Chapter 1

Introduction

1.1. Background

In the modern era, the existence of a reliable well-functioning road network is of critical importance. The investment in road construction provides many benefits to both the social and economic sectors of the nation. Personnel and freight transportation has major impact on the economic growth of the nations. Majority of the public drive their vehicles to commute to work. In addition to this, some of the employees use buses as the main public mode of transportation. In addition, freight is transported by trucks using the highway and road network. The Highway and road network pavement condition plays a vital role in the social and economic development of Canada. Pakistan as a whole has high population density and even higher densities in the major cities. Due to the high population density, the Highways and road networks are serving high volumes of traffic. This high traffic is applying extremely heavy loads over the highway network which causes tremendous deterioration of the pavement condition in the major highways. The network of motorways is the most vital highway network in the country that connects major cities and business centers. Due to its critical contribution to the social and economic development of the country, the government heavily invests in the construction, maintenance and rehabilitation of this highway network to preserve, maintain and enhance the structural condition. Perpetual asphalt pavement designs are characterized by having multiple asphalt layers installed over sound base and sub base. Although the total thickness of perpetual pavement designs can be less than that of the conventional pavement designs, they are expected to withstand the traffic loads and environmental impacts with minimum deterioration and crack propagation. The installation of stiff and thick asphalt layers enhances the ability of pavement section to resist permanent distresses as rutting, high shear stresses in the surface binder course, high tensile strain at the bottom of the layers that would lead to bottom-up fatigue cracking and high vertical stress at the top of subgrade [Huang 2004].

1.2. Problem statement

The ever-increasing traffic is causing more deterioration to the surface and structures of the pavements. If the structure can be made sound for a longer life cycle so that only the surface has to be treated periodically the cost of maintain the highways, in addition to the overall life cycle costs can be reduced. During this process the time spent and delays encountered by the traffic can also be brought to a minimum. The M2 was recently rehabilitated after being in service for almost 16 years. The rehabilitation process took almost a year as it was done section by section to cause minimum disruption to the traffic. Still congestion was experienced in the sections where the rehabilitation process was going on. If we can limit this repair to the wearing course than the repair time can be reduced considerably and traffic flow can be smoothened.

1.3. Purpose of research

The purpose for this research was to perform a performance evaluation of the perpetual asphalt pavement designs and the conventional asphalt pavement designs that would validate the costs and benefits of perpetual pavement designs in terms of technical, economic and environmental aspects. The need to quantify the perpetual pavement design performance was established by using pavement structural evaluation software KENPAVE to predict the pavement performance in the form of design life cycle as we look to control rutting depth, bottom-up fatigue cracking propagation, and permanent deformations in pavement sections. The structural performance evaluation of pavement sections depends on its ability to withstand the shear stresses at the top asphalt layer course, the tensile strain at the bottom of asphalt layers and the vertical pressure at the top of subgrade layer.

1.4. Scope and Objectives

The objective of this thesis can be summarized as follows:

1. To provide a pavement with a much longer service life than the conventional asphalt pavement keeping in mid the economy of the project.
2. To reduce pavement repair times by substituting the conventionally designed asphalt pavements with perpetual pavement designs.
3. Evaluate the costs and benefits of perpetual and conventional pavement designs under the three traffic volume levels.
4. Recommend the best pavement design methodology with respect to traffic, environmental and economic conditions.

1.5. Organization of report

Chapter 1 gives a brief overview of the scenario. The overview includes the problem statement, objectives, purpose of the research and scope of the project.

Chapter 2 includes literature review on performance of perpetual pavements and its advantages over the conventional asphalt pavement. The literature review further delineated the tests that were to be conducted and how to progress with the project step by step.

Chapter 3 explains the methodology that was adopted in this research project which includes the selection of material and the laboratory characterization of those materials, the Marshal mix design and performance testing.

Chapter 4 presents the performance test results along with the software analysis and the costs estimated.

Chapter 5 Summarizes and concludes the laboratory tests, cost comparison and life cycles.

Chapter 2

LITERATURE REVIEW

2.1 General.

Asphaltic Pavements are used widely in transportation sectors as they offer great benefits. But when they are compared with the rigid pavements, the service life of rigid pavement makes it more preferable. The service of Rigid Pavements is more than that of Asphalt Pavements. Our study will focus on "increasing the service of asphaltic pavement while making it more economical (in the long run) ". The asphaltic roads of Pakistan have a design life of ten to fifteen years depending upon their functional class and design but we need to increase this life.

Perpetual Pavement is a result of studies done to increase the service life of asphaltic roads. Perpetual means "long lasting" while Perpetual Pavement means long lasting pavement. These types of pavements are not being made or studied in Pakistan before. We have the honor to introduce this topic of advance pavement for the research in Pakistan. In 2013, many rehabilitation projects started in Pakistan including Lahore-Islamabad Motorway (M-2). When the service life of the road will be increased, the rehabilitation projects will not be as extensive as they are now and they'll not require much time and money as they require now. Users of the road will have to face less delay due to rehabilitation.

2.2 Objectives of Perpetual Pavement.

All the research is carried out to benefit the society and the users of that commodity. In the same way, the most important objective of this pavement is to increase the service life of roads along with reducing their cost. Users of roadways always complain about the quality of riding experience on those roads which have been serving them from eight to ten years. When the rehabilitation project initiates the users have to face delays due to reconstruction of the road which also becomes problematic for them. As the complete structure of road (sub base course, base course and wearing course) has to be built again, it becomes costly for the authorities but this is the general practice till now.

For the solution of user delays and costly rehabilitation, Perpetual Pavement can be constructed which offers much longer service time than the traditional highway. Perpetual Pavement is also more economical as their life is about three to four times than the traditional highway. With all the benefits of asphaltic pavement it can give the service life of the rigid pavement. To increase the service life, our objective of the study is to carter two parameters which are responsible for damaging the pavement. First one is rutting and the second one is Bottom-up Fatigue Cracking. To overcome these Rut and Fatigue Resistant gradation is used and study is carried out.

2.3 Literature Review.

Perpetual Pavement is an output of Advanced Pavement Design. Perpetual Pavement means "long life Pavement". This pavement is full depth Asphalt Pavement designed to bear the loads for 50 years. Its long life is due to the increased resistance against Rutting and Bottom up Fatigue Cracking. The idea of perpetual pavement was not formalized until 1990 but this type of road was being tested in US in 1950's. Perpetual Pavement was built in US in early 1950's but the idea was formally accepted after the success of these roads. Ohio University and other Research Institutes of US studied these kinds of pavements.

New Jersey Turnpike is one of the first perpetual pavements designed and built in the world. It was built in 1950 by New Jersey Department of Transportation. It has never been reconstructed till now, only wearing course is being replaced periodically. It serves 175,000 ADT with 40% Trucks in it. This highway encouraged the engineers to study and research more about perpetual pavements. New Jersey Turnpike highway was the first winner of "Perpetual Award". This road has 16 inches depth till subgrade. Advantages of Perpetual Pavement include that its cross-section is thinner than that of the traditional highways because it doesn't contain the thick granular courses.

Washington State Interstate 90 (I-90) is a road from Seattle, Washington to Boston, Massachusetts which didn't require any structural repair on any section and their ages range from 20 to 30 years. It took 10 to 15 years to surface again. Estimated ADT is 148,000 on this highway.

Kansas Interstates shows that Perpetual Pavements are more economical than Rigid Pavement for the life span over 40 years.

California Interstate 710 (I-710) is an interstate highway in the area of Los Angeles area of California State. Its perpetual pavement was built in 2003 with very heavy traffic loading of 200 Million ESAL's

Interstate 695 (I-695) around **Baltimore** and **Marquette Interchange Winconsin** are also examples of Perpetual Pavement Highways.

All of these examples are studied by **Rebecca McDaniel** who is **Technical Director** in **North Central Superpave Center**, Perdue University, West Lafayette, Indiana, and United State.

“Perpetual Pavement is engineered so that any distress that occurs is confined to the upper pavement layer,” is said by **David Newcomb**, **Vice President** for Research and Technology at the **National Asphalt Pavement Association**.

Lee Gustavus, Stephen Sebesta, Rick Canatella, Gerry Harrison, Tony Barbosa, Wenting Liu, and Vivekram Umashankar from the **Texas Transportation Institute** also studied the Perpetual Pavement.

The Asphalt Pavement Alliance (APA) formally defined perpetual pavements in 2000, as “an asphalt pavement designed and built to have a design life more than 50 years without requiring any major structural rehabilitation and needing only periodic surface renewal (wearing course) in response to distresses confined to the top of the pavement”. In 2001, this Alliance also started to give **“Perpetual Pavement Award”** which was given to the pavements which are in service for at least last 35 years without major rehabilitation. After the start of this award, it was awarded to 69 in around 30 States of United States of America. Seven awards are hold by Tennessee while Minnesota has eight.

New Jersey Turnpike was the first one to get Perpetual Pavement Award, which was 50 years old at that time. Eighty Pavements were nominated in the period of ten years from 2001 to 2011 for this. Winners pavements were of major interstate highways. Some of the winners of this award are as follows: -

- Hal Rogers Parkway in US.
- Interstate Highway No. 65
- US Highway of route 60.
- Some part of Julian and Jackson Parkway of US
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Benefits of Perpetual Pavement

Perpetual is an asphalt pavement but a strong one which is not damaged for a very long time, while handling extreme level of traffic. Their structure includes asphaltic layers to the bottom (sub grade). The deepest asphalt layer is designed in such a way that it shows stiff behavior for a long time while keeping its identical flexible behavior of asphalt so that no crack can develop from bottom which could develop itself to the top. A layer of having almost same properties is added in the middle so that the safety of pavement is ensured. The top layer is of wearing course which provides the smooth surface and it needs to be replaced after a time period of around ten to fifteen years.

It might seem obvious that pavement having strong flexible layers will have a long life and will not need reconstruction for the whole structure of the road. Some of their advantages are as follows:

a. Saves time, as only top layer needs to be repaired so it saves time when rehabilitation is to be done.
b. Saves money. The initial cost of Perpetual is no doubt, higher than that of ordinary pavement but life cycle cost is 25% lower than ordinary pavement.
c. Recyclable material is used.
d. It has all the other benefits of normal asphalt pavements.

2.4. How Perpetual Pavement Works?

Lloyd U. Casey Noland explains the phenomena that the key challenge perpetual pavement overcomes are the elimination of **bottom-up fatigue** cracking. When the load is repeatedly applied on the road then the fatigue resistant layer of the pavement which is the bottom layer experiences fatigue and can crack which can develop and can make their way to the top layers.

According to the **National Asphalt Pavement Association, US** the design of the perpetual road starts from the bottom layer, which is designed to resist the tensile strain produced by the traffic load, which helps to stop crack formation. Another similar middle layer makes the structural portion strong enough to tackle rutting and other distresses while the top layer is made for the better skid resistance and have service life less than the other two layers.

According to the **Ohio Research Institute for Transportation and the Environment, Russ College of Engineering and Technology, Ohio University,** the most important feature in the perpetual concept of pavement is to completely remove the bottom up fatigue cracking, while keeping in mind to keep the product economical. To handle the problem of crack formation at the bottom of the road structure due to the cyclic loading of traffic, perpetual pavement uses a mix that is resistant to rutting and thermal cracking to create a pavement designed to be strong enough that traffic-induced strains will remain at or below a threshold value (typically 60-70$\mu\varepsilon$) known as the "endurance limit", so that cracking of the asphalt will never occur. Perpetual pavement is typically designed in layers using Mechanistic-Empirical (ME) design principles. From surface to base, these layers consist of a thin durable surface course, an intermediate layer, a thick high-modulus asphalt layer, and a fatigue-resistant course which is placed on top of an aggregate base (in this case the rubberized preexisting PCC pavement) over the subgrade. The top layer absorbs damage due to traffic and environmental factors over the life of the pavement and may be ground off and replaced from time to time to rejuvenate the surface. In this project, the main difference between conventional HMA (control section) and the perpetual pavement is a thicker bottom layer of the HMA. It is designed to a thickness where the endurance limit is never exceeded. Proper design and preparation of the road foundation is also crucial for the durability of perpetual pavement. **ORITE** has tested this concept on Interstate 77 in Canton and US Route 23 in Delaware County. ORITE also monitored the first perpetual pavement designed and built in New York on its I-86 test road near Angelica.

"Perpetual Pavement" was described by ***Future Highway Research Program Project*, National Academy of Sciences.US** as a road having long life design and needs minimal rehabilitation during its service life. If the perpetual pavement is designed and constructed accurately according to the standards then it can give a service life of more than fifty years without demanding any significant repair work while the top wearing surface layer will need resurfacing.

Perpetual Pavement involves asphaltic layers having higher modulus. **Resilient Modulus** and modulus of elasticity are almost the same phenomena which is stress by strain but one is for rapidly applied loads (for resilient modulus) and the other is for slowly applied loads (for modulus of elasticity). And in the field road exhibit rapidly applied load behavior. Resilient Modulus is found by using UTM machine which gives the stress and strain values, using which Modulus is calculated.

The increased life of perpetual pavement is due to the increased resistance against rutting and bottom up cracking. These two parameters are responsible for durability issues of pavement. These are explained as:

2.4.1. Rutting is the vertical depression in wheel path on the pavement. A depression or groove worn into a road or path by the travel of wheels is known is "Rut”. Rutting is referred to as the vertical and lateral distortion manifested at the asphalt pavement surface under conditions of heavy or repeated traffic loading, loss of foundation support or deep-seated differential expansion and settlement. In this mode of’ failure, the stiffness of the asphalt layers is the predominant factor. Thus, instability in hot climatic regions (such as Pakistan) is greatly contributed by the reduction in asphalt layer stiffness due to the rise in temperature. There can be several other reasons for rutting which are as follows:

- Pavement Base inadequate for handling traffic loads.
- Plastic flow of the surface material (Asphalt).
- Asphalt Mix Design issues.
- It can be due to inaccurate selection of the grade of bitumen according to the climate of the area.

2.4.1.1. Problems of Rutting in Pakistan: Sampak International (Pvt) Ltd. carried out a study in 1992 on “the Problems of asphalt concrete rutting in Pakistan” and evaluated the reasons responsible for the longitudinal wheel track rutting, which are as follows:

a. Use of natural sand in asphalt concrete.

b. Use of high-grade (penetration) bitumen.

c. Dense graded asphalt concrete.

Similarly, transverse corrugated rutting results due to these following reasons:

a. Use of uncrushed coarse aggregates in asphalt concrete.

b. Use of excessive bitumen in the tack coat.

c. Use of high grade (penetration) bitumen.

d. Use of dense mix for asphalt wearing and base course.

e. Other aspects of rutting

(1) Excessive bitumen in asphalt mix than as determined for the job mix design.

(2) Improper aggregate gradation of course and fine aggregates.

(3) Improper mixing in asphalt plants.

(4) Improper compaction of mix at site.

2.4.1.2. Remedies: As a result of Sampak study of failed roads and good roads following observations were observed: -

a. Use of natural sand should not be used as fine aggregate due to the presence of silica particles, which have very little affinity for asphalt. Fine particles start moving to the sides of wheel track and accumulate there, forming a longitudinal rut.

b. Penetration grade bitumen should be according to the climatic conditions, to be used in Asphalt mix.

Denser mixes tend to rut due to less air voids. As a result of heavy traffic air voids are minimized to 1 % or sometimes less than 1 %, thereby bringing the mix to no air voids condition. Asphalt carpet in this condition squeezes the bitumen out of mix under pressure, due to which bleeding takes place and rutting starts. In order to avoid this condition a stiffer mix with higher stability and modulus is desirous; to attain this mix should be made coarser.

The types of rutting are as follows:

2.4.1.3. Types of Rutting: There are three types of rutting, which, are as follows

2.4.1.3.1. Plastic movement is found at the center of applied load of traffic with slight humps on one or both sides of the rut. Usually the reason behind this is low voids in the pavement material that allows the asphalt to act as a lubricant rather than a binder. The phenomenon is shown by the following figure.

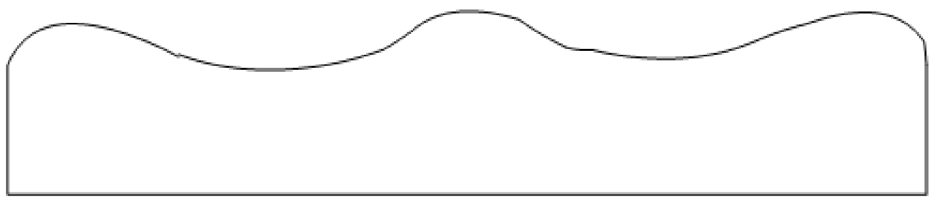

Figure 2-1: Plastic movement

2.4.1.3.2. Consolidation is found around the center of applied load of the traffic without having a hump on any side of rut. The reason behind this is commonly too high voids in the asphalt concrete wearing course. Immediately after construction that allows the material to consolidate in the wheel paths when subjected to traffic. The following figure shows the phenomena:

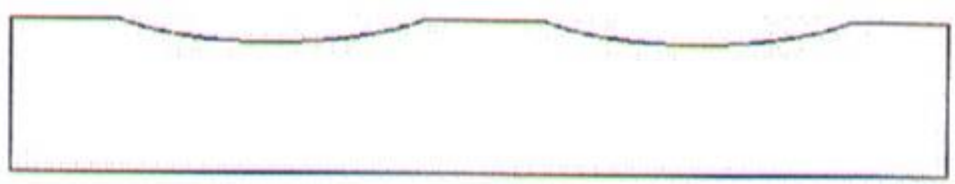

Figure 2-2 Consolidation-Depression along the wheel path.

