ACCELERATED TESTING METHODOLOGY FOR EVALUATING PAVEMENT PATCHING MATERIALS

by
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Abstract

This research describes a proposed accelerated testing procedure for evaluating pavement patching materials under the simulation of traffic loading and environmental conditions such as freeze-thaw cycles. Potholes were constructed in concrete blocks with different tilt angles (13˚, 17˚ and 22˚) to simulate normal and shear wheel surface stresses. Different patching materials, including hot mix, cold mix and commercial cold patch were tested.

Various cyclic loads accompanied with cycles of freezing and thawing were applied to the patch. Patch performance is assessed by visual monitoring of the surface distresses and measuring surface elevation for rutting and shoving determination. Applied vertical loads varied between 2,250 and 4,500 pounds at a frequency of 2 Hz. Patch performance comparisons were made as a function of the patch mix, applied load, number of applied loads, frequency of loading, and applied freeze/thaw cycles. The new method of accelerated testing is successful in differentiating the performance of good and poor quality mixes. The proposed test could be used as a reliable method by state highway agencies for establishing acceptance criteria for selecting pothole patching mixtures.

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1 Introduction

Most of the pavements placed throughout United States have shown some type of deterioration such as rutting, fatigue cracking and thermal cracking. Rutting has been recognized as one of the most common problems affecting pavements. Rutting or permanent deformation in pavements become a serious problem all around the world. Rutting affects the performance of asphalt mixtures in particular Hot Mix Asphalt (HMA). At the same time it symbolizes a serious safety issue because the possibility of hydroplaning when water accumulates in ruts. Rutting can be defined as the "accumulation of small amounts of unrecoverable strain resulting from loads acting on the pavement"(1). As a result it can be considered as a distress mechanism in the pavement, which is time dependent. Rutting and shoving has increased in highways due to high increment in vehicle load and volume of traffic. The creation of radial tires which can handle higher pressures will produce an increase in rutting and shoving of pavements. The only way to prevent rutting is by optimizing the structural and material design specifications. In a well-designed mix pavement, the rutting and shoving distresses take years to develop. Therefore, the development of an accelerated testing procedure to evaluate pavement performance is required.

The major objective in this research is to investigate an accelerated testing method to assess performance of asphalt patching materials. Since there is no mechanistic test available to test patching materials and the possibilities of the patch to withstand rutting effects the implementation of this testing procedure can help pavement engineers to better understand the mix performance under traffic loads. Most of the tests available for asphalt performance are mainly based on material properties. By using the proposed testing procedure will allow for prediction of rutting which will allow for better design of pavement structures.

It has always been assumed that the higher the load the higher the rutting. This theory has been accepted for years. With this new testing procedure being studied in this research will allow a better understanding of how rutting and shoving is affected as normal and shear forces increases in pavements. Experts on the field have always show concern about how freezing and thawing affects the behavior and integrity of pavements. If this test proves to be successful it can save time and taxpayers money. It will allow simulating in a matter of hours real life scenarios which take years to develop under regular traffic and environmental conditions.

The study of various mixes was performed during this research in order to understand different material behaviors. HMA, Instant Road Repair and emulsion mixes were subjected to shear, normal stresses, and freezing and thawing cycles. All the mixes were tested at different angles, which will vary shear and normal stresses, however, the number cycles applied and the load remained constant.

2 Objective

The objective consists on a proposal of an accelerated experimental procedure for evaluating pavement patching materials under simulated traffic loading and environmental effects. Patch performance was assessed as a function of load and cycling temperatures by visual monitoring surface distresses and elevation measurements to demonstrate the existence of rutting and shoving.

3 Scope

The scope of work consisted on building concrete blocks with different angles in order to simulate different shear and normal forces. The concrete blocks are to be the host material for the patching mixes. Three different patching materials consisting of Hot Mix Asphalt (HMA), Instant Road Repair (IRR) and emulsion mix were tested on the Instron machine.

The HMA and emulsion mix were fabricated on our facility with aggregates obtained from an aggregate plant. The Instant Road Repair was obtained from International Roadway Research. In order to prepare the emulsion and HMA a sieve analysis was also performed in order to obtain the appropriate gradation to be used for the mix design. Once the right gradation was obtained, the aggregate was mixed with a PG 64-28 grade asphalt binder (from Aggregate Industries, Swampscott plant).

In order to compact in the pothole the materials to be tested, a steel roller was used. Each mix was rolled and then let each of them cure overnight in order to achieve appropriate bonding between the aggregates and the emulsifying agent.

4 Literature Review

According to the American Society of Testing Material (ASTM) asphalt can be defined as “a dark brown to black cementitious material in which the predominant constituents are bitumens which occur in nature or are obtained in the petroleum processing”(2). Asphalt is especially valuable to engineers due to the fact that it has a strong bonding between the aggregates. It is also readily adhesive and impermeable which makes it a highly waterproof material providing the mix with long life span. Today about 85% of the asphalt used throughout the world is refined from petroleum. Asphalt has a certain characteristic that when it is heated it acts as a lubricant, which allows the aggregate to be mixed, coated, and tightly-compacted forming a smooth and dense surface. After it cools down, the asphalt acts like glue which will hold the aggregate together. At this stage the behavior of asphalt can be termed as a viscoelastic material; since it will have both elastic and viscous characteristics which will depend on the temperature and the loading rate to which it is subjected.

4.1 Chemical Composition of Asphalt

“Asphalt is made from crude petroleum which is naturally formed from organic matter. This organic matter is subject to various changes of temperature and pressure for over millions of years” (2). Asphalt consists of petroleum derivates, such as carbon and hydrogen, which constitute about 90 to 95% by weight of the asphalt. This is the reason why it is also called hydrocarbon. The remaining portion consists of two types of atoms: heteroatoms and metals.

Nitrogen, oxygen and sulfur are heteroatoms which often replace carbon atoms in the asphalt molecular structure. This is the reason why the asphalt chemical and physical properties are unique. The crude petroleum and its exposure to aging will determine the amount and type of heteroatoms present in the asphalt.

Proper balance between polar and non-polar molecules tends to appear critical in the performance of the mix according to recent research. Asphalt which contains large quantities of high-molecular weight, non-polar molecules tend to exhibit poor low-temperature behavior or brittleness" (2).

Because its viscoelastic nature asphalt cement behavior depends on the temperature and the loading rate to which the asphalt is subjected. The effects of time and temperature are related and the asphalt behavior at high temperatures over short periods of time is similar to what occurs in long periods of time at lower temperatures. This is often known as the time-temperature shift or the superposition concept of asphalt cement.

When asphalt is subjected to high temperatures or under sustained loads asphalt tends to behave like a viscous liquid. Under these conditions the aggregates used will be the part of the Hot Mix Asphalt (HMA) that will bear the load. When asphalt is subjected to temperatures higher than 60°C it behaves like a Newtonian fluid. It is necessary to remember that Newtonians fluids have a linear relationship, which passes through the origin, between the resisting force and its relative velocity. The constant of proportionality is known as the viscosity.

Viscous liquids like Hot Asphalt (HA) are sometimes called plastic because once they start flowing, they don't tend to return to their original position. This is the main reason why in hot weather HMA pavements flow under repeated wheel load and rutting occurs. However, the type of aggregate used in the mix also affects how rutting occurs and therefore it is correct to say that the asphalt mixture is behaving like a plastic material.

When asphalt is subjected to low temperature and under rapidly applied loads, the asphalt cement behaves like an elastic solid. Elastic solids have the characteristic that when they are subjected to loads they deform and once the load is removed they will return to their original shape. However, if the asphalt is stressed beyond the material capacity of strength, it may break.

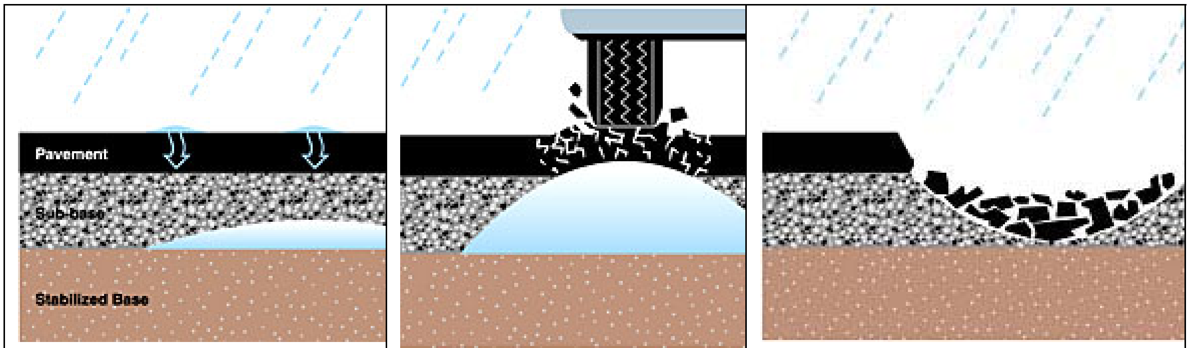
Asphalt cements are composed of organic molecules which will react with the oxygen present in the environment causing oxidation which will change the structure and composition of the asphalt making it brittle. This introduces the concept of oxidative hardening or age hardening. Oxidative Hardening occurs at a slow rate on pavements, however it occurs quicker on warmer weathers. Due to the hardening effect on pavements, cracks tend to appear on old asphalt first. Another factor that affects the oxidation of asphalt is the way it is compacted. When asphalt is inadequately compacted the amount of air voids in the asphalt is elevated, allowing air to enter the mix, which leads to a more oxidative hardening.

In real life a considerable amount of oxidative hardening occurs before the asphalt is placed. Other forms of hardening include volatilization and physical hardening. As the name implies volatilization hardening occurs during mixing and construction, when volatile components tend to evaporate from the asphalt. Meanwhile, physical hardening occurs when asphalt cements have been exposed to low temperatures for long periods of time.

Asphalt cement materials are commonly used all around the world to fabricate HMA. HMA mixes are the main components on the construction of flexible pavement. Flexible pavements can be liquefied by applying heat for mixing with mineral aggregates to produce HMA. The final result obtained from heating the flexible pavement and mixing it with aggregates, is a very sticky mix that adheres to the aggregates and then binds to form the HMA. Once the HMA cools down under ambient conditions, it becomes a very strong material which can sustain heavy traffic loads such as the ones experienced in today's interstate highways. According to Roberts, Kandhal et al. "out of the 2.3 million miles of paved roads in United States, 2.2 million miles (around 96%), are surfaced with asphalt of some type"(3).

Out of these 2.2 million miles of paved roadways in United States, many experience some type of damage throughout their life cycle. Usually roadways are designed to withstand a life cycle of 20 years. However, this is not true, since the traffic loads and environmental conditions in some areas are more critical than the one used as design parameters. This is the main reason why potholes and cracks appear on pavement materials.

As defined by the Federal Highway Administration (FHWA) a pothole is a bowl-shaped depression in the pavement surface. Potholes are always compromising road safety. Vehicles are exposed to damage, and drivers are exposed to hazards due to sudden veering. The formation of a pothole begins when precipitation percolates through fissures and air voids in pavement into the sub-base. Then this water freezes and expands to about 9% of its volume creating an upward push while traffic stresses produce a downward push in the pavement. After the pavement thaws a depression appears were the void, created by the expanding ice, was. After the first symptom of the hole appears, the traffic loads break the edges making it larger. Figure 1 shows the formation process of a pothole in a graphical manner.



Water enters the sub-base and form “ponds”	Water expands creating an upward push force.	When the pavement thaws it will depress into the void left behind by the ice.

Figure 1 Pothole formation process (4).

Fortunately today’s researchers have shown a great progress towards the pothole patching design starting with materials used. By using quality, high-performance materials, potholes can be patched under any environmental condition, which is beneficial in colder weathers. This broad range of new patching materials can work in virtually any weather condition. One of the main problems experienced with this high performance patching materials is the temptation to use them on disintegrating pavements that are to be scheduled for reconstruction, producing a waste of product and taxpayer money.

In Kuennen’s (4) publication, it is stated that research performed by the FHWA has shown that using high quality materials is one of the most important parameters in a patch success. It was shown that the old fashioned technique of “throw and roll” cold mix patching was as effective as any other method as long as quality material is used. According to Roberts, Kandhal et al (3), in 1996, in the majority of the cases failure of cold mixes may be traced to improper construction practices such as "dump and run", (i.e. throw and roll) where the material is dumped into a pothole on the run with little or no compaction. Failures are often related to the lack of desirable properties in cold mix patching materials. Some of the desirable properties of patching materials are as follows (3):

- **Stability:** A patching mixture should be able to show stability after placement. It should be able to withstand vertical and horizontal displacements exerted by traffic loads. The stability of the mix should be evident while the material cures. If lack of stability is present, dishing and shoving of the mixture will occur.
- **Stickiness:** The bond that exists between the mix itself, the underlying pavement, and the sides of the pothole (host material). In most cases the working crews do not take the time to dry or clean the hole, therefore, the use of a proper tack coat is suggested. In most scenarios a stickier mix might be helpful.
- **Resistance to water action:** When the asphalt mix is not able to keep water from entering the hole, stripping starts to occur. Stripping can be defined as the separation between the aggregate and the asphalt binder in presence of water. When a mix is susceptible to stripping, the cold mix patch can ravel, which causes the failure of the patch. Cold patching mixes should be designed to reduce or eliminate stripping.
- **Durability:** As it name states, this is the ability of the mix to withstand external loading and demonstrate resistance to raveling under traffic loads. Raveling is the loss of aggregate from the surface of a repair. The main factor affecting raveling is inadequate cohesion among aggregate particles and the mix, in addition to stripping.
- **Skid resistance:** Is the frictional resistance that the surface of the patch offers to skid. Usually poor skid resistance occurs when the mix contains aggregates

that can be easily polished. Another factor affecting the skid resistance is the excess of asphalt binders causing flushing or bleeding at the surface of the patch.

- **Workability:** A patching mix should be adequately soft and pliable, in order to facilitate placement and compaction using hand tools. It should not contain any lump that cannot be broken down easily. Lack of workability will produce a mix that is hard to place, and as a result, it will affect the durability and stability of the patch.
- **Storageability:** For those patching materials that can be stored it is important to conserve their workability. When the mix does not have the right asphalt binder, it can lose volatiles rapidly, making it harder with time. The manner or environment under the mixes are stored can extend or reduce storage time. The mixture should not contain excess binder, which drains and settles in the bottom.
- **Freeze-thaw resistance:** Consists on the capability of the patching mixture to withstand stresses caused by thermal expansion and contraction forces resulting from freezing and thawing cycles. Freeze and thawing cycles play a vital role in the durability of the mix. Therefore, having a well design drainage system to allow water to escape the sub-base is the key to success in pavement design.

The best way to prevent pothole problems is by spending more money upfront to build a well drained roadway since water weakens pavement support and contributes to frost heaves and cracking. The main goal of pavement researchers is to find a way to keep asphalt cracks and concrete joints sealed. This concept has changed in recent years new investigations have proven that as long as the base is well drained the pothole appearance will be reduced (4).

4.2 Testing Methods in the Past

With new materials being researched, pavement engineers are on a continuous search for better performance. Therefore, making the right decision on evaluating the performance of the material to be used is crucial. It has been proven that the best way to test the material is by using it in the field in the host material, under traffic loads and environmental conditions. However, this technique of evaluating the performance of the patching material is time dependant, impractical and high in cost. In the field it might take months, or even years, to obtain the required feedback to analyze the performance of the pavement materials. This is the main reason why an accelerated method of testing the performance of asphalt patching material is required. With this new method realistic conditions can be simulated in order to identify field performance.

In the past, researchers used to test asphalt materials with machines that required time to operate and generate feedback with the design information. In 1912 (5), in the city of Teddington, London, the machine shown in Figure 2 was constructed. This machine consisted of six wheels with an adjustable load in order to give the required wheel load spectrum. This machine was operated in a temperature controlled building. The maximum load that could be used was 2,800 lbs (1,270 Kg) and it was able to generate frequency of 80,000 wheel coverage in a 24hr period. The main purpose of this machine was to obtain the specifications for stable bituminous mixtures.

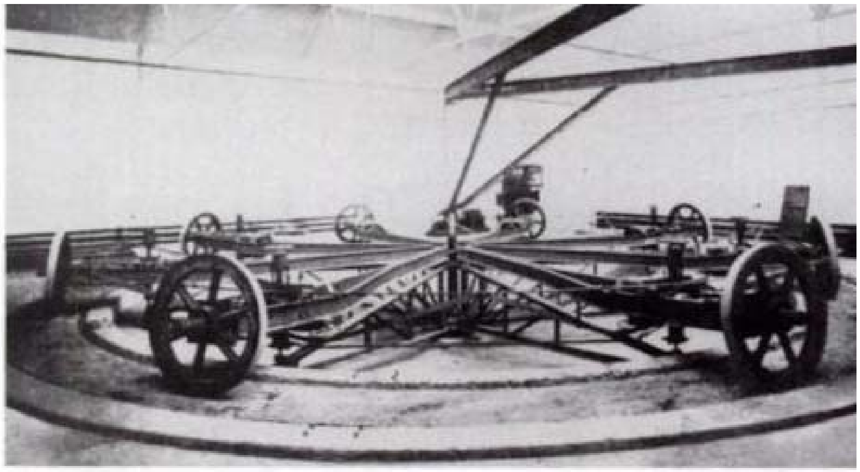


Figure 2 Teddington road testing machine (1912) (5)

As years passed, the need to test bituminous mixtures increased, and it was in 1925 when the Bureau of Public Roads in the United States constructed the circular test track shown in Figure 3. This open-air facility was used to test a range of bituminous materials under heavy loading condition.

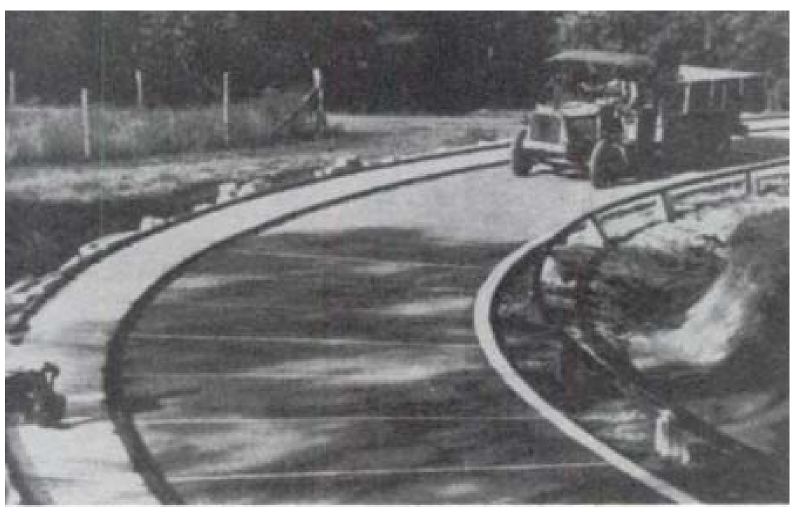


Figure 3 Bureau of Public Roads test track (1925) (5)

In 1933, in the U.K.'S Road Research Laboratory, the circular road machine shown in Figure 4 was constructed. With this machine, road sections were trafficked by a commercial vehicle using electric propulsion. After few years this machine was modified to have a heavily loaded central wheel assembly as shown in Figure 5 which was primarily used to study stresses generated in pavements.

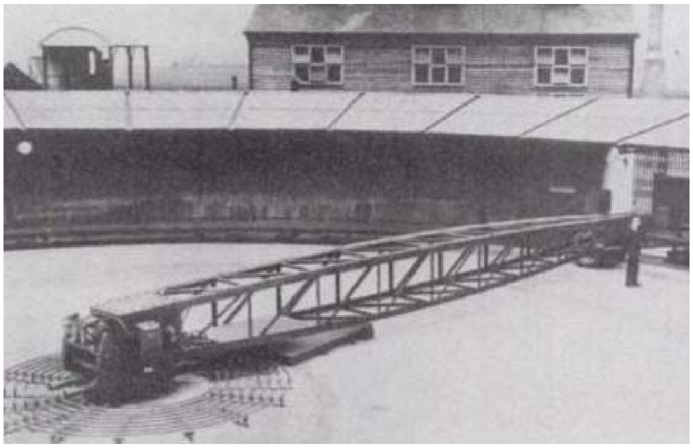


Figure 4 Road Machine as Constructed Originally in U.K. (1933) (5)

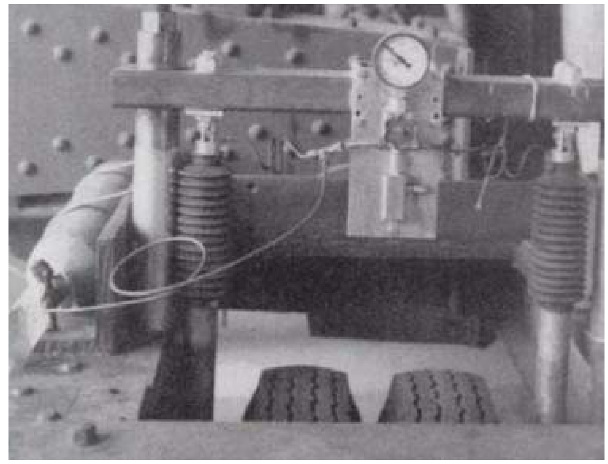


Figure 5 Wheel Modification to apply heavy loads (5)

In 1985, a machine working with a linear principle was constructed at the Crowthorne site at the U.K. Transport Research Laboratory. The test pit was 25 m long and 10 m wide, which allowed the accommodation of several test pavements samples to measure stress and deflections. The machine design can be seen in Figure 6.

