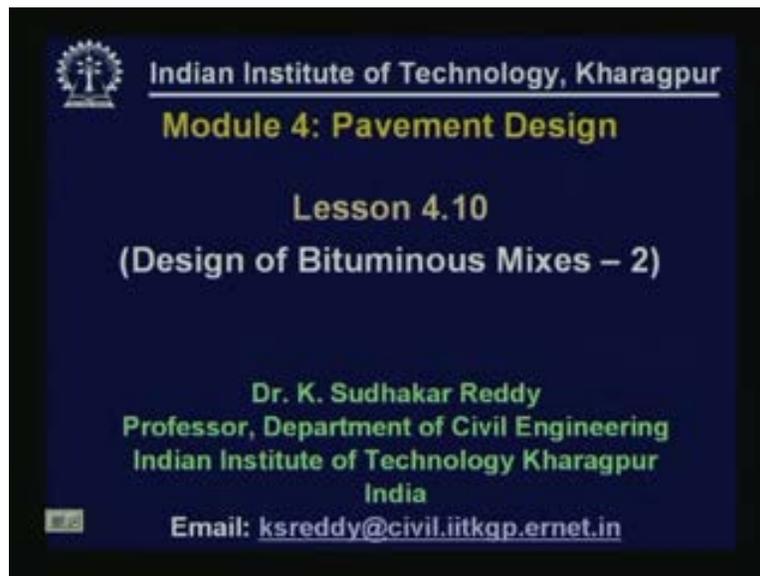


Introduction to Transportation Engineering
Prof. K. Sudhakar Reddy
Department of Civil Engineering
Indian Institute of Technology Kharagpur
Lecture - 33
Design of Bituminous Mixes - II

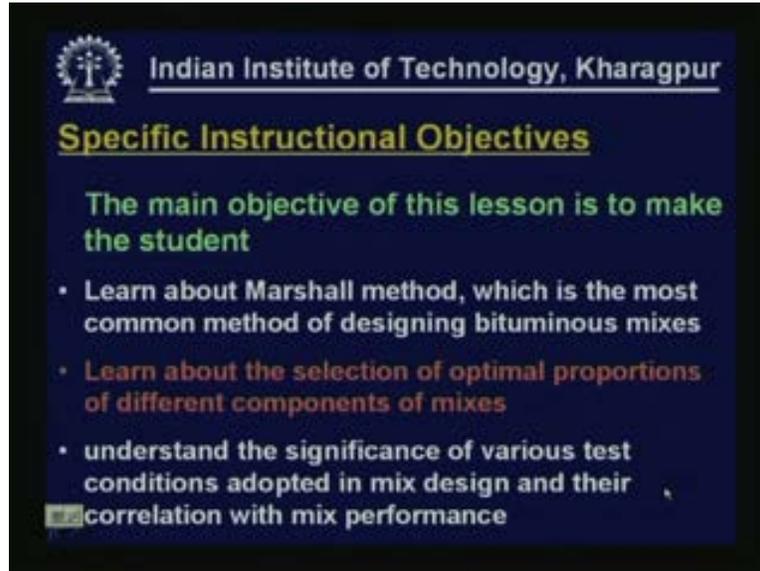
Welcome to lesson 4.10 design of bituminous mixes part II.

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This is second part of the presentation on design of bituminous mixes. And as you recollect this is a part of module IV which is on pavement design.

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The slide features the IIT Kharagpur logo and name at the top. Below it, the title "Specific Instructional Objectives" is written in yellow. The main objective is stated in green text, followed by three bullet points in red text.

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Specific Instructional Objectives

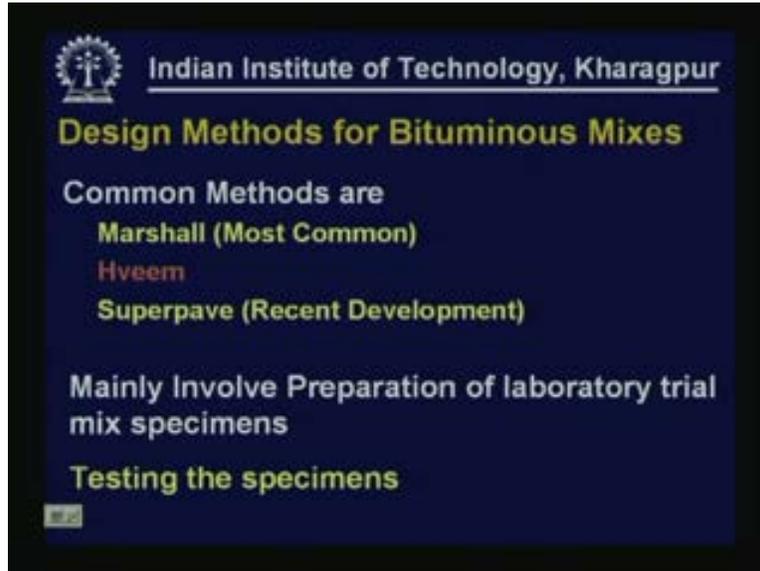
The main objective of this lesson is to make the student

- Learn about Marshall method, which is the most common method of designing bituminous mixes
- Learn about the selection of optimal proportions of different components of mixes
- understand the significance of various test conditions adopted in mix design and their correlation with mix performance

The main objective of this lesson is to make the student learn about Marshall Method. In fact in the previous lesson on bituminous mixed design part I we have covered various aspects such as; what are the important parameters that are to be considered in designing mixes, what are the requirements of mix design and we have also identified that air voids which is a volumetric parameter of bituminous mix is one of the most important parameters to be considered in designing the mixes and mix design is a process in which we have to identify a proper aggregate skeleton **sketcher** because mix after all consists of aggregates of different sizes or any bituminous binder has a **binder and is compacted**. So we have to find out the optimum combination of aggregates and binder. we also have to find out what is an appropriate aggregate skeleton and also the type and then content of the bitumen that we are going to use and of course we have to also think in terms of what is an appropriate compaction effort to be used for preparing this specimen and then for testing and evaluating them.

Therefore we would like to discuss Marshall Method of mix design which is the most commonly used method for designing bituminous mixes. Also, learn about the selection of optimal proportions of different components of mixes, what should be the guidelines that we should adopt in selecting optimum bitumen content, having selected what is the appropriate aggregate skeleton, aggregate gradation and is also expected that the student would be able to understand the significance of various test conditions adopted in the mix design procedure because we are going to test bituminous mixes and then find out various parameters. So these tests are going to be conducted under various conditions. So, what is the implication or significance of these different conditions, how they are correlated to actual conditions and what is the influence of these parameters on the performance of these mixes will be understood.

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Design Methods for Bituminous Mixes

Common Methods are

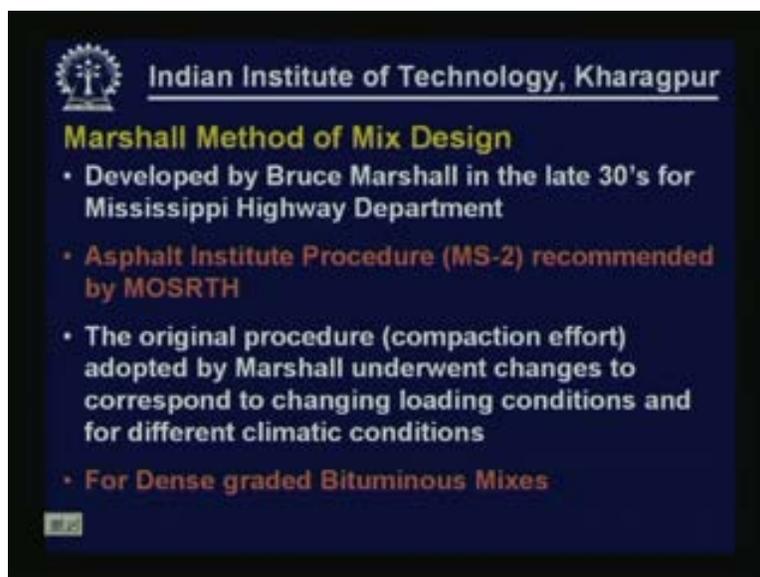
- Marshall (Most Common)
- Hveem
- Superpave (Recent Development)

Mainly Involve Preparation of laboratory trial mix specimens

Testing the specimens

As I indicated there are various methods of designing bituminous mixes. A few common methods are Marshall Method this is the most commonly used method, Hveem method and Superpave mix design method, as I indicated when we were discussing bituminous binders Superpave refers to superior performing pavements this is of a more recent development. All these mix designs mainly involve preparation of laboratory trial mix specimens. That means a number of specimens would be prepared with various combinations of aggregates and binders and all these specimens will be tested and then on the basis of the results that we obtain on these trial mixes optimum combination of binder and aggregates will be selected.

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Marshall Method of Mix Design

- Developed by Bruce Marshall in the late 30's for Mississippi Highway Department
- Asphalt Institute Procedure (MS-2) recommended by MOSRTH
- The original procedure (compaction effort) adopted by Marshall underwent changes to correspond to changing loading conditions and for different climatic conditions
- For Dense graded Bituminous Mixes

Marshall Method of mix design was developed by a gentleman named as Bruce Marshall in the late thirties for the Mississippi highway department in the United States. Ministry of shipping and road transport highways recommends that the Asphalt institute procedure manual MS2 should be followed for design of bituminous mixes so most of these provisions that we are going to discuss in terms of Marshall Mix design will be as per Asphalt institute procedure. The original procedure for designing bituminous mixes that were originally developed by Marshall especially in terms of the compaction effort used underwent a lot of changes over all these years so that the mix design corresponds to the actual conditions of traffic, different climatic conditions that are prevalent now. So the mix design procedure that we are now adopting is expected to be stimulating different traffic conditions and also various climatic conditions. And the Asphalt institute MS2 mix design guidelines are mainly meant for dense graded bituminous mixes.

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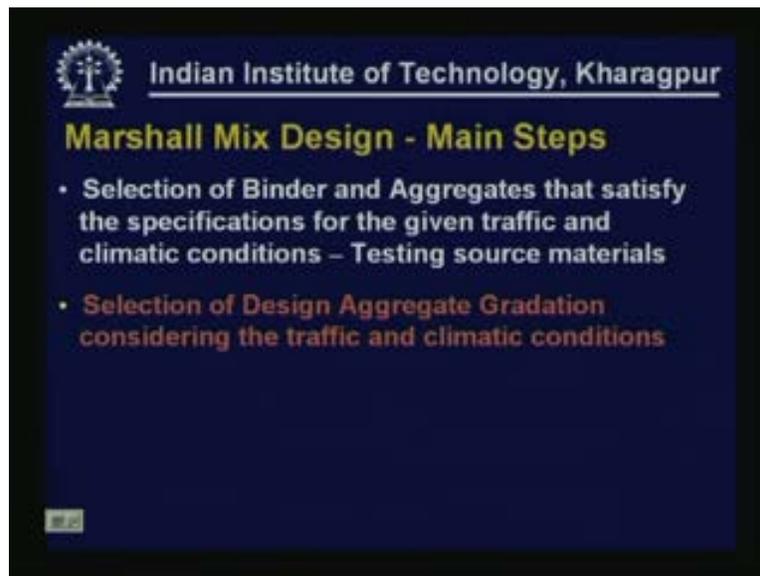
The main steps involved in Marshall Mix design method are selection of mix type. We have to first identify what is the type of mix that we are trying to design; is it the bituminous concrete, is it dense bituminous concrete or any other type of mix. So obviously we will first try to identify whether I am trying to provide a dense graded mix, or am I trying to provide a gradation which has got more coarser fraction, am I trying to design a mix where only the surface characteristics are important, should I get good surface characteristics or am I designing a mix where rutting is a major problem because of high temperatures, heavy loads etc.