2.4.1.3.3. Mechanical Deformation occurs due to a subsidence in the base layer or the layer below it, or subgrade accompanied by a distress-cracking pattern. The following figure shows the phenomena:

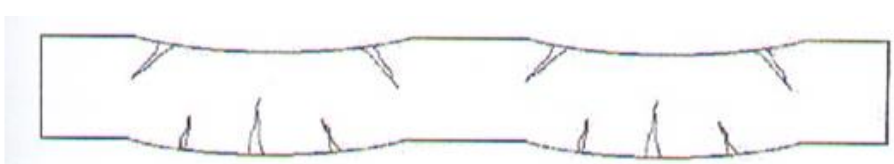

Figure 2-3 Mechanical deformation

2.4.2. Bottom Up Fatigue Cracking: significantly affects the performance of the compacted aggregate. When it is too less, the mix may suffer durability problems but at the same time if it is too large, the mix may show stability problems and also may be uneconomical to produce. The asphalt binder volume in the aggregate mix along with the aggregates determines the thickness of the asphalt film around each aggregate particle.

2.5. Marshall for OBC

Usually, the parameter measured with the Marshall mix design are:

a. Percentage of Voids in Aggregate (VMA)
b. Acceptable Air Voids (AV)
c. Relation between Stability and Flow with Bitumen.
d. The percent of Voids Filled with Asphalt (VFA)

2.5.1. Voids in the Mineral Aggregate (VMA)

VMA is the percentage of total volume of voids within the asphalt mix thus it has two components, the volume of the voids that is filled with the asphalt, and the volume of voids remaining after the compaction has been done which are available for thermal expansion of the asphalt binder during hot temperature.

VMA significantly affects the performance of the compacted aggregate. When it is too less, the mix may suffer durability problems but at the same time if it is too large, the mix may show stability problems and also may be uneconomical to produce. The asphalt binder volume in the aggregate mix along with the aggregates determines the thickness of the asphalt film around each aggregate particle. Without adequate film thickness, water can easily penetrate which adversely affects the tensile strength. The VMA must be sufficiently high so that it must be ensured that there is room for the asphalt plus the required air voids.

2.5.2. Voids in Total Mix (VTM)

The VTM in the compacted dense-graded Hot Mix Asphalt sample at optimum bitumen content is suggested to lie between 3 to 5 percent. Asphaltic pavement layers transfer the load to underlying layers through inter granular contact and resistance to flow of the binder matrix; therefore, to achieve adequate performance of HMA pavements high shear resistance must be developed and also to prevent additional compaction under traffic, which can cause result in rutting in the wheel paths or other distresses like flushing and bleeding of the asphalt cement at the surface, high shear resistance must be present. In addition, the dense-graded HMA wearing course must also provide a surface that is relatively impermeable to both air and water, so that the air and water cannot enter the pavement layers. Low air void contents reduce the aging of the bitumen films within the aggregate mass and also reduce the possibility of water entrances into the mix, which could penetrate into the thin asphalt cement film and strip the asphalt cement off the aggregates. The HMA should be compacted to a laboratory density that approximates the ultimate density achieved under traffic and at the same time have an air void content in the 3 to 5 percent range to achieve satisfactory service from the pavement. The in-place air void content should initially be slightly higher than 3 to 5 percent to incorporate some additional compaction by the traffic.

2.5.3. Density.

It is very importance that how close the density calculated in the laboratory is to the density achieved in the field after several years of traffic load. A percentage of theoretical maximum density is mostly referred as Density. It is easy to understand that when the in-place air voids are decreased then there will be increase in the percent density. Increasing the bitumen content and the amount of stone dust in a mix can increase the both, percent density and air voids but does not necessarily have a positive effect on performance. Therefore, it important that compaction of Marshall Specimens using field produced materials. By increasing density due to increased compaction of the mix will increase shear strength and improve the performance of the mix, if there is adequate asphalt cement available to prevent durability problems and not too much asphalt cement to cause permanent deformation problems. Usually, in the procedure of Marshall mix design, the density initially increases with the increase in asphalt content because the hot asphalt cement lubricates the particles allowing the compaction to force them closer together. The density reaches a peak point and then begins to decrease because adding more asphalt produces thicker films around the individual aggregates due to which aggregates are pushed apart which results in decrease in density.

2.5.4. Stability.

Stability is generally the measure of viscosity of the aggregate-bitumen mix and is affected significantly by the angle of internal friction of the aggregates and the viscosity of the bitumen at 60 ˚C (140 ˚F). One way to increase the stability of an asphalt mix is to change to a selecting higher viscosity grade bitumen or it can also be done by selecting aggregate which have higher angularity measure. Marshall Stability is increased with the increment of viscosity of the bitumen. Marshall Stability and the field stability are not necessarily related rather to Marshall stability is a proxy measure for the field stability. The stability of a mix in the field is affected by the surrounding temperature, rate of loading, types of loading, tire contact pressure, and numerous mix properties whereas the laboratory Marshall stability only takes into account one of the factor mentioned above. Therefore, if field stability is a problem, then it should be determined that which of the factor mentioned above is responsible for causing the problem rather than assuming that by having higher laboratory stability will solve the problem. The primary use of Marshall Stability is to aid in selection of the optimum bitumen content (OBC).

2.5.5. Flow

The flow and Stability are measured at the same time. Flow is vertical deformation of the specimen which is measured from the start of loading on the sample to the point where stability begins to decrease; the deformation is measured in hundredths of an inch. Generally, Plastic mix have higher flow values which indicate that it will experience permanent deformation under traffic, whereas low flow values may indicate a mix which have higher than normal air voids and insufficient bitumen for durability. Low flow value also indicates that mix may be more brittle then desired which can cause problems during the life of the pavement.

2.5.6 Percent Voids Filled with Asphalt (VFA)

At times the Percent Voids Filled with Asphalt (percent VFA) is also considered in the criteria. If during construction the VMA requirement and air voids are controlled than the percent VFA is a redundant requirement for dense-graded HMA. Typically, requirement to specify the VFA ranges from 70 to 85 percent.

2.6. Marshal Method

In 1939, Bruce Marshall developed the earliest version of the Marshall method at the Mississippi State Highway Department. In 1943, The Corps of Engineers Waterways Experiment Station (WES) began a study to develop a simple portable apparatus and procedure for designing asphalt mixtures for airfield pavements. The increase in wheel load of aircrafts during World War II prompted this study. Tire pressures and tire contact pressures were also increased which demanded a suitable mix design method to cope with increased tire pressures. The Corps began experimentation with Bruce-Marshall's apparatus and embarked on a series of laboratory and field experiments. Mixes were designed in the laboratory using a variety of compaction which involved different drop hammer weights, numbers of blows, different compactor foot designs, different mold base shapes and materials, while in an attempt to produce densities which were similar to those achieved in the field under construction and simulated aircraft loading. The aim was to adopt a procedure which can be portable involving minimum effort and time and providing basis for selecting the proper optimum bitumen content.

During the late 1940s and early 1950s, aircraft size and weight continued due to which tire pressures were increased to 200 psi. This increase in tire pressure caused the significant increment in the near surface compaction of traffic.

In 1950s, performance problems of rutting on many projects were seen. Investigations found that large quantities of natural sand were present in those mixes which experience rutting problems. In attempts to control the use of natural sand resulted in raising the Marshall stability to 1800 pounds and advised a limitation on the allowable amount of natural sand that could be used in airfield pavements. In the development and evolution of the Marshall method, the asphalt content and density are the two variables which stand out in the design and performance of HMA. Therefore, in field the bitumen content at which density achieved under traffic that is significant is the highest satisfactory, selection of compaction procedure is an important feature which represents traffic-induced density, and then selecting response properties that can be averaged to yield asphalt content that will produce satisfactory performance. The Marshall Test procedures are standardized by ASTM Designation D 1559, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus and AASHTO T 425 "Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus".

2.6.1. Marshall Test Procedure

Marshall Test method has three test methods, which are: calculation of bulk specific gravity, determination of Marshall Stability and flow and measurement of specimen density and voids content.

2.6.2. Bulk Specific Gravity Determination

As soon as the freshly compacted specimens have cooled to room temperature that is 25 Degree Celsius, the bulk specific gravity of each specimen is determined. This measurement is done for an accurate density and air voids analysis. AASHTO procedure T 166 governs the method of Bulk specific gravity.

2.6.3. Stability and Flow Tests

Stability tests measures the highest resistance offered to deformation under load. Flow test measures the amount of deformation that occurs in the mix under loading. The test procedure is as follows: -

a. The specimens are heated in a water bath having temperature of 140°F (60°C), which represents the warmest in-service temperature that the pavement will normally experience.
b. The warmed specimen in 140°F (60°C) in water bath is removed from the water bath and damp dried after which quickly placed in the Marshall apparatus. The apparatus has a device which exerts a load on the specimen and have gauges for measuring the load and measuring flow.
c. The resting load is applied to the specimen at a constant rate of 2 in (51 mm) per minute until the specimen fails. Failure is defined as the maximum load taken by the specimen.
d. The load at failure is noted as the Marshall Stability value and the flow meter reading is noted as the flow value.

2.6.3.1. Marshall Stability Value

The Marshall Stability value is a measurement of the load taken by the specimen until it totally yields or fails. During the test the load is slowly applied, the upper and lower head of the testing apparatus get closer to each other and the load on the specimen increases and the reading on the dial gauge slowly increase. When the load reaches its maximum value, loading is discontinued. The maximum load is indicated by the gauge of apparatus is noted as the Marshall Stability Value.

Because Marshall Stability is the measure of resistance of the mix to deformation, there is a natural tendency to think that if a certain stability value is good, a much higher value must be much better. This tendency, however, will lead to the use of those mixes which have stability values that are too high.

In engineering materials, the strength of the material is usually the measure of its quality; however, this is not the case with hot-mixed asphalt paving. Mixes having higher stability are often obtained at the expense of durability.

2.6.3.2. Marshall Flow Value

Marshall Flow value is measured in one-hundredths of an inch which represents the total deformation of the specimen. The deformation is actually the decrease in the vertical diameter of the specimen. Mixes which have very low flow values and abnormally high Marshall Stability values are taken as too brittle and rigid for pavement service and are not desirable. Those with high flow values on other hand are considered too plastic and have a tendency to distort easily under traffic loads. This type of mixes is also not preferred. Optimum relation between flow and stability is preferred.

2.6.4. Density and Voids Analysis

After obtaining the results of stability and flow tests, density and voids analysis are performed for each series of test specimens. This analysis is done to determine the percentage of air voids present in the compacted mix.

2.6.4.1. Voids Analysis

The air voids are the air entrapped between the asphalt coated aggregate. The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture which have no voids. The latter is measured from the specific gravities of the asphalt and aggregate in the mix, with an adequate allowance made for the amount of asphalt absorbed by the aggregate, it can also be determined directly by a standard test which is AASHTO T 209, performed on an uncompact sample of mix. The bulk specific gravity of compacted specimens is determined by weighing specimens in air and immersed in water (water absorption).

2.6.4.2. Unit Weight Analysis

The average unit weight for each sample is determined by just multiplying the bulk specific gravity (which was determined earlier) of the mix by 62.4 lb/ft^3 (1000 kg/m^3).

2.6.5. VMA Analysis

The air voids are the air entrapped between the asphalt coated aggregate. The percent air voids are calculated from the bulk specific gravity of each compacted specimen and the maximum specific gravity of the paving mixture which have no voids. The latter is measured from the specific gravities of the asphalt and aggregate in the mix, with an adequate allowance made for the amount of asphalt absorbed by the aggregate, it can also be determined directly by a standard test which is AASHTO T 209, performed on an uncompact sample of mix. The bulk specific gravity of compacted specimens is determined by weighing specimens in air and immersed in water (water absorption).

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2.6.6. VFA Analysis

The voids filled with asphalt is known as "VFA" and these voids are the percentage of the inter granular void space between the aggregate particles that is the VMA, that are filled with asphalt/bitumen. As VMA includes asphalt and air due to which the VFA is calculated by subtracting the air voids from the VMA and dividing it from VMA and then expressing the value as a percentage.

Chapter 3

RESEARCH AND TESTING METHODOLOGY

3.1. Introduction

This chapter explains the methodology adopted to achieve the objectives of our project which includes collection of materials, testing of materials, specimen's preparation and different tests on specimens. The study was carried out under controlled conditions. In this chapter, determination of OBC of both wearing and base course at varying percentages of asphalt (3% to 5%) using Marshal Mix Design is explained. Based on the OBC results, performance testing was done. Performance testing includes resilient modulus and Fatigue testing. The equipment used, the procedures used for the preparation of samples along with the input parameters used for testing on the specimens prepared will be explained in this chapter.

3.2. Methodology

Aggregate was collected from Margallah hills crush plant site. Asphalt of grade 60/70 was bought for the project. These materials were brought to lab of NIT and some standard tests were conducted on aggregates and bitumen. After that Marshall Specimens were prepared to find OBC of samples. These OBC's were then used to prepare samples to perform Performance tests. After completing the performance tests, its results were used in Kenpave software to determine the Design Life of Perpetual Pavements.

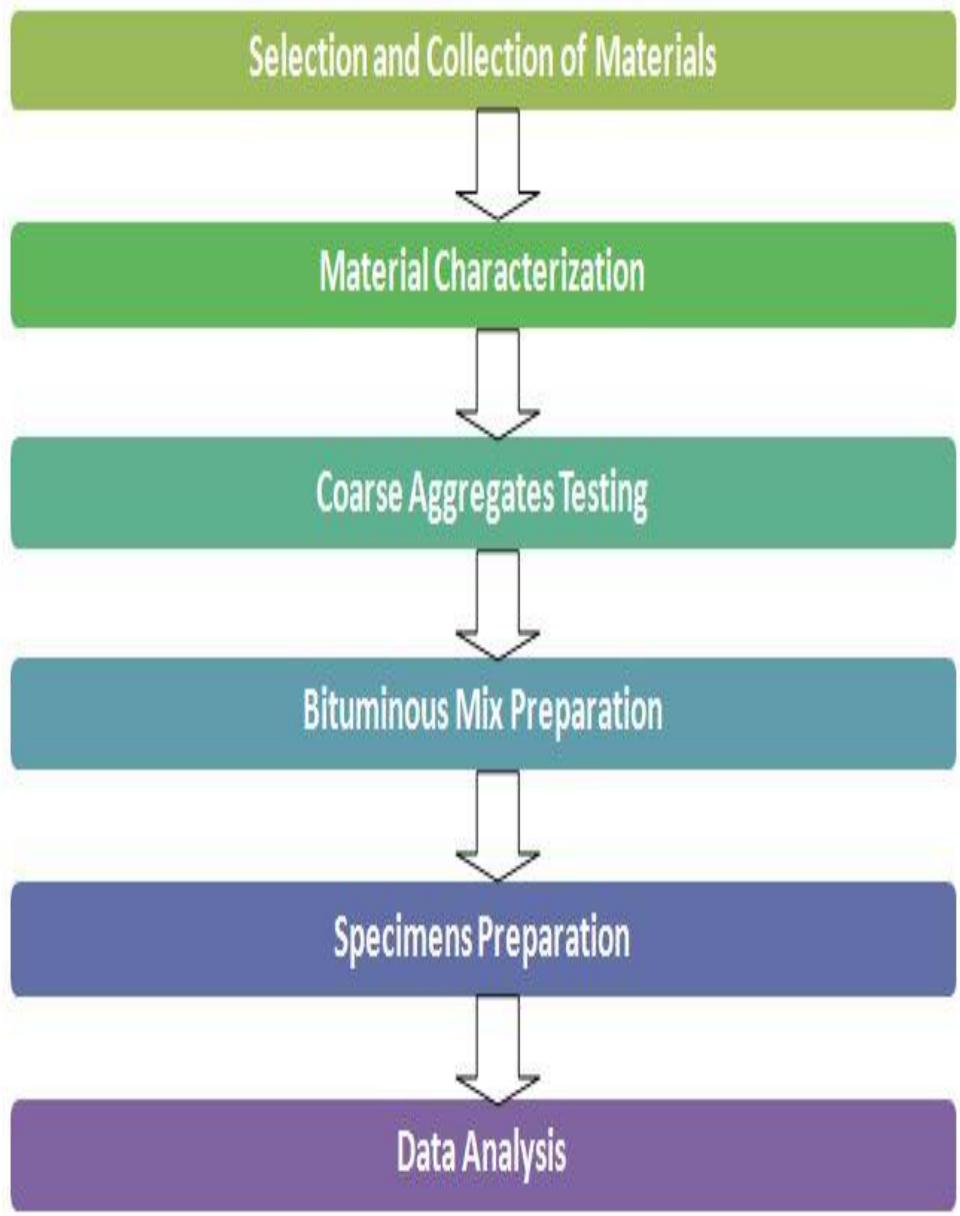


Figure 3.1: Flow Chart of Research Methodology

3.3 Material Collection

3.3.1 Aggregate

Figure 3.2: Margallah Hills Crush Plant

3.3.2 Bitumen

In Pakistan, mostly bitumen of grade 60/70 is utilized per weather conditions. So, bitumen of grade 60/70 was collected from Attock Oil Refinery (ARL).