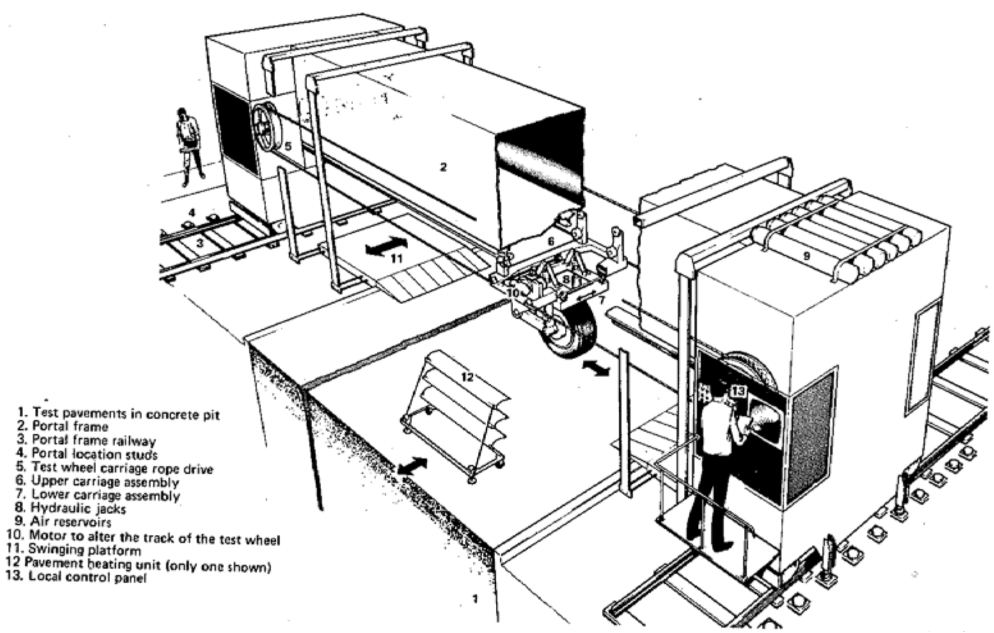


Figure 6 Linear Principle Machine Designed at U.K. Transport Research Laboratory (5)

Even though, all the testing machines described above were useful in the past, they were mainly used to explore the stress and specification of pavement materials; they did not provide a significant advantage when compared to a full scale road experiment. However, there are other factors that also affect pavement performance. Some of these factors include the patch material, the construction, bond and interaction between patch and hosting material, traffic loading and environmental factors. In the environmental factors category the following should be considered: temperature, UV exposure, oxygen, moisture, etc. It is important to understand that the performance under one set of conditions may not be used to predict the performance under a different set of conditions. Even the prescribed standards are not a guarantee for success.

4.3 Current Accelerated Testing Equipment

With a community which is constantly demanding better roads, the need of investigating how pavement mixes will perform under heavier and greater traffic loads is required. Therefore, researchers have suggested using different methods that have proven to be successful in the optimization process of asphalt mixes. Some of these testing methods are: Smartroad, CATT, etc.

The smartroad test road consists of a 5.7miles long limited access highway, located in Virginia. The first 2miles of this test road is designated to be a controlled pavement facility. The road is 4 lanes wide, 2 lanes in each direction and a 3m wide shoulder on each side. The facility is equipped with supplies to re-route the traffic around the controlled zones to allow for testing. All the pavement layers are equipped with equipment to monitor loads and the environment. The facility is capable of simulating as well different environmental conditions. Underground conduits network provides data acquisition. The road pavement includes 12 flexible pavement test sections and a continuously reinforced rigid pavement. Some of the sensors used in this facility are strain gages, pressure cells, thermocouples, time-domain reflectometry (TDR) probes, and resistivity probes among others. This facility have its own characteristics of allowing for some unique measurements, which include, measuring strain in the aggregate layer, pressure underneath the hot-mix asphalt (HMA) layer and direct measurements of moisture.

Figure 7 represents the actual setup of the smartroad test road. As it can be seen it shows the idea of how snow and rain affects the asphalt. This is a new development; however, the smartroad test road is an expensive setup to build. The test studied in this research if proven to be successful to evaluate the performance of patching materials under environmental and traffic conditions, will allow for lower cost in analysis. Therefore, the lower the cost of analysis, the more money available for optimizing mixes used in the field.

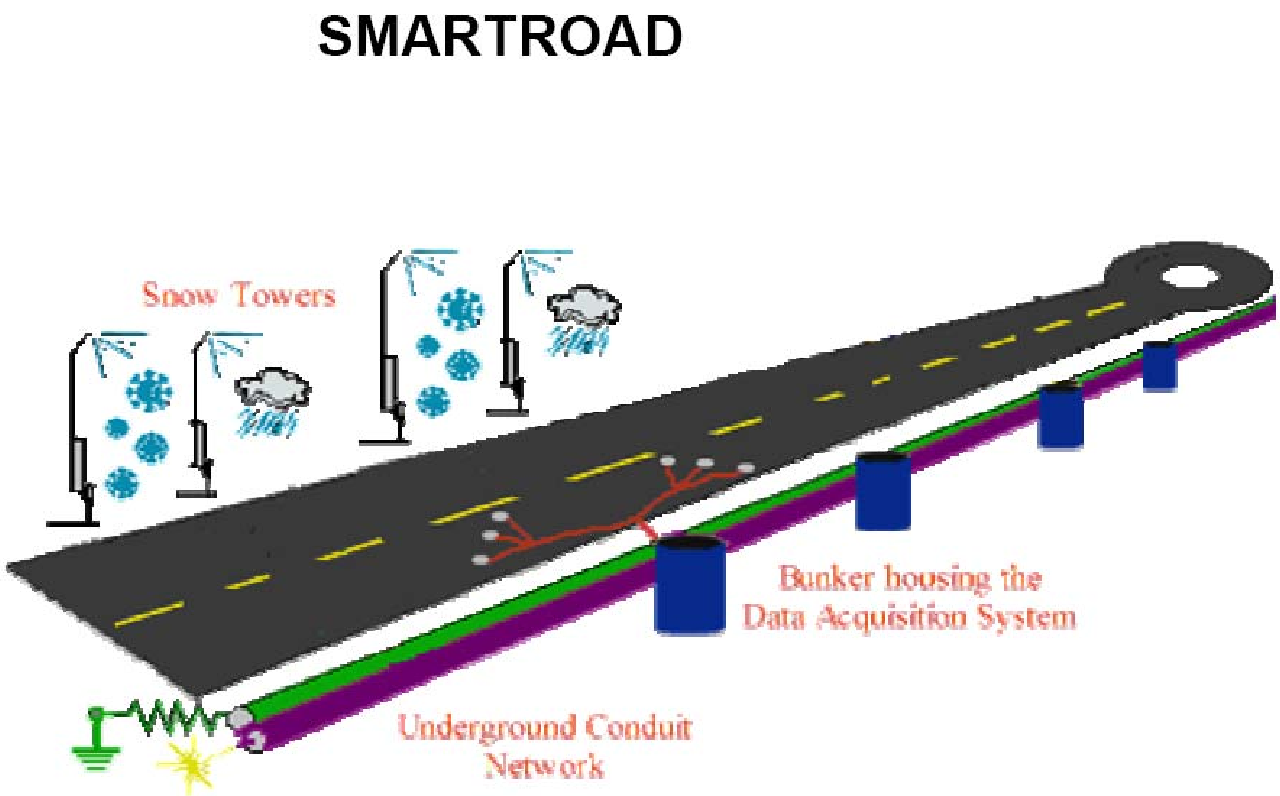


Figure 7 Smartroad Schematic View (6)

University of Central Florida has an example of an outdoor accelerated testing facility. In this facility patching performance were conducted on fast setting cement and elastomeric mixes. About 500,000 load repetitions were applied to 14 different patched areas in the track. Stresses were observed in the elastomeric concrete mostly due to bond breaking and shrinkage that occurred quickly and showed cracking near the interface. The 500 thousand load repetitions of 44.5KN wheel load was equivalent to approximately 15 years of in field test. It is important to recognize that these types of testing track facilities are available at only few institutions. Most DOT'S require their use and sometimes the equipment is being used, preventing agencies to used it on regular basis.

Chatterje et al (7) has carried out detailed investigations on performance of different cold mix patches in Texas. They start by point out that the existing test method fails to evaluate the performance of cold patches in the field. They have done a series of studies in order to assess problems in the performance of cold mix patches. Chatterje (7) has studied and listed different problems such as poor workability, moisture susceptibility and potential to raveling and shoving, as well as stability problems. They found out that the main problem affecting pavements are shoving and raveling and dishing and depression from heavy traffic loads. Tests were performed in the Hamburg Wheel Tracking Device (HWTD) in order to evaluate for stability, moisture susceptibility, indirect and tensile strength. During this study the authors also developed and evaluated a method to test for cold patch slump. The slump is a measure of workability. They used homemade and commercial brand patching materials for filling potholes in the field and monitoring was required after specific time periods. By using a simulative wheel tracking device in cold mix patching materials the authors acknowledge that the using the HWTD is too harsh for testing cold patching materials.

Similarly the New Jersey Department of Transportation (8) conducted a test to evaluate pothole patching materials based on Strategic Highway Research Project recommendations for evaluating proprietary mixes. Field performance was monitored. Based on field performance laboratory characterization a developed design and construction recommendation technique was developed. However, no accelerated testing of in place mixes were conducted. Lacking of an accelerated testing method represents how critical the need for developing a suitable accelerated test protocol can be to evaluate pothole behavior on regular basis.

4.4 Asphalt Patching Mixtures

Most asphalt patching mixtures consist of a combination of aggregates, asphalt binders and, if needed, some additives. These mixtures are constantly used to perform repairs on potholes, spalled cracks, severely raveled areas and small cracks. According to Germann and Lytton publication entitled "Cracking Life of Asphalt Concrete Overlays", they define three general types of asphalt patching mixtures (3).

4.4.1 Hot-mixed, hot-laid patching mixtures

These are mixtures essentially consisting of HMA. These HMA consist of a mix of well graded aggregates and asphalt cement. The only problem with these types of mixes is that they must be used while hot. It has been proven that HMA are the highest quality of asphalt patching material available in the market. However, some drawbacks are also present on this type of patching material and some of them are:

A. Availability: Most HMA facilities especially in the northern part of United States close during the winter months. This is the reason why the use of HMA as patching material during winter months is scarce.

B. Quantity: The amount of asphalt that can be delivered to site sometimes is greater than the amount required to patch potholes. Patching potholes is a very slow and time consuming task, which will produce the cooling of the mix before it is totally used. Once the HMA cools before being placed, poor compaction is more likely to occur. Therefore, using hot boxes or small recycling units can be the solution to this problem.

4.4.2 Hot-mixed, cold-laid patching mixtures

These types of mixtures are prepared and produced in HMA facilities, which will provide the mix with the adequate mix design. Most of the material that constitutes this type of patching is properly proportioned and thoroughly mixed. Aggregates are heated and dried at a temperature which substantially lower than that used to produce HMA mixture. Liquid asphalt binders such as emulsified asphalt and cutback asphalts are used. Usually these mixes will be piled up and saved for later use. This mix design is workable under all weather conditions, however, high mixing temperatures should be avoided otherwise volatiles will be driven off from the bituminous binder, which will reduce the storability of the mix.

4.4.3 Cold-mixed, cold-laid patching mixtures

As stated by its name, this type of mixture is produced from aggregate and liquid asphalt binders which are not heated prior to mixing. Mixing can be done in a HMA facility, a stabilization plant, or any other mean of mixing aggregates and liquid asphalt. The final mixture is then stockpiled and stored to be used when needed. According to researchers, these types of mixes have the lowest quality of all the asphalt patching mixtures.

Throughout this research different material such as HMA, emulsion mix, and Instant Road repair materials will be tested under dynamic loads in order to simulate for traffic loading. Freezing and thaw were applied as well in order to investigate how the behavior and performance of the patching material is affected by weather conditions. Also one of the most influential characteristics on the performance of pavements is the particle size distribution or gradation. In most HMA mixes, the gradation helps to determine properties such as stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. The gradation of aggregates is commonly specified by agencies.

5 Methodology

5.1 Pavement Block Design and Construction

In order to simulate the effect of normal and shear forces applied to the pavement patch during traffic loading, an accelerated experimental procedure is proposed. To achieve the normal and shear forces, with a standard universal testing machine that applies a vertical load, the host pavement block was constructed with an angled face as shown in Figure 8.

Figure 8 Angle Demonstration of the Host Pavement

To achieve the desired normal to shear force or stress ratio, different inclination angles were selected. Figure 9 shows the relationship between block angle to stress ratio. The chart bellow was constructed from the Appendix Table of Angle Effects on Normal and Shear Stresses

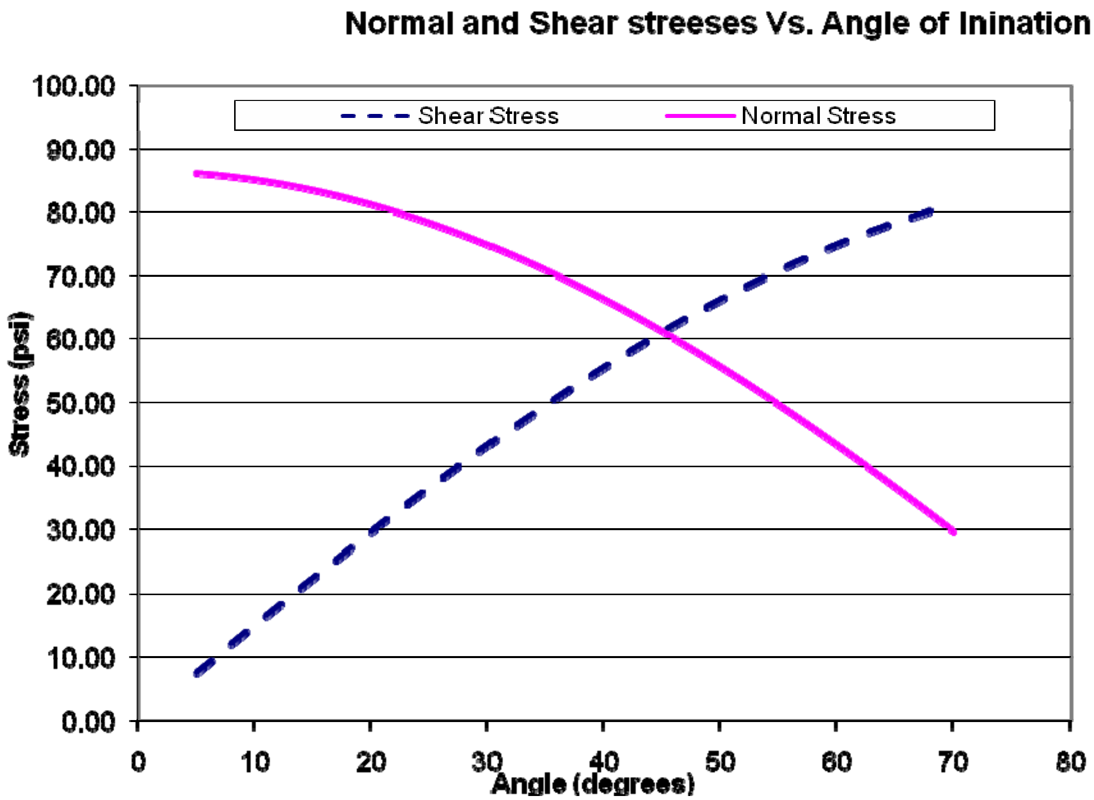


Figure 9 Effect of the Applied Stress Vs. Angle.

Host concrete pavement blocks were designed with the appropriate geometry to insure adequacy for inclination, pothole volume and size constrains within the Instron universal testing machine. Figure 10 shows detailed drawing of the host pavement block including pothole geometry and reinforcement.

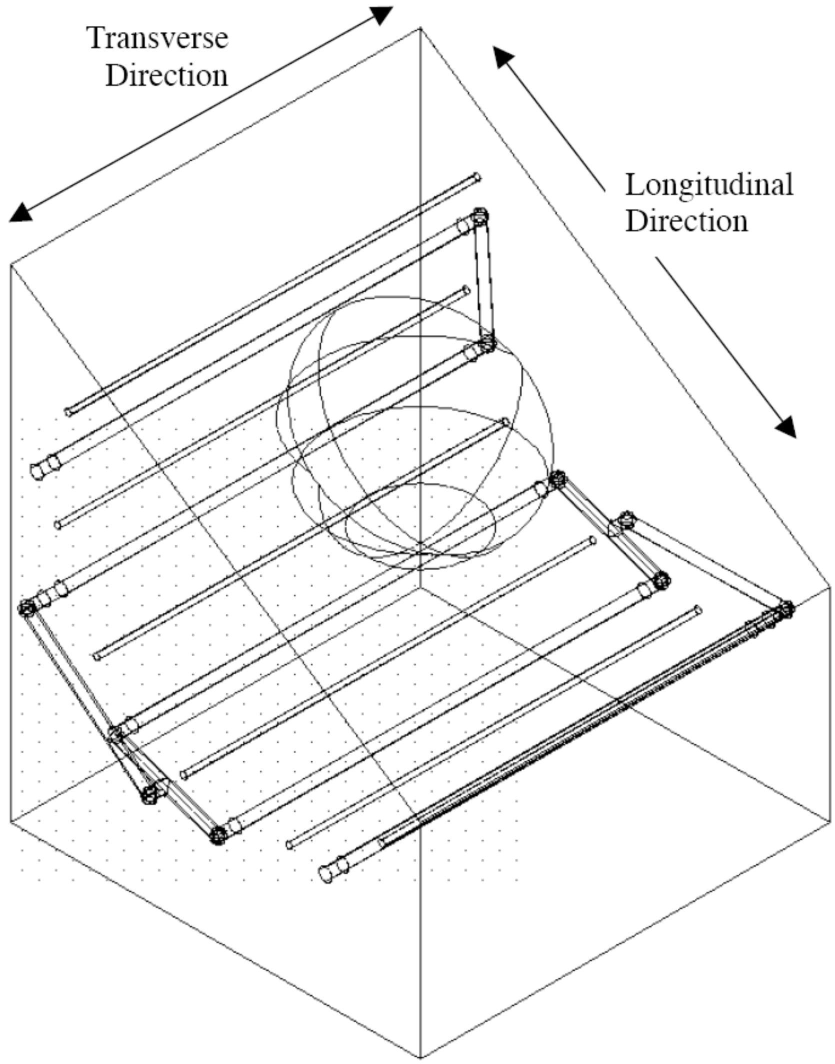


Figure 10 Diagram of Angled Pavement Block with rebar, cooling pipes and pothole (9)

Wood molds were used to cast the concrete blocks using ready mix concrete. The molds were oiled prior to concrete pouring to aid in form release after curing. The molds were wedged so the open face remained horizontal during concrete pouring. A 4,000 psi concrete was ordered from a local ready mix concrete plant. The construction process is shown in Figure 11, including form fabrication, concrete casting and block curing.

Mold Preparation

Leveling Mold Opening

Concrete Pouring

Concrete Curing

Figure 11 Concrete Block Construction Process.

Once the concrete was placed and leveled, an empty semi-spherical bowl was inserted in the concrete as shown in Figure 13. This process minimized the amount of concrete needed to be removed for the construction of the pothole. The molds were cured outside and watered periodically. The concrete blocks were de-molded after 14 days. The pothole was completed by chipping an additional 1 inch of concrete beyond the semi-sphere previously molded. The concrete chipping was performed by using an air gun, and hand tools to produce a host material with a rough surface.

Figure 12 Concrete Pouring into Wood Molds

Figure 13 Bowl Placement in Concrete Block

Each block was then moved into the pavement laboratory to be prepared for testing. An approximate volume of the pothole was calculated in order to determine the quantity of patch material to be used.

5.2 Patch Materials

The materials used for patching consisted of an HMA mix that was prepared in the laboratory and a commercial patch material. It was determined that preparing batches of HMA of approximately 9Kgs (19.84 Lbs.) was sufficient material to patch the pothole. The commercial patch material was Instant Road Repair™ produced by International Roadway Research in Texas (10). The HMA was prepared by following a gradation curve used by the Minnesota Department of Transportation (MNDOT) as shown in Figure 14. Each batch was made of about 9,000g of aggregates and approximately 473g of asphalt, producing a mix with an asphalt content of 5%. In order to achieve the proper workability the aggregates were heated over night at 150°C. The asphalt was placed 4 hrs prior to mixing in the oven in order to obtain the adequate flow and workability. Once the mix was placed in the pothole it was left to cure overnight.

