NATIONAL TRANSPORT RESEARCH CENTRE

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REVIEW OF MIX DESIGN METHODS

(DESK STUDY)

NTRC-227

M. Naeem
Assistant Chief

October, 2000

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CHAPTER - 1

1.1 Introduction

The design of asphalt mix is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction. The main objective for the design of asphalt mixes is to determine an economical blended gradation of aggregates and asphalt that should produce a mix with the following properties.

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

For a specific mix design, it is necessary to make several trial mixes and to find out one, that meets all the criteria of the design method used. Each trial mix design, serves a guide line for evaluating and adjusting the next trial. It is always advisable to start with an aggregate of a gradation that approaching the median of the specified limits. When the initial trial mix fail to meet the design creteria it will be necessary to modify or in some cases redesign the mix. Adjustments in the grading of the original aggregate blend will be required to correct the deficiency. For many engineering materials, the strength of the material frequently is thought of as denoting quality, however, this is not necessarily the case for hot mixed asphalt paving. Extremely high stability often obtained at the expense of lowered durability and vise versa. Therefore, in evaluating and adjusting mix design always keep in mind that the aggregate gradation and asphalt content in the final mix design must strike a favorable balance between the stability and durability requirements, moreover, the mix must be produced as a practical and economical construction operation.

The two properties are determined in the Marshall Method, the maximum load the specimen will carry before failure known as the Marshall stability and the amount of deformation of the specimen before failure occurred, this is known as Marshall flow. The ratio of stability to flow is known as the Marshall quotient, a sort of psendo stiffness which is a measure of the material's resistance to permanent deformation.

The Marshall method uses standard test specification of 64 mm (2 1/2") height 102 mm (4 in.) diameter stability is at 60 C^{o} (140^{o} F). The original Marshall Method is applicable only to hot-mix asphalt paving mixtures containing aggregates with maximum 25 mm (1 inch) or less. A modified Marshall Method has been proposed for aggregate with maximum upto 38 mm (1.5 inch). The Marshall Method is intended for laboratory design and field control of asphalt mix dens-graded paving mixture. Because the Marshall stability test is empirical in nature, the meaning of the results estimating relative field behaviour is lost when any modification is made to this standard procedure.

The principal features of Hveem Method of mix design are surface capacity and centrifuge Kerosene Equilateral (CKE) test on the aggregate to estimate the asphalt requirement of this mix followed by a stabilometer test, a cohesiometer test, a swell test and a density voids analysis on test specimens of the compacted paving mixture.

The stabilometer test utilizes special triaxial-type testing cell for measuring the resistance of the compacted mix to lateral displacement under vertical loading and the swell test measures the resistance of the mix to the action of water. The specimens are maintained of 60 ^{0}C (140 ^{0}F) for stability test and the swell test is performed at room temperature.

The introduction of mechanical property specifications for asphalt mixtures requires appropriate testing facilities. The Nottingham Asphalt Tester (NAT) has proved to be appropriate testing equipment, where measurement of strippings stiffness modulus, fatigue cracking resistance and permanent deformation characteristics can be made. This suit of tests is suitable for mix design, problem solving and has the potential to assist with providing data for predictive computations for pavement design.

The basic NAT is equipped for the assessment of resistance to permanent deformation using either creep or repeated load axial (RLA) test. RLA test as it is more simulative of traffic loading and it has been found to be more sensitive to the effect of small variation in mix composition. In RLA test a specimen is subjected to repeated application of an axial stress. The load pulse wave shape is effectively square and the standard test applies load pulse of one second duration separation by one second test period, however other times, can be used if required.

The NAT is most suitable equipment for designing the mix design but unfortunately this is not available in Pakistan. The Marshall Method, Hveem Method are not suited to field condition as the NAT. Refusal density test may also be tested till the availability of NAT as the idea behind the refusal is that the material should have at least 3% voids in the mix at the refusal, that is the mix cannot be further compacted and if 3% voids is there then the resistant of plastic deformation may be minimise.

1.2 Objective of the Study

These days, bitumen mixes are mostly used on our main roads. However, they mostly fail prematurely. In most cases, the mix gets rutted soon after its laying. One of the reason identified for this poor performance of asphaltic mix is the inappropriate mix design for our local conditions.

The objective of the study is to examine the existing mix design methods so that besides identifying the merits and demerits of these methods, the critical limitations of these methods are fully known so that these may be appropriately taken care of while implementing the road project.

Bitumen mixes are designed to fulfill some designated requirements, which they have to perform during their design life. Currently mixes are designed to some standard mix design methods such as Marshall Design Method, Hveem Design Method etc. These methods have been reviewed in the report. In addition to these the University of Notingham has also developed (NAT) Notingham Asphalt Tester and TRL has developed Refusal Density Test. The study also reviews these tests which are considered to be more simulative to our actual field conditions.

CHAPTER - 2

2.1 Literature Review

General Introduction of Bituminous Mixes:

There are many factors which affect the design properties of asphalt mixes, but they can be covered in three general areas of aggregate, bitumen binder and Compaction.

Aggregate

About 95% of mixture by weight or about 85% by volume consists of mineral aggregates. The shape, type and other characteristics of aggregates contribute to the:

1) Stability by the gradation, particle surface texture and particle shape.

2) Durability by the gradation, cleanliness, and chemical composition.

3) Fatigue resistance by gradation, surface texture and particle shape.

Bitumen Binder

Though the binder content is usually about 5% by weight of mixture, its contribution to the total life of the mixture is extremely high and important. In asphaltic mixture, the asphalt acts as a binder which holds the mixture together and also affects the following properties:

1) Stability by its viscosity and during compaction process by its lubricating action.

2) Durability by its resistance to aging, its adhesiveness, cohesion and viscosity temperature susceptibility.

Compaction

Compaction is also very important like aggregates and asphalt because compaction also affects mixture properties, such as:

1) Stability by the degree that density affects, (ϕ) the angle of internal friction and tensile strength.

2) Durability by the control of air void content to make the mixture impermeable for air and water to penetrate in to lower layers and this could be achieved by proper compaction.

3) Fatigue resistance by reducing the areas of stress concentration through control of voids and by increasing tensile strength.

Requirements of Bituminous Mixes

The bitumen mixes are designed to fulfill the following requirements in general.

Flexibility

The mix should be flexible to resist the tensile stresses without cracking.

Stability

The mix should be able to withstand traffic stresses without excessive deformation, also it should be stable against cracking due to heavy and repeated traffic loading.

Good Durability

The mix should be durable to resist the bitumen hardening and loss of adhesion, in other words it could resist wearing effects of traffic and weathering.

Workability

The mix should be easily spreaded and compacted. The stability and flexibility are also dependent on workability but not easily quantifiable.

Impereability

It should be impermeable so that it could resist the air and water entering to lower layers and so resist hardening of bitumen due to oxidation.

Skid Resistance

The mix should have good skid resisting ability for wearing courses for the safety of road users.

The following table-1 shows how various mixes can be prepared by changing aggregate quality, bitumen grade and content, to achieve desired mix characteristics.

Table - 1 Summary of Requirements of Asphalt Mixes

Requirement For	Aggregate	Binder Grade	Binder Content
Stability	Dense Grading High Texture	Hard	Low
Flexibility	Dense Grading	Soft (for thin carpet) Hard (for thick carpet)	High
Workability	Rounded	Soft	High
Durability	Dense Grading	*	High
Impermeability	Dense Grading	*	High
Stiffness	Dense Grading	Hard	Low
(Skid Resis.)			
Reveling	*	Soft	Low

* No special requirement. The choice depends on climate, material available and the layer concerned [1].

Types of pre-mix in use

The main types of pre-mix in use these days are asphaltic concrete, bitumen macadam and hot rolled asphalt. Each type can be used in surfacings or road bases.

Asphaltic Concrete

Asphaltic concrete (AC) is a dense, continuously graded mix which relies for its strength on both the interlock between aggregate and, to a lesser extent, on the properties of the bitumen and filler. The mix is designed to have low air voids and low permeability to provide good durability and good fatigue behaviour but this makes the material particularly sensitive to errors in proportioning and mix tolerances and therefore lacking in tolerance.

It is common practice to design the AC mix using the Marshall test and to select the binder content by calculating the mean value of binder contents for maxium stability, maximum density, the mean value for the specified range of void contents. However to ensure that mixes are resistant to deformation, a minimum value of Marshall Quotient i.e. stability divided by flow, should also be specified (2). To provide a surfacing material which will be resistant to deformation under traffic, it has been proposed (Jackson and Brien (1962)) that the Marhall Quotient be related to the expected tyre pressure of commercial vehicles where

$$\frac{\text{Marhall Stability (KN)}}{\text{Marshall Flow (mm)}} > 0.003 * \text{tyre pressure (KN/m2)}$$

It is frequently found that mixes are designed to have the highest possible stabilities. This usually means that the binder content is reduced resulting in mixes which are more difficult to compact and are less durable. To ensure that the compacted mineral aggregate in continuously graded mix has a voids content large enough to contain sufficient bitumen, a minimum value of the voids in the mineral aggregate (VMA) should also be specified. To ensure that the material will not compact under traffic to such an extent that the voids in the mix decrease to near zero, reulting in instability, the mix should be tested using the Percentage Refusal Density test.