So, according to the requirement you have to select what is the type of mix that we are going to select. And having done that we will select what is the maximum aggregate size and select an appropriate aggregate gradation. Maximum aggregate size as we have indicated earlier will be selected on the basis of the thickness of the layer that is going to be provided and usually most agencies have a specified gradation given for each mix. So normally it is expected that those are to be followed unless it can be shown that deviating from the specified gradation is for good and

if you can convince the agency then you can go for other gradations other than what has been specified by either a [montage 7:47] or other gradation.

The minimum layer thickness is usually more than two to three times the maximum aggregate size. This is just to give an indication of what can be the maximum size of aggregate that you can use. It is a function of thickness of layer that we are going to provide. Similarly, the aggregate fractions are usually designated as coarse, fine and then filler. Coarse is the aggregate that is retained on 2.36 mm size, fine aggregate is passing 2.36 mm size and retained on 75 micron sieve, mineral filler is that which passes 75 micron sieve.

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The next step that we follow in Marshall Mix design method is the selection of binder that is type of binder also has to be selected. We had in the earlier lessons given guidelines of what is the type of binder to be selected for different traffic conditions and for different climatic conditions represented in terms of what is the maximum temperature and also what is the minimum temperature. So we know how to select an appropriate grade of binder for different situations.

After selecting the binder we also have to select the aggregates. There are specifications available for what is the quality of aggregates that we have to use for different types of layers. If an aggregate is to be used in surface coarse it will have to satisfy different requirements, if it is used in a binder coarse its requirement will be different so we have to select the binder and aggregates satisfying the requirements for a specific project and for a specific layer. These are to be selected on the basis of traffic and climatic conditions and these materials have to be tested for the source properties. As soon as we get these materials from source normally these are tested and once they are satisfied subsequently they may be tested at regular intervals. The next step is to select design aggregate gradation considering the traffic and climatic conditions.

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The next step is preparing test specimens of bituminous mixes using the aggregate gradation that is selected and the binder that is selected with appropriate compaction effort. We also have to select what is an appropriate compaction effort. Ministry of shipping and road transport suggests a specified compaction effort as per as the specified procedure for all highways. For all highways we are talking about heavy traffic volumes so we are talking about compaction that is produced by heavy traffic over some period of time.

Therefore we are talking about heavy compaction and rather all these specifications are of the ministry of shipping and road transport and highways that is based on heavy compaction effort. But if you are designing mixes for roads having very low traffic we can go for smaller compaction efforts so the corresponding equipment the corresponding compaction effort also can be used and the mixes are tested corresponding to that compaction effort. Thus we also have to select a compaction effort then those specimens that are prepared will be tested.

We have to make a number of additional trails. If the initial trails are made when these specimens are tested they do not yield required properties or they do not satisfy the specifications that are meant for a specific mix. Then the final step would be the selection of optimum binder content as per the specified criteria; how to select the optimum binder content, what is the criteria to be adopted for selecting the optimum binder content also is usually specified in a given design procedure.

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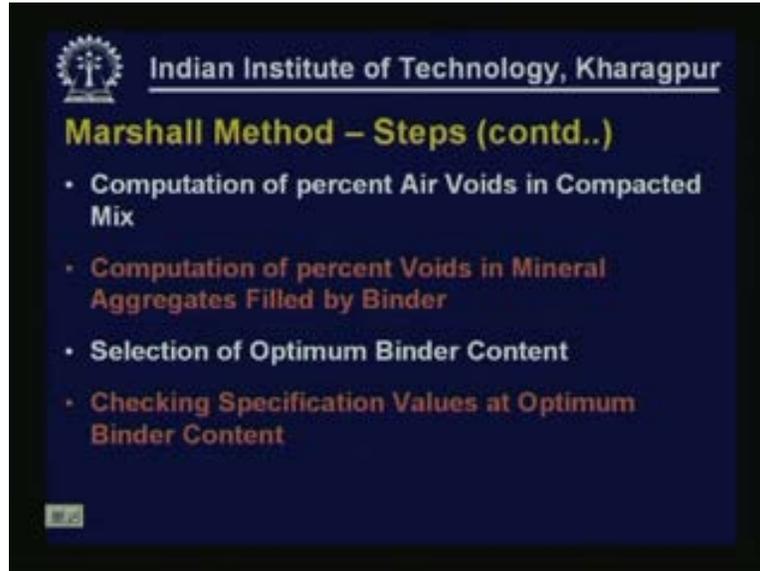


The steps include grading of commercially available mineral aggregates because we are not going to have aggregates crushed and then sieved as per individual sieves, but we are going to get aggregates like either twenty mm aggregates, 12 mm aggregates or in whatever manner it is supplied so we would select appropriate sizes of aggregate that are available, aggregates that are having suitable quality then those aggregates will have to be blended as we have discussed in the previous lesson. So the proportioning of mineral aggregates will have to be done by blending then we have to find out this specific gravities of the binder and the aggregates.

The specific gravity of binder can be determined using a pigma meter method. The specific gravity of aggregates has to be determined for their bulk specific gravities and also for the apparent specific gravity though normally apparent specific gravity is not used in mix design. Then we have to prepare Marshall Specimens because we are talking about Marshall Method of mix design then using the selected aggregates and after blending the aggregates we mix the aggregates in the blending proportion that we arrived at. It should then give you a grading that is within this specification limit.

Therefore using that blended portion and the binder that we have selected both have to be taken together and then Marshall Specimen has to be prepared. These Marshall Specimens have to be tested for the bulk specific gravity. Marshall Specimen is nothing but adding aggregates and bitumen together and compacting them. These specimens have to be tested for their bulk specific gravity of the compacted specimen, they have to be tested for stability, they have to be tested for flow and we also have to find out the specific gravity of the loose mix. We have discussed in the previous lesson terms such as void-less, volume of mix which would give you Gmm which is the maximum specific gravity of the loose mix, these are the parameters that we have to measure.

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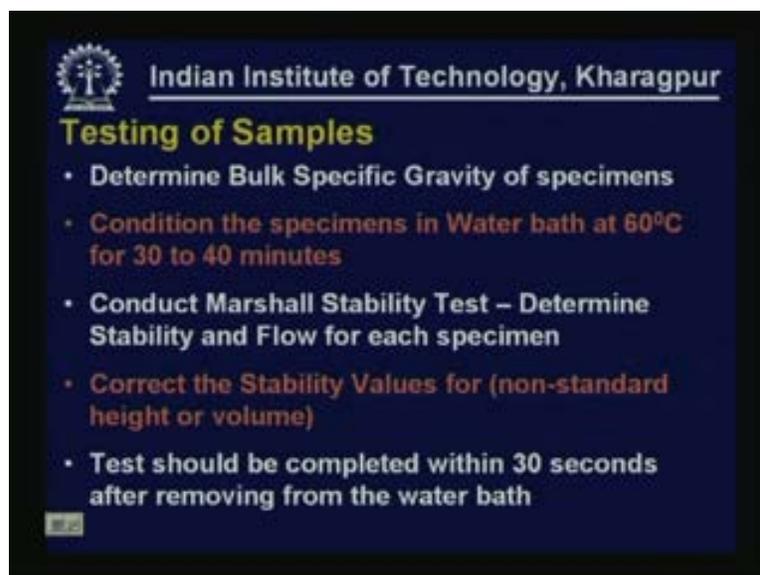
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Marshall Method – Steps (contd..)

- Computation of percent Air Voids in Compacted Mix
- Computation of percent Voids in Mineral Aggregates Filled by Binder
- Selection of Optimum Binder Content
- Checking Specification Values at Optimum Binder Content

So using this information we can calculate the air void content in the compacted mix, we can calculate the percentage voids in the mineral aggregate filled by the binder or bitumen and using all these information we can also calculate other volumetric parameters and using all these information we will select an appropriate binder content known as optimum binder content. Then we will check at this optimum binder content what are the various parameters the mix will have in terms of strength, in terms of flow, in terms of various volumetric parameters so at optimum binder content what are the properties this mix is going to have. So those properties have to satisfy these specifications that are given for the mix.

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Testing of Samples

- Determine Bulk Specific Gravity of specimens
- Condition the specimens in Water bath at 60°C for 30 to 40 minutes
- Conduct Marshall Stability Test – Determine Stability and Flow for each specimen
- Correct the Stability Values for (non-standard height or volume)
- Test should be completed within 30 seconds after removing from the water bath

For testing the samples we have to determine the bulk specific gravity of the specimens. Once we compact the specimen prepare a specimen by adding aggregates and binder together and compact them and then we have a specimen prepared. That compacted specimen's bulk specific gravity has to be determined and all these specimens will have to be conditioned by keeping them in a water bath and maintained at 60 degree centigrade for period of thirty to forty minutes duration.

Basically the idea is to test these specimens at a temperature of 60 degrees. For this we have to condition these specimens by putting them a water bath. This is the way how it has to be conditioned which is maintained at 60 degrees and the conditioning has to be done for about thirty to forty minutes. These condition specimens will have to be tested in a Marshall testing apparatus for determining the stability and flow of each one of these specimens. These stability values have to be corrected for non standard height or volume.

We will discuss about what are the standard dimension of this specimen that we are expected to maintain in terms of its diameter and also in terms of the height that is expected to be attained. So, we are talking about a standard size specimen but it is not always possible to get the same height because of the compaction effort that we put and also because of the mass of the total aggregate and binder that we take so we may get different heights.

So the volume of the specimen is going to be different and as the volume differs this stability value that is attained in the Marshall testing machine will have to be corrected to correspond to a standard volume. There are correction factors available that can be done. Then the test should be completed within thirty seconds after removing from the water bath. This is to ensure that the temperature does not fall below 60 degree centigrade, there should not be any significant difference so we should not wait for two minutes or three minutes before the test process is completed. As soon as this specimen is removed from the water bath which is at 60 degree centigrade the test should be completed quickly.

