[2nd semester 1433H]
CE432-Highway Engineering
LABORATORY

MARSHALL MIX DESIGN PROJECT

Project Details

	Group 1 (Mix 1)	Group 2 (Mix 2)	Group 3 (Mix 3)	Group 4 (Mix 4)	Group 5 (Mix 5)
Binder Content (%)	4	4.5	5	5.5	6.0

(1) Prepare three pills and compact 75 blows each side.
<u>Before breaking the pills:</u>

- Determine the density of each pill and calculate the average density (γ)
- Determine the specific gravity for each of the compacted pills and calculate the average (G_{mb})

<u>Break the bills to determine:</u>

- The stability for each specimen and calculate the average.
- Flow for each specimens and calculate the average.

(2) Prepare a loose specimen to determine the theoretical maximum density (G_{mm})
(3) Prepare a table containing the data obtained by your group and pass it to the laboratory supervisor. A complete table (results for all binder contents) will be established and provided to all groups.
(4) As soon as receiving the complete table, student shall carryout the Marshall analysis and provide a complete report.

The data that each group needs to provide includes

Group Number				
Compacted Specimens				
	Pill Number			Average
	1	2	3	
Stability (unit)				
Flow (unit)				
Density (unit)				
Specific Gravity (G_{mb})				
Loose Specimen				
Maximum Theoretical Specific Gravity (G_{mm}) =				

Marshall Mix Design
OBJECTIVES OF ASPHALT PAVING MIX DESIGN

The design of asphalt paving mixes is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction. The overall objective of the design of asphalt paving mixes is to determine an economical blend and gradation of aggregates and asphalt that yields a mix having:

- Sufficient asphalt to ensure a durable pavement
- Sufficient mix stability to satisfy the demands of traffic without distortion or displacement
- Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding, and loss of stability
- Sufficient workability to permit efficient placement of the mix without segregation.

Marshall Method of Mix Design:

Outline of Method:

1. The materials should meet the project specifications.
2. The aggregate gradation should not meet the project specifications.
3. The bulk specific gravity of aggregates and the specific gravity of the asphalt cement are determined.

General:

ASTM D1559 has standardized the Marshall Test procedures.

- Only applicable for hot-mix paving mixture
- Asphalt cement have to be used
- Maximum size of aggregate = 1” (25 mm) or less
- Standard test specimens are 2.5” high by 4” diameter
- Two principles features of the method:
    - density - voids analysis
    - stability - flow test of the compacted test specimens
- The stability of the specimen is the maximum load resistance in pounds which the specimen can carry at 140 °F (60 °C)
- The flow value is the total movement or strain in units of 1/100 in. (0.25 mm) occurring in the specimen between no load and maximum load during the stability test
- For preparation of specimens:
    - Aggregate weight used is 1200 g
    - Aggregate should be heated to 160 °C for 3 to 4 h
    - Asphalt cement should also be heated to 155 °C for not more than one hour to prevent over heating
- Mixing temperature is (155 °C) which produce kinematic viscosity of 170 ± 20 cst
- Compaction temperature is (145 °C) which produce kinematic viscosity of 280 ±30 cst
- The molds, hammer should be heated between 93 °C (200 °F) and 149 °C (300 °F)

- Use 75 blows on each side of the specimen to compact the specimens for heaving traffic (hammer weight = 10 pound and drop = 18 in)
- Specimens are allowed to cool overnight
- Trial specimen is prepared:

  Adjusted Wt. of Agg. = 2.5 (Wt. of Agg. used) ÷ Spec. Ht. (in) obtained
  (U.S. Units)
  AdjustedWt.of Agg .= 63.5 (Wt. of Agg. used) ÷ Spec. Ht. (mm) obtained
  (SI Units)

In the Marshall method, each compacted test specimen is subjected to the following tests and analysis in the order listed:

- Bulk Specific Gravity Determination
- Stability - Flow Test
- Density & Voids Analysis

