

**Mechanical Characterization of Bituminous Materials**  
**Dr. Neethu Roy**  
**Asst. Dean (R&D), Professor**  
**Department of Civil Engineering**  
**Mar Baselios College of Engineering and Technology-Thiruvananthapuram**

**Lecture - 47**  
**Laboratory Investigation for Rutting of Bituminous Mixtures - Part 2**

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### Outline

- Development of Asphalt Mixture Performance Tests
- Specimen Preparation
- Flow Time Test
  - Post-processing of data
- **Flow Number Test**
  - **Post Processing Techniques**
- Post-processing Issues
- Development of Failure Criteria for Rutting

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Let us next see what is a flow number test, how the test is to be conducted and what are the post processing techniques.

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### Flow Number Test

*The flow number is a property related to the resistance of asphalt mixtures to permanent deformation. It can be used to evaluate and design asphalt mixtures with specific resistance to permanent deformation.* AASHTO :T 378-2017

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Now the test procedure for flow number is AASHTO T 378-2017. This is the latest AASHTO standards for flow number test. So I will read out from the AASHTO

standard what is flow number. Flow number is a property related to the resistance of the asphalt mixture to permanent deformation. It can be used to evaluate and design asphalt mixtures with specific resistance to permanent deformation.

Now what we have seen in the flow time test is that you are applying a constant load on the material. It is a constant creep load. But what we observe actually in the field is that there is always certain recovery that is given to the loading. So even if you consider one truck that is moving, there will be one axle load and there is certain recovery period then only the next axial load comes at that point.

Likewise, if you have multiple vehicles moving, there is always a recovery time that is given between the loadings. So during this recovery time there is the chances of the material to recover. This is because you have a viscoelastic material. So this aspect is not considered in the flow time test where a static load is applied. So that is how the development of flow number test happened.

Wherein you have to apply a load and then also you have to provide a recovery period. So this is the test procedure or protocol for a flow number test. You do a haversine loading as you see here. So this bottom figure is the stress versus time and you apply a haversine loading for a time period of 0.1 seconds. Then you give a rest period of, that is zero loading, for a time of 0.9 second.

So this is one cycle. There is a 0.1 second loading and 0.9 second rest period. This forms 1 cycle or 1 second. So your frequency will be 1 Hz or 1 cycle per second. Flow number test, it is necessary that certain amount of load has to be always applied which you call it as the contact stress or the seating load.

Otherwise, if you try to give it as a zero stress what may happen is that this contact between the loading frame and the specimen will be lost and there will be difficulty in capturing the data. So there is always certain amount of contact stress which is say 5% of the deviatoric stress, but this forms the deviatoric stress application and again this test can be done in a confined or unconfined condition.

So if it is a confined condition you will have the confining pressure also. So at the bottom figure what you can see is that these are the test cycles. So this is cycle number 1, this is cycle number 2 and so on. And this is the confinement pressure here and this forms the contact pressure. So this much is the contact pressure that is always applied on the material.

Now what will happen to the material when it is loaded like this? As we know that when it is loaded, the material starts deforming and when you unload this loading, the material starts recovering. And during the rest period also there will be recovery in the material. So if I draw the response here, during loading, during this portion, your material starts deforming.

And then when it is recovered, the material starts recovering like this. And during the rest period, there will be recovery that is continuing. And it is not necessary that the entire deformation that has happened will completely recover. There will be always or there could be certain amount of permanent deformation in the material.

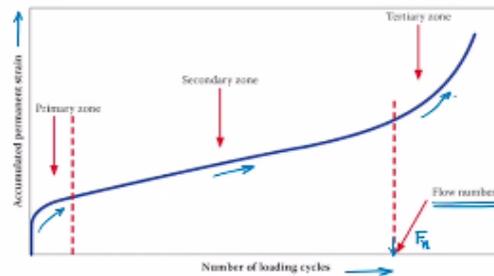
As we can see here in the first cycle see there is a deformation, it goes down and there is a permanent deformation of  $\delta_p(1)$  after the first cycle. Now it will remain there, then you are again loading it and again it deforms. During the rest period it will recover and the accumulated deformation now, permanent deformation now is marked as  $\delta_p(2)$ .

So you can see that every time there will be certain amount of accumulated deformation. So if I draw  $\delta_p$  here that is the accumulated permanent deformation. This keeps on increasing like this. So what we are interested in looking at is this permanent deformation that happens in the material.

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## Flow Number Test

*Flow Number—the number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated-load test*



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So if I keep on collecting this  $\Delta p$  that at the end of every cycle, this is how it is going to look like. So this is the accumulated permanent strain. Deformation you get, you can convert it to strain by dividing it with the gauge length as I already mentioned, and here it is the number of cycles. So this is a plot with number of cycles versus the accumulated permanent strain.