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Marshall Method of Mix Design

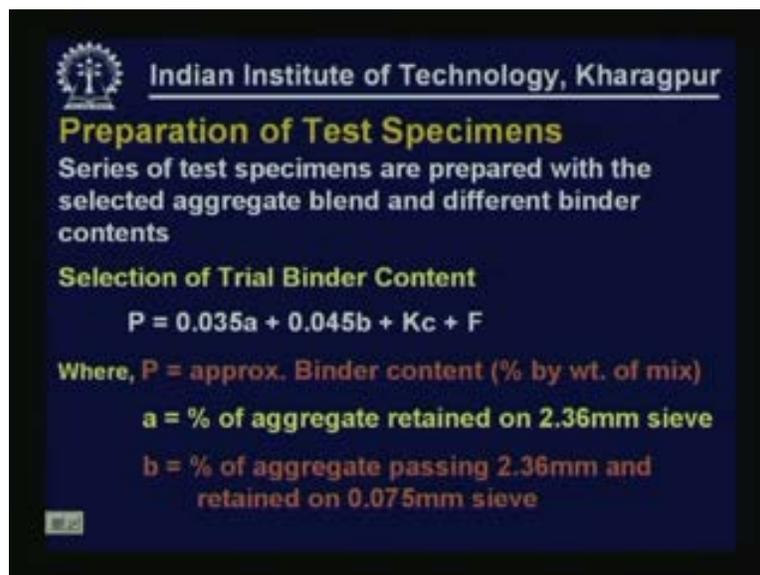
- Standard Marshall Method involves preparation of a 4 inch dia (102mm), 2.5 inch (64mm) thick specimen of bituminous mix with a selected gradation of aggregates and binder content.
- Standard Compaction effort is used 4.5kg (10lb) mass and a free fall of 457mm (18 inches)
- Maximum size of aggregate = 25.4 mm (one inch)

 6-inch (150mm) mould for larger aggregate size

The standard Marshall Method involves preparing a 4 inch diameter specimen, 102 mm dia and 2.5 inch height or thick specimen which is about approximately 64 mm height of bituminous mix with a selected gradation of aggregates and binder content. As we have already discussed we are going to select aggregate gradation and also binder type and then certain binder content. So with this compaction effort that we adopt we should be able to produce 4 inch dia specimen having a height of about 2.5 inches. The standard compaction effort used is by dropping a hammer of 4.5 kg 10 pounds mass through a free fall of 457 mm that is 18 inches.

So the compaction is done by using a compaction Marshall hammer weighing 4.5 kg and falling from a height of 457 mm. As we are using a 4 inch dia specimen normally the maximum size of aggregate that we can use is one inch or 25.4 mm. But if you want to test the mix having a gradation having a larger size more than 25.4 mm where some of these mixes have got more than 30, 40 mm size so if you want to test those mixes you have to prepare larger size specimen. Normally a 6 inch specimen also can be tested.

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The slide is a presentation slide with a dark blue background and white and yellow text. At the top left is the IIT Kharagpur logo. The title is 'Preparation of Test Specimens' in yellow. Below it, the text reads: 'Series of test specimens are prepared with the selected aggregate blend and different binder contents'. The next section is 'Selection of Trial Binder Content' in yellow, followed by the formula $P = 0.035a + 0.045b + Kc + F$. Below the formula, it says 'Where, P = approx. Binder content (% by wt. of mix)'. Then it defines 'a = % of aggregate retained on 2.36mm sieve' and 'b = % of aggregate passing 2.36mm and retained on 0.075mm sieve'.

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Preparation of Test Specimens

Series of test specimens are prepared with the selected aggregate blend and different binder contents

Selection of Trial Binder Content

$$P = 0.035a + 0.045b + Kc + F$$

Where, P = approx. Binder content (% by wt. of mix)

a = % of aggregate retained on 2.36mm sieve

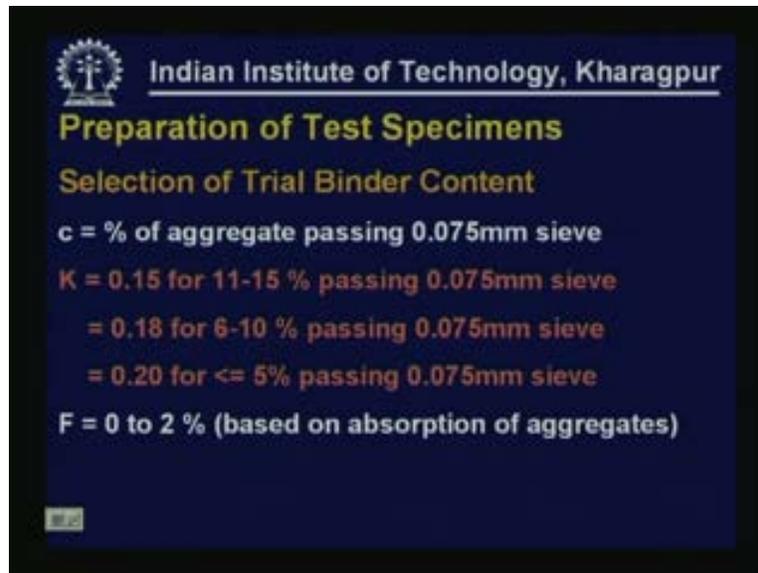
b = % of aggregate passing 2.36mm and retained on 0.075mm sieve

We have to prepare a series of test specimens with the selected aggregate blend and with different binder contents. So we will keep the aggregate gradation fixed the blend fix but we will go on varying different binder contents. Thus for each binder content we will prepare number of samples. therefore will have specimens prepared at varying binder contents and then we can find out what is effect of varying binder contents on various mix parameters and then select one of these binder contents or any optimum binder content which gives us optimum performance.

If you do not have an idea of what could be the range within which optimum binder content is going to lie the selection of initial trial binder content can be made as $P = 0.035$ multiplied by $a + 0.045$ multiplied by $b + K$ into $c + f$. P is the approximate binder content this is expressed as the percentage by weight of total mix whereas 'a' is the percentage of aggregate retained on 2.36 mm sieve, 'b' is the percentage of aggregates passing 2.36 mm sieve and retained on 0.075 mm

sieve, 'c' is the percentage of aggregate passing 0.075 mm sieve, 'k' has got different values 0.15, 0.18, 0.20 for various percentage of filler which is the material passing 75 micron sieve.

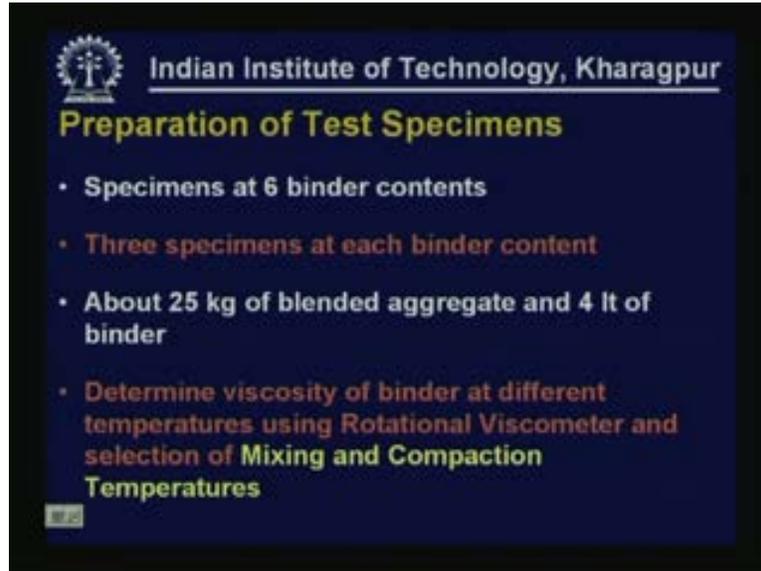
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For example, if the filler content is 11 to 15% the value of k is taken as 0.15, if the filler content is less than 5% the value of K is taken as 0.2, F is a value that is to be selected on the basis of the assessment of absorption by aggregates of bitumen. So what is the expected quantity of bitumen that is going to be there in the aggregate pores? If you know the absorption of aggregates the F can vary from 0 to 2%. For a completely non absorbable aggregate we can take a value of 0 and for highly pores aggregates the value of two can be taken.

The initial binder content is normally assessed in terms of the film thickness that is required depending on the gradation. so depending on the size of particles that we have, percentage of different fractions we can approximately calculate the surface area and we can find what is the minimum thickness of binder that has to be there coating these aggregates from the point of view of durability of these mixes. Thus normally the initial trial binder is on the basis of the film thickness that is required to coat these aggregates and also taking into consideration if these aggregates are absorptive then some amount of bitumen is going go into these pores. Therefore taking into consideration this is an empirical formula. Obviously this will serve only as an initial trial thickness so we can take this initial trial binder content. You can start with this binder content and select other binder contents on either side of this.

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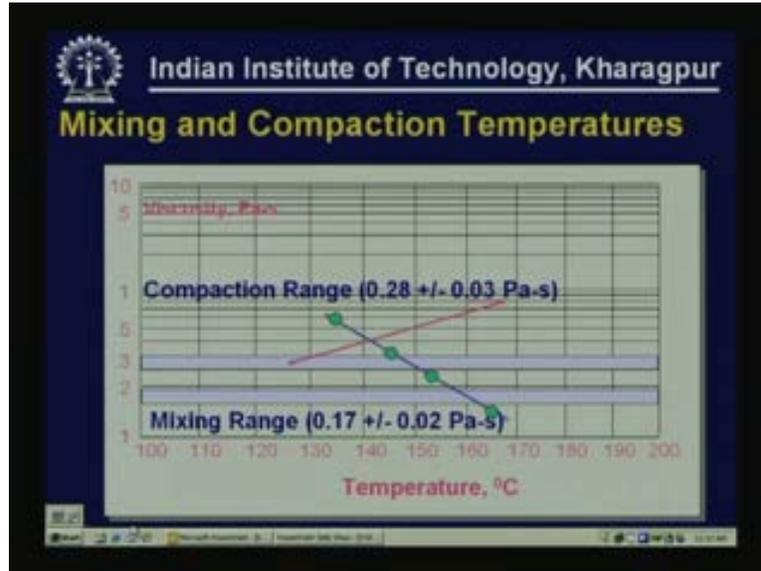
Preparation of Test Specimens

- Specimens at 6 binder contents
- Three specimens at each binder content
- About 25 kg of blended aggregate and 4 lt of binder
- Determine viscosity of binder at different temperatures using Rotational Viscometer and selection of Mixing and Compaction Temperatures

Normally specimens have to be tested are prepared at six different binder contents. And at each binder content normally three specimens have to be prepared. So, if you take about 25 kg of blended aggregate and about four liters of binder that would be normally be sufficient to cover these six binder contents and three specimens at each binder content.

Before we go about preparing these specimens we have to determine the viscosity of binder at different temperatures using rotational viscometer. We have discussed about Brookfield viscometer in the previous lessons and then measuring absolute viscosity using rotational viscometers. So we have to determine the viscosity of bituminous binder at various temperatures. This exercise is necessary to select the mixing and compaction temperatures.

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There are guidelines that are available about what is the consistency of the binder that we should adopt for compaction process, what is the consistency of the binder that is to be adopted for mixing the aggregates with binder. Therefore as you seen in this sketch the specifications are; for mixing typically these the viscosity should be ranging from 0.17 +/- 0.02 Pascal seconds.