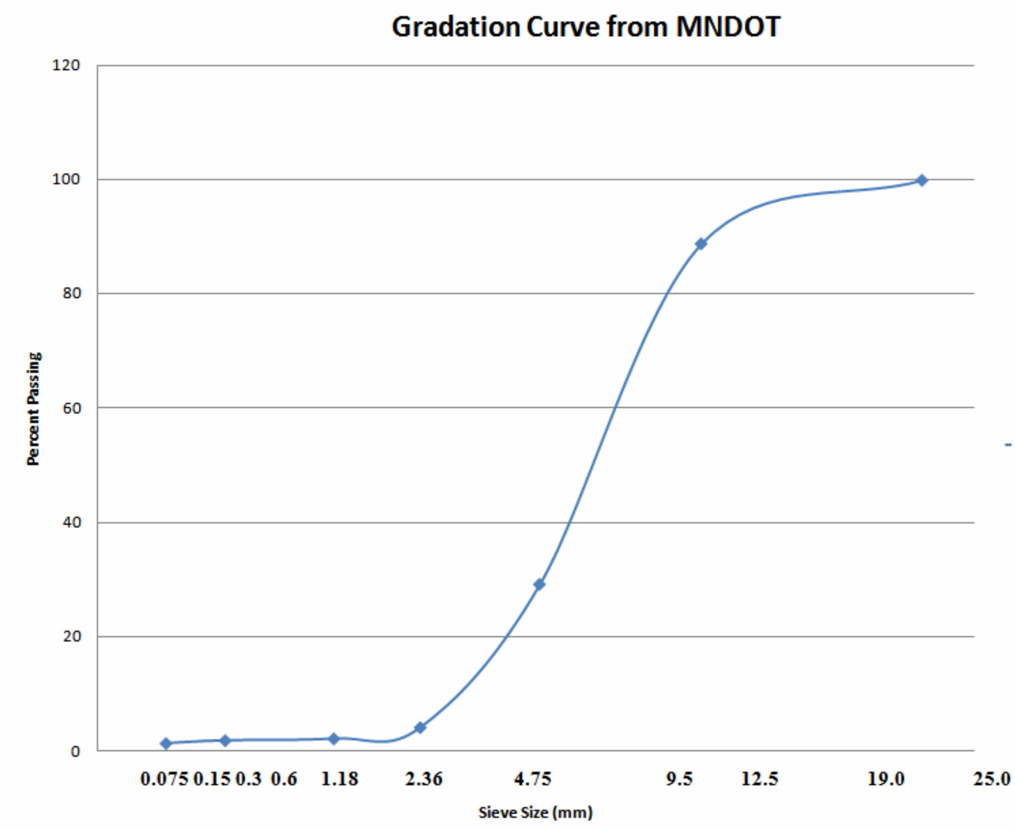


Figure 14 Aggregate Gradation Curve Used in This Research Based on MNDOT Recommendations

The instant road repair material is a "ready to use mix" cold patch without heating or pretreatment in the field and it has a shelf life of approximately three years. According to the manufacturer Instant Road Repair® is a special blend of asphaltic polymers and graded limestone. Instant Road Repair (IRR) was chosen as a commercial product due to its long history in the market. IRR material is provided in small quantities of 5 gallon buckets which make it practical for our pothole patching.

Figure 15 Bucket of Instant Road Repair (10)

5.3 Pothole Construction

The pothole is constructed by placing enough material to overflow the pothole elevation by an inch. The patch is then compacted using a 182 lb steel roller. The pothole is then left to cure overnight. The construction sequence can be seen in Figure 16.

Pothole Creation Placement of Asphalt Rolling Mix in Place

Figure 16 Construction Sequence for the Creation of the Pothole

5.4 Block Preparation for Elevation Profile Measurement

Prior to testing, an elevation reference line is constructed using guide pins and a calibrated rigid bar. The guide pins were placed into holes that were previously drilled in the concrete block and held in place using high strength epoxy. Initial elevation readings are taken in the longitudinal and transverse directions along the center of the footprint. Figure 17 shows the location of the elevation readings. Elevation readings are taken every half inch along the line of interest. After all the readings were recorded, the block was moved to the Instron machine for cyclic load testing.

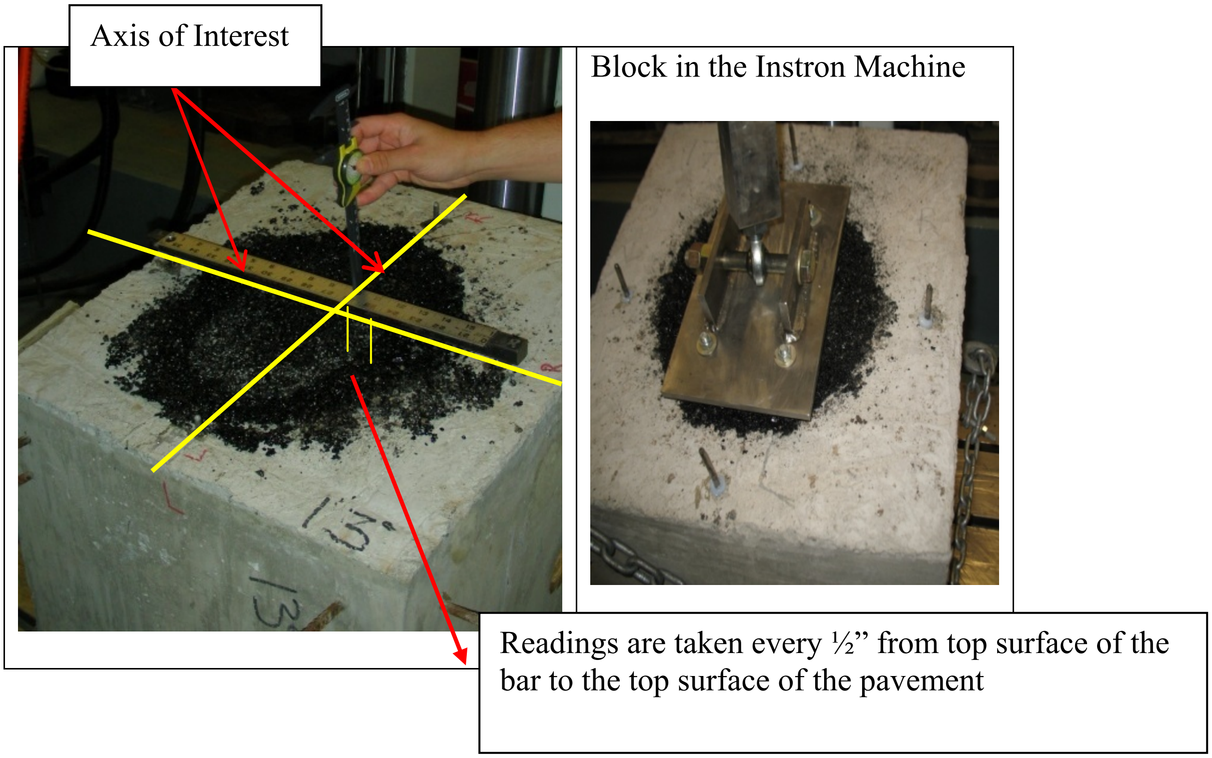


Figure 17 Taking Elevation Readings

Since the blocks are at an angle, the vertical load produces a shear and normal force component at the patch surface. Figure 14 shows the relationship between tilt and shear and normal stresses. Table of Angle Effects on Normal and Shear Stresses, in the Appendix, shows the shear to normal stress ratios are 23%, 30% and 40% for 13˚, 17˚, and 22˚ respectively. The stress ratios were selected similar to those applied by truck tires to a pavement (11).

5.5 Freeze-Thaw Testing

The constructed potholes in the pavement blocks were subjected to cycles of freezing and thawing in order to assess effects of environmental distress. The freezing was conducted outside during the winter months where freezing temperatures ranged between -10 to -20˚C.

Once the pothole was constructed and cured overnight, pothole saturation was achieved by adding enough water to fill the volume of voids. The block was then moved outside for the freezing cycle which lasted approximately 12 hours. The thawing cycle was conducted at room temperature with the addition of heater fan. This process was repeated for four cycles.

5.6 Block and Pothole Testing in the Instron Machine

Each of the blocks was tested in the Instron machine. The Instron is a computer controlled servo-hydraulic testing machine with static and dynamic capabilities. The maximum static load capacity is 110 Kips and cyclic loading can be applied at a maximum frequency of 10 Hz.

5.7 Load Applicator

The load applicator consists of a steel foot attached via a ball joint connection to allow for X and Y articulation, to a steel bar as shown in Figure 18. On the bottom of the foot, a high density rubber membrane which is approximately 1 inch thick was used to simulate a foot print of a truck tire.

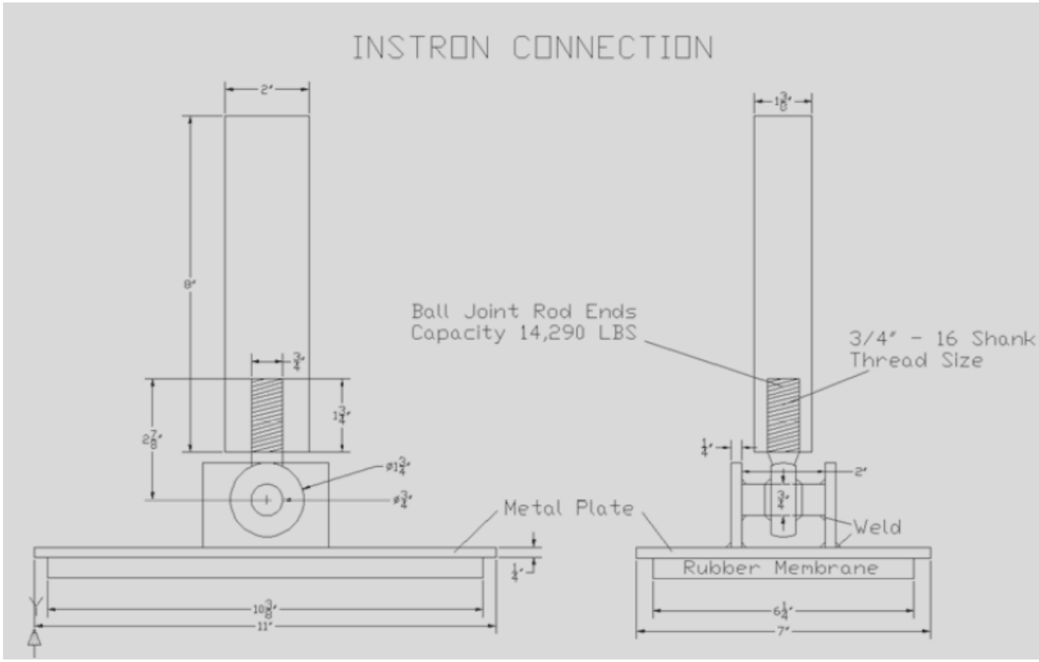


Figure 18 Diagram of Load Applicator with Ball Joint Connection

The experimental setup for the blocks can be seen in Figure 19. As a comparison with the block test, the Model Mobile Load Simulator (MMLS) was also used to assess performance of the patching materials. Results obtained from the experimenting with the concrete block are compared with results obtained by using the Model Mobile Load Simulator (MMLS) machine.

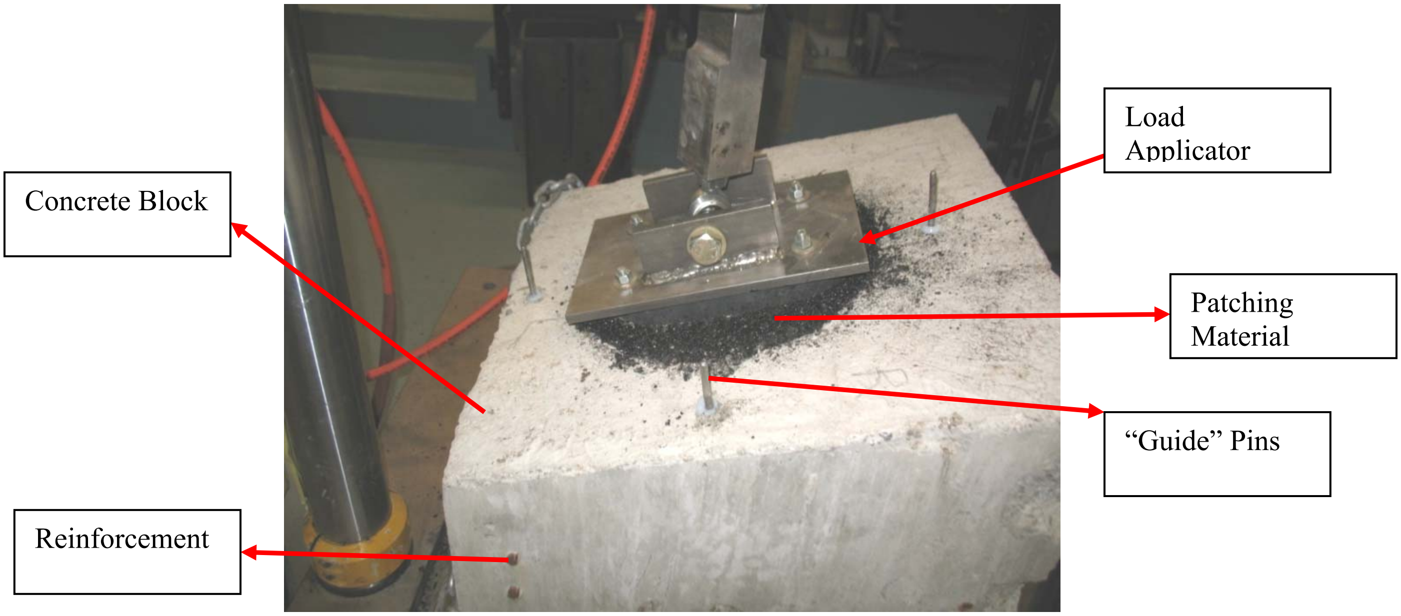
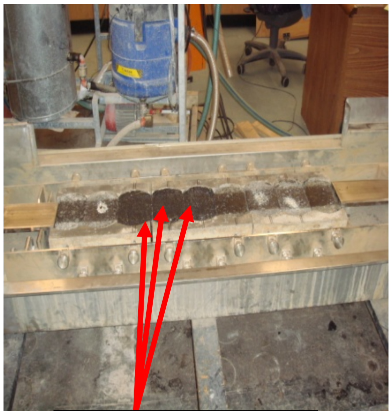
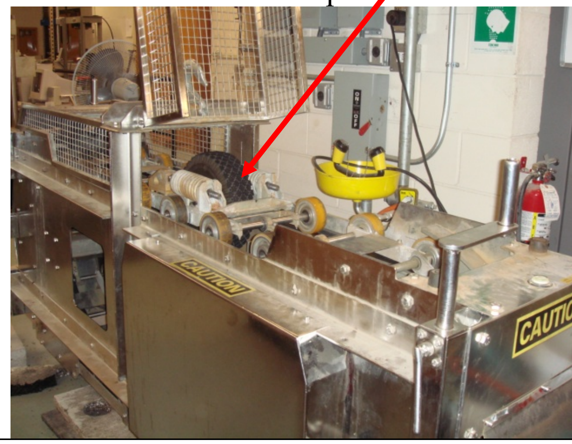


Figure 19 Pavement Block Loaded Instron Machine

5.8 Model Mobile Load Simulator (MMLS)

The Model Mobile Load Simulator (MMLS 3) machine is capable of simulating vehicle loading by moving four pressurized rubber tires in the same direction. The setup for the MMLS machine consists of 4 pneumatic tires, which can handle a maximum inflation pressure of 800 KPa (116 psi) at a maximum wheel load of 2700 N (607 lbf). The pneumatic tire used in the MLLS machine can be seen in Figure 20. The MMLS machine is capable of applying 7,200 axle loads per hour. Variables such as the load magnitude, operating speed, lateral wander, and the tire inflation pressure can be adjusted. Samples to be tested are placed in a steel form as shown in Figure 20 that prevent the samples from moving sideways. The wheels will run on top of the samples until the desired numbers of passes have been achieved. Common distresses observed in this test are shoving, rutting and fatigue cracking.

Sample placed in MMLS Machine	One of the Wheels that apply the load to the samples
	

3 HMA Samples

Figure 20 MMLS Configuration

The MMLS machine is capable of applying stresses of 100 psi, and a force of 2.5 KN. In order to simulate this type of stresses in the proposed testing configuration, the following conversions were required.

- Since the values for stress is give in psi, the load had to be converted from SI Units to British Units

$$(2500\,N)*\left(\frac{0.224808\,lbf}{N}\right) = 562\,lbf$$

- Once the force is known, the contact area can be calculated by dividing the applied load by the stress.

$$A = \frac{P}{\sigma} \qquad 5.8.1$$

Footprint Area Calculation
In which P is the Load (Lbf)
and σ is the stress (psi)

- The contact area is assumed to be a circle.

Since the contact area applied from the MMLS tires is smaller than the footprint designed to test stresses in the concrete block, it is required to back-calculate the load to be applied to produce the same stresses as the MMLS machine. In order to do so, since the desired stress and area are known, the load can be easily calculated by using equation 5.8.2.

$$P = \sigma * A \qquad 5.8.2$$

Load to be Applied

Area and load calculation used in the blocks to obtain the same stresses as the ones exerted by the MMLS can be found in the MMLS Analysis section of the Appendix.

5.9 Finite Element Modeling (FEM) Using ANSYS

The commercial FEM software ANSYS was used to model the pothole and applied load. A 2D Finite Element Model was used. To simplify the modeling, the patch material was assumed to behave elastically, and that the load applicator and the asphalt layer was always in contact and frictional forces were not accounted for. In addition, A bonded interface was assumed between the patching material and the host pavement.

Shear and normal stresses were represented as forces acting in the X and Y axis respectively Figure 21. A finer mesh was used for the pothole patching material in order to increase the precision for deformation and stresses results. Figure 21 shows how the concrete block was modeled in ANSYS

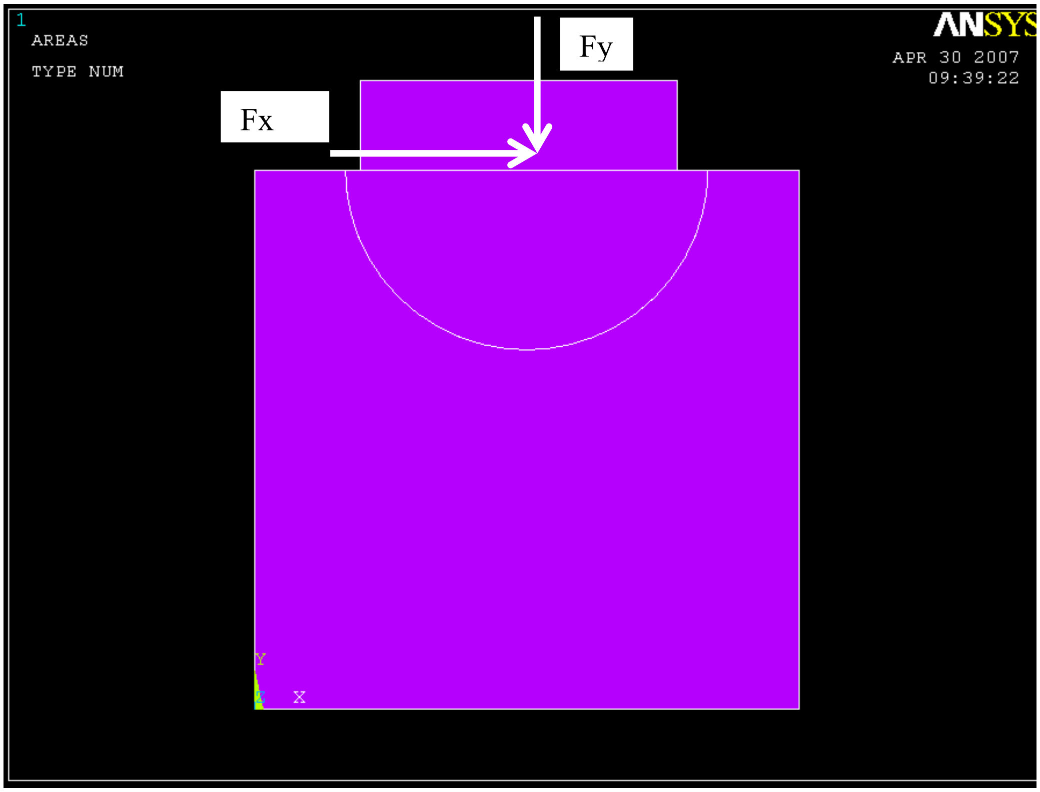


Figure 21 Finite Element Model Using ANSYS

5.10 Bulk Specific Gravity

Mix density and volumetric properties were calculated by determining the bulk specific gravity. The bulk specific gravity of the different mixes was determined using ASTM No. D2726. Density specimens were cored from constructed potholes. This coring process did not yield samples adequate enough for BSG testing. The structural integrity of the samples was impaired. Another alternative was used for sample preparation. The gyratory compactor was used to compact BSG samples at similar energy input of 50 gyrations.

Bulk specific gravity values for the different materials are shown in Table 1 were performed on three samples of HMA and Instant Road repair. Results obtained from the analysis shows that both materials have almost the same BSG. Results obtained from this test can be seen in Table 1.

Table 1 BSG for HMA and IRR

Specimen	Dry weight (gms)	Under Water weight (grms)	SSD (grms)	Density (BSG)
HMA1	3348	1876.3	3417.9	2.171
HMA2	3497	1953.9	3580	2.150
HMA3	3526.4	1954.6	3599.6	2.143
IRR1	3505.5	1992.1	3526.7	2.284
IRR2	3494.3	1980.8	3508.8	2.286
IRR3	3477.5	1971	3491.5	2.287

6 Results

6.1 Rutting and Shoving Elevation Profiles

To assess performance of the patching materials, an elevation profile of the transverse and longitudinal segments was first determined. An initial "zero" reading was determined prior to cyclic loading. As described in Section 5: Methods, all elevation readings are taken from the reference datum (rigid bar and guide pins). Subsequent readings are obtained after N-number of cycles. Relative elevation profiles are calculated as the difference between the current readings at N-number of cycles and the initial "zero" readings. The elevation profiles in the transverse and longitudinal direction is defined as a "Rut Profile" and the "Shoving Profile" respectively. All calculations were conducted using an Excel spreadsheet. (Tables of the elevation profiles are presented in the Tables of the elevation profiles at the Appendix section) Rutting and shoving elevation profiles as a function of cyclic load are presented in Figure 22 and Figure 23 respectively.