Bitumen Macadam

Close - graded bitumen macadams (formerly called dense bitumen macadams or DBM's) are continuously graded mixes similar to asphaltic concretes but usually with a less dense aggregate structure. They have been developed in the United Kingdom (British Standard 4987 (1984)) from empirical studies over many years and are made to recipe specifications without reference to a formal design procedure. In the Middle East they are designed by Marshall procedure and have an excellent record of deformation resistance.

Macadams of high quality are used for wearing courses and the so called heavy duty macadam is similar to AC. For lower layers in the pavement different specifications are used which allow larger maximum sizes of stone and slightly less bitumen. The higher level of voids enure so that the mix proportions are not as critical as for AC, so that they are easier to make. But they are not as durable as the denser mixes e.g. the best quality AC and hot rolled asphalt, hence they are usually used as road base or binder courses.

Hot Rolled Asphalt

Rolled asphalt is a gap - graded mix which relies for it properties primarily on the mortar of bitumen, filler (< 0.075 mm) and fine aggregate (0.075 - 2.36 mm). The coarse aggregate (> 2.36 mm) act as an extender, but its influence on stability and density increases particularly as the proportion of coarse aggregate in the mix increases particularly at the higher percentages. If the coarse aggregate content is less than about 40 percent, pre-coated chippings should be rolled into the surface to provide texture for good skid resistance where necessary. Rolled asphalt has been developed in the United Kingdom to recipe specifications but can also be designed using the Marshall test so that physical characteristic of the fine aggregate can be taken into account (British Standard 594 (1984).

Stabilities obtained in case of rolled asphalts are not as high as those attainable with asphaltic concrete. However, stabilities far above the minimum requirements can easily be obtained with rolled asphalt mixes. They have a greater tolerance to proportioning errorss than AC and are more flexible and more durable. However, rolled asphalt has not proved successful when incorporated to overseas. They were found fairly susceptible to deformation in hot climates.

CHAPTER - 3

3 : Mix Design Methods

3.1 Marshall Design Method:

This method was developed by Bruce Marshall of the Mississippi State Highway Department. The US Army crops of Engineers, latter on after extended research and correlation studies improved and added certain features for Marshall Method and developed mix design criteria. The Marshall test procedure have been standardized by American Society for Testing and Materials. Procedures are given by ASTM Designation D 1559. (Resistance to plastic flow of Bituminous Mixtures using Marshall Apparatus).

The procedure for the Marshall Method start with the preparation of test specimen to see the following:

- That the materials proposed for use meet the requirements of the project specifications.
- That aggregate blend combinations meet the gradation requirements of the project specifications.
- That, for use in density and voids analysis, the bulk specific gravity of all aggregates used in the blend and specific gravity of the asphalt cement, are determined.

The Marshall Method uses standard test specimens of 64mm (2-1/2 in.) height x 102mm (4 in.) diameter. These are prepared using a specified procedure for heating, mixing, and compacting the asphlat-aggregate mixtures. The two principal features of the Marshall Method of mix design are a density-voids analysis and a stability-flow test of the compacted test specimens.

The stability of the test specimen is the maximum load resistance in Newton (1b.) that the standard test specimen will develop at 60 c (140 f). The flow value is the total movement of strain, in units of 0.25 millimeter (1/100 in.) occurring in the specimen between no load and maximum load during the stability test. [2].

Test specimen

To determine the optimum asphalt content for a particular blend or gradation of aggregates by the Marshall Method, a series of test specimens are prepared for a range of different asphalt contents so that the test data curves show a well-defined "optimum" value. Tests specimens are prepared on the basis of 1/2 percent increments of asphalt content, with atleast two asphalt contents above "optimum" and at least two below "optimum". Usually three test specimens are minimum prepared for each asphalt content.

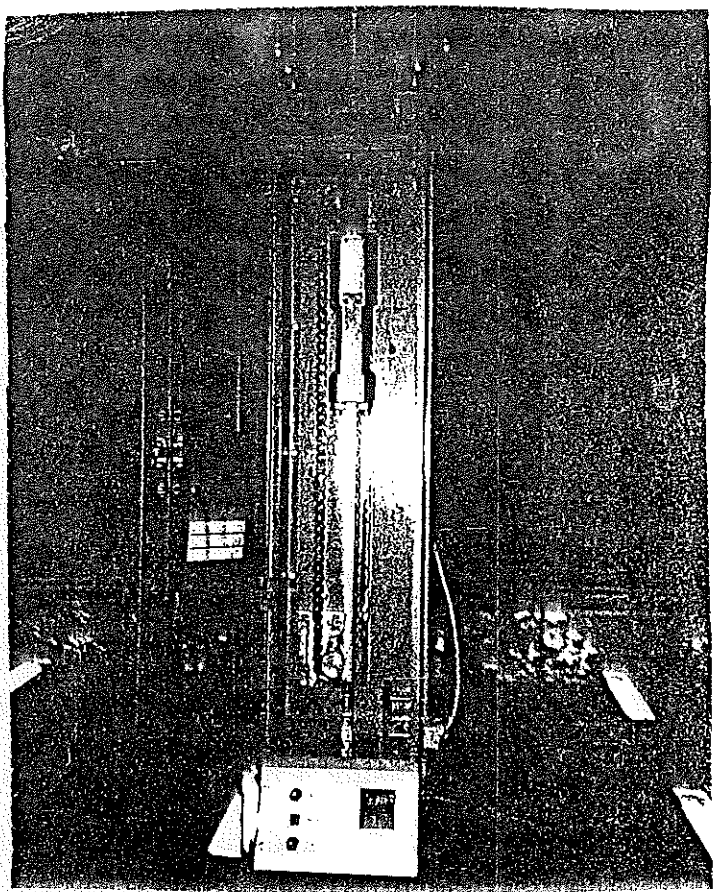
Before preparation of laboratory sample, the aggregates are dried at 105^{o} C (221^{o} F) to 110^{o} C (230^{o} F) and are separated by dry seiving to desired fraction. The temperature to which the asphalt must be heated to produce viscocities of 170 $\pm$ 20 centistoke kinematic and 280 $\pm$ 30 centistokes kinematic shall be established as the mixing temperature and compaction temperature respectively. After cleaning the mould assembly and the face of the compaction hammer and heating them in a boiling water bath or on hot plate to a temperature between 93^{o} C (200^{o} F) to 149^{o} C (300^{o} F). The mould is than ready so that the mixture is put inside it. Place a peace of filter paper inside the mould before the mixture is placed in the mould. Weigh into separate pans for each test specimen, the amount of each size fraction required to produce a batch that will result in a compacted specimen 63.5 + 1.3 mm (2.5 + 0.05 in.) in height. When the aggregates and asphalt are heated and ready for mixing they are put in the mechanical mixture. The temperature of the mixture prior to compaction shall be within the limits of the compaction temperature. Asphalt should not be held at mixing temperatures for more than one hour. Before using mix the aggregate and asphalt cement preferably with a mechanical mixer or by hand with a trowel to have a uniform distribution of asphalt throughout. The mixture is then put in the mould assembly placed on the compaction pedestal and apply either 35,50 or 75 blows as specified according to design traffic category with the compaction hammer using a free fall of 457 mm (18 in.). Then remove the base plate and coller and reverse and re-assemble the mould and again apply the same number of blows to the face of the reversed specimen. After compaction, remove the base plate and allow the specimen to cool in air until no deformation will result when removing it from the mould.

Testing of Specimen :

Every compacted test specimen is subjected to the following tests and analysis in the order listed below.

- Bulk specific gravity determination .
- Stability and flow test.
- Density and Voids analysis.

The test specimen is then placed in the testing machine. The loads are applied through semi-circular testing head at a constant rate of strain of 51mm (2 in.) per minute. This is also equipped with a calibrated proving ring to determine the applied load, Marshall stability and Marshall flow. A universal testing machine equipped with suitable load & deformation indicating devices may be seen at Fig 1& 2.



