Stability and Flow by Means of the Marshall Apparatus

Lab Experiment #10

Submitted to:

Matthew Church

CE 361: Highways Materials Laboratory

Prepared by:

Christopher M. Smemoe
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Brigham Young University
Provo, UT 84602

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II. Results

Table 2.1: Stability and Flow data from 6.5% asphalt concrete specimens.

Specimen #	Stability Reading	Stability (lbs.)	Correction Factor	Actual Value (lbs.)	Flow (1/100 in.)	Height (in.)
1	26.7	2725	0.86	2343.5	13.0	2.75
2	20.1	1700	0.93	1581.0	7.5	2.63
3	22.6	1775	0.96	1704.0	8.0	2.56
4	9.8	775	1.09	844.8	7.5	2.38

Ave. Stability (Specimens 2,3)=	1642.50
Ave. Flow (Specimens 2,3)=	7.75

Table 2.2: Stability and Flow data from 6.0% asphalt concrete specimens.

Specimen #	Stability Reading	Stability (lbs.)	Correction Factor	Actual Value (lbs.)	Flow (1/100 in.)	Height (in.)
1	20.8	1600	0.86	1376.0	14.8	2.75
2	27.7	2100	0.86	1806.0	8.5	2.75
3	21.7	1625	0.89	1446.3	8.5	2.69

Ave. Stability=	1542.75
Ave. Flow=	10.60

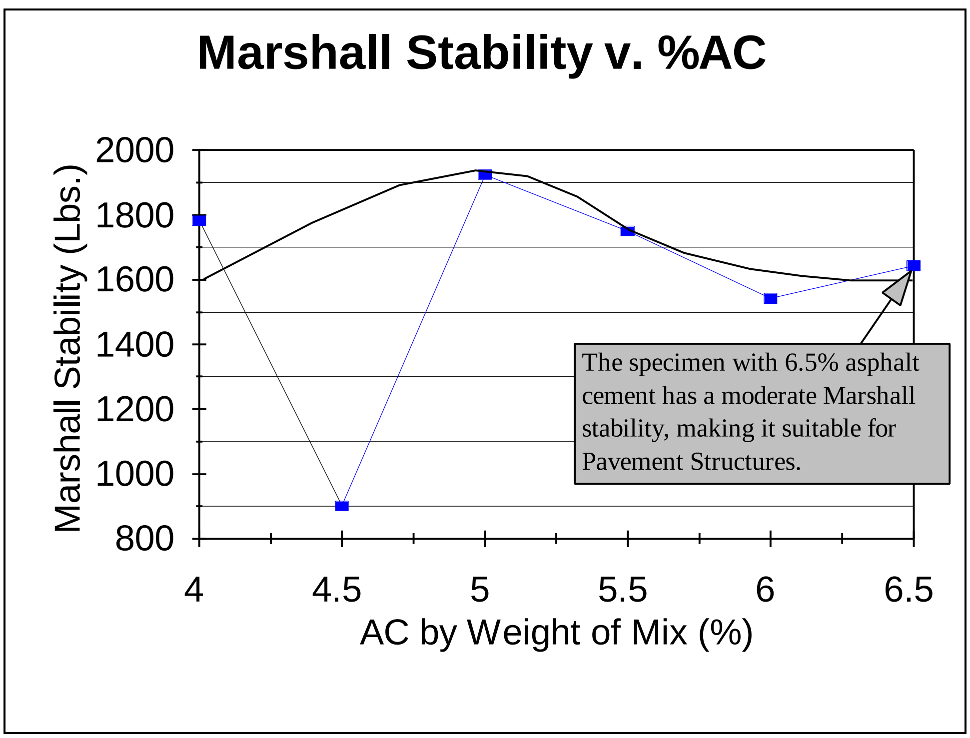

Figure 2.1: Marshall Stability versus Asphalt Content

*Table 2.3: Combined Specific Gravity and Test Data**

Asphalt Cement Content (%)	Bulk Specific Gravity	Maximum Specific Gravity	Total Voids in mix (%)	Specific Gravity of Asphalt Cement (%)	Voids in Mineral Aggregate (VMA) (%)	%VMA Filled (%)	Unit Weight (lb/ft^3)	Adjusted Average Marshall Stability (lbs.)	Flow (1/100 in.)
4.0	2.13	2.42	11.98	1.03	20.26	40.84	132.80	1783	9.7
4.5	2.13	2.38	10.50	1.03	19.81	46.98	132.80	902	9.4
5.0	2.19	2.44	10.25	1.03	20.88	50.92	136.70	1925	8.0
5.5	2.19	2.41	9.13	1.03	20.82	56.16	136.70	1751	11.7
6.0	2.21	2.39	7.53	1.03	20.41	63.09	137.70	1543	10.6
6.5	2.22	2.30	3.48	1.03	17.49	80.11	138.30	1643	7.8