So here also you expect that this follows a three stage creep behavior with a primary stage, secondary stage and then a tertiary stage. And flow number is defined as the number of load cycles corresponding to the minimum rate of change of permanent axial strain during a repeated load test. So as I said, for the flow time also, here, the rate will be rate of change of permanent strain increases at a decreasing rate, then it goes to a constant rate and then it starts increasing.

So that point at which it starts increasing or which is the minimum rate of change of permanent strain is there, that number of cycle corresponds to flow number or that number is called flow number  $F_n$ . Now again how you can arrive at  $F_n$  is that you can draw the rate of change of strains and see where the rate of change of strain is minimum.

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## Flow Number Test Parameters

AASHTO :T 378-2017

- Short-term conditioning of mixture : R 30-02 (2015)

**Table X2.1**—Flow Number Specimen Conditioning Criteria

Criteria	HMA	WMA
Conditioning time	4 h ± 5 min ✓	2 h ± 5 min ✓
Conditioning temperature	135 ± 3°C ✓	Field compaction temperature, °C ✓

**Table X2.3**—Flow Number Test Parameters

Test Parameter	Value
Test temperature	Adjusted PG temperature <sup>a</sup> ✓
Repeated axial stress	600 kPa ✓
Contact stress <sup>b</sup>	30 kPa - 5% of deviator stress ✓
Confining stress	0 kPa (unconfined) ✓

- Air voids : 7.0 ± 0.5% (SGC specimen - AASHTO PP 60-14)

For a flow number test, the material has to be short term aged. And these are the conditions for short term ageing of the asphalt mixture. You mix the aggregates and the binder and you condition it as per R 30 protocol. And the conditioning time is 4 hours plus or minus 5 minutes if you are dealing with hot mix asphalt. Now the same test can be done for warm mix asphalt also.

If you are using warm mix asphalt the code specifies that you have to condition it for at least 2 hours. And then the temperature of conditioning of the mixture is 135 degrees Celsius for hot mix asphalt and it should be the field compaction temperature for the warm mix asphalt. So we are discussing about hot mix asphalt here in this lecture. And then the test has to be done at a repeated axial stress of 600 kPa.

And the latest code says that it has to be done in unconfined condition, you need not do the test in a confined condition. And the contact stress as I said is 5% of the deviator stress. So this comes to around 30 kPa and then the test temperature is mentioned as the adjusted PG temperature. Let us see what is that.

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## Flow Number Test Parameters

### Adjusted PG Temperature ✓

Use LTPP Bind Version 3.1 software, selecting the project location climatic data from the nearest weather station

Table X2.2—LTPP Bind Version 3.1 Temperature Evaluation Parameters

Evaluation Parameter		HMA and WMA
Desired reliability, %		50 ✓
Target rut depth, mm		12.5 ✓
Adjustment for traffic loading and speed		0.0
Depth of layer, mm	Surface layers	20 ✓
	Intermediate and base layers	Depth at the top surface of the layer

- Choose 60 °C, if data not available ✓

In order to get this adjusted PG temperature you have to find the temperature for a reliability level of 50% for a target rutting in the field of 12.5 mm and if the material is to be used in the surface layer, you consider the depth of 20 mm from the top or if it is a bottom layer the top of that bottom layer bottom layer has to be considered.

And then you collect the information from the climatic data from a nearby location or climatic station from your project region and use all this information in the Long Term Pavement Performance Bind version 3.1 software and then you find out what is the adjusted PG temperature. So this is how you have to find out what is the temperature at which you have to test the flow number, you have to do the flow number testing.

But if this information is not available, normally you do it at a higher temperature say 50 or 60 degrees Celsius.

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## Flow Number Test Parameters

AASHTO :T 378-2017

- Short-term conditioning of mixture : R 30-02 (2015)

**Table X2.1**—Flow Number Specimen Conditioning Criteria

Criteria	HMA	WMA
Conditioning time	4 h ± 5 min ✓	2 h ± 5 min ✓
Conditioning temperature	135 ± 3°C ✓	Field compaction temperature, °C ✓

**Table X2.3**—Flow Number Test Parameters

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Confining stress	0 kPa (unconfined) ✓

- Air voids : 7.0 ± 0.5% (SGC specimen - AASHTO PP 60-14)

Now the specimen are to be cast at an air void of 7% and the specimen is to be cast using a Superpave gyratory compactor as per AASHTO PP 60.