Similarly the viscosity range for compaction is 0.28 +/- 0.03 Pascal seconds. For example, if you typically have a plot between temperature and then viscosity on y axis given by this line you can select the range within which mixing can be done, the range within which this requirement is satisfied so this temperature range can be selected and similarly you can find the range within which compaction can be done given by these two temperatures. So this is normally how we select the range of temperatures for mixing and also the range of temperature for compaction operation.

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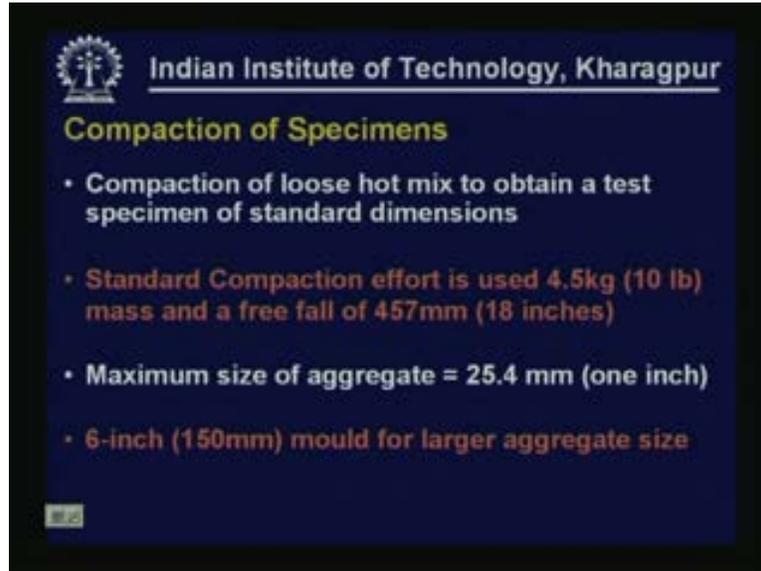
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Preparation of Specimens

- Compaction of loose hot mix to obtain a test specimen of standard dimensions
- Mixing temperature corresponding to a viscosity of 0.17 Pa-s
- Dry aggregates heated to a temperature not exceeding (mixing temp. + 28)
- Binder heated to mixing temperature (different for different types of binders)
- Place the heated mix in compaction mould (pre-heated) and compact

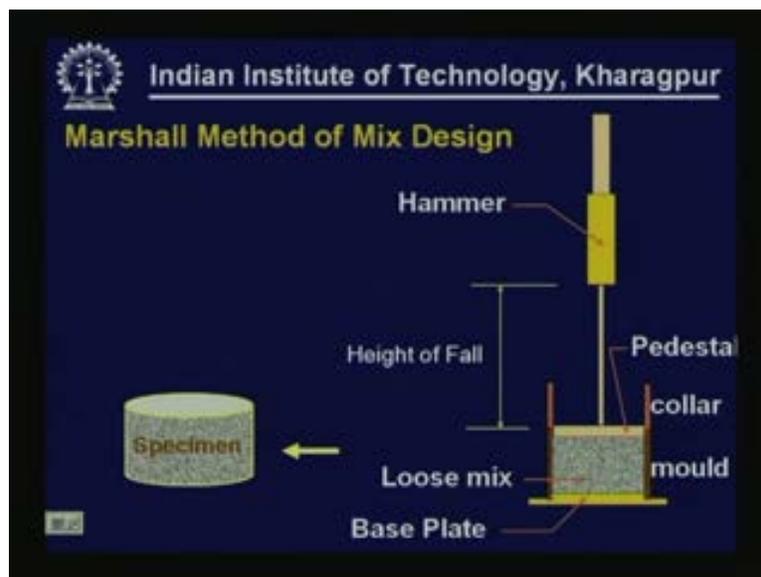
For preparing the specimens the compaction of loose hot mix obviously we have to add aggregates and then binder and then heat it to the temperature that we have just indicated and then that loose mix will have to be compacted so that we get standard test specimen dimensions. The mixing temperature is corresponding to a viscosity of 0.17 Pascal seconds similarly the dry aggregates are heated to a temperature not exceeding mixing temperature plus about 28 degree centigrade, the binder should be heated to mixing temperature which will be different for different types of binders because those viscosity ranges are attained at different temperature ranges for different types of binders. The binder plus aggregate mix is placed in the compaction mould which is to be pre-heated and the loose mix heated mix is compacted.

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As we indicated in the previous slide we have the compaction of loose hot mix to obtain a test specimen of standard dimensions. Standard compaction effort used is by a 4.5 kg hammer having a free fall of 457 mm, the maximum size of aggregate that we can use is 25.4 mm and for largest size of aggregates we can also use 6 inch dia moulds.

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On the left hand side you see typically a sketch of specimen that we are trying to prepare and this is the mould that we are using and this is the loose mix that we have placed here and this is the pedestal of the hammer and this is the mass (Refer Slide Time: 26:40) that is going to fall from a specified height. The hammer is not seen here so we have the hammer here and this is the height

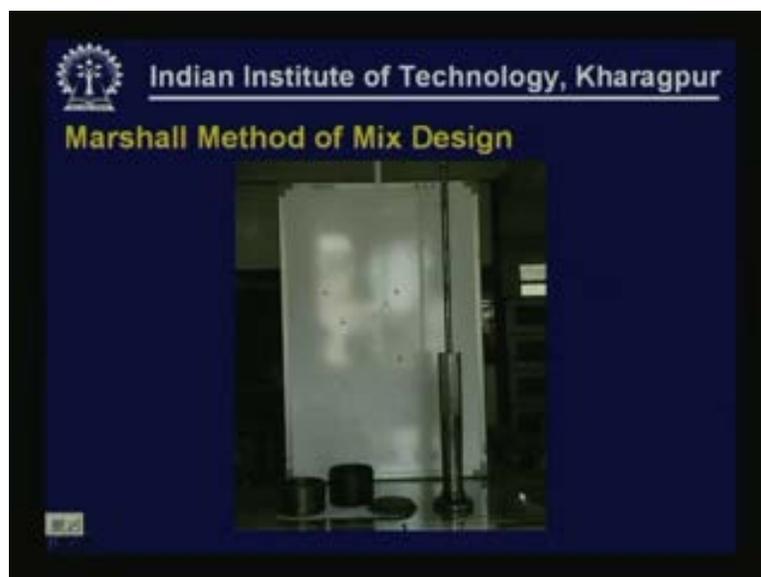
of fall that we are going to get and below this there is a base plate. You see the hammer here now, so we also see the height of fall so the hammer will be lifted up and allowed to drop freely and this exercise is repeated a number of times.

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You see two different photographs of an automated Marshall compaction equipment. On the left hand side you see the hammer. This is the hammer and this is an arrangement in which you can set the number of blows you want to apply and then the hammer gets lifted up and then repeatedly dropped and this is where the mould is fixed.

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This is a manual Marshall hammer and these are moulds, base plate.

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Typically for preparing this specimen **MORTH** specifies for heavy compaction 75 blows are to be applied using Marshall compaction hammer on both faces. first you have to compact it on one side then the specimen has to be reversed then again 75 blows of Marshall hammer have to be applied on the other face also. So this is the standard compaction that is recommended for all the mixes that we use for highways. So the specimens that are compacted will have to be extracted from the mould.

Of course before that we will how to determine this specific gravity of aggregates and also binders and the specimen that is extracted from the mould we have to find out its bulk specific gravity of the compacted mix that is Gmb. This is obtained by measuring the dry mass of the mix, you take the dry mass of this specimen and find out the volume of water replaced by the saturated surface dry specimen.

The specimen has to be saturated then the surface water has to removed and its weight has to be taken and then its weight in air has to be taken. Therefore the difference in weights will give us the volume of water replaced by saturated surface dry specimen so the dry mass of the specimen divided by volume of water replaced by the saturated surface dry specimen which is nothing but the bulk volume gives us bulk specific gravity of the compacted mix.

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Then the specimen is put in a Marshall testing machine and Marshall Test is conducted. Marshall Test is nothing but these are the breaking head put on both sides of the specimen so a compressive load is applied along the diameter of the specimen at a rate of 51 mm per minute, we know that the temperature of the specimen is going to be maintained at 60 degree centigrade and the inside radius of the breaking head is going to be approximately equal to that of the specimen which is 51 mm so load at this rate is applied.

What we observe is the load at which the specimen breaks. so either in a proving ring or in a dial case or in any automatic measurement we see the load increasing then after a certain stage once the specimen fails the load starts decreasing. So we have to observe what the failure load is and we also have to observe what deformation this specimen undergoes when this specimen fails. Starting from an initial deformation of zero the deformation at failure condition has to be observed. So the breaking load is known as stability and the deformation at failure is known as flow. So these are known as Marshall Stability and Marshall Flow.

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This is an automated Marshall testing machine which uses LVDTs and load cells to automatically measure the load and the corresponding deformation and it can automatically be recorded onto a computer. Of course you can use other simple equipment also.

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This is a water bath which is used to maintain constant temperature.

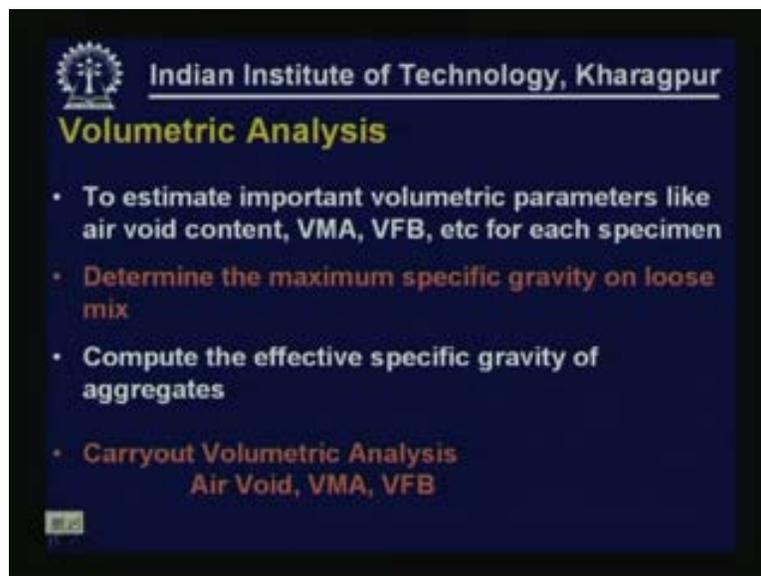
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Volume cc	Correction Factor	Volume cc	Correction Factor
432-443	1.32	547-559	0.89
444-456	1.25	560-573	0.86
457-470	1.19	574-585	0.83
471-482	1.14	586-598	0.81
483-495	1.09	599-610	0.78
509-522	1.00	611-625	0.76
523-535	0.96		
536-546	0.93		

The stability that is obtained from Marshall testing machine as I said ought to be corrected for nonstandard volume. If the dimensions attained are 4 inch dia and 2 ½ inch height there would not be any correction that is required but if mostly the height varies there is certain correction that is to be applied. For example, if the volume is within 509 to 522 cc there would not be any correction but if it is more the stability will be reduced and if the volume is less the stability will be increased.