3.4. Material Testing

3.4.1. Aggregate Tests

Aggregate resists deformation in pavements so it should have sufficient strength, texture so that it can withstand its purpose in pavement. Following tests were performed on aggregate.

- Shape Test.
- Specific Gravity and Water absorption test.
- Impact value of Aggregate.

- Los Angles Abrasion Test.

  Three samples were prepared for each test and their results were compiled in the table below and their average taken.

3.4.1.1 Shape test of Aggregate (ASTM D 4791-99)

This test determines the percentage of flaky and elongated particles in aggregate. Flaky particles are defined to be those having their least dimension lesser then 0.6 times their mean dimension. While elongated particles are defined to be those having their greatest dimension greater than 1.8 times their mean dimension. For better interlocking of aggregate particles angular shape is preferred. The flakiness index should be less than 15% while elongation index less than 15%.

Figure 3.3: Shape Test Apparatus.

3.4.1.2. Specific Gravity Test (ASTM C 127 & ASTM C 128)

Specific gravity is the ratio of weight of given volume of aggregate to weight of equal volume of water at room temperature. This test was performed according to standard ASTM C 127-88. Three different weights were determined for calculating Specific gravity i.e. weight of oven dried aggregates, weight of aggregates completely submerged in water, and Saturated surface dry weight of aggregates. Specific Gravity of Fine aggregates and water absorption was determined using standard ASTM C 128.

Figure 3.4: Specific Gravity Test

3.4.1.3 . Impact Value of Aggregate (BS 812)

The impact value of aggregate gives its relative strength against impact loading. The equipment required was impact testing machine, temping rod, sieves of sizes 1/2", 3/8" and #8 (2.36mm). About 350 grams of sample passing sieve ½" and retained on 3/8" was put in impact testing machine cup in three layers. Then each layer was tamped 25 times with the help of tamping rod. After that it was subjected to 25 blows from hammer of impact machine having weight 14 kg and free fall of 38 cm. After that aggregate was taken out from cup and passed through sieve #8. The percent passing through sieve #8 gives impact value of aggregates.

Figure 3.5: Impact value Test Apparatus

3.3.1.4 Los Angles Abrasion Test (ASTM C 535)

This test is used to check resistance of aggregate to wear and tear due to heavy traffic load. More the abrasion value of aggregate more the performance of pavement is adversely affected. The equipment used was LOS angles machines, sieve set, balance and eleven steel balls. NHA Gradation A was used for this test. About 5kg of sample, containing 2500g retained on sieve ½" and 2500g retained on 3/8", was placed in Los Angles Machine along with 11 steel balls and drum was rotated at speed of 30-33 rpm for 500 revolutions. After that material from machine was passed through 1.7mm sieve and weight (W2) of sample passing it was noted. The abrasion value is defined to be = W2/W1 *100.

Figure 3.6: Los Angles Abrasion Machine

3.4.2. Bitumen Tests

The experimental phase of this research started with the preparation of control samples, which basically represent unmodified/conventional HMA. The tests made on the binder are as follows:

- Penetration Test
- Ductility Test
- Flash and Fire Point Test

3.4.2.1 Penetration Test (AASHTO T 49-03)

The penetration test is used to determine the penetration grade of bitumen by measuring the depth in tenths of a millimeter up to which a standard loaded needle will vertically penetrates the bitumen specimen under given conditions of loading, time and temperature. Softer binder gives greater values of penetration. According to AASHTO T

49-03 temperature used was 25°C, load of 100 grams, while time for the test equal 5 seconds, until unless the situations are not explicitly stated. Using two ARL 60/70 specimens, five values from each specimen were taken after performing penetration tests.

Figure 3.7 Penetration Test Apparatus

3.4.2.2. Ductility (AASHTO T 51-00)

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample of the material will be elongated without breaking with a specific speed i.e. 5 cm/min and at a specific temperature of 25 ± 0.5 °C (AASHTO T 51-00). Different samples of bitumen were tested and all gave the ductility value greater than the least limit of 100 cm.

Figure 3.8 Ductility Test of bitumen.

3.4.2.3. Flash and Fire point (D3143/D3143M-13)

- Flash point is that least temperature at which the bitumen momentarily flashes at specified conditions.
- Fire Point is the temperature at which the material gets fire and burn under specific conditions. Flash and Fire point test was conducted as per D3143/D3143M-13 standards.

3.5. GRADATION SELECTION

Roberts et al. (1996) suggested that "gradation is perhaps the most important property of an aggregate. It affects almost all the important properties of a HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage."

In our project, NHA Class A wearing course and base course gradation was used, which is further discussed in this chapter. Base Course sample is of 6 inches diameter due to presence of 1 ½ sized aggregate while the Wearing course sample is of 4-inch diameter, for the Marshall method.

3.5.1 Wearing course

From NHA specifications of gradation for asphalt concrete wearing course Class 'A' aggregate gradation is used in this study. Following tables show different gradations.

Sieve Size		% Cumulative passing	% Passing (Avg)	% Retained Cumulative	% Retained each sieve	Retained weight(g)
(mm)	(inch)				(%)	(gm)
25	1	100	100	0	0	0
19	3/4	90-100	95	5	5	57.5
9.5	3/8	50-70	63	37	32	368
4.75	#4	35-50	42.5	57.5	20.5	235.75
2.38	#8	23-35	29	71	13.5	155.25
1.18	#16	5-12	8.5	91.5	20.5	235.75
0.075	#200	2-8	5	95	3.5	40.25
pan					5	57.5
						1150

Table 3.1: NHA Class 'A' Wearing Course Aggregate Gradation

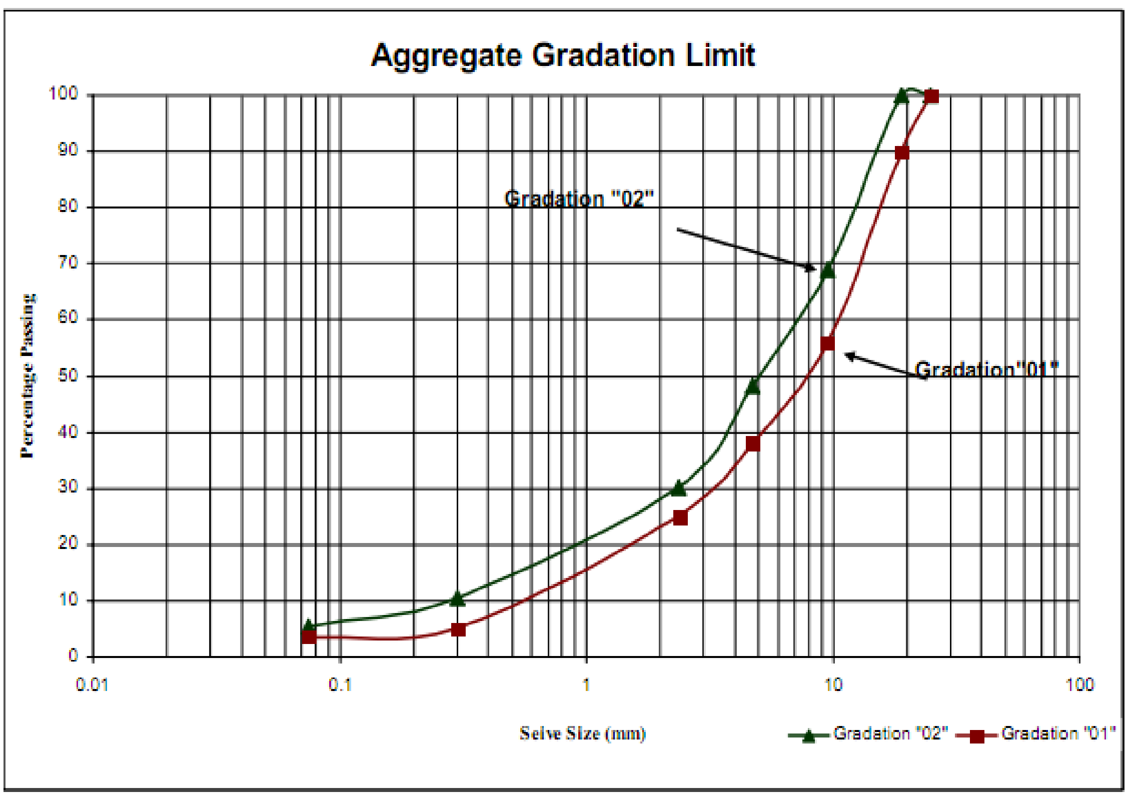


Figure 3.9: Aggregates Gradation '01' and '02' Under NHA Class 'A'

3.5.2 Base Course

Asphaltic Base Course gradation is also Class "A' NHA gradation. As there is no gradation available for asphaltic sub base in Pakistan so we used the same gradation for our asphaltic sub base.

Sieve Size		% Passing	% Passing (Avg)	% Retained Cumulative	% Retained each sieve
(mm)	(inch)				(%)
50	2	100	100	0	0
38	11/2	90-100	90	10	10
19	3/4	50-61	60.5	39.5	29.5
4.75	#4	30-33	31.5	68.5	29
2.38	#8	21-24	22.5	77.5	9
0.300	#50	20-21	20.5	79.5	2
0.075	#200	15-21	18	82	2.5
pan				100	18

Table 3.2: NHA Class 'A' Base Course Aggregate Gradation

3.6. DETERMINATION OF OBC FOR WEARING COURSE

To determine OBC,3 samples for each percentage were prepared i.e. 12 samples were made for both wearing and base course OBC determination.

3.6.1. Preparation of Aggregate and Bitumen

After sieving the aggregate according to the NHA class A standard. They are mixed with asphalt by heating at about 150-160C. The total sample weight of Marshall Mix is 1200gm. The weight of Asphalt varied according to its percentage which is from 3.5% to 5% of mix. Three samples for each percentage i.e. total 12 samples were formed.

The weight of asphalt and aggregates can be obtained by following formula:

WT =WB + WA

WB = X/100 * WT

3.6.2 Compaction of Specimen

According to Marshall Mix design, there are three criteria for compaction depending on either the surface is prepared for light, medium or heavy traffic. In this project we have designed pavement for heavy traffic so 75 blows on each side of specimen are applied to achieve compaction. The loose mix obtained from heating aggregate with bitumen is transferred to mold have base plate. A filter paper was placed below and above the specimen. After achieving 75 blows on one side, specimen was inverted and 75 blows were applied in other side of specimen. This compaction was achieved by Marshall Compactor.

3.7. MARSHAL Mix Design Method

After the cooling of Specimen to room temperature the volumetric properties of specimen are calculated by determining Gmb and Gmm values. The tests for Gmb and Gmm are performed in accordance with ASTM D2726 AND ASTM D2041 respectively. For determination of Gmb firstly weight in air of specimen is determined, after which its weight in water and SSD weight determined.

After the determination of Gmb the specimen is transferred to water bath for 30-40 minutes at 60 °C then tested for Marshall Stability and flow using Marshall Equipment. After placing the sample in Marshall Apparatus, it is loaded at constant deformation rate of 5mm/minute until the specimen fails. The maximum load that the specimen takes is its Stability value and the strain that occurs at maximum load is recorded as flow number in mm. According to Marshal Mix design Criteria MS-2, for surface designed for heavy traffic load should have Stability value not less than 8.006 KN and Flow should be between 2 to 3.5 mm.

Figure 3.10. Gmb Calculation for Marshall Samples.

3.8. GRAPHS PLOTATION and Determination of OBC

After determination of various volumetric properties graphs were plotted between asphalt and different volumetric properties. Total six graphs were plotted. For determining OBC the following steps are taken:

- Max % bitumen corresponding to max stability.
- Max % bitumen corresponding to unit weight.
- Max % bitumen corresponding to 4% Air Voids.

Taking Average of these 3 % Bitumen gives us OBC.

3.9. DETERMINATION OF OBC FOR BASE COURSE

3.9.1 Preparation of Aggregate and Bitumen

After sieving the Aggregate into different sizes required for the project, they are mixed with asphalt by constant heating at about 150-160C. The total sample weight of Marshall Mix is 4200gm. The weight of Asphalt Cement varied according to its percentage which is from 3% to 4.5% of mix.

3.9.2. Compaction of Specimen

According to standard for 6in sample 112 blows on each side of specimen are applied to achieve compaction. The loose mix obtained from heating aggregate with bitumen is transferred to mold have base plate. A filter paper was placed below and above the specimen. After achieving 112 blows on one side, specimen was inverted and 112 blows were applied in other side of specimen. This compaction was achieved by Marshall Compactor.

After that Gmb and Gmm are determined by the same procedure. After the determination of G_{mb} the specimen is transferred to water bath for 30-40 minutes at 60 °C then tested for Marshall Stability and flow using Marshall Equipment. After placing the sample in Marshall Apparatus, it is loaded at constant deformation rate of 5mm/minute until the specimen fails. The maximum load that the specimen takes is its Stability value and the strain that occurs at maximum load is recorded as flow number in mm. According to Marshal mix design Criteria MS-2, for surface designed for heavy traffic load should have Stability value not less than 8.006 KN and Flow should be between 2 to 3.5 mm.

3.10. Preparation of Sample for Performance Tests

After determining OBC of wearing and base course, samples were prepared at OBC for performance testing. For Base Course the samples had to be cut to 62.5 mm thickness with help of saw according to the standard for both the tests.

Two tests were performed on both samples i.e. wearing and base course samples which are

- Indirect Tensile Strength on UTM
- Resilient Modulus Test on UTM

Figure 3.11 Sample Cut with Help of Saw

3.10.1 Indirect tensile strength (ASHTOD6931)

The Test was performed on Universal Testing Machine. A 25®C temperature was selected for this test and the samples were placed in the vacuum chamber for almost 2 hours. After that the samples were placed horizontally in the Machine and the Load was applied till failure of the sample. The Machine stopped as the samples failed and the Max Value Gave us the Peak Load. A total of 2 samples were made for this test and their Average Peak load taken. The Indirect Tensile Strength was calculated with the formula:

$2000P/\pi Dh$

Where:

p= peak load

D= Diameter of sample

h= Height of sample

3.10.2. Resilient Modulus Test (ASHTO D7369-09)

The Universal Testing Machine was used for this and the samples have to be placed horizontally in the machine. Before placing the sample, the temperature in the vacuum chamber was adjusted at 25 ®C and the samples were put in the chamber for about 2 hours before test. 20% of peak load of ITS test was taken as input to the machine and a total of 100 conditioning pulses were applied on the sample as according to the Standard and then the last 5 pulses were recorded and their mean taken. Conditioning Pulses were required so that it eliminates any error in the test.

Figure 3.12 Samples placed horizontally for Resilient Modulus Test.

3.11. KENPAVE SOFTWARE

For the determination of Design life of Perpetual Pavement KenPave Software is used. Kenpave uses multi-layer theory to calculate the stresses and strains on the top and bottom of each layer, by using which it calculates the damage ratio of the road, which helps to give the design life. This Software requires multiple inputs to calculate the Design Life of pavement. The Inputs are:

- Thickness of each layer
- Resilient Modulus of each Layer
- Number of ESAL's
- Poison Ratio of each layer

Figure 3.13 Kenpave Software Main Screen.

3.12. Summary

This chapter explains the testing of Aggregate, Bitumen, and determination of OBC and performance tests. The volumetric properties of mix were calculated and OBC was determined. The OBC determined was then used for performance testing i.e. Resilient Modulus, Indirect Tensile Strength. The results were then compared with the standard values for the aggregate mix. At the end, work on KenPave these results were then used in KenPave Software and its methodology was explained.

Chapter 4

Results and Analysis

4.1 General

The main aim of the research was to analyse Perpetual Pavement and how adding more asphaltic thickness of the pavement effects its design life. Also comparison of the design life and price between the Perpetual and Pakistan best road Motorway was done. Bitumen of Grade 60/70 was used throughout the project and the material used was brought from Margalla. NHA Class A gradation was initially proposed for this project for both Wearing Course and Base Course but after Resilient Modulus Test the Base Course was changed to NHA B gradation after it violated the law of Elastic Theory.

Marshal Mix Design Method was used for finding the Optimum Bitumen Content for both the courses and after that two-performance test were performed Tensile Strength and Resilient Modulus Test for which both UTM was used. At last the design life of the pavement was determined using KenPave software and at last cost comparison was done.

4.2. Laboratory Characterization of material

Various tests were performed in the laboratory to determine the physical properties of the material brought from the Margalla, Taxila. A summary of laboratory test results is shown in the 4.1 and 4.2 table.