A new performance rutting and shoving area statistic parameter to be named the rutting area index (RAI) and the shoving area index (SAI) is defined. This area statistic is determined by calculating the two dimensional area of the rutting or shoving profile in the z-plane. Two approaches of determining the rutting area index (RAI) and the shoving area index (SAI) will be demonstrated using the integral method and the geometric method.

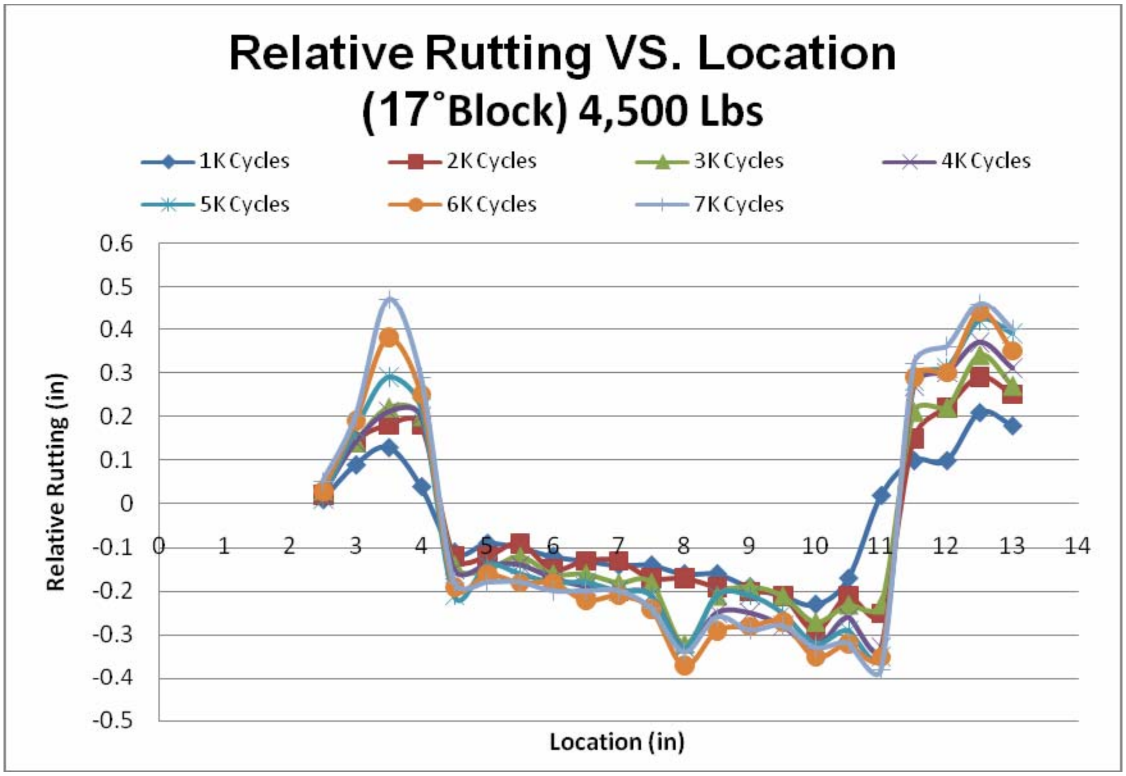


Figure 22 Relative Rut Profile for IRR Material as a Function of Cyclic Loads for the 17˚ Pavement Block

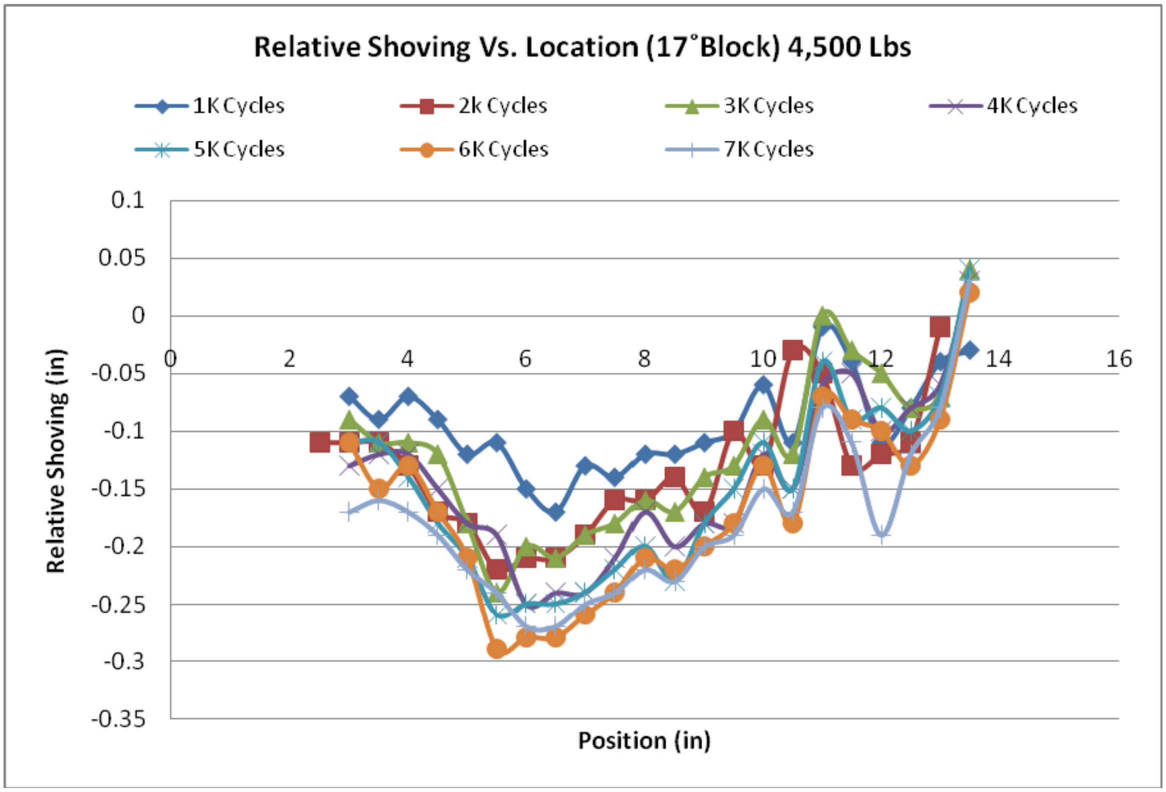


Figure 23 Relative Shoving Profile for IRR Material as a Function of Cyclic Loads for the 17˚ Pavement Block

6.2 Determination of the Rutting Area Index (RAI) Using the Integral Method

This method applies the definition of an integral as shown in Figure 24. It consists of calculating the area under the curve after N-number of cycles. A horizontal reference line is located by identifying the average peak of the rut profile as shown in Figure 25. The sum of the areas between the reference and the bottom of the rut profile and having a constant width of 0.5 inches is calculated.

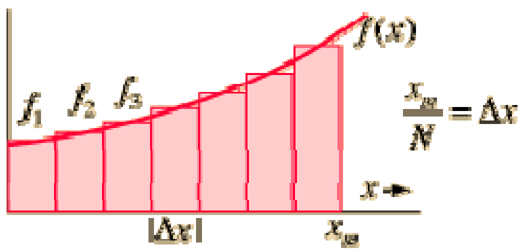


Figure 24 Integral Concept (12)

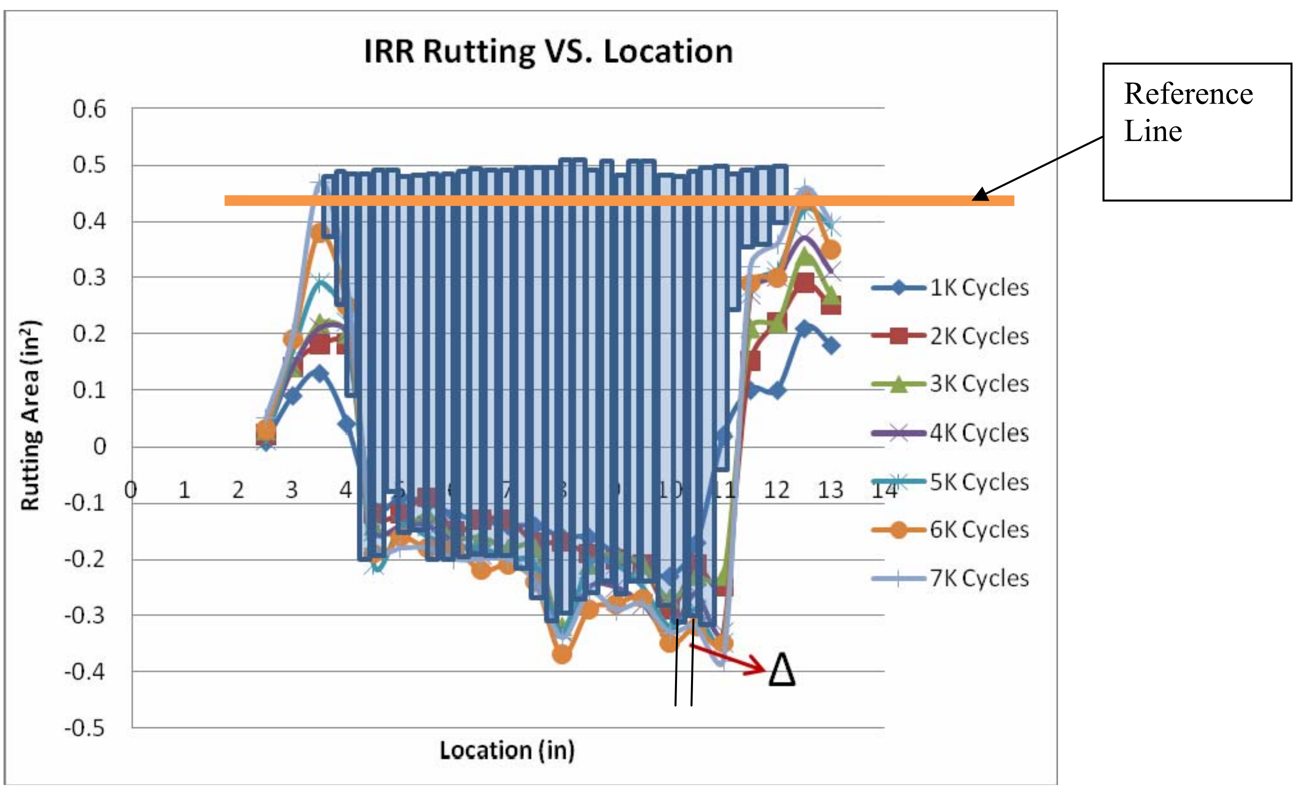


Figure 25 Raw Data Analysis using Integral Concept

6.3 Determination of the Rutting Area Index (RAI) Using the Geometric Method.

Determination of the area statistic using the geometric method consists of calculating the area under the elevation profile by approximating a prismatic section. The base is defined as the elevation profile crosses the X-axis. The height is defined by an average peak height and average base point. An example of the geometric method can be seen Figure 26. Area static parameters using both methods have produced consistent results.

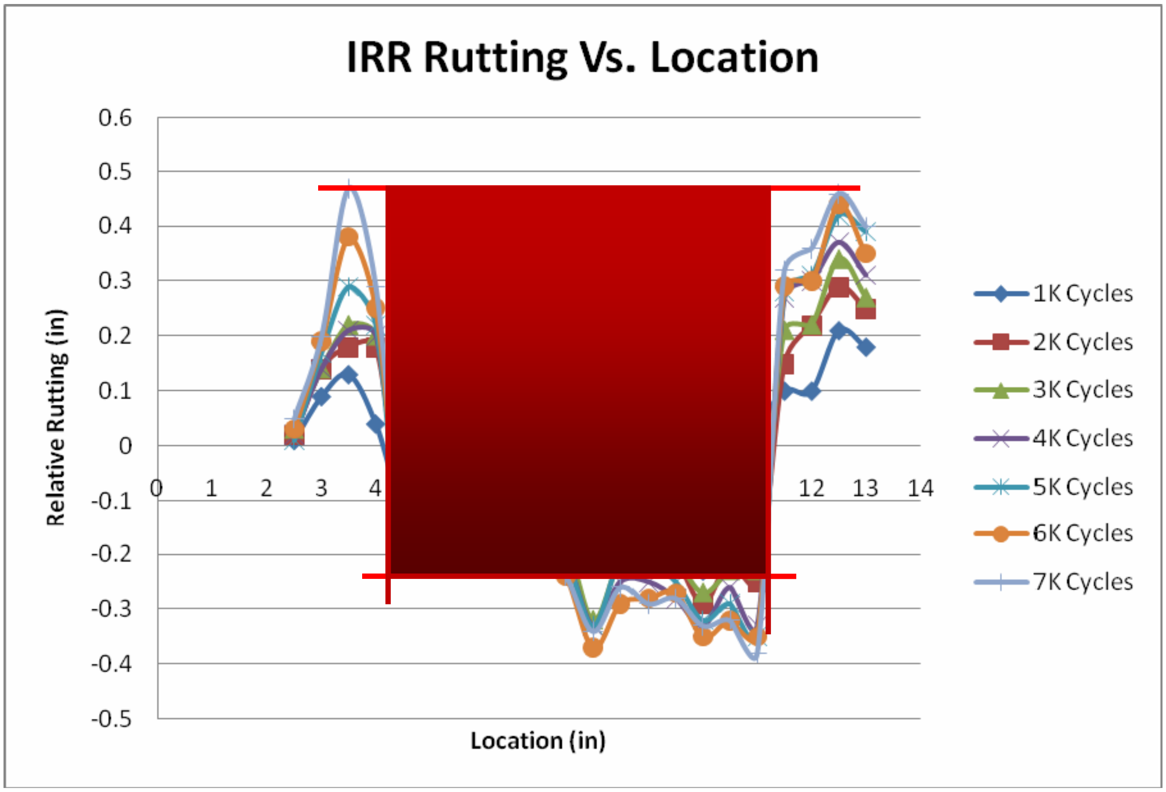


Figure 26 Determination of the Rutting Area Using the Geometric Method

6.4 Determination of the Shoving Area Index

Figure 27 shows an example of a longitudinal elevation profile. A shoving area index was also determined using the integral method. Since the elevation profile follows the longitudinal axis and the block tilt angle, the equation of the line was determined to locate the height of each integral area. This method is shown in Figure 27.

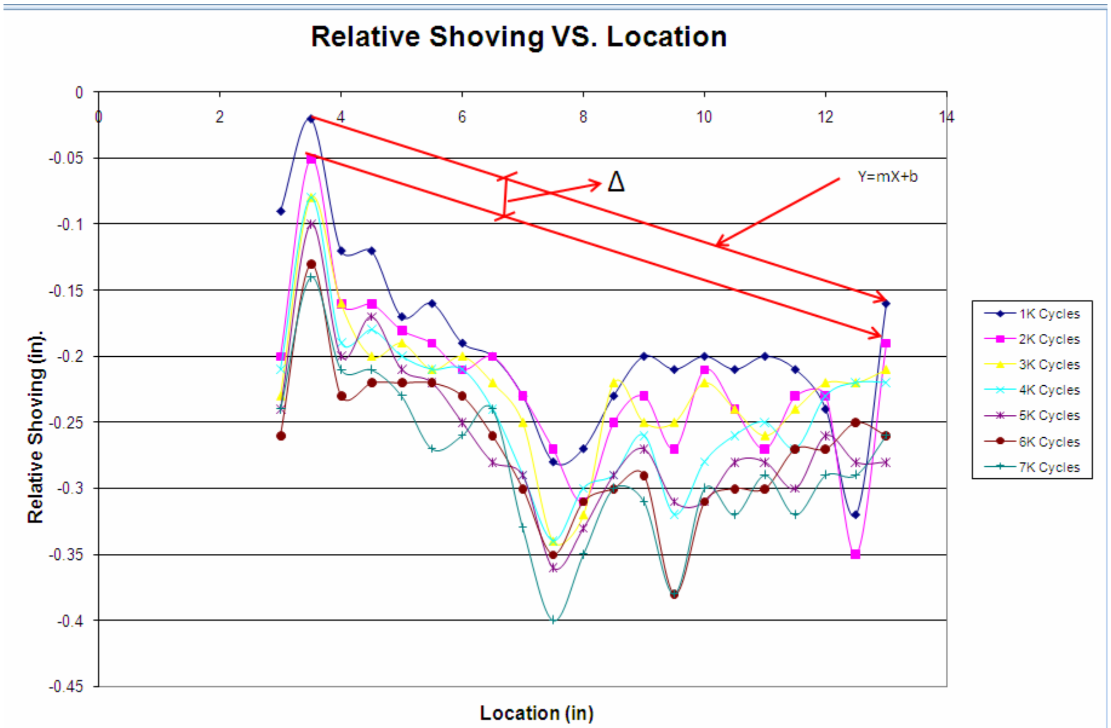


Figure 27 Relative Longitudinal Elevation Profile as Number of Cycles Increases

6.5 Rutting Area Index and Shoving Area Index for IRR Patch Material

Figure 28 shows the results of the rutting area index (RAI) as a function of the number of load applications or cycles and the tilt of the block angle. The rutting area index increases with both the number of load cycles and the increase in tilt angle. Figure 29 shows the results of the rutting area index (RAI) as a function of the number of load applications and the vertical applied load. The two vertical applied loads selected were 4,500 and 2,250 lbs. The loads are comparable to a truck tire load and light truck tire load. The effect of cycles of freezing and thawing is shown in Figure 30. The RAI is not affected after four cycles of freezing and thawing. However, the RAI increases with increased load cycles.

The relative Shoving Area Index as a function of the number of load applications for the IRR patch material can be seen in Figure 31. The SAI increases as the number of load cycles increases. This shows that more material is being displaced as the number of load applications increases and will have an influence on the resulting Rutting Area Index as well.

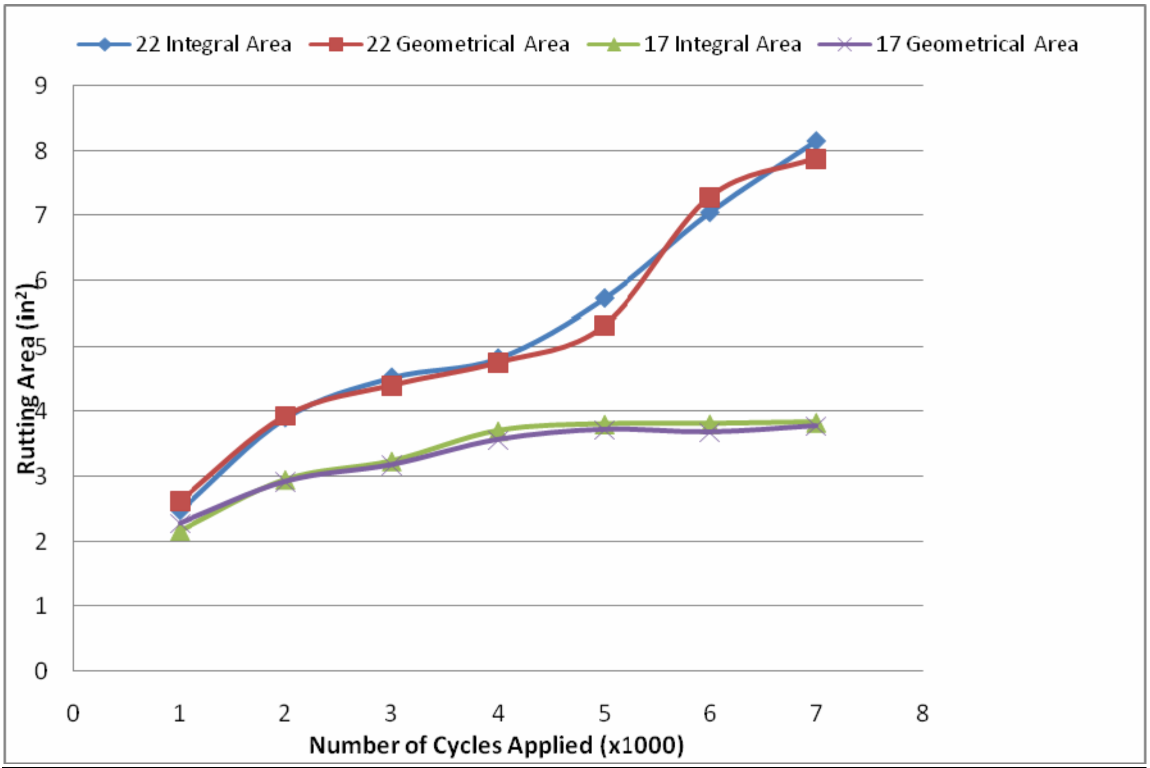


Figure 28 RAI as a Function of Load Applications and Pavement Block Angle

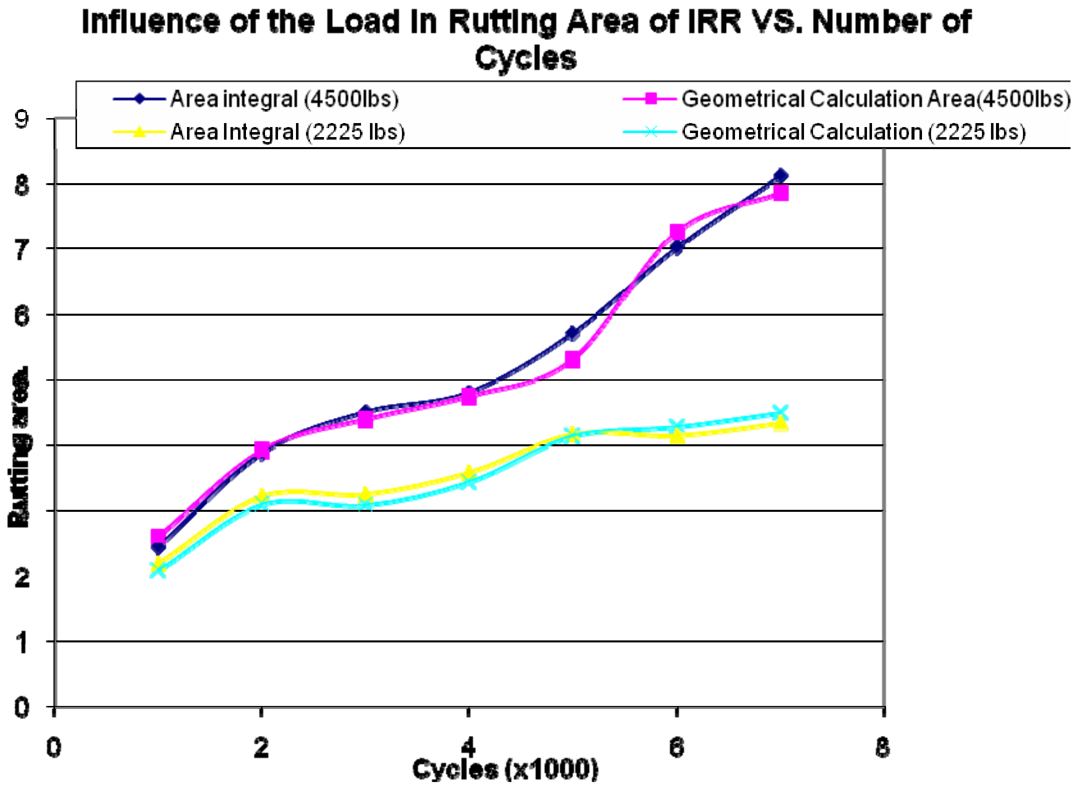


Figure 29 RAI as a Function of Load Applications and Magnitude of Vertical Load for the IRR Patch Material