**** These calculations were made according to the plan set forth by the Utah Department of Transportation's bituminous pavement design procedure, found in Budge's <u>Highway Materials Laboratory</u>. A copy of this sheet and Sample calculations with data are located in the appendix.***

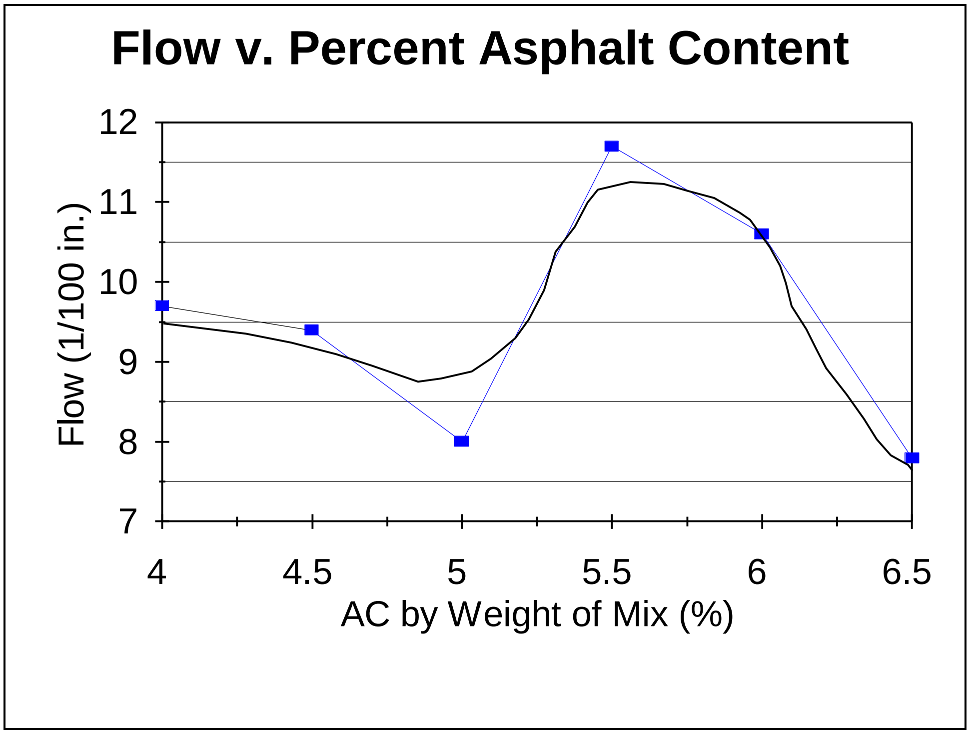

Figure 2.2: Specimen Flow versus Asphalt Content

Tables 2.1 and 2.2 give the stability and flow test data and calculations for the 6.0 and 6.5% asphalt concrete specimens. For the 6.5% asphalt concrete, only the data from specimens 2 and 3 were used in calculating the average stability and flow. The data from specimens 1 and 4 is considered bogus because of errors which occurred in the testing procedure.

Table 2.3 shows the accumulation of test data and calculations from Experiment numbers 8, 9, and 10. The voids in total mix, voids in mineral aggregate (VMA), %VMA filled, unit weight, adjusted average Marshall stability, and flow were all calculated. The graphs of stability and flow versus asphalt cement content are located in figures 2.1 and 2.2.

From figures 2.1 and 2.2, the maximum stability was observed at an asphalt content of 5%, while the minimum flow was observed at an asphalt content of 6.5%.

In addition, the 6.5% asphalt concrete would be the optimum asphalt content for *durability*, or resistance to weathering. As the asphalt cement content increases beyond optimum stability and the air voids are filled by the asphalt cement, durability increases because of the protective asphalt coating.