Compaction Hammer

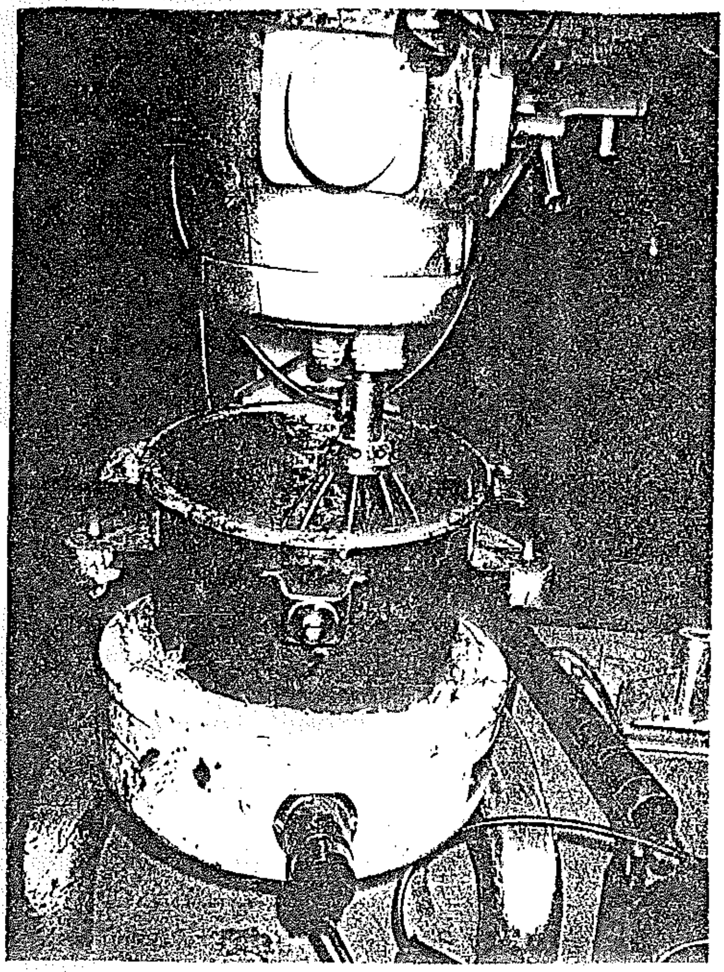
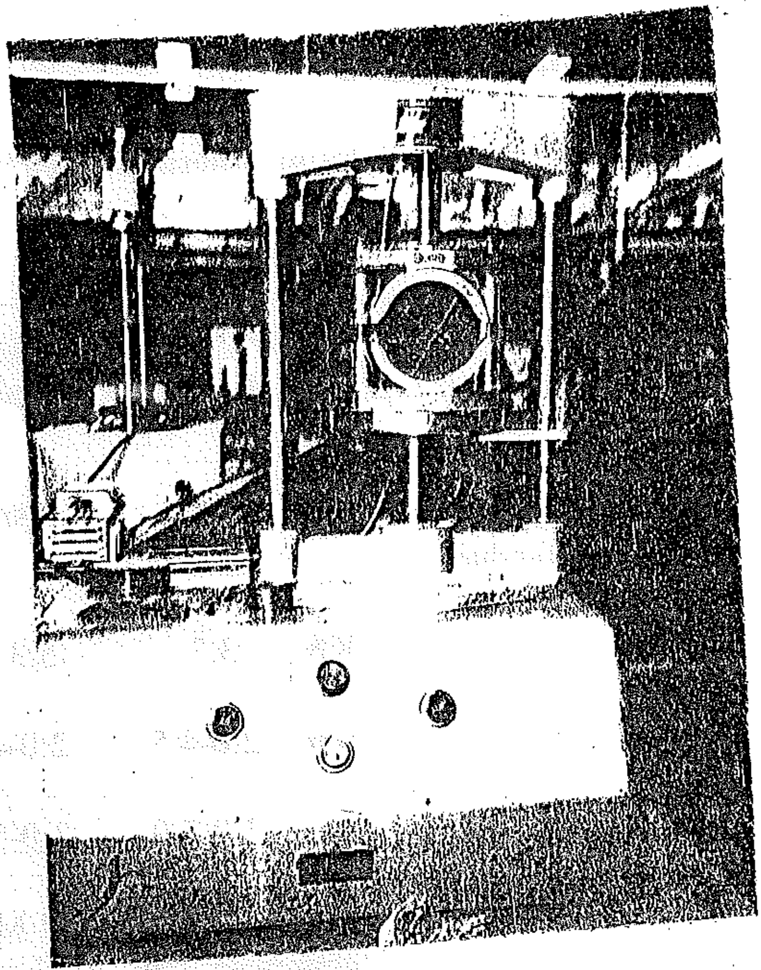


Fig. 1 Mechanical Mixer



Marshall Testing Machine

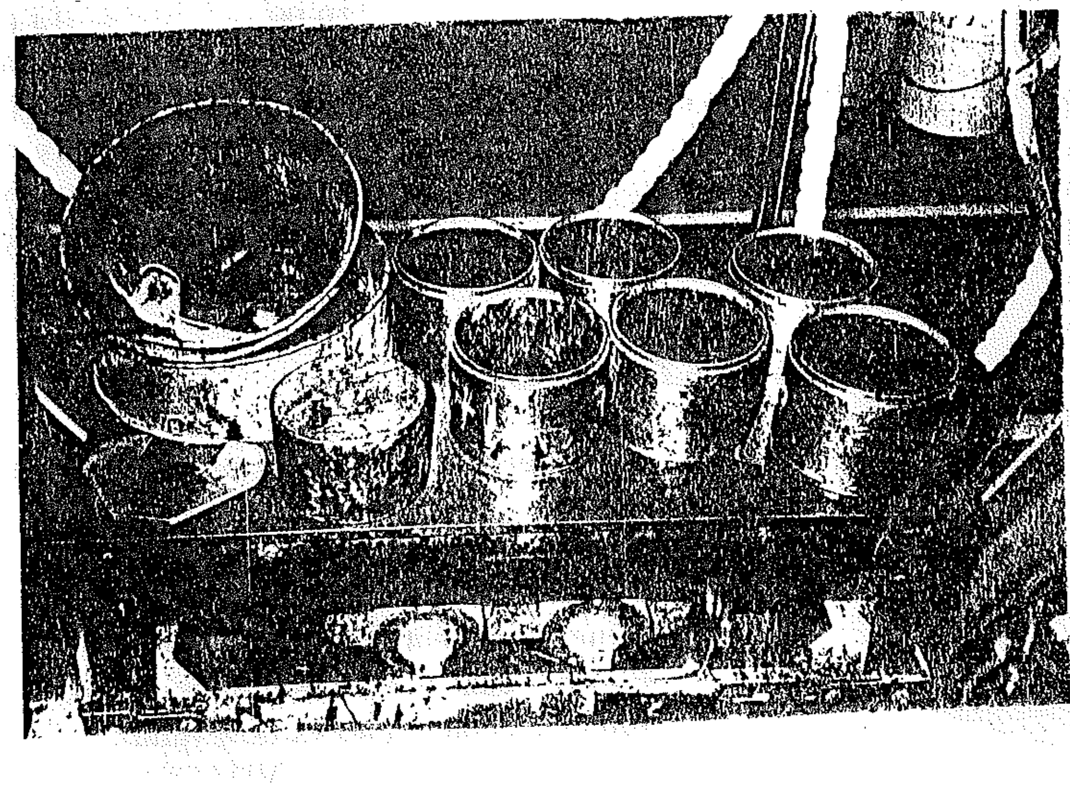


Fig. 2

Marshall Design Criteria :

The Marshall design criteria is given in the following table: 2

Table No. 2

Mix Criteria		Traffic Category Light	Medium	Heavy
Number of compaction Blows		2x35	2x50	2x75
Minimum Marshall Stability,	KN	3.3	5.3	3.0
Marshall flow.	mm	2.0-4.5	2.0-4.0	2.0-3.5
Void content,	%	3.0-5.0	3.0-5.0	3.0-5.0

	Maximum size of aggregate, mm	! Minimum voids in ! mixed aggregate. %
Voids in mixed aggregate (%)	25.00	13.0
	19.00	14.0
	12.50	15.0
	9.50	16.0
	4.75	18.0
	2.36	21.0
	1.18	23.5

Optimum Binder Content :

To determine optimum binder content and other mix properties the following graphs are plotted:-

Bitumen content (%) vs density (gm/cc).
Bitumen content (%) vs air void (%).
Bitumen content (%) vs stability (KN).
Bitumen content (%) vs flow (mm).
Bitumen content (%) vs VIM (%).

In each graphical plot connect the plotted values with a smooth curve that obtains the, best-fit for all values. From the graphs, (Fig. 3) trends generally noted as below:-

The stability value increases with increases in asphalt content up to a maximum after which the stability decreases.

The flow value increases with increases in asphalt content.