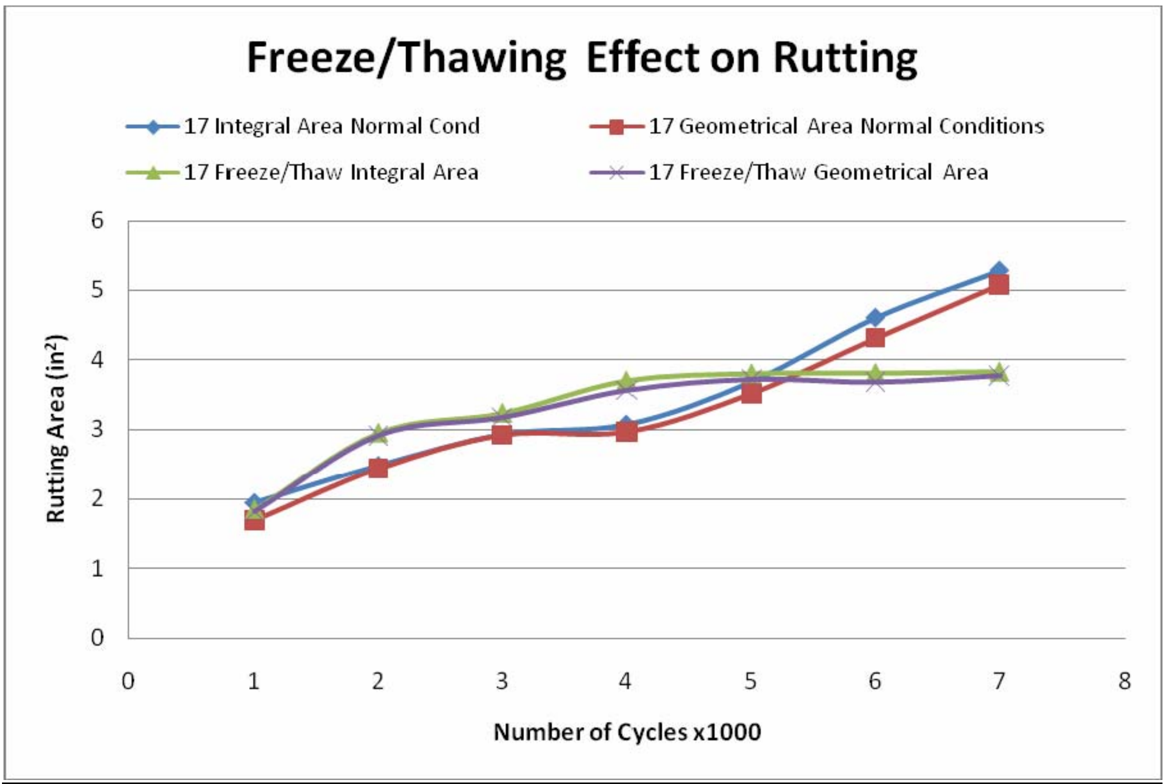


Figure 30 RAI as a Function of Load Applications and After Four Cycles of Freezing and Thawing

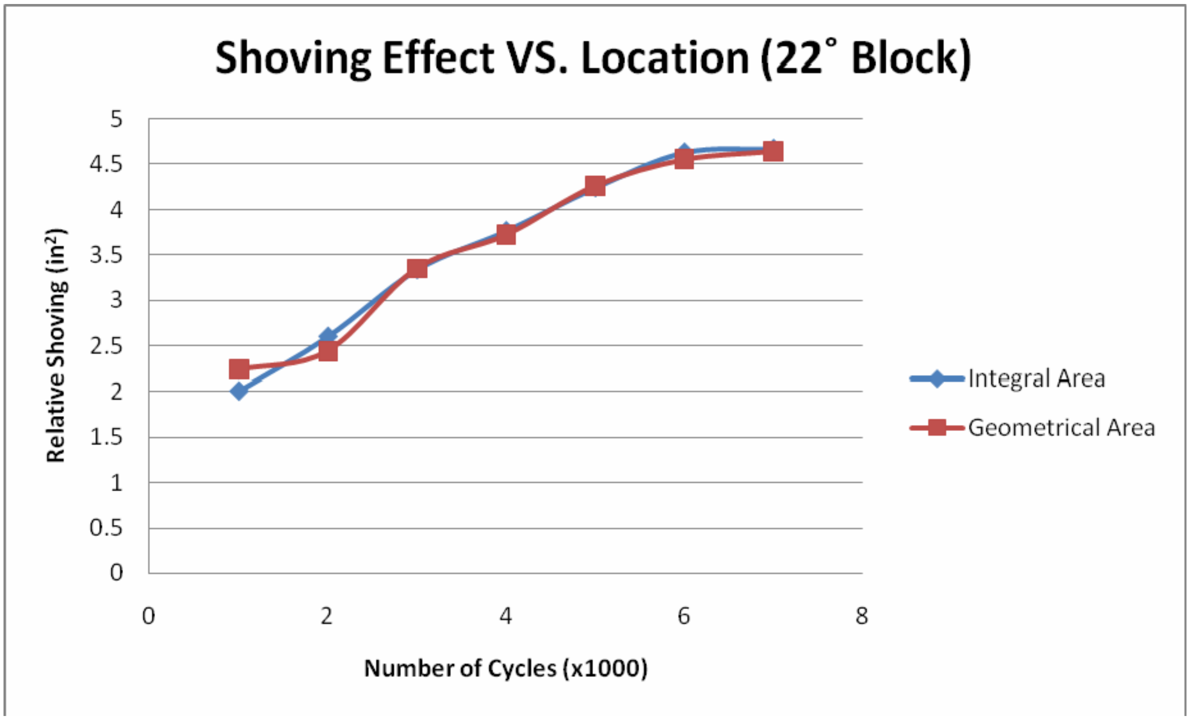


Figure 31 Relative Shoving as Number of Cycles Increased

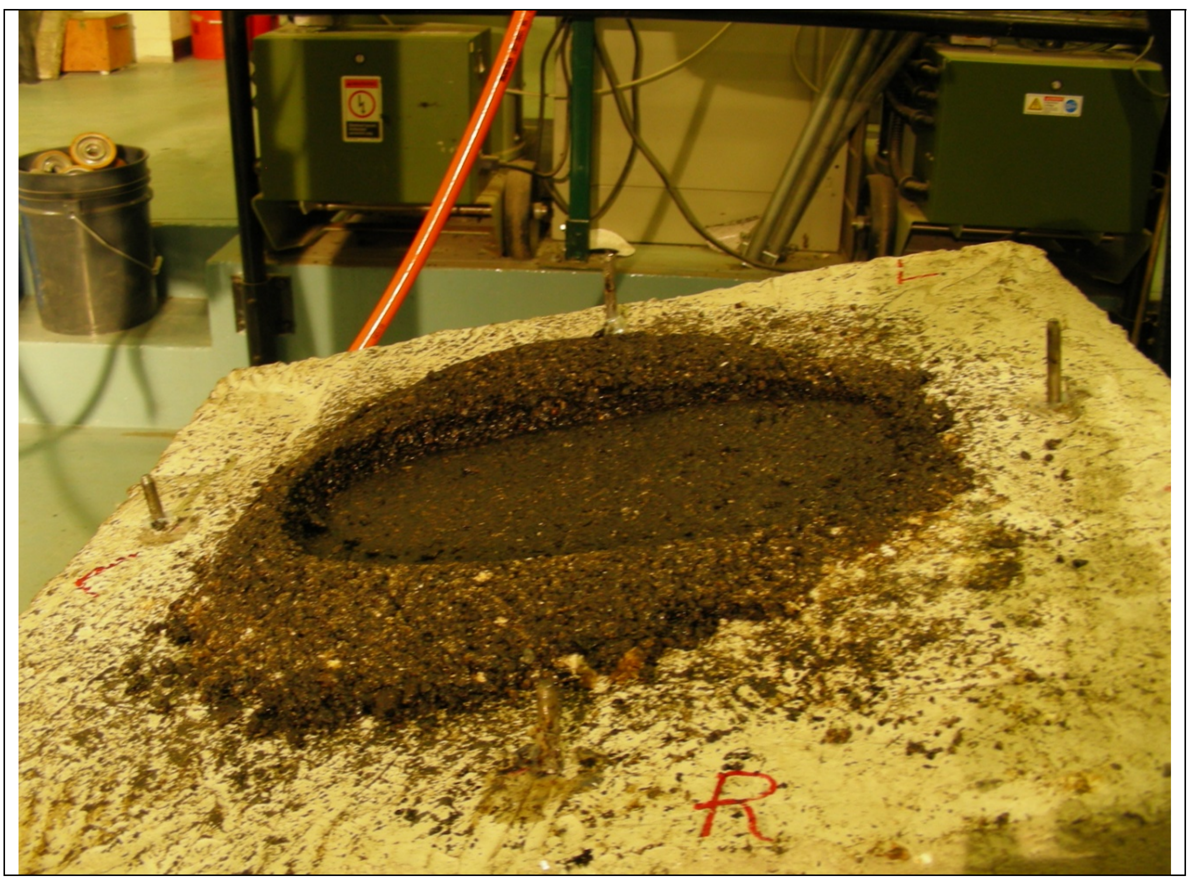


Figure 32 Rutting and Shoving in IRR

6.6 Rutting Area Index and Shoving Area Index for HMA Patch Material

Figure 33 shows the results of the rutting area index (RAI) as a function of the number of load applications or cycles and the tilt of the block angle. The rutting area index increases with both the number of load cycles and the increase in tilt angle. Figure 34 shows the results of the rutting area index (RAI) as a function of the number of load applications and the vertical applied load. The effect of cycles of freezing and thawing is shown in Figure 35. The RAI is not affected after four cycles of freezing and thawing. However, the RAI increases with increased load cycles.

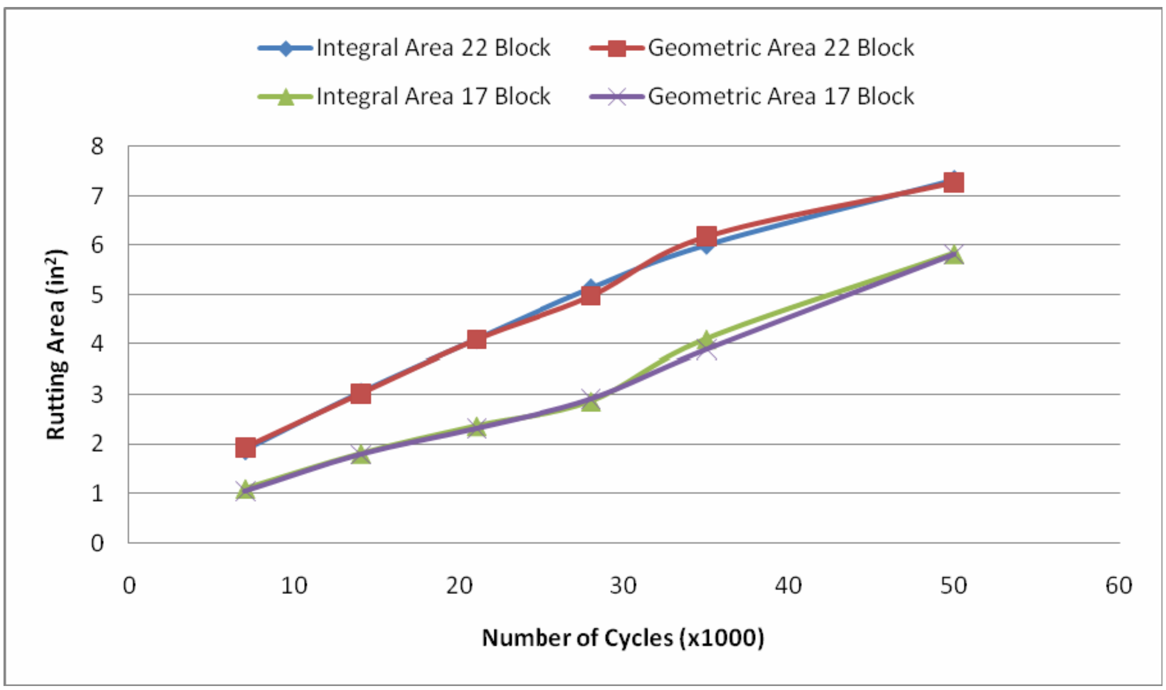


Figure 33 RAI as a Function of Load Applications and Pavement Block Angle

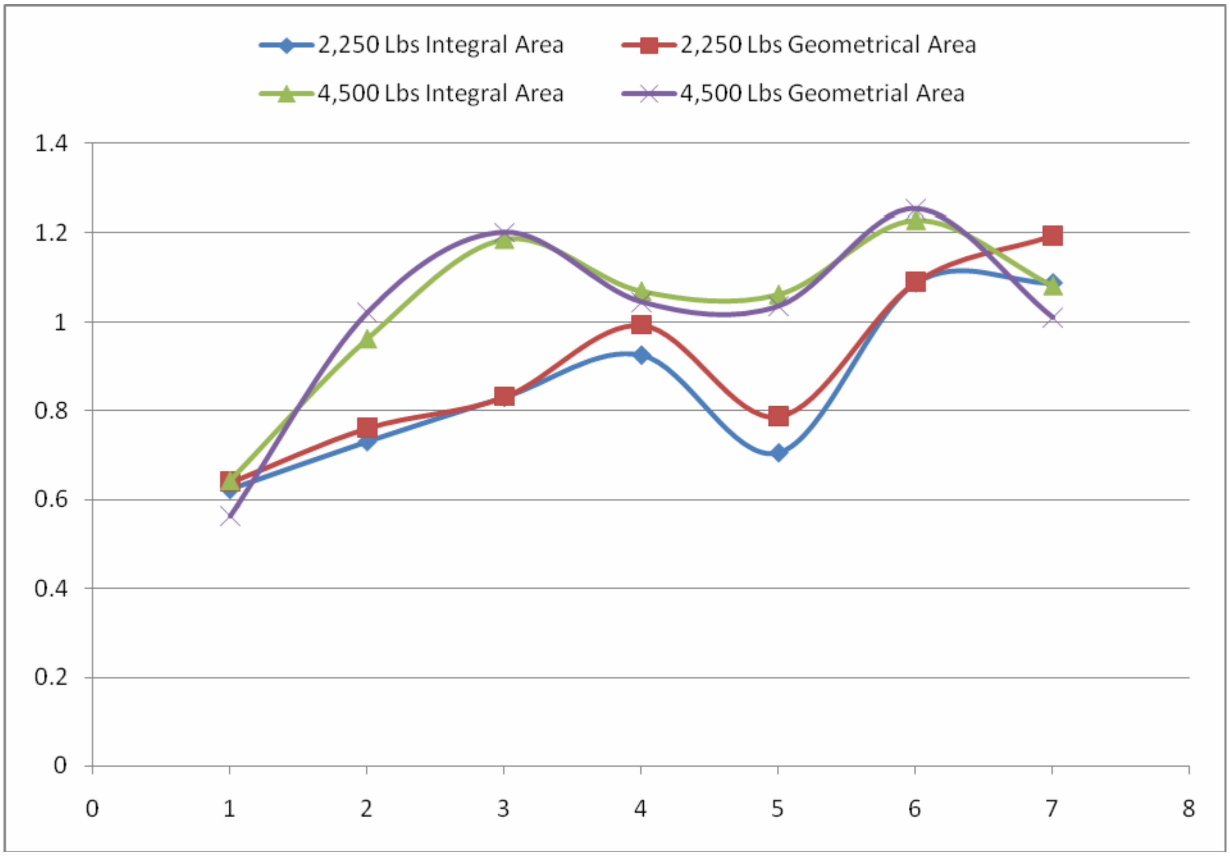


Figure 34 RAI as a Function of Load Applications and Magnitude of Vertical Load for the HMA Patch Material

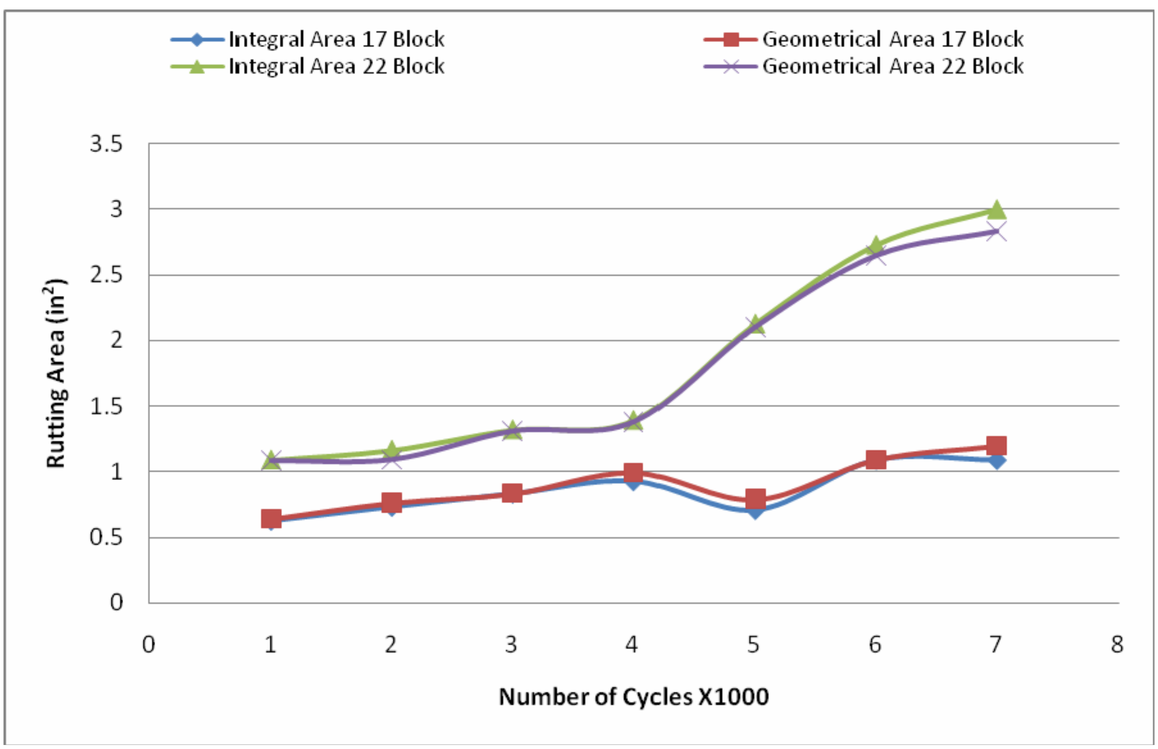


Figure 35 RAI as a Function of Load Applications and After Four Cycles of Freezing and Thawing

6.7 MMLS Results

Results obtained from the MMLS will generate a rutting profile along the wheel path. The maximum rut depth will be used as the performance indicator for these results and compared to the maximum rut depth for the concrete pavement block. As expected, the maximum rut depth increases with increase in load applications for all tests. The MMLS rut curve appears similar to that for the 17˚ block. The rut curve for the 22˚ block is much higher, and therefore the rutting is more pronounced. This behavior follows the belief that a higher rutting and shoving will occur with the larger tilt angle. The rutting curve for the 13˚ block appears to be similar to the 22˚ curve. This level of rutting can be achieved by a higher normal force or by a combination of normal and shear forces. This appears to be the prevailing rutting mechanism in the 13˚ and 22˚ blocks shown in Figure 36.