III. Discussion

Procedure

Preparation of the specimens

The specimens used for this study were the same specimens used in experiment number 8 in testing the bulk specific gravity of compacted pavement specimens containing 6.5% asphalt cement. For the Marshall stability test, at least three specimens must be tested, each of which is 4 inches diameter by 2.5 inches wide. For more information concerning the preparation or errors in preparation of these specimens, observe experiment number 8: ***Bulk Specific Gravity of Laboratory Compacted Asphaltic Concrete Specimens***.

Methods used in Testing Marshall Stability and Flow

The test was conducted at 70 F. First, a water bath was brought to a temperature of 140 F and all 4 specimens were immersed in the water. The Marshall stability testing machine was cleaned and set up to begin the test.

Second, after the specimens had been in the water bath for 30 to 40 minutes, they were placed on the lower assembly of the breaking head. The top head was placed over the specimen and the specimen was placed on the machine.

Third, the flow meter was placed on top of a guide rod and adjusted to zero. A load was then applied to the specimen at a constant rate, observing the flow and stability while loading.

Fourth, when the stability gage reading reached its maximum and began to drop, the stability and flow gages were read. The specimen was removed from the testing machine, the heads were cleaned, and another sample was tested.

Finally, the equivalent stability load, in pounds, was determined from the graph located on the Marshall testing apparatus. The stability and flow data are located in table 2.1. Using the ***Utah D.O.T. bituminous pavement design sheet***, located in the appendix, all necessary calculations for the 6.5% asphaltic mixture were accomplished. The calculations were then made for the other asphalt concrete specimens. The results of these calculations are located in table 2.3.
The following curves, located in the **Conclusion**, were then used to determine the optimum asphalt content:

1. Percent of asphalt by weight of mix versus unit weight, in pounds per cubic foot.
2. Percent of asphalt by weight of mix versus Marshall Stability, in pounds.
3. Percent of asphalt by weight of mix versus percent total voids in mix.

This content was calculated to be **6.0%**, but the 6.0% asphalt concrete does not satisfy the criterion for percent voids in total mix. Thus, the asphalt cement content of ***6.5%*** was chosen, as it meets the design criteria perfectly. (See table 4.1 in **Conclusions**). The asphalt cement content of 6.5% would be suitable for any purpose, including heavy traffic highways with a design ESAL above 1 million.

In addition, the following curves were constructed from the results of the Marshall stability and specific gravity tests:

1. Percent of asphalt by weight of mix versus flow, in 1/100 inch.
2. Percent of asphalt cement by weight of mix versus percent voids in mineral aggregate filled with asphalt cement.

These curves are located in the conclusion.

Answers to "Observations and Discussion"

1. What is the significance of the five calculated charts and how are they used?

The first chart, unit weight versus asphalt content, is a measure of the specific gravity of the bulk mixture. At the optimum unit weight, the asphalt specimen is well-compacted, and, at this unit weight, the most asphalt cement has been added to the mixture before the unit weight begins to decrease.

The second chart, flow versus asphalt cement content, is a measure of the deformation of the specimen under applied loads. As flow increases, the deformation with applied loads will also increase.

The third chart, Marshall stability versus asphalt cement content, is a measure of the resistance to deformation of the specimen under applied loads (the *stability*). The ability to resist deformation under applied loads is an important quality for pavement structures.

The fourth chart, voids in mineral aggregate versus asphalt content, is a measure of the total void spaces between the aggregates of a compacted asphaltic specimen. As more asphalt cement is applied to an aggregate mixture, more of these void spaces will be filled with asphalt cement.

The fifth chart, voids in total mix versus asphalt cement content, is used to determine whether or not the material has the required amount of void spaces. The void spaces must be somewhere between 2 and 5% for asphaltic pavement mixtures.

As mentioned above, the unit weight, Marshall stability, and percent total voids in mix curves are examined. These graphs are then used to select the asphalt contents for maximum stability, maximum unit weight, and percent voids in total mix within the limits specified (usually use 3.5%). The average of the asphalt contents is the optimum asphalt content.

The optimum asphalt content is then used in plant mixes to create asphalt cement-aggregate pavement mixtures.