Table 4.1. Properties of Material

Test type	Standard value	Test result	Specification
Impact value	<30%	29%	BS 812
Los Angeles abrasion value	<45%	31%	ASTMC131
Shape test			
Flakiness index	<15%	4.7%	ASTM D 4791
Elongation index	<15%	2.9%	ASTM D 4795
Specific gravity		2.61	ASTM C 127

Table 4.2. Properties of Bitumen

Test type	Standard value	Test result	Specifaction
Ductility @ 25°C, cm	50	114	ASTM-113-99
Flash Point, COC, °F	232	290	ASTM:D-92
Penetration @ 25°C, mm	60-70	66	ASTM D: 5-06
Specific gravity		1.03	ASTM D 70

4.3. MARSHALL MIX DESIGN

Using Marshall Mix Method, specimens were prepared at 3.5%, 4.0%, 4.5%, 5.0%, and 5.5% asphalt contents for wearing course while for Base 3%, 3.5%, 4%, 4.5% were made. Three specimens were prepared for each percentage for wearing course and for Base course 2 specimens were prepared on each percentage contents. The Marshall parameters determined for Wearing Course (75 blows) are shown in Table 4.3 and graphically illustrated in Fig. 4.1 to Fig. 4.5 and its OBC determined at standard compaction is tabulated in Table 4.4. Base Course

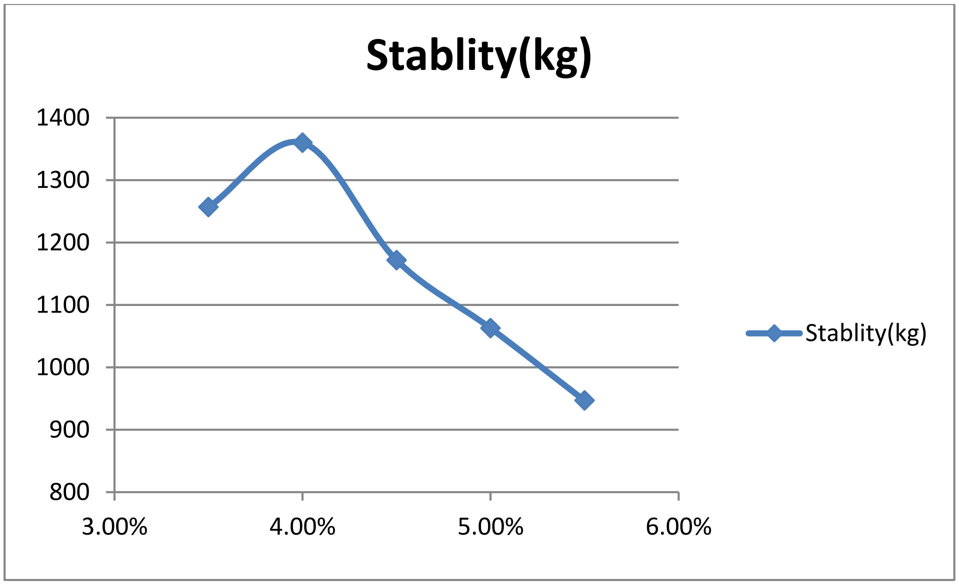
(112 Blows) parameters are shown in table 4.6 and graphs 4.6 to 4.10 illustrates its result. Its OBC is tabulated in table 4.7.

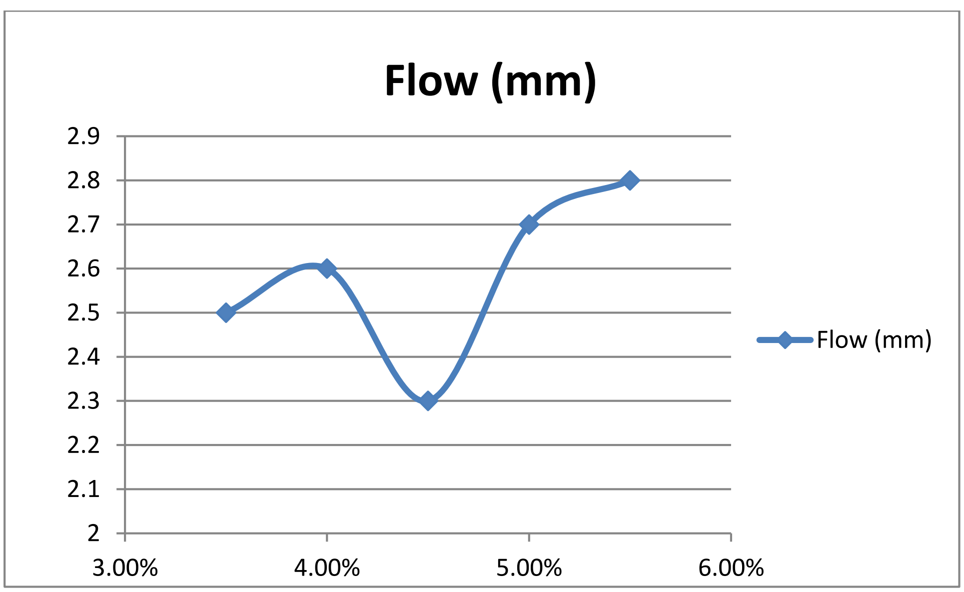
4.3.1. Wearing Course

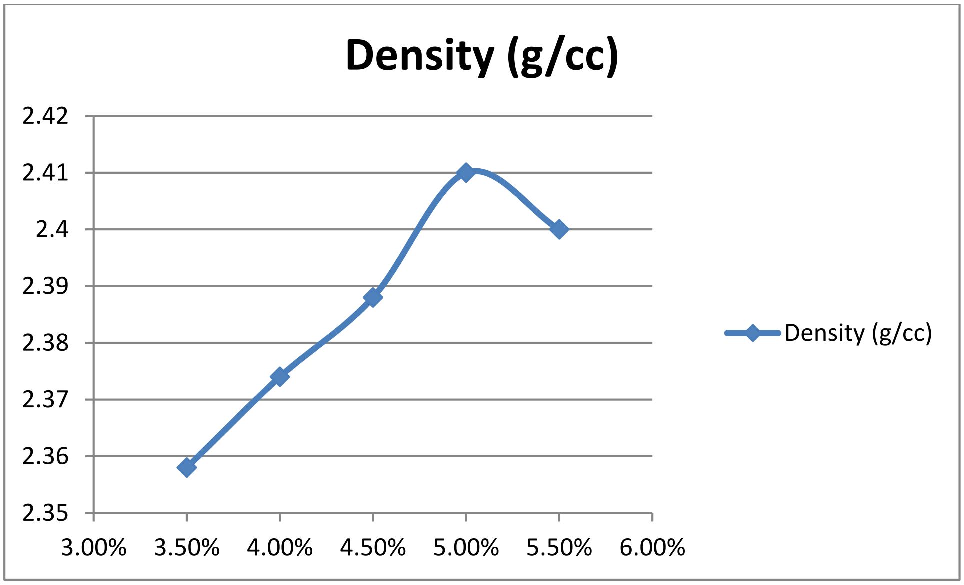
Table 4.3. Marshall Parameters Determined for Wearing course Compacted at 75 blows

Percentage	**3.50%**	**4.00%**	**4.50%**	**5.00%**	**5.50%**
Stability(kg)	1257	1360	1172	1063	947
Flow (mm)	2.5	2.6	2.3	2.7	2.8
Density (g/cc)	2.358	2.374	2.388	2.41	2.4
% AV	6.39	5.2	3.67	2.5	2.18
% VMA	14	14.11	13.72	13.8	14.61
% VFA	54	63.1	73.2	81.88	85.07

Fig 4.1. to 4.6. Marshal Mix Design Graph for wearing course.






Density (g/cc)
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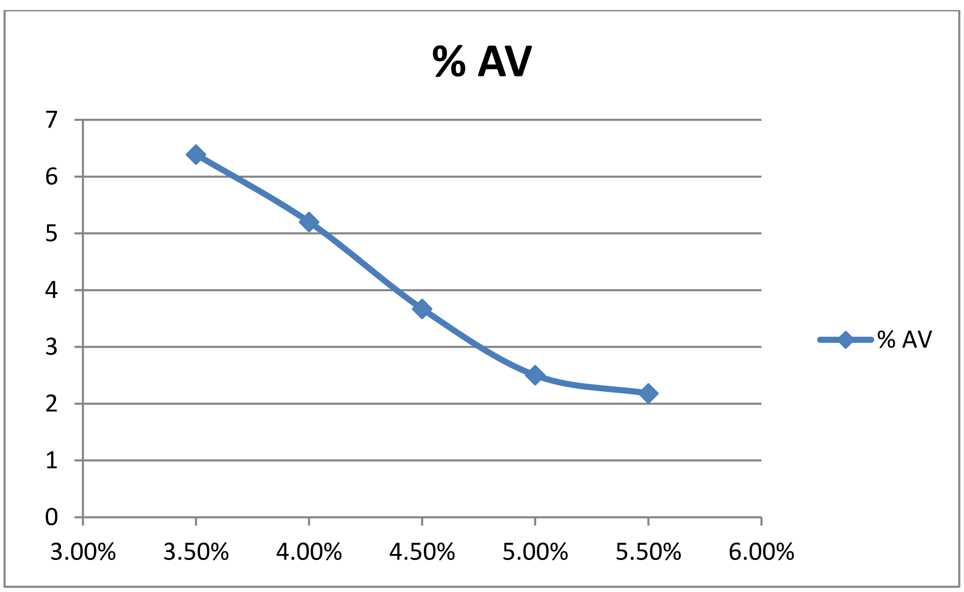
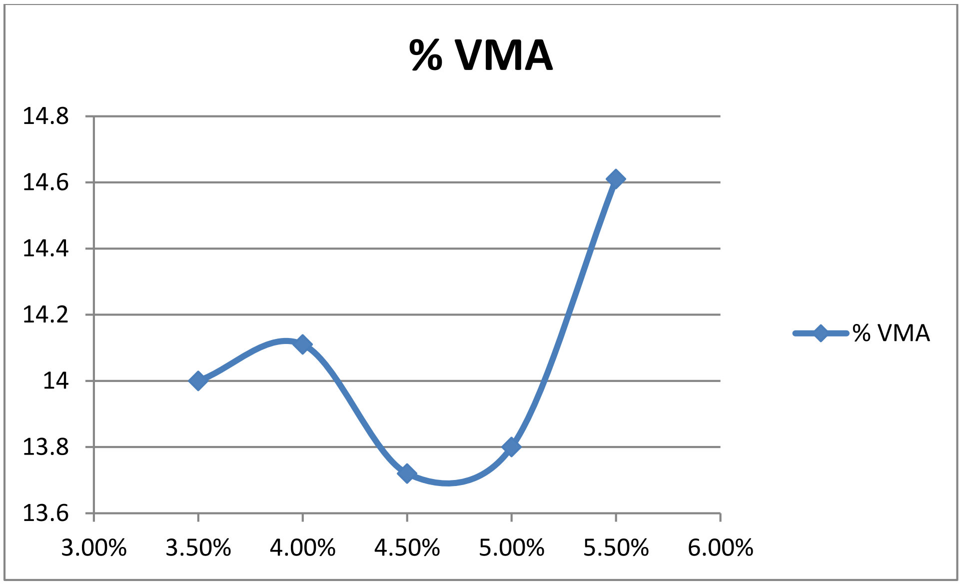
2.4
2.39
2.38
2.37
2.36
2.35
3.00%
3.50%
4.00%
4.50%
5.00%
5.50%
6.00%
Density (g/cc)


% AV
7
6
5
4
3
2
1
0
3.00%
3.50%
4.00%
4.50%
5.00%
5.50%
6.00%
% AV


% VMA
14.8
14.6
14.4
14.2
14
13.8
13.6
3.00%
3.50%
4.00%
4.50%
5.00%
5.50%
6.00%
% VMA

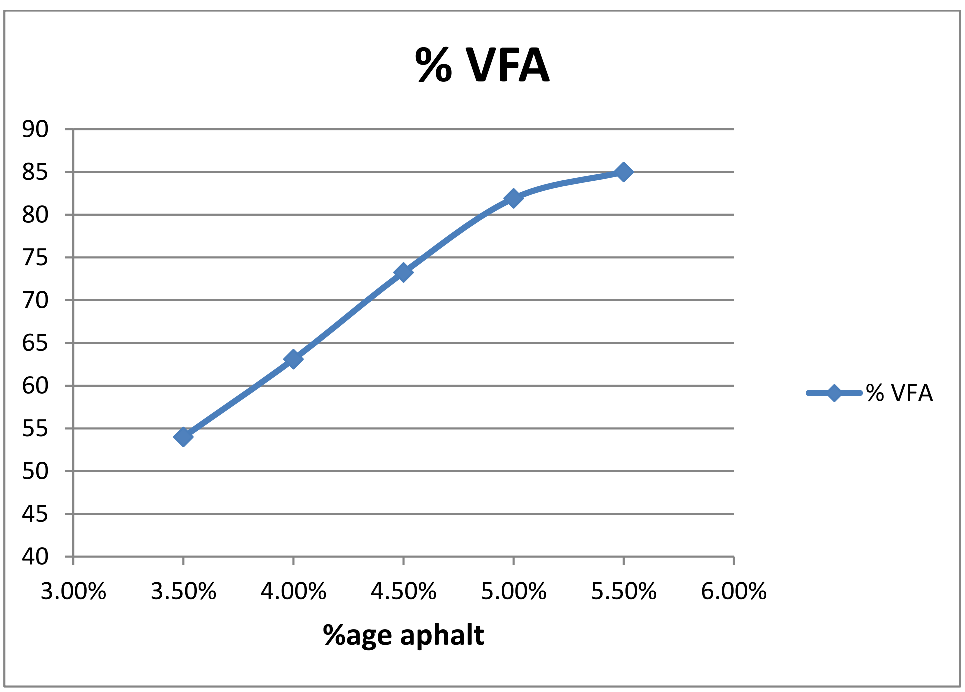

% VFA
90
85
80
75
70
65
60
55
50
45
40
3.00%
3.50%
4.00%
4.50%
5.00%
5.50%
6.00%
%age aphalt
% VFA

Table 4.4. Determination of Optimum Asphalt Content for wearing course

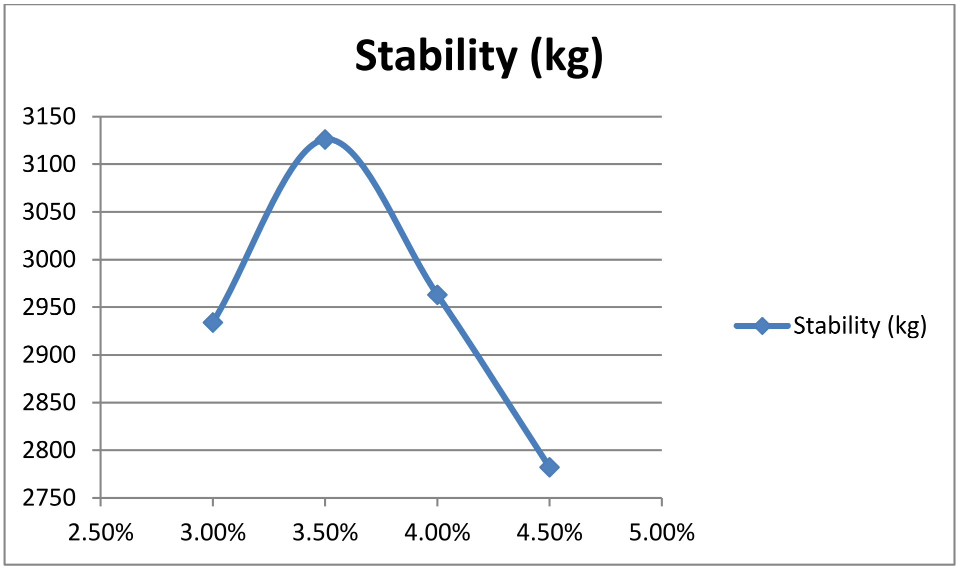
Marshall Mix Design Characteristic	Bitumen content (%)
Max Stability	4
Max Unit Weight	5
At 4.0% AV	4.4
Average	4.4 (OBC)

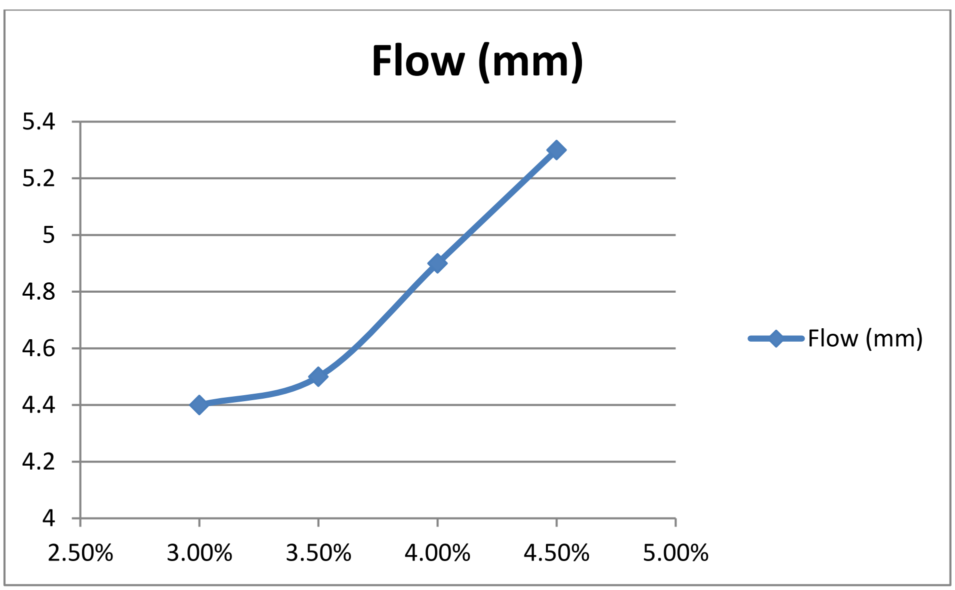
4.3.2. Base Course

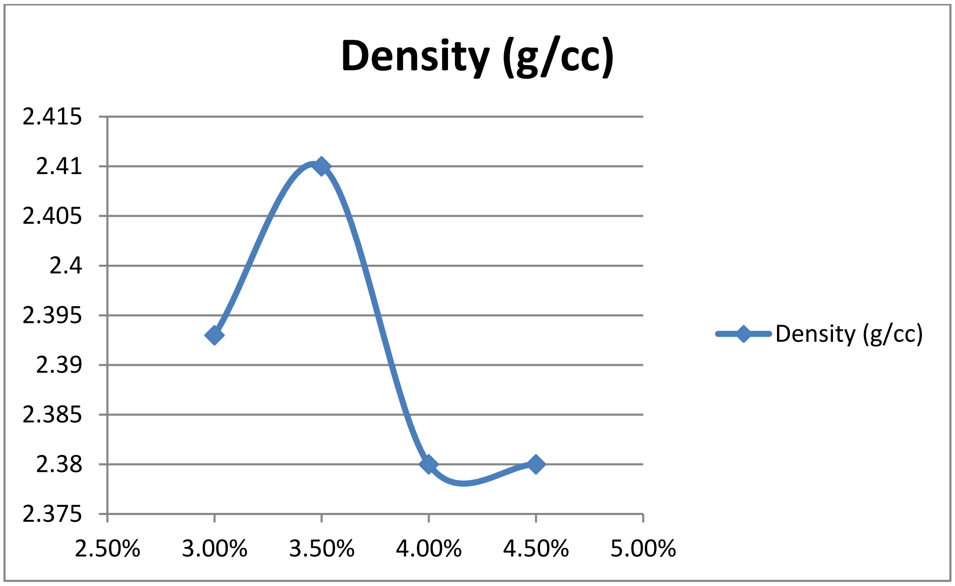
Table 4.5. Marshall Parameters Determined for Base course Compacted.