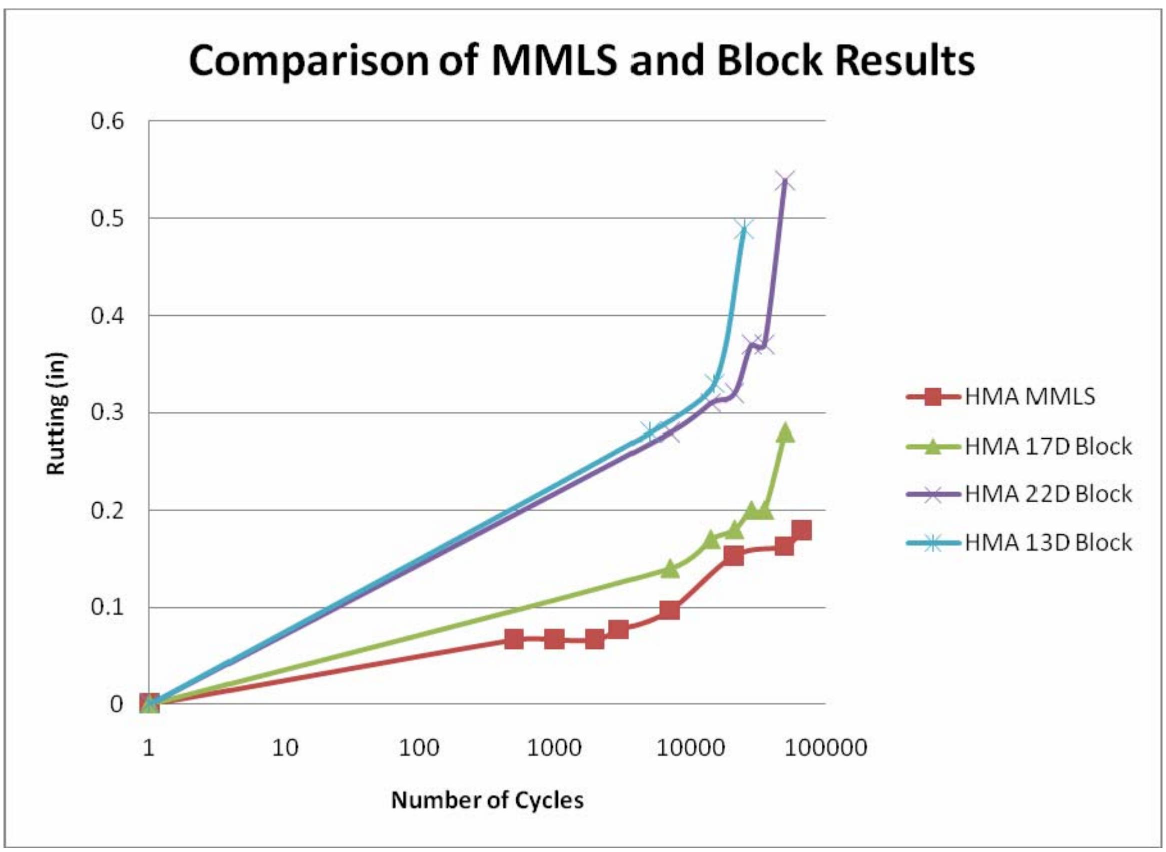


Figure 36 MMLS Results Compared to Results Obtained from Testing Blocks

After knowing that results obtained from testing the concrete blocks showed some correlation with results obtained in the MMLS machine a 2D finite elements analysis was performed in order to investigate correlation between actual testing and commercial software.

6.8 Modeling Results Using ANSYS

The ANSYS software was used to model the behavior of the pothole under applied load and tilt angle. This is accomplished by applying a normal and shear force to the surface of the loading block. Numerous assumptions and simplifications had to be made to a very complex problem. Therefore the results for the deformation profiles are relative to the material characteristics and interface bonds selected. A deformation mesh for the modeled block can be seen in Figure 37, note that the higher deformation occurs at the location indicated by the arrow.

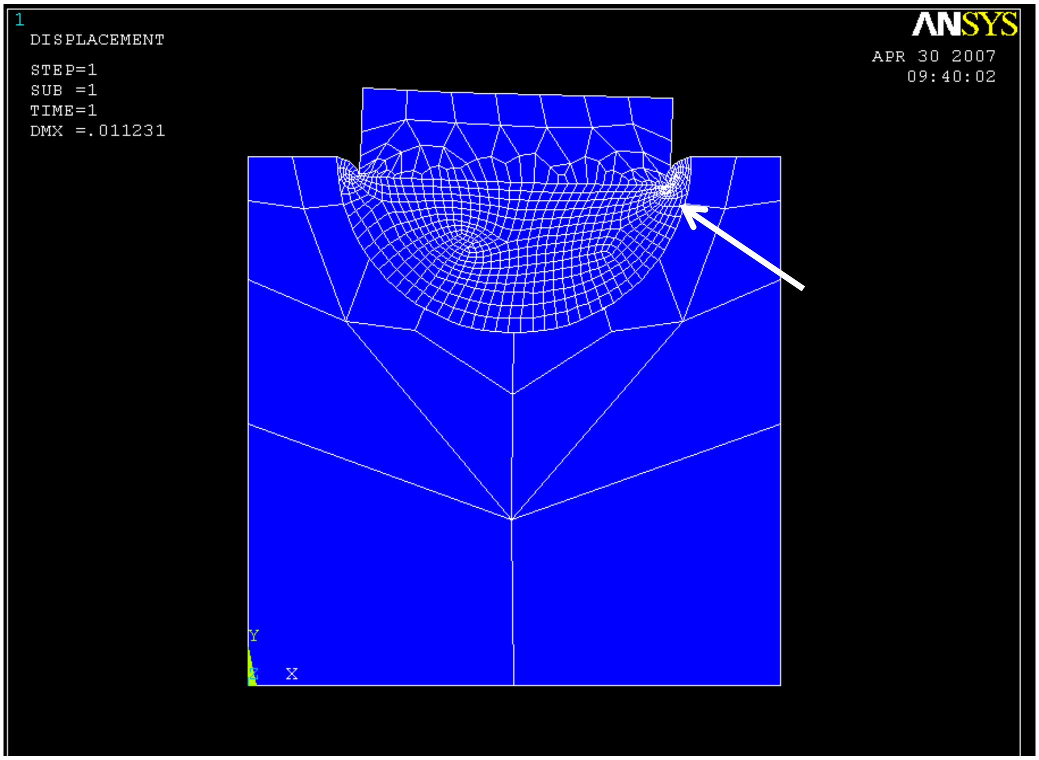


Figure 37 Deform Shape of the Pothole Mix Modeled in ANSYS

Figure 37 also shows the deformation in the nodes located underneath the load applicator. Figure 38 shows the characteristic shoving profile due to the load applicator. The shoving response shows that the higher the modulus of elasticity the lower the shoving.

FEM results in Figure 38 support our experimental results using the MMLS and block testing. A certain level of rutting and shoving can be achieved by the application of a normal force or by the appropriate combination of normal and shear stresses. This can be seen in Figure 38 where the 17˚ and 22˚ shoving profiles for the higher modulus of elasticity material is less than the shoving for the lower modulus with similar tilt angle. The higher shoving profile is also achieved with the 13˚ block and both the high and low moduli.

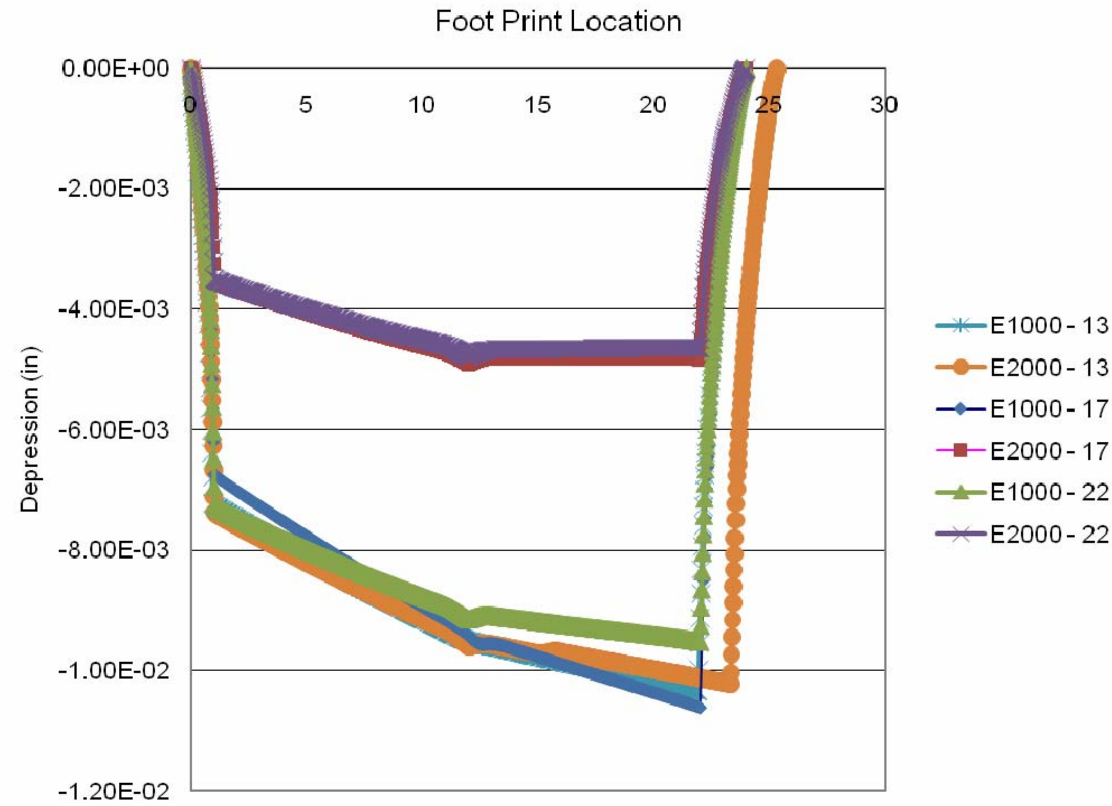


Figure 38 Relative Shoving Profile from ANSYS with Respect to Modulus and Tilt Angle

7 Discussion of Results

The results have shown that in general, the Rutting Area Index and the Shoving Area Index increase with an increase in the number of applied cycles, block tilt angle and magnitude of normal and shear stress. The increase in shear stress will increase the SAI and therefore the RAI. An increase in RAI will also be observed with an increase in the normal stress applied to a horizontal patch without tilt or shear stress. The MMLS rut curves shown in Figure 36 reflects a threshold where the combination of shear and normal stresses will produce the same level of rutting as a high level of normal force on a horizontal patch.

The effect of different materials on pothole performance is evident between the HMA and the IRR. The HMA used in this project performed better that the IRR as expected. The HMA achieved a RAI and SAI similar to the IRR but at an applied number of cycles that is an order of magnitude higher. This can be seen for the IRR performance curve in Figure 29 and the HMA performance curve in Figure 33.

The effect of freezing and thawing is less pronounced after only four cycles of freezing and thawing. For the IRR, the performance with and without freeze-thaw cycles is the same up to 7,000 loading cycles. The RAI increases with loading as expected.

Results comparing the MMLS and the block test have proved that the block testing is a much harsher accelerated test. The MMLS rut curve was similar to the 17˚ block and much lower than the 13˚ and 22˚ block. This is predictable since the 4,500 lb vertical load simulates a truck tire load which has no wonder and is dynamic along the same footprint.

The ANSYS model results have proved that a rutting and shoving mechanism is more detrimental to patch performance since more material is being displaced within the footprint area. The FEM results have also corroborated the results seen with the MMLS and block testing data. It shows that a certain level of rutting or RAI can be achieved with the right combination of normal and shear stresses.

8 Conclusion and Recommendation

The proposed accelerated test has proved successful in assessing pothole patching materials with respect to cyclic load applications, load magnitude, shear to normal stress ratios and freeze thaw cycles.

Based on this research, an acceptance criteria is proposed for patching materials:

For HMA type materials, the RAI should not exceed 5 in^2 at 30,000 cycles with a shear to normal stress ratio less than 40% with a vertical load of 4,500 lbs. For a stress ratio of 30% the RAI should not exceed 5 in^2 at 50, 000 cycles.

For the IRR type material, the RAI should not exceed 5 in^2 at 4,000 cycles with a shear to normal stress ratio less than 30% with a vertical load of 4,500 lbs. For a stress ratio of 40% the RAI should not exceed 4 in^2 at 3, 000 cycles.

9 Future Work

Future research should validate the Rutting and Shoving Index with field performance.

Improvements in computing the shoving area index for HMA.

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Mixtures; Patching; Potholes (Pavements); Repeated loads; Traffic loads; Hot mixed asphalt)

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Appendix

Table of executed test setups

Material Tested	22˚ Angle Block	17˚ Angle Block	13˚Angle Block
UPM (YB)	Normal condition/ F&T	Normal condition/ F&T	Normal condition
HMA	Normal condition/ F&T	F&T	Normal condition
Emulsion Mix	Normal condition/ F&T	Normal condition	Normal condition
Black Bucket	Normal condition/ F&T		Normal condition

Table of Angle Effects on Normal and Shear Stresses

Angle (Degrees)	Angle radian	Shear Force (Lbs)	Normal Force (Lbs)	Shear Stress (σ_s)	Normal Stress (σ_n)	σs/σn
9	0.16	703.96	4444.60	13.54	85.47	0.158
10	0.17	781.42	4431.63	15.03	85.22	0.176
11	0.19	858.64	4417.32	16.51	84.95	0.194
12	0.21	935.60	4401.66	17.99	84.65	0.213
13	0.23	1012.28	4384.67	19.47	84.32	0.231
14	0.24	1088.65	4366.33	20.94	83.97	0.249
15	0.26	1164.69	4346.67	22.40	83.59	0.268
16	0.28	1240.37	4325.68	23.85	83.19	0.287
17	0.30	1315.67	4303.37	25.30	82.76	0.306
18	0.31	1390.58	4279.75	26.74	82.30	0.325
19	0.33	1465.06	4254.83	28.17	81.82	0.344
20	0.35	1539.09	4228.62	29.60	81.32	0.364
21	0.37	1612.66	4201.11	31.01	80.79	0.384
22	0.38	1685.73	4172.33	32.42	80.24	0.404

Tables of the elevation profiles

Initials

Horizontal Measurement

Point #	Location (inch)
R	2.23
L	2.43
3	2.48
3.5	2.48
4	2.45
4.5	2.43
5	2.45
5.5	2.42
6	2.4
6.5	2.4
7	2.42
7.5	2.37
8	2.36
8.5	2.36
9	2.35
9.5	2.4
10	2.37
10.5	2.37
11	2.44
11.5	2.4
12	2.45
12.5	2.35
13	2.39
13.5	2.37

Vertical Measurement

Point #	Location
R	2.33
L	2.5
3	2.55
3.5	2.69
4	2.59
4.5	2.59
5	2.56
5.5	2.54
6	2.51
6.5	2.49
7	2.45
7.5	2.41
8	2.42
8.5	2.45
9	2.44
9.5	2.41
10	2.43
10.5	2.42
11	2.44
11.5	2.43
12	2.45
12.5	2.46
13	2.43

After 1000 cycles.

Horizontal Measurement	
Point #	Location (inch)
R	2.23
L	2.43
3	2.48
3.5	2.38
4	2.38
4.5	2.5
5	2.61
5.5	2.61
6	2.61
6.5	2.63
7	2.64
7.5	2.65
8	2.61
8.5	2.59
9	2.59
9.5	2.58
10	2.57
10.5	2.6
11	2.58
11.5	2.56
12	2.31
12.5	2.3
13	2.31
13.5	2.34

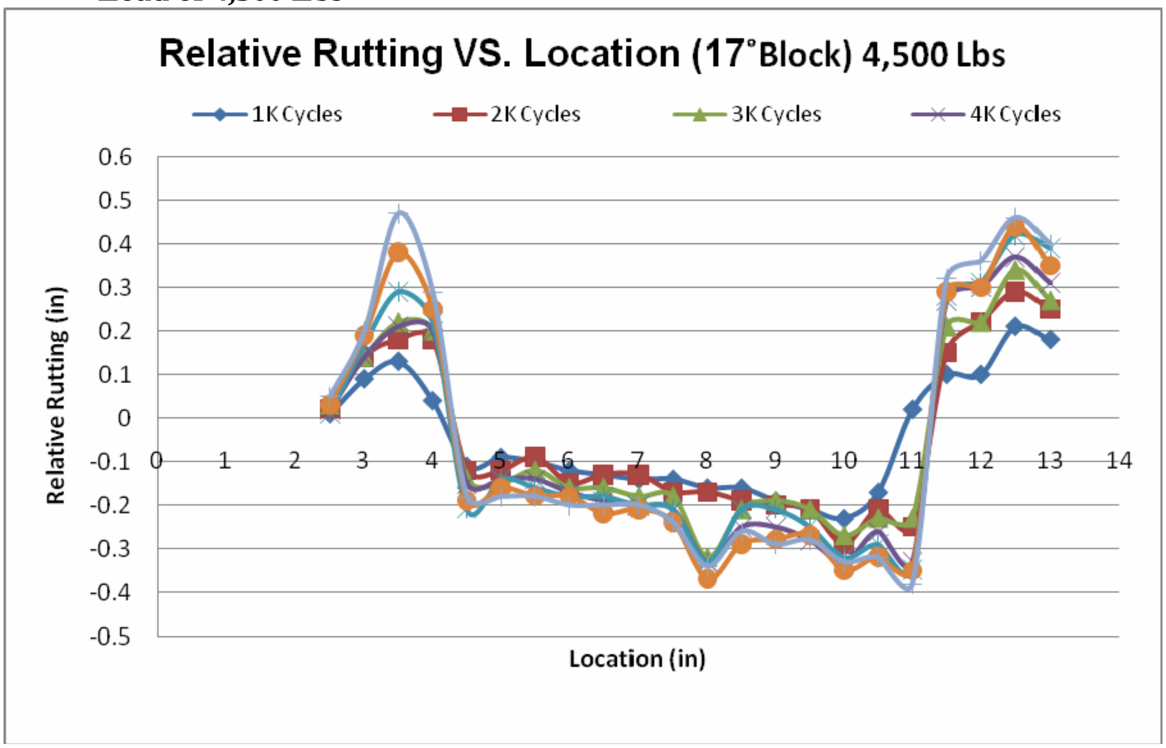
Vertical Measurement	
Point #	Location
R	2.38
L	2.3
3	2.64
3.5	2.71
4	2.71
4.5	2.71
5	2.73
5.5	2.7
6	2.7
6.5	2.69
7	2.68
7.5	2.69
8	2.69
8.5	2.68
9	2.64
9.5	2.62
10	2.63
10.5	2.63
11	2.64
11.5	2.64
12	2.69
12.5	2.78
13	2.59

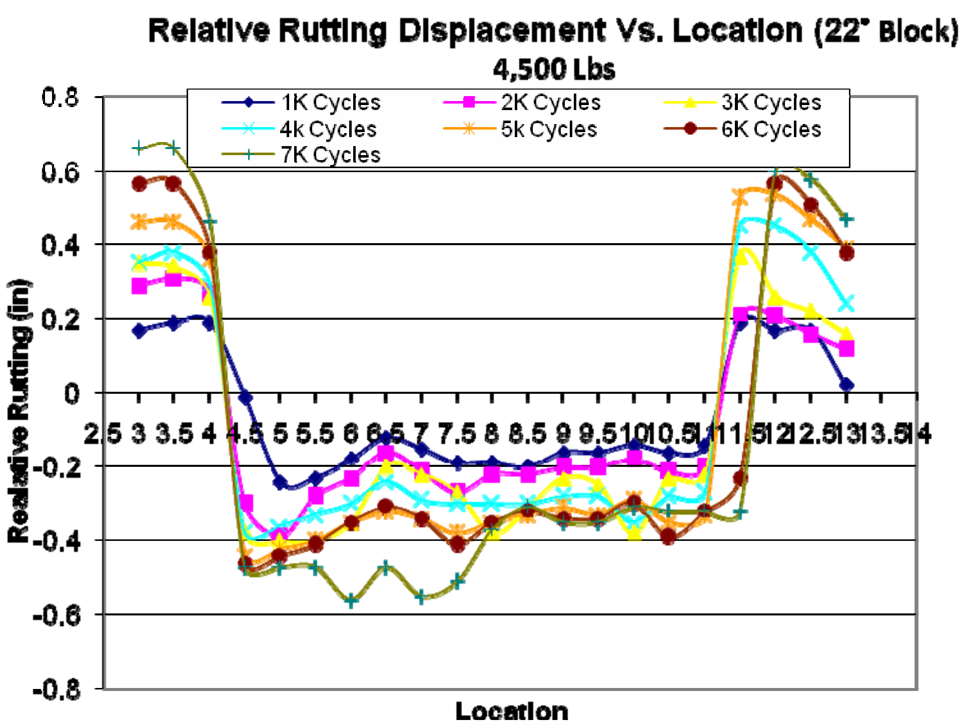
Vertical Measurement										
Point #	Location									
R	2.38	True Horizontal	True Vertical				Shoving			
L	2.3	Displacement	Displacement		y	DIF	Area Calculation			Area Calculation
3	2.64	0	-0.09	FALSE			Vertical			Horizontal
3.5	2.71	0.1	-0.02	TRUE	-0.020	0.000	-0.023			0.035
4	2.71	0.07	-0.12	FALSE	-0.027	-0.093	-0.044			0.0925
4.5	2.71	-0.07	-0.12	FALSE	-0.035	-0.085	-0.053			0.1225
5	2.73	-0.16	-0.17	FALSE	-0.042	-0.128	-0.060			0.135
5.5	2.7	-0.19	-0.16	FALSE	-0.049	-0.111	-0.061	max Y		0.145
6	2.7	-0.21	-0.19	FALSE	-0.057	-0.133	-0.067	-0.02		0.1475
6.5	2.69	-0.23	-0.2	FALSE	-0.064	-0.136	-0.074	delta y		0.16
7	2.68	-0.22	-0.23	FALSE	-0.072	-0.158	-0.090	-0.14		0.1675
7.5	2.69	-0.28	-0.28	FALSE	-0.079	-0.201	-0.096	delta x		0.155
8	2.69	-0.25	-0.27	FALSE	-0.086	-0.184	-0.080	9.5		0.1525
8.5	2.68	-0.23	-0.23	FALSE	-0.094	-0.136	-0.059	Slope		0.14
9	2.64	-0.24	-0.2	FALSE	-0.101	-0.099	-0.050	-0.014736842		0.13
9.5	2.62	-0.18	-0.21	FALSE	-0.108	-0.102	-0.046	xmax		0.1425
10	2.63	-0.2	-0.2	FALSE	-0.116	-0.084	-0.043	3.5		0.1275
10.5	2.63	-0.23	-0.21	FALSE	-0.123	-0.087	-0.039	B		0.11
11	2.64	-0.14	-0.2	FALSE	-0.131	-0.069	-0.035	0.031578947		0.04
11.5	2.64	-0.16	-0.21	FALSE	-0.138	-0.072	-0.042			
12	2.69	0.14	-0.24	FALSE	-0.145	-0.095	-0.066		Integral Concept	2.0025
12.5	2.78	0.05	-0.32	FALSE	-0.153	-0.167	-0.042		Hand Calculation	2.244
13	2.59	0.08	-0.16	FALSE	-0.160	0.000				
		0.03					**1.07**			