2. The Utah State Department of Transportation uses 2% air voids to design from as a starting point. Why?

An asphaltic pavement mixture must have at least 2% air voids as in the compacted pavement mixture because a small amount of compaction room in the pavement must be available when traffic load is applied without loss of stability. In addition, having at least 2% air voids in the mix prevents flushing and bleeding of the pavement under design loads.

3. How are stability and durability related?

Stability is the ability of an asphalt mixture to resist deformation. ***Durability*** is the ability of an asphalt mixture to resist weathering. When a pavement mixture has an increased amount of asphalt cement beyond that required for optimum stability, durability increases. And in general, *before the asphalt content reaches maximum stability, both durability and stability increase with increased asphalt content*. But, *as asphalt content increases beyond maximum stability, durability increases while stability decreases*. This phenomenon occurs because the increased asphalt content coats the aggregates better, creating a more weather-resistant material.

4. What asphaltic concrete properties are required for a quality pavement?

A quality pavement should have the following properties:

1. High Stability and strength
2. High Bulk specific gravity (Unit weight)
3. Between 3 and 5% air voids
4. A low Flow value
5. Resistance to weathering
6. Resistance to bleeding and flushing
7. Resistance to infiltration of water

It has been determined that the asphalt-aggregate mixture containing ***6.5%*** asphalt concrete should be used in the design of flexible pavement structures. This has been determined by comparing the test results with design specifications. (See table 4.1).

5. What precautions must be met in the above test?

As mentioned in experiment number 8, care must be taken when preparing the specimens for testing, or errors may result when testing the specimen for stability, especially if the specimen is not completely mixed. In addition, the following precautions must be taken when performing the test:

1. It is necessary that the specimens are tested within 30 seconds of removal from the water bath, as the temperature and water content of the specimen will drop rapidly after it is taken out of the bath.

2. The stability gage and flow meter must be operated properly. The flow meter must be set in the proper position before beginning the test. While the specimen is being tested, the stability gage must be watched closely to observe when the maximum is reached. At this point, the stability and flow of the specimen must be immediately read and recorded.

3. The height of the tested specimen should be recorded before putting it in the water bath, as expansion because of temperature may result. In addition, this height should be associated with a stability correction ratio to adjust the measured stability of the specimen.

4. The temperature of the water bath should be kept at a constant temperature of 140 +/- 2 F. If this is not done, differing stability and flow readings between the specimens will be the result.

Uses of the test

The Marshall stability test is used to find the stability and flow for prepared test specimens. From the stability and flow values, the stability and flow versus percent asphalt content graphs may be constructed. And taking the asphalt content at maximum stability, this value is combined with the asphalt content at maximum unit weight and optimum air voids to achieve an optimum percent asphalt content. This asphalt content is then used in plant mix operations to create an strong, stable, and durable pavement mixture.

Advantages/Disadvantages

Advantages:

The Marshall stability test is an uncomplicated test which directly measures the stability and "flow" of an asphaltic concrete specimen being tested. These measures are representative of the plastic flow characteristics of the bituminous material being tested. From these characteristics, as well as other properties of bituminous mixtures at different asphalt contents, the proper asphalt-aggregate mix may be determined.

Disadvantages:

One disadvantage of the Marshall stability test is that the loading rate of 2 in./minute creates a test which goes so quickly that an accurate reading is difficult to obtain. It was thus necessary to "hand-crank" the testing apparatus, creating a much lower loading rate than that which was specified. This may have resulted in a large degree of error in the flow values and stabilities of the specimens.

In addition, in order to check the stability and flow values obtained and to obtain relatively accurate results, at least 3 specimens must be used in the test. Four specimens were used when testing the stability and flow of the 6.5% asphalt specimens. The procedures involved in obtaining and testing these specimens can be time consuming and costly.

Possible Errors

The possible errors include the following:

1. When testing the specimen, it was necessary to lower the rate of loading of the specimen in order to obtain accurate stability and flow readings. The rate of loading has a significant impact on the stability and flow of the specimen, and the stability and flow values were affected by the slow rate of loading. Another test to determine the degree of error the change in loading rate may have on the specimen may be useful.

2. In the preparation of the specimens, especially in the first and second samples, the asphalt cement did not completely mix with the aggregate mixture. Specimens 1 and 2 had this problem, and the variation in amount of asphalt mixing throughout the specimen resulted in an inaccurate stability reading for these specimens.