The curve for unit weight is similar to the stability. It increases with increase in bitumen content and decreases with further increase in bitumen content.[3]

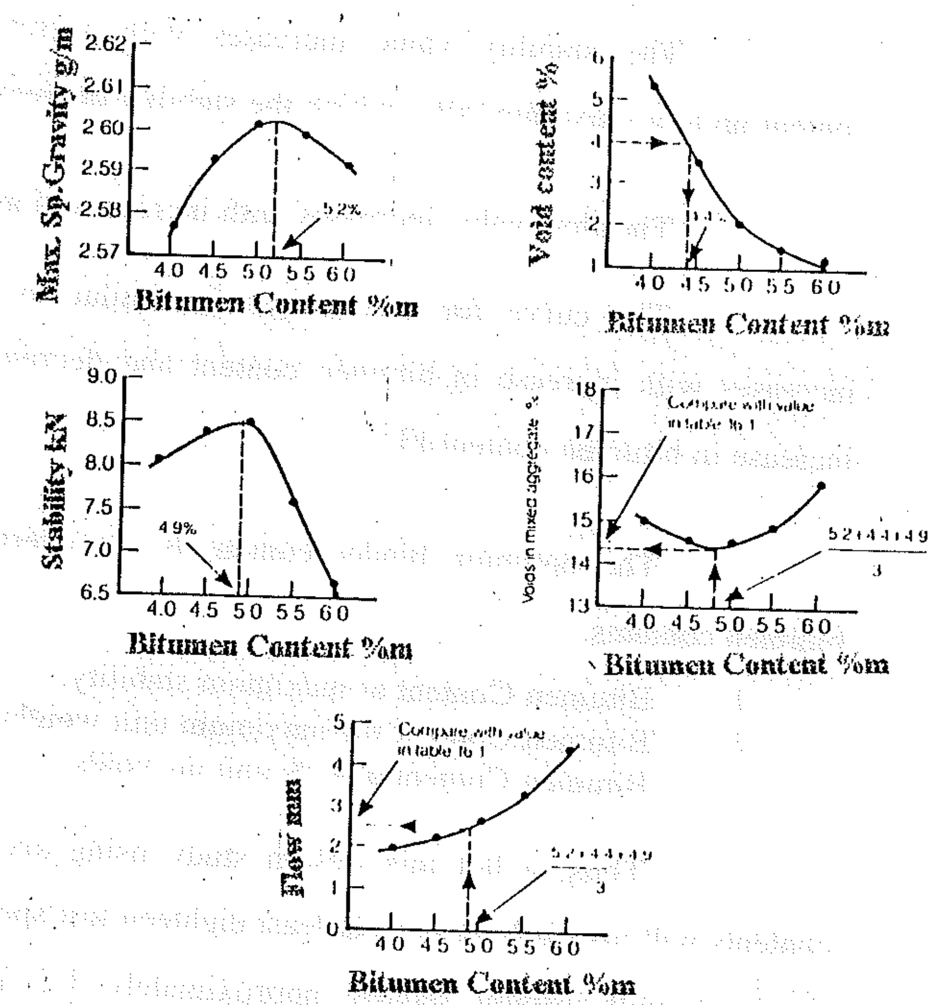
The optimum binder content is the average of the three bitumen contents.

1. Bitumen Content at maximum stability.
2. Bitumen Content for maximum unit weight.
3. Bitumen Content at 4 % unit air voids.

Thus, a hot mix design study using six different asphalt contents will normally require at least eighteen test specimens. Each test specimen will usually require approximately 1.2 Kg of aggregate. Therefore, the minimum aggregate requirements for one series of test specimens of a given blend and gradation will be approximately 23 Kg or approximately 50 lb. Four litters (one gallon) approximately of asphalt cement will be adequate.

3.2 Hveem Method of Mix Design:

This method was developed by Francis N. Hveem, California Division of Highway. This method is applicable to paving mixture using both penetration grade and liquid grade of asphalt and aggregate up (1 in.) maximum size. The Hveem method uses standard



$$\textbf{Optimum bitumen content} = \frac{52 + 44 + 49}{3} = 4.8\%$$

Marshall design Curves, the Asphalt Institute method

Fig. 3

test specimens of 64mm (2-1/2") highest by 102mm (4 in.) diameter. The principal features of the Hveem Method of mix design are the surface capacity and Centrifuge-Kerosene Equivalent (CKF) test on aggregates to estimate the asphalt requirement of mix, and followed by stabilometer test, a cohesiometer test, a swell test, and a density void analysis of test specimens of compacted paving mixtures. The stability test is performed at 60° C (140° F) and swell test at room temperature. Usually samples are prepared above and below the estimated optimum asphalt content. The compaction of the test specimen is done by a mechanical compactor which imparts a kneading action to consolidate by a series of individual impression made with a ram having a face shaped as a sector of a 100 mm diameter circle. The optimum binder content would be that which gives the required stabilometer value, cohesiometer value and swell test values in the design criteria.[2]

Hveem Design criteria:

The suitability of hot mix design by the Hveem Method is determined on the basis of whether the asphalt content and aggregate grading will satisfy the following requirements.

Traffic Category	Heavy		Medium		Light	
Test property	Min	Max	Min	Max	Min	Max
Stabilometer value	37	-	35	-	30	-
Swell	Less than 0.762 mm (0.00 in.)					

Although not a routine part of the design method, an effort is made to provide a minimum percent air voids of approximately 4 percent.

All criteria, and not stability value alone, must be considered in designing an asphalt paving mix. Hot mix asphalt bases that do not meet these criteria when tested at 60^{O} C (140^{O} F) are satisfactory, if they meet the criteria when tested at 38^{O} C (100^{O} F) and are placed at 100 mm (4 in.) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United states. A different lower test temperature may be considered in regions having more extreme climatic condition.

Traffic Classification:

Light: Traffic conditions resulting in a design EAL $< 10^4$.

Medium: Traffic condition resulting in a design EAL between 10^4 & 10^6

Heavy: Traffic condition resulting in a design EAL $> 10^6$.

In applying these requirements, the design asphalt content should be the highest percentage the mix will accommodate without reducing stability or void content below minimum values.

3.3 Hubbard-Field Method

The Hubbard-Field Method of designing hot mix asphaltic paving mixtures developed by prevost Hubbard and F. C. Field, both formally associated with Asphalt Institute. The original design method was developed primarily for sheet-type paving mixture but, later on it was modified to design paving mixture [3].

Like Marshall Test, the two principal features of Hubbard Field Method are also density voids analysis and a stability test. The latter consists of applying a vertical loading to the specimen at 60^{O} C supported by a circumferential orifice. The original method for sheet type mixes used standard test specimens, 50 mm diameter by 25 mm height. In the modified method the test specimen is prepared of 150 mm diameter and 68.75 mm to 75 mm height. A series of test specimen are prepared by 1/2 percent increment in binder content and specific gravity, stability and density/voids analysis are performed on each specimen. After plotting the graphs between unit weight Vs binder content, Hubbard Field stability Vs binder content, percent voids content Vs binder content, the optimum binder content simply a matter of comparing the test property curves with the applicable limits of the criteria. Usually at 3 % or 3.5 % voids, stability is read from the graph. The optimum binder content has to fulfil both stability and voids requirements and if it does, the mix is satisfied or re-designed if not.

3.4. <u>Smith Tri-Axial Method:</u>

This method was developed by Vaughn R.Smith of California Research Corporation. This method is applicable to dense paving mixture using penetration grades of asphalt cement and containing aggregate up to 25 mm maximum size. The standard test specimens of 95.5 mm diameter and 200 mm height, are prepared by specified procedure of heating, mixing and compacting the asphalt aggregate mixtures. The main features of this design are a density void analysis and a triaxial stability test of the compacted specimen.[3]

The suitability of mix design is determined by the use of a test evaluation chart. The obtained values of $\not\subset$ and c are plotted on the chart and checked whether they fall within satisfactory area or not. The voids in test specimen should be in between 5 % and 10 %. If criteria are not satisfied the test is repeated after making proper adjustments.

3.5 (NAT) Notingham Asphalt Tester:

The Nottingham Asphalt Tester (NAT) was developed at the University of Notingham to enable mechanical properties of asphaltic materials to be measured and assessed on a routine basis for pavement engineers. This equipment has an important role in areas of quality control, failure investigation and pavement evaluation and for the assessment of new materials.

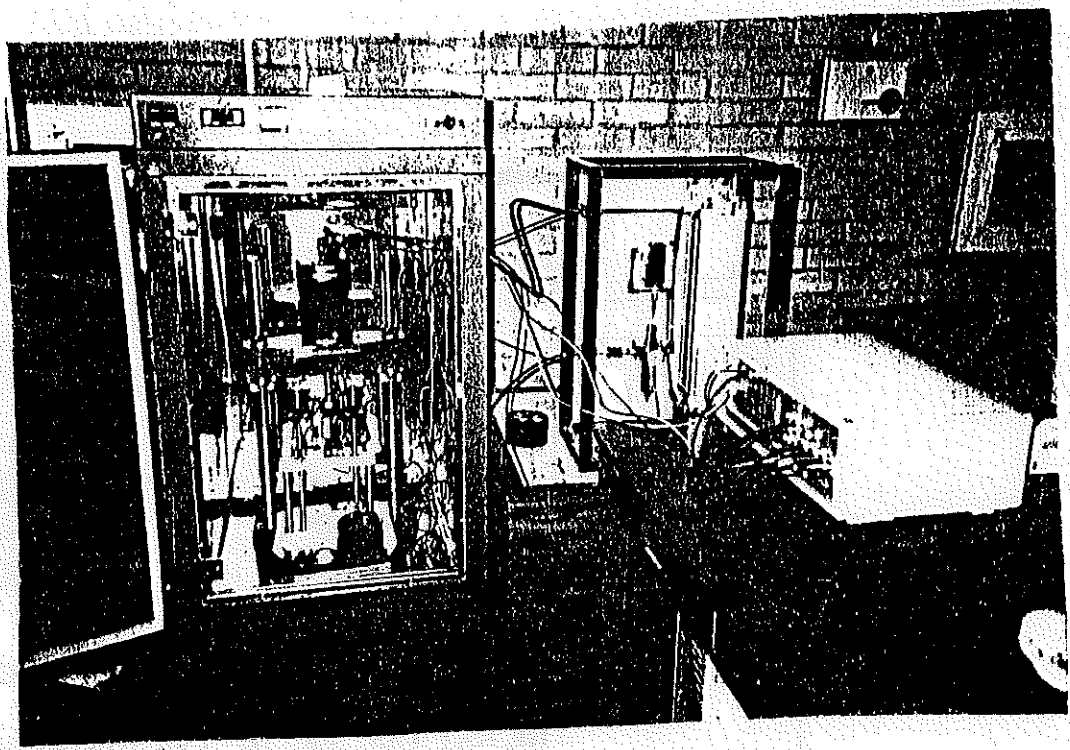
The NAT machine can be used to perform the following main Tests:-

- Elastic Stiffness (Resilient Modulus)
- Repeated load Axial (RLA) test for Resistance to Deformation.
- Dynamic Creep (an advance version of RLA Test).
- Uni-axial Creep (Resistance to Deformation).