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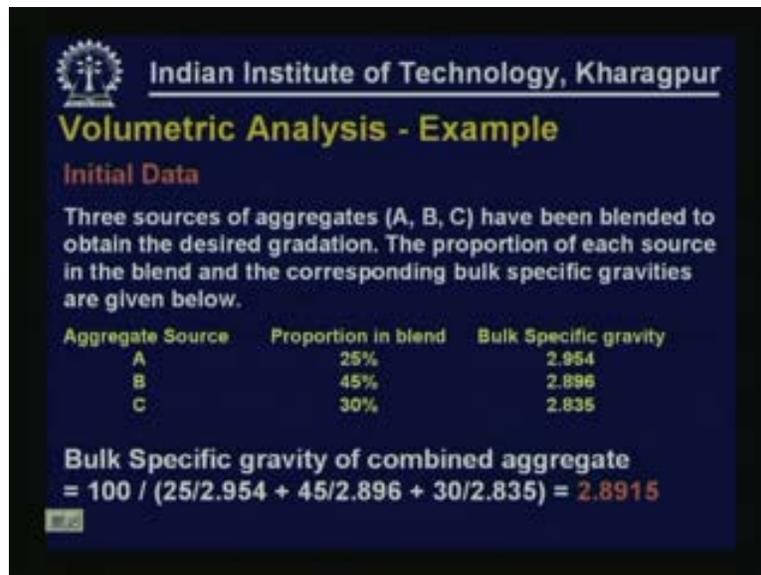


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Volumetric Analysis	
• To estimate important volumetric parameters like air void content, VMA, VFB, etc for each specimen	
• Determine the maximum specific gravity on loose mix	
• Compute the effective specific gravity of aggregates	
• Carryout Volumetric Analysis Air Void, VMA, VFB	

After the Marshall test is done we will have to carry out volumetric analysis. This is to estimate important volumetric parameters such as air void content, voids and mineral aggregate, mineral

aggregate voids filled with bitumen and so on for each of these specimens. And for each binder content we have to determine the maximum specific gravity. This is the specific gravity of the void-less loose mix this has to be determined and using all this information we calculate the effective specific gravity of aggregates and carry out the volumetric analysis to compute air voids VMA and VFB.

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Volumetric Analysis - Example

Initial Data

Three sources of aggregates (A, B, C) have been blended to obtain the desired gradation. The proportion of each source in the blend and the corresponding bulk specific gravities are given below.

Aggregate Source	Proportion in blend	Bulk Specific gravity
A	25%	2.954
B	45%	2.896
C	30%	2.835

Bulk Specific gravity of combined aggregate
 $= 100 / (25/2.954 + 45/2.896 + 30/2.835) = 2.8915$

A typical example of volumetric analysis is given here. For example, if you have the initial data where in we have taken three different sources A B C of aggregates and they have been blended in let us say this proportion 25%, 45% and 30% to obtain the desired gradation and the bulk specific gravity of source A B C are 2.954, 2.896 and 2.835 respectively these have been measured. So the bulk specific gravity of the combined aggregate will be 100 divided by 25 is a proportion of aggregate A in the blend divided by the corresponding bulk specific gravity 2.954 + 45 by 2.896 + 30 by 2.835 so the bulk specific gravity of the blended combined aggregate is 2.8915.

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The slide features the IIT Kharagpur logo and title at the top. Below, it lists several key parameters: bitumen content (5.0%), specific gravity of bitumen (1.03), bulk specific gravity of the specimen (2.552), and maximum specific gravity of the loose mix (2.729). It then defines the effective specific gravity of the aggregate (Gse) and provides a step-by-step calculation using the formula $G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$, resulting in a value of 2.9884.

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Volumetric Analysis – Example (contd)

Bitumen content = 5.0 % (by weight of mix)

Specific Gravity of bitumen , $G_b = 1.03$

Bulk Specific Gravity of the specimen (G_{mb}) = 2.552

Max. Sp. Gr. of loose mix for 5% binder (G_{mm}) = 2.729

Effective Specific Gravity of Aggregate (G_{se})
(including all voids except those that absorb bitumen)

$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$
 $= \frac{(100 - 5.0)}{(100/2.729 - 5.0/1.03)} = 2.9884$

Let's say we have added five percent bitumen by weight of the total mix and the specific gravity of the bitumen was measured as 1.03 G_b . This is one specimen that we are talking about, we have measured the bulk specific gravity of the specimen that is 2.552 and maximum specific gravity of the loose mix for 5% binder content is 2.729 so the effective specific gravity of the aggregate G_{se} which is calculated taking into consideration all the voids except those that absorb bitumen is given as $P_{mm} - P_b$ divided by $\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}$ where P_b is the proportion of binder, G_b is the specific gravity of binder, G_{mm} is the maximum specific gravity of loose mix, P_{mm} is the percentage of total loose mix this will of course be 100 so $100 - 5$ divided by $\frac{100}{2.729} - \frac{5}{1.03}$ which gives us 2.9884.

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Volumetric Analysis – Example (contd)

Maximum Specific gravity of loose mix for other binder contents (approximately) $G_{mm} = P_{mm} / (P_s/G_{se} + P_b/G_b)$
(eg: for 6% binder content, $G_{mm} = 100 / (94 / 2.9884 + 6/1.03)$
 $= 2.6823$ (2.729 for 5%))

Bitumen absorption (for 5% binder content case)
 $P_{ba} = 100 * ((G_{se} - G_{sb}) / (G_{sb} * G_{se})) * G_b$
 $= 100 * ((2.9884 - 2.8915) / (2.8915 * 2.9884)) * 1.03$
 $= 1.155 \%$

Effective Bitumen = $P_b - P_{ba} * P_s / 100$
 $= 5.0 - 1.155 * 95 / 100 = 3.90 \%$

The maximum specific gravity of loose mix for other binder contents can be determined by preparing specimen set of other binder contents. but that has to be calculated on the basis of what has been determined for one binder content so this expression can be used to calculate the maximum specific gravity of loose mixes for other binder contents given by $G_{mm} = P_{mm}$ by P_s divided by $G_{sc} + P_b$ by G_b . For example, for 6% binder content 100 by 94 divided by 2.9884 + 6 by 1.03 is the binder that we are referring to divided by 1.03 so that's about 2.6823.

We can compare the specific gravity that we obtained for 5% which is 2.729. The bitumen absorption for 5% binder content case can also be calculated using this expression that is 1.155% and the effective bitumen content after deducting the bitumen that has gone into the surface pores of aggregates can be calculated using this expression $P_b - P_{ba}$ into P_s where P_s is the proportion of aggregates divided by 100 so $5 - 1.155$ is the percentage of bitumen that is observed into 95 is the proportion of aggregates divided by 100 that's about 3.9%. So we have put 5% bitumen but 3.97% is what is available to effectively coat the aggregates.

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Volumetric Analysis - Example

Voids in Mineral Aggregate (VMA)
= $100 - Gmb \cdot Ps / Gsb$
= $100 - 2.552 \cdot 95 / 2.8915 = 16.15\%$

Air Voids, Va
= $100 \cdot (Gmm - Gmb) / Gmm$
= $100 \cdot (2.729 - 2.552) / 2.729 = 6.49\%$

Voids Filled with Bitumen, VFB
= $100 \cdot (VMA - Va) / VMA$
= $100 \cdot (16.15 - 6.49) / 16.15 = 59.81\%$

Then we calculate the voids and mineral aggregates using the expression $100 - Gmb$ into Ps by Gsb so it works out to 16.15% and air void content using specific gravity of loose mix and bulk specific gravity of the compacted mix so $- Gmb$ by Gmm is expressed as percentage so air void content in this case for this specimen is worked out to be 6.49%. Voids filled with bitumen is nothing but total voids in mineral aggregate minus air void and the rest is bitumen so $VMA - Va$ divided by VMA is expressed as percentage so this is working out to 59.81%.

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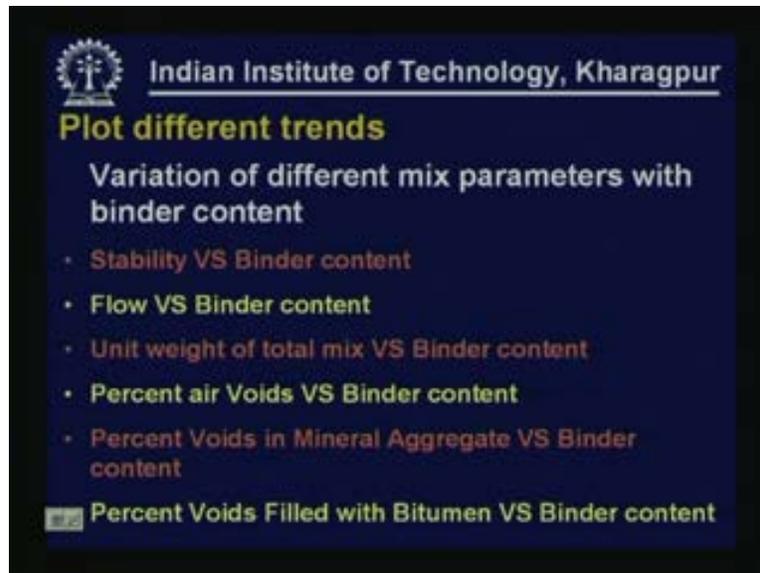
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Selection of Optimum Binder Content

If for example, we have approximately about six binder contents, for each binder content we have about three specimens so we can take the average of those three specimens. So basically we

have all results for six different binder contents. Thus we have to select an optimum binder content that is giving us satisfactory properties.