3. When testing the first specimen, inaccurate stability and flow readings were obtained because the maximum stability had occurred before it was realized. Thus, the stability and flow values had to be estimated for this specimen.

4. The testing of the specimens was *not* completed within 30 seconds of removal from the water bath. In most cases, however, the testing was completed within 2 minutes of removal from the water bath. This may have resulted in error since the temperature and water content of the specimen drop after it is taken out of the bath.

5. The height of the specimens should have been measured and recorded *before* placing them in the water bath, not *after*. While the asphaltic specimens were in the bath, swelling may have occurred due to thermal expansion. This phenomenon may have resulted in an inaccurate height reading of the specimen.

Limitations of this Lab

One of the main limitations of this lab is that in order to obtain stability and flow readings, the rate of loading must be reduced significantly below the specified value (2 inches/min.). This causes errors in the stability and flow readings of the specimen which are undesirable.

In addition, the experiment itself passes quickly, but the preparation of the pavement specimens for testing may take large amounts of time and energy from mixing and compacting the specimens.

IV. Conclusions

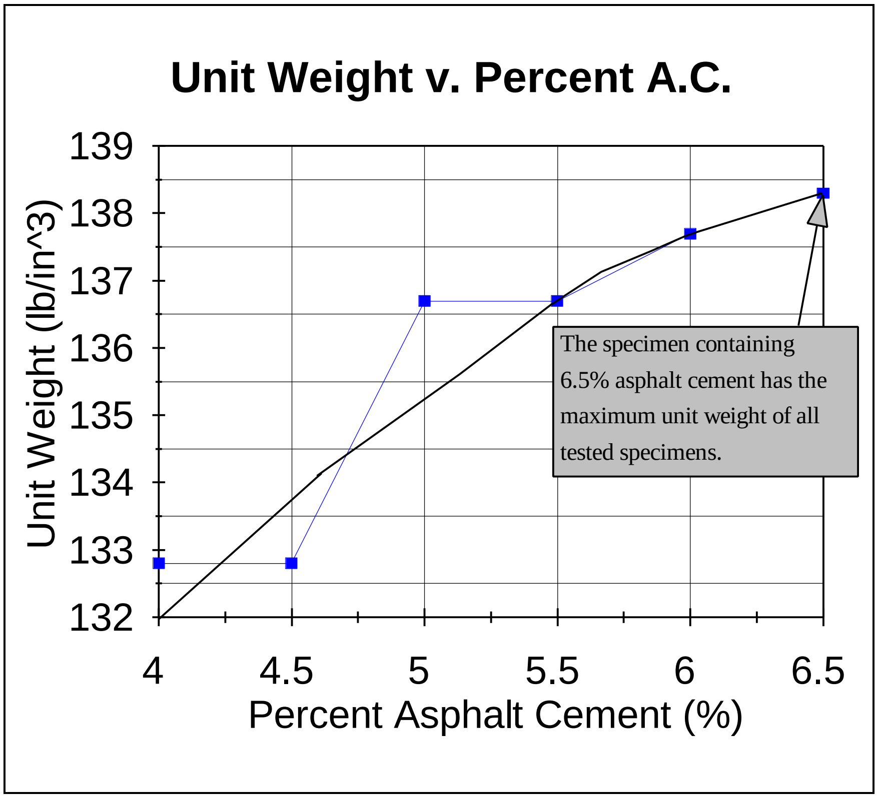

Figure 4.1: Unit Weight versus Asphalt Content.

1. One can observe a general upward trend in the unit weight as the percent asphalt content of the specimen increased. The specimen containing 6.5% asphalt was found to have the maximum unit weight of all the tested asphalt specimens.