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## Flow Number Test Protocol

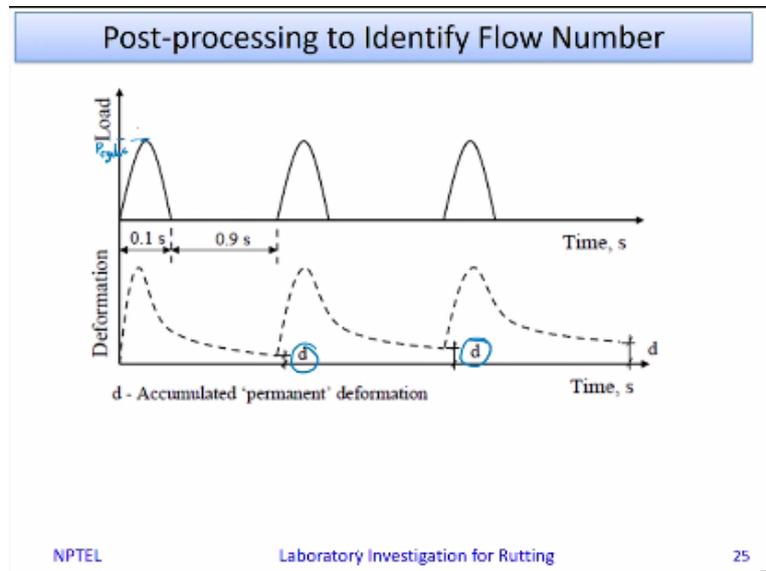
$$P_{\max} = P_{\text{contact}} + P_{\text{cyclic}}$$


- $P_{\text{cyclic}}$  is the load used to calculate the permanent deformation parameters
- 10 000 cycles or until the specimen fails by excessive tertiary deformation

So the maximum load that you are applying is as I have shown here, you have a contact load, then you have a cyclic load or this is a deviatoric load. So the maximum load here is the sum of the contact load and the cyclic load. What you are using for all your analysis is this  $P_{\text{cyclic}}$  because contact load, we will consider it as a minimum value which is used as a seating load which will not be used for any further computations.

At least 10,000 test cycles are to be done or until you see that the specimen fails by excessive tertiary deformation or there is excessive deformation in the material then you can stop the test.

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So this is how the data is collected. I have not shown the seating load or anything here, just the cyclic loads. So you have, so this is the P cyclic, the maximum load and you have 0.1 second loading and 0.9 second recovery, next 0.1 second loading and 0.9 second recovery and so on. I mean rest period and so on.

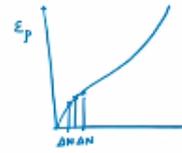
So the deformation is there will be deformed and then there is the recovery and the accumulated permanent deformations are shown here. You collect this accumulated permanent deformation for all the test cycles. Let us see how to post process this data.

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## Post-processing to Identify Flow Number

(i) Smoothed Central Difference Approach

$$\frac{d(\epsilon_p)_i}{dN} \cong \frac{(\epsilon_p)_{i+\Delta N} - (\epsilon_p)_{i-\Delta N}}{2\Delta N}$$



Smoothen by five point averaging

$$\frac{d(\epsilon'_p)_i}{dN} = \frac{1}{5} \left[ \frac{d(\epsilon_p)_{i-2\Delta N} + d(\epsilon_p)_{i-\Delta N} + d(\epsilon_p)_i + d(\epsilon_p)_{i+\Delta N} + d(\epsilon_p)_{i+2\Delta N}}{dN} \right]$$

**Flow number** - cycle number corresponding to the minimum smoothed creep rate

Now your aim is to identify the flow number. As I said, flow number is the point at which the material starts flowing or it is the start of the tertiary stage or it is defined as the minimum rate of change of strain happens, what is that point? So in order to identify that, two methods are specified by the protocol, one is a smoothed central difference approach.

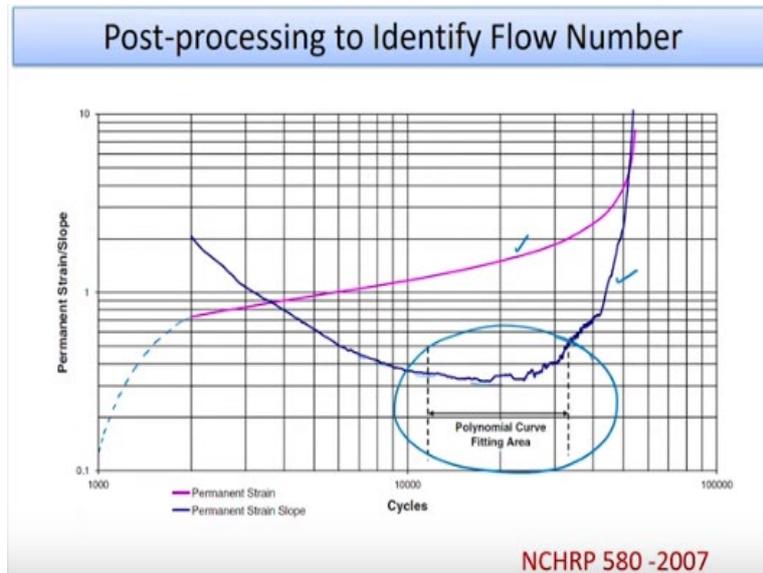
What you do is that at every data point, you consider one point to the left and one point to the right. Say here, suppose this is my permanent deformation or the permanent strain. At every point you choose one data point to the left and one data point to the right and suppose this is the delta n is the interval of every cycle then take the differential of that.