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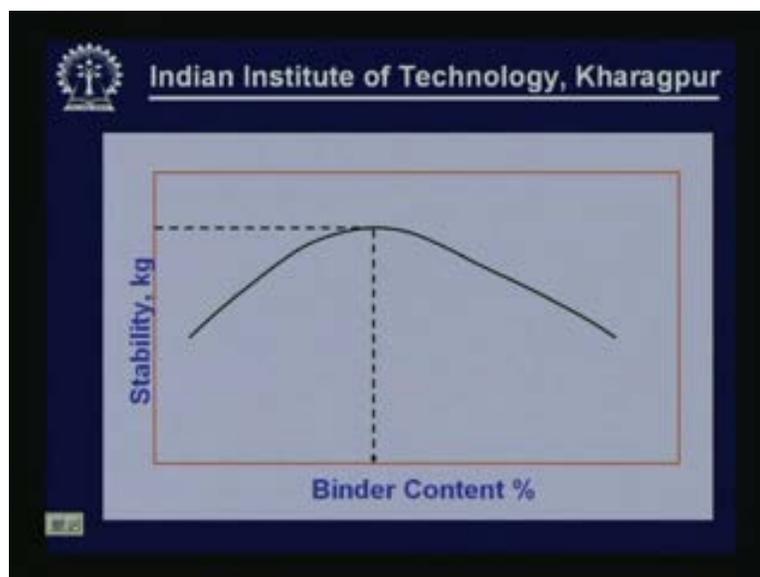
Plot different trends

Variation of different mix parameters with binder content

- Stability VS Binder content
- Flow VS Binder content
- Unit weight of total mix VS Binder content
- Percent air Voids VS Binder content
- Percent Voids in Mineral Aggregate VS Binder content
- Percent Voids Filled with Bitumen VS Binder content

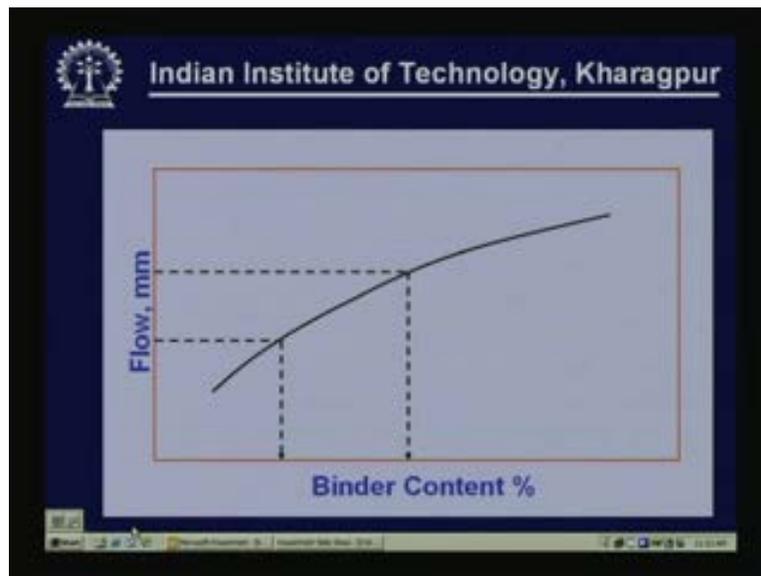
This can be selected by observing various mix parameters with binder content. What we normally examine is how stability varies with binder content, how flow varies with binder content, how the unit weight of the total mix varies with binder content, what is the variation of percentage of air voids, variation of percentage voids and mineral aggregate, and variation of percentage of voids filled with bitumen.

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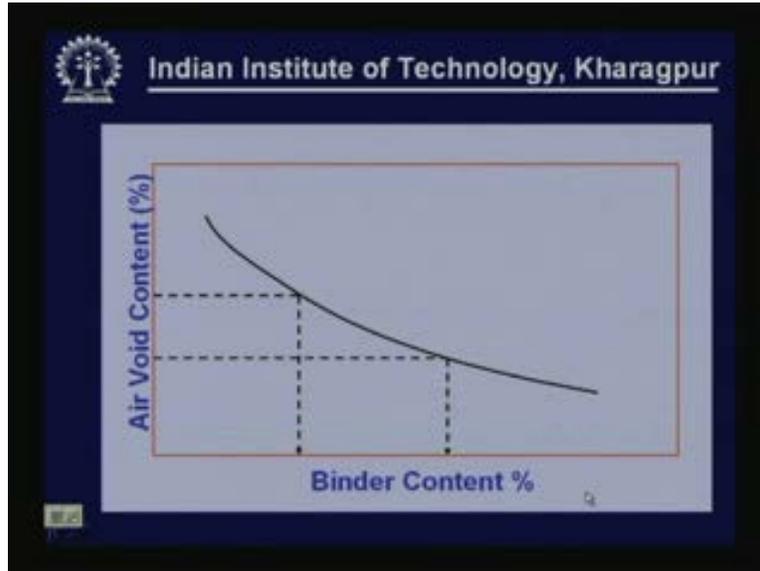
Typically this is the trend that we expect to get in terms of stability. As binder content varies it is normally expected to initially increase and reach a peak and then start decreasing afterwards. The unit weight also is expected to display a similar trend, it will start increasing initially because of the increased density that is made possible by re-orientation of the particles which are lubricated by the binder but subsequently once it attains its densest position any addition of binder having low specific gravity is only going to decrease its unit weight so we can expect that unit weight is going to decrease after some binder content. Therefore we are normally interested in binder content that give us maximum unit weight, we are also interested in binder content that give us maximum stability but they may not exactly coincide.

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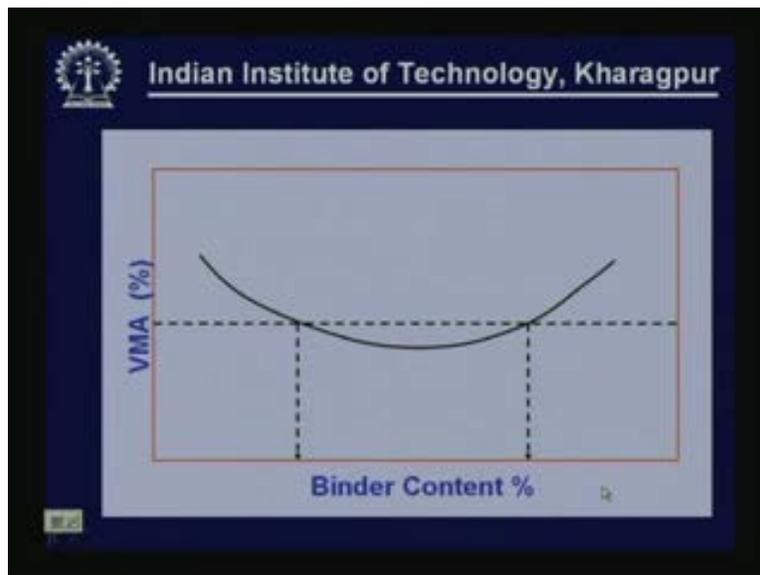
This is how the flow is going to increase. As you go on increasing the binder content typically the flow is going to increase because of increasing binder contents. So we normally have specifications in terms of range of flow and this is the corresponding range of binder content within which the specified range of flow is satisfied.

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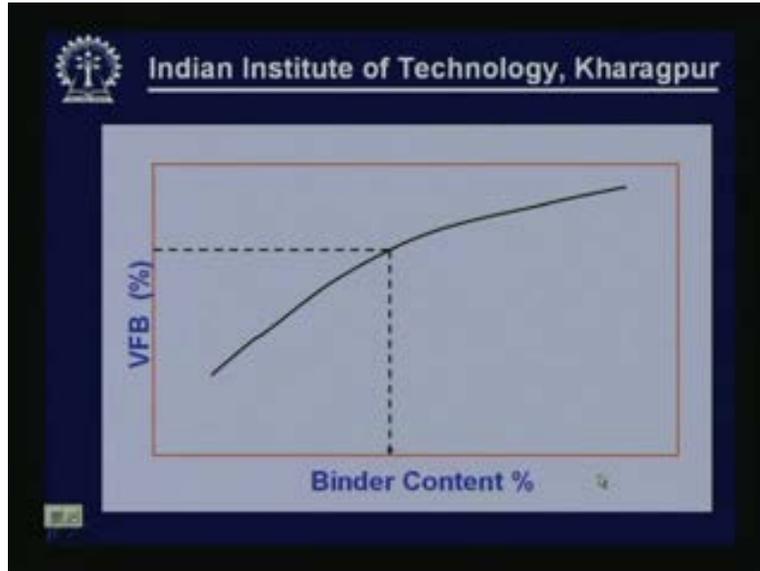
This is how the air void content is going to vary with binder content. As the binder content is increased, air void content is decreased. So, in the case of air void, this specification will normally be in terms of a range, and we can identify what is the corresponding binder content within which the given range of air void contents can be obtained.

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Voids and mineral aggregate usually start decreasing and then start increasing. It is not necessary that in all cases you exactly get a similar shape. So, once you get the shape depending upon where the minimum of VMA specification is, whether it is here or here or there, so accordingly we can identify what is the binder content that can be selected.

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Similarly these are voids and mineral aggregates that are filled with bitumen. So, as the binder content increases the voids filled with bitumen will go on increasing. So the specification for this will also be available and the corresponding binder content can be identified.

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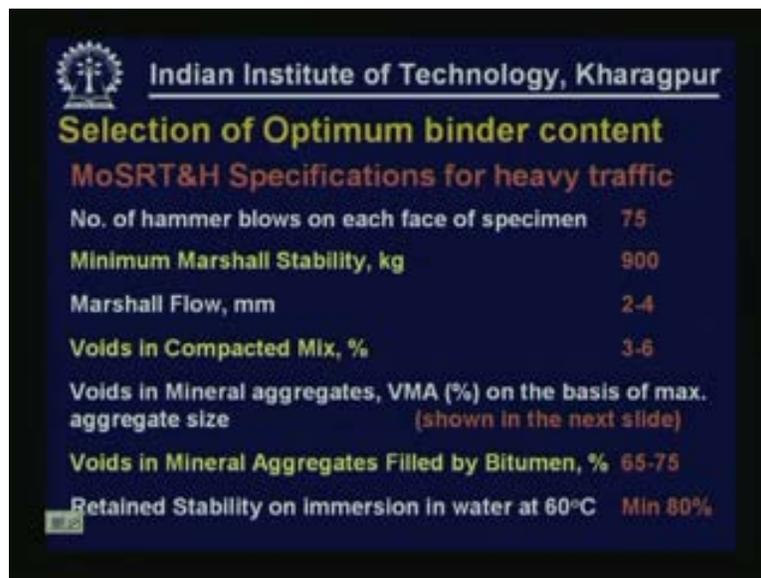
The slide is titled 'Selection of Optimum binder content' and contains the following text:
Binder content that satisfies all the mix requirements (specifications) should be selected
The specifications should normally be developed on the basis of performance mixes under specified conditions
Asphalt Institute main criterion is a median air void content of 4%. Binder content corresponding to 4% air voids should be selected as OBC if other criteria are satisfied

Thus for selecting the optimum binder content we normally have to select a binder content that satisfies all the mix requirements that is specifications given by a **given agency**, these are to be selected. The specifications should normally be developed on the basis of performance of mixes under specified conditions. So we believe that whatever specifications are given by MORTH or

Asphalt institute or other agencies are on the basis of observation of the mixes and about their performance under varying conditions.

The Asphalt institute's main criterion for selection of optimum binder content is a median value of 4% air void content. So the binder content that gives us 4.4% air void content is the optimum binder content provided it satisfies all the other requirements that are given. If it does not satisfy any particular requirement we can make slight adjustment to the binder content that we obtain for 4% air void content.