TABLE 18.1 - Marshall Design Criteria

Marshall Method Mix Criteria	Light Traffic Surface & Base Min	Max	Medium Traffic Surface & Base Min	Max	Heavy Traffic Surface & Base Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability, N (lb)	3336 (750)	-	5338 (1200)	-	8006 (1800)	-
Flow, 0.25 mm	8	18	8	16	8	14
Percent Air Voids	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)			See Figure 16-1			
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

Standard Test Method For
RESISTANCE TO PLASTIC FLOW OF BITUMINOUS MIXTURES USING MARSHALL APPARATUS
(ASTM D 1559 - 89)

<u>Purpose</u>: This test method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. This test method is for use with mixtures containing asphalt cement, asphalt cut-back or tar, and aggregate up to 1-in. (25.4-mm) maximum size.

<u>Apparatus Required</u>:

- *Specimen Mold Assembly* - Mold cylinders 4 in. in diameter by 3 in. in height, base plates, and extension collars
- *Specimen Extractor*, steel, in the form of a disk with a diameter not less than 3.95 in. and ½ in. thick for extracting the compacted specimen from the specimen mold with the use of the mold collar.
- *Compaction Hammer* - The compaction hammer shall have a flat, circular tamping face and a 10-lb sliding weight with a free fall of 18 in.
- *Compaction Pedestal* - The compaction pedestal shall consist of an 8 by 8 by 18-in. wooden post capped with a 12 by 12 by 1-in. steel plate.
- *Specimen Mold Holder*, mounted on the compaction pedestal to center the compaction mold over the center of the post. It shall hold the compaction mold, collar, and base place securely in position during compaction of the specimen.
- *Breaking Head* - The breaking head shall consist of upper and lower cylindrical segments or test heads having an inside radius of curvature of 2 in.
- *Loading Jack* - The loading jack shall consist of a screw jack mounted in a testing frame and shall produce a uniform vertical movement of 2 in. / min.
- *Ovens or Hot Plates*
- *Mixing Apparatus* - Mechanical mixing is recommended.
- *Water Bath* - The water bath shall be at least 6 in. deep and shall be thermostatically controlled so as to maintain the bath at 140 ± 1.8 °F (60 ± 1.0 °C). The tank shall have a perforated false bottom or be equipped with a shelf for supporting specimens 2 in. above the bottom of the bath.
- *Miscellaneous Equipment:*
- *Containers*
- *Mixing Tool*
- *Thermometers*
- *Balance*
- *Gloves*
- *Rubber Gloves*
- *Marking Crayons*
- *Scoop*
- *Spoon*

Preparation of Test Specimens:

- *Number of Specimens* - Prepare at least three specimens for each combination of aggregates and bitumen content
- *Preparation of Aggregates* - Dry aggregates to constant weight at 221 to 230 °F (105 to 110 °C) and separate the aggregates to dry sieving into the desired size fractions.
- *Determination of Mixing and Compacting Temperatures:*
- The temperatures to which the asphalt cement must be heated to produce a viscosity of 170 ±20 cSt shall be the mixing temperature.
- The temperature to which asphalt cement must be heated to produce a viscosity of 280 ± 30 cSt shall be the compacting temperature.
- *Preparation of Mixtures:* Weigh into separate pans for each test specimen the amount of each size fraction required to produce a batch that will result in a compacted specimen 2.5 ± 0.05 in. in height (about 1200 g). Place the pans on the hot plate or in the oven and heat to a temperature not exceeding the mixing temperature by more than approximately 28 °C . Charge the mixing bowl with the heated aggregate and dry mix thoroughly. Form a crater in the dry blended aggregate and weigh the preheated required amount of bituminous material into the mixture. Mix the aggregate and bituminous material rapidly until thoroughly coated.
- *Compaction of Specimens:*
- Thoroughly clean the specimen mold assembly and the face of the compaction hammer and heat them either in boiling water or on the hot plate to a temperature between 200 and 300 °F (93.3 and 148.9 °C). Place a piece of filter paper or paper toweling cut to size in the bottom of the mold before the mixture is introduced. Place the entire batch in the mold, spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and 10 times over the interior. Remove the collar and smooth the surface of the mix with a trowel to a slightly rounded shape.