So it is strain corresponding to the  $(i + \Delta n)$  cycle minus strain corresponds to the  $(i - \Delta n)$  cycle. So there will be two intervals divided by  $2 \Delta n$  will give you the differential value or the rate of change at the  $i^{\text{th}}$  point. Now similarly, you find the rate of change at every point in the data.

Now since this is a very heterogeneous material and you are loading it like with a heavy loading like this, you need not get a very smoothed data. So there is always going to be a lot of noise in the data. So before processing what you do is that you the rate of change that you have determined you will smoothen it by a 5 point averaging.

So what you have done is that every rate of change that you have determined as per the first equation, you take at every point, you take 2 points to the left and 2 points to the right. So altogether you have 5 data points and you average it out. So you take average of 5 data points at every data point and then you will get the smoothed rate of change of creep. And the cycle number which corresponds to the minimum smoothed creep rate will be your flow number.

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So as you can see here, this pink line represents the permanent strain graph and this blue line here represents the permanent strain slope, the slope that you have determined using the expression. So you see that somewhere here it is going to be, so somewhere here, you are going to see the minimum strain.

But what you can see is that there is lot of noise in this region. So you know finding one point as a minimum value will be difficult there. So what you can do is that you again fit a polynomial in this region and find out which is the minimum value. So that is the best way to do that.

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## Post-processing to Identify Flow Number

(ii) Francken Model Approach (power + exponential)

$$\checkmark \varepsilon_p = \underline{An^B} + \underline{C(e^{Dn} - 1)} \quad A, B, C, D$$

First derivative – permanent axial strain rate

$$\checkmark \frac{d\varepsilon_p}{dn} = ABn^{B-1} + CDe^{Dn}$$

✓ Second derivative

$$\frac{d^2\varepsilon_p}{dn^2} = \underline{AB(B-1)n^{B-2} + CD^2e^{Dn}}$$

Now the second approach that is suggested for processing the data is to fit certain equation for the, for this entire data. As you know that this is having a power law kind of relation and then there is an exponential kind of relation. The Francken Model approach is suggested in this code. In the Francken Model, this is a combination of two models. One is a power law equation and the second one is an exponential equation.

As you here, see here, the permanent strain is given by  $An^B$  which is the power law and  $C(e^{Dn}-1)$  is the exponential equation where A, B, C, and D are the regression coefficients. You can use any optimization algorithm to fit the data using this curve and then you can find what are these coefficients.

Once you get the coefficients you can find the first derivative using this expression and then you take the second derivative also. Once you get the second derivative, the point at which the derivative changes sign from negative to positive will give you the flow number. So this is the Francken Model approach.

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## Post-processing to Identify Flow Number

(iii) Zhou's Approach (Zhou et al., 2004)

$$\varepsilon_p = \underline{aN^b}, N \leq N_{PS} \quad \text{Power}$$

$$\varepsilon_p = \varepsilon_{PS} + \underline{c(N - N_{PS})}, N_{PS} \leq N \leq N_{ST} \quad \text{— straight line}$$

$$\varepsilon_p = \varepsilon_{ST} + \underline{d(e^{f(N-N_{ST})} - 1)}, N \geq N_{ST} \quad \rightarrow \text{exponential}$$



Now what we have observed is that this material actually exhibits a three stage creep response. But in the Francken model what is used is a two stage like a power law and an exponential model is used. Whereas, Zhou et al in 2004 has suggested another approach which is termed as the Zhou's approach wherein, three models are used to fit this entire data. For example, this is the first one.

The first part you can fit it using a power law and the second part that is the secondary stage you can fit using a straight line and the third part which is the tertiary stage, you can use an exponential function. So this is a combination of power law in the primary stage, then a straight line in the secondary stage and an exponential in the third stage. So this is your first, second, and third stage.