Percentage	3.00%	3.50%	4.00%	4.50%
Stability (kg)	2934	3126	2963	2782
Flow (mm)	4.4	4.5	4.9	5.3
Density (g/cc)	2.393	2.41	2.38	2.38
% AV	5.06	3.42	2.48	2.01
% VMA	11.36	11.04	10.88	11.8
% VFA	54	67.34	77.44	80.28

Fig 4.7. to 4.12. Marshal Mix Design Graph for Base course.






Density (g/cc)
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2.405
2.4
2.395
2.39
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2.38
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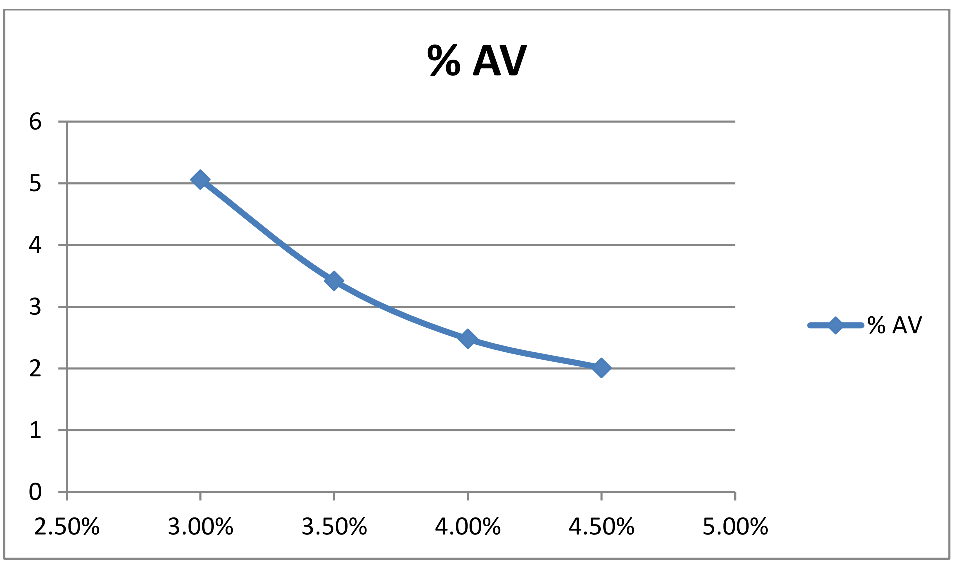
2.50%
3.00%
3.50%
4.00%
4.50%
5.00%
Density (g/cc)


% AV
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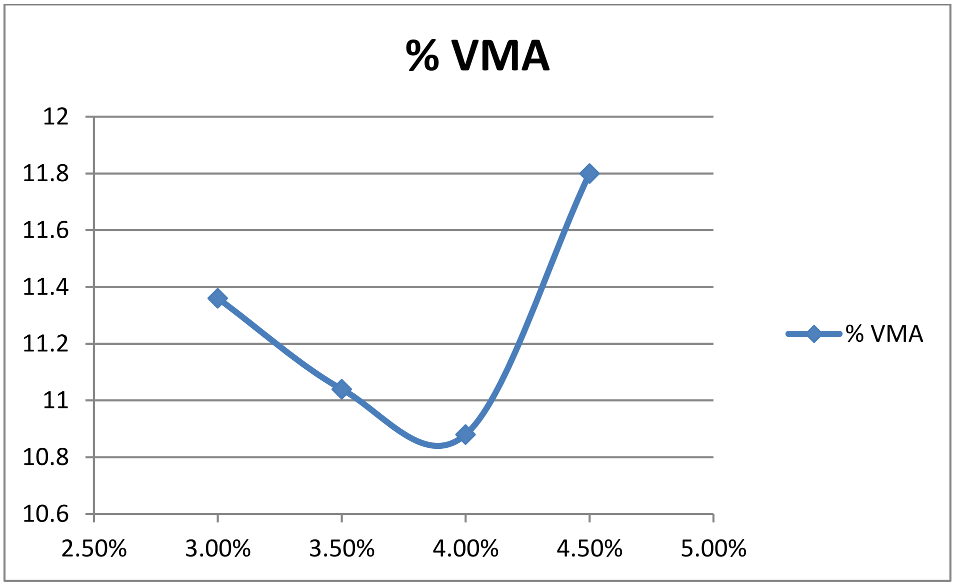
5
4
3
2
1
0
2.50%
3.00%
3.50%
4.00%
4.50%
5.00%
% AV


% VMA
12
11.8
11.6
11.4
11.2
11
10.8
10.6
2.50%
3.00%
3.50%
4.00%
4.50%
5.00%
% VMA

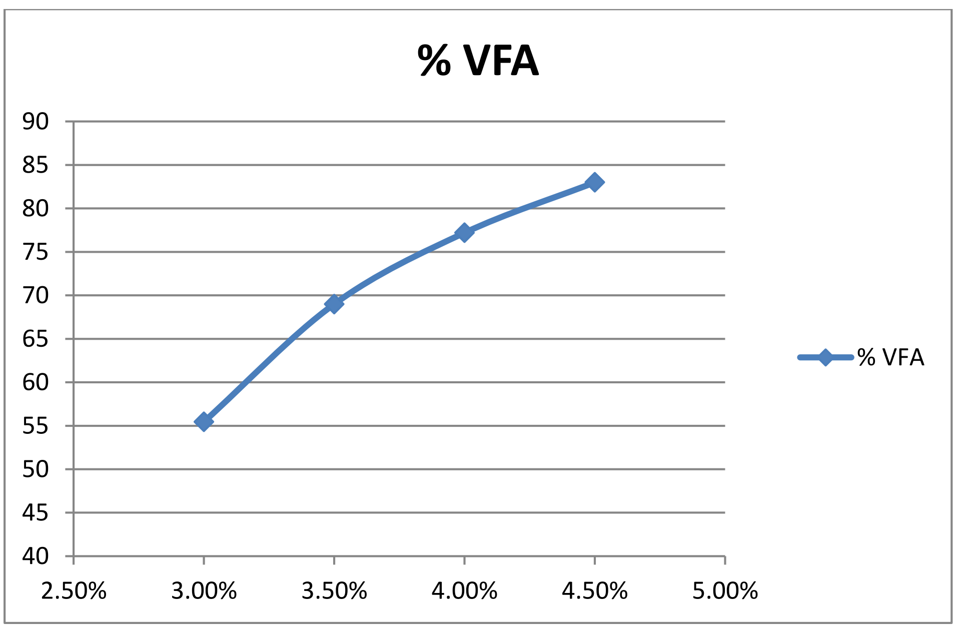

% VFA
90
85
80
75
70
65
60
55
50
45
40
2.50%
3.00%
3.50%
4.00%
4.50%
5.00%
% VFA

Table 4.6. Determination of Optimum Asphalt Content for base course

Marshall Mix Design Characteristic	Bitumen content (%)
Max Stability	3.5
Max Unit Weight	3.5
At 4.0% AV	3.2
Average	3.4 (OBC)

4.4. Performance Tests

In total two tests were conducted.

- Indirect Tensile Strength Test on Universal Testing Machine
- Resilient Modulus Test on Universal Testing Machine

4.4.1 Indirect Tensile Strength

The test was followed as according to ASHTOD6931. The Test was performed on Universal Testing Machine. The Base Course Sample had to be cut with help of saw to a 62.5 mm thickness according to the standard so that it could fit in the machine plate. A total of 2 sample for Wearing and 2 for Base course were prepared. The Specimens were placed horizontally in the machine and the load applied till failure and the peak load noted. The table shows the result of ITS test.

Table 4.7. ITS result on UTM Machine.

Layer	Specimen Size (mm)	Mean Size (mm) (h)	Diameter (mm) (D)	Peak Load (N)	Mean load (N) (P)	Tensile Strength (N)
Wearing	63.1	63.35	101.6	8724	8443	835.52
Wearing	63.6		101.6	8186		
Base	63.9	63.45	152.4	9041	8814	580.6
Base	63.3		152.4	8587		

After the Test the Tensile Strength of each course was calculated the formula:

Indirect Strength=$\frac{2000P}{\pi Dh}$

Where:

p= peak load

D= Diameter of sample

h= Height of sample.

4.4.2 Resilient Modulus Test

This was the last test performed and the standard followed was ASHTO D7369-09. The Universal Testing Machine was used for this test and the sample of 6 inch had to be cut down the same was as in ITS test to a 62.5 mm and placed horizontally in the machine. Before placing the sample, the temperature in the vacuum chamber was adjusted at 25 ®C and the samples were put in the chamber for about 2 hours before test. 20% of peak load of ITS test was taken as input to the machine and a total of 100 conditioning pulses were applied on the sample as according to the Standard and then the last 5 pulses were recorded and their mean taken.

Table 4.8. Resilient Modulus Result.

	Base Course Resilient Modulus (Mpa)	**Wearing Course Resilient Modulus (Mpa)**
Pulse 1	3663	3290
Pulse 2	3587	3241
Pulse 3	3571	3161
Pulse 4	3556	3055
Pulse 5	3513	2983
Mean	**3578**	**3146**

As the Modulus of Base Course turned out to be greater than the Wearing Course, it contradicted the law of modulus Elasticity which states that the upper layer Modulus should always be more than the lower layer. For this reason, NHA B gradation was then used for Base layer. The Modulus of NHA B Base Course Asphaltic was obtained from previous researches as 2758 MPa.

4.5. KenPave Software

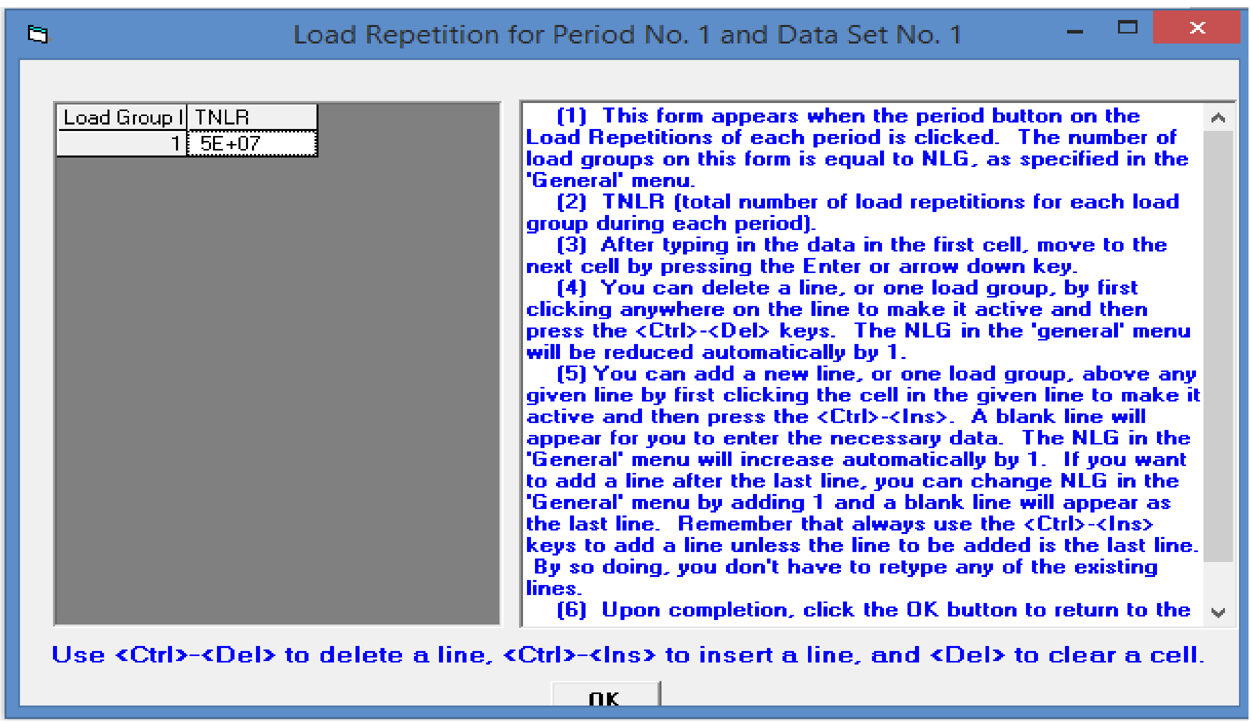
After Resilient Modulus test, its results were used in this software to determine design life of Perpetual Pavement by calculating the tensile and compressive forces upon the road due to given numbers of ESAL's. Other inputs include:

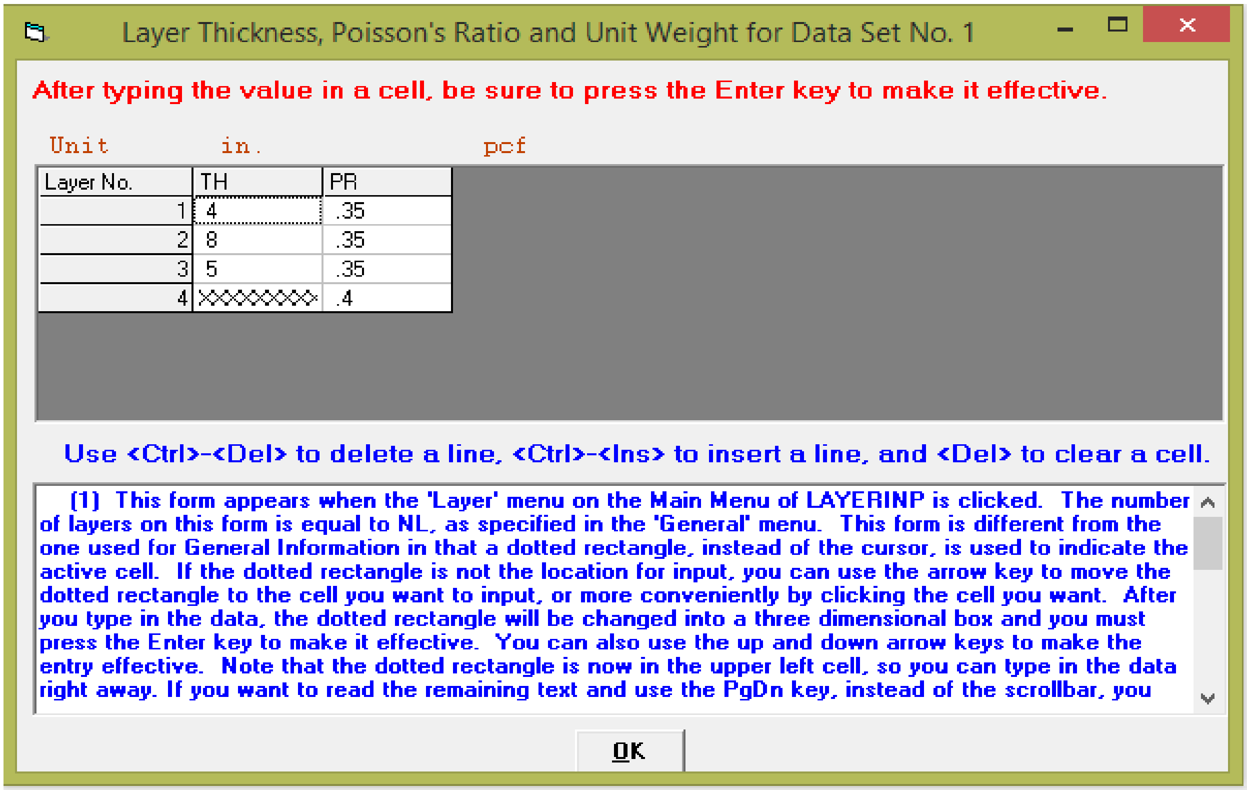
- Thicknesses of each layer.
- Poison's Ratio of each layer.
- Number of ESAL's.