Replace the collar, place the mold assembly on the compaction pedestal in the mold holder, and apply 75 blows with the compaction hammer with a free fall in 18 in. Remove the base plate and collar, and reverse and reassemble the mold. Apply the same number of compaction blows to the face of the reversed specimen. After compaction, remove the base plate and place the sample extractor on that end of the specimen. Place the assembly with the extension collar up in the testing machine, apply pressure to the collar by means by means of the load transfer bar, and force the specimen into the extension collar. Lift the collar from the specimen. Carefully transfer the specimen to a smooth, flat surface and allow it to stand overnight at room temperature. Weigh, measure, and test the specimen.

Testing Procedure:

1. Bring the specimens prepared with asphalt cement to the specified temperature by immersing in the water bath 30 to 40 min or placing in the oven for 2 h. Maintain the bath or oven temperature at 140 ± 1.8 °F (60 ± 1.0 °C) for the asphalt cement specimens. Thoroughly clean the guide rods and the inside surfaces of the test heads prior to making the test, and lubricate the guide rods so that the upper test head slides freely over them. The testing head temperature shall be maintained between 70 to 100 °F (21.1 to 37.8 °C) using a water bath. Remove the specimen from the water bath, oven, or air bath, and place in the lower segment of the breaking head. Place the upper

segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine.

2. Apply the load to the specimen by means of the constant rate of movement of the load jack or testing machine head of 2 in./min until the maximum load is reached and the load decreases as indicated by the dial. Record the maximum load and the indicated flow. The elapsed time for the test from removal of the test specimen from the water bath to the maximum load determination shall not exceed 30 s.

TABLE 18.2 Stability Correlation Ratios[A]

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.[B]	mm	Correlation Ratio
406 to 420	2	50.8	1.47
421 to 431	2 1/16	52.4	1.39
432 to 443	2 1/8	54.0	1.32
444 to 456	2 3/16	55.6	1.25
457 to 470	2 1/4	57.2	1.19
471 to 482	2 5/16	58.7	1.14
483 to 495	2 3/8	60.3	1.09
496 to 508	2 7/16	61.9	1.04
509 to 522	**2 ½**	**63.5**	**1**
523 to 535	2 9/16	65.1	0.96
536 to 546	2 5/8	66.7	0.93
547 to 559	2 11/16	68.3	0.89
560 to 573	2 3/4	69.8	0.86
574 to 585	2 13/16	71.4	0.83
586 to 598	2 7/8	73.0	0.81
599 to 610	2 15/16	74.6	0.78
611 to 625	3	76.2	0.76

[A]The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 2 1/2 in. (63.5 mm) specimen.

[B]Volume-thickness relationship is based on a specimen diameter of 4 in. (101.6 mm).

Experimental Data and Results:

- Tabulate the test data in the given *Test Data Sheet*. Report the type of sample tested (laboratory sample or pavement core specimen)
- Average maximum load in pounds-force of at least three specimens, corrected when required.
- Average flow value, in hundredths of an inch, twenty-five hundredths of a millimeter, of three specimens,
- Test temperature.