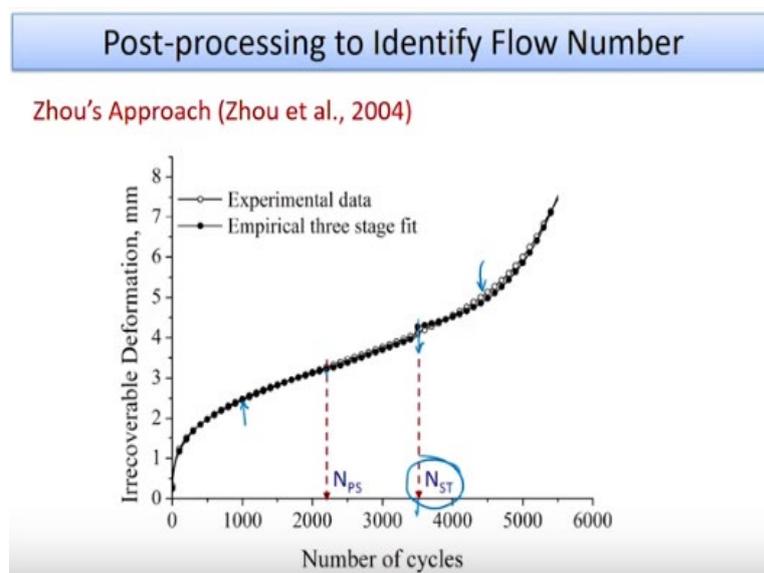
Now how to do this is that you can use any algorithm, say a MATLAB algorithm to determine which is the end point of the primary stage secondary stage and tertiary stage. Say this is the end point of your primary. So it is denoted as  $N_{PS}$ . That is the cycle from primary to secondary. And this point is marked as  $N_{ST}$  that is from secondary to tertiary.

So you first identify where is the endpoint of the primary, where is the endpoint of the secondary and so on. So what is normally done is that you start taking the data one by one from beginning and then you try to fit a power law equation first. So whenever your data starts deviating, the prediction starts deviating from the actual curve, you can stop the cycle there.

You can stop it there as that will be the end of the primary stage. So that deviation can be taken as say 1% or say 2% and whenever it starts deviating from the curve, you can stop there and find out that as the  $N_{PS}$ . Then for the remaining data you start fitting a secondary, for the secondary stage you start fitting a straight line and see when it starts deviating from a straight line.

So that point you can take as the end point of your secondary stage or it will denote the  $N_{ST}$  and the remaining data will be obviously in the tertiary stage. So this way you can find out what is the primary, secondary and tertiary and once you fit this data you know that  $N_{ST}$  is actually your flow number where it starts in the, starts behaving in the tertiary way.

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So this is one sample data that we have fitted with Zhou's approach that the plot here with that hollow circles represent the experimental data and the solid circles here are your fit, experimental fit using Zhou's approach. So till here was identified as the primary stage and this point is taken as the starting of the tertiary stage. So this here is the, this cycle here, say 3500 something represents the flow number. So that is an example.

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## Flow Number Test - Precision

$$s_r \% = 37.0 \times \ln(NMAS) - 50.4$$

$s_r$  = single operator flow number repeatability coefficient of variation for unconfined flow number test

✓ Single operator precision for unconfined flow number

NMAS, mm	$s_r$ , % percent	Acceptable Range for n Specimens, % of Average				
		n=2	n=3	n=4	n=5	n=6
9.5	32.9	92	109	118	128	132
12.5	43.1	121	142	155	168	172
19	58.5	164	193	211	228	234
25	68.7	192	227	247	268	275

AASHTO : T 378-2017

Now when you do this test, it is required that you conduct multiple tests on different samples so as to ensure the repeatability of results. The code suggests that there should be a repeatability as given by this expression. This is taken from the AASHTO protocol. This is the precision that is required if you are using a single operator and in the unconfined flow number test.

And similarly for multiple operators also there is another precision that is suggested by the code. So I have just taken the single operator precision from the code which says that this is the repeatability coefficient which can be computed using this expression. And if your material is say having a nominal maximum aggregate size of 25, then the repeatability coefficient should be 68.7.

And if you have say 3 number of specimens being tested, then your acceptable range is 227%. It should not be; the variability should not be more than 227%.

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## Outline

- Development of Asphalt Mixture Performance Tests
- Specimen Preparation
- Flow Time Test
  - > Post-processing of data
- Flow Number Test
  - > Post Processing Techniques
- **Post-processing Issues**
- Development of Failure Criteria for Rutting

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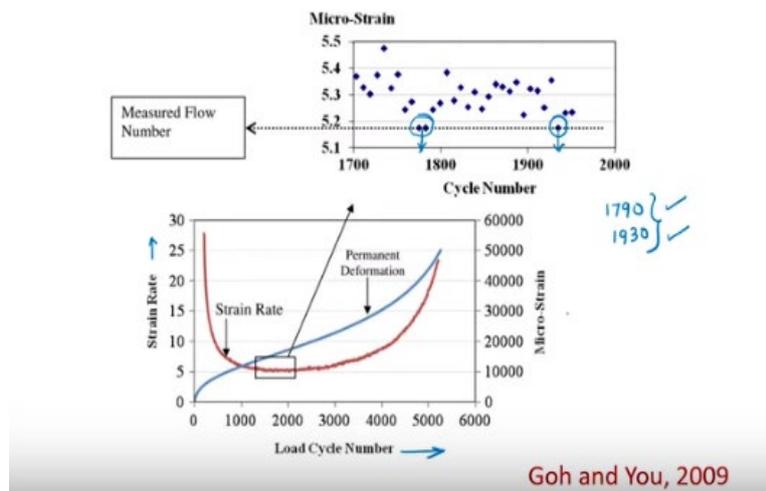
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Now let us see what are the post processing issues. We have seen different post processing methods. So one was the differential strain approach and the second one was your Francken model and the third one was the Zhou's approach. Let us see what is the issues associated with doing this flow number test.