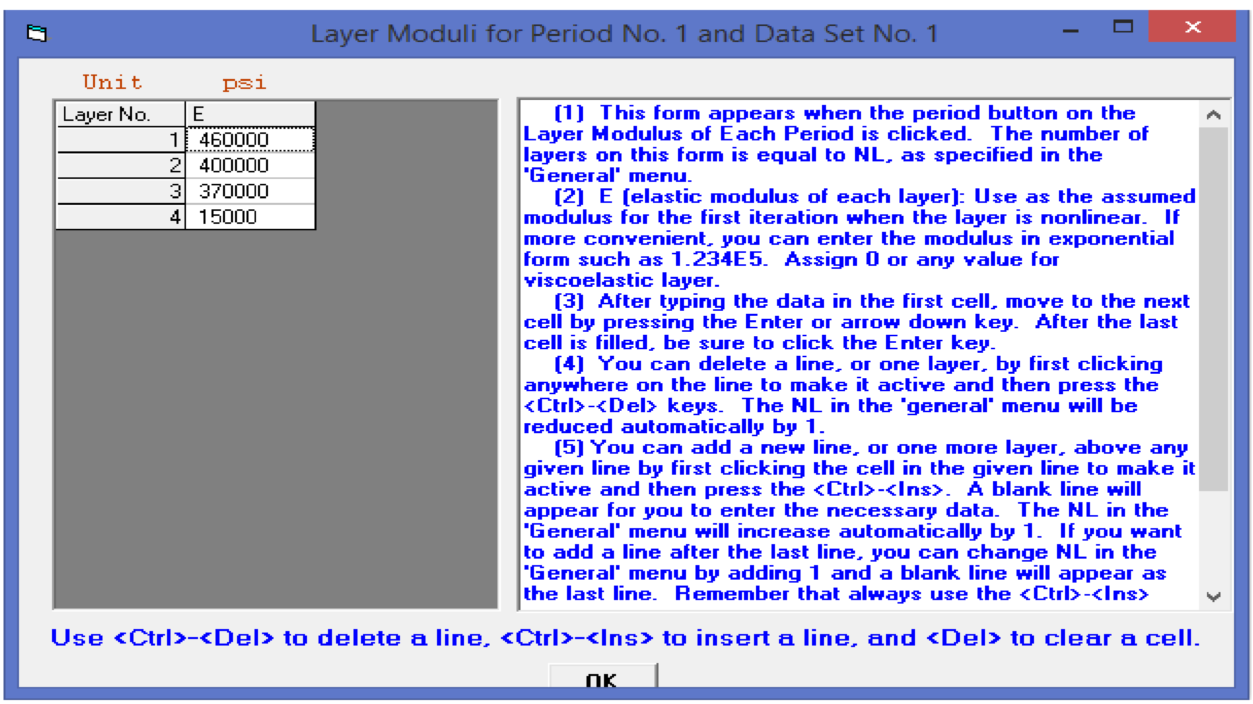
4.5.1 Use of KenPave on Perpetual Pavement

The Figure 4.17 to 4.20 shows the Inputs to the Software and Figure 4.20 shows the Result. The Design life came out to be 44 years from the software.

Figure 4.13 to Figure 4.16 For Perpetual Pavement




Layer Thickness, Poisson's Ratio and Unit Weight for Data Set No. 1
After typing the value in a cell, be sure to press the Enter key to make it effective.
Unit in. pcf
Layer No. TH PR
1 4 .35
2 8 .35
3 5 .35
4 XXXXXXXX .4
Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.
(1) This form appears when the 'Layer' menu on the Main Menu of LAYERINP is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. Note that the dotted rectangle is now in the upper left cell, so you can type in the data right away. If you want to read the remaining text and use the PgDn key, instead of the scrollbar, you
OK

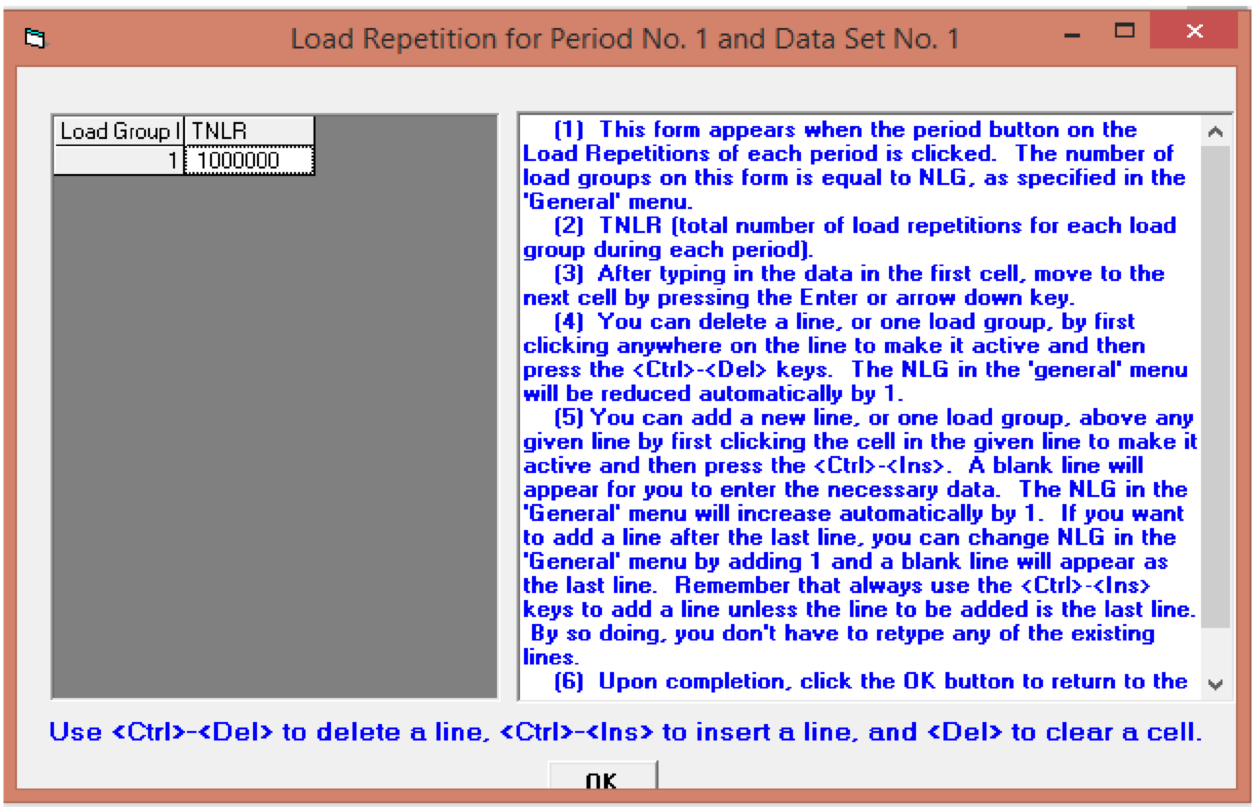

Layer Moduli for Period No. 1 and Data Set No. 1
Unit psi
Layer No. E
1 460000
2 400000
3 370000
4 15000
(1) This form appears when the period button on the Layer Modulus of Each Period is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu.
(2) E (elastic modulus of each layer): Use as the assumed modulus for the first iteration when the layer is nonlinear. If more convenient, you can enter the modulus in exponential form such as 1.234E5. Assign 0 or any value for viscoelastic layer.
(3) After typing the data in the first cell, move to the next cell by pressing the Enter or arrow down key. After the last cell is filled, be sure to click the Enter key.
(4) You can delete a line, or one layer, by first clicking anywhere on the line to make it active and then press the <Ctrl>-<Del> keys. The NL in the 'general' menu will be reduced automatically by 1.
(5) You can add a new line, or one more layer, above any given line by first clicking the cell in the given line to make it active and then press the <Ctrl>-<Ins>. A blank line will appear for you to enter the necessary data. The NL in the 'General' menu will increase automatically by 1. If you want to add a line after the last line, you can change NL in the 'General' menu by adding 1 and a blank line will appear as the last line. Remember that always use the <Ctrl>-<Ins>
Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.
OK

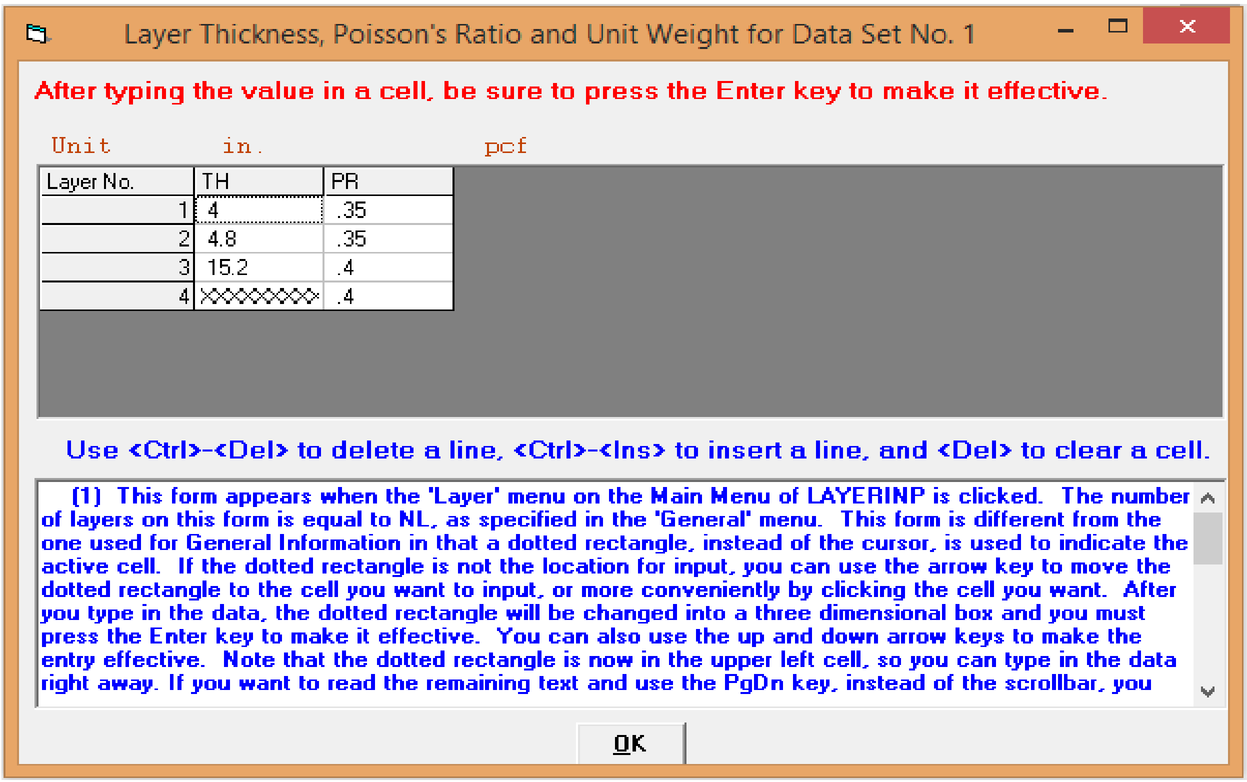
```
FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :    1  4.600E+05   2  4.000E+05
   3  3.700E+05   4  1.500E+04

LOAD GROUP NO. 1 HAS 1 CONTACT AREA
CONTACT RADIUS (CR)--------------- =  5
CONTACT PRESSURE (CP)------------- =  80
RADIAL COORDINATES OF  15  POINT(S) (RC) ARE :  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0

NUMBER OF LAYERS FOR BOTTOM TENSION (NLBT)---- =  1
NUMBER OF LAYERS FOR TOP COMPRESSION (NLTC)--- =  1
LAYER NO. FOR BOTTOM TENSION (LNBT) ARE: 2
LAYER NO. FOR TOP COMPRESSION (LNTC) ARE: 3

LOAD REPETITIONS (TNLR) IN PERIOD 1  FOR EACH LOAD GROUP ARE : 5E+07

DAMAGE COEF.'S (FT) FOR BOTTOM TENSION OF LAYER 2  ARE: 0.0796  3.291  0.854

DAMAGE COEFICIENTS (FT) FOR TOP COMPRESSION OF LAYER 3  ARE:  1.365E-09 4.477

DAMAGE ANALYSIS OF PERIOD NO.  1  LOAD GROUP NO.  1

AT BOTTOM OF LAYER  2   TENSILE STRAIN =  -2.404E-05
ALLOWABLE LOAD REPETITIONS =   2.080E+09  DAMAGE RATIO =   2.403E-02

AT TOP OF LAYER  3   COMPRESSIVE STRAIN =   4.229E-05
ALLOWABLE LOAD REPETITIONS =   5.208E+10  DAMAGE RATIO =   9.601E-04

******************************
* SUMMARY OF DAMAGE ANALYSIS *
******************************
AT BOTTOM OF LAYER  2     SUM OF DAMAGE RATIO = 2.403E-02
AT TOP OF LAYER  3        SUM OF DAMAGE RATIO = 9.601E-04

MAXIMUM DAMAGE RATO =   2.403E-02   DESIGN LIFE IN YEARS = 44.61
```

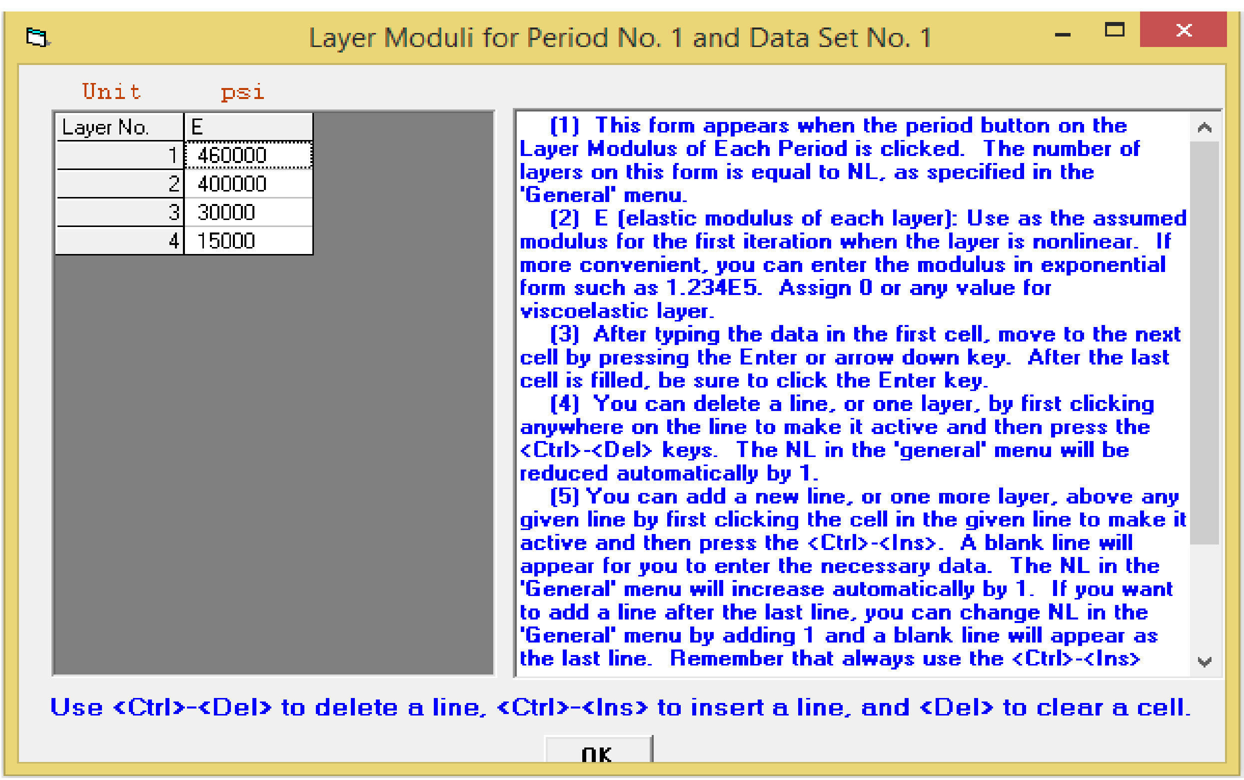
4.5.2 Use of KenPave on M3 Motorway section Abdul Hakeem to Lahore

The Figure 4.21 to 4.23 shows the Inputs to the Software and Figure 4.24 shows the Result. The Design life came out to be 12 years from the software.

Figure 4.17 to Figure 4.20 For M3 Motorway




Layer Thickness, Poisson's Ratio and Unit Weight for Data Set No. 1
After typing the value in a cell, be sure to press the Enter key to make it effective.
Unit in. pcf
Layer No. TH PR
1 4 .35
2 4.8 .35
3 15.2 .4
4 .4
Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.
(1) This form appears when the 'Layer' menu on the Main Menu of LAYERINP is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu. This form is different from the one used for General Information in that a dotted rectangle, instead of the cursor, is used to indicate the active cell. If the dotted rectangle is not the location for input, you can use the arrow key to move the dotted rectangle to the cell you want to input, or more conveniently by clicking the cell you want. After you type in the data, the dotted rectangle will be changed into a three dimensional box and you must press the Enter key to make it effective. You can also use the up and down arrow keys to make the entry effective. Note that the dotted rectangle is now in the upper left cell, so you can type in the data right away. If you want to read the remaining text and use the PgDn key, instead of the scrollbar, you
OK


Layer Moduli for Period No. 1 and Data Set No. 1
Unit psi
Layer No. E
1 460000
2 400000
3 30000
4 15000
(1) This form appears when the period button on the Layer Modulus of Each Period is clicked. The number of layers on this form is equal to NL, as specified in the 'General' menu.
(2) E (elastic modulus of each layer): Use as the assumed modulus for the first iteration when the layer is nonlinear. If more convenient, you can enter the modulus in exponential form such as 1.234E5. Assign 0 or any value for viscoelastic layer.
(3) After typing the data in the first cell, move to the next cell by pressing the Enter or arrow down key. After the last cell is filled, be sure to click the Enter key.
(4) You can delete a line, or one layer, by first clicking anywhere on the line to make it active and then press the <Ctrl>-<Del> keys. The NL in the 'general' menu will be reduced automatically by 1.
(5) You can add a new line, or one more layer, above any given line by first clicking the cell in the given line to make it active and then press the <Ctrl>-<Ins>. A blank line will appear for you to enter the necessary data. The NL in the 'General' menu will increase automatically by 1. If you want to add a line after the last line, you can change NL in the 'General' menu by adding 1 and a blank line will appear as the last line. Remember that always use the <Ctrl>-<Ins>
Use <Ctrl>-<Del> to delete a line, <Ctrl>-<Ins> to insert a line, and <Del> to clear a cell.
OK

```
FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :    1  4.600E+05   2  4.000E+05
   3  3.000E+04   4  1.500E+04

LOAD GROUP NO. 1 HAS 1 CONTACT AREA
CONTACT RADIUS (CR)--------------- =  5
CONTACT PRESSURE (CP)------------- =  80
RADIAL COORDINATES OF  15  POINT(S) (RC) ARE :  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0

NUMBER OF LAYERS FOR BOTTOM TENSION (NLBT)---- =  1
NUMBER OF LAYERS FOR TOP COMPRESSION (NLTC)--- =  1
LAYER NO. FOR BOTTOM TENSION (LNBT) ARE: 2
LAYER NO. FOR TOP COMPRESSION (LNTC) ARE: 3

LOAD REPETITIONS (TNLR) IN PERIOD 1  FOR EACH LOAD GROUP ARE : 1000000

DAMAGE COEF.'S (FT) FOR BOTTOM TENSION OF LAYER 2  ARE: 0.0796  3.291  0.854

DAMAGE COEFICIENTS (FT) FOR TOP COMPRESSION OF LAYER 3  ARE:  1.365E-09 4.477

DAMAGE ANALYSIS OF PERIOD NO.  1  LOAD GROUP NO.  1

AT BOTTOM OF LAYER  2   TENSILE STRAIN =  -1.064E-04
ALLOWABLE LOAD REPETITIONS =   1.556E+07  DAMAGE RATIO =   6.427E-02

AT TOP OF LAYER  3   COMPRESSIVE STRAIN =   2.713E-04
ALLOWABLE LOAD REPETITIONS =   1.267E+07  DAMAGE RATIO =   7.895E-02

******************************
* SUMMARY OF DAMAGE ANALYSIS *
******************************
AT BOTTOM OF LAYER  2     SUM OF DAMAGE RATIO = 6.427E-02
AT TOP OF LAYER  3        SUM OF DAMAGE RATIO = 7.895E-02

MAXIMUM DAMAGE RATO =   7.895E-02   DESIGN LIFE IN YEARS = 12.67
```

The Thickness, Poison Ratio and Resilient Modulus of Perpetual and M3 Motorway Section Abdul Hakeem to Lahore are also tabulated below which were used in the software. The value of subgrade was taken as standard 15000 psi which has a max value of 20000 psi.

Table 4.9. Perpetual Pavement Inputs

Layer	Thickness (in)	Poison's Ratio	Modulus （ E ） in Psi
Wearing Course	4	0.35	460,000
Base Course	8	0.35	400,000
Asphaltic Sub Base	5	0.35	370,000
Subgrade	Standard (by Software)	0.40	15,000

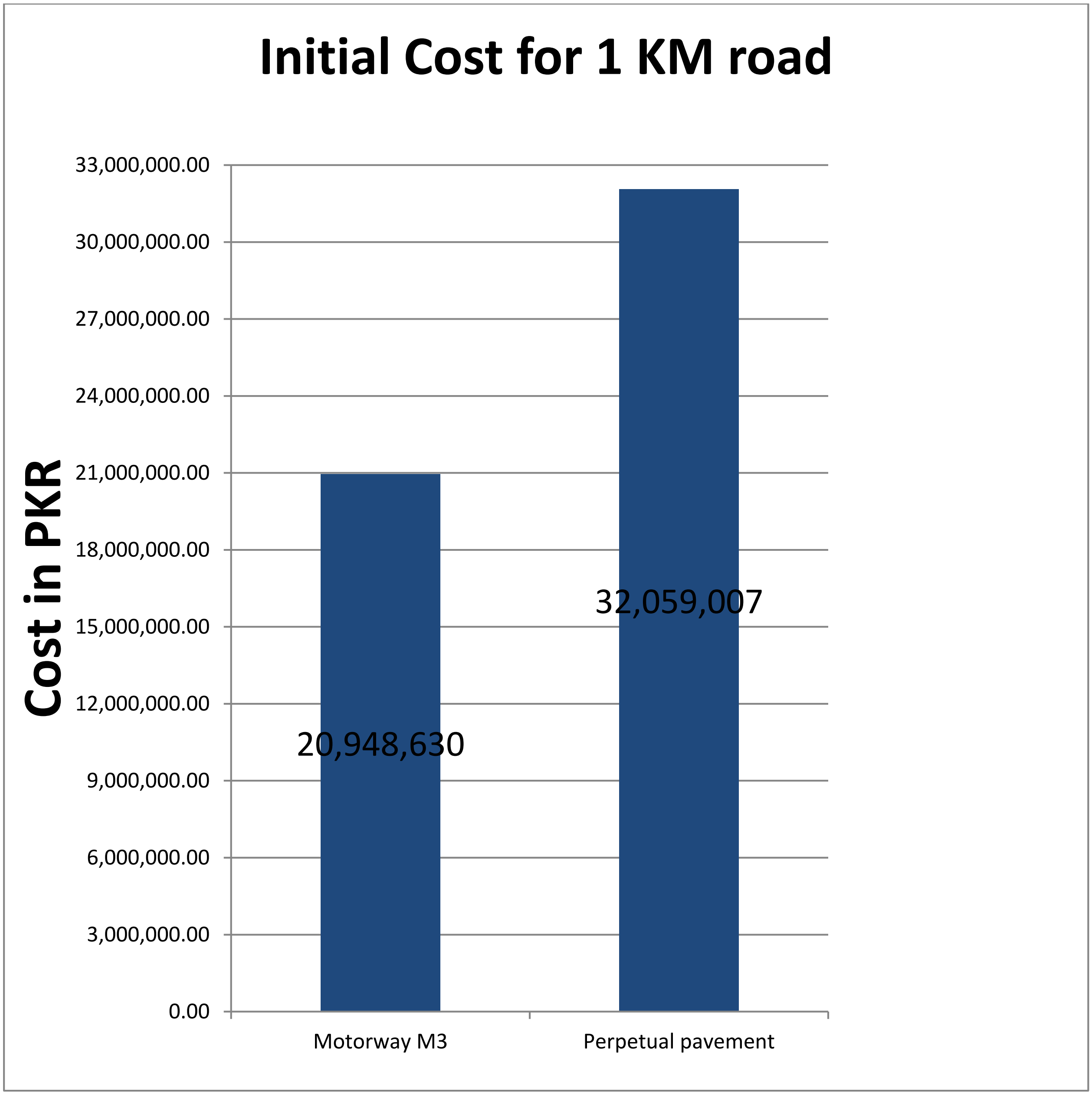
Table 4.10. M3 Motorway Inputs

Layer	Thickness (in)	Poison's Ratio	Modulus （ E ） in Psi
Wearing Course	4	0.35	460,000
Base Course	4.8	0.35	400,000
Sub Base	15.2	0.40	30,000
Subgrade	Standard (by Software)	0.40	15,000

4.6. Price Comparison of Perpetual Pavement and M3

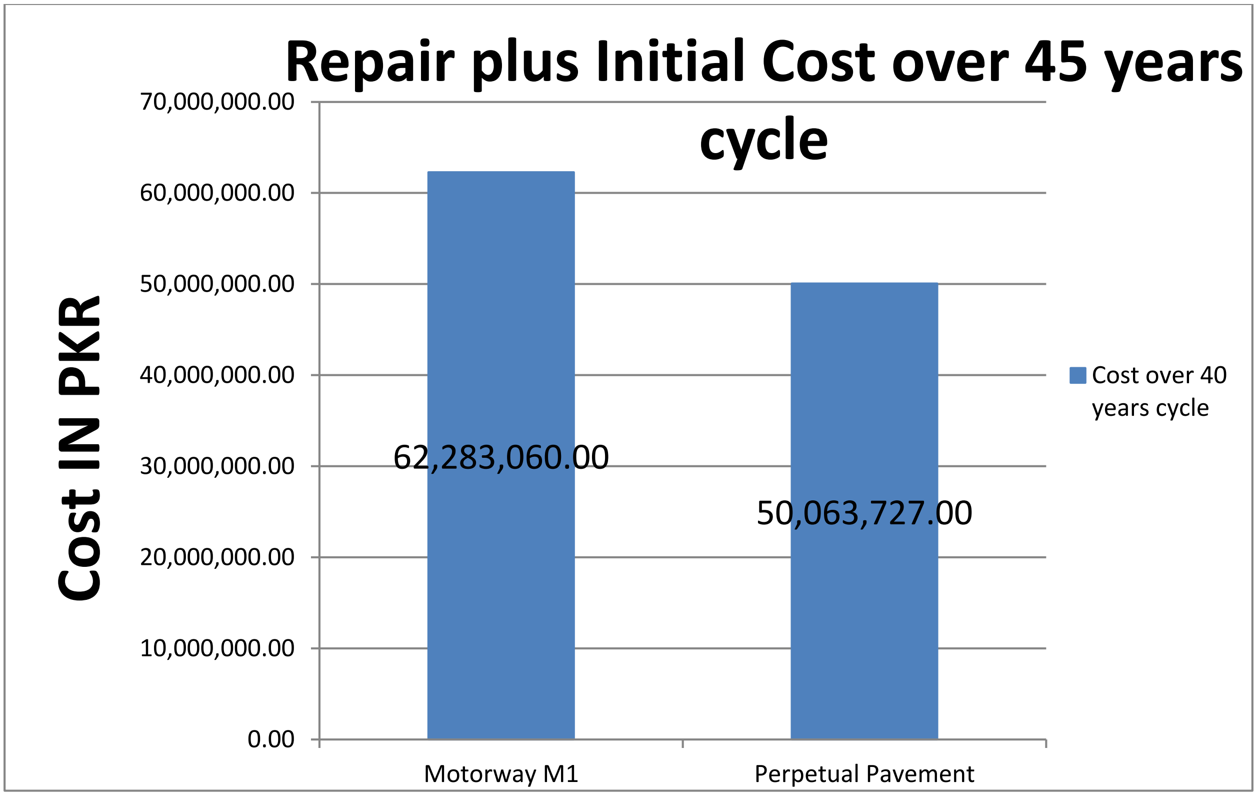
NHA composite schedule of rates 2015 was used to determine the price of each road section of 1 km. Also cost over 45 years life cycle was calculated. A total of 4 layers and coating cost were determined. Layers costs were given in Cubic Meters and in case of coating in Square Meters. They were multiplied with the respective depth, thickness and length in meters to calculate the total cost in Pakistani Rupees and the results are illustrated in the graphs. For the 45 years life cycles it was taken that wearing course had to be replaced twice for perpetual pavement after 15 years while for M3 the whole road section from sub grade to wearing has to rehabilitated and reconstructed fully 2 times in 45 years after initially constructed. These life cycles of 15 years were taken from prior researches.

Figure 4.21 Initial Cost of 1 KM road



.

Figure 4.22 Cost over 45 Years life Cycle including initial and repair costs.



4.7 Summary

In this Chapter the detailed analysis of the results of the tests performed were discussed and shown either in form of tables or graphs. The standard and the procedure were also discussed in detailed and so was the reason to change from NHA class A to class B explained. The results were put in KenPave and the procedure and inputs required were discussed. In last after the design life was obtained we used M3 Motorway classification in the same software to compare how both pavements will react over time against traffic and then lastly with those design lives we did an analysis of the cost of the pavements that gave us an overview of the total cost against life of the pavement. Perpetual Pavement turned out to be costlier while initially constructed but in 45 years' time it would save up to 12 million rupees per KM if used as alternative to M3 Motorway.

Chapter 5

CONCLUCIONS AND RECOMMENDATIONS

5.1. Summary

The project was aimed to perform a performance evaluation of the perpetual asphalt pavement designs and the conventional asphalt pavement designs that would validate the costs and benefits of perpetual pavement designs in terms of technical, economic and environmental aspects. The need to quantify the perpetual pavement design performance was established by using pavement structural evaluation software KENPAVE to predict the pavement performance in the form of design life cycle as we look to control rutting depth, bottom-up fatigue cracking propagation, and permanent deformations in pavement sections. In addition, the design lives and the estimates of initial cost and the estimates of life cycle cost of the perpetual asphalt pavement and conventional asphalt pavement were to be determined.

5.2. Conclusions

The conclusions that were drawn from the test results and the software analysis conducted in the previous sections are as follows:

- Perpetual pavements have a service life much longer than the conventional asphalt pavements. The life of the perpetual pavement is estimated to be 44 years and compared to the 12 years of life estimated for the conventional asphalt pavement.

- The life of the perpetual pavement is at least three times longer than that of the convention asphalt pavement.
- The initial cost of the perpetual pavement is much higher than that of the conventional asphalt pavement due to the use of asphaltic base and sub base as compared to the granular ones.
- The repairing time can be considerably reduced as on the top layer has to be repaired.
- The perpetual pavement is designed for heavy traffic and high volumes so it can be used as an alternative to the reinforced rigid pavement.
- Any rigid pavement substituted by the asphalt pavement has the following advantages:
  - ➢ Asphalt is highly recyclable.
  - ➢ More environment friendly.
  - ➢ Asphalt has rougher surface and provides more skid resistance adding safety
  - ➢ Provides a better visual contrast with road lines and other markings

5.3. Recommendations

- A gradation needs to be developed for the asphaltic sub base as it is not available in Pakistani standards
- Further research should be conducted to provide a comparison between rigid and perpetual pavement to make it more environment friendly.