TABLE 18.3: BITUMINOUS WEARING COURSE
Optimum Blending for Marshall Mix Design
(M.O.C. Class “A” Aggregate Blending)

Sieve Size	% Individual	Individual Weights g	Cumulative Weights g	Specification Limits % Passing	% Mean	Tolerance
3/4”	0.0	0	0	100	100	± 6
1/2"	16.0	192	192	76 - 92	84	± 6
3/8"	12.5	150	342	64 - 79	71.5	± 5
# 4	23.0	276	618	41 - 56	48.5	± 5
#10	10.5	222	840	23 - 37	30	± 4
#40	16.5	198	1038	7 - 20	13.5	± 4
#80	4.5	54	1092	5 - 13	9	± 3
#200	3.5	42	1134	3 - 8	5.5	± 1.5
Filler	5.5	66	1200	-	-	

Coarse Aggregate,% = Passing 3/4” to Retained # 4
= 51.5 %

Fine Aggregate, % = Passing # 4 to Retained # 200
= 43 %

Filler, % **=** Passing # 200
= 5.5 %

Total Aggregate % 100.0

Standard Method of Test For
THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF BITUMINOUS PAVING MIXTURES
(ASTM D 2041-91)

Purpose: This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25 °C

Summary of Test Method: A weighed sample of oven-dry paving mixture in the loose condition is placed in a tared vacuum vessel. Sufficient water at a temperature of 25 ± 4 °C is added to completely submerge the sample. Vacuum is applied for from 5 to 15 min to gradually reduce the residual pressure in the vacuum vessel to 30 mm Hg or less. At the end of the vacuum period, the vacuum is gradually released. The volume of the sample of paving mixture is obtained by filling the vacuum container level full of water and weighing in air. At the time of weighing, the temperature is measured as well as the mass. From the mass and volume measurements, the specific gravity or density at 25 °C is calculated. If the temperature employed is different from 25 °C, an appropriate correction is applied.

Apparatus Required:

- *Vacuum Container* - A small volumetric flask with a capacity of approximately 2000 mL.
- *Balance* - with ample capacity, and with sufficient sensitivity to enable the specific gravity of samples of uncompacted paving mixtures to be calculated to at least four significant figures.
- *Vacuum pump or water aspirator,* capable of evacuating air from the vacuum container to a residual pressure of 30 mm Hg.
- *Residual pressure manometer* - To be connected directly to the vacuum vessel and to be capable of measuring residual pressure down to 30 mm of Hg.
- *Manometer or Vacuum Gauge* - Suitable for measuring the vacuum being applied at the source of the vacuum.
- *Thermometers* - Calibrated liquid-in-glass thermometers of suitable range.

Sampling: Obtain the sample according to the following size requirements:

Size of Largest Particle of Aggregate: Mixture, in.	Minimum Sample Size, g
1 ½	4000
1	2500
¾	2000
½	1500
¼	1000
No. 4	500

Calibration of Flask:

- Calibrate the flask by determining the mass of the flask when filled with water over the range of water temperatures likely to be encountered in service. Designate this mass as *D.* Plot a graph of mass of flask filled with water versus water temperatures.

Procedure:

1. Separate the particles of the sample of paving mixture by hand, taking care to avoid fracturing the aggregate, so that the particles of the fine aggregate portion are not larger than 1/4 in. If a sample of paving mixture is not sufficiently soft to be separated manually, place it is a flat pan, and warm it in an oven until it can be separated.
2. Unless the paving mixture has been prepared in a laboratory using oven-dry aggregates, oven-dry the sample to constant mass at a temperature of 105 ± 5 °C.
3. Cool the sample to room temperature, place it in a tare container and weigh. Designate the net mass of the sample as *A.* Add sufficient water at a temperature of approximately 25 °C to cover the sample completely.
4. Remove air trapped in the sample by applying gradually increased vacuum until the residual pressure manometer reads 30 mm Hg or less. Maintain this residual pressure for 5 to 15 min. Agitate the container and contents during the vacuum period either continuously by a mechanism device, or manually by vigorous shaking at intervals of about 2 min.
5. At the end of the vacuum period, gently release the vacuum and fill the flask with water and adjust the contents to a temperature of 25 ± 1 °C. Determine the mass of the container (and contents), completely filled. Designate this mass as *E*.