It was designed to carry out tests on either 100mm, 150mm or 200mm diameter specimens so that either laboratory moulded specimens or cores cut from the road could be used. The NAT uses a pneumatic loading system which is supplied with air at a pressure of 7 bar. The frame is made of stainless steel and the height of the crosshead is adjusted to accommodate specimens of different heights and diameters. A rolling diaphragm air actuator applies loads up to approximately 4.3 KN. Load is measured with a precision strain gauged load cell, deformations are measure with LVDT traducers. NAT is shown in Fig.4 -Fig.5.

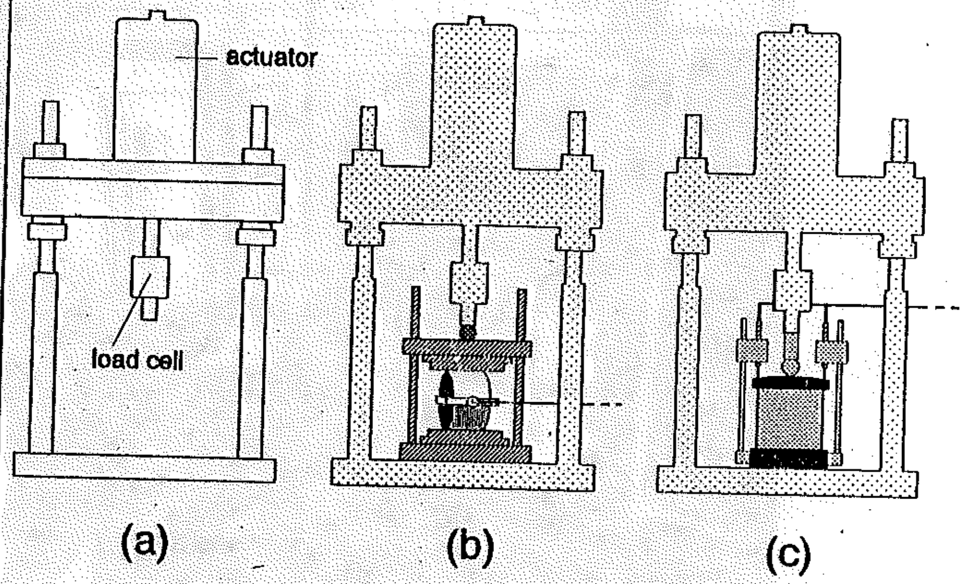
3.6. The Measurement of Stifness Modulus (Indirect Tensile Stiffness Modulus (ITSM).

In this test a cylindrical specimen is subjected to a load pulse along the vertical diameter axis and the resultant peak transient deformations along the horizontal diameter is measured. This is a very



Nottingham Asphalt Tester Machine

Fig. 4



THE NAT TEST FRAME AND SUBSYSTEMS

Fig. 5

simple and non-destructive test and is relatively quick to carry out as many as hundred specimens may be tested in a working day. Stiffness is a measure of the load spreading ability of the material and is strongly dependent on the binder properties and the volumetric composition of the mixture in particular VMA (voids in minor aggregate). The test provides important information which relates to binder grade and compaction level.

The test is normally carried out at a minimum of two temperatures in order to characterize the stiffness dependency on temperature. A standard loading time of approximately 0.12 seconds is used., although this can be varied if required. However, care must be taken to ensure that the specimens are at the correct temperature, an error of 1°C could result in a 10 % difference in stiffness modules. It is good practice to carry out two tests on each specimen, rotating the specimen through 90 degree for the second test and taking the mean of the two results as the elastic stiffness of the specimen [4].

The diagram No. 6 shows the testing of specimen for stiffness modules and Fig No. 7 shows the schematic layout of Notingham Asphalt Tester (NAT) and Fig No. 8 and 9 show the typical printout of elastic stiffness modules results.

3.7 <u>Permanent Deformation</u>

The NAT is equipped for the assessment of resistance to permanent deformation using either static creep or repeated load axial (RLA) test: Most users prefer the RLA test as it is more simulative of traffic loading and it has been found to be more sensitive to the effect of small variation in mix composition. In this test a 150 mm diameter

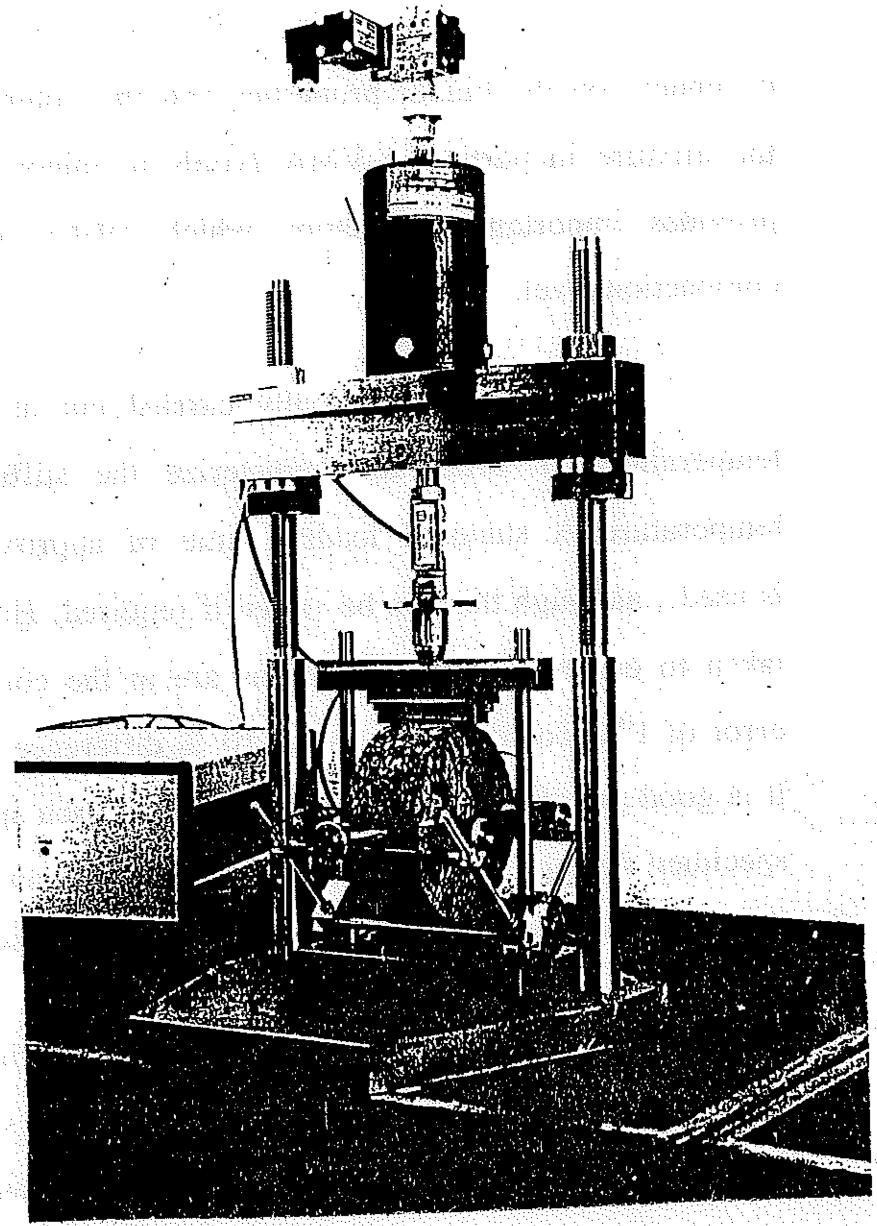
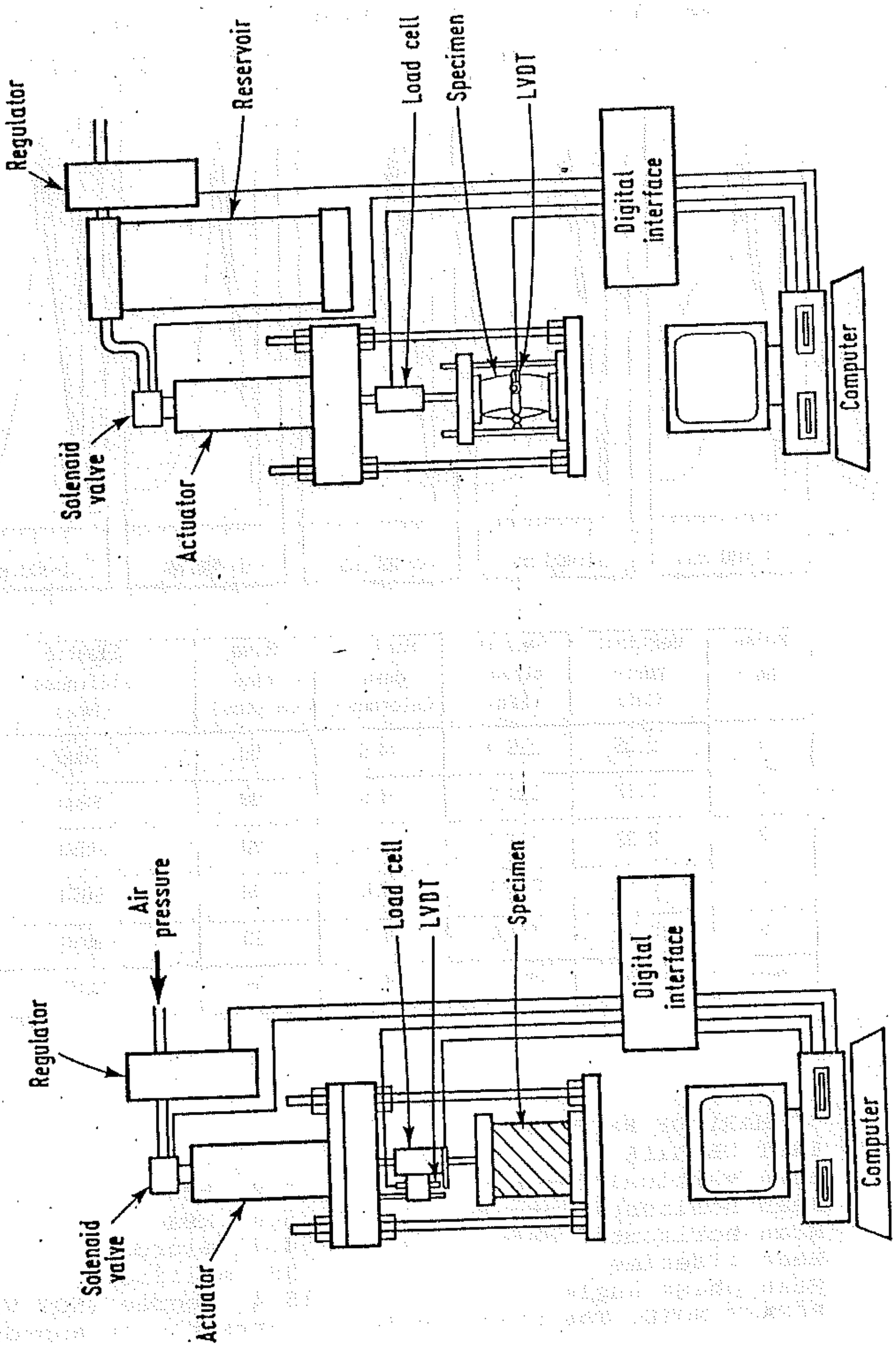


