1. For asphalt cement:

   $$P = 0.02a + 0.07b + 0.15c + 0.20d$$

   where:

   P = percent (expressed as a whole number) of asphalt material by weight of dry aggregate

   a = percent (expressed as a whole number) of mineral aggregate retained on the No. 50 sieve

   b = percent (expressed as a whole number) of mineral aggregate passing the No. 50 and retained on the No. 100 sieve

   c = percent (expressed as a whole number) of mineral aggregate passing the No. 100 and retained on the No. 200 sieve

   d = percent (expressed as a whole number) of mineral aggregate passing the No. 200 sieve

   Absorptive aggregates, such as slag, limerock, vesicular lava, and coral, will require additional asphalt.

2. For asphalt emulsion:

   $$P = 0.05 A + 0.1 B + 0.5 C$$

   where:

   P = percent (expressed as a whole number) by weight of asphalt emulsion, based on weight of graded mineral aggregate

   A = percent (expressed as a whole number) of mineral aggregate retained on the No. 8 sieve

   B = percent (expressed as a whole number) of mineral aggregate passing the No. 8 sieve and retained on the No. 200 sieve

   C = percent (expressed as a whole number) of mineral aggregate passing the No. 200 sieve

Summary

In this chapter we discussed the elements of designing concrete and bituminous mixtures. When designing a concrete mixture, you must take into account the end use of the concrete and the conditions at the time of placement. You must also consider the water-cement ratio, aggregate characteristics, amount of entrained air, and slump. Two ways of calculating and evaluating your concrete mix designs are the trial batch method and the absolute volume method.

When you design a bituminous mix, you must determine an economical blend and gradation of aggregates and the proportion of bituminous cement needed to produce a durable, workable mixture that results in a surface with the stability to withstand traffic loads. The procedure for bituminous mix design includes testing, plotting the results on graphs, and checking the readings against values from the design tables.

Trade Terms Introduced in this Chapter

Absolute volume method	Method of proportioning concrete mixtures based on estimated weight of concrete per unit volume
FSM	Free surface moisture; used to describe aggregates
OAC	Optimum asphalt content
SSD	Saturated, surface dry; used to describe aggregates
Trial batch method	A method of proportioning concrete mixtures based on calculations of the absolute volume occupied by the ingredients used in the concrete mixture

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Materials Testing, FM 5-472 Ch.2 /NAVFAC MO 330/AFJMAN 32-1221(I) Headquarters, Department of the Army, Washington, DC, 1 July 2001

Standard Method for Particle-Size Analysis of Soils, ASTM D422-63, American Society for Testing and Materials, Philadelphia, Pa., 2007.

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