Instant Road Repair

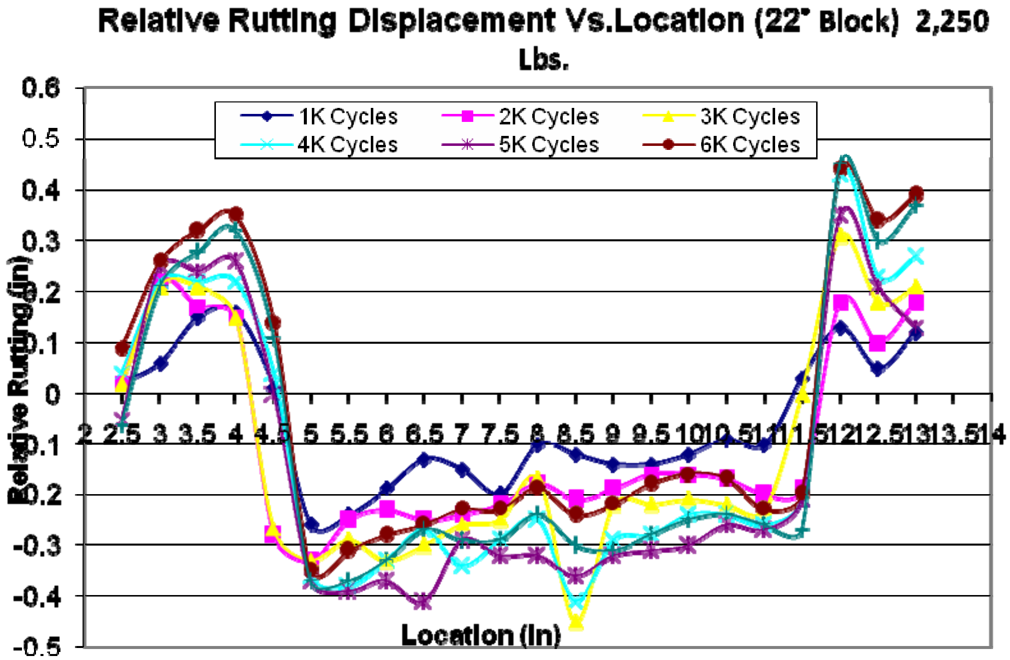
Rutting Distresses.

Load of 4,500 Lbs



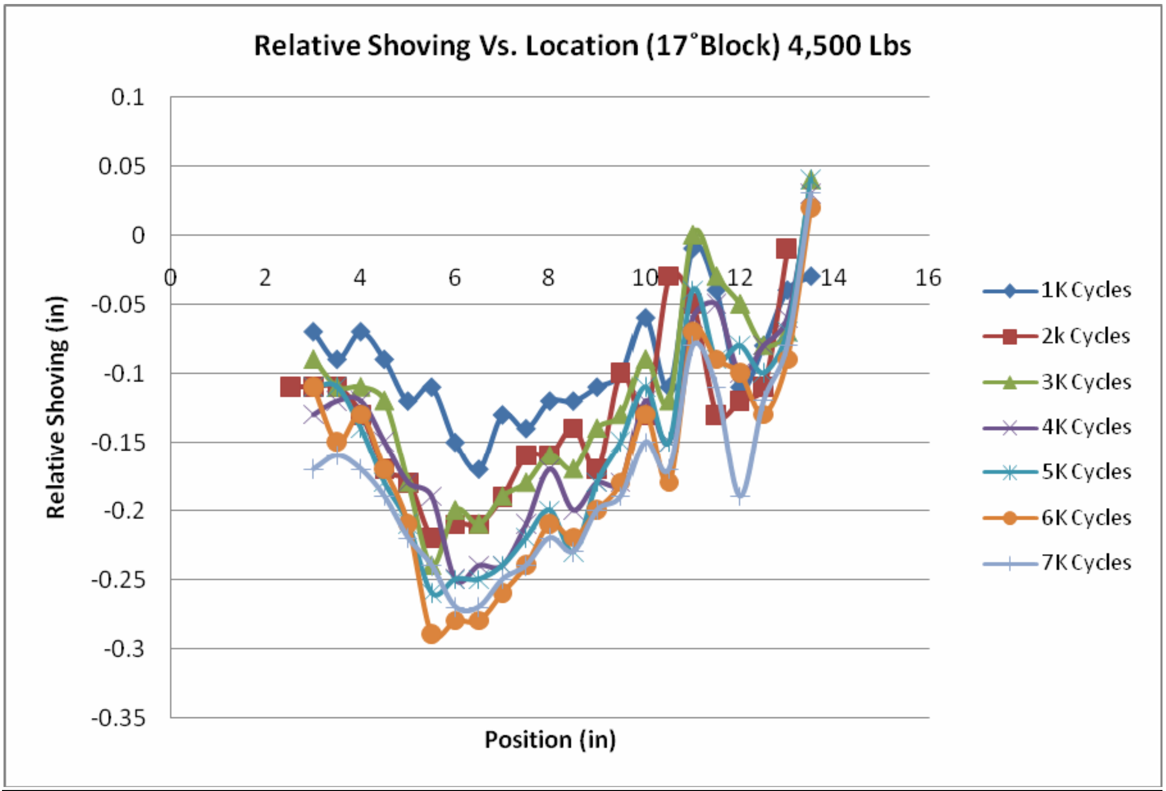


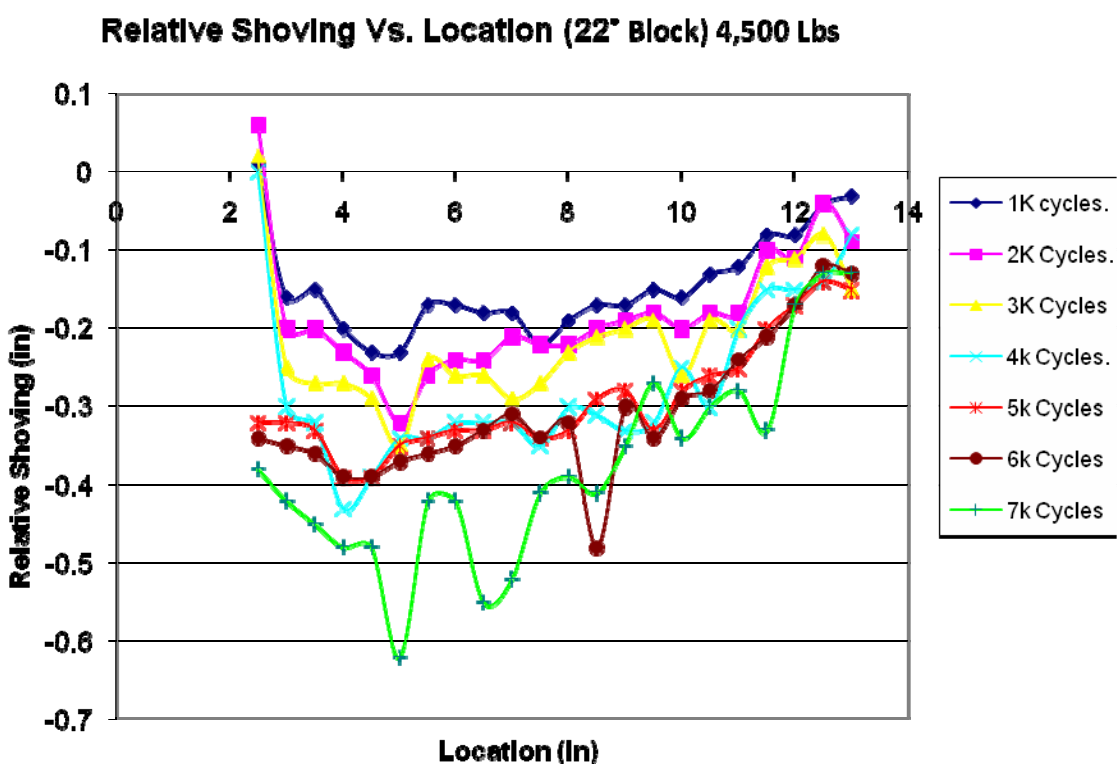
Load 2,250



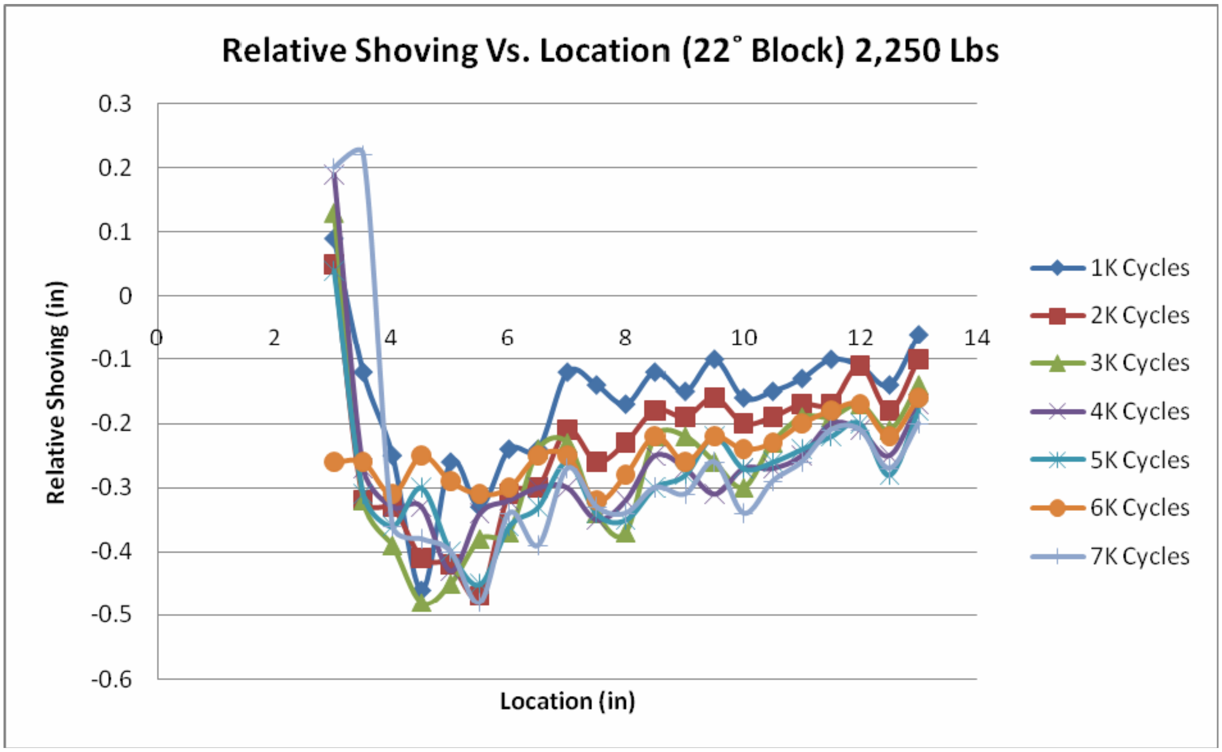
Relative Rutting Displacement Vs.Location (22" Block) 2,250 Lbs.
1K Cycles
2K Cycles
3K Cycles
4K Cycles
5K Cycles
6K Cycles
Relative Rutting (in)
Location (in)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14

Shoving Distresses
4,500 Lbs.





2,250 Lbs

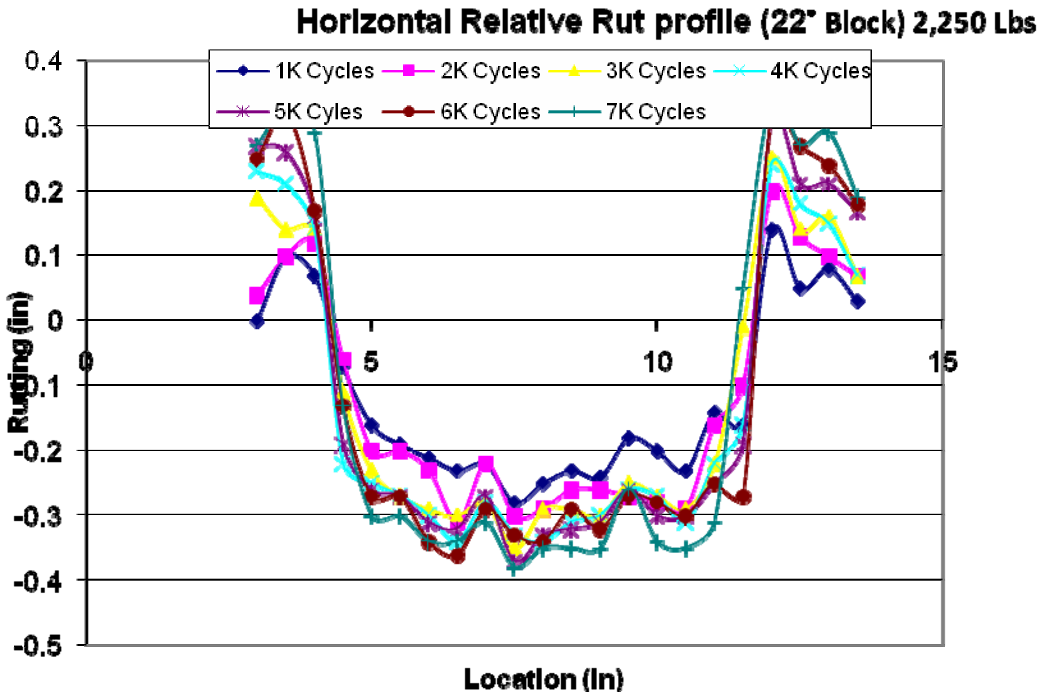


Relative Shoving Vs. Location (22˚ Block) 2,250 Lbs
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
2
4
6
8
10
12
14
Relative Shoving (in)
Location (in)
1K Cycles
2K Cycles
3K Cycles
4K Cycles
5K Cycles
6K Cycles
7K Cycles