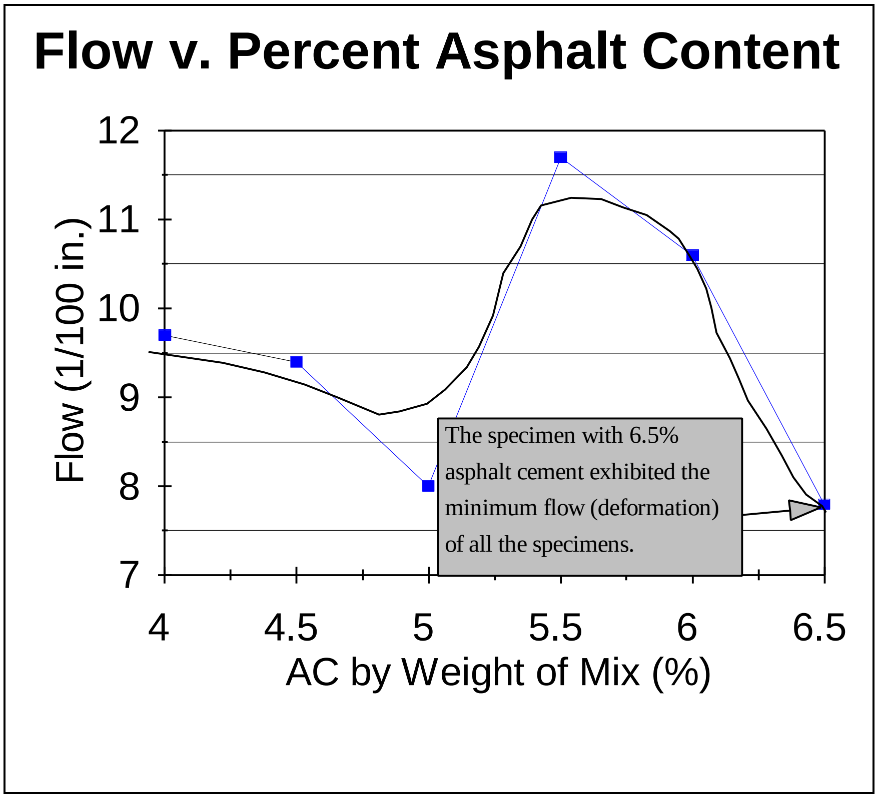

Figure 4.2: Flow versus Asphalt Content.

2. The specimen which exhibited minimum flow was the 6.5% asphalt concrete specimen. This indicates that the specimen containing 6.5% asphalt would be the least susceptible to deformation under saturated, hot conditions.

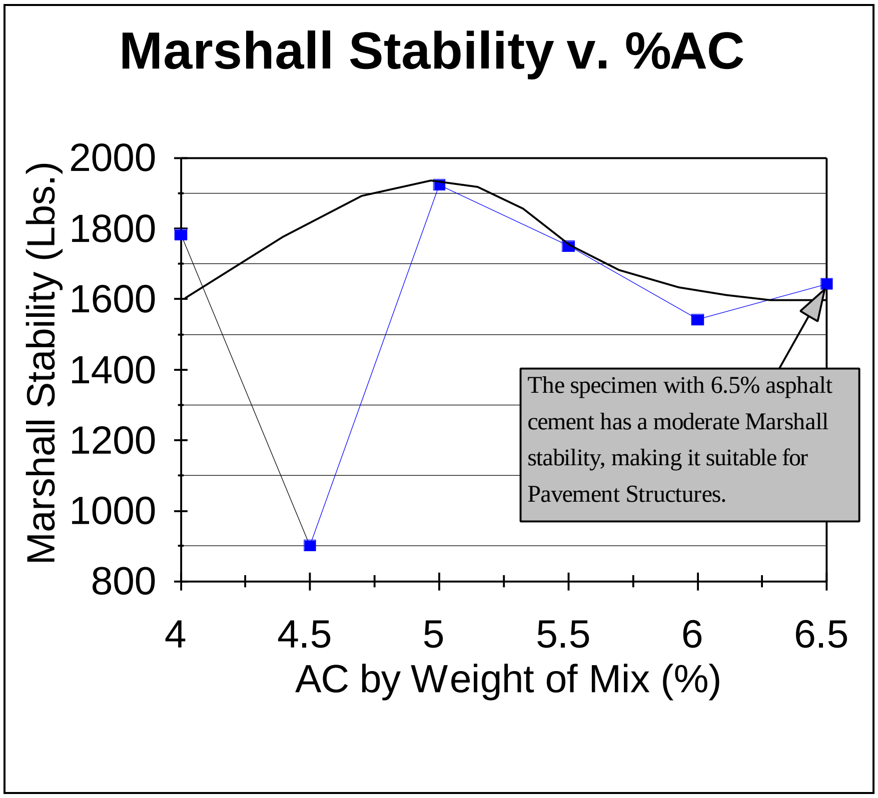

Figure 4.3: Marshall Stability versus Asphalt Content.