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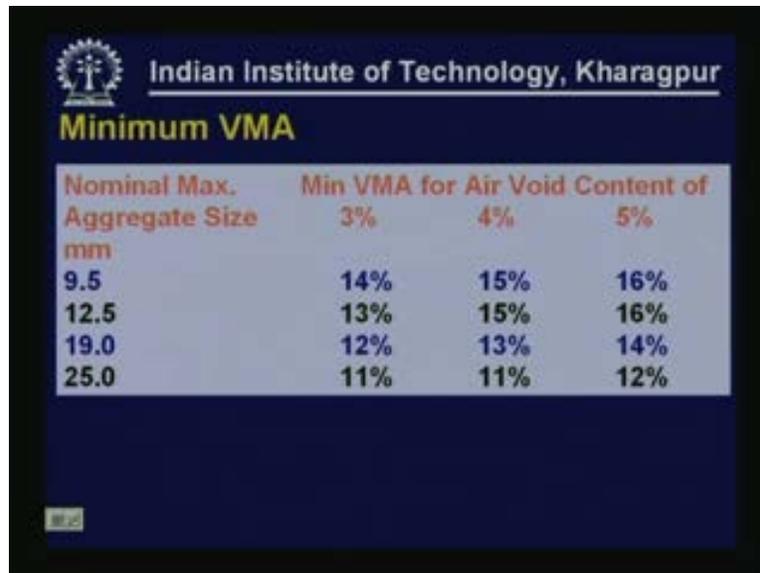
Indian Institute of Technology, Kharagpur	
Selection of Optimum binder content	
MoSRT&H Specifications for heavy traffic	
No. of hammer blows on each face of specimen	75
Minimum Marshall Stability, kg	900
Marshall Flow, mm	2-4
Voids in Compacted Mix, %	3-6
Voids in Mineral aggregates, VMA (%) on the basis of max. aggregate size	(shown in the next slide)
Voids in Mineral Aggregates Filled by Bitumen, %	65-75
Retained Stability on Immersion in water at 60°C	Min 80%

These are the specifications for heavy traffic from the Ministry of Shipping Road Transport and Highways. The number of hammer blows that are to be applied in preparing a specimen on each face of the specimen are 75 blows, the minimum Marshall Stability that has to be attained is 900 kg, the Marshall Flow should be ranging between 2 to 4 mm, the air voids in the compacted mix should be ranging from 3 to 6% the voids in the mineral aggregates VMA percentage which is calculated or rather based on maximum size of aggregate we have different specifications for different maximum aggregate size, **I will put this information in the next slide,**

Voids in the mineral aggregates filled by bitumen range from 65 to 75 and the retained stability on immersion in water at 60 degree centigrade should be a minimum of 80 degree centigrade. This is the test that has to be conducted the retained stability test on immersion. This has to be conducted to assess the damage that could be caused to the mixes when it is subjected to moisture especially in locations where you have heavy rainfall and also when you are using aggregates that are likely to strip. So we are concerned about the loss in stability because of moisture. so what we do in this test is we test normal specimens which are conditioned to normal testing procedure say thirty to forty minutes and we also prepare a separate set of specimens and put them in water bath for longer specified periods at 60 degree centigrade and test them also and find out the Marshall Stability of those specimens and compare the condition specimens and see

what is the loss in Marshall strength. So they should have a minimum of eighty percent of retained Marshall Stability.

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The slide displays the Indian Institute of Technology, Kharagpur logo and title. Below the title, the heading "Minimum VMA" is shown. A table provides the minimum VMA percentages for various aggregate sizes (9.5 mm, 12.5 mm, 19.0 mm, 25.0 mm) corresponding to air void contents of 3%, 4%, and 5%.

Nominal Max. Aggregate Size mm	Min VMA for Air Void Content of		
	3%	4%	5%
9.5	14%	15%	16%
12.5	13%	15%	16%
19.0	12%	13%	14%
25.0	11%	11%	12%

This is the criteria for minimum voids in mineral aggregates depending on nominal maximum aggregate size, if we are targeting an air void content of 3% then for 9.5 mm aggregate which is the maximum size then 14% is the minimum voids in mineral aggregate that has to be provided. As you see for smaller aggregate size the voids in mineral aggregates are specified to be larger because we have to put more bitumen into the mix so we have to create more voids in the mineral aggregates so that we can put more bitumen. More bitumen is required for smaller size of aggregates because the surface area is going to be more. So the binder that is required to coat the smaller size fractions will be larger that's why we have to create more voids in the mineral aggregates so that we can put more bitumen there.

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Minimum VMA

Nominal Max. Aggregate Size (mm)	Min VMA for Air Void Content of 3%	4%	5%
9.5	14%	15%	16%
12.5	13%	15%	16%
19.0	12%	13%	14%
25.0	11%	11%	12%

On the other hand when you consider larger size aggregates for example when you see 25 mm size and we are trying to create let's say 3% air void content then the minimum VMA (()) (00:46:26) is 11% for smaller size.

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Selection of Optimum binder content

IRC:SP-53-2002 Specifications Bituminous Mixes with modified binders

No. of hammer blows on each face of specimen 75

Parameter	Requirement		
	Hot Climate	Cold Climate	High Rainfall
Min. Stability	1200 kg	1000	1200
Flow, mm	2.5 - 4.0	3.5 - 6.0	3.0 - 4.5
Marshall Quotient (Stability/flow)	250-500	250 - 500	250 - 500
Air Voids in Mix, %	3 - 5	3 - 5	3 - 5
Retained of Stability	Min 90%	Min 95%	Min 100%

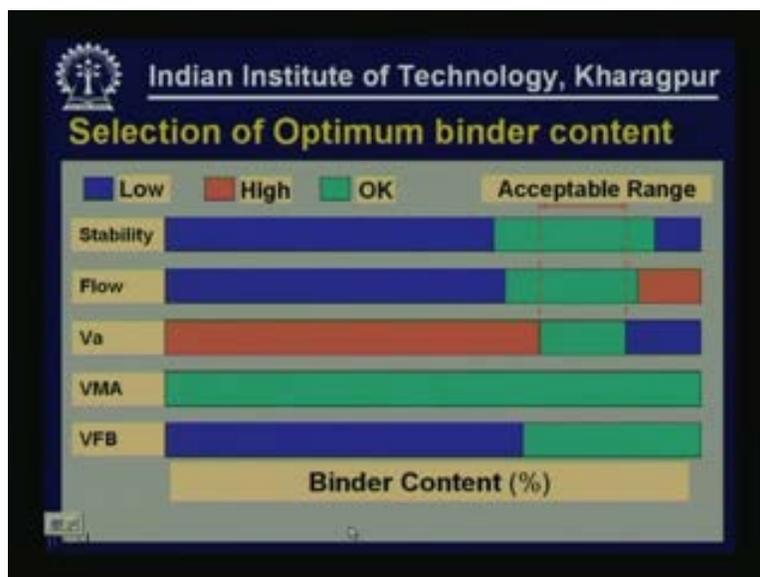
Those are considered as for MORTH for normal mixes. But as per IRC special publication 53 - 2002 which deals with specifications of bituminous mixes with modified binders, polymer modified, rubber modified and various other types of modified binders the number of hammer blows is of course 75 only and these are the parameters that we consider. The requirements for various climatic conditions such as hot climate, cold climate, high rainfall area are; the minimum

stability for hot climate conditions is 1200, for cold condition it is 1000 and again if it is high rainfall area we have to have a minimum of 1200 kg minimum stability. Flow range is 2.58 to 43.5 to 5324.5.

Similarly there is another parameter that is considered which is called as Marshall Quotient which is nothing but Marshall Stability divided by Marshall Flow which should range between 250 to 500.

Retained stability requirement is also there which is of a minimum of 90%, 95%, 100% and air void requirement is 3 to 5%.

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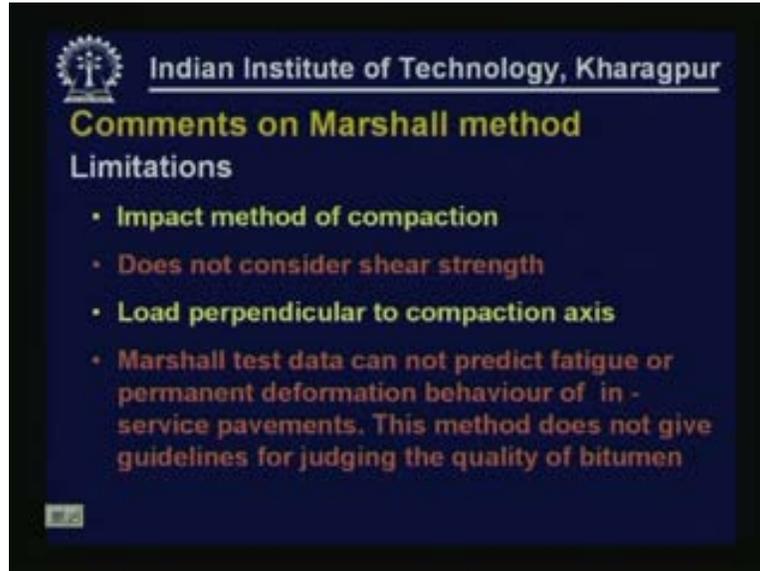
As I indicated normally the binder content will be selected either corresponding to 4% air void content and that is optimum binder content if it satisfies all the other requirements. Or on the other hand we can also examine the binder content range that satisfies all the criteria. For example, if this is the acceptable range for minimum stability on this side of the binder content you will have low stability and on this side of the binder content you will have low stability. So this is the range within which we get acceptable stability and this is the range of binder content within which the flow is going to be satisfied, this is the binder content range within which air void content specification is going to be satisfied and let us assume in a given case for all binder contents VMA is satisfied and more than this binder content is required we have the VFB consideration satisfied. So from this we can identify this is the range of binder content which satisfies all the requirements. So possibly then you can select the mid point of this as your optimum binder content.

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The main advantage of adopting Marshall Mix design method is it is relatively inexpensive, inexpensive especially when we are comparing this with more recently developed superpave mix design procedures. This is convenient for design and also for quality control. we can have a Marshall mix equipment kept in field laboratory also, even the compactor can be taken to the field and then mixes can directly be collected from field and then compacted there itself then the specimen can be brought to the laboratory and then tested. So it can be considered to be a convenient method for field quality control and for laboratory testing also. Lot of importance is given to air void in this mix design method. As we already established earlier air void content is a key parameter towards the performance of the pavements. It also accounts for the strength and durability requirements of the mix, it can be used on site also.

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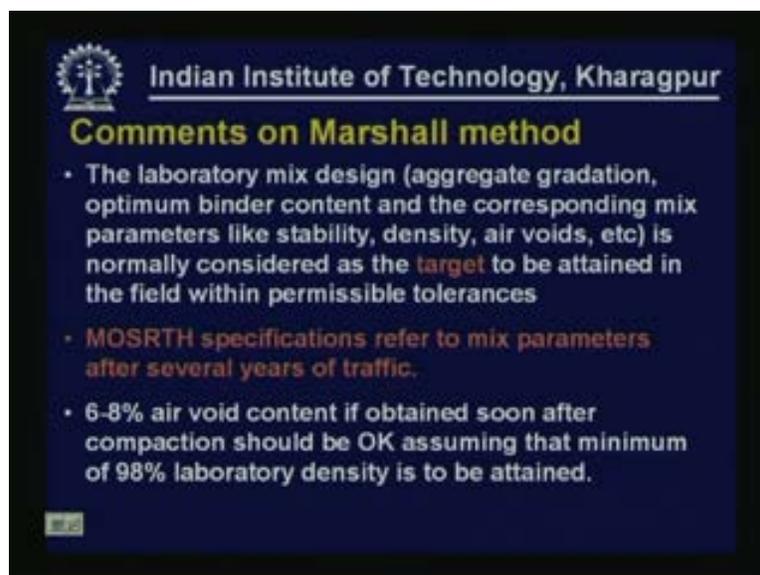


The slide features the IIT Kharagpur logo and name at the top. The main title is 'Comments on Marshall method' in yellow. Below it, the word 'Limitations' is written in white. A bulleted list follows, with each item starting with a white dot. The text in the list is white, except for the words 'Does not' and 'This method does not' which are in red.