Experimental Data, Results and Calculations:

- Tabulate the data in the given *Test Data Sheet*. Report the theoretical maximum specific gravity to the nearest third decimal.
- Calculate the theoretical maximum specific gravity of the sample at 25 °C as follows:

$$\text{Theoretical Maximum Specific Gravity} = A / (A + D - E)$$

Where:

A = mass of oven dry sample in air, g
D = mass of container filled with water at 25 °C
E = mass of container filled with sample and water at 25 °C

Discussion: Discuss about the test and results in the given *Test Data Sheet.*

Test Data Sheet
THEORETICAL MAXIMUM SPECIFIC GRAVITY OF LOOSE PAVING MIXTURE

Sample No. __________ Description of Material: ____

Tested by: ________________________________ Date of Testing: __________________________

Test Temperature: _____________ ° C; Sample Type: ______________________ ;

Test No.	Mass of Oven Dry Sample in Air, g *A*	Mass of Container filled with water at 25 °C *D*	Mass of Container filled with sample and water at 25 °C *E*	Theoretical Maximum Specific Gravity *A / (A+D-E)*
1				
2				
3				
Average Theoretical Maximum Specific Gravity				

Discussion of Test Results: ____

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ANALYSIS OF COMPACTED PAVING MIXTURES

General: The analytical procedures described herein apply either to paving mixtures that have been compacted in the laboratory, or to undisturbed samples that have been cut from a pavement in the field. When a paving mixture is compacted in the laboratory, the compactive effort should provide a density equal to the density the mixture will ultimately attain under traffic following compaction by rolling during construction.

By analyzing a compacted paving mixture (V_a), voids in the mineral aggregate (VMA), and effective asphalt content (P_{be}), some indication of the probable service performance of the pavement is provided. The efficacy of compaction, either during construction or after years of service can be determined by comparing the specific gravity of an undisturbed sample cut from a pavement with the laboratory compacted specific gravity of the paving mixture.

Definition:

- **Bulk Specific Gravity (G_{sb}):** The ratio of the weight in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of equal volume of gas free distilled water at a stated temperature. Refer to Figure 18-3.
- **Apparent Specific Gravity (G_{sa}):** The ratio of the weight in air of a ;unit volume of an impermeable material at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature. Refer to Figure 16-3.
- **Effective Specific Gravity (G_{se}):** The ratio of the weight in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the weight in air of equal density of an equal volume of gas free distilled water at a stated temperature. Refer to Figure 18-3.
- **Voids in the Mineral Aggregate (VMA):** The volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the voids and the effective asphalt content, expressed as a percent of the total volume of the sample. Refer to Figure 18-3.
- **Effective Asphalt Content (P_{be}):** The total asphalt content of a paving mixture minus the portion of asphalt that is lost by absorption into the aggregate particles. Refer to Figure 18-3.
- **Air Voids (V_a):** The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture. Refer to Figure 18-3.
- **Volume Relationships in a Compacted Mix:** Figure 18-4 depicts the volume relationships between aggregate, air voids in mineral aggregate, total asphalt content, asphalt lost by absorption into the aggregate particles, and effective asphalt content.

OUTLINING PROCEDURE FOR ANALYZING A COMPACTED PAVING MIXTURE:

1. Measure the bulk specific gravities of the coarse aggregate and of the fine aggregate.
2. Measure the specific gravity of the asphalt cement and the mineral filler.
3. Calculate the bulk specific gravities of the aggregate combination in the paving mixture.
4. Measure the maximum specific gravity of the loose paving mixture. (ASTM D 2041)
5. Measure the bulk specific gravity of the compacted paving mixture.
6. Calculate the effective specific gravity of aggregate.
7. Calculate asphalt absorptions of aggregate.
8. Calculate the effective asphalt content of the paving mixture.
9. Calculate the percent voids in the mineral aggregate in the compacted paving mixture.
10. Calculate the percent air voids in the compacted paving mixture.