3. The specimen having the highest stability was the specimen containing 5% asphalt cement. Thus, the specimen with 5% asphalt cement will be included in determining the optimum asphalt mix. However the specimen containing 6.5% asphalt had adequate stability as well. This factor was considered in determining the optimum mix design. Both specimens exhibited a stability above the required 1500 lbs.

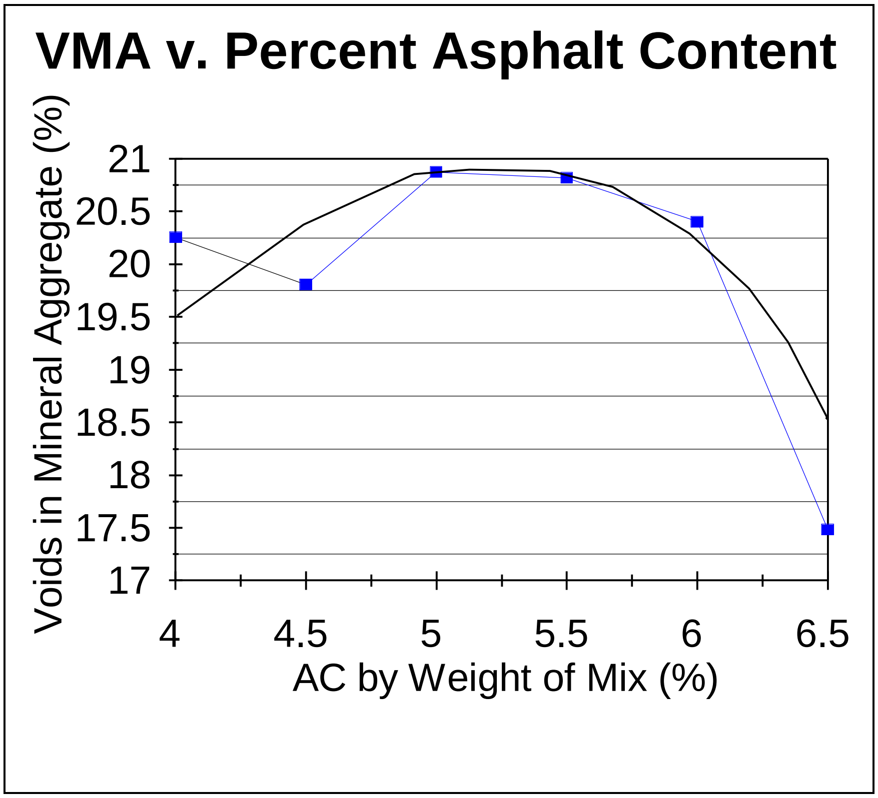

Figure 4.4: VMA versus Asphalt Content.

4 - 5. Initially, large amounts of void spaces existed between the specimens. But then, the addition of greater amounts of asphalt cement caused the mixture to become more compacted, and the void spaces decreased. Since %VMA considers the amount of asphalt between the particles as well, these values are somewhat different than those for the voids in total mix, but the same general pattern is observed since the specimens become more compact as more asphalt is added (until the maximum unit weight is reached). The optimum percent asphalt content for voids in total mix was determined to be 6.5%. (This specimen contained 3.48% voids in the total mix, which is almost perfectly within the limits of 2-5% asphalt).