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## Post-processing - Issues

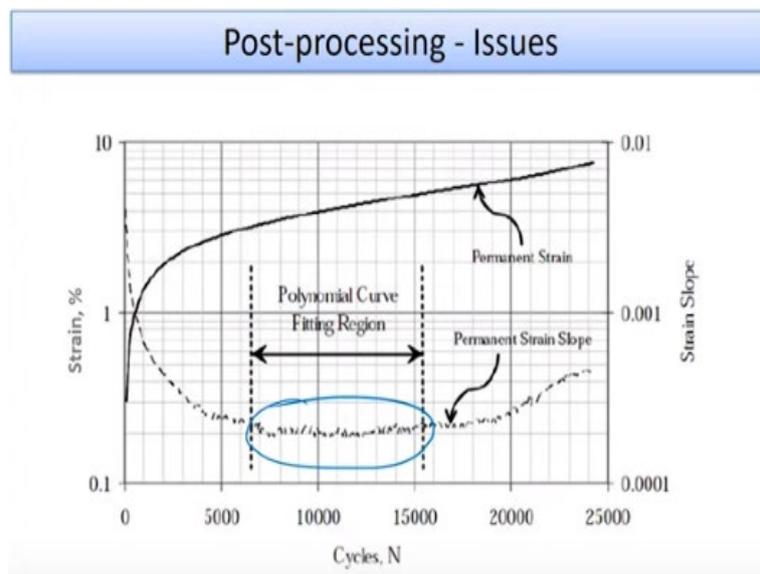


So the one which I have already discussed is that you may not be able to identify one cycle number, which is the starting of the tertiary stage or which can be represented as a flow number. As you can see here, this is taken from a study by Goh and You. This is the load cycle number on the x axis and the strain rate on the y axis and the permanent deformation is also marked here.

So the blue line represents the permanent deformation and this is the strain rate, red is the strain rate diagram. If you zoom it and see you see that there are different points which shows the minimum value. So there are different points having the same minimum strain rate. So if I take this value, this is somewhere around 1790 and if I take this value this is somewhere around 1930 or so.

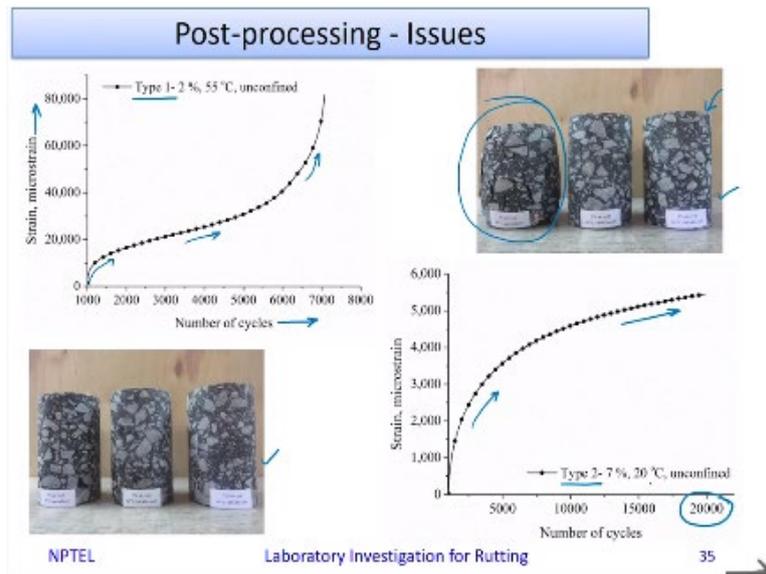
So these two values can be identified as flow number. So this is the problem. You can have multiple number of points or cycles where you get the minimum strain rate and this may be wrongly interpreted if you get different flow numbers like this. So that is one issue.

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In order to cater to this issue as I said, you can use the Zhou's approach or a curve fitting approaches can be used and even in the strain rate method also in the region where you see a lot of variability there, at that point where you can fit another polynomial and then try to find out one point which corresponds to the minimum value.

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As mentioned by the code, you have to do it at a higher temperature and on a specimen of 7% air void content. Now the response of the material will depend upon so many factors that it will depend upon the what is the aggregate skeleton, what is the binder is used, what is the stiffness of the binder, what is the binder content, air void of the specimen and whether you are doing in an unconfined or in a confined condition.