Paving Mixture Data for Sample Calculations

Material	Specific Gravity Standards		ASTM Method	Mix Composition
	Apparent	Bulk		Percent by Wt. of Total Mix
Asphalt Cement		-	D 70	P_b
Coarse Aggregate		G_1	C 127	P_1
Fine Aggregate		G_2	C 128	P_2
Mineral Filler	G_3	-	D 854	P_3

EQUATIONS FOR SAMPLE CALCULATIONS:

- **Bulk Specific Gravities of Aggregate:** When the total aggregate consists of separate fractions of coarse aggregate, fine aggregate, and mineral filler, all having different specific gravities

$$G_{sb} = \frac{P_1 + P_2 + ... + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + ... + \frac{P}{G_n}}$$

where:

G_{sb} = bulk specific gravity for the total aggregate
P_1 , P_2 , P_n = percentages by weight of aggregates 1, 2, ... n; and,
G_1 ,G_2 , G_n = bulk specific gravities of aggregate 1, 2, ... n

- **Effective Specific Gravity of Aggregate:** When based on the maximum specific of a paving mixture, G_{mm} , the effective specific gravity of G_{se} , of the aggregate includes all void spaces in the aggregate particles except those that absorb asphalt. It is determined as follows:

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

where:

G_{se} = effective specific gravity of aggregate;
P_{mm} = total loose mixture, percent by total weight of mixture = 100 percent,
P_b = asphalt, percent by total weight of mixture,
G_{mm} = maximum specific gravity of paving mixture (no air voids), ASTM D 2041, and
G_b = specific gravity of asphalt.

- **<u>Maximum Specific Gravities of Mixtures with Different Asphalt Contents</u>:** In designing a paving mixture with a given aggregate, the maximum specific gravities, G_{mm} , at different asphalt contents are needed to calculate the percentage of air voids for each asphalt content. While the same maximum specific gravity can be determined for each asphalt content by ASTM test method (D 2041).
  After getting the results from these tests and calculating the effective specific gravity of the aggregate, the maximum specific gravity for any other asphalt can be obtained as shown below. For all practical purposes, the effective specific gravity of the aggregate is constant because asphalt absorption does not vary appreciably with variation in asphalt content.

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}}$$

where:
G_{mm} = maximum specific gravity of paving mixture (no air voids)
P_{mm} = total loose mixture, percent by total weight of mixture = 100 percent
P_s = aggregate, percent by total weight of mixture
P_b = asphalt percent by total weight of mixture
G_{se} = effective specific gravity of aggregate, and
G_b = specific gravity of asphalt

- **<u>Asphalt Absorption</u>:** Absorption is expressed as a percentage by weight of aggregate rather than as a percentage by total weight of mixture. Asphalt, P_{ba} absorption is determined as follows:

$$P_{ba} = 100 * \frac{G_{se} - G_{sb}}{G_{se} * G_{sb}} * G_b$$

where:
P_{ba} = absorbed asphalt, percent by weight of aggregate,
G_{se} = effective specific gravity of aggregate,
G_{sb} = bulk specific gravity of aggregate, and
G_b = specific gravity of asphalt

- **<u>Effective Asphalt Content of a Mixture</u>:** The effective asphalt content, P_{be} of a paving mixture is the total asphalt content minus the quantity of asphalt lost by absorption into the aggregate particles. It is the portion of the total asphalt content that remains as a coating on the outside of the aggregate particles, and is the asphalt content on which service performance of an asphalt paving mixture depends. The formula is:

$$P_{ba} = P_b - \frac{P_{ba}}{100} * P_s$$

where:

P_{be} = effective asphalt content, percent by total weight of mixture,
P_b = asphalt, percent by total weight of mixture,
P_{be} = absorbed asphalt, percent by weight of aggregate, and,
P_s = aggregate, percent by total weight of mixture.