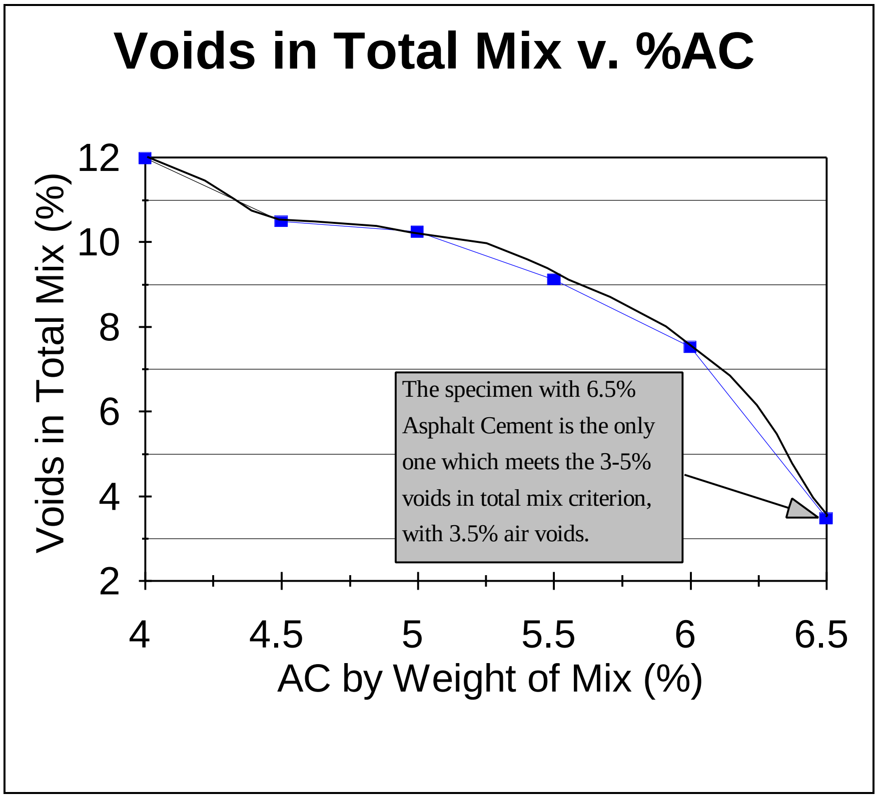

Figure 4.5: Voids in Total Mix versus Asphalt Content.

The specifications for the optimum asphalt concrete mixes are located in table 4.1. Calculating the optimum asphalt cement content, we obtain 6.0%. But this asphalt content does not meet specifications for percent voids in total mix. Therefore, 6.5% asphalt content should be used in asphalt concrete mixes using the type of aggregate used in this laboratory. Slightly lower levels of asphalt may be used as well (such as 6.3% asphalt), but these mixtures should be tested as well to assure they meet the required specifications.

Table 4.1: Specifications for Optimum Asphaltic Concrete Mixes.**

	Heavy Traffic*		Medium Traffic*		Light Traffic*		Properties of Specimen Containing 6.5% asphalt (the only mix which meets specifications)	Properties of Specimen Containing 6.0% asphalt (Calculated Optimum Mix)
Properties of Asphaltic Mixture	Min.	Max.	Min.	Max.	Min.	Max.		
Stability, lbs.:	1500	----	750	----	500	----	1643	1543
Flow, units of .01 in.:	8	16	8	18	8	20	7.8	10.6
Percent Air Voids-	----	----	----	----	----	----	----	----
Surfacing or Leveling:	3	5	3	5	3	5	3.48	7.53
Base:	3	8	3	8	3	8	3.48	7.53
Percent VMA:	10	23	10	23	10	23	17.49	20.41

****Traffic Classifications:***
Light: Equivalent 18000 lb. single axle load (ESAL) less than 10,000.
Medium: ESAL between 10,000 and 1,000,000.
Heavy: ESAL above 1,000,000.

*****Adapted from Garber and Hoel, <u>Traffic and Highway Engineering</u>, p. 768. Properties of 6.0 and 6.5% asphalt concrete specimens are the results from the lab testing.***

Engineering Significance of this lab

The purpose of the Marshall stability and flow test is to determine the stability and flow values of asphaltic specimens. The Marshall method of mix design uses these values as well as the unit weight and the voids in the total mix to determine an optimum mix design. This optimum mix was determined in this lab to be 6.5% asphalt concrete. 6.5% asphalt concrete by weight would be added in a plant mix and the result would be a pavement which would have high stability and strength, good weathering characteristics, resistance to bleeding and flushing, and resistance to infiltration of water.

V. Appendix

The following books were used for reference:

American Society for Testing and Materials. ***1978 Annual Book of ASTM Standards.*** Part 15. American Society for Testing and Materials, 1978.

Garber, Nicholas and Lester A. Hoel. ***Traffic and Highway Engineering***. West Publishing Company, 1988.

Calculations and Data on Next Page.