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APPENDIX

WEARING COURSE - 19 MM NOMINAL AGGREGATE SIZE

Table A-1 Marshal Test Result of 19 mm Nominal Aggregate Size Obtaining Optimum Bitumen Content-60/70 Grade

Bulk Specific Gravity of Aggregate = 2.61

Max Specific Gravity of Mix = 2.5481

Water Bath Temperature = 60ºC

Compaction Criteria = 75 Blows

Sample Nos	Bitumen Content (%)	Weight in Air (gms)	Weight in SSD (gms)	Weight in Water (gms)	Volume of Specimen (cc)	Theoretical Density (gms/cc)	Bulk Density (gmb/cc)	Percent Air Voids (%)	Voids in Mineral Agg (%)	Voids Filled with Bitumen (%)	Stability (kg)	Corrected Stability (kg)	Flow (mm)
1	3.5	1208.4	1214.3	702.6	531.2	2.548	2.363	6.4	13.92	54.0	1311	1276	2.7
2	3.5	1206.3	1213.2	698.3	530.8	2.548	2.373	6.49	14.00	53.6	1285	1224	2.3
3	3.5	1212.9	1221.7	704.8	527.4	2.548	2.338	6.29	14.18	55.7	1297	1264	2.5
Average							2.358	6.39	14.00	54		1257	2.5

WEARING COURSE - 19 MM NOMINAL AGGREGATE SIZE

Table A-1 Marshal Test Result of 19 mm Nominal Aggregate Size for Obtaining Optimum Bitumen Content-60/70 Grade

Bulk Specific Gravity of Aggregate = 2.61

Max Specific Gravity of Mix = 2.530

Water Bath Temperature = 60ºC

Compaction Criteria = 75 Blows

Sample Nos	Bitumen Content (%)	Weight in Air (gms)	Weight in SSD (gms)	Weight in Water (gms)	Volume of Specimen (cc)	Theoretical Density (gms/cc)	Bulk Density (gmb/cc)	Percent Air Voids (%)	Voids in Mineral Agg (%)	Voids Filled with Bitumen (%)	Stability (kg)	Corrected Stability (kg)	Flow (mm)
1	4.0	1210.4	1215.1	702.6	533.2	2.530	2.376	5.31	14.05	62.2	1379	1351	2.5
2	4.0	1204.2	1212.2	698.3	530.2	2.530	2.413	5.14	14.24	63.9	1402	1372	2.6
3	4.0	1197.4	1202.1	704.8	527.5	2.530	2.338	5.23	14.15	63.2	1388	1362	2.6
Average							2.374	5.20	14.11	63.1		1360	2.6

WEARING COURSE - 19 MM NOMINAL AGGREGATE SIZE

Table A-1 Marshal Test Result of 19 mm Nominal Aggregate Size for Obtaining Optimum Bitumen Content-60/70 Grade

Bulk Specific Gravity of Aggregate = 2.61

Max Specific Gravity of Mix = 2.510

Water Bath Temperature = 60ºC

Compaction Criteria = 75 Blows

Sample Nos	Bitumen Content (%)	Weight in Air (gms)	Weight in SSD (gms)	Weight in Water (gms)	Volume of Specimen (cc)	Theoretical Density (gms/cc)	Bulk Density (gmb/cc)	Percent Air Voids (%)	Voids in Mineral Agg (%)	Voids Filled with Bitumen (%)	Stability (kg)	Corrected Stability (kg)	Flow (mm)
1	4.5	1206.3	1214.2	699.3	531.7	2.510	2.331	3.05	14.09	78.4	1185	1166	2.1
2	4.5	1202.6	1209.9	696.3	529.4	2.510	2.363	3.85	13.63	71.7	1174	1154	2.2
3	4.5	1202.4	1209.2	696.1	528.6	2.510	2.325	4.11	13.44	70.9	1228	1196	2.6
Average							2.338	3.67	13.72	73.8		1172	2.3

WEARING COURSE - 19 MM NOMINAL AGGREGATE SIZE

Table A-1 Marshal Test Result of 19 mm Nominal Aggregate Size for Obtaining Optimum Bitumen Content-60/70 Grade

Bulk Specific Gravity of Aggregate = 2.61

Max Specific Gravity of Mix = 2.510

Water Bath Temperature = 60ºC

Compaction Criteria = 75 Blows

Sample Nos	Bitumen Content (%)	Weight in Air (gms)	Weight in SSD (gms)	Weight in Water (gms)	Volume of Specimen (cc)	Theoretical Density (gms/cc)	Bulk Density (gmb/cc)	Percent Air Voids (%)	Voids in Mineral Agg (%)	Voids Filled with Bitumen (%)	Stability (kg)	Corrected Stability (kg)	Flow (mm)
1	5.0	1195.1	1202.3	695.2	527.4	2.477	2.431	2.53	13.83	81.71	1059	1059	2.9
2	5.0	1207.3	1212.5	698.7	531.5	2.477	2.367	2.21	13.91	84.11	1045	1045	2.6
3	5.0	1202.1	1209.8	695.4	529.1	2.477	2.432	2.76	13.66	79.80	1088	1088	2.6
Average							2.410	2.50	13.80	81.88		1063	2.7

WEARING COURSE - 19 MM NOMINAL AGGREGATE SIZE

Table A-1 Marshal Test Result of 19 mm Nominal Aggregate Size for Obtaining Optimum Bitumen Content-60/70 Grade

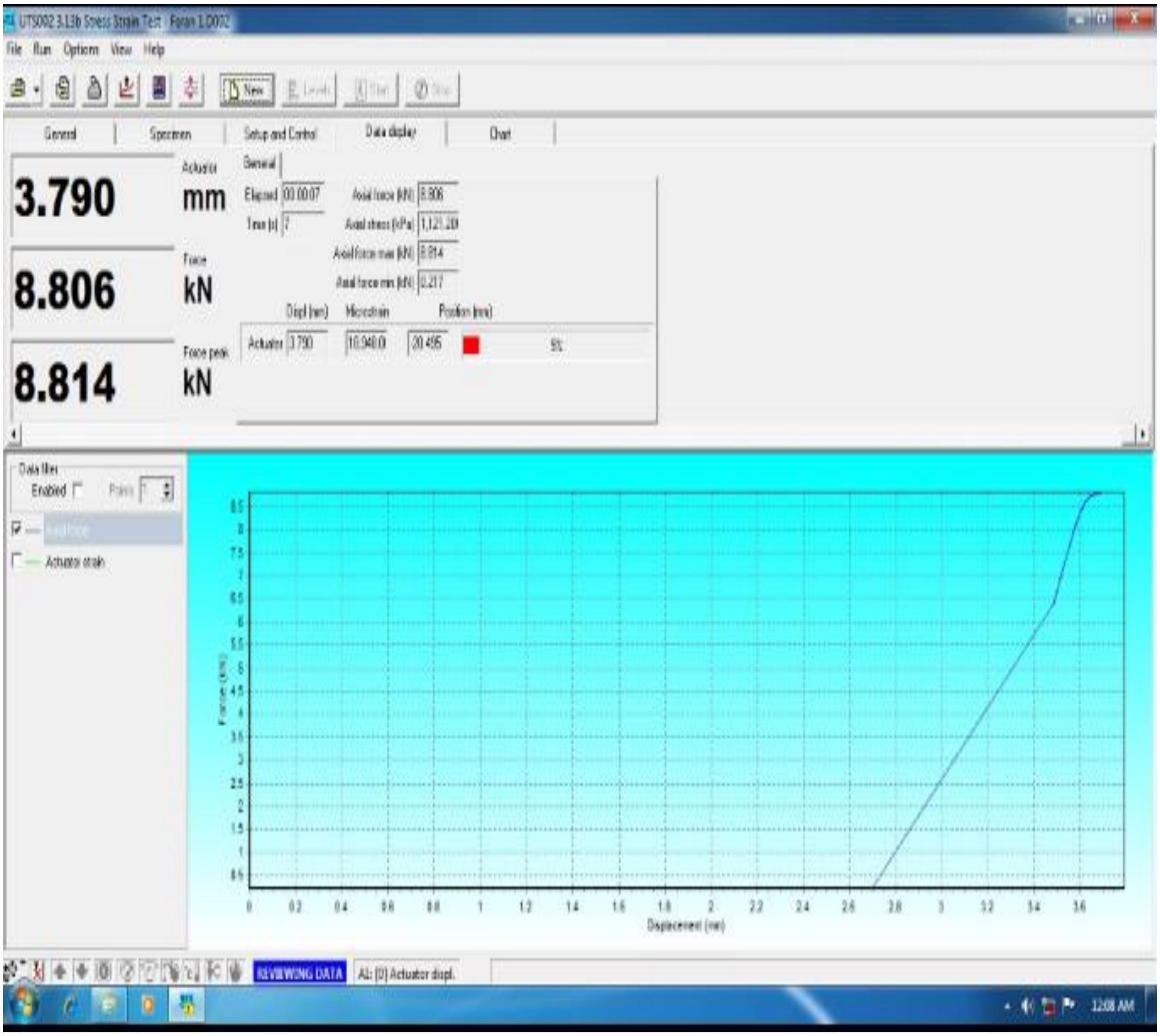
Bulk Specific Gravity of Aggregate = 2.61

Max Specific Gravity of Mix = 2.510

Water Bath Temperature = 60ºC

Compaction Criteria = 75 Blows

Sample Nos	Bitumen Content (%)	Weight in Air (gms)	Weight in SSD (gms)	Weight in Water (gms)	Volume of Specimen (cc)	Theoretical Density (gms/cc)	Bulk Density (gmb/cc)	Percent Air Voids (%)	Voids in Mineral Agg (%)	Voids Filled with Bitumen (%)	Stability (kg)	Corrected Stability (kg)	Flow (mm)
1	5.5	1199.6	1204.9	698.1	527.4	2.451	2.370	2.07	15.31	86.47	1059	913	2.8
2	5.5	1200.7	1205.2	699.1	531.5	2.451	2.419	2.04	14.29	85.72	1045	922	2.6
3	5.5	1208.3	1215.4	702.6	529.1	2.451	2.411	2.43	14.23	82.92	1088	1006	3.0
Average							2.400	2.18	14.61	85.07		947	2.8



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New
General
Specimen
Setup and Control
Data display
Chart
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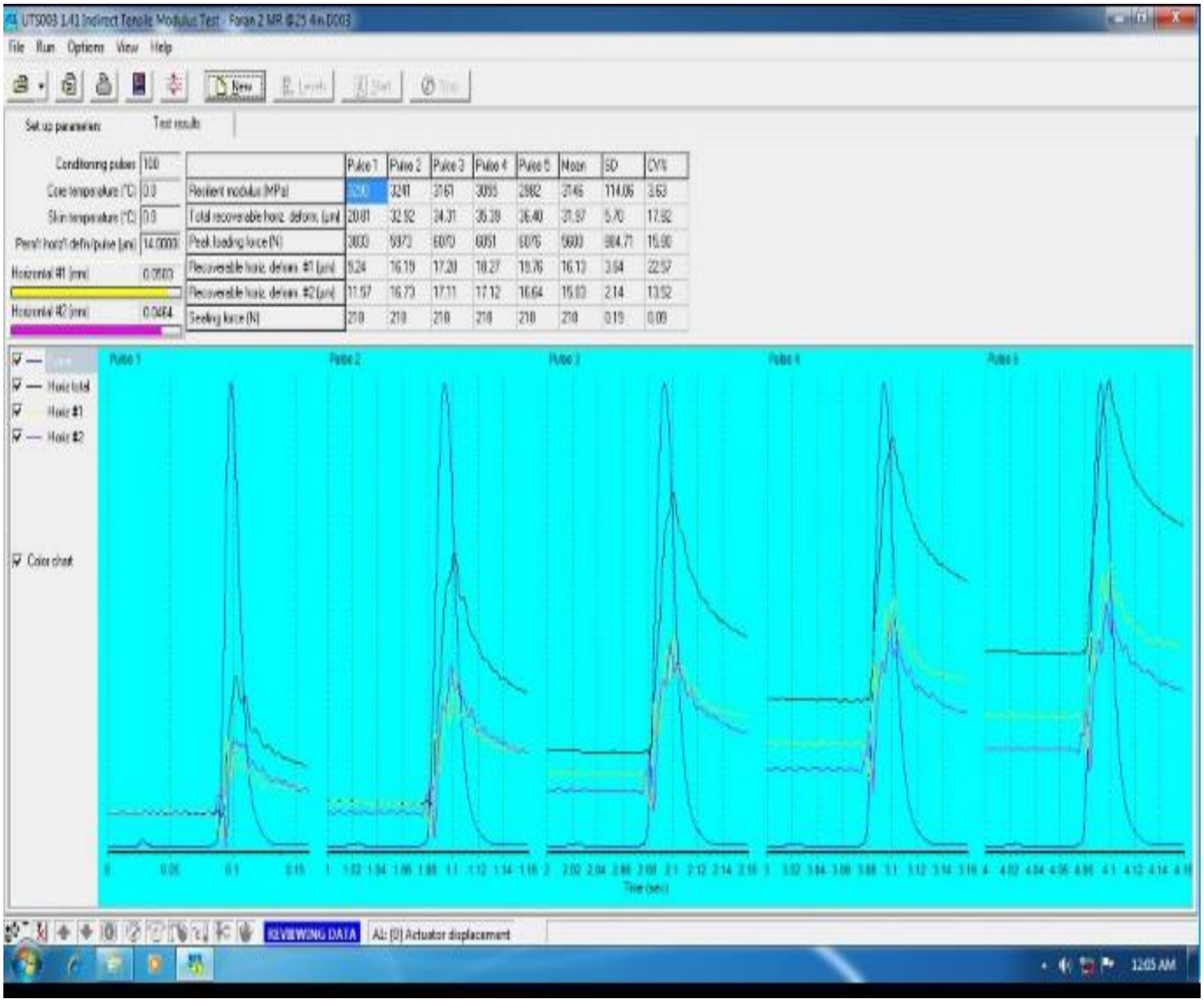
Actuator
mm
8.806
Force
kN
8.814
Force peak
kN
Actuator
Displacement (mm)
REVIEWING DATA


File Run Options View Help
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Set up parameters
Test results
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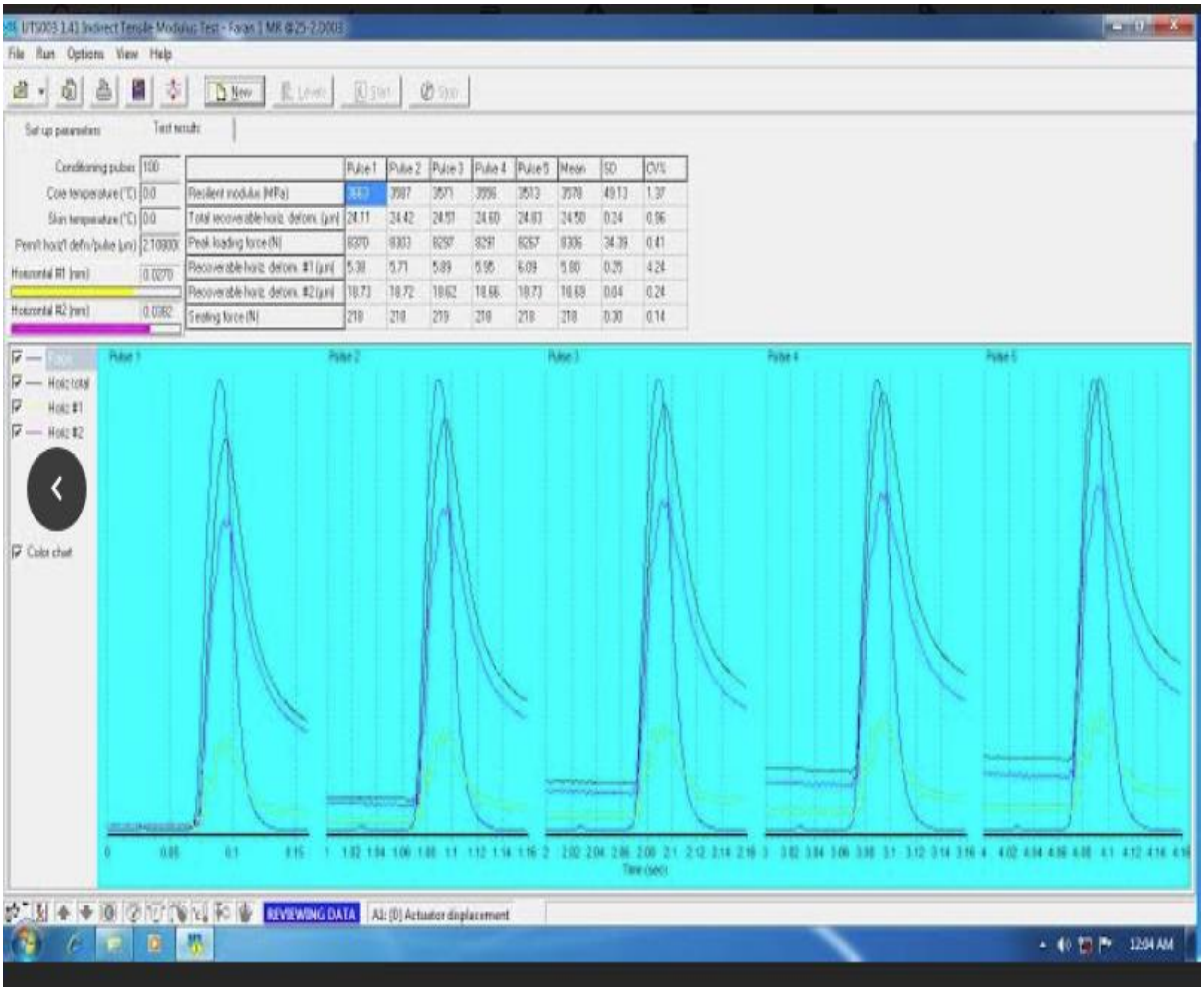
Horizontal #1 (mm) 0.0503
Horizontal #2 (mm) 0.0464
Pulse 1
Pulse 2
Pulse 3
Pulse 4
Pulse 5
Mean
SD
CV%
Resilient modulus (MPa)
Total recoverable horiz. deform. (µm)
Peak loading force (N)
Recoverable horiz. deform. #1 (µm)
Recoverable horiz. deform. #2 (µm)
Seating force (N)
Horiz total
Horiz #1
Horiz #2
Color chart
Time (sec)
REVIEWING DATA
AI: (0) Actuator displacement


UTS003 1.41 Indirect Tensile Modulus Test
File Run Options View Help
Set up parameters
Test results
Conditioning pulses
Core temperature (°C)
Skin temperature (°C)
Resilient modulus (MPa)
Total recoverable horiz. deform. (µm)
Peak loading force (N)
Recoverable horiz. deform. #1 (µm)
Recoverable horiz. deform. #2 (µm)
Seating force (N)
Pulse 1
Pulse 2
Pulse 3
Pulse 4
Pulse 5
Mean
SD
CV%
Horiz total
Horiz #1
Horiz #2
Color chart
Time (sec)
REVIEWING DATA
A1: (0) Actuator displacement