- **Percent VMA in Compacted Paving Mixture:** The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The VMA is calculated on the basis of the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture.

$$VMA = 100 - \left(\frac{G_{mb} * P_s}{G_{sb}} \right)$$

where:

VMA = voids in mineral aggregate (percent of bulk volume),
G_{sb} = bulk specific gravity of aggregate,
G_{mb} = bulk specific gravity of compacted mixture, and,
P_s = aggregate, percent by total weight of mixture.

- **Calculating Percent Air Voids in Compacted Mixture:** The air voids P_a , in a compacted paving mixture consist of the smaller air spaces between the coated aggregate particles. The percentage of air voids in a compacted mixtures can be determined by the following equation:

$$V_a = 100 * \left(\frac{G_{mm} - G_{mb}}{G_{mm}} \right)$$

where:

V_a = air voids in a compacted mixture, percent of total volume,
G_{mm} = maximum specific gravity of paving mixture (as determined above) or as determined directly for a paving mixture by ASTM D 2041,

G_{mb} = bulk specific gravity of compacted mixture.

- **Voids Filled with Asphalt:** The voids in the aggregate filled with asphalt, VFA, are defined as, the amount of voids in the aggregate of a compacted bituminous mixture is equal to the apparent volume of the mixture minus the true volume of the mineral aggregate. The percentage of the voids in the aggregate are calculated as follows:

$$VFA = \left(\frac{P_{be} * G_{mb}}{G_b * VMA} \right) * 100$$

where:

VFA = voids in the aggregate filled with asphalt,
P_{be} = effective asphalt content, percent by total weight of mixture,
G_{mb} = bulk specific gravity of compacted mixture,
VMA = voids in mineral aggregate (percent of bulk volume), and,
G_b = specific gravity of asphalt.

The voids in the aggregate filled with asphalt can also be calculated as:

$$VFA = \left(\frac{VMA - P_a}{VMA} \right) * 100$$

where:
P_a = air voids in compacted mixture, percent of total volume,

- **<u>Trends and Relations of Test Data</u>:** The test property curves, plotted as described in Figure 18-5, should follow the pattern as described in the figure in a consistent form. Trends generally noted are outlined as follows:

1. The stability value increases with increasing asphalt content up to a maximum after which the stability decreases.
2. The follow value increases with increasing asphalt content.
3. The curve for unit weight of total mix is similar to the stability curve, except that the maximum unit weight normally (but not always) occurs at a slightly higher asphalt content than the maximum stability.
4. The percent of air voids decreases with increasing asphalt content, ultimately approaching a minimum void content.
5. The percent voids in the mineral aggregate generally decrease to a minimum value then increase with increasing asphalt contents.
6. The percent voids in the aggregate filled with asphalt rises rapidly at low binder contents and tends to level off at high binder contents.

- **<u>Graphical Charts</u>:**

Prepare a graphical plot for the following values from the data obtained:

1. Stability verses asphalt content
2. Flow verses asphalt content
3. Specific gravity of total mix verses
4. Percent Air voids verses asphalt content
5. Percent Voids in Mineral Aggregate (VMA) versus asphalt content
6. Voids Filled with Asphalt (VFA) versus asphalt content

- **<u>Specification Limits</u>:**

<u>Class A</u> <u>Percent</u>

Total Mineral Aggregate	96 - 93
Asphaltic Binder	4 - 7
Stability (kgs)	820 min.
Voids in total mix	3.0 - 5.0
Flow, 0.25 mm	8.0 - 14.0
Voids Filled with Asphalt (VFA), %	65 - 75
VMA, %	See Figure 16-4

Determination of Optimum Asphalt Content: The optimum asphalt content of the asphalt paving mix is determined from the test curves to be used for the medium traffic category. Compute asphalt content as follows:

		Percent
1. Asphalt content at maximum specific gravity	=	
2. Asphalt content at maximum stability	=	
3. Asphalt content at 4 % Air Voids	=	
4. Asphalt content at 75 % V.F.A.	=	
		________
Optimum asphalt content, average		________