Fig. 6 Nottingham Asphalt Mix Tester
(repeated load indirect tensile test)



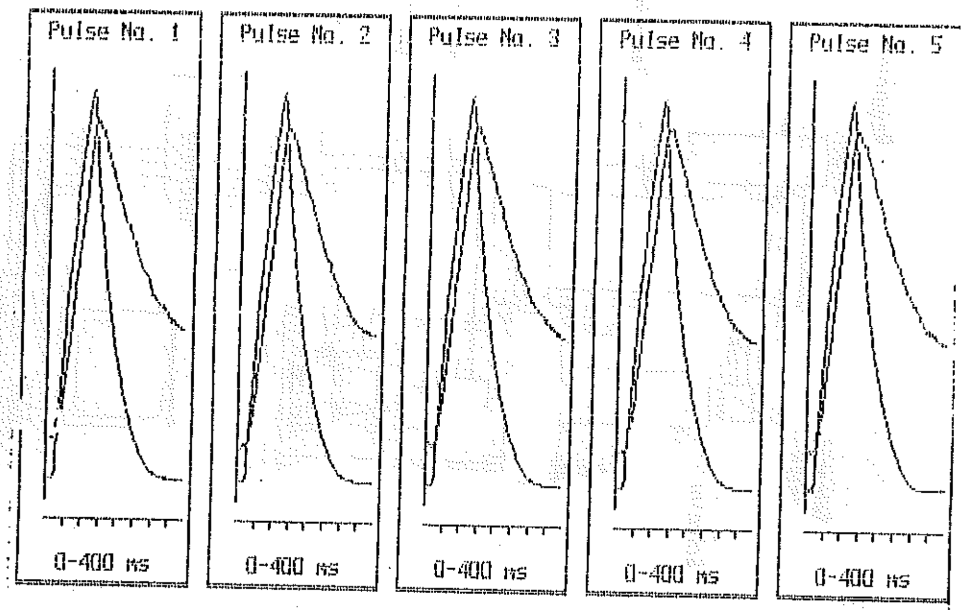
(a) Uniaxial creep and repeated load axial test configuration

(b) Repeated load indirect tensile test configuration

Schematic Layout of Nottingham Asphalt Mix Tester

Fig. 7

REPEATED LOAD INDIRECT TENSILE TEST (Gradation GA)
Date = 25 6 93 Operator Naeem
Specimen name nga1
Temp (C) = 20 Poisson ratio = 0.35
Specimen dia. = 101 mm Thickness = 63 mm



Pulse No.	Vertical force (kN)	Tensile stress (kPa)	Horiz. defm (microns)	Rise time (m.secs)	Elastic stiffness (MPa)
1	2.35	235.4	4.6	98	5000
2	2.37	236.8	4.6	98	5000
3	2.37	236.7	4.7	98	4950
4	2.36	236.4	4.6	98	5050
5	2.37	236.6	4.7	98	4950
Mean	2.36	236.4	4.7	98	5000

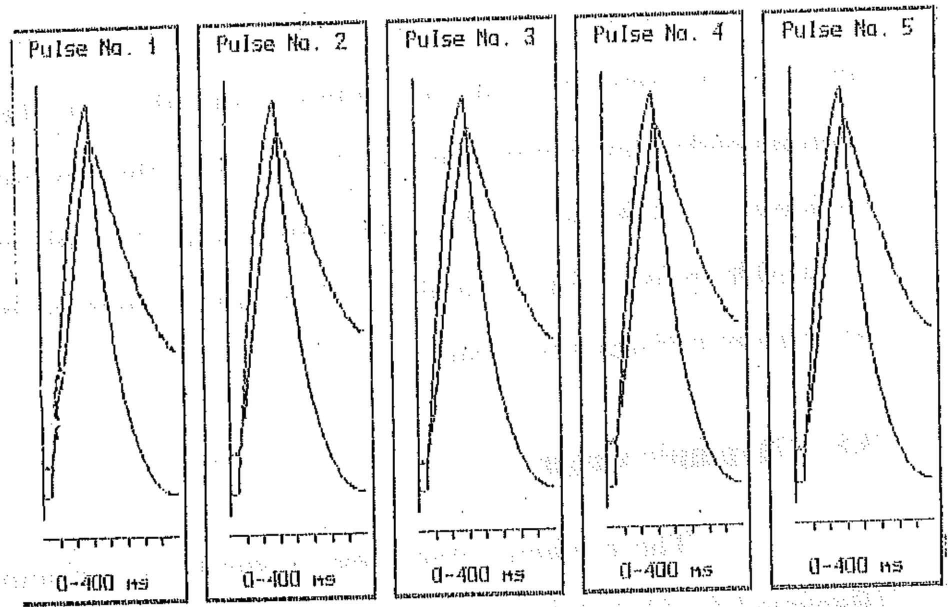
SUMMARY OF RESULTS
TEST DETAILS
Mean vertical force = 2.4 kN
Mean horizontal stress = 236.4 kPa
Mean horizontal defm = 4.7 micron
Mean risetime = 98 millisecs
Mean phase angle = 15.4 degree (NOT VALIDATED)
PLEASE NOTE. The phase angle is currently an approximation

ELASTIC STIFFNESS DETAILS

minimum = 4942 MPa. maximum = 5046 MPa
range = 103 Mpa. mean = 4991 MPa
std dev = 41 MPa. median = 5011 MPa

Fig. 8

REPEATED LOAD INDIRECT TENSILE TEST (Gradation CA)
Date = 14 6 93 Operator Naeem
Specimen name na1
Temp (C) = 20 . Poisson ratio = 0.35
Specimen dia. = 101 mm Thickness = 63 mm



Pulse No.	Vertical force (kN)	Tensile stress (kPa)	Horiz. defm (microns)	Rise time (m.secs)	Elastic stiffness (MPa)
1	3.60	360.6	4.1	120	8650
2	3.64	364.0	4.4	120	8150
3	3.64	364.5	4.2	120	8450
4	3.64	364.1	4.4	120	8100
5	3.64	364.4	4.3	120	8350
Mean	3.63	363.5	4.3	120	8350

SUMMARY OF RESULTS

TEST DETAILS

Mean vertical force	=	3.6 kN
Mean horizontal stress	=	363.5 kPa
Mean horizontal defm	=	4.3 micron
Mean risetime	=	120 millisecs
Mean phase angle	=	7.2 degree (NOT VALIDATED)

PLEASE NOTE. The phase angle is currently an approximation

ELASTIC STIFFNESS DETAILS

minimum =	8097 MPa.	maximum =	8626 MPa
range =	529 Mpa.	mean =	8335 MPa
std dev =	213 MPa.	median =	8443 MPa

Fig. 9

specimen is loaded axially between 100mm diameter plates. The specimen is given a repeated applications of axial stress. The load is applied for one second and then there is one second rest before the second load pulse is applied, 100 Kpa load is applied in each load pulse and this is considered to be suitable, but this can be changed. The recommended test temperature is 40^{o} C, and that specimen is normally subjected to 3600 pulse which takes two hours but this can be increased to 10,000 pulse. Fig.10 and 11 show the computer print out of the permanent deformation results.