All these factors will affect the response of the material. So we have collected lot of information at IIT Madras to identify or to look at the three stage behavior of mixtures. These are some of the samples that we have used for testing and these are the samples after the testing. You can see that some of the samples are intact even after the test duration where some has failed by excessive tertiary deformation as you can see here it has bulged out and failed.

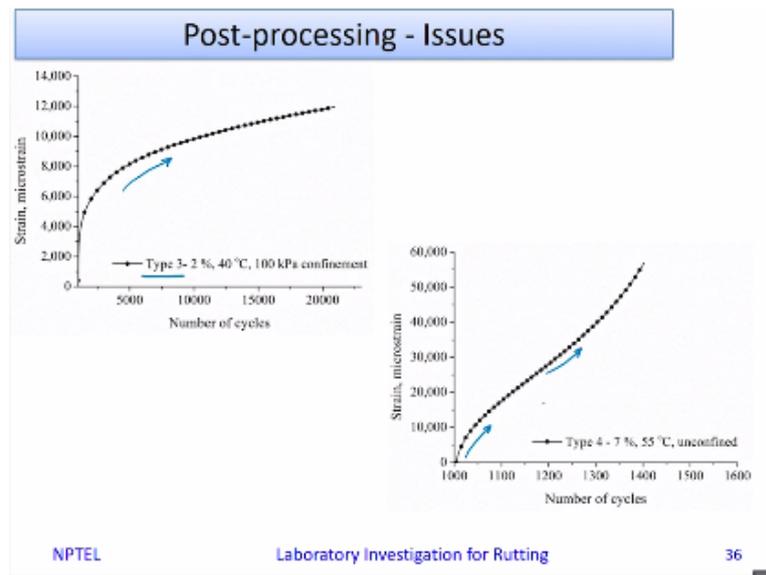
So we tried to draw the three stage creep response or the strain response of all these samples and we could identify many types of three stage responses or the creep responses. As you can see, we have named it as type 1, 2, 3 and 4. As you can see here, this is type 1 response. What you see is the number of cycles in the x axis and strain in the y axis. What you see is a typical three stage creep response.

So you have a primary here you have a secondary stage and also a tertiary stage so that it is easy for you to identify what is the flow number for this material. Whereas in this type 2 type as I have shown here, what we see is that, there is a primary stage and

maybe a secondary stage also but it has not reached a tertiary stage even after we have done this test for 20,000 cycles.

As prescribed by the protocol it is like 10,000 cycles, but we have extended it till 20,000 cycles. But we were not able to see the flow number in this case.

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Now the third case is that you have only a primary stage. This has not even reached the secondary stage. So this is a type three type of creep curve. And there is another type in which it went from primary directly to the tertiary. There is not even a stable secondary stage that you could observe.

So when one does this experiment in the laboratory it is every possibility is that you may encounter any of these types of flow behavior or the creep behavior. So you may not be able to identify one number as flow number.

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Development of Failure Criteria				
Relation between $F_{nr}$ field rut depth, and traffic level ?				
Test Site	Test Type	Rutting Model	R <sup>2</sup>	S <sub>y</sub> /S <sub>x</sub>
ALF—Field Cores	U	$R_d = 1.0989 * (N)^{0.3848} * (Fn)^{-0.0119 * \text{Log}(N) - 0.230}$	0.97	0.20
ALF—Field Cores	C	$R_d = 1.2552 * (N)^{1.072} * (Fn)^{-0.2428 * \text{Log}(N) - 0.3301}$	0.89	0.40
ALF—Lab Blend	U	$R_d = 1.4646 * (N)^{0.2738} * (Fn)^{0.1185 * \text{Log}(N) - 0.4029}$	0.56	0.78
MnRoad—Plant Mix	U	$R_d = 1.2483 * (N)^{0.9435} * (Fn)^{0.1609 * \text{Log}(N) - 1.3745}$	0.93	0.29
MnRoad—Plant Mix	C	$R_d = 1.20326 * (N)^{0.21285} * (Fn)^{0.2882 * \text{Log}(N) - 1.58221}$	0.93	0.28
WesTrack—Plant Mix	U	$R_d = 0.00341 * (N)^{0.3646} * (Fn)^{0.0000 * \text{Log}(N) - 0.0485}$	0.89	0.35
WesTrack—Plant Mix	C	$R_d = 0.00042 * (N)^{0.4083} * (Fn)^{0.0540 * \text{Log}(N) - 0.1805}$	0.95	0.24

Note: U = unconfined testing; C = confined testing.

**NCHRP 580-2007**

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So now let us see how this is related to mix design procedure. First of all, as I mentioned for flow time test also the NCHRP has tried out different ways in which this flow number that is determined in the laboratory is correlated to the rutting in the field. So these are some of the relations that are developed between the flow number of the mixture, the field rut depth and the traffic level.

So such relations are easy or are possible to be developed once you have enough information or enough studies conducted in the field or on accelerated test tracks or on any other accelerated loading facility as well. So what you can see is that these are some of the relations developed from an accelerated loading facility and MnRoad, WesTrack etc. here are the test track data collected from the test track.

And also these tests are conducted in the laboratory in the unconfined as well as in the confined conditions and then this is a typical relation that is developed, I have just taken a snapshot from NCHRP 580 of certain models that are developed. So this is  $R_d$  is the rut depth,  $N$  is the number of ESALs or the traffic in equivalent standard axial loads and  $F_n$  is the flow number of the mixture that is used in that accelerated loading facility.

So such relations can be developed once you have substantial amount of field data that will be correlated to the laboratory investigation.

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## Performance Testing Recommendations for Superpave Mix Design

**Table 6-4. Recommended performance tests for HMA made with conventional materials including most modified binders.**

Property	Recommended Test	Design Traffic Levels for Which Property Should be Evaluated
Moisture Sensitivity ✓	AASHTO T 283	All
Permanent Deformation ✓	Flow Number or Dynamic Modulus, AASHTO TP 79-09	3 Million ESAL and greater
Fatigue Cracking ✓	None	NA
Thermal Cracking ✓	None	NA

NCHRP 673-2011

In the Superpave method of mix design, as I mentioned in the beginning of this lecture, that these tests are developed as part of the Superpave mix design method and the mechanistic empirical payment design methodology. The recommended test for HMA as per the latest NCHRP protocol is that for all the materials that you use, for all the design traffic levels you have to do a moisture sensitivity test.

And if your traffic is 3 million ESALs or more a flow number test or a dynamic modulus test as per the AASHTO standards in order to determine its resistance to permanent deformation. So this AASHTO TP 79 is the old protocol which has been revised lately, which we have been discussing. So but and the protocol does not necessarily recommend the fatigue cracking test or thermal cracking test.

You need not do these two tests, but what is necessary is that you have to conduct the moisture sensitivity test and the permanent deformation that has to be established using a flow number test or you can go for a dynamic modulus test. The dynamic modulus test we have discussed in some other lecture.

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## Guidelines for $F_n$ and $F_t$ Requirements for Superpave Mix Design

Recommended minimum flow number requirements ✓		Recommended minimum flow time requirements ✓	
Traffic Level Million ESALs	Minimum Flow Number (Cycles)	Traffic Level Million ESALs	Minimum Flow Time (s)
<3	--- ✗	<3	---
3 to <10	53	3 to <10	20
10 to <30	190	10 to <30	72
≥ 30 ✓	740	≥ 30	280

NCHRP 673-2011

And these were the recommendations that are given so that you can use this mix in the field. There was minimum values recommended for the flow time as well as flow number earlier. So these are the values given here. The minimum flow number requirements, if you have a traffic of less than three ESALs, million standard axles, there is no recommendation given here.

Whereas, if you have a standard axle load traffic of more than 30 million standard axles, you should have a flow number of at least 740 when you test the material in the laboratory. Similarly, the flow time values were that were recommended are for greater than 30 msa, the minimum flow time that is required is 280 seconds.

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## Guidelines for $F_n$ Requirements (as per AASHTO : T 378-2017)

**Table X2.4—Minimum Average Flow Number Requirements<sup>a</sup>**

Traffic Level, million ESALs	HMA Minimum Average Flow Number	WMA Minimum Average Flow Number ✓
<3	—	—
3 to <10	50	30
10 to <30	190	105
≥30 ✓	740	415

<sup>a</sup> Minimum flow number values were established using the average of four specimens, using the short-term conditioning criteria in Table X2.1 and the flow number test parameters in Table X2.3.

But now in the latest guidelines as per AASHTO T 378-2017 the average flow number requirements are provided whereas the flow time test is not recommended in the latest guidelines as I mentioned. So as per the new revised guidelines, if the traffic is more than 30 msa, this should be 740 is the average flow number and when I say average flow number for at least four specimens should be tested and an average value of at least 740 flow number should be there for the specimen.

Then only you can recommend that material to be used in the field. Now these are the guidelines for warm mix asphalt. It recommends that at least 415 should be the flow number if it is a warm mix asphalt. So I conclude. What we have discussed, so the summary is that what we have discussed so far is what is the motivation for the development of tests such as flow time and flow number as far as rutting is concerned and how we do this flow time and flow number test in the laboratory.

What are the different test procedures and what are the protocols and then how the post processing of the data is done in order to identify what is the flow time and flow number of the mixture? And also what are the guidelines that helps to identify what is the best mix to be used in the field. Thank you.