- Impact method of compaction
- Does not consider shear strength
- Load perpendicular to compaction axis
- Marshall test data can not predict fatigue or permanent deformation behaviour of in - service pavements. This method does not give guidelines for judging the quality of bitumen

But the limitations of this method are, this is an impact method of compaction so it does not really simulate what is the happening in field. In the field there is some needing action that is taking place so that is not exactly simulated in this impact method of compaction. It does not consider the shear strength in the method of testing the specimen which is diametrical loading, it does not take into account the shear strength of the specimen because the load is perpendicular to the compaction axis. Marshall Test data cannot normally predict fatigue and permanent deformation behavior of in service pavements. This method also does not give proper guidelines for selecting the quality of bitumen.

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The slide features the IIT Kharagpur logo and name at the top. The main title is 'Comments on Marshall method' in yellow. Below it, a bulleted list follows, with each item starting with a white dot. The text in the list is white, except for the words 'target' and 'after several years' which are in red.

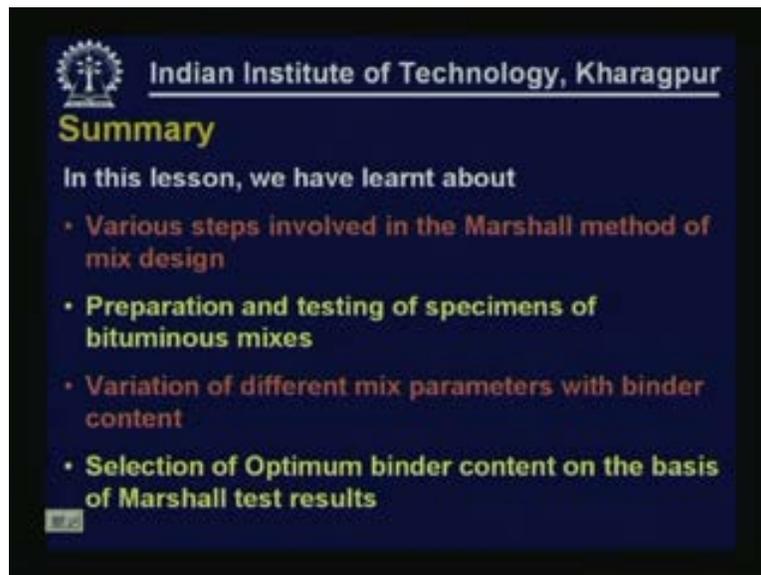
- The laboratory mix design (aggregate gradation, optimum binder content and the corresponding mix parameters like stability, density, air voids, etc) is normally considered as the target to be attained in the field within permissible tolerances
- MOSRTH specifications refer to mix parameters after several years of traffic.
- 6-8% air void content if obtained soon after compaction should be OK assuming that minimum of 98% laboratory density is to be attained.

The laboratory mix design that is aggregate gradation, optimum binder content and the corresponding mix parameters like stability, density, air voids etc is normally considered as the target to be attained in the field within permissible tolerances. Whatever is established in the laboratory and you say this is the binder content and these are the corresponding properties that we obtained in the laboratory these are to serve as target values to be checked for in the field.

MORTH specification refers to mix parameters to be attained after several years of traffic. Normally if we start with six to eight percent initial air void content, this is soon after initial compaction. That should be considered to be okay assuming that a minimum of 98% laboratory density is attained. Normally the specification is that whatever is laboratory density that you obtain corresponding to optimum binder content at least ninety eight percent of that should be attained in the field.

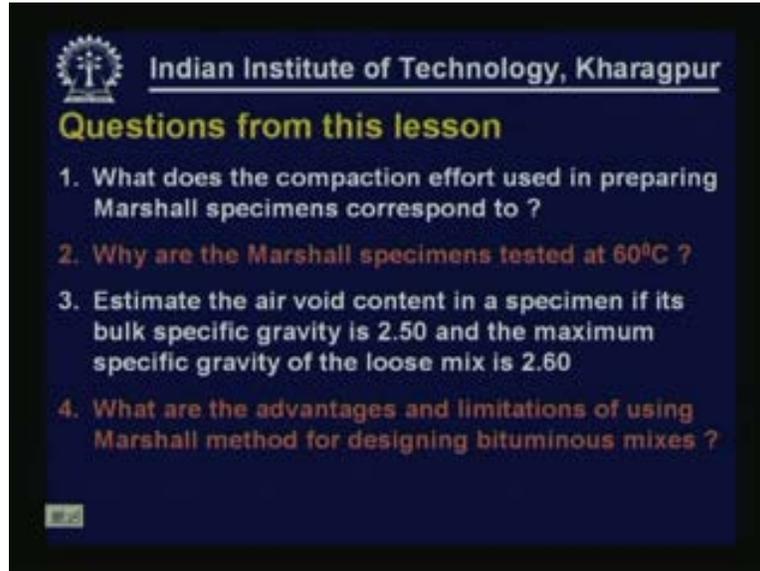
So, if you can maintain about 6 to 8% assuming that we are getting only 98% in the field that would correspond to 100% compaction of about 4% which is expected to be attained after several years of traffic. So we are starting with initial of 6 to 8 we expect that there is going to be some secondary compaction about another 2%, 3% then the air void content after several years can get reduced to 3 to 4% or 2% which should be considerably an acceptable thing. But if it gets reduced further that is a problematic mix.

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To summarize; in this lesson we have learnt about various steps involved in the Marshall Method of mix design. We also discussed about the preparation and testing of specimens of bituminous mixes. We also discussed how various mix parameters vary with binder content and also discussed how to select optimum binder content on the basis of Marshall Test results.

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Questions from this lesson

1. What does the compaction effort used in preparing Marshall specimens correspond to ?
2. Why are the Marshall specimens tested at 60°C ?
3. Estimate the air void content in a specimen if its bulk specific gravity is 2.50 and the maximum specific gravity of the loose mix is 2.60
4. What are the advantages and limitations of using Marshall method for designing bituminous mixes ?

Let us take a few questions from this lesson.

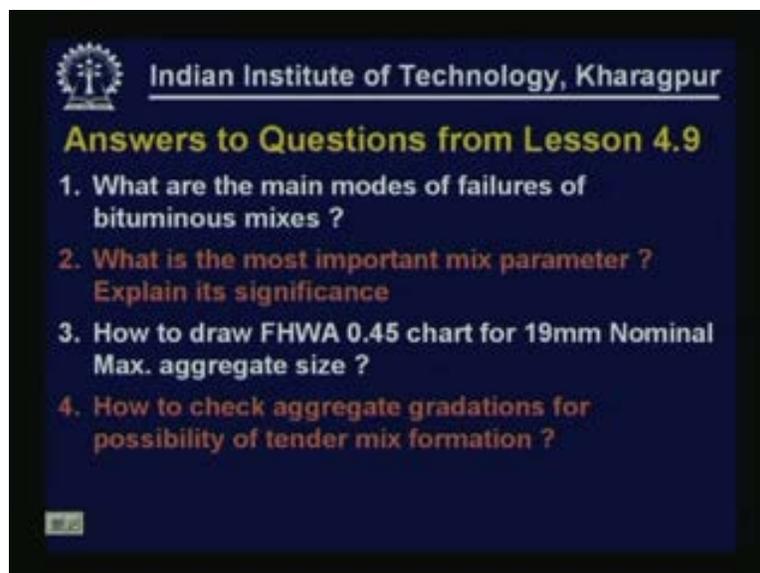
What does the compaction effort used in preparing Marshall Specimens correspond to?

Why are the Marshall specimens tested at 60 degree centigrade?

Estimate the air void content in a specimen. If its bulk specific gravity is 2.50 and the maximum specific gravity of the loose mix is 2.60.

What are the advantages and limitations of using Marshall Method for designing bituminous mixes?

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Answers to Questions from Lesson 4.9

1. What are the main modes of failures of bituminous mixes ?
2. What is the most important mix parameter ?
Explain its significance
3. How to draw FHWA 0.45 chart for 19mm Nominal Max. aggregate size ?
4. How to check aggregate gradations for possibility of tender mix formation ?

Now we will take up the answers for the questions that we asked in lesson 4.9, this was part one of bituminous mixes or design of bituminous mixes.

What are the main modes of failures of bituminous mixes?

Bituminous mixes normally fail in various modes one of them being cracking of different types. cracking that can start from bottom, bottom up cracks, cracking that can start from top, top down cracks caused by various reasons; reputed application of loads, climatic conditions, cyclic variation of thermal stresses, various parameters can cause cracking of these mixes they can be starting from bottom or they can start from top also so cracking either fatigue or other type of cracking is a major problem.

Also, rutting is one of the major failures of many bituminous pavements in India because of the high temperature conditions. So rutting or permanent deformation which occurs mostly in bituminous mixes if they are thick at high temperatures and it can of course also occur in other layers starting from sub grade, sub-base, base and which then gets reflected onto the surface. But of course in this lesson we were concerned about the failures that were occurring in bituminous layer so we were concerned about the rutting that is occurring in bituminous layer.

Other types of failures are bleeding that is seen on the surface because of the presence of excess of bitumen on surface, because of very little air void that was present, secondary compaction so bitumen coming to the top which was another failure we saw. Similarly these three or four types of failures can lead to secondary types of failures also.

How to draw FHWA 0.45 chart for 19 mm nominal maximum aggregate size?

FHWA chart makes use of 0.45 rule for finding out the percentage part to be passing through a particular sieve size if you know what is the maximum size of aggregate that we are referring to.

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Answers to Questions from Lesson 4.9

1. What are the main modes of failures of bituminous mixes ?
2. What is the most important mix parameter ?
Explain its significance
3. How to draw FHWA 0.45 chart for 19mm Nominal Max. aggregate size ?
4. How to check aggregate gradations for possibility of tender mix formation ?

For example, in this case if 13.2 is the maximum nominal size then we take a convenient length of x axis and also convenient length for y axis. The y axis will be percentage passing 0 to 100 then let us join this line, on this if you want to identify a 2.36 mm size so we calculate the percentage to be passing through 2.36 so we will calculate 2.36 divided by 13.2 to the power 0.45 into 100 so we will identify that percentage here and then locate 2.36 here. So on this any given gradation can be plotted and this is the densest gradation and then any gradation can be compared to the densest gradation.

The last question was how to check aggregate gradations for possibility of tender mix formation. This can be identified by checking whether a given gradation has a deviation of more than 3% from a line which connects origin to 4.75 mm sieve size. So, if a gradation has got deviation by more than 3% that is consider to be leading to a tender mix, thank you.