3.8 Dynamic Creep

The dynamic creep test is similar in principal to the RLA (Repeated Load Axial) test in that the specimen is subjected to repeated application of axial stress. Both axial and radial deformations are monitored. Normally a load pulse of 0.2 second duration is applied for every 2 seconds, and the output of load and deformation transducers during a pulse and the subsequent rest period are captured and stored at intervals during a test. As air is compressible, it is difficult to achieve completely square waveforms with basic pneumatic system [6]. A typical load pulse and resultant axial strain out put is shown in the following Fig.12.

3.9 Refusal Density Design:

Bitumen Mixes usually experience secondary compaction in the wheel paths under severe loading condition. Severe condition cannot be defined precisely but will consist of a combination of two or more of the following:

NOTTINGHAM ASPHALT TESTER
REPEATED LOAD AXIAL TEST FOR GA
Conditioning period to be used

Date is 30 6 93
Specimen is ngb1
Temperature = 40 Celsius
Specimen height = 64 mm
Specimen dia. = 101 mm
Axial test stress = 100 kPa
Strain during conditioning = 2057

2	2364
4	2610
6	2787
8	3025
10	3280
20	3900
40	4357
60	4644
80	4836
100	4960
200	5375
300	5627
400	5790
500	5938
600	6080
700	6142
800	6282
900	6316
1000	6339
1100	6443
1200	6489
1300	6537
1400	6603
1500	6631
1600	6688
1700	6694
1800	6714
1900	6789
2000	6833
2100	6833
2200	6853
2300	6874
2400	6891
2500	6915
2600	6990
2700	6991
2800	7005
2900	7026
3000	7043
3100	7053
3200	7073
3300	7108
3400	7126
3500	7167
3600	7173

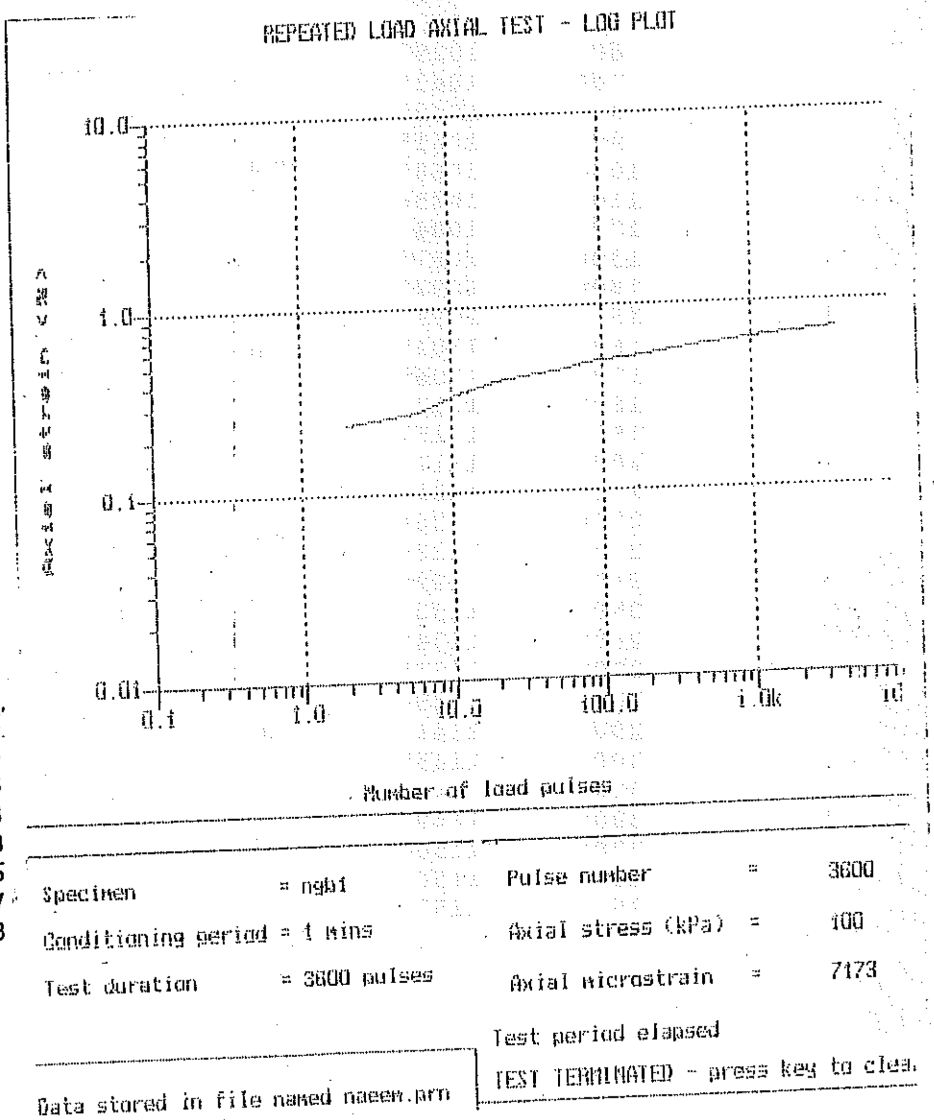


Fig. 10

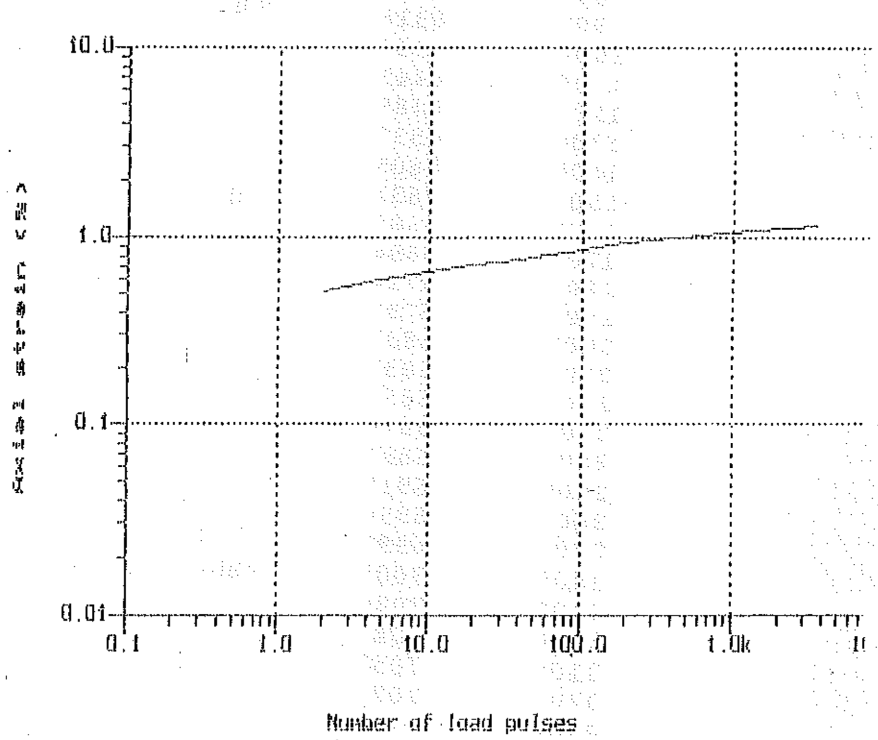
NOTTINGHAM ASPHALT TESTER
REPEATED LOAD AXIAL TEST FOR CA

Conditioning period to be used.

Date is 17 6 93
Specimen is na1
Temperature = 40 Celsius
Specimen height = 61 mm
Specimen dia. = 101 mm
Axial test stress = 100 kPa
Strain during conditioning = 2576

2	5249
4	5807
6	5807
8	6394
10	6590
20	7147
40	7747
60	8120
80	8409
100	8616
200	9297
300	9686
400	9939
500	10126
600	10292
700	10415
800	10490
900	10615
1000	10689
1100	10756
1200	10842
1300	10879
1400	10922
1500	10997
1600	11015
1700	11065
1800	11121
1900	11157
2000	11173
2100	11213
2200	11264
2300	11284
2400	11296
2500	11327
2600	11343
2700	11375
2800	11394
2900	11415
3000	11450
3100	11486
3200	11491
3300	11502
3400	11509
3500	11537
3600	11548

REPEATED LOAD AXIAL TEST - LOG PLOT



Specimen = nai
Conditioning period = 1 mins
Test duration = 3600 pulses

Pulse number = 3600
Axial stress (kPa) = 100
Axial microstrain = 11548

Test period elapsed

Data stored in file named naeem.prn

TEST TERMINATED - press key to clea

Fig. 11

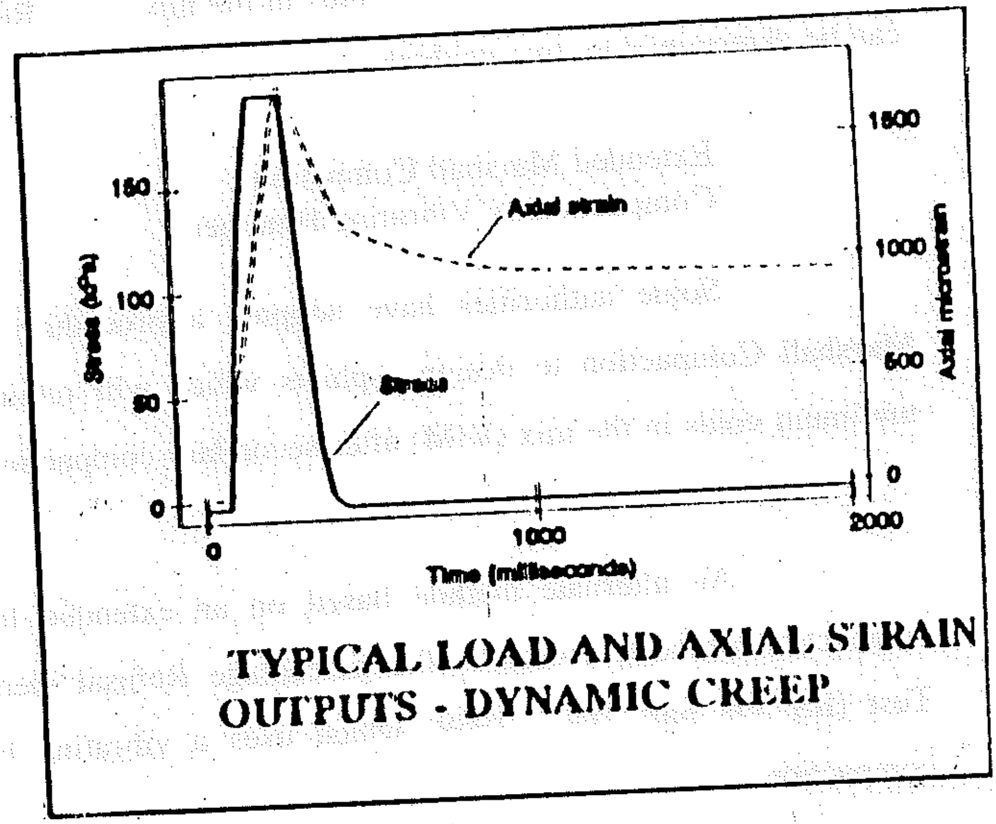

Axial strain
Stress
Stress (kPa)
Axial microstrain
Time (milliseconds)
TYPICAL LOAD AND AXIAL STRAIN OUTPUTS - DYNAMIC CREEP

Fig. 12

High Maximum Temperature

Very Heavy Axle Loads

Very Channeled Traffic

Slow moving Heavy Traffic

When VIM are below 3% then failure by plastic deformation occurs very rapidly. The aim of refusal density design is to ensure that at refusal there is 3% voids in the mix. Refusal density can be determined by two methods

- Extended Marshall Compation
- Compaction by Vibrating Hammer

Some authorities have adopted a procedure of extended Marshall Compaction to design asphalts which will retain a required minimum voids in the mix (VIM) after secondary compaction by traffic.

An alternate method based on an extended form of that compaction procedure used is the percentage Refusal Density (PRD) Test (BS 598 part 104 - 1989) which uses a vibrating hammer for compaction.

3.10 Extended Marshall Compaction

For severe sites, the following specification for base course are likely to be the most appropriate. First of all the normal Marshall design procedure using 75 blows on each face should be completed to provide an indication that Marshall design parameter will be met.

SUGGESTED MARSHALL TEST CRITERIA

Total Traffic (10 esa)	<1.5	1.5-10.0	>10.0	Severe Sites
Traffic	T1,T2,T3	T4,T5,T6	T7,T8	-
Minimum Stability (KN at 60° C)	3.5	6.0	7.0	9.0
Minimum Flow (mm)	2	2	2	2
Compaction level (No. of blows)	2x50	2x75	2x75	2x75
Air Voids (%)	3-5	3-5	3-5	3-5

Traffic Classes (10^6 m esa)

T1	=	< 0.3
T2	=	0.3 -0.7
T3	=	0.7 - 1.5
T4	=	1.5 - 3.0
T5	=	3.0 - 6.0
T6	=	6.0 - 10.0
T7	=	10 - 17
T8	=	17 - 30

Suggested Marshall Criteria for Close Graded Bitumen Macadam

Design Traffic (10^6 esa)	<1.5	1.5-10.0	>10	Severe Sites
Traffic Classes	T1,T2,T3	T4,T5,T6	T7,T8	-
Maximum Stability (KN at 60° C)	3.5	6.0	7.0	9.0
Minimum Flow (mm)	2-4	2-4	2-4	2-4
Compaction level (No. of blows)	2x50	2x75	To refusal	To refusal

The binder content corresponding to 6% VIM obtained in the Marshall test should be noted and additional test samples prepared at each of three binder contents namely the binder content at 6% VIM and also binder contents, which are 0.5 above and 9.5 percent below this value. Then these samples must be compacted to refusal. The nember of blows required to produce refusal condition will vary from one mix to another. It is preferable to conduct a trial using the lowest binder content and to compact using an increasing nummer of blows, 200, 300, 400 etc. until no further increase in density occurs. Usually 500 blows on each face is found to be sufficient. After that a graph of VIM at the refusal density against binder content is the plotted and design which corresponds to VIM of 3% can be determined [7].

3.11 Extended Vibrating Hammer Compaction

In the vibrating hammer method the samples are compacted in 152-153 mm diameter moulds to a thickness approximately the same as will be laid on the roads. The BS 598 compaction procedure for the PRD test is repeated if necessary to achieve an 'absolute' refusal density. The electric vibrating hammer having a power consumption of 750 watts or more and a frequency 20 to 50 HZ is used. Samples should be mixed so that they can be compacted immediately afterwards at an initial temperature of 140 $\pm$ 5°C for 80/100 penetration grade bitumen or 145$\pm$ 5°C for 60/70 penetration grade bitumen.

This is the standard PRD compaction procedure but to ensure that the refusal density is reached, it may be necessary to repeat this procedure a second time. It is suggested that trial mixes with a bitumen content which corresponds to approximately 6%VIM in the Marshall test are used to.

(i) determine the mass of material required to give a compacted thickness of approximately the same thickness as for the layer on the road.

(ii) determine the number of compaction cycles which will ensure that absolute refusal density is achieved.

After these tests have been completed, the samples are made with bitumen contents starting at the Marshall optimum and decreasing in 0.5 percent steps until the bitumen content at which 3 percent voids is retained at absolute refusal density can be determine [6].

CHAPTER-4

Conclusions and Recommendations

The use of asphaltic mixes is becoming more popular in developing countries like Pakistan. In Pakistan almost all the major roads are being paved with asphaltic concrete mixes. This material is considered as ideal for roads carrying heavy traffic and has a good riding quality. But this material has not produced the desired results in most of the cases in Pakistan as most of the road sections have shown plastic deformation sooner or later within the first few years after laying and opening to traffic.

Many factors could be responsible for this plastic deformation but one factor could be the mix design method itself. Mostly for the design of asphaltic mixes, the Marshal Method is being used in Pakistan which is not simulative to our field conditions and does not seem capable of coping with extreme environmental and loading conditions prevailing in our country. There is an urgent need for using some other techniques like Refusal Density Test and Repeated Load Axial Test Technique.

According to research carried out by the Transport Research Laboratory (TRL), U.K., a minimum of 3% air voids after several years of heavy traffic (3% air voids at refusal density) is required to minimize the risk of deformation in the asphaltic layers.

The Notingham Asphalt Tester (NAT) also provides a convenient method of measuring the elastic stiffness and repeated load axial test which is more simulative to field conditions. In Pakistan, it would be better if some test sections are made by using refusal density test and with repeated load axial test and after continuous monitoring, the performance of these test sections, we can design bitumen mixes which would be more suited to our environment and field conditions.

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