IRR Freeze and Thawing Cycles

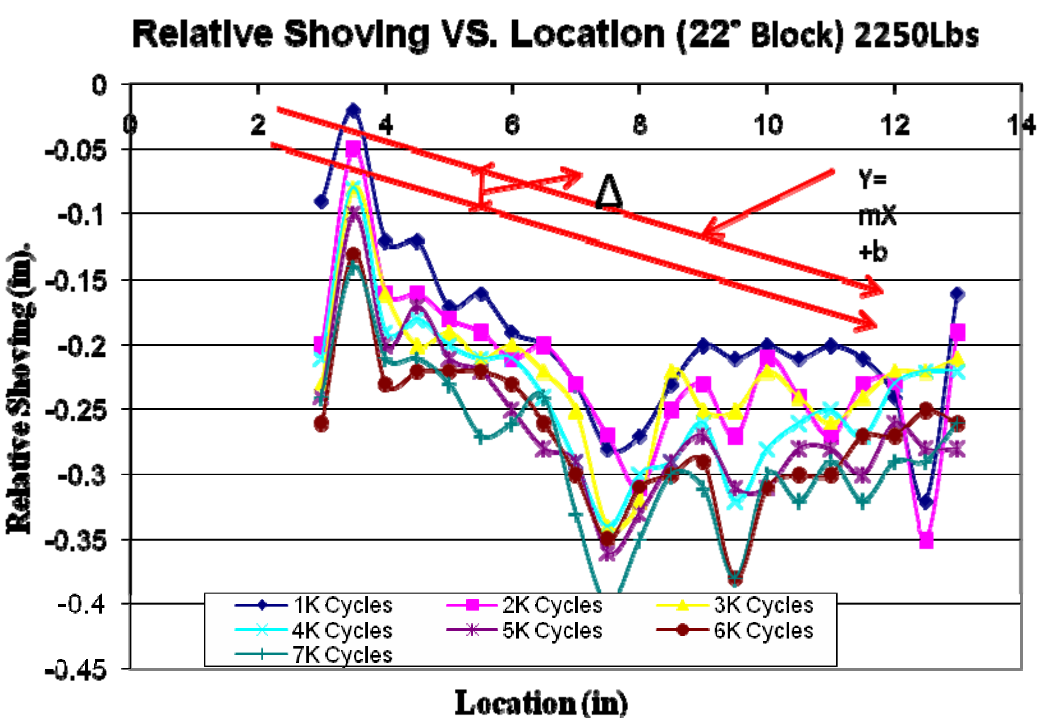
Rutting Distresses

2,250 Load

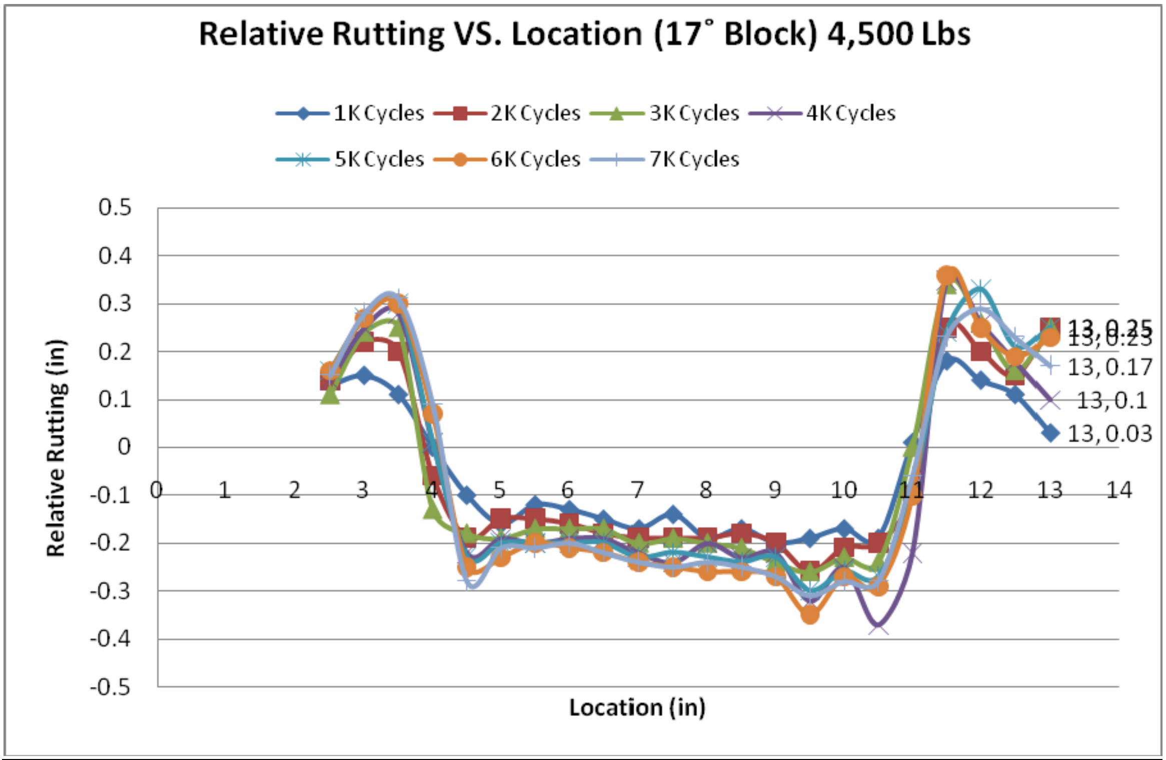


Shoving Distresses

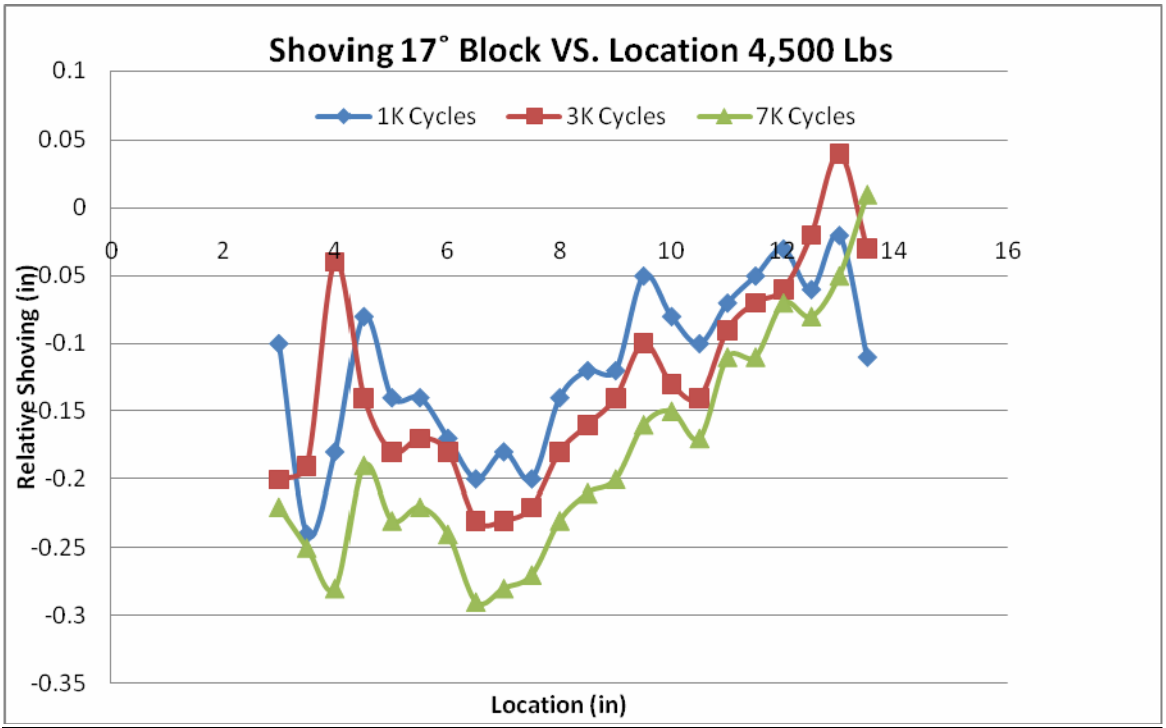
2,250 Load



IRR Freezing and Thawing Cycles
4,500 Lbs
Rutting



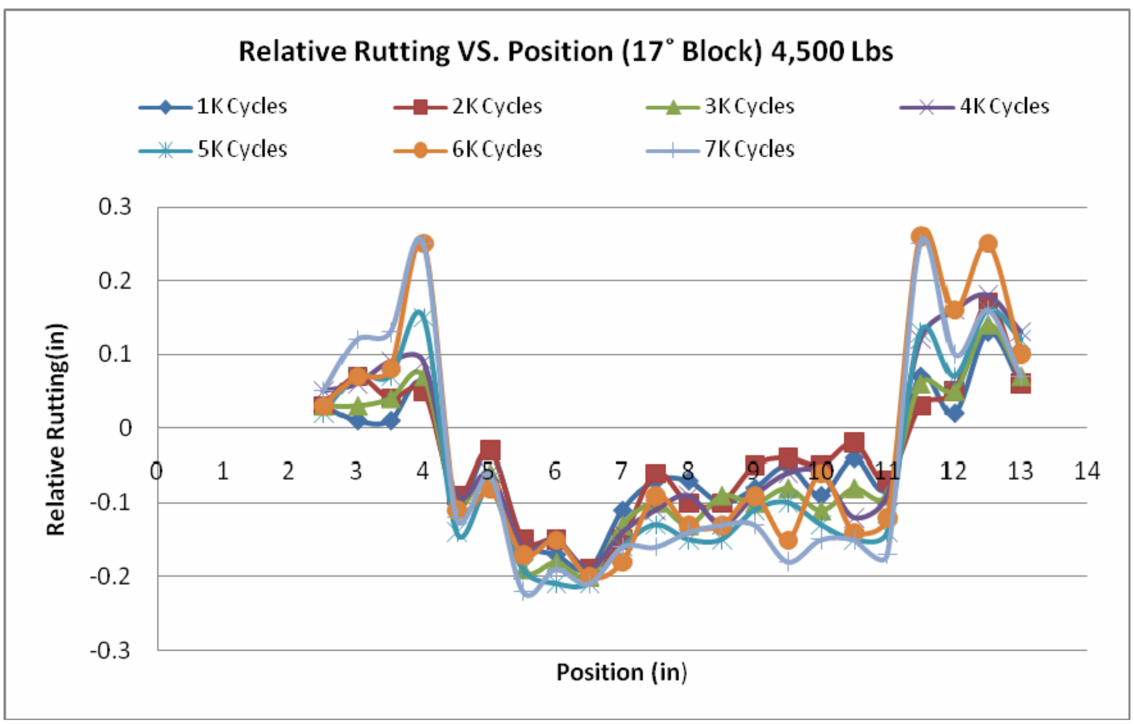
Shoving

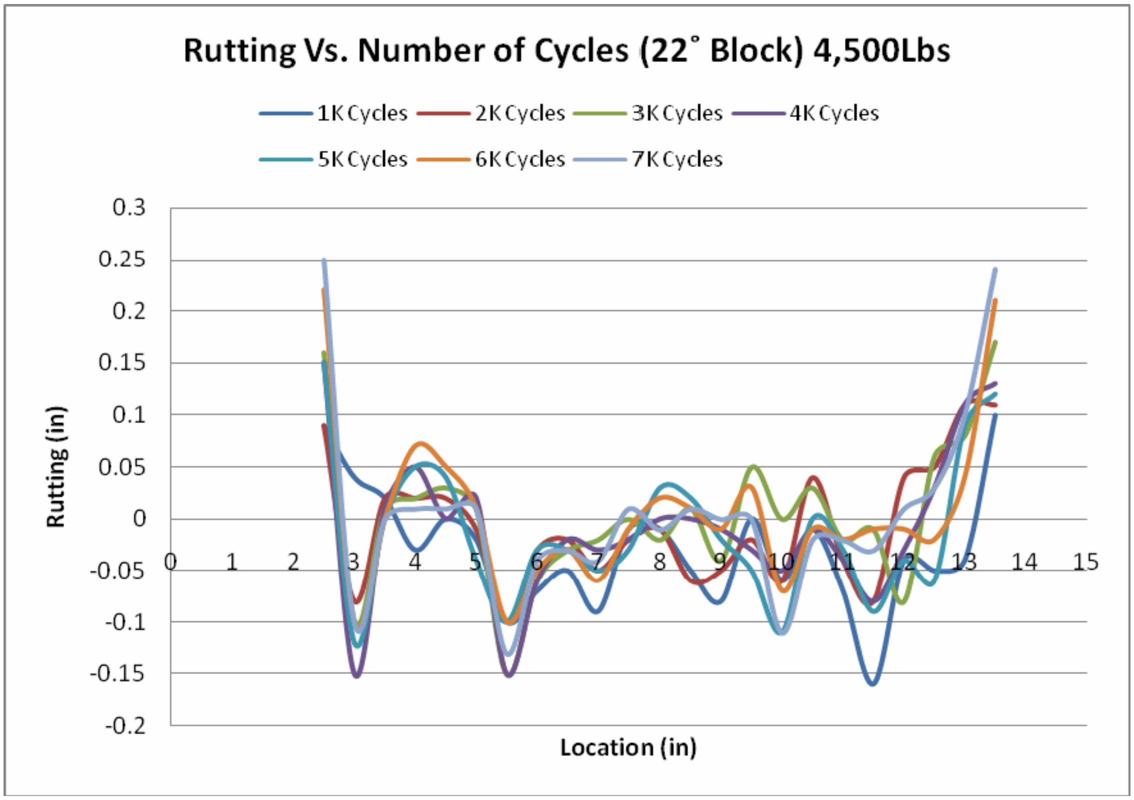


HMA

4,500 Lbs

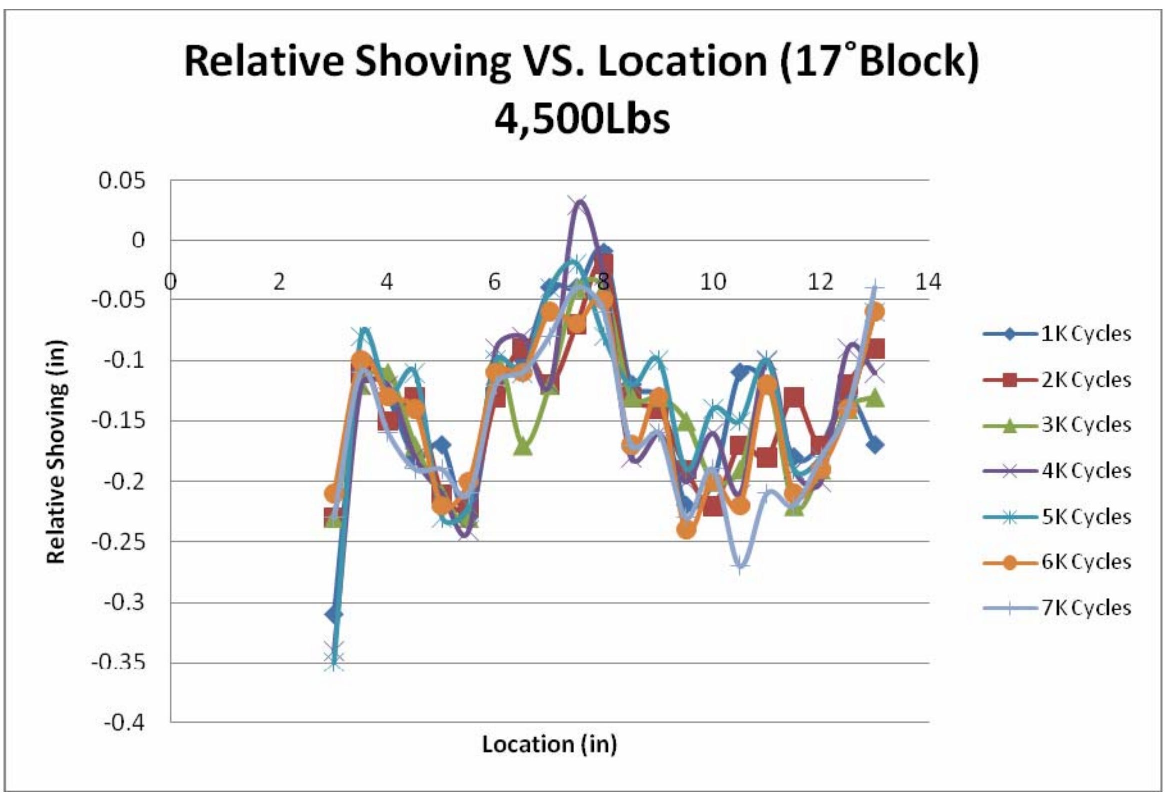
Rutting



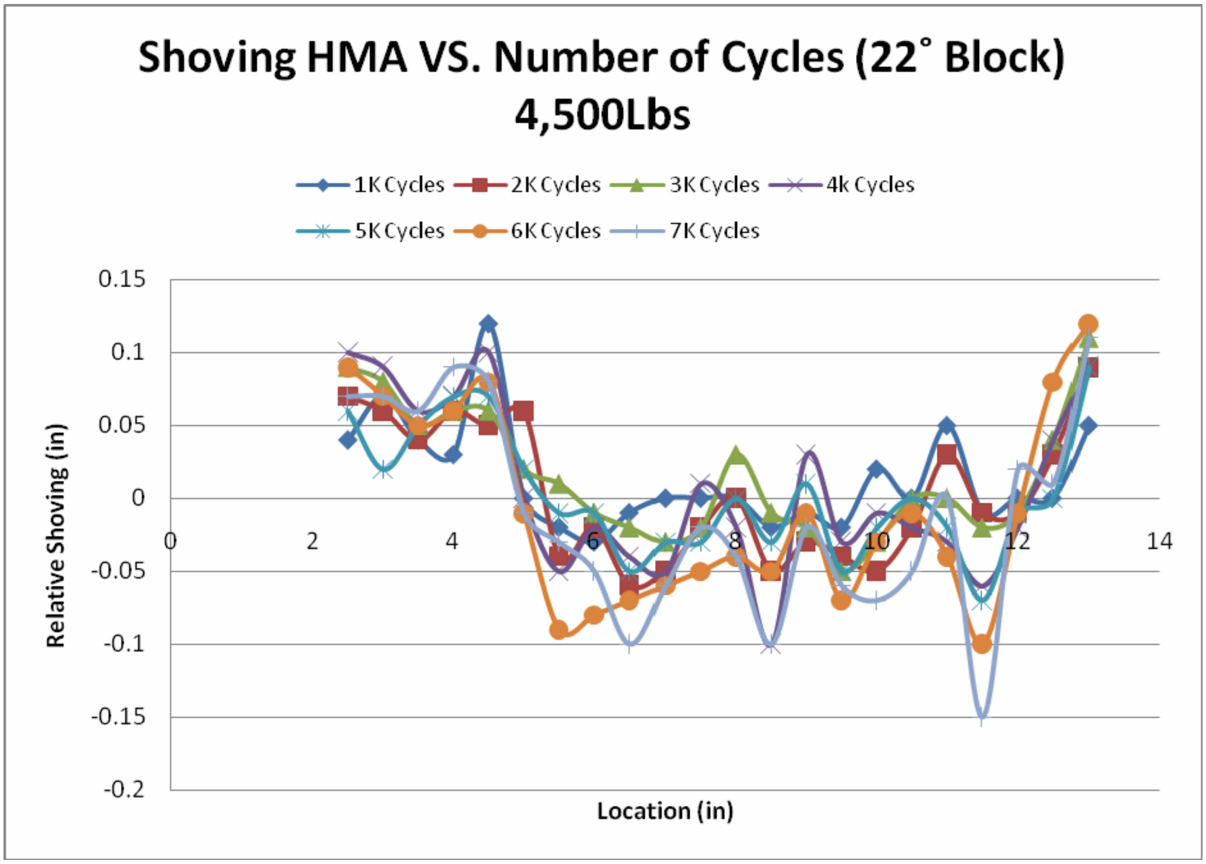


Rutting Vs. Number of Cycles (22˚ Block) 4,500Lbs
1K Cycles
2K Cycles
3K Cycles
4K Cycles
5K Cycles
6K Cycles
7K Cycles
Rutting (in)
Location (in)

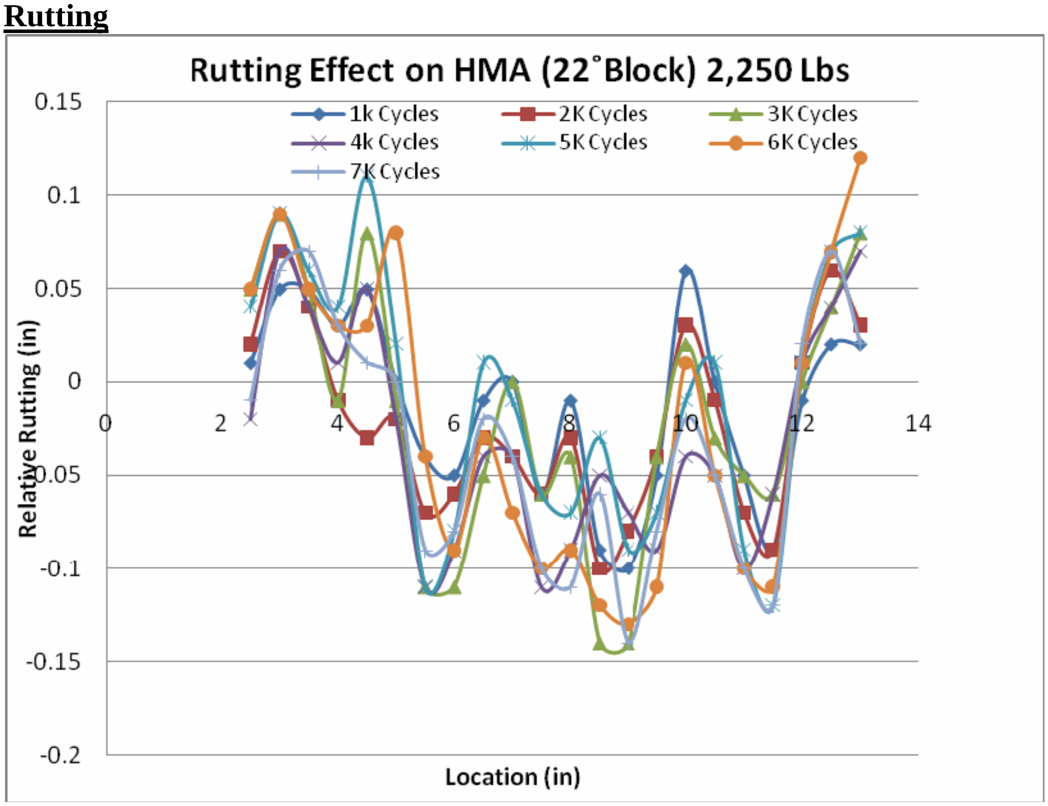
Shoving



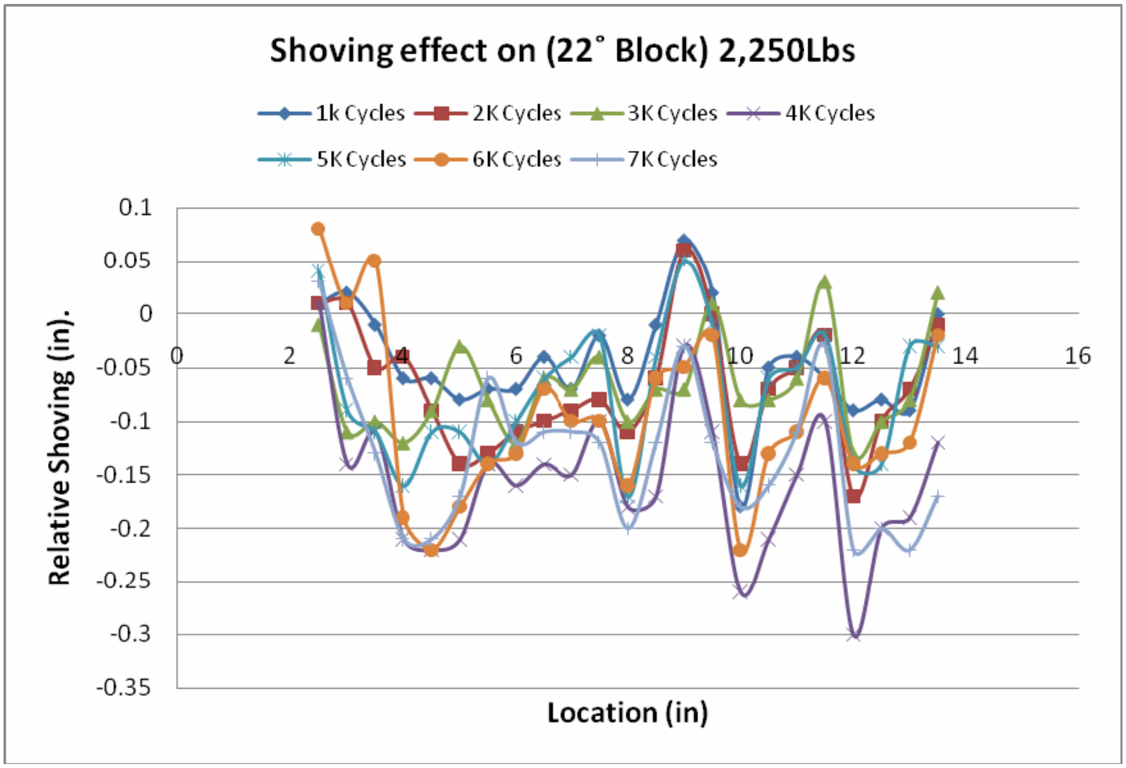
Relative Shoving VS. Location (17˚Block) 4,500Lbs
1K Cycles
2K Cycles
3K Cycles
4K Cycles
5K Cycles
6K Cycles
7K Cycles
Relative Shoving (in)
Location (in)



HMA
2,250 Lbs
Rutting



Shoving



Shoving effect on (22˚ Block) 2,250Lbs
1k Cycles
2K Cycles
3K Cycles
4K Cycles
5K Cycles
6K Cycles
7K Cycles
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
0
2
4
6
8
10
12
14
16
Relative Shoving (in).
Location (in)

MMLS Analysis

MMLS Analysis

KNOWN: $\sigma = 100\ psi$

$F = 2.5\ KN = (2500\ N)\left(0.224808\ \frac{lbf}{N}\right) = 562\ lbf$

$\sigma = \frac{P}{A} \Rightarrow A = \frac{P}{\sigma} = \frac{562}{100} = 5.62\ in^2$ AREA COVERED BY MMLS TIRE.

$A = \pi r^2 \Rightarrow r = \sqrt{\frac{5.62}{\pi}} = 1.338\ in$

CONCRETE BLOCK.

$\sigma = \frac{P}{A} \Rightarrow P = (\text{Approx. footing AREA})(100\ psi\ \sigma) \Rightarrow P = (52)(100)$

Approx LOAD = 5200 lbs

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD