THE ENHANCEMENT OF RESTORING ASPHALT CORE HOLES USING THE INNOVATION OF A CAP DEVICE

by

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ABSTRACT OF THE DISSERTATION

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Pavement maintenance is the key to pavement preservation. Effective pavement preservation programs integrate many maintenance strategies and treatments, such as preventive, corrective and emergency maintenance. However, a common practice in pavement construction, core hole testing, and often leaves newly constructed roadways vulnerable to premature damage that can inhibit effective pavement preservation. There is no doubt that asphalt pavement needs to be tested for evaluation, verification and research purposes, and that core hole testing is a cost-effective and diagnostic method by which to verify asphalt properties, as dictated by the specifications, such as thickness, structural integrity, specific gravity, air void content and percent compaction. Nonetheless, Federal and State agencies currently enforce specific procedures for asphalt core hole restoration and the current construction practice for asphalt core hole restoration does not enforce proper compaction to the restoration fill material, adequate protection to the edge and tips of the existing structure resulting from core drilling and adequate aesthetic physical appearance of the pavement structure. The lack of proper

restoration of asphalt core holes leads to multiple potential asphalt fatigues, such as partial weaknesses in pavement structures due to low compaction, initiation of cracking, spalling and/ or potholes at the edges of the existing surrounding pavement structure. Dispersion of the top surface of the core hole restoration material will also result to scattering of debris throughout the roadway, disintegration of restoration material from the existing paved structure and an overall poor physical appearance of the pavement structure. The need of inventing a new device to improve the core restoration procedures is crucial and much needed to enhance the construction practice of restoring and protecting asphalt core holes. This study presents the development of the core hole Cap device in addition to full investigation of the technical and practical application and feasibility of the asphalt core hole Cap innovation. This study also presents a finite element modeling of the Cap device performance and a life-cycle cost analysis (LCCA) of the pavement structure using the Cap device. The Cap device for asphalt core holes should enhance the compaction of the asphalt core restoration material, enhance the physical appearance of pavements and protect asphalt core holes and hence, the pavement structure.

ACKNOWLEDGEMENT AND DEDICATION

All praise is due to God, who helped me complete this work.

I would like to express my sincere appreciation to Dr. Trefor Williams for chairing my committee and his guidance and support throughout the course of my research. I would also like to thank my committee members of Dr. Hao Wang, Dr. Peter Jin and Dr. Sherif Atallah for their advice and mentoring during my studies. I also appreciate the immense support and help from Dr. Husam Najm throughout my journey at Rutgers University.

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I am truly blessed to have such a great mother who did everything possible for me to be the man I am today. I am also so grateful and fortunate to be married to the most patient and supportive person I know. I am so thankful to my wife Diane for being by my side on all ups and downs and for her continuous and unconditional care and love. I would like to dedicate this work to my mother and daughters, Ayah, Hana and Mialena, who cherish my life and enlighten my days with their presence. They are indeed the comfort of my eyes and the energy that recharges my spirit and faith daily.

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CHAPTER 1 - INTRODUCTION

Man built roads as a consequence of civilization. History testifies that provision of roadways is necessary to draw a country out of a state of barbarism, but that civilization is not attained until communications between neighbors is made so easy that the local differences, which breed narrowness and bigotry, are minimized. O'Flaherty continued in Volume 1, Chapter 1 of his Book "Highways and Traffic" that a particular type of administration has grown up in order to manage the highways and cope with the problems, which they create. Transport, in general, and particularly highway transport, plays an essential role in the life of a community today. Good highway transport facilities are the result of sound planning. Roads serve multiple functions. They make it possible for government to render various essential services, supply avenues of intercommunity mobility for persons and goods, facilitate these movements within each neighborhood, and give access to land and dwellings. The government adopted the notion that financial responsibility for transportation should be assigned among the beneficiaries based on the benefits of each receives. The beneficiaries are the taxpayers and the federal government in the form of federal aid, state fund, funds most highway administering agencies and other appropriations for transportation coming from the general funds of the federal government, as stated in Chapter 5 of the Highway Engineering Book.

The United States Department of Transportation (USDOT) is a federal cabinet overseeing the transportation system in the country. The Federal Highway Administration (FHWA) is a division of the United States Department of Transportation (USDOT) and it is the entity administering the highway transportation system in the United States of

America. The FHWA has numerous activities and programs; however, most of these activities are grouped into two main programs, which are:

1- The Federal-aid Highway Program

2- The Federal Lands Highway Program

The Federal Highway Administration (FHWA) has "A Guide to Federal-Aid Programs and Projects" that states in this guide's introduction that Federal-Aid highway funds are authorized by Congress to assist the States in providing for construction, reconstruction, and improvement of highways and bridges on eligible Federal-Aid highway routes and for other special purpose programs and projects.

The standard construction practice of pavement is continuously improving as new studies reveal enhanced methodologies, materials, procedures and/ or preventive plans for best construction practices in asphalt pavement. Research and development of asphalt pavement has been evolving recently around pavement preservation and maintenance Galehouse et al. (2003) showed on the Principles of Pavement Preservation Report that pavement preservation gives highway agencies an economical alternative for addressing pavement needs. Moreover, with pavement preservation, highway agencies gain the ability to improve pavement conditions and extend pavement life and performance without increasing expenditures. The focus is on preserving the pavement asset while maximizing the economic efficiency of the investment. Pavement preservation provides greater value to the highway system and improves the satisfaction of highway users. Pavement preservation is not about a single treatment, nor is it a one-size-fits-all philosophy. Instead, pavement preservation must be tailored to each highway agency's system needs in the most cost-effective manner (Asphalt Pavement of Indiana). This involves using a variety of treatments and pavement repairs to extend pavement life. A pavement preservation program aims at preserving investment in the pavement network, extending pavement life, enhancing pavement performance, ensuring cost-effectiveness, and reducing user delays. All pavement maintenance, rehabilitation or preservation programs will require securing funds to allow for works required for enhance pavement systems and perform what is necessary to extend pavement life spans and improve the pavement performance (Byrne, 1893).

As mentioned in the "Best Practices Handbook on Asphalt Pavement Maintenance", today's increasing budget constraints require that state and local agencies perform more work with less money. Historically, the emphasis of local highway departments has been on building new roads, but the new focus is on maintaining and preserving existing pavement surfaces. This shift has resulted in three types of pavement maintenance operations:

1- Preventive Maintenance: Performed to improve or extend the functional life of a pavement. It is a strategy of surface treatments and operations intended to retard progressive failures and reduce the need for routine maintenance and service activities.

2- Corrective Maintenance: Performed after a deficiency occurs in the pavement, such as loss of friction, moderate to severe rutting, or extensive cracking and may be referred to as “reactive” maintenance.

3- Emergency Maintenance: Performed during an emergency, such as a blowout or severe pothole that needs repair immediately. This also describes temporary treatments designed to hold the surface together until more permanent repairs can be performed.

All types of maintenance are needed in a comprehensive pavement maintenance program. However, emphasizing preventive maintenance may prevent a pavement from requiring corrective maintenance. Preventive maintenance is completing the right repair on the right road at the right time (Johnson, 2000). The current practice in condition rating varies between states. Agencies use methods customized to meet the needs of the individual state. A lack of consistency in the methodology, data collection, and rating calculation techniques makes it difficult to compare sets across state borders and across asset types. J. Verhoeven and G. Flintsch (2011) continued to explain in the Journal No. 2235 of the Transportation Research Board that improving the overall condition of National Highway System (NHS) routes, a unified method of condition rating needed. Infrastructure management systems are tools that help engineers and planners make decisions about maintenance and rehabilitation techniques that extend or renew the life of critical assets one asset that is essential to the United States is the National Highway System (NHS). The NHS is the major connection between ever corners of the United

States and is an economic lifeline that transports people, goods and services. To keep the system functioning efficiently, an effective infrastructure management system proves requires condition ratings of the assets to make reasonable decisions about what needs to be done. Condition ratings are used to assign a numerical value to an asset based on visual or automatically collected data. Efficient, accurate, and fair budgeting and reporting procedures also are requirements of an effective management system, and a number of them are in use. Implementing them is difficult, as many administrative and behavioral problem must be overcome. A number of tools and methodologies is available to the highway engineer and administrator to assist in making decisions as to appropriate rehabilitation strategies. Visual surveys and observations of pavement conditions is the assessor's first practice to assess the condition of the asphalt pavement structure (Deen et al., 1985).

Every highway agency deals with the effects of regional environments on pavement performance, in addition to the effects of traffic. Pavement sections originally projected to last many years can accumulate distress at an accelerated rate and fail prematurely. Most highway agencies experience and understand this problem but are daunted when budget all locations do not keep pace with the needs of highway pavement upkeep (Galehouse et al., 2003). The Distress identification manual for the Long-Term Pavement Performance Program identifies the most common types of distress in pavements, such as:

A. Cracking:
   1. Fatigue Cracking
   2. Block Cracking
   3. Edge Cracking

5. Longitudinal Cracking
4a. Wheel Path Longitudinal Cracking
4b. Non-Wheel Path Longitudinal Cracking
5. Reflection Cracking at Joints
6. Transverse Cracking

B. Patching and Potholes
7. Patch/Patch Deterioration
8. Potholes

C. Surface Deformation
9. Rutting
10. Shoving

D. Surface Defects
11. Bleeding
12. Polished Aggregate
13. Raveling

The Department of Transportation of every State is the agency responsible for transportation issues and policies in the respective State, such as maintaining and operating the State's highways and public roadway systems. The New Jersey Department of Transportation (NJDOT), as an example of one of the USDOT State Agencies, that adopts a set of standard specifications for road and bridge Construction, which outlines the directions, requirements and guidelines of the description of work, method and manner to perform the work, the acceptance criteria and measurement and payment statement for a particular item of work. The set of standard specifications includes a specific section for Pavement, Division 400, which specifically provides guidance and regulations of pavement construction.

1.1 Problem Statement

Research and development of asphalt pavement in the 21st century has been evolving around pavement preservation and maintenance. The standard construction practice of pavement is continuously improving as new research and development endeavors reveal enhanced technologies and methodologies, materials, procedures and preventive plans for better construction practices in asphalt pavement. However, one area that has not been investigated and researched quite enough despite the fact that it often leads to poor compaction, asphalt surface failures, poor physical appearance and lack of proper restoration process is known to the researchers and professionals, namely, asphalt core restoration when sampling asphalt cores after pavement activities. Although asphalt cores are essential to measuring the thickness, compaction, air voids and other properties of the paved structure, poor post-coring restoration procedures often lead to increased air voids in the restored pavement material, the disintegration of the surface of the asphalt core restoration fill material and exposing the edges of the existing pavement structure to damage by vehicular impact. Although other parts of the roadway construction process are highly regulated, the restoration procedures for asphalt core holes do not always include proper or adequate compaction of the restoration fill material, proper design and construction compaction procedures. The insufficient core hole restoration procedures often result in weaker pavement structure at cored locations, disintegration by impact from weighty vehicles and poor physical appearance of the pavement surface. These issues can lead to asphalt failures, reduced asphalt life cycle and unpleasant physical appearance of the pavement structure. The need of inventing a new device that may immensely enhance the pavement compaction, performance and life cycle is necessary.

This study proposes a use of an asphalt core hole Cap device to enhance the compaction percentage of the restoration material and also enhance the overall construction practice of asphalt core hole restoration. The hypothesis of this study investigates the effectiveness and practicality of using the Cap device on asphalt core holes to enhance the restoration and protection of asphalt core holes.

1.2 Thesis Objectives

The goal of this study is to identify and evaluate the current construction practice of asphalt core hole protection and restoration. Once identified, it is proposed to develop a Cap device and study the effectiveness of using the device to enhance the compaction quality of the restoration material used in core holes, the protection of the asphalt core hole and the physical appearance of the overall pavement structure. The specific objectives of this study are:

1- Design a Cap to improve the current construction practice of asphalt core restoration;

2- Investigate the mechanism and analyze the applications and benefits of the Cap device with finite element modeling of compacting core holes;

3- Field testing of the functionality and behavior of the Cap device and statistically model the performance of the Cap device;

4- Finite element modeling of the Cap and compaction performance;

5- Conduct LCCA, Cost-benefit and time analysis of using the Cap device.

1.3 Thesis Organization

CHAPTER ONE: Problem description and statement of thesis objectives

CHAPTER TWO: Background and literature review to identify asphalt coring practices, restoration techniques and protection of asphalt core holes. Research relevant literature and technologies.

CHAPTER THREE: Presentation of the Innovation of the patented Cap Device used to enhance the restoration of asphalt core holes. Design development and investigating the mechanism, applications and benefits of the asphalt core hole Cap device

CHAPTER FOUR: Field evaluation and testing of the asphalt core hole Cap device, analysis of the field data and statistical modeling of the device behavior

CHAPTER FIVE: Finite element modeling of the performance of the Cap device and compacting the restoration material in asphalt core hole.

CHAPTER SIX: Life-cycle Cost Analysis (LCCA), Cost-benefit and time analysis of restoring asphalt core holes using the Cap device.

CHAPTER SEVEN: Conclusions of the Research Study.

CHAPTER EIGHT: Recommendation for Future Research.

CHAPTER 2 - LITERATURE REVIEW

2.1 Background of Asphalt Preservation

Asphalt preservation is a system of treating pavements to extend their useful life. There are many transportation agencies in the United States shifting their focus on transportation and highway and specifically pavement system expansion to an increasing focus on pavement system preservation. Many government agencies supervising and administering transportation systems and highways have recognized the cost-effectiveness associated with the use of preventive maintenance treatments to slow the rate of deterioration and to mitigate the need for anticipated expensive rehabilitation plans (Zimmerman et al., 2010). A study conducted by Utah Department of Transportation (UDOT) in 1977 demonstrated the concept that it costs less to maintain roads in good condition than it does roads in bad condition (Peterson, 1977).

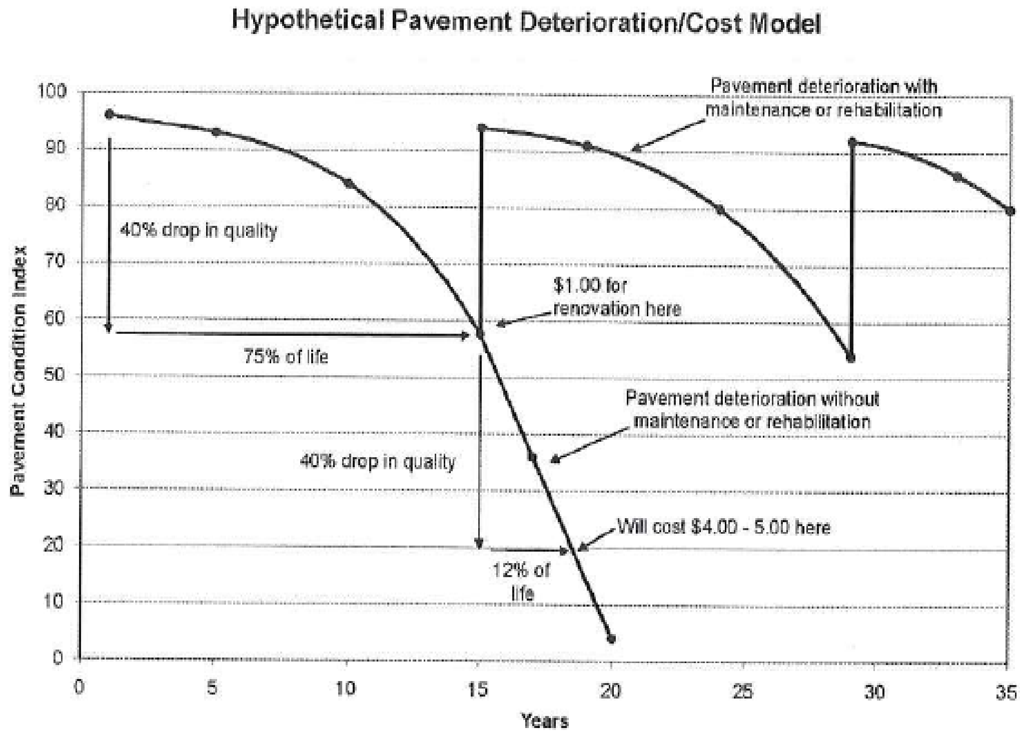


Figure 2.1.1 – Hypothetical Pavement Deterioration/ Cost Model Graph (Peterson, 1977)

Many transportation agencies use pavement preservation programs to manage their pavement assets cost-effectively. One important aspect of pavement preservation is the use of preventive maintenance treatments to improve the functional condition of the network and retard the overall rate of deterioration. Because preventive maintenance treatments are less expensive than resurfacing or reconstruction projects, a preventive maintenance program can provide a cost-effective means of meeting pavement performance goals. Pavement management systems support pavement preservation strategies in important ways. They assist in identifying and prioritizing preventive maintenance needs, justifying funding levels, and evaluating the long-term impacts of various preservation strategies. A pavement preservation treatment is a proactive, planned strategy applied in a timely manner to extend the life of the pavement without adding structural strength to the pavement. The time frame to apply pavement preservation is early in the pavement's life; once the pavement has deteriorated to a certain condition, a rehabilitation treatment is required instead of applying the more sustainable pavement preservation treatment. The key to a successful pavement preservation program is to apply the right treatment to the right road at the right time. S. Chan et al. (2011) continued in Journal No. 2235 of the Transportation Research Board and explained that pavement preservation solutions satisfy the definition of sustainable pavements. These solutions begin with the concept that the treatments are cost-effective, and they are applied when the pavement is still in a relatively good condition.

A transportation agency that wishes to integrate preventive maintenance and pavement management might be required to make several changes. Specific technical areas in which changes might be needed include condition surveys and condition index calculations, pavement performance models, treatment rules, and program development. The role of pavement management is certainly changing as a result of the shift in interest from pavement construction to pavement preservation as pavement management was primarily considered to be used for assessing and reporting pavement conditions, prioritizing capital improvements, and estimating funding needs. A pavement management system has the potential to fulfill a much broader and more significant role within a transportation agency (Zimmerman et al.., 2010). Pavement preservation focuses on preserving the pavement asset while maximizing the economic efficiency of the investment. The United States maintains nearly 3.95 million miles of public roads, much of which is wearing out because of increased traffic, environmental effects, and a lack of proper maintenance. By developing a strategic plan that includes pavement preservation, the United States can finance future highway capacity while addressing the needs of the current system. This article presents a discussion of the need for standard definitions of terms; establishing a customer-focused program to provide and maintain serviceable roadways cost-effectively, encompassing preventive and corrective maintenance, as well as minor rehabilitation; the benefits of pavement preservation; the need for support and input from staff in planning, finance, design, construction, materials, and maintenance, as well as long-term commitment from agency leadership and a dedicated annual budget; and issues and barriers (Galehouse et al.., 2003).

The effectiveness of preservation treatments is an integral part of all evaluation processes. Generally, the effectiveness, for benefits only, can be measured in the short and long term by using the attributes determined from the observed pavement performance with and without preservation treatments. Haider et al. (2011) mentioned that the evaluation of pavement preservation interventions is the most important component of a pavement management system. A rational methodology is needed to evaluate pavement preservation alternatives to maximize project- and network- level benefits. A lack of adequate guidance on the timing of preventive maintenance treatments was the main motivation for this study. Extending the life of roadway pavements with the timely use of preservation techniques has been an important strategy for highway agencies for many years for pavement preservation on high-traffic-volume roadways (Smith, 2011). Agencies that have strong pavement preservation programs in place have recognized a number of benefits, including those listed below (Peshkin et al., 1999):

- Higher consumer satisfaction
- More informed decisions
- Improved strategies and techniques
- Improved pavement condition
- Cost savings
- Increase safety

As Griffin and Brown (2011) stated in the "Flowable Fill for Rapid Pavement Repair" Journal; the federal, state and local highway authorities in the United States invested $3.9 billion in the rehabilitation of roughly 8,000 mi of pavement in 2008. This significant investment emphasizes the importance of ensuring that rehabilitation techniques perform well to help reduce the high annual cost for repairs. Billions of dollars are spent every year across the United States repairing pavements that have failed permanently. The importance of timely maintenance and rehabilitation efforts is well known. However, with the decreasing availability of funds for these activities, timely repair has become more critical than ever to reduce the potential for follow-up repairs. One of the biggest problems in making repairs is the difficulty in achieving adequate density site limitations, soil conditions, equipment availability and laborer experience all affect the ability to achieve required compaction levels. Inadequate compaction increases the potential for undesired settlement of the repair, decreasing ride quality and increasing potential for premature failure.

2.2 Background of Asphalt Pavement Performance

Performance means sustainability. All federal and state agencies overseeing and administering the highway systems are focusing on pavement longevity and preserve pavement performance over the years. As Hajj et al. (2011) mentioned that pavement performance is defined as the serviceability trend of the pavement over a design period; serviceability indicates the ability of the pavement to serve the demand of the traffic in the existing condition. A pavement performance model is defined as an equation that relates a pavement performance index such as the pavement serviceability index, with time and can be used to predict the future pavement condition of the pavement on the basis of the current pavement condition data. In that regard, pavement performance models are critical to the pavement management process because the scheduling of maintenance and rehabilitation activities is based on the present pavement serviceability conditions measured in the field and future pavement service conditions predicted with pavement performance models.

The Asphalt Institute Handbook stated that by slowing the rate of pavement deterioration on these roads, an agency could maintain a road network at a higher overall condition level and defer the need for more costly rehabilitation treatments. The basic idea in building a road for use by vehicles to construct a pavement that will have sufficient strength to carry expected traffic loads, impermeable enough and smooth, skid resistant, resistant to wear, resistant to distortion and deterioration. The figure below Figure 2.2.1 shows the wheel load, W, being transmitted to the pavement surface through the tire at an approximately uniform vertical pressure, P_0. The pavement then spreads the wheel load to the subgrade so that the maximum pressure on the subgrade is only P_1. By proper selection of pavement materials and with adequate pavement thickness, P_1 will be small enough to be easily supported by the subgrade. The figure below Figure 2.2.2 shows the pavement deflection results in tensile and compressive stresses in pavement structures resultant from wheel load, W.

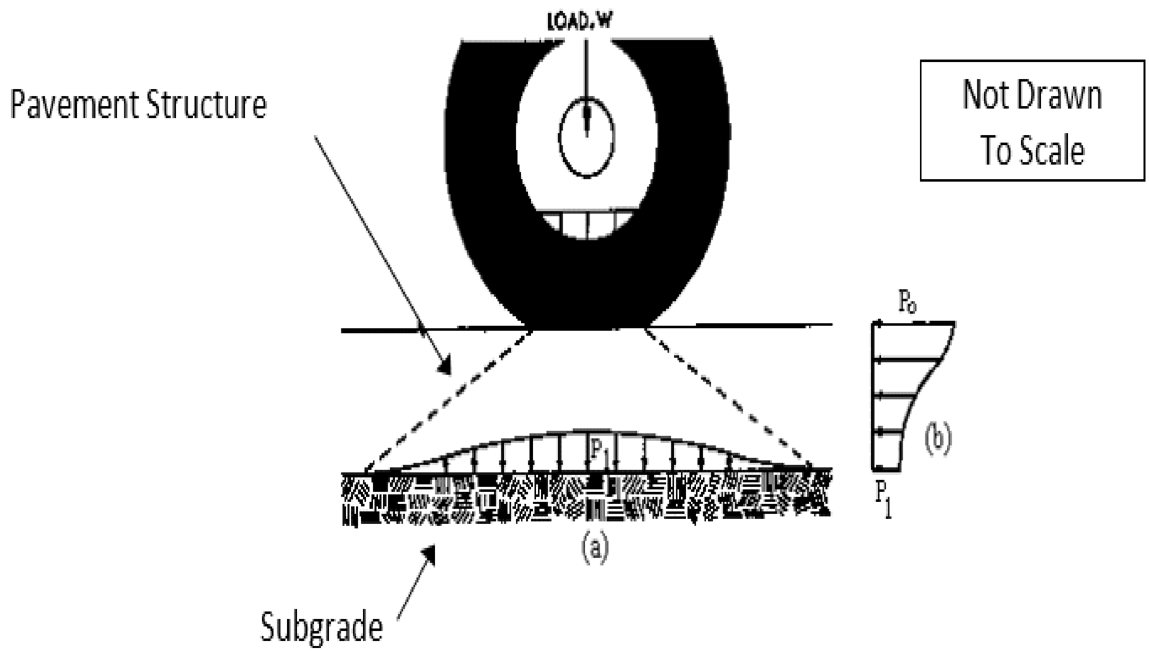


Figure 2.2.1 Spread of Wheel Load through Pavement Structure

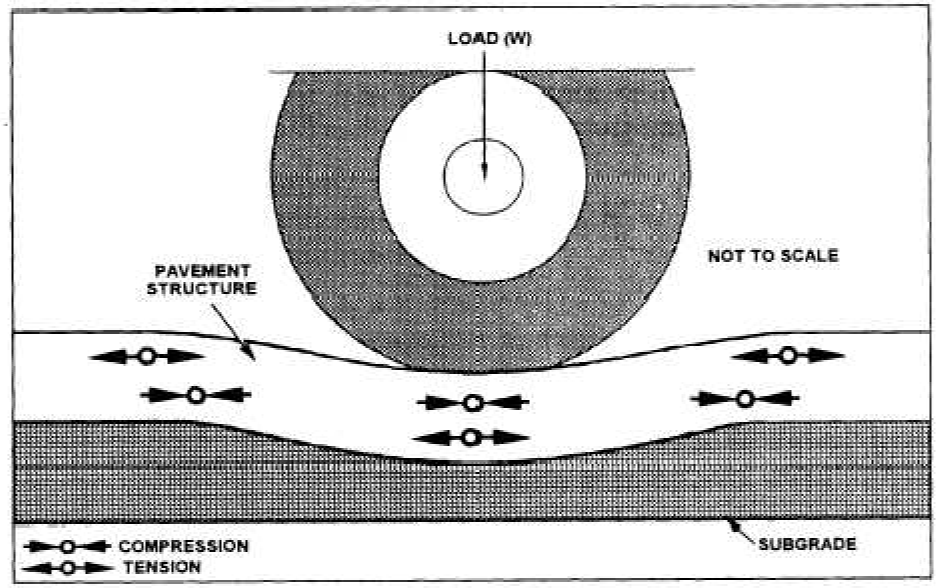


Figure 2.2.2 Pavement Deflection Results in Pavement Structure

A significant advancement in highway engineering is the realization and demonstration that the structural design of asphalt pavements is similar to the problem of designing any other complex engineering structure. Determining the right and proper asphalt properties is a matter of empiricism and opinion based on experience. Asphalt pavement properties are all connected, relate, and depend on each other. The performance of structurally adequate asphalt pavements is affected by two primary factors: a properly designed mix and compaction. Neither of these factors alone can assure satisfactory pavement life. Even the best-designed mix will be subject to reduced performance if not compacted sufficiently. Good compaction; however, can effectively improve the performance of a mix that is less than ideal. For this reason, compaction is considered to be the single most important factor affecting the performance of asphalt pavements (Hughes, 1989).

Compaction of Asphalt Concrete (AC) is one of the most important steps in controlling the quality of pavement construction, as detailed in the Mechanics of Asphalt: Microstructure and Micromechanics book. More importantly, many problems arise during compaction: some mixes may not be easy to compact compared to others (perhaps indicating a good mix); too thin a layer thickness may prevent effective compaction; a weaker mastic may make compaction easy but it does not indicate good quality; a soft base or sub-base may cause difficulties for compaction (compaction energy is absorbed by the base of sub-base); the non-uniformity of the base of sub-base support causes non-uniform compaction if operation parameters do not vary correspondingly; and a change of environmental conditions such as temperature and wind speed results in a change of viscosity and therefore compaction effectiveness. Compaction is not a problem that is unique to asphalt concrete. It is also a problem studied in soil, granular materials and cement concrete (Wang, 2011).

2.3 Background of Asphalt Compaction

The compaction has been defined by the Asphalt Institute Handbook as the process used to densify, or reduce the volume of, a mass of material. For hot mix asphalt (HMA), compaction locks aggregate particles together to provide stability and resistance to deformation while simultaneously reducing the permeability of the mixture and enhancing its durability. During the compaction of HMA, three very important factors that affect pavement performance take place. The asphalt-coated aggregate particles are pressed together, air voids are reduced and the mix density (weight-to-volume-ratio) increases. This squeezing together of the aggregates increases their surface-to-surface contact and inter-particle friction, resulting in higher mix stability and pavement strength. The goal of compacting HMA is to achieve the optimum air-voids content. Behind the paver, the HMA typically has 15 to 20 percent in-place air voids. It is the task of the rollers to reduce that void content to 8 percent or less for dense-graded HMA mixes. It is apparent that in the evolution of asphalt pavements, certain concepts, principles, and relationships were developed very early that are still regarded as fundamental today (Goetz, 1989). Compaction is the process of reducing the air voids content of an asphalt concrete mixture. It involves the packing and orientation of the solid particles within a viscoelastic medium into a denser and more effective particle arrangement. Ideally, this process takes place under construction conditions rather than under traffic. Increasing density and reducing the percentage of air voids in asphalt concrete has a positive influence on the ability of the mix to perform as designed. Marker stated in the Proceedings of the Association of Asphalt Paving Technologists (AAPT) that the compaction and densification of asphalt mixtures are the most important construction operations with regard to the ultimate performance of the completed pavement, regardless to the thickness of the course being place. Asphalt technologists around the world understand that achieving proper density of hot-mix asphalt (HMA) pavements in the field is the single most important factor in determining the performance of the pavement. There are literally hundreds of references in the technical literature on the subject. Compaction of the mix at the time of placement is the process whereby density is achieved (Decker, 2006).

The single most important construction control that will provide for long-term serviceability is compaction (Noel, 1977). Pell stated that many researchers have shown that fatigue properties are greatly improved with decreased air voids. Pell and Taylor concluded that voids have a detrimental effect on fatigue life, showing that an increase in void content is associated with a decrease in fatigue life. The following figure illustrates in general the correlation between fatigue life and the air void content in asphalt mixes.

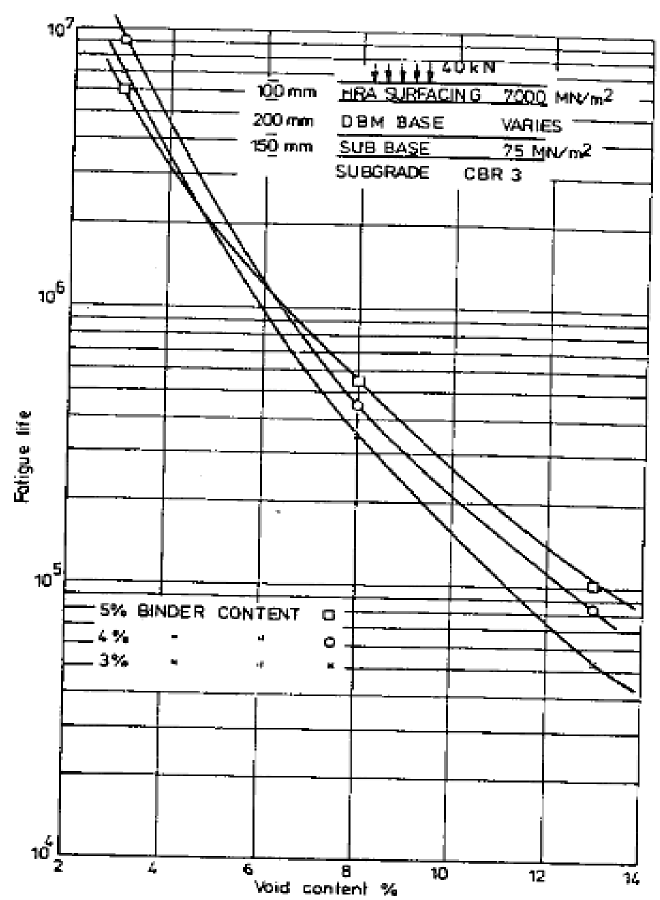
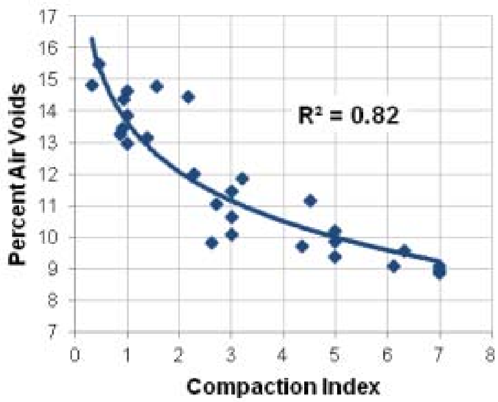


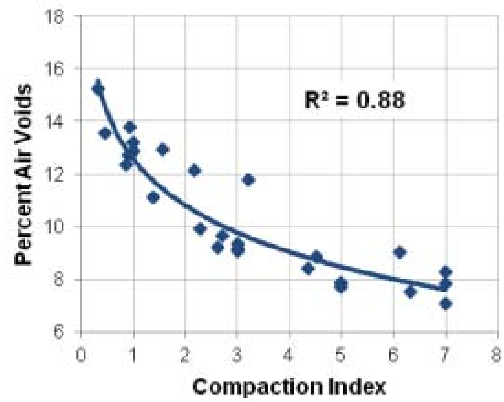
Figure 2.3.1 Fatigue of Dense Macadam Base

It is well known that a lack of optimum compaction can cause segregation and high air voids in the mixture, which ultimately leads to premature failure of the pavement

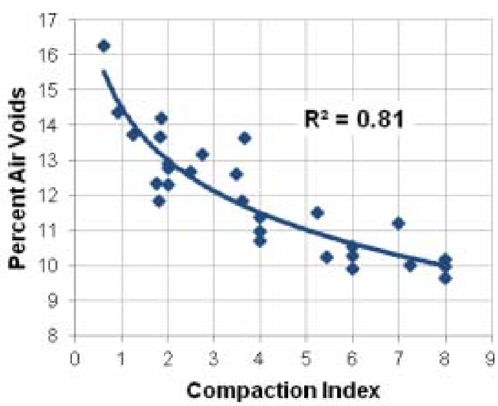
(Rahman et al., 2010). Researchers examined the influence of compaction method on the density and compaction ratio of the pavement, as detailed by Kassem et al., 2012. Researchers examined the change in density with the Compaction Index (CI) in multiple sub-test sections to evaluate the influence of the compaction method on achieving the required compaction level. The results were consistent for all test sections, showed, as expected, that applying more compactive increases the CI, and decrease the air void content in the area under compaction. The figure below from (Kassem et al., 2012) shows the relationship between percent air voids and the compaction index (CI). The CI was proposed to quantify the compaction effort at any point in the pavement.



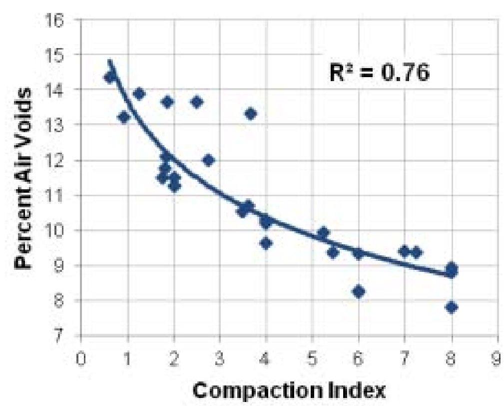
(a) Test Section 1 (Static Roller)



(b) Test Section 1 (Vibratory Roller)



(a) Test Section 5 (Static Roller)



(b) Test Section 5 (Vibratory Roller)

Figure 2.3.2 Percent Air Voids vs Compaction Index

The volume of air or the air void content in hot mix asphalt (HMA) pavements is vital as long-term pavement performance significantly correlates and relies on the compatibility of the mix. An approximate “rule-of-thumb” is for every 1 percent increase in air voids (above 6-7 percent), about 10 percent of the pavement life may be lost (Linden et al., 1989). Keep in mind that this rule-of-thumb was developed using limited project data, should be used with extreme caution and applies to air voids above 6 – 7 percent. According to Roberts et al. (1996), there is considerable evidence that dense graded mixes should not exceed 8 percent nor fall below 3 percent air voids during their service life. Air voids that are either too great or too low can cause a significant reduction in pavement life. For dense graded HMA, air voids between 3 and 8 percent generally produce the best compromise of pavement strength, fatigue life, durability, raveling, rutting and moisture damage susceptibility. Permanent deformation (rutting) in hot mix asphalt (HMA) is one of the most common pavement distresses. Rutting in HMA is the accumulation of permanent strains from applied wheel loads (Bennert and Maher, 2003). The contributions of both shear failure and volume distortion play significant roles in the rutting of HMA, which typically occurs within the top 100 mm of the HMA structure (Brown and Cross, 1992). This is because high air void content (above 8 percent) or low air void content (below 3 percent) can cause the following pavement distresses to dense-graded HMA:

- Decreased stiffness and strength: Kennedy et al. (1984) concluded that tensile strength, static and resilient moduli, and stability are reduced at high air void content;
- Reduced Fatigue Life: fatigue properties can be reduced by 30 to 40 percent for each one percent increase in air void content." Another study concluded that a reduction in air voids from eight percent to three percent could more than double pavement fatigue life (Scherocman, 1984);
- Accelerated Aging/ Decreased Durability: compacting a well-designed paving mixture to low air voids retards the rate of hardening of the asphalt binder, and

results in longer pavement life, lower pavement maintenance, and better all-around pavement performance (McLeod, 1967);

- Raveling: raveling becomes a significant problem above about eight percent air voids and becomes a severe problem above approximately 15 percent air voids (Kandhal & Koehler, 1984);
- Rutting: the amount of rutting which occurs in an asphalt pavement is inversely proportional to the air void content (Scherocman, 1987). Rutting can be caused by two different mechanisms: vertical consolidation and lateral distortion. Vertical consolidation results from continued pavement compaction (reduction of air voids) by traffic after construction;
- Lateral distortion: shoving of the pavement material sideways and a humping-up of the asphalt concrete mixture outside the wheel-paths – is usually due to a mix design problem. Both types of rutting can occur more quickly if the HMA air void content is too low (Scherocman, 1984);
- Moisture Damage: air voids in insufficiently compacted HMA are high and tend to be interconnected with each other. Numerous and interconnected air voids allow for easy water entry (Cooley et al., 2002) which increases the likelihood of significant moisture damage. The relationship between permeability, nominal maximum aggregate size and lift thickness is quite important and can change significantly as these parameters change.

Compaction is the process by which the volume of air in an HMA mixture is reduced by using external forces to reorient the constituent aggregate particles into a more closely spaced arrangement. This reduction of air volume produces a corresponding increase in HMA density (Roberts et al., 1996). Compaction is the greatest determining factor in dense graded pavement performance (Geller, 1984). Inadequate compaction results in a pavement with decreased stiffness, reduced fatigue life accelerated aging/decreased durability, rutting, raveling, and moisture susceptibility (Hughes, 1984; Hughes, 1989). Compaction reduces the volume of air in HMA. Therefore, the characteristic of concern is the volume of air within the compacted pavement or the percentage of air voids, which is typically quantified as a percentage of air voids in relation to total volume, as mentioned in the Pavement Interactive website. Percent air voids is calculated by comparing a test specimen's density with the density it would theoretically have if all the air voids were removed, known as "theoretical maximum density" (TMD) or "Rice density" after the test procedure inventor. Although the percent of air voids is the HMA characteristic of interest, measurements are usually reported as a measured density in relation to a reference density. This is done by reporting density as:

- Percentage of TMD (or "percent Rice"). This expression of density is easy to convert to air voids because any volume that is not asphalt binder or aggregate is assumed to be air. For example, a density reported as 93 percent Rice means that there are 7 percent air voids (100% – 93% = 7%);
- Percentage of a laboratory-determined density. The laboratory density is usually a density obtained during mix design;
- Percentage of a control strip density. A control strip is a short pavement section that is compacted to the desired value under close scrutiny then used as the compaction standard for a particular job.

Each contracting agency or owner usually specifies the compaction measurement methods and equipment to be used on contracts under their jurisdiction. Pavement air voids are measured in the field by one of two principal methods:

- Cores: a small pavement core is extracted from the compacted HMA and sent to a laboratory to determine its density. Usually, core density results are available the next day at the earliest. This type of air voids testing is generally considered the most accurate but is also the most time consuming and expensive;
- Nuclear gauges: a nuclear density gauge measures in-place HMA density using gamma radiation. Readings are obtained in about 2 – 3 minutes. Nuclear gauges require calibration to the specific mixture being tested. Usually nuclear gauges are calibrated to core densities at the beginning of a project and at regular intervals during the project to ensure accuracy.

2.3.1 Background of In-Place Asphalt Compaction

The Department of Transportation of every State has specifications, regulations and guidelines to identify the quality of asphalt pavement placed on roadways. In most construction specifications, in-place air void is measured as a percent of maximum theoretical density in statistical terms. The specification limits (Wang et al., 2015) should be relatively loose to allow a certain amount of testing, sampling, and inherent material variability. The Department of Transportation of Delaware for example has 92%-96% as specification limits of quality characteristics for In-Place Density of HMA in the field. In most of DOT construction specifications, in-place density is measured as a percent of maximum theoretical density with ranges between 91 and 98 percent (mostly between 92 and 97 percent) to control the air void contents of the constructed pavements (Wang et al., 2015). It appears that the national average of acceptable density of HMA at the mix design phase or laboratory testing is 96% and the national average of acceptable of in-place density of HMA is 92%. In-pace air void (or density) is an important factor as an asphalt pavement quality indicator, which is dependent on the asphalt content, aggregate gradation, and nominal maximum aggregate sizes. Overall, air void has a direct impact on density, rutting, fatigue life, permeability, oxidation, bleeding and so on. The in-place air void content (or density) has been found as the most influential property affecting the performance and durability of an HMA pavement by previous studies.

2.4 Background of Asphalt Core Holes

The Asphalt Institute Handbook indicates in Chapter 10 that core sampling is the most common form of sampling from completed HMA pavements. The current asphalt pavement sampling techniques have been under research and study for the past few decades in an effort to enhance the procedures and results. One of the most common sampling ways of asphalt pavement is coring. Insuring the integrity and security of hot mix asphalt (HMA) samples is critical to assuring the quality of the installed product and complying with Federal requirements. Samples of HMA are often taken at the plant with limited state supervision. Further, samples are taken from a truck where obtaining a representative sample can be difficult. The concept of moving the sample location to the job site offers the potential to address the weaknesses cited above (Elseifi, 2007). Research and surveys have shown the poor guidance of asphalt core sampling available which hence leads to a poor guidance of core restoration guidance. Many federal and state agencies require asphalt sampling and restoration; however, the specifications and procedures guiding the works involved are inadequate for quality and desired results.

There is not much literature on asphalt cores, asphalt core hole protection and/or asphalt core hole restoration. The set of standard and specific specifications included in the United States Department of Transportation State books dictates certain quality assurance and quality control measures on the construction practice of pavement construction. One of the measures to control the quality of pavement construction is taking asphalt cores. There are numerous benefits of taking asphalt core holes, such as determining the depth of asphalt pavement layers placed, specific gravity of paved area and asphalt density. The current State Department of Transportation Standard Specifications in New Jersey (NJDOT) includes the following asphalt core hole restoration guidelines as part of Division 400, Pavements, Section 401- Hot Mix Asphalt (HMA) Courses and Section 405 Concrete Surface Course. The set of standard specifications of the sub-section 401.03.05 of Hot Mix Asphalt (HMA) for Core Samples states the following;

> "Upon completion of an HMA lot, drill cores at random locations determined by the RE at least 12 hours after paving. Take cores in the presence of the RE. Do not drill additional core samples unless directed by the RE. Use drilling equipment with a water-cooled, diamond-tipped, masonry drill bit that shall produce 6-inch nominal diameter cores for the full depth of the pavement.

Remove the core from the pavement without damaging it. After removing the core, remove all water from the hole. Apply an even coating of tack coat to sides of the hole. Place HMA in maximum lifts of 4 inches in the hole and compact each lift. Ensure that the final surface is 1/4 inch above the surrounding pavement surface."

The set of standard specifications of the sub-section 405.03.03 of the Concrete Surface Course for Core Samples states the following;

"Drill cores before performing diamond grinding operations. Drill cores in the concrete pavement at locations as directed by the RE for thickness testing. Drill 3-inch diameter cores through the entire thickness of the concrete pavement. Use a water-cooled, diamond-tipped, masonry-type drill bit Capable of obtaining a valid test sample through the entire pavement thickness."

Asphalt coring is a standard construction quality control measure set in many sets of standard and specific specifications and manuals. Asphalt coring has numerous benefits, such as but not limited to;

1- Determination method of pavement repair is needed;

2- Exploration of pavement sub-grade layers and identify potential problems before occurring;

3- Test the drainage Capacity of underlying soil and design drain locations;

4- Identify pavement thickness, pavement classification and soil classification;

5- Determination of type of bonds between asphalt layers and failure causes;

6- Determination of the specific gravity and density of in-place asphalt;

7- Determination of the percent compaction and percent of air voids of asphalt;

8- Determination of the asphalt mixture structural properties, integrity and behavior;

9- Research the behavior and structural dynamics of the existing pavement material;

10- Determination of optimized sampling locations.

It is worthy to note the literature of the closest asphalt core restoration practices and technologies currently published and previously researched. The first technology to be noted herein is "Utilicoring". Utilicoring is a unique pavement excavation and restoration technology. This technology was developed and field-proven over the last ten years by Enbridge Consumers Gas. This process facilitates utility access to underground plant and is a key cost-saving element in the growing utility maintenance trend to "keyhole" technology, which allows crews to cost-effectively perform repair or maintenance work on underground pipe or other buried plant from the road surface without resort to more costly, disruptive and inherently more dangerous excavation methods. It also has direct application to other utility service and trenchless operations including test holes and daylighting for directional drilling, inspection holes for pipeline integrity and subsurface utility engineering (Pollock, 2003). Utilicoring is catered to provide core holes for utility access rather than asphaltic coring for testing. Utilicoring also relies on using the same drilled and removed bulk material in the restoration process, which is neither allowed nor possible in the asphalt coring practices of highway pavement construction. Asphalt cores are taken to be tested at an asphalt lab to determine qualitative data of the paved area cored and asphalt cores are usually disposed and become unsalvageable after testing. The Utilicoring process also includes the use of special cementitious bonding agent, which require testing and approvals by the appropriate State agency overseeing the paving construction project. In essence, the Utilicoring technology is not developed for testing purposes of asphaltic structures and is a different technology than the Cap device.

The second core restoration technique that was previously researched is included in the Core Hole Plug Assembly Patent Application No. US 10/225,895. The abstract of the Core Hole Plug Assembly patented device states that a core hole plug assembly for covering and sealing a hole in a paved surface, wall or other structure. The core hole plug assembly includes a cover plate, a resilient expansible cylindrical plug, a compression plate, and a bolt and nut assembly for moving the compression plate relative to the cover plate to expand or reduce the outside diameter of the expansible plug. The compression plate is permanently secured to a lower end portion of the expansible plug and, preferably, the upper end of the expansible plug is permanently secured to the underside of the cover plate. It is apparent that this core hole plug assembly is useful but has different mechanism and purposes from the Cap device under this research study. The core hole plug assembly permanently caps and seals empty asphalt core holes while asphalt core holes shall be restored with commercially approved asphaltic material. It also requires securing the upper plate of the plug with a screw for permanent sealing of the core hole, which is also not allowed on highways as it creates a permanent bump to traveling traffic and requires maintenance. This core hole plug assembly was invented to seal core holes in structures but not to improve the restoration practice of asphalt core holes. The set of standard specifications of the sub-section 401.02.01 of the Hot Mix Asphalt (HMA) Courses in the New Jersey Department of Transportation Standard Specifications states the following;

> "Use HMA specified for the roadway surface as patching material for HMA pavement repair. The Contractor may use a commercial type of cold mixture as patching material for filling core holes if HMA surface course is not being placed when coring. The Contractor may use an approved HMA surface course to fill core holes, provided the material remains hot enough to compact."

2.5 Background of Restoring Asphalt Core Holes

The current set of standard and specific specifications dictates very basic restoration procedures of asphalt core holes. The set of standard specifications of the sub-section 405.03.03.C.6 of the New Jersey Department of Transportation (NJDOT) Standard Specifications for Quality Control Core Density Test Results state the following;

> "Use drilling equipment with a water-cooled, diamond-tipped, masonry drill bit that shall produce 6-inch nominal diameter cores for the full depth of the

pavement. Remove the core from the pavement without damaging it. After removing the core, remove all water from the hole. Fill the hole with HMA or cold patching material and compact the material so that it is 1/4 inch above the surrounding pavement surface.”

2.6 Background of Protecting Asphalt Core Holes

The current construction practice for asphalt core hole restoration does not require protection to the top surface of the restoration material and tips and edges of the existing surrounding pavement structure, proper compaction to the restoration fill material. The current asphalt core hole restoration procedures do not ensure proper compaction mechanism to warrant intact restoration of the asphalt core hole. The poor current restoration practice of asphalt core holes results in many problems that risk the quality of the asphalt core hole and the surrounding pavement structure to the asphalt core hole after drilling and restoration, such as, but not limited to:

1- Improper and insufficient compaction of the restoration fill material due to lack of enforcement of proper design and construction compaction procedures causing settlement of the asphalt fill material used in the restoration process and hence creating voids within the asphalt core hole;

2- Disintegration of the top surface of the asphalt core restoration fill material due to impact from weighty vehicles and inclement weather conditions;

3- The exposure, consequently, of the edges of the surrounding pavement structures and making it vulnerable to damages, cracks, failures and fatigues.

The figures below- Figure 2.6.1 and Figure 2.6.2 clearly show some of the failure problems to the surrounding pavement structures due to the current poor protection of asphalt core holes.

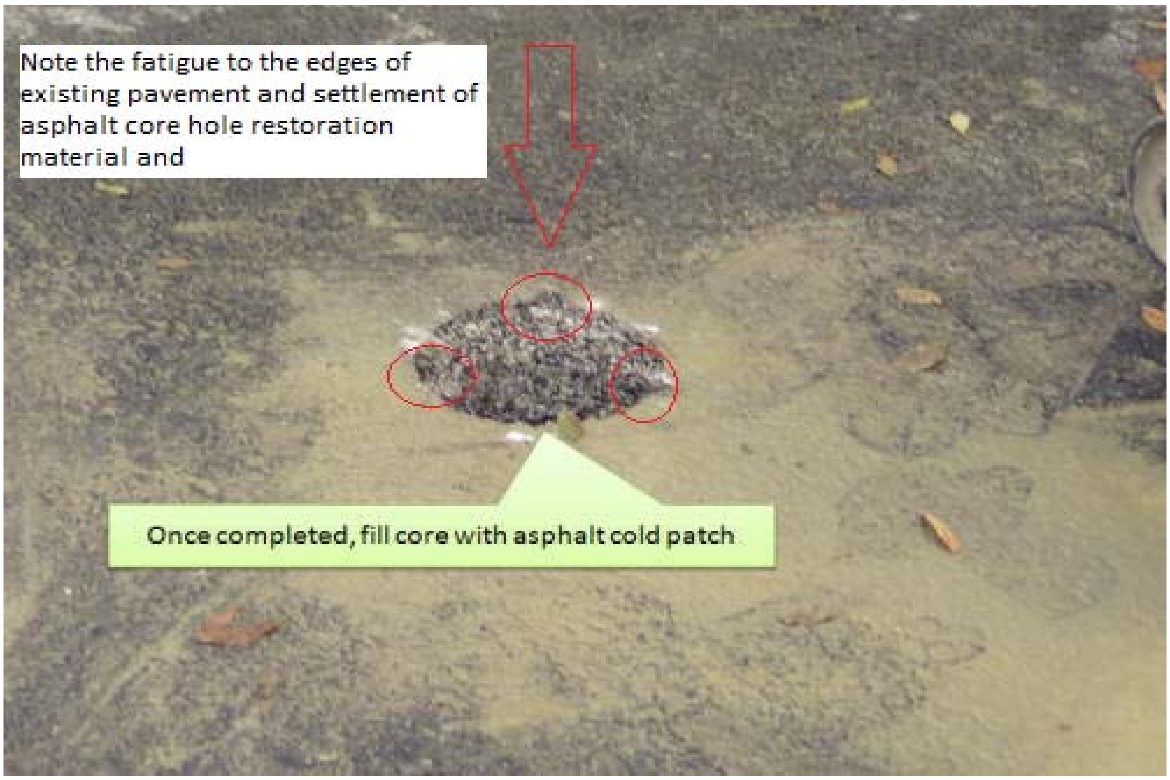


Figure 2.6.1 – Fatigues to Existing Pavement Structure

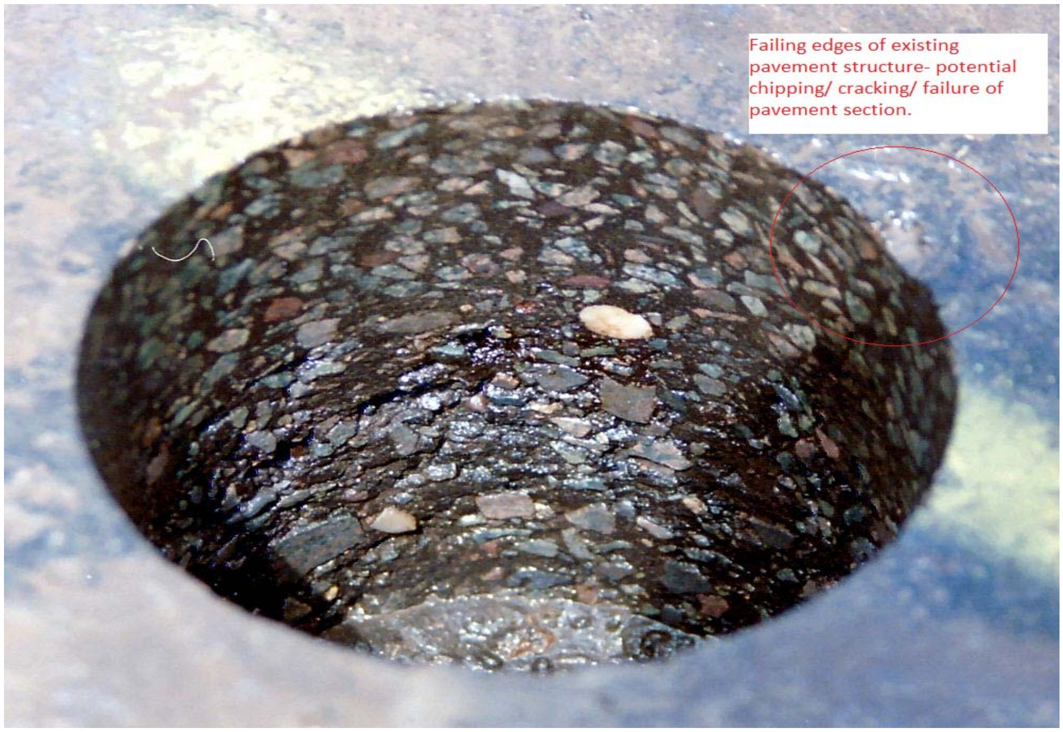


Figure 2.6.2 – Failure of Pavement Edges

2.7 Summary of Literature Review

There is not much literature on asphalt core hole protection and asphalt core hole restoration. The above is a collective literature review and background of asphalt pavement preservation, performance, compaction and construction practices of coring, core hole protection and core holes restoration. More literature review and background research will be conducted on relevant qualitative and quantitative references on asphalt coring and asphalt quality control. There are relevant technologies regarding drilling and coring asphalt but used for different purposes rather than restoring asphalt pavement cores for testing and quality control. The next chapter will present the invention of a Cap device that will enhance the construction practice of asphalt core hole restoration and protection.

CHAPTER 3 - DESIGN DEVELOPMENT, MECHANISM AND INNOVATION OF THE ASPHALT CORE HOLE CAP DEVICE

This chapter will introduce the innovation of the Cap device invented to enhance the construction procedures of restoring and protecting asphalt core holes. The chapter will present a prototype of the innovation, dimensions, design, mechanism and final shape of the asphalt core hole Cap device.

3.1 Introduction

The invention of a Cap device for asphalt core holes is intended to enhance the compaction percentage and hence reduce the air voids inside the restoration material used to restore asphalt core holes. The Cap device also helps protect asphalt core holes and the restoration material by provide better compaction for the top asphalt core restoration material resulting in smoother and flatter surface. Having a flat and smooth finished surface on asphalt core holes protects the edges of the existing and surrounding existing pavement structure and enhance the physical appearance of the pavement structure as a whole. This invention provides a useful Cap device to help improve the compaction measures of the asphalt core hole restoration material, which ultimately help protect the restored asphalt core hole. Although it is almost impossible to remove all air voids from a pavement, failing to achieve target densities implies excessive air voids in the compacted mixtures (Rahman et al., 2010).

The Cap device for enhancing and protecting fill material of asphalt core hole comprises a top plate and a hollow tubular member. The Cap device can also comprise of a top and a bottom plates and a hollow tubular interior or in other forms to serve as a Cap device for enhance core hole restoration process. The tubular member is attached to the top plate or to both top and bottom plates, and the tubular member is substantially perpendicular to the top plate, and also the bottom plate. The Cap device is a method to enhance the compaction percentage of the restoration material used to restore asphalt core holes and hence protect asphalt core holes, which comprises the steps of placing fill materials to fulfill an asphalt core hole, forming a top of the fill material, placing a circular Cap on the top of the fill material, forming a gap between the circular Cap and the asphalt core hole, compacting the fill material by putting pressure on the circular Cap, removing the circular Cap from the asphalt core hole, filing a bonding agent into the gaps and the void space to fulfill the asphalt core hole and leaving the bonding agent to cure for one day. The Cap device can also be used for more uniform tamping over the restoration material of asphalt core holes. The Cap device is not intended to be left in the core hole neither intended to create voids for fill material. Using fill material to bond between the restoration material and the existing pavement structure to be field tested and validated in this study. The Cap device is invented and designed to provide sturdy flat surface for tamping and compacting the asphaltic restoration material used to fill and restore the core holes. The Cap's flat surface provides a smoother finish of the asphalt restoration material which leads to better physical appearance of the pavement and extra protection to the existing pavement structures edges. As explained in many literatures such as the book of Design and Construction of Asphalt Overlays and Hot-mix Asphalt Construction Practices, the compaction technique indefinitely improves the chances of the smoothness of the pavement surface (Collins et al., 1996).

Before the present invention is described in greater detail, it is to be understood that this invention is not limited to particular embodiments described. It is also understood that the terminology used herein is not intended to be limiting, since the scope of the present invention will be limited only by the appended procedures and applications throughout this study.

3.2 Prototypes of the Cap Device

Prototypes of the Cap device were fabricated at:

Castillo Iron Work

1039 Webster Ave

Bronx, NY 10456

(718) 294-9145

Prototypes are made from Steel Metal, in conformance with ASTM A500-13 Grade B&C and each Cap device costs $10/ each. All material properties are shown on the Material Certification in Appendix A-2. The 4” diameter Cap device with top plate and bottom opening prototype is shown in Figure 3.2.1, the 4” diameter Cap device with both top and bottom plates closed prototype is shown in Figure 3.2.2 and the 6” diameter prototype with top plate and bottom opening prototype is shown in Figure 3.2.3.

Figure 3.2.1 – 4” dia Cap Device with Top Plate and Bottom Opening Prototype

Figure 3.2.2 – 4” dia Cap Device with Top and Bottom Plates Closed Prototype

Figure 3.2.3 – 6” dia Cap Device with Top Plate and Bottom Opening Prototype

3.3 Design of the Cap Device

The Cap design has been filed to the United States Patent and Trademark Office (USPTO) on August 26, 2015. The title of the invention is “Cap for Restored Asphalt Core and Methods of Protecting Asphalt Core Hole” under Application No. US 14/836,951. The patent application identified above has been examined, allowed for issuance and published as a patent on March 07, 2017 (Appendix A). The Cap used for the purpose of this research and dissertation is a tubular and circular steel Cap to restore and Cap asphalt core holes. A Cap device in Figures 3.3.1 has a top plate and a tubular member (Open). The top plate can be substantially circular, rectangular, or square; however, circular shape is the most commonly and commercially used in the pavement industry, as drilling core bits are mostly circular. The tubular member can be substantially circular, rectangular, or square; however, circular shape is the most commonly and commercially used in the pavement industry, as drilling core bits are mostly circular. The Cap device could be made of material, such as steel, cast iron, high strength aluminum, high strength plastic that can sustain vehicular weight, such as 4-axle trucks, 6-axle trailer or bulldozer; however, steel is the most commonly used in the pavement industry. The top plate is attached to the tubular member by methods known to the person having the skill of art such as welding, screwing, bolting, adhesion, or forging ways; however, welding is the most commonly and commercially used in the construction industry with steel material. The top plate and the tubular member can be made with one piece such as casting or molding. The top plate contains a small hole for a tool insertion helps removing the Cap device off the core hole as shown in Figures 3.3.1.

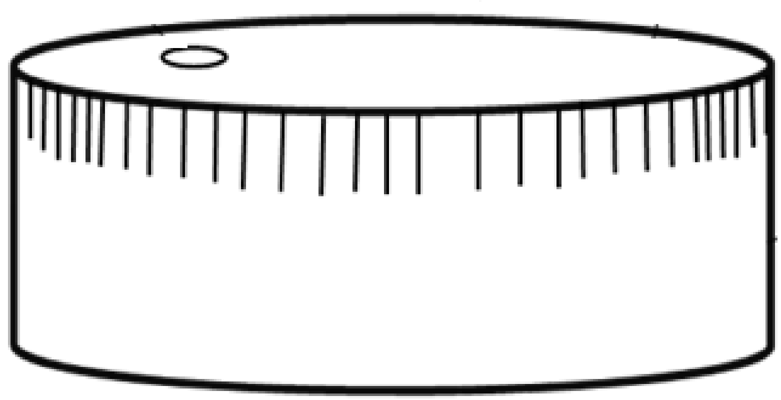


Figure 3.3.1 – Elevation View of Cap Device (Open)

The Cap device sections are clearly shown on Figure 3.3.2 and described herein for detailed overview of the device design. The Cap contains of one embodiment showing a top plate having an upper side and bottom side, a tubular member having a top edge, a tubular body and a bottom edge, where tubular body is substantially axially hollow (Open). The Cap device contains of one embodiment of a Cap showing a top plate and an opposed bottom side of that top plate, where opposed bottom side is connected to top edge of tubular member. The tubular member of the Cap device is substantially perpendicular to the top plate. The hole in the Cap is formed through the top plate allowing insert of tools, such as screwdriver, pry bar, or steel bar, to remove the Cap from an asphalt core hole. The Cap device shown in Figure 3.3.2 is similar to the Cap device shown in Figures 3.3.1 with a top plate containing hatched edges.

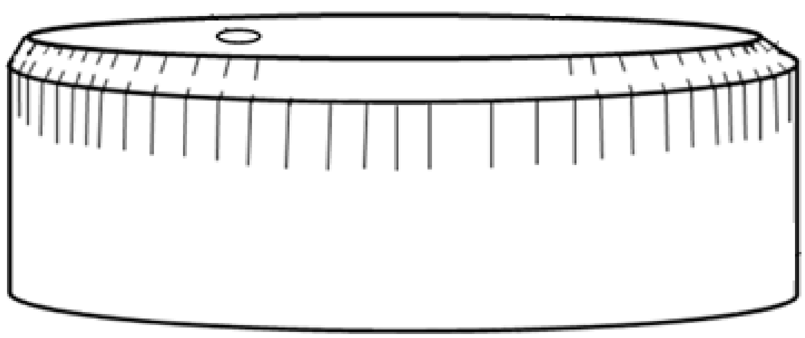


Figure 3.3.2 – Elevation View of the Cap Device with Hatched Edges (Open)

In Figure 3.3.3 below, another embodiment of Cap contains of one embodiment, showing a top and bottom plates (closed); having a tubular member having a top edge, a tubular body and a bottom edge, where tubular body is substantially axially hollow. The Cap device contains of one embodiment of a Cap showing a top plate and an opposed bottom plate, where opposed bottom side is connected to top edge of tubular hollow member. The tubular hollow member of the Cap device is substantially perpendicular to the top and bottom plates. The hole in the Cap is formed through the top and bottom plates allowing insert of tools, such as screwdriver, pry bar, or steel bar, to remove the Cap from an asphalt core hole. The Cap device shown in Figure 3.3.3 is similar to the Cap device shown in Figures 3.3.2 with a bottom plate similar to the top plate acting as a closed Cap device.

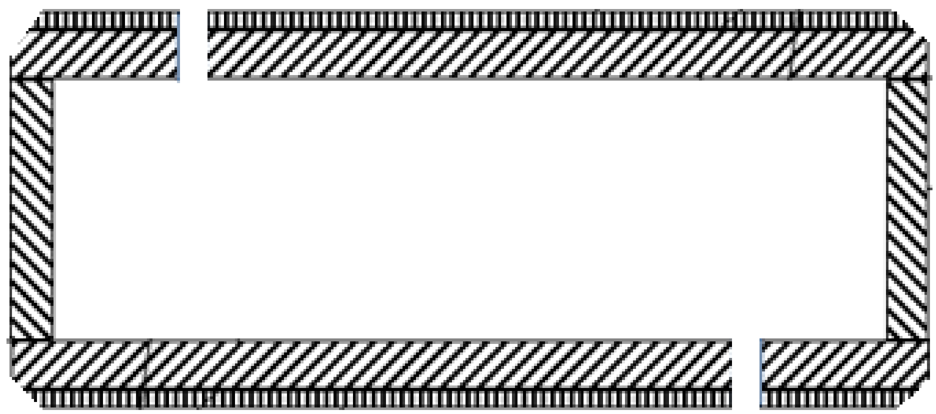


Figure 3.3.3 – Elevation showing components of the Cap Device (Closed)

The details of the Cap on Figure 3.3.4 show a Cap device is inserted inside an asphalt core hole formed in an existing asphalt structure. The fill material has been placed to fulfill the asphalt core hole, and in where the Cap device is placed on top of fill material as shown on Figure 3.3.5. The fill material is compacted by pressed down the Cap device and the Cap device forcing the fill material into the asphalt core hole by hammering, tamping or other forceful way.

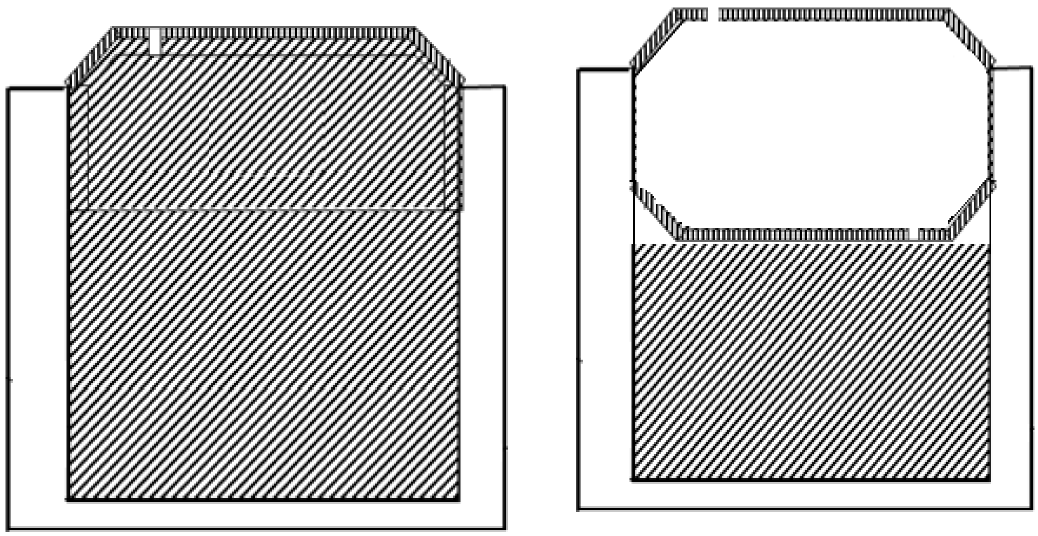


Figure 3.3.4 – Section Views of the Cap Device (Inserted)

Figure 3.3.5 shows the Cap device fully inserted into the asphalt core hole in asphalt pavement. The figure shows both Cap device types; an open Cap device and a closed Cap device.

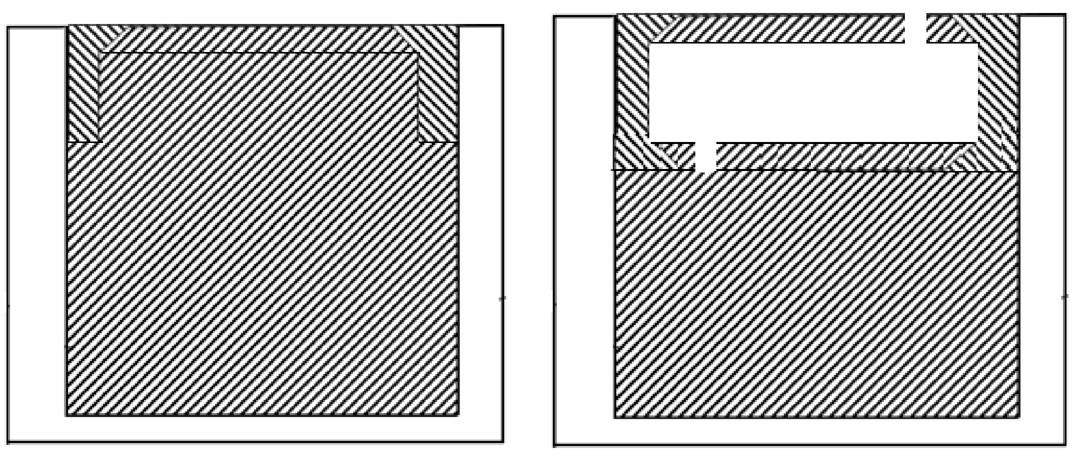


Figure 3.3.5 – Section View of the Cap Device (Fully Embedded)

Figure 3.3.6 shows a plan view of the Cap device inserted and/ or embedded into the existing asphalt structure.

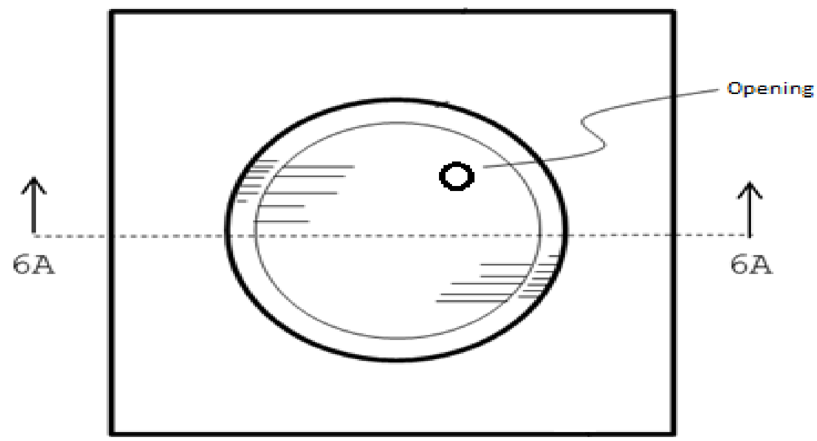


Figure 3.3.6 – Plan View of the Cap Device (Inserted and Embedded)

3.4 Cap Device Patent Application

The Cap device design has been filed to the United States Patent and Trademark Office (USPTO) on August 26, 2015. The title of the invention is: Cap for Restored Asphalt Core and Methods of Protecting Asphalt Core Hole under Application No. US 14/836,951. The patent application identified above has been examined and is allowed for issuance as a patent on January 17, 2017 (Appendix A). The patent application fees were paid, and the patent application was published in on March 07, 2017.

The Cap for restored asphalt core and methods of protecting asphalt core hole patent application contained 9 claims for the design and the application of the Cap. The named Patent Application No. US 14/836,951 has been examined and is allowed for issuance as a patent on January 17, 2017 (Appendix A). The design, mechanism of application and methods of Cap use are all claimed under the same aforementioned patent application.

3.5 Investigation of Cap Device Mechanism

The Cap device mechanism is simple, circular and solid. After drilling for an asphalt core and removing the asphalt core, cleaning of the core hole is required from any debris or foreign materials. The core hole shall be restored using materials approved by the State agency supervising the construction project. The most common approved materials for core hole restoration are commercially approved cold patch asphalt and same hot mix asphalt used during the paving activity requiring coring. The standard specifications of NJDOT dictates to fill the core hole with commercially approved asphalt cold patch mix and compact it with hammering methods to ¼" above the existing surface to allow for settlement over time and due to vehicular loadings. Overfilling of holes allows better compaction and restoration of final surface and makes up for the settlement due to vehicular loading and pressure (Elseifi, 2007).

After applying all standard specifications of NJDOT to restore the asphalt core hole, the Cap shall be used on the top of the restoration material placed inside the core hole. The Cap device shall be forced in by methods of applying pressure or hammering. The fill material could be gathered toward the center of the core holes for easy placement and insertion of the Cap device in the case of tamping the first layer of restoration material. The fill material shall be ½" above the existing surrounding pavement surface and the Cap device will be placed on top of the fill material and inserted into the asphalt core hole as shown on Figure 3.5.1. The Cap device shall be used to tamp, compact and force the asphaltic restoration material inside the core hole by methods of hammering. The Cap device shall transfer the hammering pressure and hence, compacts the asphaltic fill material as shown on Figures 3.5.2 and 3.5.5. As vehicles and trucks drive on surface of the restored asphalt core hole, the restoration material shall settle another ½" over time and due to vehicular loadings to flush with the existing pavement structure. Once the Cap device compacts the asphalt restoration material to approximately ½" above the surrounding pavement surface level as shown on Figure 3.5.1, the Cap device could be remove as shown on Figure 3.5.3 and 3.5.5. The bonding agent, if required, such as hot poured asphalt shall be applied immediately after removal of the Cap device off the asphalt core hole. The bonding agent could be applied to fill the voids created by the volume of the Cap device and to fill the all voids in the asphalt core hole until fully filled and level with the surrounding pavement surface, if required. The hot poured asphalt shall be left to set according to the manufacturer's recommendation or the set of specifications governing the quality control of hot poured asphalt applications, if required. The dimension noted on the Figures below are for demonstration and information purposes only and may change according to the requirements of the governing agency or testing lab. Cap dimensions may also vary according to the testing entity requirement or the governing agency specifications.

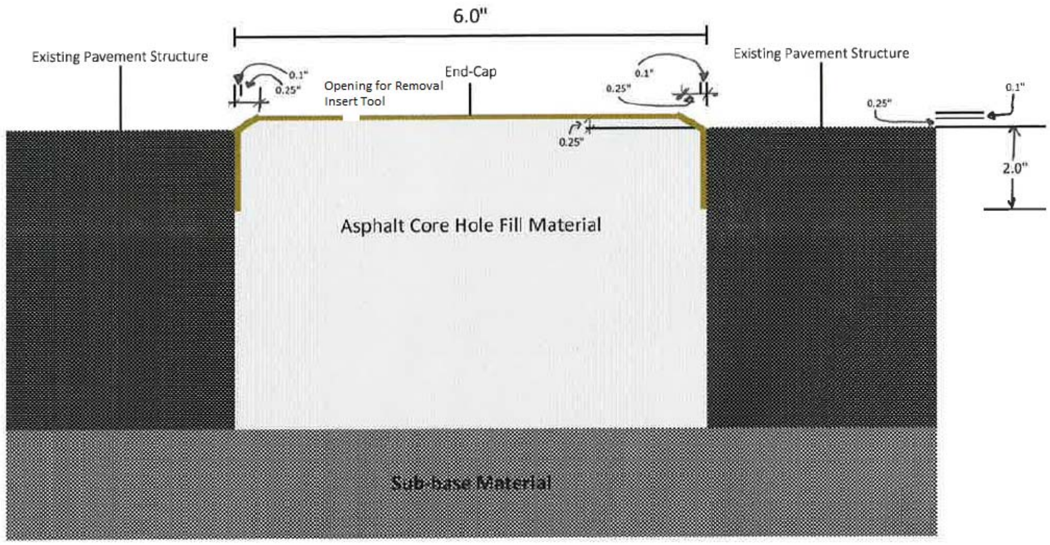


Figure 3.5.1 – Cap Device Inserted into an Asphalt Core Hole

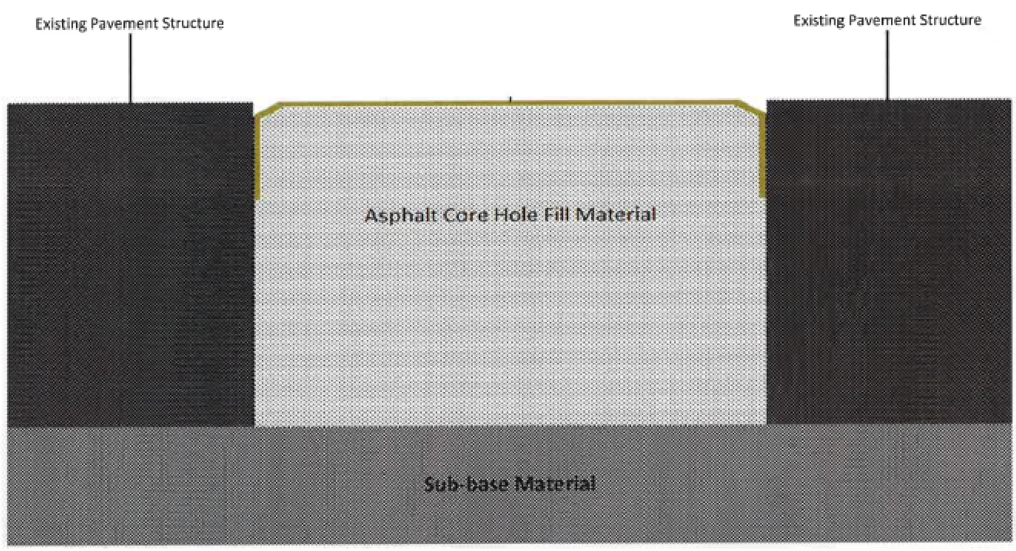


Figure 3.5.2 – Compressed Cap Device into the Asphalt Core Hole

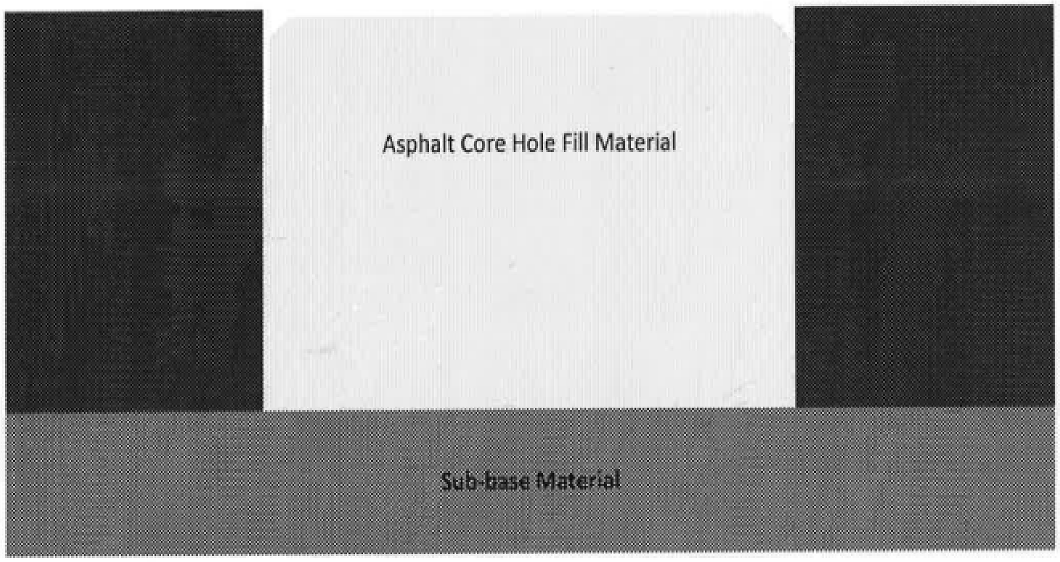


Figure 3.5.3 – Compacted Asphalt Core Hole Fill Material (without the Cap)

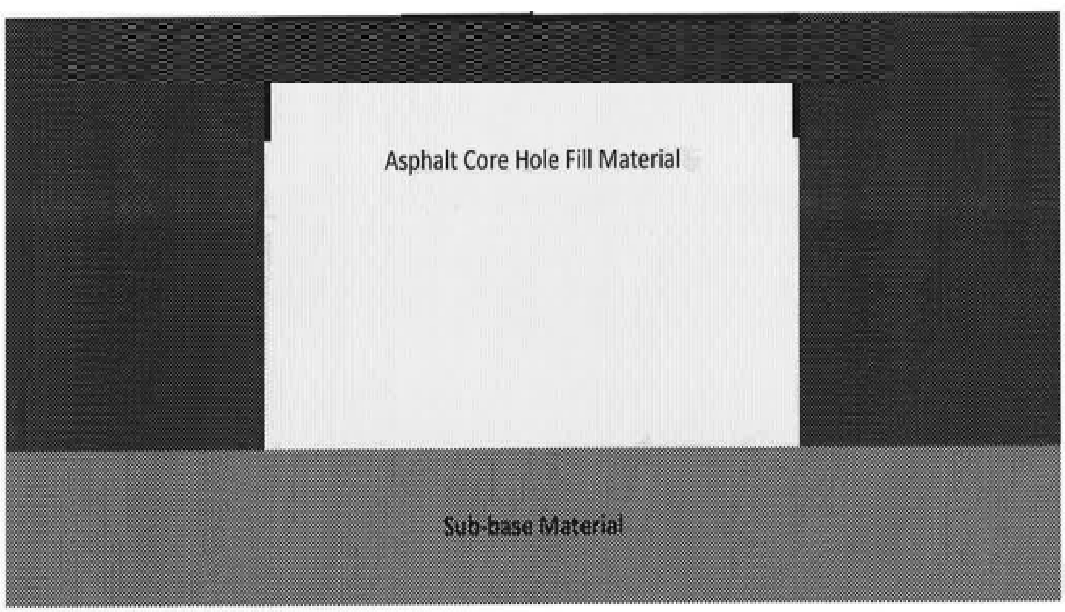


Figure 3.5.4 – Asphalt Core Hole with Compacted Fill Material

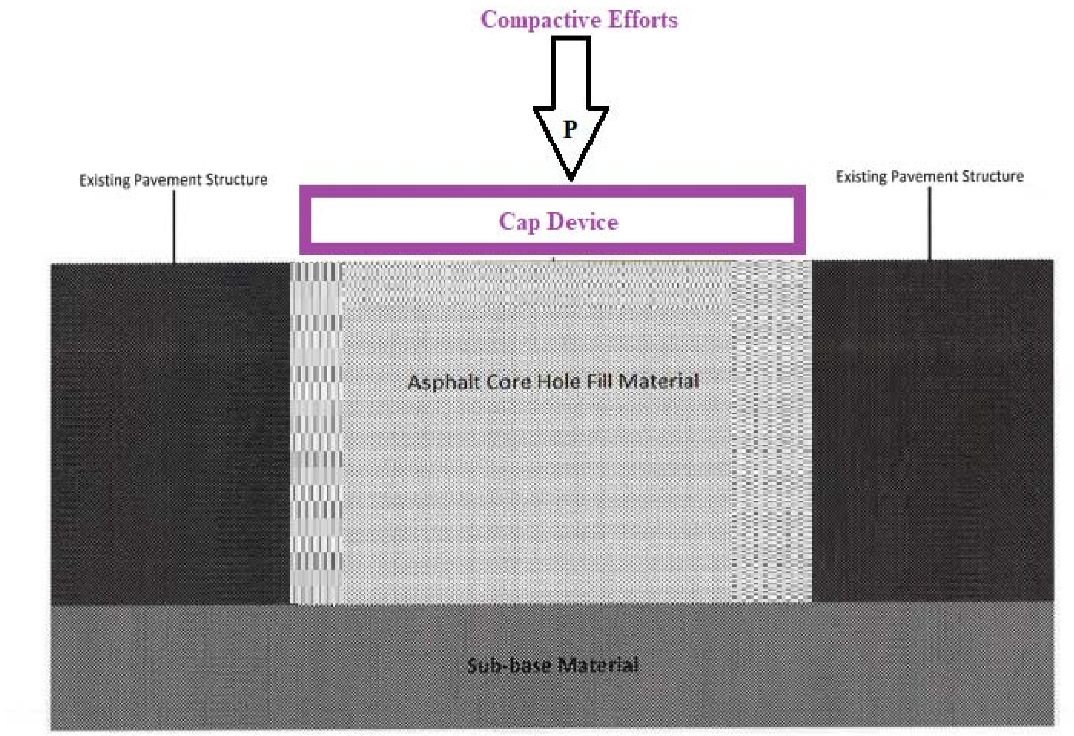


Figure 3.5.5 – Compactive Efforts on Closed Device into the Asphalt Core Hole

3.6 Cap Device Applications Analysis

The Cap for restored asphalt core and methods of protecting asphalt core hole patent application contained nine (9) claims for the design and the application of the Cap. The named Patent Application No. US 14/836,951 has been examined and is allowed for issuance as a patent on January 17, 2017 (Appendix A). The following claim represents the application of the Cap device in restoring asphalt core holes included in the named patent application;

> "A method to protect an asphalt core hole, comprising the steps of placing fill materials to fulfill an asphalt core hole formed in an existing asphalt structure,

forming a top of the fill materials, placing a circular Cap on the top of the fill materials, compacting the fill materials by putting pressure on the circular Cap, applying force on the circular Cap until the circular Cap into the asphalt core hole, use the cap to compact the restoration material, removing the circular Cap from the asphalt core hole, and filing an emulsifying bonding agent between the fill material and the existing asphalt structure as needed."

It is obvious from the presentation in Chapter 3 of this study the numerous benefits of using the Cap device to restore and protect asphalt core holes. It is a state-of-the-art technology to enhance the compaction of the restoration material, protect the edges of pavement structures and improve the final physical appearance of drilled asphalt cores in roadways and highways by providing a flatter surface of the restoration material inside the core holes. The field study and data analysis will determine whether applying an asphaltic bonding agent in the restored core holes along with the restoration material enhances the compaction ratio or not.

3.7 Discussion of the Cap Device

Numerous characteristics, advantages, and embodiments of the invention have been described in detail in the forgoing description with reference to the accompanying drawings. However, the invention is not limited to the illustrated embodiments, and all embodiments of the invention need not necessarily achieve all of the advantages or purposes, or possess all characteristics, identified herein. Although example materials and dimensions have been provided, the invention is not limited to such materials and dimensions have been provided, the invention is not limited such materials or dimensions unless specifically required. The elements and uses of the above-described embodiments can be rearranged and combined in manners other than specifically described above, with any and all permutations within the scope of the inventions. The Cap device will be tested in the field on multiple core holes with different diameter sizes, depths, material types, weather conditions and also different installation mechanisms and number of tamps used to compact the asphaltic material inside the core holes used for this study.

CHAPTER 4 - FIELD EVALUATION AND TESTING OF THE ASPHALT CORE HOLE CAP DEVICE PERFORMANCE

This chapter should present the data collected from testing the asphalt core hole Cap device on one of the construction sites in the State of New Jersey. The field tests could take in a test site or in a controlled environment. The behavior of multiple Caps will be monitored after the application at multiple asphalt core hole locations. The Chapter is organized in a way to reveal the conditions of the asphalt coring methods, Cap device applications, visual survey of Cap device performance, monitoring and documenting the performance of the Cap device, data collection of the behavior of the device and a summary of the field-testing and evaluation. This Chapter will also include a statistical modeling for the Cap Device performance and behavior based on data collected from field-testing.

Contractors are usually forced to follow a certain set of specifications, plans and rules. A room for creativity shall be open to Contractors and researchers to allow for further discoveries, explorations and hence, enhance the industry practices and construction quality. For many years, highway pavement structures have been constructed using “method” specifications. This type of specification is a cookbook, or recipe, approach to construction. Under method specifications, the contractor is told how to do the work required- the specifications list the equipment, which can be used, the steps to be followed in the building process and the results, which must be obtained when the construction is completed. Before any contractor thinks about undertaking an end-result specifications (ERS) project, he should be completely familiar with the requirements of the specifications. The contractor should understand what the governmental agency is trying to accomplish by converting from method specifications to statistical-type ERS. It is also very important that each supplier and subcontractor be cognizant of his responsibilities under the new type of specifications (Jones et al., 1980). End-result specifications (ERS) allow a contractor a degree of independence not possible under method specifications. ERS allow a contractor to participate in the decision-making process on a public paving contract, which is similar to what a contractor des for his private customers. ERS promote good workmanship and quality construction, to the benefit of both the owner and the contractor. The governmental agency or the owner may impose penalty point system to control the results of the ERS project.

4.1 Introduction

As funding for rehabilitation of pavements becomes scarcer, the ability of maintenance agencies to extend pavement service life with patching and other maintenance techniques becomes more critical (Wilson, 1993). Density is one of the most important properties of asphalt concrete layers in flexible pavement. It is critical to monitor the change in asphalt concrete density during compaction; GPR can be used to measure asphalt mixture density nondestructively and rapidly. Traditionally, there are two methods for measuring the density of pavement. One method uses laboratory measurements of cores extracted from the asphalt pavement. The other method uses a nuclear density gauge to measure in-place density (Shangguan, 2013).

4.1.1 Field Testing Locations

The field-testing took place in three (3) locations in the Bronx County, New York State. Locations of field-testing of the Cap device;

1- WB of Clay Ave between E168 Street and E169 Street, approximately 50 feet North off the E168 Street & Clay Ave intersection;

2- EB of Webster Ave between E167 Street and E168 Street, approximately 150 feet South of the E168 Street & Webster Ave intersection;

3- WB of Webster Ave between E167 Street and E168 Street, approximately 100 feet South of the E168 Street & Webster Ave intersection.

4.2 Sampling Asphalt After Compaction (Obtaining Cores)

Taking asphalt cores is one of the most common quality assurance and quality control measures agencies and owner require. Core testing is an extremely precise tool to determine what method of pavement repair is needed. Cores may range in size from 2 inch to 12 inch inner diameter width according to the specification of the owner or agency ordering the asphalt cores. Cores of sizes 4 inches and 6 inches are most common in the construction industry and 4 in cores have been used in this study as the very most common core size and to reduce the destructiveness on the tested asphalt pavement structure. Nondestructive testing NDT is to evaluate the structural capacity, performance and density. NDT allows for investigating pavement properties, mix design and material behavior without causing destruction or distress to the pavement structure (Tayabji et al., 2000). The United States Department of Transportation dictates scope, purpose, apparatus, procedures, sampling and restoring asphalt core holes. The following is an illustration of sampling procedures from the Washington State Materials Manual;

"**Apparatus:**

• Core Drill Machine –A Core Drill Machine of sufficient horsepower and depth to minimize distortion of the compacted cores of Hot Mix Asphalt.

• Core Bit – The cutting edge of the core drill bit shall be of hardened steel or other suitable material with diamond chips embedded in the metal cutting edge or as recommended by the core drill bit manufacturer. Typically, the core drill bit should have an inside diameter of 4" ± 0.25" (100 mm ± 6 mm) or 6" ± 0.25" (150 mm ± 6 mm), these core bit dimensions are agency preferred alternatives. Suitable larger and smaller diameter core bit alternatives shall be employed as required by the agency.

• Tools – Core layers may be separated using a saw or other suitable device, which provides a clean smooth surface and does not damage the core.

• Retrieval Device (Optional) –The retrieval device used for removing core samples from holes must preserve the integrity of the core. The device may be a steel rod of suitable length and with a diameter that will fit into the space between the core and the pavement material. There may be a 90-degree bend at the top to form a handle and a 90-degree bend at the bottom, approximately 2 in (50 mm) long, forming a hook to assist in the retrieval of the core or other suitable device.

Procedure

• For freshly placed Hot Mix Asphalt materials, the core shall be taken when the material has had sufficient amount of time to cool to prevent damage to the core.

• Pavement may be cooled to expedite the removal of the core by the following methods;

water, ice water, ice, or dry ice or liquid nitrogen.

• Place the coring machine and core bit over the selected location.

• Keep the core bit perpendicular to the Hot Mix Asphalt surface during the coring process.

Note 1: If any portion of the coring machine shifts during the operation, the core may break or distort.

• Constant downward pressure should be applied on the core bit. Failure to apply constant

pressure, or too much pressure, may cause the bit to bind or distort the core.

• Continue the coring operation until the desired depth is achieved.

• If necessary, use a retrieval device to remove the core.

• Clearly identify the cores location and offset without causing damage (i.e., lumber crayon or grease pencil).

Note 2: If the core is damaged to a point that it cannot be used for its intended purpose,

a new core shall be obtained within 6 inches of the original location.

Filling Core Holes

• When necessary, the hole made from the coring operation shall be filled with a material that will not separate from the surrounding material. If Hot Mix Asphalt is available and used, it shall be compacted into the hole. A ready-mix concrete or fast set grout product may be used in lieu of a Hot Mix Asphalt. A black dye can be used to color the grout on driving surface.

• Prior to backfilling a core hole on a bridge deck, ensure that the hole and sidewalls are dry enough to bond with the sealant before applying.

• Acceptable sealants include; asphalt binder or any waterproof sealant designed for asphalt applications as stated by the manufacturer.

• Apply sealant to bottom surface and side walls of core hole as needed.

• Backfill the core hole with Hot Mix Asphalt, cold mix asphalt, ready mix concrete or grout and compact as needed."

The above apparatus and procedures used to sample asphalt pavements and restore the asphalt core holes sampled are common and similar to the rest of literature in other standard specifications governed by the Federal Government, the State's Department of Transportation or other asphalt organizations. The apparatus core-drilling machine and drilling bit used in the field-testing are shown in Figure 4.2.1 below.

Figure 4.2.1 Core Drilling Machine and Drilling Bit

The procedures of sampling asphalt and restoring the asphalt core holes are explained in detail in Chapter 3. The below figures demonstrate photos taken during the field testing of applying the asphalt core Cap device to enhance the restoration procedures of the current asphalt core hole restoration. The figure below Figure 4.2.2 shows the asphalt core taken for field-testing on Webster Ave between E168 Street and E167 Street. The photo shows cores taken using the Hilti Core Drilling Machine; apparatus used such as Cap device, generator, paint, screwdriver to remove the cap and commercially used asphaltic restoration material.

Figure 4.2.2 Asphalt Core Holes and Apparatus

The figure below shows the filling of asphalt core holes, tamping asphaltic material in core holes, using the Cap device in compacting the asphaltic restoration material inside core holes, finishing the restoration of core holes and using asphaltic filler in restoration of core holes in Model 4 as explained in section 4.3 of this chapter.

Figure 4.2.3 Filling Asphalt Core Holes

Figure 4.2.4 Tamping Cap Device

Figure 4.2.5 Filling Asphalt Core Holes with Speed-Fill

Figure 4.2.6 Restored Asphalt Core Holes

It is apparent from the literature in all standard specification for asphalt sampling and core restoration that the procedures of backfilling the core hole is inadequate and required additional research to enhance the quality of core hole restoration. This Chapter discusses in details the current restoration method as detailed in the States' standard specification in comparison to restoring asphalt core holes using the Cap device to compact the restoration material inside the core hole. The next section will present the 4 models of asphalt core hole restoration proposed in this study for research and comparison.

4.2.1 Asphalt Core Restoration Material

The set of standard specifications of the sub-section 401.02.01 of the Hot Mix Asphalt (HMA) Courses in the New Jersey Department of Transportation Standard Specifications states the following;

> "Use HMA specified for the roadway surface as patching material for HMA pavement repair. The Contractor may use a *commercial* type of cold mixture as patching material for filling core holes if HMA surface course is not being placed when coring. The Contractor may use an approved HMA surface course to fill core holes, provided the material remains hot enough to compact."

There are three common commercial types of asphaltic cold mixture for patching and core filling and all three types were used during the field-testing and verification field-testing phase in this study. Asphalt properties are initially tested in a closed environment or laboratory to determine initial properties of the asphalt mix material (Atkins, 1983). The three commercial types of cold mixture asphaltic material are:

1- Sakrete® All Weather Blacktop Patch

Sakrete® All Weather Blacktop Patch is a ready to use asphalt repair product designed for the permanent repair of potholes, large cracks and other defects in asphalt surfaces. Repairs can be opened to traffic immediately after proper compaction. The unique design provides an environmentally friendly low VOC product, as stated in the Sakrete Product Data Sheet included in Appendix A-3. The Sakrete product data sheets include details of product features, uses, color, preparation tips, safety tips, placement and compaction procedures and warranty info. This commercial type of cold asphalt patch material is the most common and lowest in price in the market and available in stores such as Home Depot and Lowe's. The figure below (Figure 4.2.1.1) shows a sample of a Sakrete® All Weather Blacktop Patch bag used in the field for this study on Models 1-4.

Figure 4.2.1.1 Sakrete® All Weather Blacktop Patch Asphalt Fill Material

2- QPR No VOC Repair Material

QPR No VOC Repair Material shall be a plant or pug mill mixed, high performance pavement patching material capable of storage in an uncovered outdoor stockpile for a maximum of 12 months. It shall be composed of laboratory approved mineral aggregates and modified bituminous QPR® No VOC Liquid capable of coating wet aggregates (up to 4% moisture) without stripping and have stripping resistance of retained coating of not less than 95%. The permanent asphalt repair shall be uniform, remain flexible and cohesive to -15°F and be capable of retaining adhesive qualities in wet applications. The patching materials shall be able to repair asphalt, concrete, surface treated roads and shall not require removal and replacement if ever the pavement is overlaid, as stated in the QPR No VOC Repair Material Product Data Sheets included in Appendix A-4. The QPR No VOC Repair Material data sheets include details of product features, environmental impact, material data, plant mix, preparation and operations tips, safety tips and other scientific and regulatory information. This commercial type of cold asphalt patch material is also one of the most common in the market and available in stores such as Home Depot and Lowe's. The figure below (Figure 4.2.1.2) shows a sample of a QPR No VOC Repair Material bag used in the field for this study on Models 1-4.

Figure 4.2.1.2 QPR No VOC Repair Material Asphalt Fill Material

3- Latexite® Super Patch

Latexite® Super Patch is a stone asphalt patch for driveways and pavements. It is recommended for POTHOLES, large cracks and joints. It can be used on both asphalt and concrete and is designed to be used year-round. Latexite® Super Patch contains asphaltic binders which give it maximum adhesion and longer life, as stated in the Latexite® Super Patch Product Data Sheets in Appendix A-4. The Latexite® super patch product data sheets include details of product features, physical properties, application, surface preparation, precautions, handling and storage, warranty information and safety tips. This commercial type of cold asphalt patch material is also one of the most common in the market and available in stores such as Home Depot and Lowe's. The figure below (Figure 4.2.1.3) shows a sample of a Latexite® super patch bucket used in the field for this study on Models 1-4.

Figure 4.2.1.3 Latexite® Super Patch Asphalt Fill Material

4- Drive-Patch Blacktop Crack & Hole Repair

Drive-Patch Blacktop Crack & Hole Repair is a ready to use cement textured patching compound. It is a latex fortified and provides a long-lasting durable patch that resists gas, oil and chemical deterioration. Use Drive-Patch Blacktop Crack & Hole Repair to repair small holes and cracks (up to 3” deep) or to smooth out surfaces that are damaged by gasoline and oil spillage, as stated in the Drive-Patch Blacktop Crack & Hole Repair Product Data Sheets in Appendix A-6. This fill material was used on Model 4 of this study to seal and fill at the bottom of asphalt core holes and seal around the compacted asphalt restoration material against the existing asphalt pavement structure. This commercial type of asphaltic fill material is also one of the most common in the market and available in stores such as Home Depot and Lowe’s. The figure below (Figure 4.2.1.4) shows a sample of a Drive-Patch Blacktop Crack & Hole Repair Speed-Fill container used in the field for this study.

Figure 4.2.1.4 Black Jack Speed-Fill Asphalt Fill Liquid

4.2.2 Asphalt Density Testing

The importance of proper compaction of asphalt pavements has been recognized for many years. Investigators have shown that pavement stability, durability, tensile strength, fatigue resistance, stiffness, and flexibility are controlled to a certain degree by the density of asphalt concrete. To insure adequate compaction, several agencies specify "in place" density requirements. These in-place requirements are commonly expressed as a percent of a standard laboratory compaction density. Laboratory tests are intended to give the engineer needed information about the density of the surfacing material as it ultimately appears on the roadway. This will include field data collection of testing the performance of the asphalt core hole Cap device (Epps, 1969). Traditionally, there are two methods for measuring the density of pavement. One method uses laboratory measurements of cores extracted from the asphalt pavement. The other method uses a nuclear density gauge to measure in-place density. The nuclear density gauge was used on this field study to determine the compaction ratio of the compacted asphaltic restoration material used to restore the cored holes. Significant time and financial resources are routinely spent on QC/QA testing of asphalt pavement construction projects. A substantial amount of research has been performed on several nondestructive testing (NDT) technologies for flexible pavements, with the goals of improving the speed and accuracy of QC/QA methods and enabling practice to evolve beyond destructive testing. Some examples of these NDT technologies are nuclear gauges, electromagnetic gauges, permeability-based approaches, seismic testing techniques, and intelligent compaction based on measurement of machine variables during the construction process (Lin et al./, 2015).

Field-testing of compacted and restored asphalt core holes took place on Friday August 11, 2017 at 9am. The company provided the inspector is:

Haider Engineering PC

91 Toledo Street, Farmingdale, NY 11735

Ph.: 631-777-2280

Fax: 631-777-2284

Email: info@haiderengineering.com

The Certified New York State Density Testing Inspector performed the nuclear gauge testing and readings;

Noel Gonzalez, Nuclear Density Inspector

Lab Supervisor at Haider Engineering PC

The density gauge used on this field study is "Troxler" 3450 RoadReader Plus, Moisture – Density Gauge. It is the most versatile moisture/density gauge ever produced. The RoadReader Plus combines the measurement modes proven in thousands of Troxler 3400 series gauges with a patented method for true thin layer asphalt and concrete bridge deck overlay density measurement. By combining thin layer and full depth measuring capabilities in one instrument, the RoadReader Plus is our flagship gauge in the 3400 series. With its versatility, speed, and economy the RoadReader Plus is designed to satisfy your compaction control needs at every stage of your project. Like all 3400 series gauges, the Model 3450 meets ASTM Standard Test Methods D-6938 (replaced ASTM

D-2922 and ASTM D-3017 as of November 2006), D-2950, C-1040 and AASHTO T-310, as per the Troxler Models 3400 – 4640 Basic Gauge Operations Manual.

Figure 4.2.2.1 Asphalt Density Testing

4.3 Asphalt Core Restoration Models

This section discusses in details the different restoration models of asphalt core restoration, where;

- Model No. 1 represents the current core restoration practice by the FHWA and States;

- Model No. 2 represents a new restoration technique of asphalt core holes using the invention of a Cap device, compacting one layer of asphalt fill material inside the core hole;

- Model No. 3 represents a new restoration technique of asphalt core holes using the invention of a Cap device, compacting two layers of asphalt fill material inside the core hole;

- Model No. 4 represents a new restoration technique of asphalt core holes using the invention of a Cap device, compacting one layer of asphalt fill material and filling the hole and edges with asphaltic filler material.

Under this study, 32 asphalt core holes were taken to access the efficiency and validity of using the Cap device to enhance the restoration practice for asphalt core holes versus the current practice that relies on hand compactive tamping method, as listed above in Section 4.3. Three (3) difference materials has been used under this study:

1- Sakrete® All Weather Blacktop Patch

2- QPR No VOC Repair Material

3- Latexite® Super Patch

The above listed 3 types of asphalt patch material were used as they were the most commercially used material in the market (Home Depot, Lowe's and Materials Suppliers) for asphalt patching and hole restoration. The Sakrete® All Weather Blacktop Patch was chosen as it was the most available, cheapest and was used to restore 19 out of 32 cores. The Sakrete® All Weather Blacktop Patch was selected for the main fielding testing and data collection. QPR No VOC Repair Material was used for verification of the data collected using the Sakrete® All Weather Blacktop Patch. The QPR Material was selected because it was also available at most material stores and cheap and was used to restore 6 out of 32 cores. The Latexite® Super Patch was also used for verification of the data collected using the Sakrete® All Weather Blacktop Patch. The Latexite® Super Patch was selected because it was also available at materials stores, the most expensive but yielded the best results and data in the field on 7 out of 32 cores. Each core of the 32 cores taken were restored and compacted according to the Model as indicated above. Each restored and compacted core was tested for compaction ratio using the Nuclear Gauge Monitor noted in Section 4.2.2. 7-8 readings were taken for each restored and compacted core in the field. The table below Table 4.3.1 indicates the dates cores were taken, core number, model number showing the procedures used to restore the core hole, reading number, material type used, temperature and location where tests were taken.

Date	**Core #**	**Model #**	**Reading #**	**Material**	**Temp**	**Location (Main)**	**Int. Street**
6/6/17	Test1	3	1	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	2	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	3	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	4	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	5	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	6	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	7	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	Avg	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	1	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street

6/6/17	Test2	2	2	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	3	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	4	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	5	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	6	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	7	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	Avg	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	1	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	2	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	3	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	4	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	5	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	6	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	7	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	8	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	Avg	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	1	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	2	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	3	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	4	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	5	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	6	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	7	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	Avg	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	1	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	2	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street

6/6/17	Test5	4	3	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	4	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	5	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	6	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	7	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	Avg	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	1	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	2	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	3	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	4	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	5	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	6	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	7	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	Avg	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
7/20/17	1	1	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street

7/20/17	2	2	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street

7/20/17	5	1	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	1	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	2	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	3	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	4	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	5	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	6	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	7	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	Avg	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
8/1/17	7	3	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	9	1	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	12	4	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	15	3	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	1	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	2	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	3	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	4	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	5	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	6	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	7	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	Avg	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	18	2	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	22	4	1	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	2	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	3	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	4	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	5	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	6	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	7	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	Avg	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	1	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	2	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	3	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	4	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	5	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	6	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	7	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	Avg	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	1	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	2	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	3	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	4	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	5	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	6	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	7	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	Avg	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	1	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	2	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

8/2/17	25	3	3	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	4	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	5	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	6	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	7	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	Avg	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	1	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	2	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	3	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	4	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	5	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	6	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	7	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	Avg	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

Table 4.3.1 Cores Data Table

The next sections 4.4, 4.5, 4.6 and 4.7 will cover in details of the field-testing of the asphalt cores taken, restored, compacted and tested for each model. Each section will present the methodology of the named model, photos of the field-testing showing procedures of the named model, data collected, graphs of the data showing the behavior, regression analysis of the data collected, best fit lines with analysis of the data results and the final table for each model. The linear relationship for model the relationship between the number of tamps used to compact the asphalt fill restoration material versus the compaction percentage of air voids reading taken by the nuclear gauge machine in the field. The independent variable (X) represents the number of tamps and the dependent variable (Y) representing the corresponding compaction ratio reading for the core tamped and compacted. The scattered plot shows the relationship between the number of tamps and the compaction %. The line graph shows the best-fit line and the magnitude of residuals to the best-fit line.

4.4 Asphalt Core Restoration Model No. 1

This section will cover the details of coring asphalt pavements using all three (3) commercially used restoration material. The table below Table 4.4.2.1 covers the data collected for Model No. 1 Core Test Data.

4.4.1 Procedures of Asphalt Core Restoration Model No. 1

The procedures of restoring asphalt core holes under Model No. 1 is similar to the standard procedures notes in the standard specifications of the United States Department of Transportation. The current State Department of Transportation Standard Specifications in New Jersey includes the following asphalt core hole restoration guidelines as part of Division 400, Pavements, Section 401- Hot Mix Asphalt (HMA) Courses and Section 405 Concrete Surface Course. The set of standard specifications of the sub-section 401.03.05 of Hot Mix Asphalt (HMA) for Core Samples states the following;

> "Upon completion of an HMA lot, drill cores at random locations determined by the RE at least 12 hours after paving. Take cores in the presence of the RE. Do

not drill additional core samples unless directed by the RE. Use drilling equipment with a water-cooled, diamond-tipped, masonry drill bit that shall produce 6-inch nominal diameter cores for the full depth of the pavement. Remove the core from the pavement without damaging it. After removing the core, remove all water from the hole. Apply an even coating of tack coat to sides of the hole. Place HMA in maximum lifts of 4 inches in the hole and compact each lift. Ensure that the final surface is 1/4 inch above the surrounding pavement surface."

The procedures dictate the following;

1- Drilling Asphalt Core Holes

Figure 4.4.1.1 Diamond Core Drilling Machine

2- Remove Core & Clean Core Hole

Figure 4.4.1.2 Remove Core & Clean Core Hole

3- Restore and Fill Core Hole

Figure 4.4.1.3 Restoring and Filling Core Hole

4- Tamp and Compact Restoration Material Inside Core Holes

Figure 4.4.1.4 Tamp and Compact Restoration Material Inside Core Holes – Model No. 1

5- Final Surface Cleaning

Note: uneven surface finish due to mechanism of tamping and compactive pressure applied.

Figure 4.4.1.5 Finished Restored Core Hole – Model No. 1

4.4.2 Asphalt Core Restoration Model No. 1 Data Analysis

The data below in table 4.4.2.1 represents the data collected in the field to study the behavior and correlation of the number of tamps used to compact the asphaltic material fill material in core holes and the corresponding compaction % results and reading taken by the nuclear gauge machine- for Model No. 1.

Date	Core #	Model #	Reading #	# of Tamps	Comp %	Material	Temp	Location (Main)	Int. Street
6/6/17	Test4	1	1	15-20	86.95	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	2	15-20	87.12	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	3	15-20	86.78	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	4	15-20	84.82	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	5	15-20	87.21	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	6	15-20	84.86	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	7	15-20	87.26	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test4	1	Avg	15-20	**86.57**	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
7/20/17	1	1	1	25-30	91.11	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	2	25-30	91.29	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	3	25-30	90.93	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	4	25-30	89.93	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	5	25-30	91.38	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	6	25-30	88.92	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	7	25-30	91.44	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	1	1	Avg	25-30	**90.71**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	1	25-30	91.23	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	2	25-30	91.41	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street

7/20/17	5	1	3	25-30	91.05	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	4	25-30	90.04	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	5	25-30	91.50	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	6	25-30	89.04	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	7	25-30	91.56	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	5	1	Avg	25-30	**90.83**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
8/1/17	9	1	1	15-20	90.08	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	2	15-20	88.91	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	3	15-20	87.75	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	4	15-20	88.91	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	5	15-20	87.75	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	6	15-20	86.61	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	7	15-20	87.75	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	9	1	Avg	15-20	**88.25**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	1	15-20	90.00	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	2	15-20	89.02	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	3	15-20	89.82	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	4	15-20	88.83	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	5	15-20	89.88	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	6	15-20	88.84	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	7	15-20	90.32	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	17	1	Avg	15-20	**89.53**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	1	25-30	90.89	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	2	25-30	91.07	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	3	25-30	90.71	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	4	25-30	89.71	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	13	1	5	25-30	91.16	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	6	25-30	88.71	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	7	25-30	91.22	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	13	1	Avg	25-30	**90.50**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	1	25-30	90.20	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	2	25-30	90.38	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	3	25-30	90.02	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	4	25-30	89.93	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	5	25-30	90.47	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	6	25-30	89.67	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	7	25-30	90.52	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	19	1	Avg	25-30	**90.17**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	1	25-30	91.22	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	2	25-30	91.40	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	3	25-30	91.04	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	4	25-30	90.03	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	5	25-30	91.49	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	6	25-30	89.03	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	7	25-30	91.55	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	23	1	Avg	25-30	**90.82**	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

Table 4.4.2.1 Model No. 1 Core Test Data

The following regression analysis and graphs for data collected and tested for Model No. 1 using the Sakrete® All Weather Blacktop Patch Material.

Regression Statistics	
Multiple R	0.66388552
R Square	0.44074398
Adjusted R Square	0.42210211
Standard Error	1.05310396
Observations	32

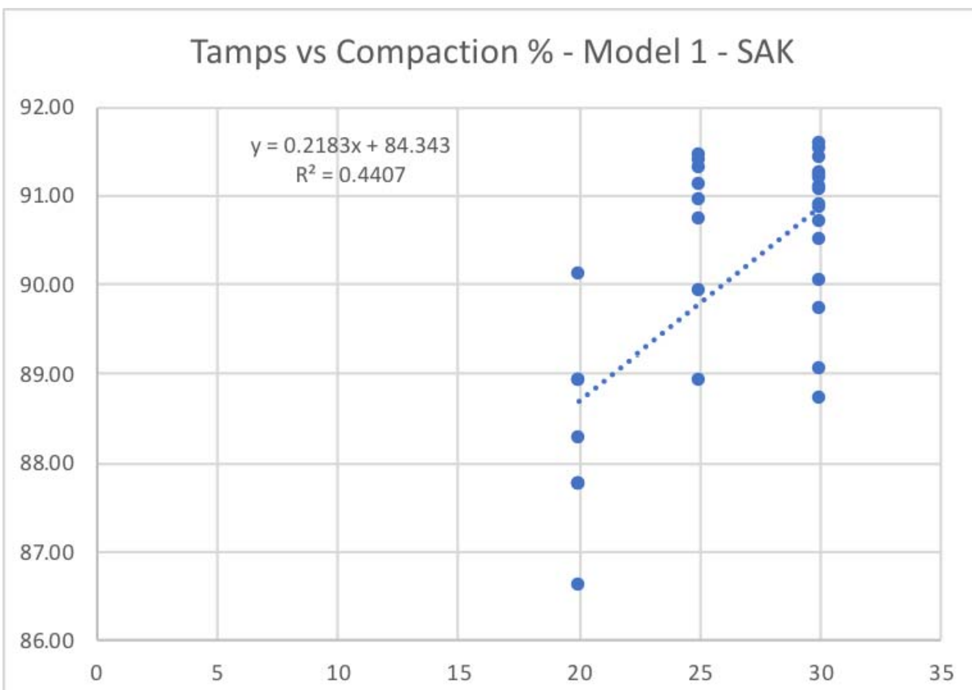


Figure 4.4.2.1 Tamps vs Compaction % - Model No. 1 – Sakrete

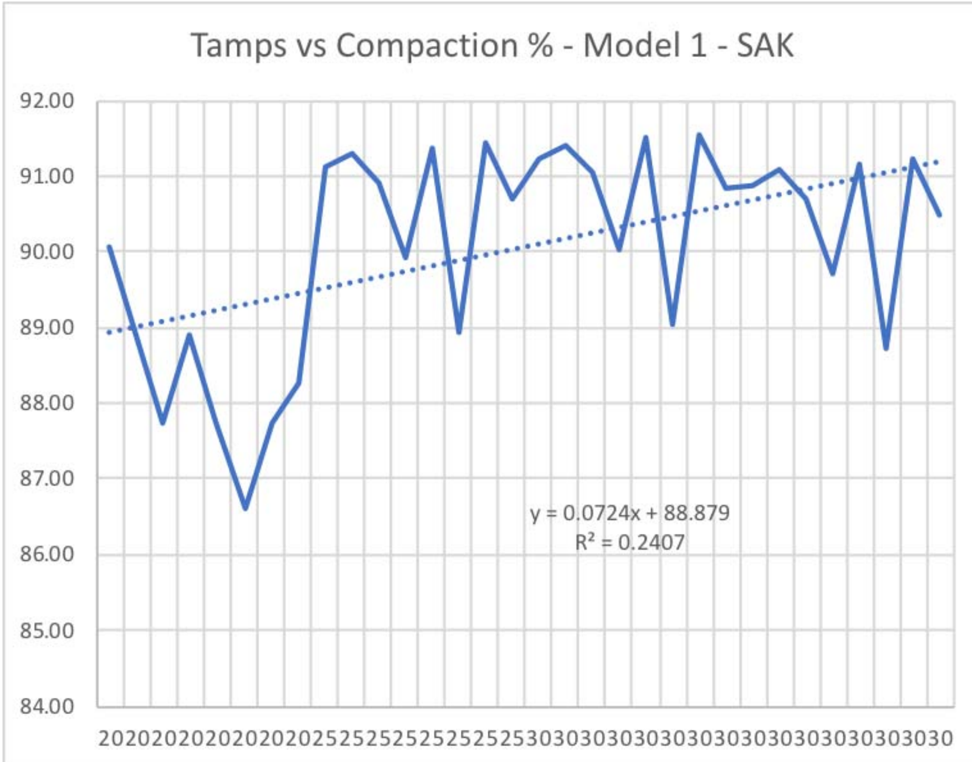


Figure 4.4.2.2 Tamps vs Compaction % Best Fit Line - Model No. 1 - Sakrete

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Sakrete® All Weather Blacktop Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 88.25% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 90.83%.

The following regression analysis and graphs for data collected and tested for Model No. 1 using the QPR No VOC Repair Material.

Regression Statistics	
Multiple R	0.60256743
R Square	0.36308751
Adjusted R Square	0.31759376
Standard Error	0.45321901
Observations	16

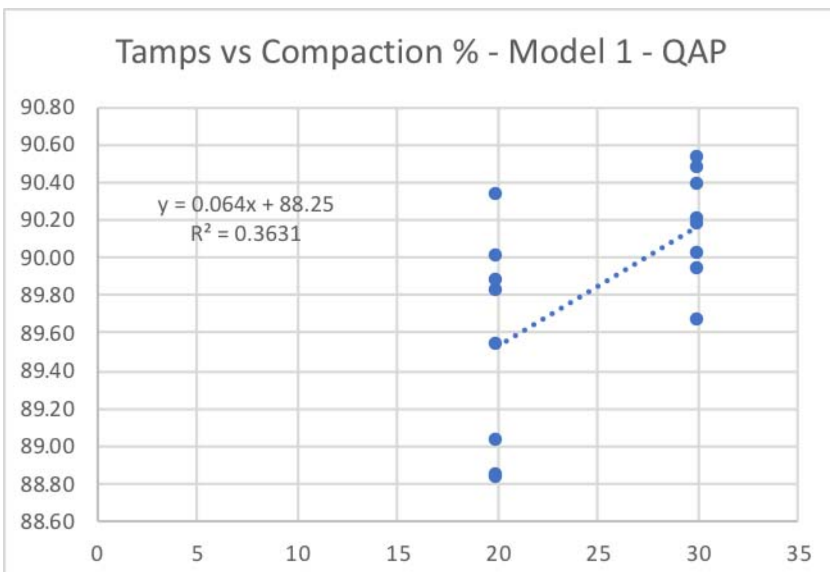


Figure 4.4.2.3 Tamps vs Compaction % - Model No. 1 - QPR

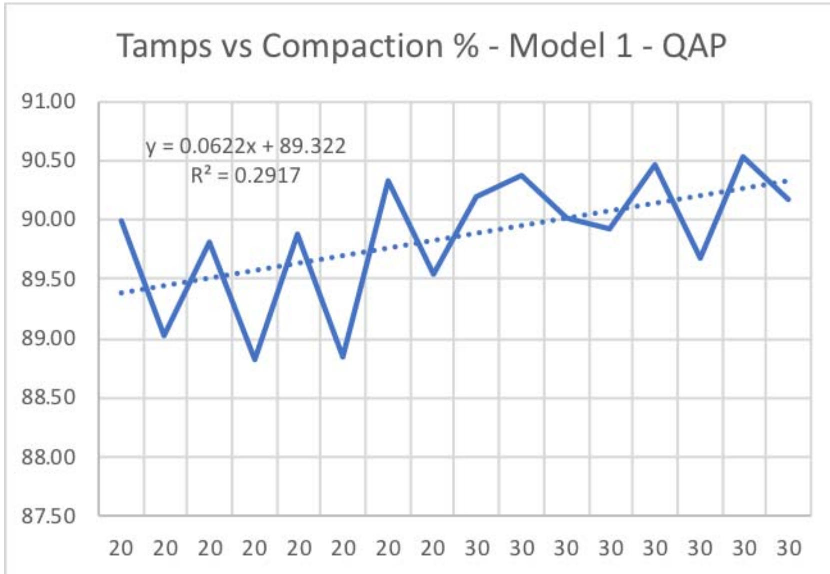


Figure 4.4.2.4 Tamps vs Compaction % Best Fit Line - Model No. 1 - QPR

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the QPR No VOC Repair Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 89.53% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 90.17%.

The following regression analysis and graphs for data collected and tested for Model No. 1 using the Latexite® Super Patch Material.

Regression Statistics	
Multiple R	0.93608166
R Square	0.87624887
Adjusted R Square	0.86740951
Standard Error	0.85401305
Observations	16

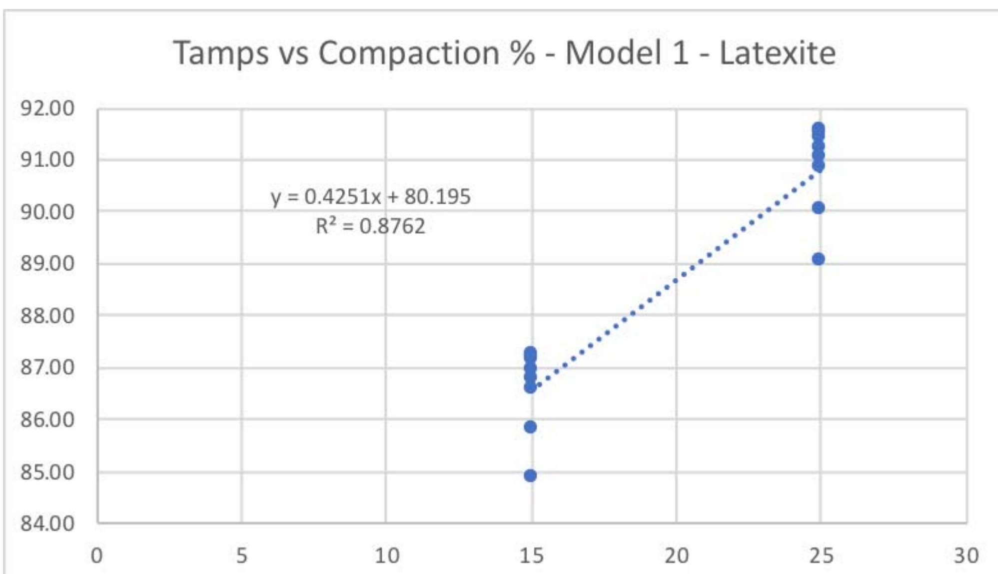


Figure 4.4.2.5 Tamps vs Compaction % - Model No. 1 - Latexite

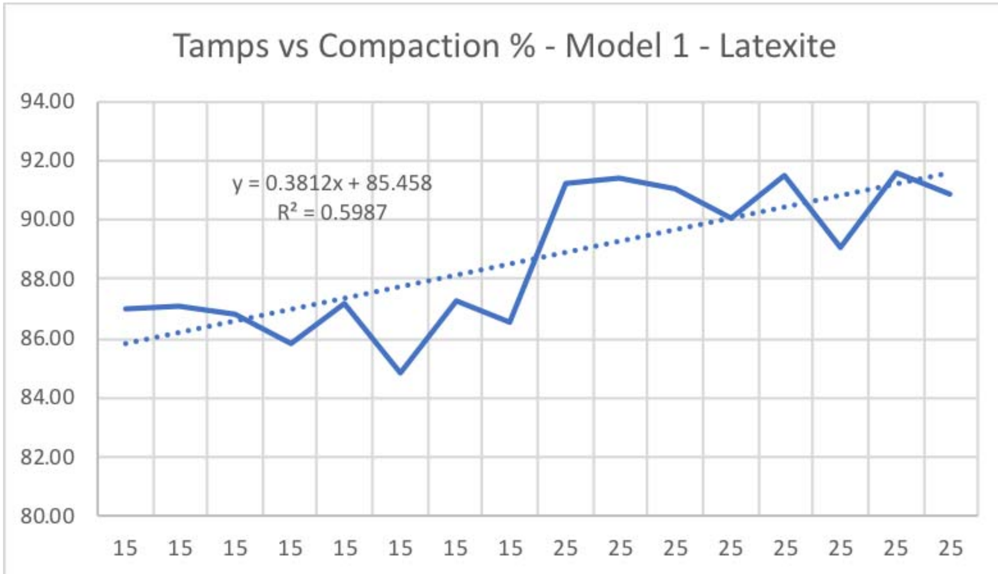


Figure 4.4.2.6 Tamps vs Compaction % Best Fit Line - Model No. 1 - Latexite

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Latexite® Super Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 86.57% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 90.82%.

4.5 Asphalt Core Restoration Model No. 2

This section will cover the details of coring asphalt pavements using all three (3) commercially used restoration material. The table below Table 4.4.2.1 covers the data collected for Model No. 2 Core Test Data.

4.5.1 Procedures of Asphalt Core Restoration Model No. 2

The procedures of asphalt core restoration in Model No. 2 is proposed to use the innovation of a Cap device to enhance the restoration practice of asphalt core holes. The detailed procedures are detailed in Chapter 3. The procedures dictate the following;

1- Drilling Asphalt Core Holes

Figure 4.5.1.1 Diamond Core Drilling Machine

2- Remove Core & Clean Core Hole

Figure 4.5.1.2 Remove Core & Clean Core Hole

3- Restore and Fill Core Hole

Figure 4.5.1.3 Restoring and Filling Core Hole

4- Tamp and Compact Restoration Material Inside Core Holes

Figure 4.5.1.4 Tamp and Compact Restoration Material Inside Core Holes – Model No. 2

5- Final Surface Cleaning

Figure 4.5.1.5 Finished Restored Core Hole – Model No. 2

4.5.2 Data Analysis of Asphalt Core Restoration Model No. 2

The data below in table 4.5.2.1 represents the data collected in the field to study the behavior and correlation of the number of tamps used to compact the asphaltic material fill material in core holes and the corresponding compaction % results and reading taken by the nuclear gauge machine- for Model No. 2.

Date	Core #	Model #	Reading #	# of Tamps	Comp %	Material	Temp	Location (Main)	Int. Street
6/6/17	Test2	2	1	15-20	94.26	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	2	15-20	94.45	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	3	15-20	94.92	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	4	15-20	94.75	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	5	15-20	94.54	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	6	15-20	94.82	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	7	15-20	94.60	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test2	2	Avg	15-20	**94.62**	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
7/20/17	2	2	1	15-20	93.02	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	2	15-20	93.21	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	3	15-20	92.83	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	4	15-20	93.60	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	5	15-20	93.30	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	6	15-20	92.99	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	7	15-20	93.35	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	2	2	Avg	15-20	**93.19**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	1	25-30	93.60	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	2	25-30	93.79	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street

7/20/17	6	2	3	25-30	93.81	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	4	25-30	93.38	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	5	25-30	93.88	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	6	25-30	93.55	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	7	25-30	93.94	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	6	2	Avg	25-30	**93.71**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
8/1/17	18	2	1	15-20	93.10	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	2	15-20	93.29	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	3	15-20	92.91	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	4	15-20	93.89	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	5	15-20	93.38	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	6	15-20	93.84	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	7	15-20	93.44	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	18	2	Avg	15-20	**93.41**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	1	25-30	93.98	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	2	25-30	94.17	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	3	25-30	94.64	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	4	25-30	93.76	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	5	25-30	93.33	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	6	25-30	94.83	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	7	25-30	93.89	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	10	2	Avg	25-30	**94.08**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	1	25-30	94.25	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	2	25-30	94.44	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	3	25-30	94.89	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	4	25-30	94.02	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	14	2	5	25-30	94.53	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	6	25-30	94.72	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	7	25-30	94.59	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	14	2	Avg	25-30	**94.23**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	1	25-30	94.20	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	2	25-30	94.39	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	3	25-30	94.01	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	4	25-30	94.95	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	5	25-30	94.49	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	6	25-30	94.21	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	7	25-30	94.54	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	20	2	Avg	25-30	**94.26**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	1	25-30	94.55	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	2	25-30	94.74	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	3	25-30	94.93	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	4	25-30	96.12	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	5	25-30	96.32	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	6	25-30	96.23	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	7	25-30	96.42	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	24	2	Avg	25-30	**96.05**	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

Table 4.5.2.1 Model No. 2 Core Test Data

The following regression analysis and graphs for data collected and tested for Model No. 2 using the Sakrete® All Weather Blacktop Patch Material.

Regression Statistics	
Multiple R	0.83614987
R Square	0.6991466
Adjusted R Square	0.68911815
Standard Error	0.334989
Observations	32

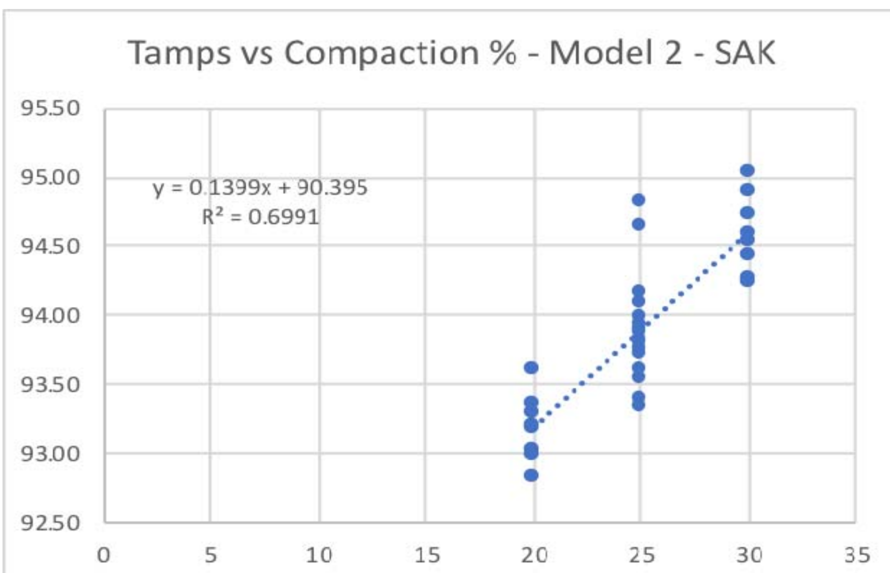


Figure 4.5.2.1 Tamps vs Compaction % - Model No. 2 - Sakrete

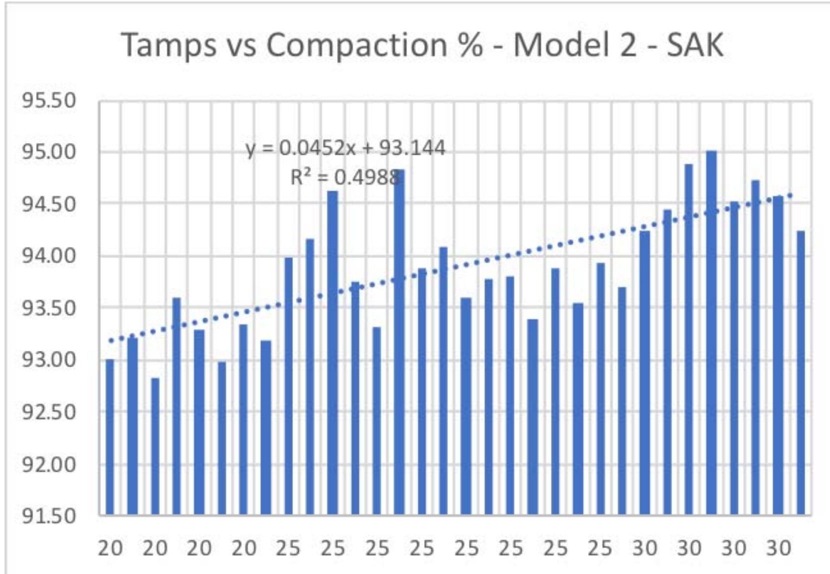


Figure 4.5.2.2 Tamps vs Compaction % Best Fit Line - Model No. 2 - Sakrete

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Sakrete® All Weather Blacktop Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 93.18% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 94.08%.

The following regression analysis and graphs for data collected and tested for Model No. 2 using the QPR No VOC Repair Material.

Regression Statistics	
Multiple R	0.96248347
R Square	0.92637444
Adjusted R Square	0.92111547
Standard Error	0.27864598
Observations	16

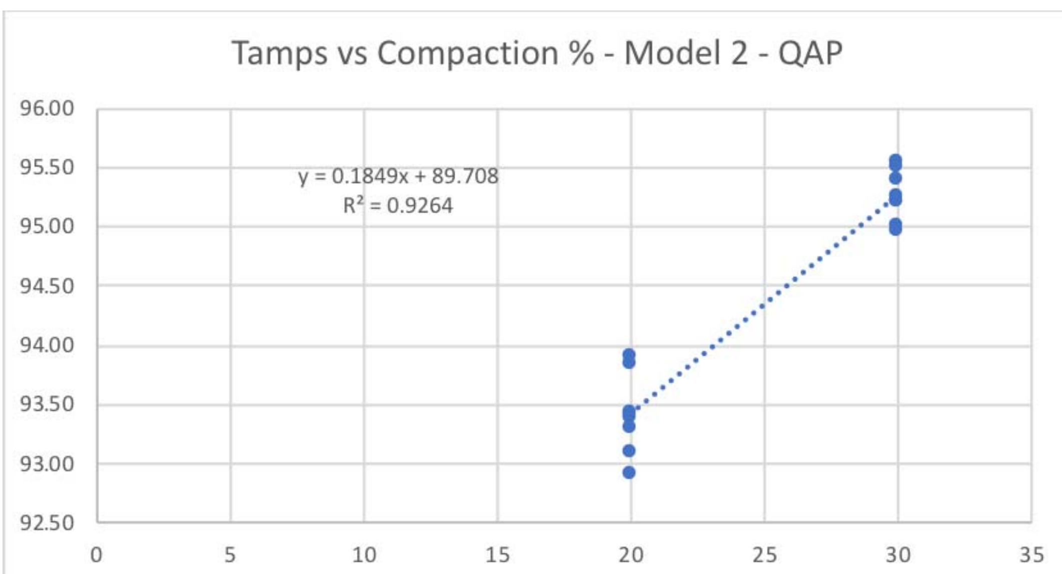


Figure 4.5.2.3 Tamps vs Compaction % - Model No. 2 - QPR

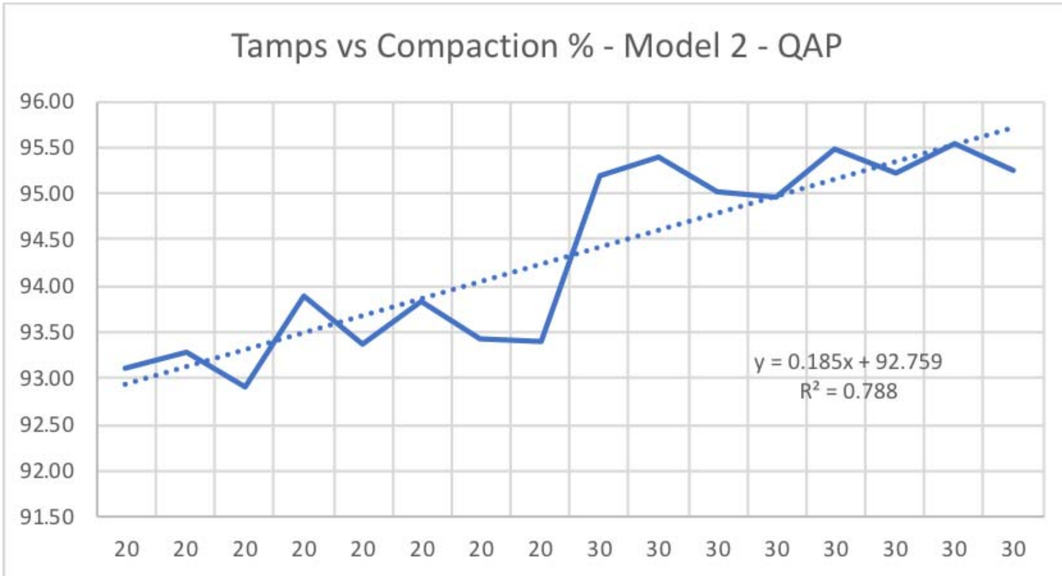


Figure 4.5.2.4 Tamps vs Compaction % Best Fit Line - Model No. 2 - QPR

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the QPR No VOC Repair Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 93.41% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 94.26%.

The following regression analysis and graphs for data collected and tested for Model No. 2 using the Latexite® Super Patch Material.

Regression Statistics	
Multiple R	0.94783303
R Square	0.89838746
Adjusted R Square	0.89112942
Standard Error	0.25621369
Observations	16

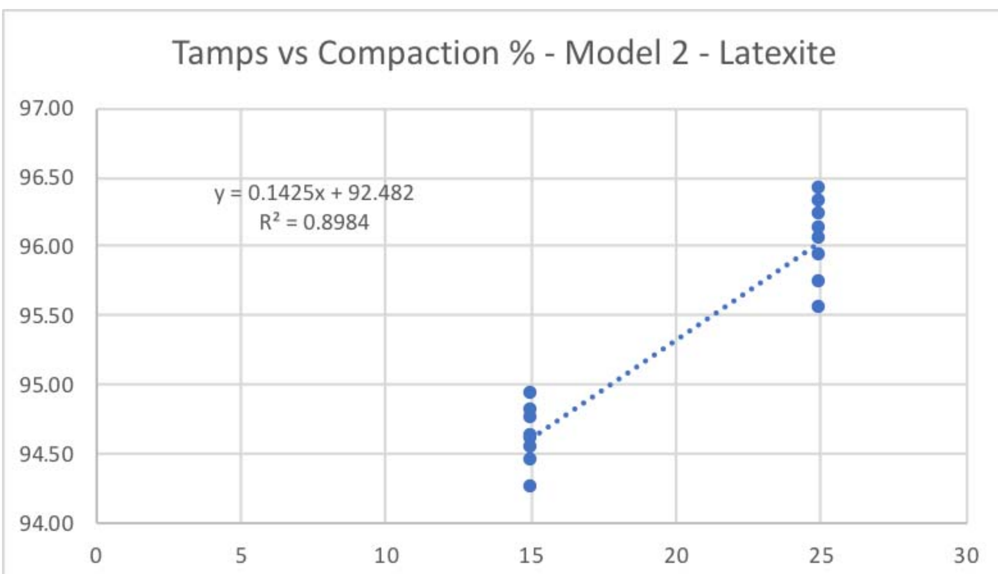


Figure 4.5.2.5 Tamps vs Compaction % - Model No. 2 - Latexite

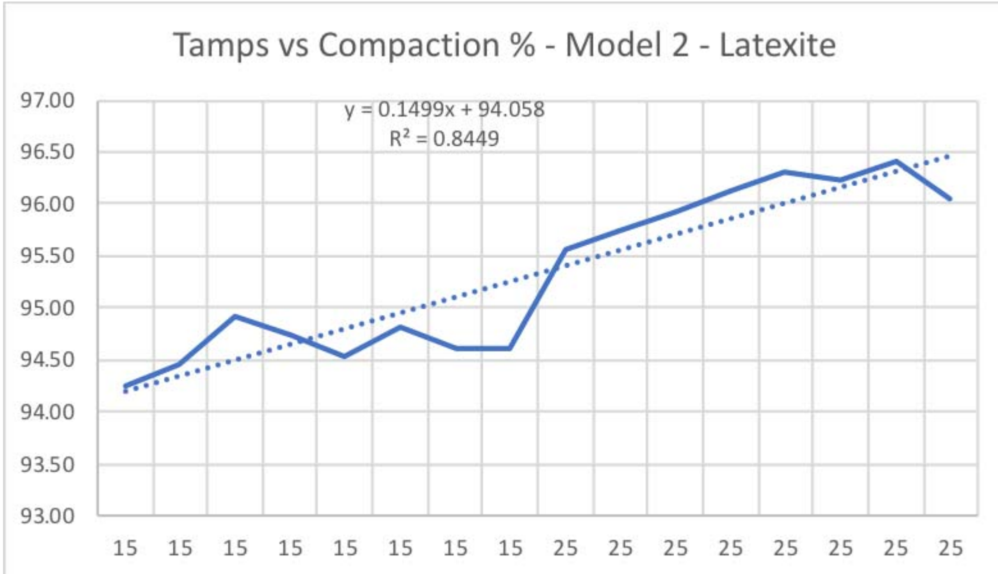


Figure 4.5.2.6 Tamps vs Compaction % Best Fit Line - Model No. 2 - Latexite

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Latexite® Super Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 94.62% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 96.05%.

4.6 Asphalt Core Restoration Model No. 3

This section will cover the details of coring asphalt pavements using all three (3) commercially used restoration material. The table below Table 4.6.2.1 covers the data collected for Model No. 3 Core Test Data.

4.6.1 Procedures of Asphalt Core Restoration Model No. 3

The procedures of asphalt core restoration in Model No. 3 is proposed to use the innovation of a Cap device to enhance the restoration practice of asphalt core holes, in 2 lifts (for core deeper than 4”). The detailed procedures are detailed in Chapter 3. The procedures dictate the following;

1- Drilling Asphalt Core Holes

Figure 4.6.1.1 Diamond Core Drilling Machine

2- Remove Core & Clean Core Hole

Figure 4.6.1.2 Remove Core & Clean Core Hole

3- Restore and Fill Core Hole

Figure 4.6.1.3 Restoring and Filling Core Hole

4- Tamp and Compact Restoration Material Inside Core Holes

Figure 4.6.1.4 Tamp and Compact Restoration Material Inside Core Holes – Model No. 3

5- Final Surface Cleaning

Figure 4.6.1.5 Finished Restored Core Hole – Model No. 3

4.6.2 Data Analysis of Asphalt Core Restoration Model No. 3

The data below in table 4.6.2.1 represents the data collected in the field to study the behavior and correlation of the number of tamps used to compact the asphaltic material fill material in core holes and the corresponding compaction % results and reading taken by the nuclear gauge machine- for Model No. 3.

Date	Core #	Model #	Reading #	# of Tamps	Comp %	Material	Temp	Location (Main)	Int. Street
6/6/17	Test1	3	1	25-30	96.93	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	2	25-30	97.12	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	3	25-30	96.74	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	4	25-30	94.67	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	5	25-30	96.12	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	6	25-30	94.60	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	7	25-30	94.51	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test1	3	Avg	25-30	**96.24**	Latexite	66/ Cloudy	Clay Ave (WB)	E168 Street
7/20/17	3	3	1	15-20	92.96	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	2	15-20	93.15	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	3	15-20	92.77	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	4	15-20	91.75	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	5	15-20	93.24	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	6	15-20	92.25	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	7	15-20	93.29	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	3	3	Avg	15-20	**92.77**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
8/1/17	7	3	1	15-20	93.25	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	2	15-20	93.44	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	7	3	3	15-20	93.06	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	4	15-20	93.64	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	5	15-20	93.53	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	6	15-20	94.01	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	7	15-20	93.59	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	7	3	Avg	15-20	**93.50**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	1	15-20	93.15	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	2	15-20	92.50	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	3	15-20	92.96	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	4	15-20	91.94	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	5	15-20	93.43	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	6	15-20	91.82	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	7	15-20	93.49	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	11	3	Avg	15-20	**92.76**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	1	25-30	93.55	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	2	25-30	93.74	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	3	25-30	93.36	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	4	25-30	93.64	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	5	25-30	93.83	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	6	25-30	94.01	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	7	25-30	93.89	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	15	3	Avg	25-30	**93.72**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	1	25-30	94.79	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	2	25-30	94.98	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	3	25-30	94.60	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	4	25-30	94.31	QPR	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	21	3	5	25-30	94.07	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	6	25-30	94.47	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	7	25-30	94.13	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	21	3	Avg	25-30	**94.91**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	1	15-20	94.91	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	2	15-20	94.10	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	3	15-20	94.29	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	4	15-20	94.48	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	5	15-20	94.67	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	6	15-20	94.86	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	7	15-20	96.05	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	25	3	Avg	15-20	**94.48**	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

Table 4.6.2.1 Model No. 3 Core Test Data

The following regression analysis and graphs for data collected and tested for Model No. 3 using the Sakrete® All Weather Blacktop Patch Material.

Regression Statistics	
Multiple R	0.70469884
R Square	0.49660046
Adjusted R Square	0.47982047
Standard Error	0.43934365
Observations	32

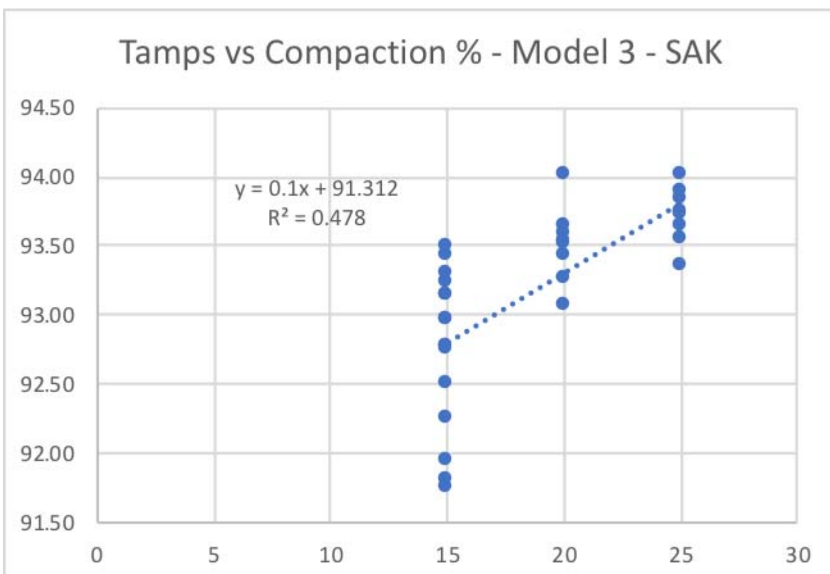


Figure 4.6.2.1 Tamps vs Compaction % - Model No. 3 – Sakrete

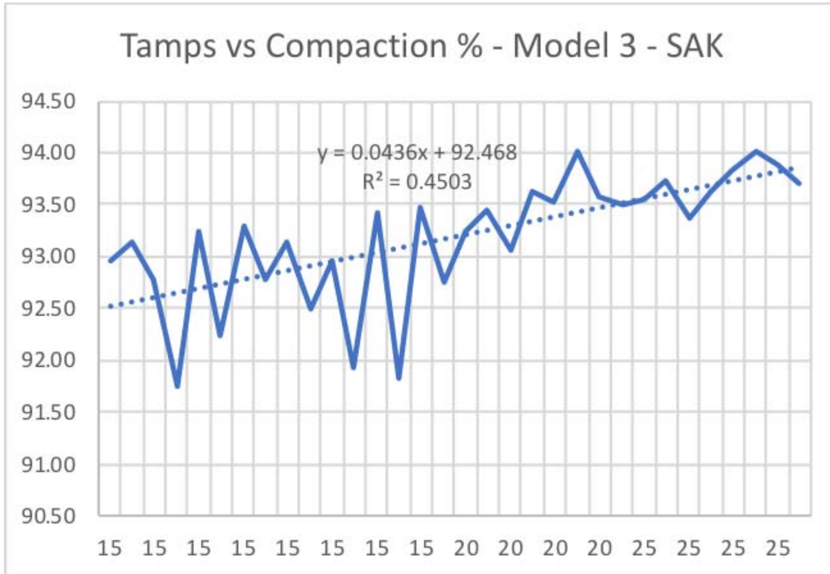


Figure 4.6.2.2 Tamps vs Compaction % Best Fit Line - Model No. 3 - Sakrete

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Sakrete® All Weather Blacktop Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 93.50% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 93.72%.

The following regression analysis and graphs for data collected and tested for Model No. 3 using the QPR No VOC Repair Material.

Regression Statistics	
Multiple R	0.11017151
R Square	0.01213776
Adjusted R Square	-0.1525059
Standard Error	0.37729817
Observations	8

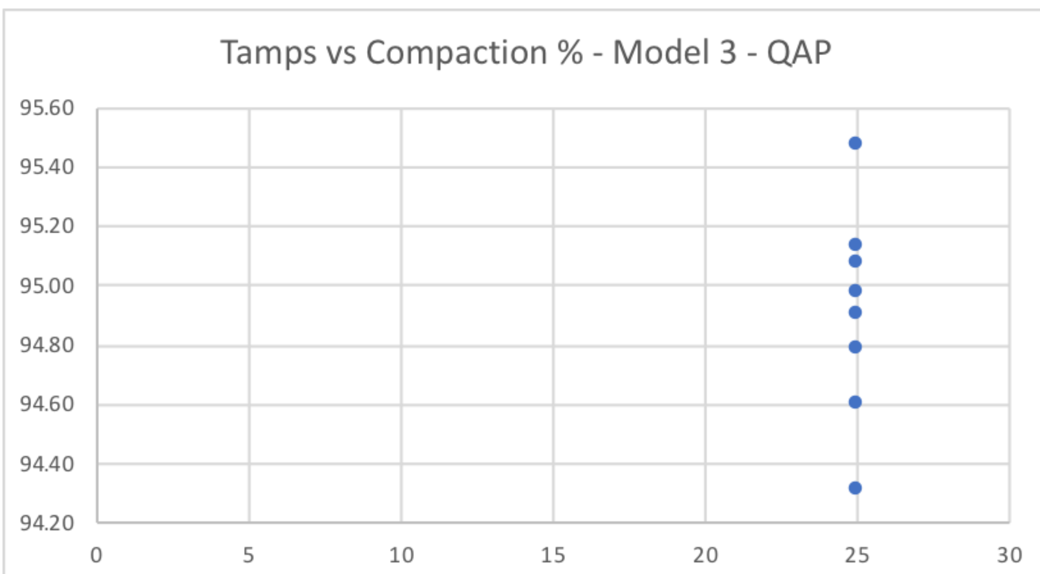


Figure 4.6.2.3 Tamps vs Compaction % - Model No. 3 - QPR

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the QPR No VOC Repair Material. The maximum compaction % reading obtained when tamping 25-30 tamps was in average 94.91%.

The following regression analysis and graphs for data collected and tested for Model No. 3 using the Latexite® Super Patch Material.

Regression Statistics	
Multiple R	0.61471285
R Square	0.37787189
Adjusted R Square	0.33343417
Standard Error	0.52128818
Observations	16

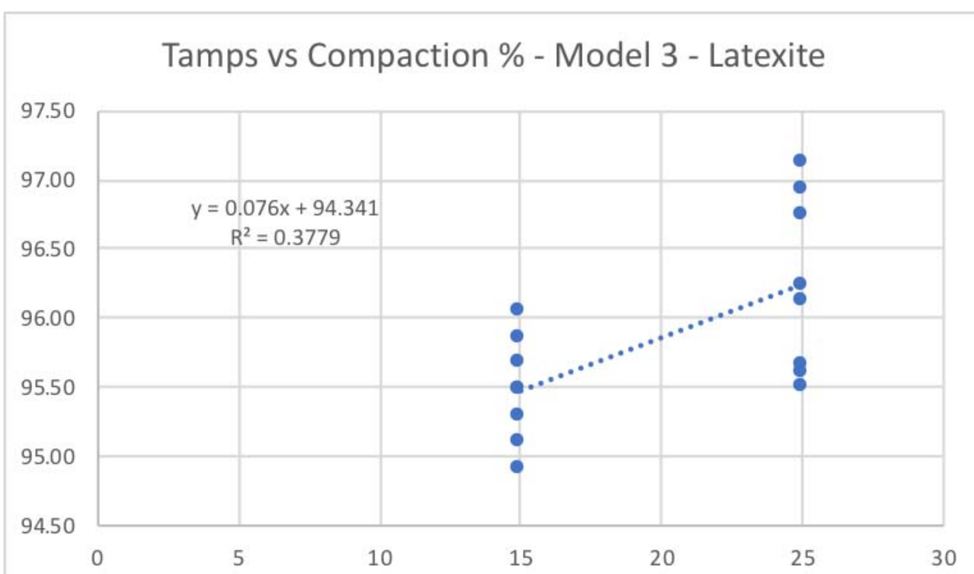


Figure 4.6.2.4 Tamps vs Compaction % - Model No. 3 - Latexite

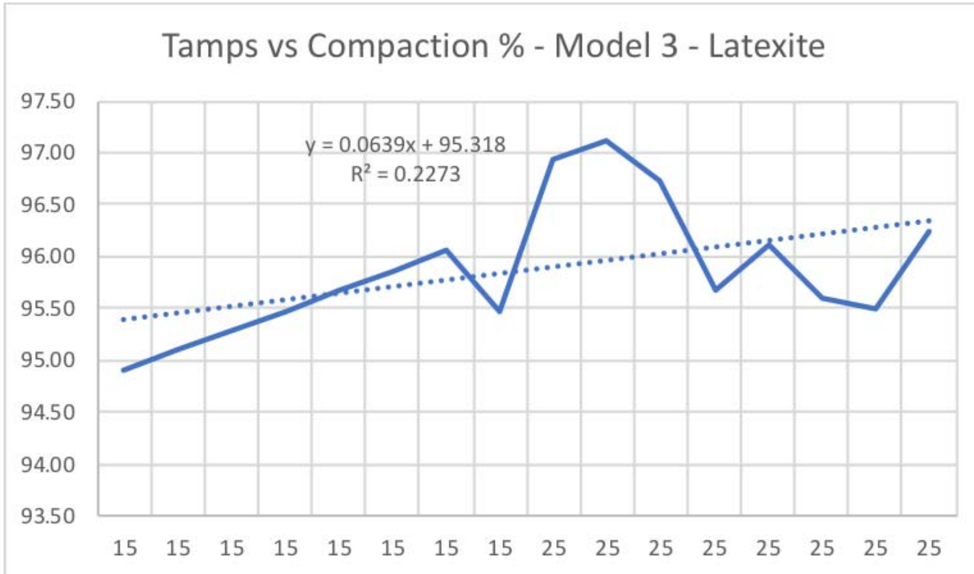


Figure 4.6.2.5 Tamps vs Compaction % Best Fit Line - Model No. 3 - Latexite

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Latexite® Super Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 94.48% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 96.24%.

4.7 Asphalt Core Restoration Model No. 4

This section will cover the details of coring asphalt pavements using all three (3) commercially used restoration material. The table below Table 4.7.2.1 covers the data collected for Model No. 4 Core Test Data.

4.7.1 Procedures of Asphalt Core Restoration Model No. 4

The procedures of asphalt core restoration in Model No. 4 is proposed to use the innovation of a Cap device to enhance the restoration practice of asphalt core holes. The detailed procedures are detailed in Chapter 3. The procedures dictate the following (similar to the procedures of asphalt core restoration of Model No. 2 except for applying the speed-fill material);

- Applying Speed-Fill Asphaltic Material

Figure 4.7.1.1 Applying Speed-Fill Asphaltic Material – Model No. 4

- Finished Restored Core Hole – Model No. 4

Figure 4.7.1.2 Finished Restored Core Hole – Model No. 4

4.7.2 Data Analysis of Asphalt Core Restoration Model No. 4

The data below in table 4.7.2.1 represents the data collected in the field to study the behavior and correlation of the number of tamps used to compact the asphaltic material fill material in core holes and the corresponding compaction % results and reading taken by the nuclear gauge machine- for Model No. 4.

Date	**Core #**	**Model #**	**Reading #**	**# of Tamps**	**Comp %**	**Material**	**Temp**	**Location (Main)**	**Int. Street**
6/6/17	Test3	4	1	15-20	89.15	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	2	15-20	89.33	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	3	15-20	89.77	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	4	15-20	89.12	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	5	15-20	89.42	Sakrete	66/	Clay Ave	E168

							Cloudy	(WB)	Street
6/6/17	Test3	4	6	15-20	89.95	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	7	15-20	89.47	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	8	15-20	89.65	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test3	4	Avg	15-20	**89.48**	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	1	15-20	93.32	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	2	15-20	93.51	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	3	15-20	93.97	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	4	15-20	93.11	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	5	15-20	93.60	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	6	15-20	94.16	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	7	15-20	93.66	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test5	4	Avg	15-20	**93.62**	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	1	15-20	91.83	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	2	15-20	92.01	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	3	15-20	92.47	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	4	15-20	90.64	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	5	15-20	92.11	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	6	15-20	92.66	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	7	15-20	92.16	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
6/6/17	Test6	4	Avg	15-20	**91.98**	Sakrete	66/ Cloudy	Clay Ave (WB)	E168 Street
7/20/17	4	4	1	15-20	92.99	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	2	15-20	93.18	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	3	15-20	93.64	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	4	15-20	93.11	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	5	15-20	93.27	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street

7/20/17	4	4	6	15-20	93.83	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	7	15-20	93.32	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
7/20/17	4	4	Avg	15-20	**93.33**	Sakrete	83/ Sunny	Webster Ave (EB)	E168 Street
8/1/17	8	4	1	25-30	94.22	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	2	25-30	94.41	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	3	25-30	94.03	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	4	25-30	93.00	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	5	25-30	94.50	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	6	25-30	91.96	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	7	25-30	94.56	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	8	4	Avg	25-30	**93.81**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	1	25-30	93.91	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	2	25-30	94.10	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	3	25-30	93.72	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	4	25-30	92.69	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	5	25-30	94.19	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	6	25-30	91.66	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	7	25-30	94.25	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	12	4	Avg	25-30	**93.50**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	1	25-30	94.74	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	2	25-30	94.93	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	3	25-30	94.55	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	4	25-30	93.51	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	5	25-30	94.02	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	6	25-30	92.47	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	16	4	7	25-30	94.08	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street

8/1/17	16	4	Avg	25-30	**94.33**	Sakrete	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	1	25-30	94.21	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	2	25-30	93.67	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	3	25-30	93.86	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	4	25-30	94.05	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	5	25-30	94.23	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	6	25-30	94.42	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	7	25-30	94.61	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/1/17	22	4	Avg	25-30	**94.15**	QPR	88/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	1	25-30	94.90	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	2	25-30	94.09	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	3	25-30	94.28	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	4	25-30	94.47	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	5	25-30	94.66	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	6	25-30	94.85	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	7	25-30	94.55	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street
8/2/17	26	4	Avg	25-30	**94.40**	Latexite	84/ Sunny	Webster Ave (WB)	E168 Street

Table 4.7.2.1 Model No. 4 Core Test Data

The following regression analysis and graphs for data collected and tested for Model No. 4 using the Sakrete® All Weather Blacktop Patch Material.

Regression Statistics	
Multiple R	0.68341745
R Square	0.46705941
Adjusted R Square	0.45736958
Standard Error	1.26240627
Observations	57

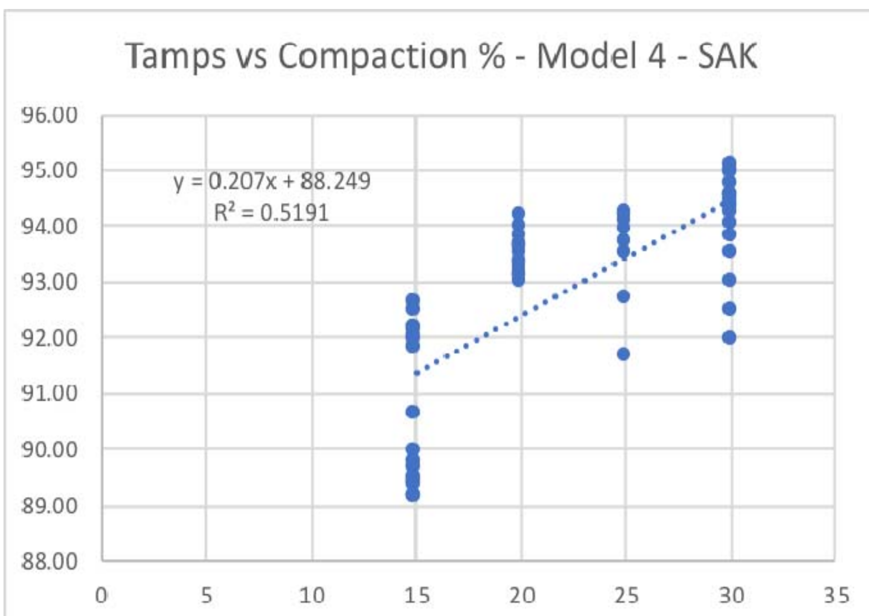


Figure 4.7.2.1 Tamps vs Compaction % - Model No. 4 - Sakrete

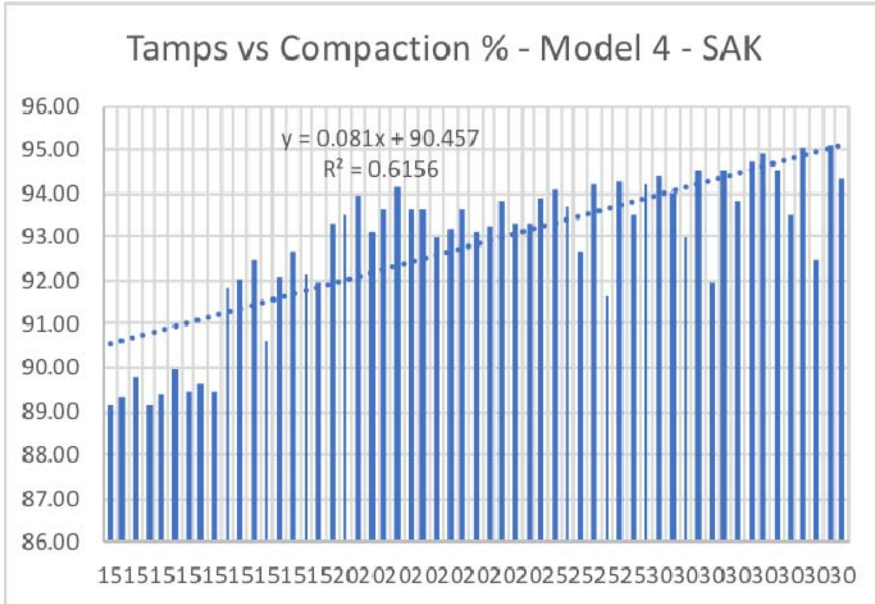


Figure 4.7.2.2 Tamps vs Compaction % Best Fit Line - Model No. 4 - Sakrete

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Sakrete® All Weather Blacktop Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 93.62% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 93.81%.

The following regression analysis and graphs for data collected and tested for Model No. 4 using the QPR No VOC Repair Material.

Regression Statistics	
Multiple R	0.62748213
R Square	0.39373382
Adjusted R Square	0.29268946
Standard Error	0.25097342
Observations	8

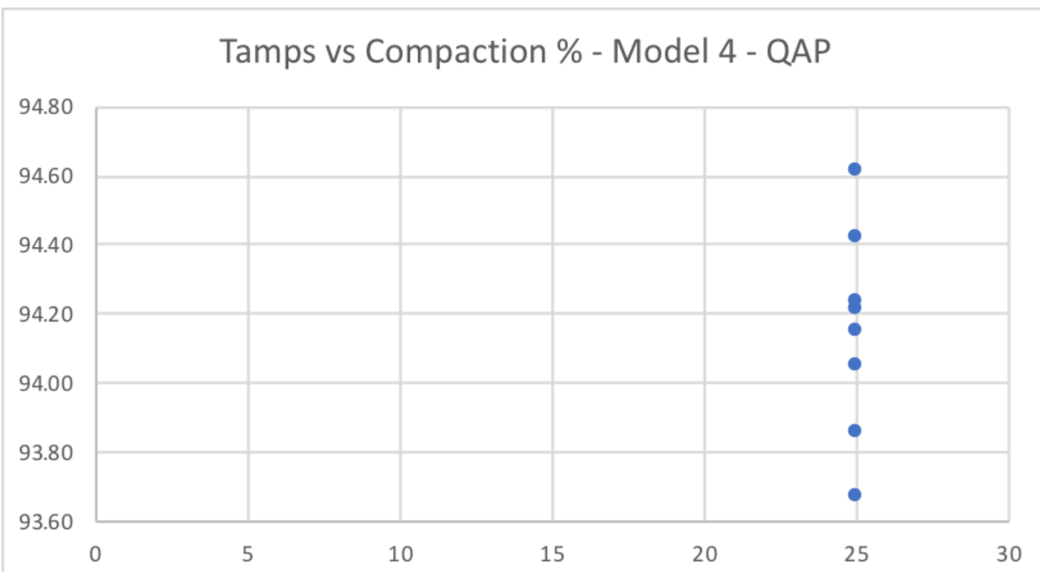


Figure 4.7.2.3 Tamps vs Compaction % - Model No. 4 - QPR

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the QPR No VOC Repair Material. The maximum compaction % reading obtained when tamping 25-30 tamps was in average 94.15%.

The following regression analysis and graphs for data collected and tested for Model No. 4 using the Latexite® Super Patch Material.

Regression Statistics	
Multiple R	0.22141568
R Square	0.0490249
Adjusted R Square	-0.1094709
Standard Error	0.323799
Observations	8

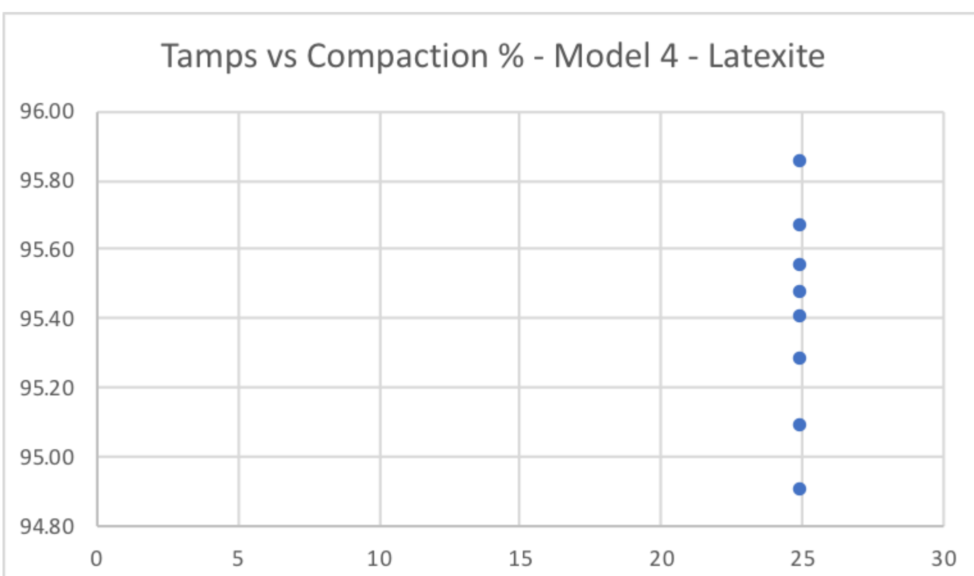


Figure 4.7.2.4 Tamps vs Compaction % - Model No. 4 - Latexite

The data shown in the table and graphs show proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Latexite® Super Patch Material. The maximum compaction % reading obtained when tamping 25-30 tamps was in average 94.40%.

4.8 Summary of Field Testing and Statistical Modeling of the Performance of Cap Device

The summary of the statistical analysis of all field data gathered and results of compaction ratios reveals that the optimum compaction results are obtained by using the Cap device for approximately 25 tamps, using the Latexite Patch Material as shown in Model 3. The data shown in the Figure 4.7.1 shows proportional relationship between the number of compactive tamps applied on the restoration material inside the core hole and the corresponding compaction % reading taken by the nuclear gauge machine, using the Latexite® Super Patch Material. The maximum compaction % reading obtained when tamping 15-20 tamps was in average 94.48% and the maximum compaction % reading obtained when tamping 25-30 tamps was in average 96.24%. The equation for optimum compaction results based on the field data analysis is:

$$\mathbf{y = 0.0639\,x + 94.318}$$

Where x = number of tamps & y = compaction %

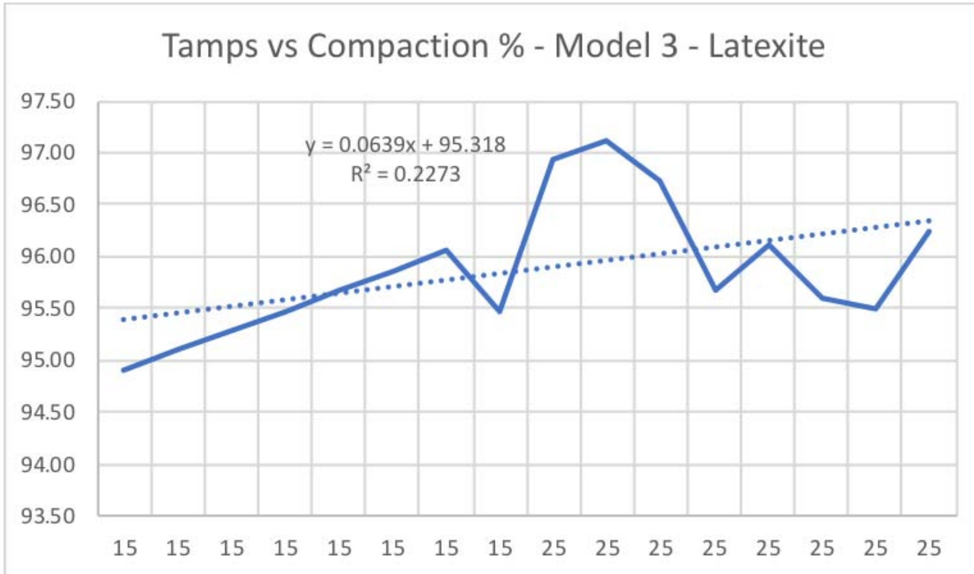


Figure 4.8.1 [Optimum Model] Tamps vs Compaction % Best Fit Line - Model No. 3 - Latexite

CHAPTER 5 –FINITE ELEMENT MODELING OF THE CAP DEVICE PERFORMANCE

The chapter will present a finite element model of comparing the compaction the asphalt restoration material using the traditional hammering techniques versus hammering the Cap device directly over the asphalt restoration material to enhance the compaction of the restoration material in asphalt core holes.

5.1 Introduction to Finite Element Modeling

This section will discuss the development and the application of a computational modeling approach to predict the performance of the compaction of asphalt mixes used in the restoration of asphalt core holes. In the model, the finite element model is intended to simulate the Compactability of hammering the asphalt restoration material inside the core holes using different techniques. The model was applied to the Latexite Asphalt Patch Material and the resulting model simulations are compared to experimental results for model and data validation. The model will potentially optimize the hammering technique to compact the asphalt restoration material inside core holes. The finite element method is a technique used to solve engineering and physics widely used in modeling the behavior of construction materials. A finite element model is conducted on the behavior of the restoration asphalt material in asphalt core holes. The finite element model revealed the strain levels, which are color coded according to the deformation magnitude. The 3D figures and the results of the finite element model for hammering the asphalt restoration material in core holes using a hammer directly on the restoration material are compared to using the hammer on top of the Cap device to distribute the stress and the strain on the asphalt restoration surface and reduce the deformation in the surface of the asphalt restoration material.

5.2 Finite Element Modeling of Compacting the Cap Device

The composite material of hot mix asphalt (HMA) consists of mineral aggregates, asphalt binders and air voids structured in flexible pavement layers. Asphalt is a complex heterogeneous material composed of aggregate, binder/ cement, additives, and void space. The load carrying behavior and resulting failure of such materials depends on many phenomena that occur at the aggregate/binder level as Masad et al. mentioned (2002). A finite elements model of the asphalt patch material used for restoration is developed to study the influence of localized strain distribution on the HMA mechanical response. This finite element model using ANSYS 18.2 is developed to study and test the performance of the hammering impact in compacting the asphalt restoration material inside the core holes. The model simulated and analyzed the behavior of the asphalt surface resulting from hammering and tamping for compaction. The deformation analysis report obtained after running the model shows favorable results to using the cap device in compacting the asphalt restoration material inside the core hole. A few assumptions have been made for the asphalt patch material used, Cap device, core hole, hammering used for stroking and compaction, indicated in this section. The following table 5.2.1 has the standard geometry data for the Cap device and asphalt core hole. The full details, geometry mesh details and core boundary conditions of the finite element model for each technique are included for all models in Appendix B of this study. The Cap device is made of steel metal A500-13 Grade B&C and weighs approximately 0.6 kilograms.

Object Name	*Cap*	*Core*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Unit System	Metric	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Bounding Box		
Length X	82,55 mm	101,6 mm
Length Y	82,55 mm	101,6 mm
Length Z	38,1 mm	101,6 mm
Properties		
Volume	74783 mm³	8,237e+005 mm³
Mass	0,58705 kg	2,2322 kg

Table 5.2.1 Geometry of the Cap Device and Core Hole

The Asphalt restoration material that yielded best compaction results and asphalt behavior is Latexite® Super Patch. The Latexite Super Patch was used in the finite element modeling of using the Cap device in restoring asphalt core holes and enhancing the compaction of the restoration inside core holes and the physical looks. The following data were noted in the product data sheet and used in ANSYS R18.2 for the Latexite® Super Patch;

Temperature: 20 Celsius

Young's Modulus: 2,e4 MPa

Poisson's Ratio: 0.35

Specific Gravity (SG): 1.400

Theoretical Maximum Specific Gravity: 1.489

RICE#: 92.93

Wet Density (wD): 2.195 grams/cm^3

The following data were assumed and programmed into ANSYS R18.2 for the Latexite® Super Patch for the finite elements modeling of compacting the asphalt core holes;

Stroke Travel Time: 1.31 Seconds

Distance of Stroke (Hammer height off the asphalt): 800mm

Acceleration of Hammer: 0.75 mm/s^2

Hammer Weight: 1100 grams

Hammer Stroke Contact Area: 506.45mm^2

Resultant Hammering Force: 825 Newtons (kg·m/s^2)

5.3 Finite Element Model Simulations

The following Figure 5.3.1 shows a section of cored asphalt structure with the Cap device inserted in the core hole, being hammered using a commercial hammer. The existing pavement structure is assumed to be hot mix asphalt (HMA) and the following sections will demonstration the outcomes of the finite element modeling of hammering the restoration material in the core hole using the hammer directly on the asphalt restoration material for 10 and 25 Tamps respectively and compared to hammering the restoration material in the core hole using the hammer on the Cap device that is placed on top of the asphalt restoration material for 10 and 25 Tamps respectively. The Cap is used to distribute the forces applied to compact the asphalt restoration material and produce an even finished and restored asphalt surface. Using the Cap device improves the finish of the finish and restored core hole and improve the aesthetic appearance of the pavement structure.

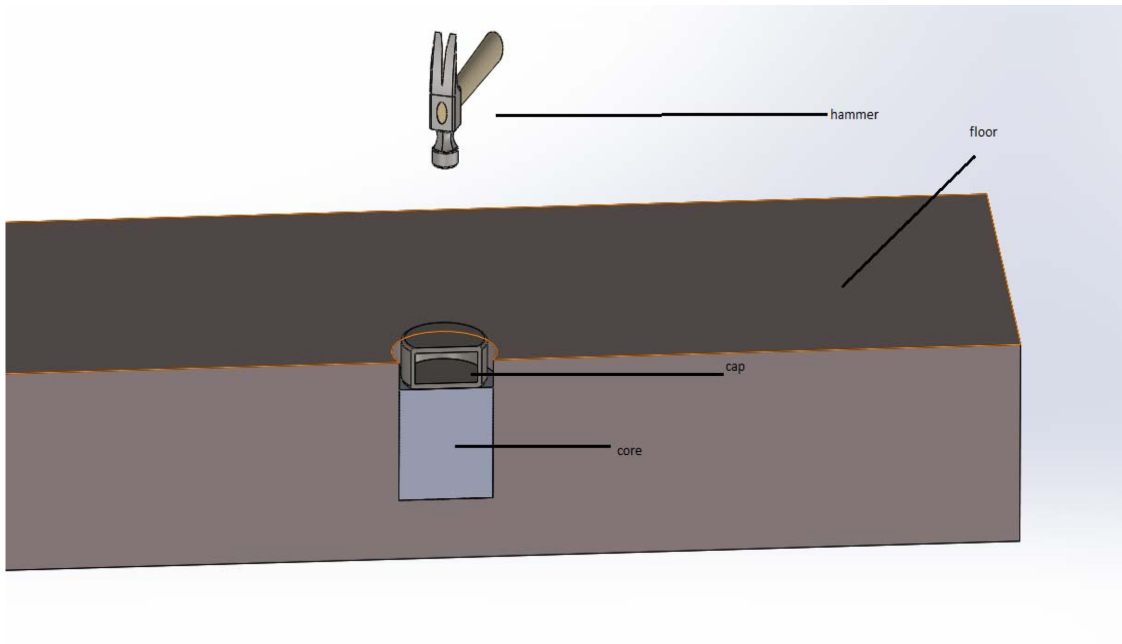


Figure 5.3.1 3D Section of Core Hole in Pavement Body with Inserted Cap Device

5.3.1 Simulation No. 1 (Hammering on the Cap, 10 Tamps)

The following Simulation No. 1 consists of modeling the deformation of the asphalt restoration material resulting from the forces applied on the Cap device and transferred from the Cap devise to the asphalt restoration material body inside the core hole. In Simulation No. 1, 10 Tamps were applied on top of the Cap device that is placed on top of the restored core hole with asphalt patch material (Latexite). 10 Tamps were applied evenly at 10 randomly and uniformly distributed locations along the top surface of the Cap device. The stresses resulting from stroking the Cap device appear to transfer to the asphalt restoration material in the core hole with somehow equal distribution cause less deformation spots within the top surface of the asphalt restoration material. Figure 5.3.1.1 shows the initial hammering of the Cap device on top of the asphalt restoration material inside the core hole and the transfer of the stresses applied throughout the Cap device.

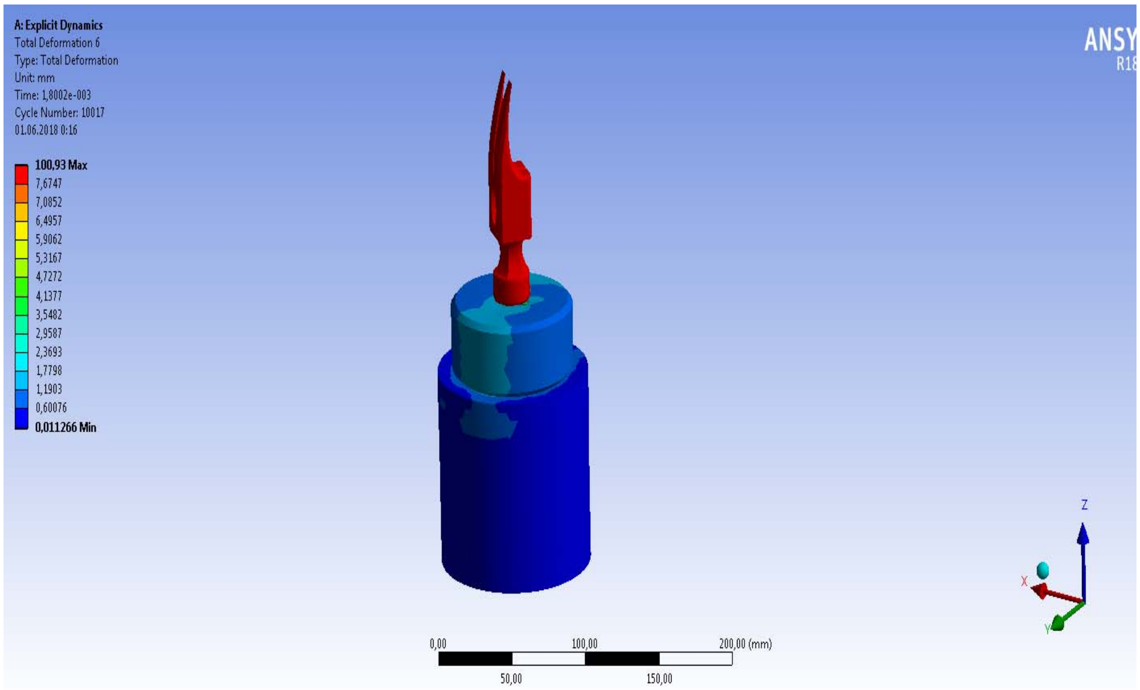


Figure 5.3.1.1 Initial Hammering on Cap Device @10 Tamps

Figure 5.3.1.2 shows the colored top of asphalt restoration material confirming the whole top surface of the asphalt restoration material receiving medium to maximum deformation impact resulting from hammering on the Cap device.

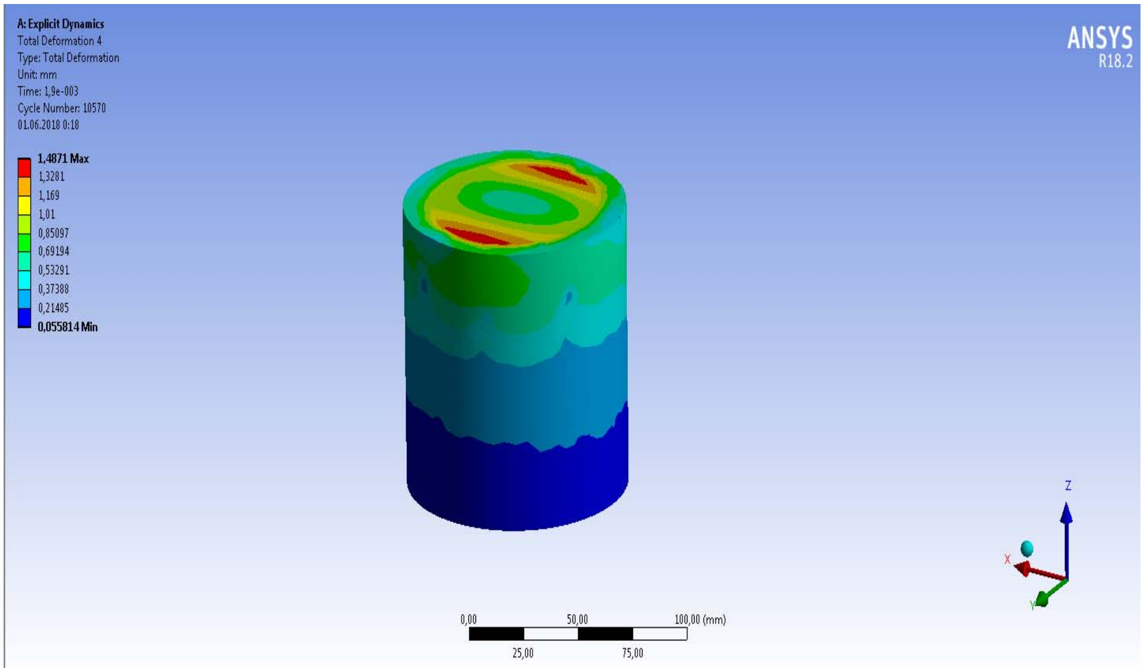


Figure 5.3.1.2 Total Deformation @10 Tamps– Hammering on Cap Device

Figure 5.3.1.3 is a graph showing the correlation core deformation (mm) on the y-axis due to tamping and the time (s) on the x-axis took the asphalt restoration material inside the core hole to deform. It is clear in the graph that the maximum deformation of the nucleus at 10 tamps against the cap is approximately 2.1 mm. The resultant deformation is distributed all over the surface area of the asphalt in the core hole as the forces are applied on the Cap device and evenly transferred to the whole surface of the asphalt restoration material.

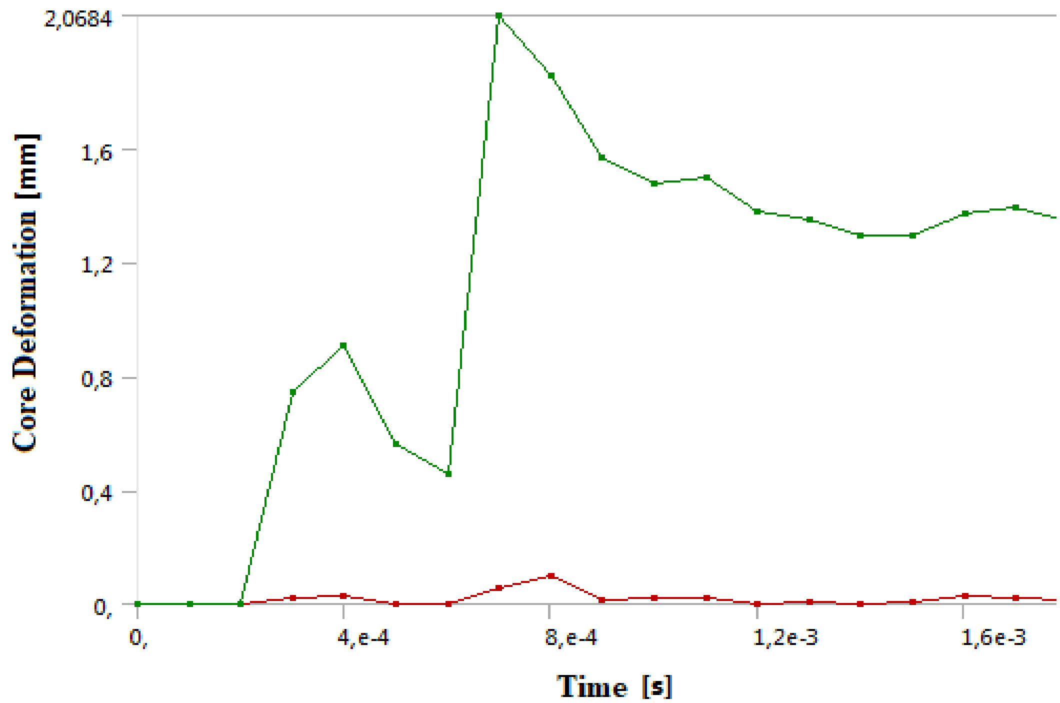


Figure 5.3.1.3 Graph of Core Deformation (mm) vs Time (s) @10 Tamps

5.3.2 Simulation No. 2 (Hammering on the Cap, 25 Tamps)

The following Simulation No. 2 consists of modeling the deformation of the asphalt restoration material resulting from the forces applied on the Cap device and transferred from the Cap devise to the asphalt restoration material body inside the core hole. In Simulation No. 2, 25 Tamps were applied on top of the Cap device that is placed on top of the restored core hole with asphalt patch material (Latexite). 25 Tamps were applied evenly at 25 randomly and uniformly distributed locations along the top surface of the Cap device. The stresses resulting from stroking the Cap device appear to transfer to the asphalt restoration material in the core hole with somehow equal distribution cause less deformation spots within the top surface of the asphalt restoration material. Figure 5.3.2.1 shows the initial hammering of the Cap device on top of the asphalt restoration material inside the core hole and the transfer of the stresses applied throughout the Cap device.

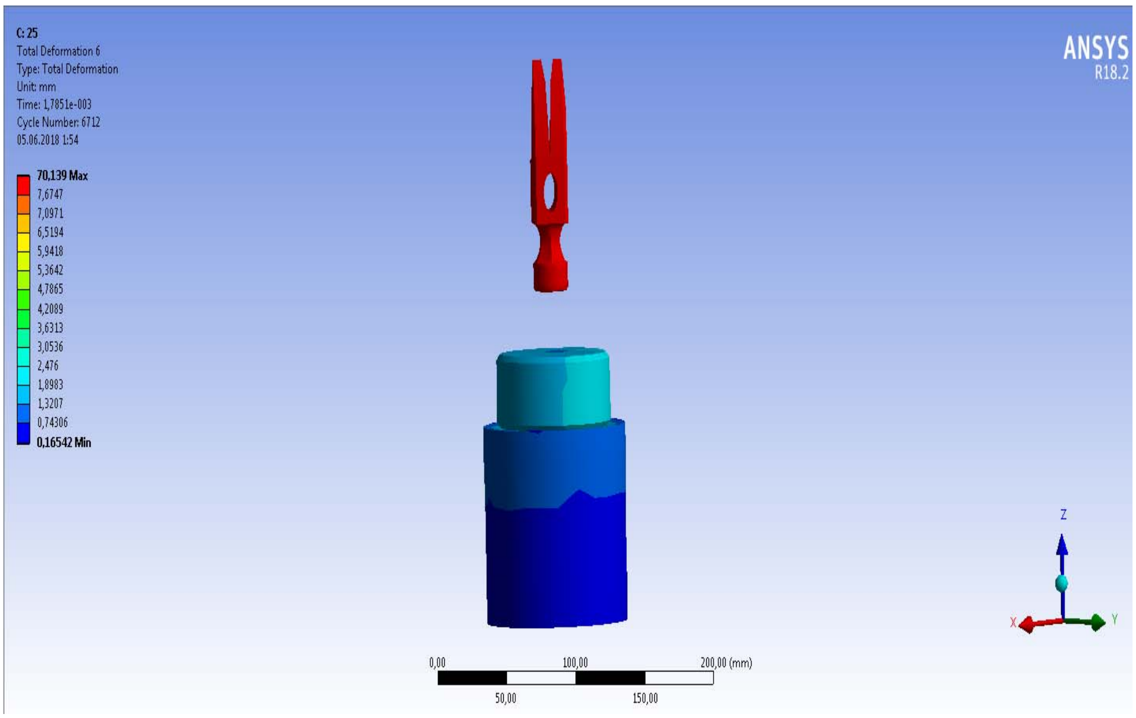


Figure 5.3.2.1 Initial Hammering on Cap Device @25 Tamps

Figure 5.3.2.2 shows the colored top of asphalt restoration material confirming the whole top surface of the asphalt restoration material receiving medium to maximum deformation impact resulting from hammering on the Cap device.

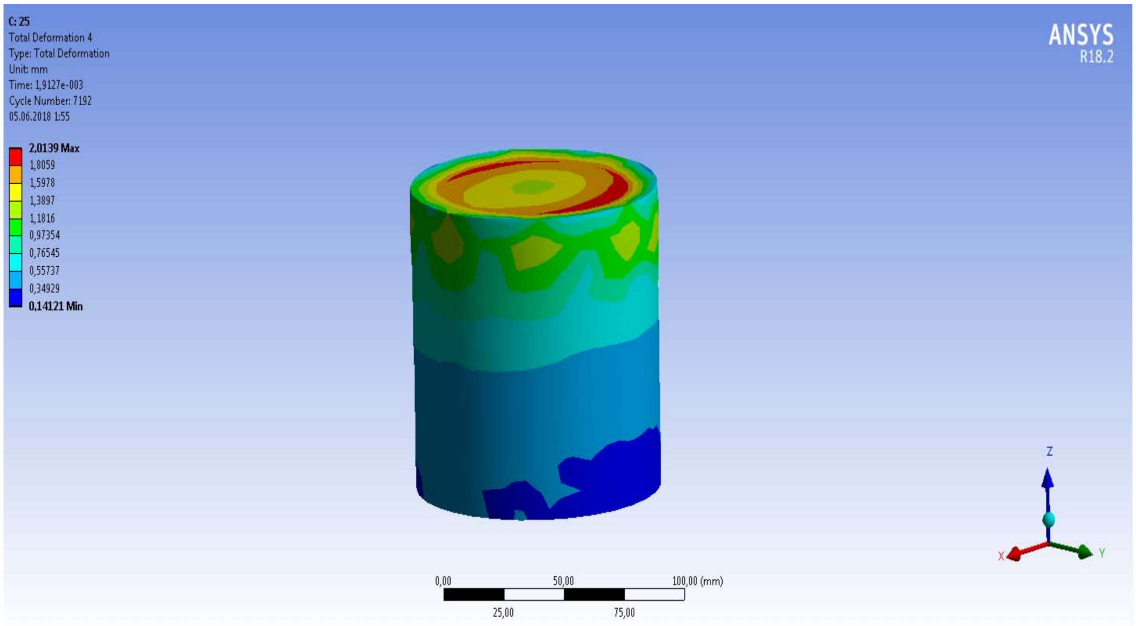


Figure 5.3.2.2 Total Deformation @25 Tamps– Hammering on Cap Device

Figure 5.3.2.3 is a graph showing the correlation core deformation (mm) on the y-axis due to tamping and the time (s) on the x-axis took the asphalt restoration material inside the core hole to deform. It is clear in the graph that the maximum deformation of the nucleus at 25 tamps against the cap is approximately 2.5 mm. The resultant deformation is distributed all over the surface area of the asphalt in the core hole as the forces are applied on the Cap device and evenly transferred to the whole surface of the asphalt restoration material.

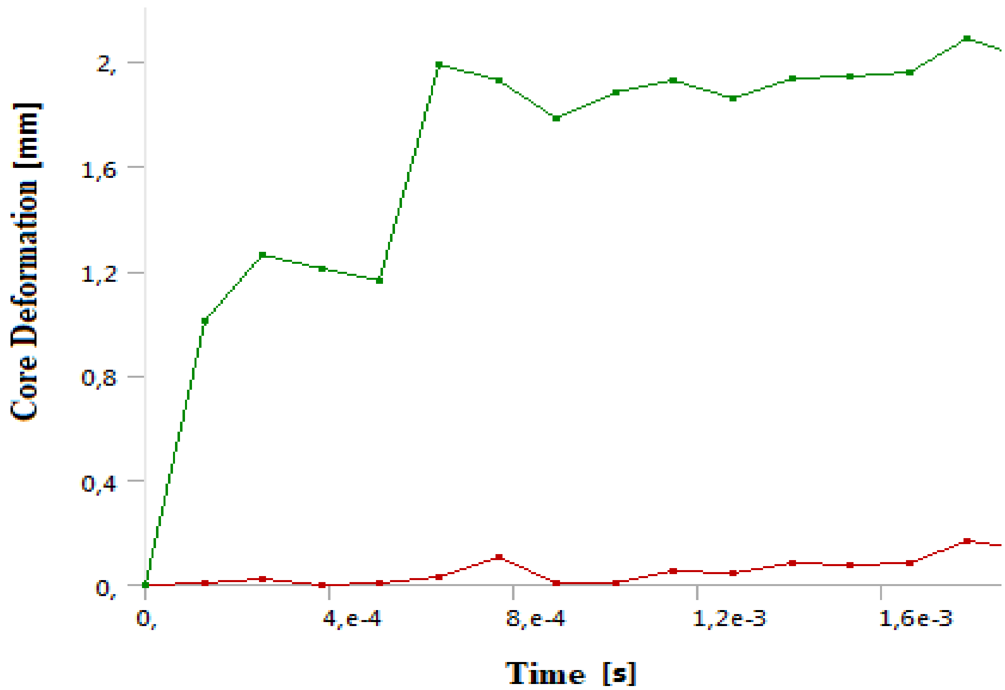


Figure 5.3.2.3 Graph of Core Deformation (mm) vs Time (s) @25 Tamps

5.3.3 Simulation No. 3 (Hammering without the Cap, 10 Tamps)

The following Simulation No. 3 consists of modeling the deformation of the asphalt restoration material resulting from the forces applied on the asphalt restoration material body inside the core hole. In Simulation No. 3, 10 Tamps were applied directly on top of the asphalt patch material (Latexite). 10 Tamps were applied evenly at 10 randomly and uniformly distributed locations along the top surface of the asphalt patch material inside the core hole. The stresses resulting from stroking the Cap device appear to concentrate where the hammer (or tamping tool) contact the asphalt restoration material in the core hole with concentrated compaction at the stroke location on the asphalt restoration material. Figure 5.3.3.1 shows the initial hammering on top of the asphalt restoration material inside the core hole.

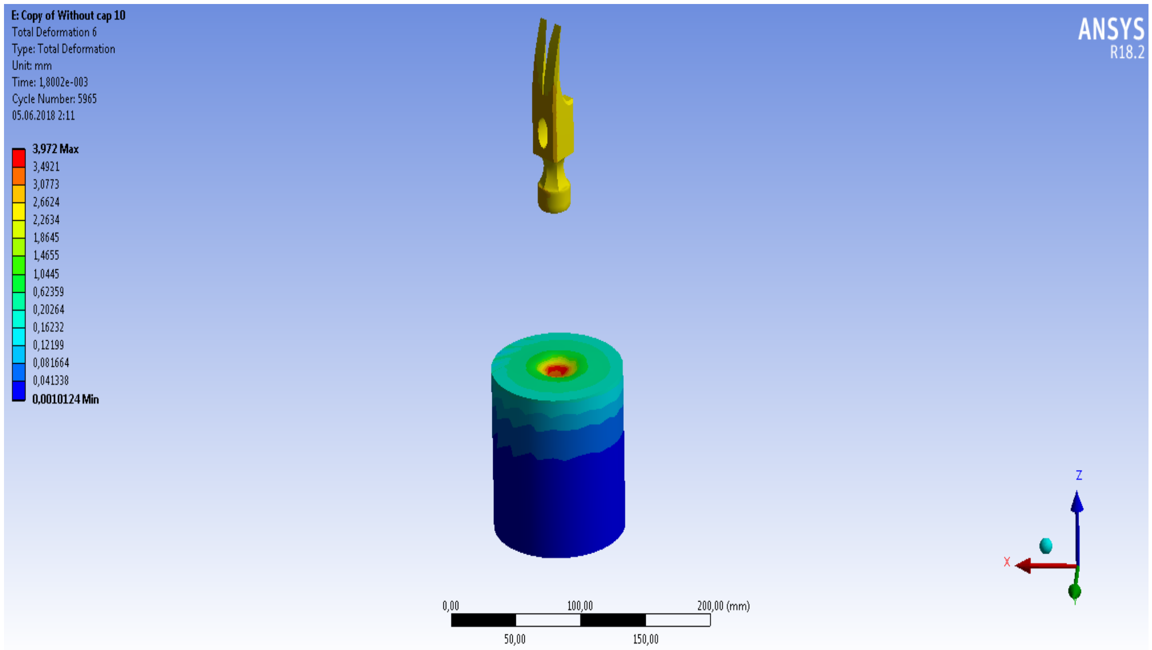


Figure 5.3.3.1 Initial Hammering Directly on Restoration Material @10 Tamps

Figure 5.3.3.2 shows the colored top of asphalt restoration material confirming the whole top surface of the asphalt restoration material receiving low to medium deformation impact resulting from hammering directly on the asphalt restoration material. The colors corresponding to the forces applied in the figure also shows the uneven stress distribution along the top surface of the hammered asphalt restoration material. The un-hammered areas on top of the asphalt restoration material have more air voids and lower compaction ratios as less stresses were applied on those locations and hence, it reduces the overall compaction ratio of the asphalt restoration material.

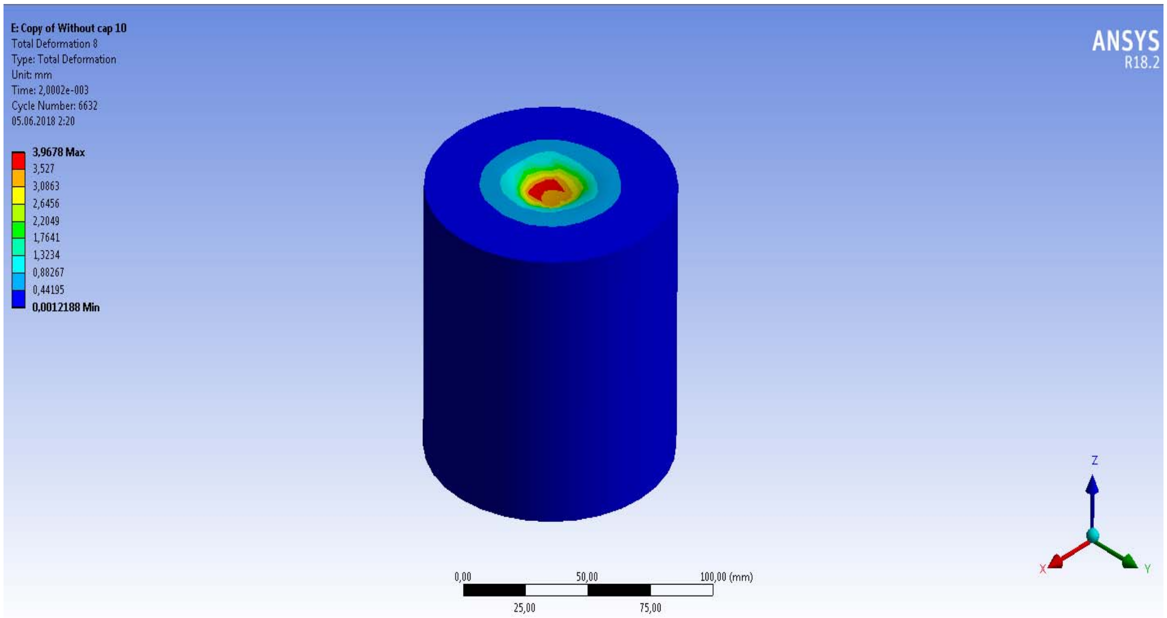


Figure 5.3.3.2 Total Deformation @10 Tamps– Hammering Directly on Restoration Material

Figure 5.3.3.3 is a graph showing the correlation core deformation (mm) on the y-axis due to tamping and the time (s) on the x-axis took the asphalt restoration material inside the core hole to deform. It is clear in the graph that the maximum deformation of the nucleus at 10 tamps directly on top of the asphalt restoration material is approximately 4 mm. The resultant deformation is unevenly distributed all over the surface area of the asphalt in the core hole as the forces are applied on the surface of the asphalt restoration material, creating air voids in the adjacent surrounding spots in the top surface of the asphalt restoration material body inside the core hole.

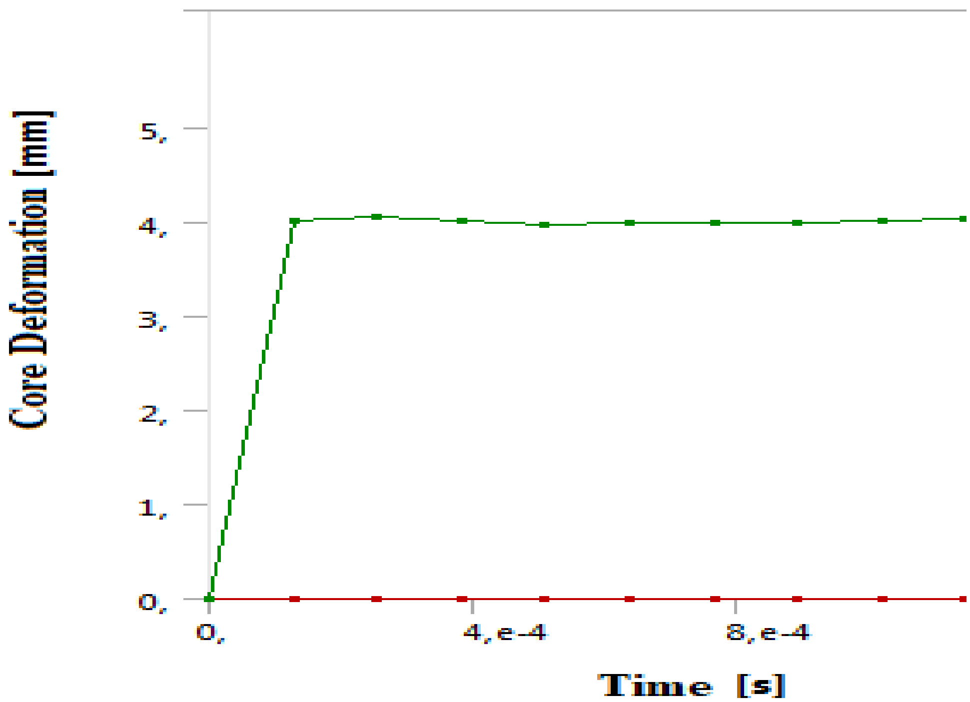


Figure 5.3.3.3 Graph of Core Deformation (mm) vs Time (s) @10 Tamps

5.3.4 Simulation No. 4 (Hammering without the Cap, 25 Tamps)

The following Simulation No. 4 consists of modeling the deformation of the asphalt restoration material resulting from the forces applied on the asphalt restoration material body inside the core hole. In Simulation No. 4, 25 Tamps were applied directly on top of the asphalt patch material (Latexite). 25 Tamps were applied evenly at 25 randomly and uniformly distributed locations along the top surface of the asphalt patch material inside the core hole. The stresses resulting from stroking the Cap device appear to concentrate where the hammer (or tamping tool) contact the asphalt restoration material in the core hole with concentrated compaction at the stroke location on the asphalt restoration material. Figure 5.3.5.1 shows the initial hammering on top of the asphalt restoration material inside the core hole.

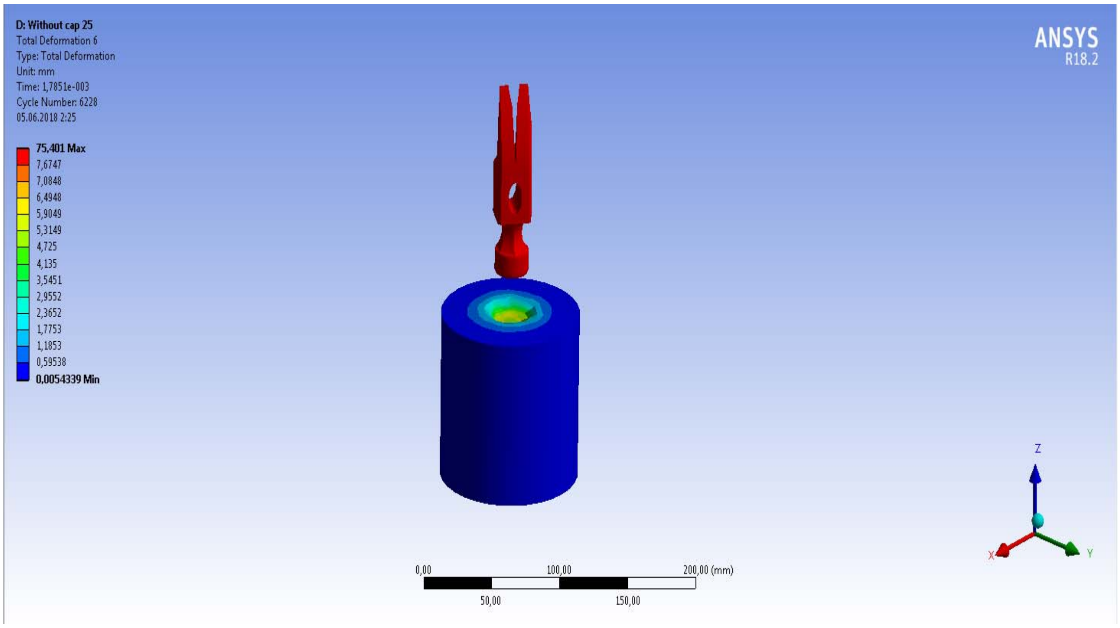


Figure 5.3.5.1 Initial Hammering Directly on Restoration Material @25 Tamps

Figure 5.3.5.2 shows the colored top of asphalt restoration material confirming the whole top surface of the asphalt restoration material receiving low to medium deformation impact resulting from hammering directly on the asphalt restoration material. The colors corresponding to the forces applied in the figure also shows the uneven stress distribution along the top surface of the hammered asphalt restoration material. The un-hammered areas on top of the asphalt restoration material have more air voids and lower compaction ratios as less stresses were applied on those locations and hence, it reduces the overall compaction ratio of the asphalt restoration material.

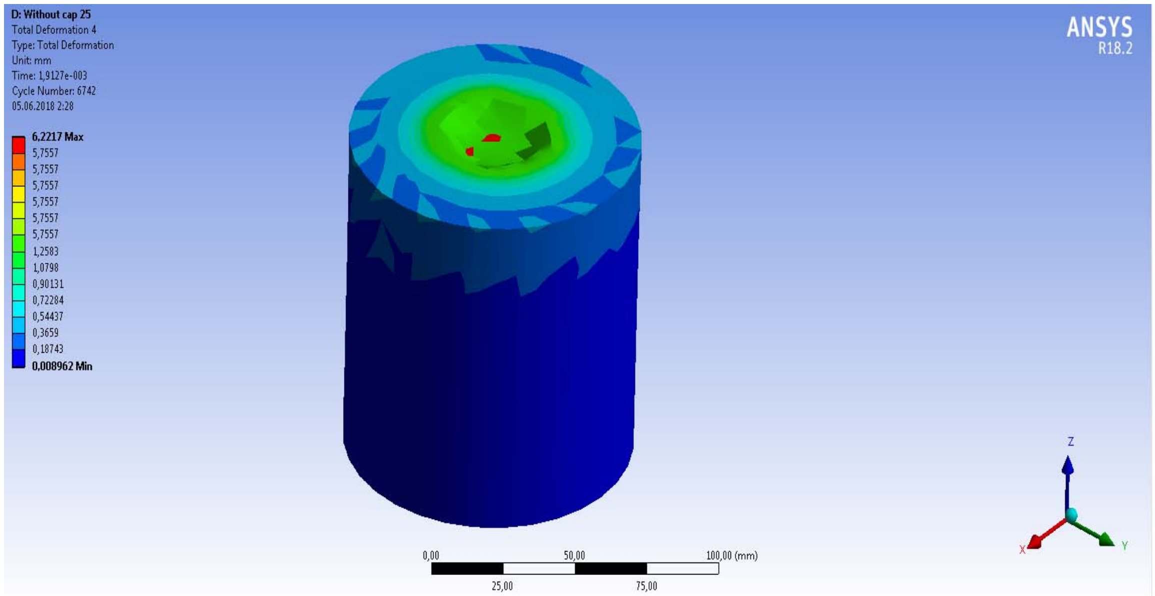


Figure 5.3.5.2 Total Deformation @25 Tamps– Hammering Directly on Restoration Material

Figure 5.3.5.3 is a graph showing the correlation core deformation (mm) on the y-axis due to tamping and the time (s) on the x-axis took the asphalt restoration material inside the core hole to deform. It is clear in the graph that the maximum deformation of the nucleus at 25 tamps directly on top of the asphalt restoration material is approximately 5.1 mm. The resultant deformation is unevenly distributed all over the surface area of the asphalt in the core hole as the forces are applied on the surface of the asphalt restoration material, creating air voids in the adjacent surrounding spots in the top surface of the asphalt restoration material body inside the core hole.

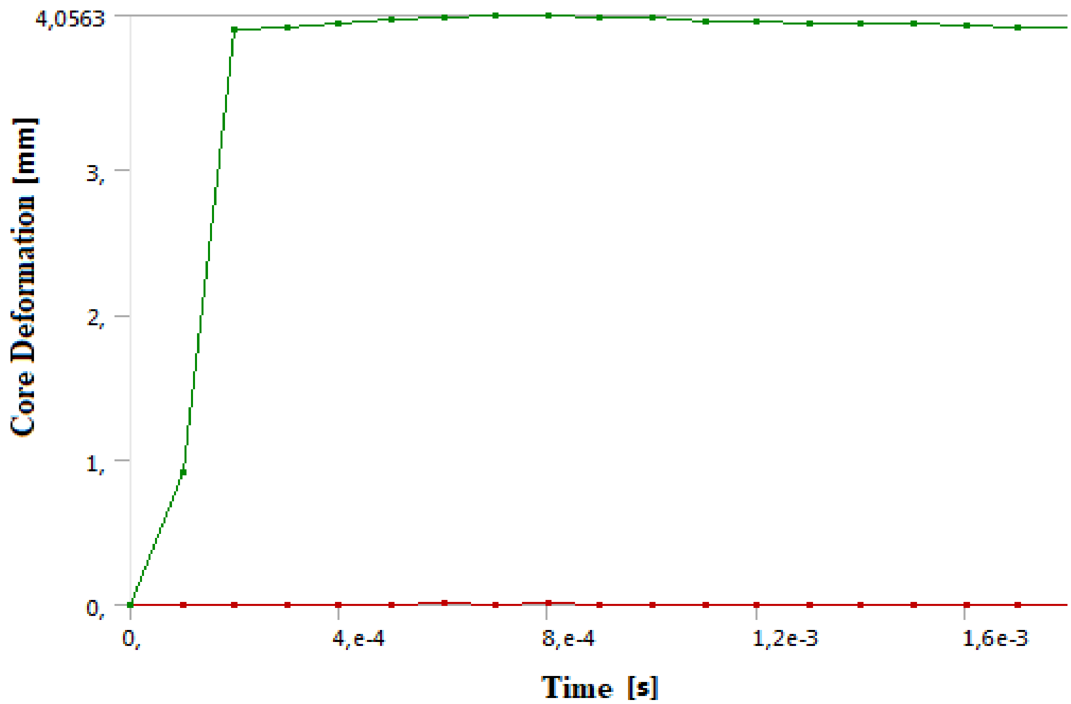


Figure 5.3.5.3 Graph of Core Deformation (mm) vs Time (s) @25 Tamps

5.4 Summary of Cap Device Finite Element Analysis

The Cap device provides many useful solutions to solve the problems resulting from the current asphalt core hole restoration and protection practices, such as but not limited to;

1- Proper Compaction to fill material of the asphalt core hole by using a uniform steel surface transferring uniform pressure from hammering methods to the top of the core hole fill. This will enhance the compaction ratio of the asphaltic restoration material inside the core hole by reducing the air voids content inside the restoration material;

2- Providing a flatter surface of the asphalt material used in restoring the asphalt core holes, which will prevent the compacted fill material from disintegration, failure and concaving below the existing pavement structure. Tips of the surrounding structure usually exhibit unevenness, missing gravel, chops, small crack or breakup due to improper core drilling practices. Using the Cap to compact the asphaltic restoration material will add protection to the tips of the existing surrounding structure from initiation crack, fractures or splits in the surrounding existing asphalt structure. This shall improve the longevity of the lifetime of the pavement structure;

3- The finite element model simulation results favorably to the field data and deformation patterns of the asphalt restoration material. The condensation of the asphalt restoration material resulting from the force of hammering causes more deformation to the asphalt restoration material surface, which leads to loss of Compactability of the adjacent areas of the asphalt restoration material inside the core hole. The field compaction testing using the nuclear gauge proved the same concept as shown in Chapter 4. Compaction test results indicated higher compaction reading at the location of the hammer stroke and very low on adjacent areas within the surface of the restoration material inside the core hole. The Cap device distributes the stresses on the whole surface on each tamp using the same hammer and results in less deformation of the asphalt restoration material. The use of the Cap is recommended when compacting the asphalt restoration material inside the asphalt core hole to increase the density and reduced the air voids.

4- Using the Cap to compact the asphaltic restoration material will improve the aesthesis of the physical condition of the core hole along with the existing paved structure.

CHAPTER 6 – LIFE-CYCLE COST ANALYSIS (LCCA), COST-BENEFIT AND TIME ANALYSIS OF RESTORING ASPHALT CORE HOLES USING THE CAP DEVICE

The main purpose of this chapter is to conduct a life-cycle cost analysis (LCCA) for 2 different construction alternatives and select the lower long-term cost for pavement life. This chapter also emphasizes the importance of cost estimation and time scheduling of all construction activities. Successful construction projects need proper and professional cost and time estimates to properly project the feasibility of the construction activities. Construction cost estimating is the process of forecasting the cost of building a physical structure in a specified time frame. All builders have to estimate to the best of their abilities the prices of various direct and indirect costs that formulate the budget of each activity and use cost estimates to determine a project's scope and feasibility and to allocate budgets. Construction project managers thoroughly prepare estimates and timelines to ensure that a project meets financial feasibility and scope requirements. Construction project managers take into consideration, while estimating the timeline, the costs of quantity takeoff, labor costs, material costs, equipment costs, fuel and energy costs, subcontractor quotes and indirect costs.

6.1 Cost-Benefit Analysis of Using Cap Device

Taking asphalt core holes is mandatory and part of the paving construction practice, not only in the United States, but worldwide. Taking cores is essential to quality control the thickness of the pavement, quality of pavement and other field and laboratory verifications as required. The restoration of asphalt core holes is also mandatory, however, the cost of the restoration is usually deemed included in the asphalt-paving price in the construction contract. The labor and equipment time plus all indirect time spent to schedule and perform asphalt core hole restorations are included in the bid price of the asphalt pavement pay item. The following Table 6.1.1 shows a typical cost estimate conducted to pave a roadway on a typical 8-hour shift (1 Day). The table contains cost estimates of delivery, laying and rolling finished 500 tons of asphalt wearing course and cost estimates include labor costs, equipment costs, material costs, compaction and coring costs, overhead and profit costs.

WORK SHEET FOR ACTIVITY: ASPHALT WEARING COURSE		ITEM #	4.02
CREW/PRODUCTION:	2HRS per SHIFT LOST		
COMPACTION TESTING	355		
10X CORES COST	670	0%	PER YEAR
TOTAL COST	$ 39,948.96	OVERHEAD	10%
UNIT PRICE, INCL. OH/P	$ 96.68 / TON	PROFIT	12%
BID QUANTITY/UNIT		500 TN/ DAY	

LABOR	$/HR	HRS	EXTENTION
LF 731	$ 98.60	8	$ 788.80
x1.5	$ 126.80		$ -
x2	$ 155.00		$ -
JM 731	$ 95.40	8	$ 763.20
x1.5	$ 121.99		$ -
x2	$ 148.59		$ -
Unskilled Labor-Flagger	$ 100.00	8	$ 800.00
x1.5	$ 105.02		$ -
x2	$ 127.34		$ -
LF1010	$ 106.62		$ -
x1.5	$ 142.34		$ -
x2	$ 178.05		$ -
Formsetter1010	$ 102.01		$ -
x1.5	$ 135.43		$ -
x2	$ 168.83		$ -
JM 1010	$ 97.05		$ -
x1.5	$ 127.99		$ -
x2	$ 158.91		$ -
OP ENG 15	$ 122.06	8	$ 976.48
OP ENG 15 OT	$ 236.44		$ -
OP ENG 14	$ 136.31	8	$ 1,090.48
OP ENG 14 OT	$ 266.70		$ -
GF1556	$ 120.67		$ -
x1.5	$ 155.28		$ -
x2	$ 189.88		$ -
F1556	$ 116.83		$ -
x1.5	$ 149.51		$ -
x2	$ 182.19		$ -
L1556	$ 112.98		$ -
x1.5	$ 143.74		$ -
x2	$ 174.50		$ -
DrillRunner29	$ 105.17		$ -
x1.5	$ 138.88		$ -
x2	$ 171.90		$ -
LF 175	$ 106.36		$ -
x1.5	$ 142.57		$ -
x2	$ 178.77		$ -
JM 175	$ 101.17		$ -
x1.5	$ 134.78		$ -
x2	$ 168.39		$ -
MASON 780	$ 11.37		$ -
x1.5	$ 190.07		$ -
MASN 780 OT	$ 222.73		$ -
JM926(CAR/TIM)	$ 110.75		$ -
x1.5	$ 140.87		$ -
x2	$ 170.98		$ -
TEAMSTER	$ 101.27	8	$ 810.16
x1.5	$ 134.40		$ -
x2	$ 167.17		$ -
		SUB-TOTAL	$ 5,229.12

EQUIPMENT	$/HR	HRS	EXTENTION
BACKHOE	$ 60.63		$ -
EXCAVATOR	$ 79.69		$ -
LOADER	$ 65.21		$ -
ROLLER	$ 81.85	4	$ 327.40
DUMP TRUCK	$ 80.83		$ -
PAVER	$ 75.22	8	$ 601.76
FLAT BED TRUCK	$ 58.27		$ -
P/U TRUCK - VAN	$ 18.92	4	$ 75.68
MAINT.TRUCK W/GEN	$ 14.11		$ -
COMPACTOR	$ 16.32		$ -
WALK BEHIND SAW	$ 39.15		$ -
COMPRESSOR	$ 16.18		$ -
VMS	$ 18.55		$ -
ARROW BOARD	$ 7.80		$ -
LIGHT TOWER	$ 15.90		$ -
		SUB-TOTAL	$ 1004.84

PERM. MATERIALS	$/UNIT	QNTY	EXTENTION
TACK COAT	$ 5.00	10	$ 50.00
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		SUB-TOTAL	$ 50.00

NOTES:

CONSTR. MATERIAL	$/UNIT	QNTY	EXTENTION
ASPHALT	$ 60.00	500	$ 32,640.00
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		SUB-TOTAL	$ 32,640.00

SUBCONTRACTOR	$/UNIT	QNTY	EXTENTION
			$ -
			$ -
		SUB-TOTAL	$ -

Table 6.1.1 – Asphalt Wearing Course Cost Estimate without Using the Cap Device

The cost estimate in Table 6.1.1 shows a projected estimate of costs for 1 ton of asphalt wearing course, which is $96.68 per tons. The average paving contractor is expected to pave 500 tons per day and use resources as detailed in Table 6.1.1. The asphalt wearing course cost estimate included in Table 6.1.1 is based on restoring the asphalt core holes using the regular method of hammering the restoration material inside the core holes using a common commercially used hammer.

The following Table 6.1.2 shows a typical cost estimate conducted to pave a roadway on a typical 8-hour shift (1 Day). The table contains cost estimates of delivery, laying and rolling finished 500 tons of asphalt wearing course and cost estimates include labor costs, equipment costs, material costs, compaction and coring using the Cap device costs, overhead and profit costs. The cost estimate in Table 6.1.2 shows a projected estimate of costs for 1 ton of asphalt wearing course, which is $96.72 per tons. The average paving contractor is expected to pave 500 tons per day and use resources as detailed in Table 6.1.2. The asphalt wearing course cost estimate included in Table 6.1.2 is based on restoring the asphalt core holes using the new method of hammering the Cap device over the restoration material inside the core holes using a common commercially used hammer.

It is apparent that the difference in price between restoring the asphalt core holes based on the current and regular method using a hammer only versus restoring the asphalt core holes hammer the Cap device is only 4 cents for the whole operation. The cost difference is extremely insignificant compared the benefits of using the Cap device in enhancing the compaction ratios of the restored material, protecting the existing pavement structure and improving the aesthetic physical appearance of the whole pavement structure.

WORK SHEET FOR ACTIVITY: ASPHALT WEARING COURSE		ITEM #	4.02
CREW/PRODUCTION:	2HRS per SHIFT LOST		
COMPACTION	355		
10X CORES COST	670	0%	PER YEAR
TOTAL COST	$ 39,968.96	OVERHEAD	10%
UNIT PRICE, INCL. OH/P	$ 96.72 / TON	PROFIT	12%
	BID QUANTITY/UNIT		500 TN/ DAY

LABOR	$/HR	HRS	EXTENTION
LF 731	$ 98.60	8	$ 788.80
x1.5	$ 126.80		$ -
x2	$ 155.00		$ -
JM 731	$ 95.40	8	$ 763.20
x1.5	$ 121.99		$ -
x2	$ 148.59		$ -
Unskilled Labor-Flagger	$ 100.00	8	$ 800.00
x1.5	$ 105.02		$ -
x2	$ 127.34		$ -
LF1010	$ 106.62		$ -
x1.5	$ 142.34		$ -
x2	$ 178.05		$ -
Formsetter1010	$ 102.01		$ -
x1.5	$ 135.43		$ -
x2	$ 168.83		$ -
JM 1010	$ 97.05		$ -
x1.5	$ 127.99		$ -
x2	$ 158.91		$ -
OP ENG 15	$ 122.06	8	$ 976.48
OP ENG 15 OT	$ 236.44		$ -
OP ENG 14	$ 136.31	8	$ 1,090.48
OP ENG 14 OT	$ 266.70		$ -
GF1556	$ 120.67		$ -
x1.5	$ 155.28		$ -
x2	$ 189.88		$ -
F1556	$ 116.83		$ -
x1.5	$ 149.51		$ -
x2	$ 182.19		$ -
L1556	$ 112.98		$ -
x1.5	$ 143.74		$ -
x2	$ 174.50		$ -
DrillRunner29	$ 106.17		$ -
x1.5	$ 138.88		$ -
x2	$ 171.90		$ -
LF 175	$ 106.36		$ -
x1.5	$ 142.57		$ -
x2	$ 178.77		$ -
JM 175	$ 101.17		$ -
x1.5	$ 134.78		$ -
x2	$ 168.39		$ -
MASON 780	$ 11.37		$ -
x1.5	$ 190.07		$ -
MASN 780 OT	$ 222.73		$ -
JM926(CAR/TIM)	$ 110.75		$ -
x1.5	$ 140.87		$ -
x2	$ 170.98		$ -
TEAMSTER	$ 101.27	8	$ 810.16
x1.5	$ 134.40		$ -
x2	$ 167.17		$ -
	SUB-TOTAL		$ 5,229.12

EQUIPMENT	$/HR	HRS	EXTENTION
BACKHOE	$ 60.63		$ -
EXCAVATOR	$ 79.69		$ -
LOADER	$ 65.21		$ -
ROLLER	$ 81.85	4	$ 327.40
DUMP TRUCK	$ 80.83		$ -
PAVER	$ 75.22	8	$ 601.76
FLAT BED TRUCK	$ 58.27		$ -
P/U TRUCK - VAN	$ 18.92	4	$ 75.68
MAINT. TRUCK W/GEN	$ 14.11		$ -
COMPACTOR	$ 16.32		$ -
WALK BEHIND SAW	$ 39.15		$ -
COMPRESSOR	$ 16.18		$ -
VMS	$ 18.55		$ -
ARROW BOARD	$ 7.80		$ -
LIGHT TOWER	$ 15.90		$ -
	SUB-TOTAL		$ 1004.84

PERM. MATERIALS	$/UNIT	QNTY	EXTENTION
TACK COAT	$ 5.00	10	$ 50.00
2 CAP DEVICES	$ 10.00	2	$ 20.00
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		SUB-TOTAL	$ 70.00

NOTES:

CONSTR. MATERIAL	$/UNIT	QNTY	EXTENTION
ASPHALT	$ 60.00	500	$ 32,640.00
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		SUB-TOTAL	$ 32,640.00

SUBCONTRACTOR	$/UNIT	QNTY	EXTENTION
			$ -
			$ -
		SUB-TOTAL	$ -

Table 6.1.2 – Asphalt Wearing Course Cost Estimate Using the Cap Device

The following sample quote shows typical average prices of hiring a professional technician to take and restore asphalt core holes for 1 day. The cost in average in the State of New York is $670 per day to hire a professional technician to take cores and restore them.

TWIN PEAKS, INC

BITUMINOUS CONCRETE (ASPHALT) INSPECTION & TESTING
NICET/ICC CERTIFIED TECHNICIAN

TECHNICIAN (PLANT) – Verify batch weights. Inspection of Stockpile Mate[illegible] and verify temperature.

Rate per trip	[illegible]

ASPHALT INSPECTION (FIELD) – Technician to monitor placement, thicknes[illegible] compaction of asphalt.

Rate per day	[illegible]60[illegible]
½ day rate	[illegible]450

ASPHALT LABORATORY SERVICES (If Ne[illegible]y)

Extraction/AC Content	$195
Bulk Specific Gravity	$75
Max. Specific Gravity (Rice Test)	$85
Air Voids	$50

CO[illegible]RETE CORE DRILLING SERVICES

CONC[illegible]E CORES:

Mo[illegible]biliza[illegible]n (per day)	$550
4" Di[illegible] Core ([illegible]ax. depth 12")	$120
Additional Charge [illegible]er 1" depth	$20
Compressi[illegible]ength Test per core	$50

ASPHALT CORES:

Mobilization/Demobilization (per day)	$550
4" Diameter Core (Max.8")	$120
6" Diameter Core (Max.8")	$120
Additional charge per 1" depth	$10

37-39 30th Street, Long Island City, NY 11101 Phone: (718) 482-1911 Fax: (718) 482-7767
www.twinpeakstesting.com, Email: info@tp-labs.com, NYC DOB License# 50, Special Inspection Agency License # 317

American Welding Society
Sustaining Company Member

IAS ACCREDITED

ASNT Corporate Partner

Figure 6.1.1 – Sample Quotation for Core Drilling and Restoration Services

6.2 Cost Benefits of Enhanced Compaction

It has been proven throughtout this study and many other publications and research that the most important factor impcting the performance of asphalt pavement structures is compaction. The amount of air voids in an asphalt mixture is controlled mainly by compactive efforts. The quality of compaction significantly contributes to the pavement life. The amount of air voids in an asphalt mixture is probably the single most important factor that affects performance throughout the life of an asphalt pavement. The voids are primarily controlled by asphalt content, compactive effort during construction, and additional compaction under traffic (Brown et al., 1990). The service life of pavement structure is hence dependant on the quality of compactive efforts. The literature review on connecting in-place density to performance of pavement in the NCAT Report 16-02 (2016) states that 5 studies cited for fatigue life and 7 studies cited for rutting proved that a 1% decrease in air voids was estimated to improve the fatigue performance of asphalt pavements between 8.2 and 43.8%, to improve the rutting resistance by 7.3 to 66.3%, and to extend the service life by conservatively 10%.

In reference to the literature review of the enhanced compaction to improve durability of pavements and extend pavement service life in the NCAT Report No. 16-02R, significant advancements in technology and techniques related to asphalt pavement design and construction yield the potential for increasing both durability and cost effectiveness. Some of these advancements can be employed immediately to enhance field compaction to reduce in-place air voids and improve mixture durability and pavement service life. It has been proved that compaction is the most important factor impacting the pavement servicibility and life span. A well compacted pavement structure is expected to perform better, experience less distress, fatigue, cracks and failures in general due to increased intactness and integrity of the structure. As stated in the aforementioned NCAT Report No. 16-02R, Past studies have shown that a small increase in in-place density through roadway design, mix design, and/or construction can lead to a significant increase in service life of asphalt pavements. According to Epps and Monismith (1971), Finn and Epps (1980), and Puangchi, et al. (1982), fatigue life (the time from original construction to significant fatigue cracking) of asphalt pavements is reduced approximately 10 to 30% for every 1% increase in inplace air voids. In summary, results from the past studies clearly indicate the adverse effect of increased in-place air voids on the fatigue performance of asphalt pavements.

In a recent study to develop performance-related pay adjustment factors for the New Jersey Department of Transportation (NJDOT), Wang et al. (2015) analyzed construction and performance data of pavements in New Jersey. Among several factors identified by the authors, the average in-place air voids measured through field core testing were found to impact the service life of asphalt mixtures, as illustrated in Figure 2. The service life is defined as the time from initial construction until the next rehabilitation activity for each pavement section. The data were mined from the NJDOT's pavement management system and Materials Bureau quality assurance testing database for 55 pavement sections. The correlation shown in Figure 6.2.1 indicates that the service life decreases approximately one year for every 1% increase in the inplace air voids. This corresponds to an approximate 10% increase in asphalt mixture service life for a 1% decrease in in-place air voids.

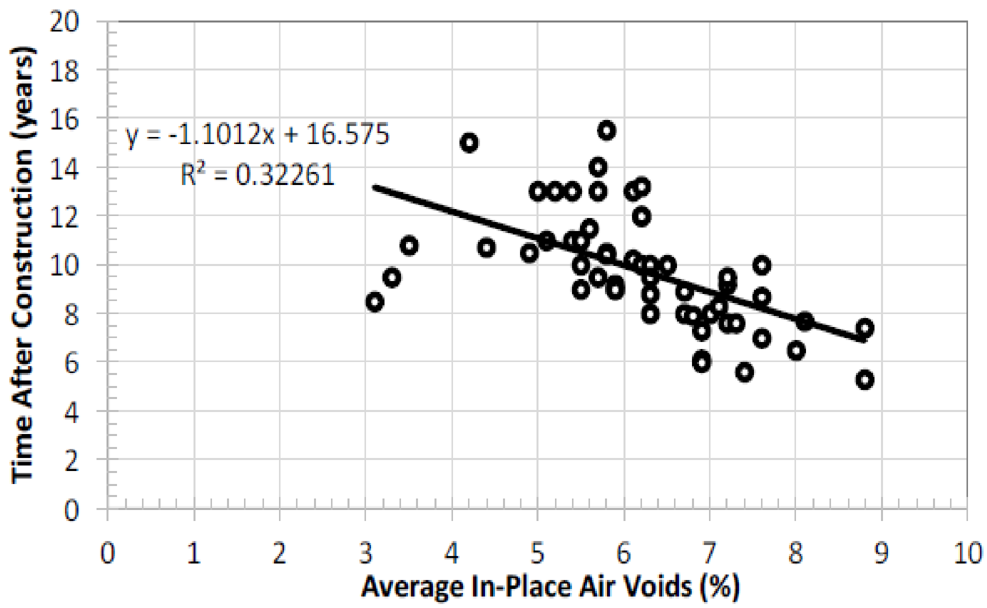


Figure 6.2.1 - Correlations between Average Air Voids and Service Life of Asphalt Mixtures (Wang et al. 2015)

The Life Cost Cycle Analysis (LCCA) of the NCAT Report No. 16-02R illustrates the effect of in-place air voids on the life cycle cost of asphalt pavements, an LCCA was conducted on two alternatives in which the exact same asphalt overlay would be constructed to 93% and 92% densities. It is assumed to gain a conservative 10% increase in service life for every 1% increase in the density of paved section. According to the ASTM Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys, at least 10% of the asphalt used for pavement shall be sampled and tested.

The Average Density % for Asphalt Restoration Material Copmacted without the Cap Device: Approximately 90.5%

The Average Density % for Asphalt Restoration Material Copmacted with the Cap Device: Approximately 94.5%

The overall enhancement in the restored core holes densities is approximately 4%. Based on NCAT Report No. 16-02R, it is safe to assume a conservative 4% improvement on 10% of the whole pavement area that has been distressed due to core sampling. The process of asphalt core drilling, sampling and restoration also causes multiple types of distress on the asphalt pavement structure, such as fatigue, cracking and surface damage. It is believed that a 4% improvement in the quality of restoration asphalt material denstities could extend, at a minimum, the life cycle of the overall asphalt pavement of approximately 4%. The enhancement in asphalt life cycle costs translates to $40,000 of every asphalt paving operation or project costing $1,000,000.

6.3 Life-Cycle Cost Analysis of Using the Cap Device

LCCA is an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments and evaluates the overall long-term economic efficiency between investment options. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures and it does not address equity issues as stated in the FHWA Report No. FHWA-SA-98-079. This chapter will present a uninque life-cycle cost analysis of two (2) alternatives of pavement construction life-cycle. The FHWA Life-Cycle Cost Analysis Primer (2002) indicates that the most basic analysis of a deterministic LCCA is to compare the agency and user cost PVs among alternatives. Ideally, the “best” alternative will have the lowest PV. The two (2) alternatives on this study represent the life-cycle cost analysis of the pavement structure considering restoring and compacting the ashphalt core holes in year “0” using the traditional and current methodology, which using compactive efforts to restore the fill material inside core holes and this is referenced here as Alternative “A”. The life-cycle cost analysis of the pavement structure considering restoring and compacting the ashphalt core holes in year “0” using the innovation of the Cap device methodology, which using compactive efforts on the Cap device to restore and compact the fill material inside core holes and this is referenced here as Alternative “B”. The following Figure 6.3.1 shows an example of a lifetime of one design pavement alternative as shown in the FHWA LCCA Primer (2002);

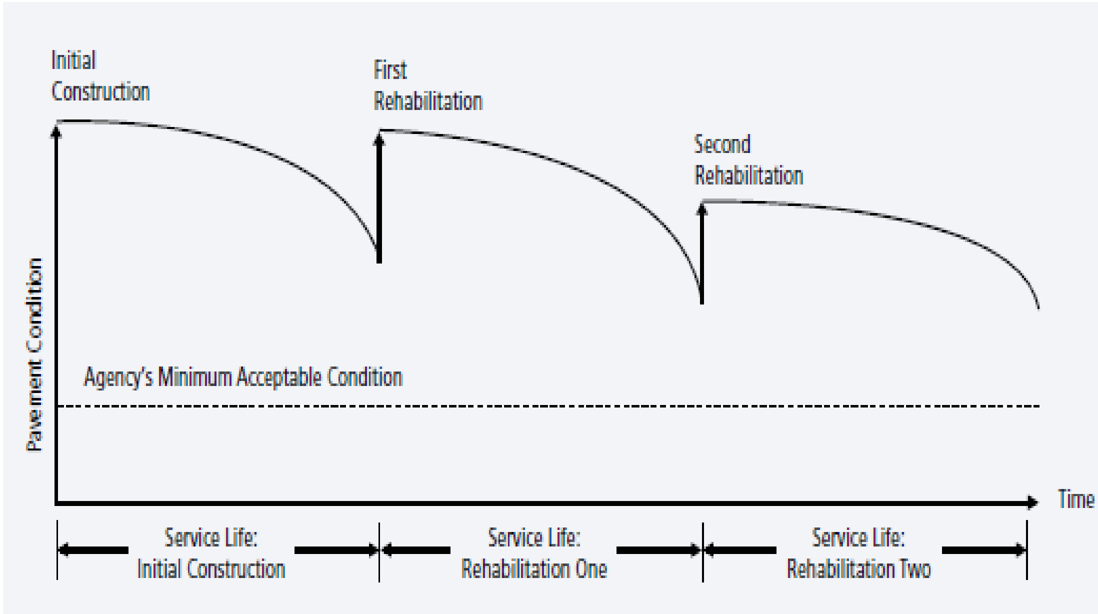


Figure 6.3.1 – Lifetime Example of One Pavement Design Alternative

It is clear that both alternatives share the same costs and the cost of the Cap device has been proven to be insignificat in Sub-section 6.1. Presented here is an example of a deterministic LCCA comparing two alternative project strategies. Each alternative will supply the same level of performance or benefit, so application of LCCA is appropriate. The discount rate is 4 percent, and a 35-year analysis period is used. The life-cycle cost analysis will demonstrate the cost savings on extended pavement life due to improved compaction on the testing areas of the pavement structure, as detailed in Sub-section 6.2 of this study. The over all improvement of the pavement life is 4%, which is 1.4 years over 35 years. The following Figure 6.3.2 shows asample pavement expenditure stream diagram, including activities, costs and timing as shown in the FHWA LCCA Primer (2002);

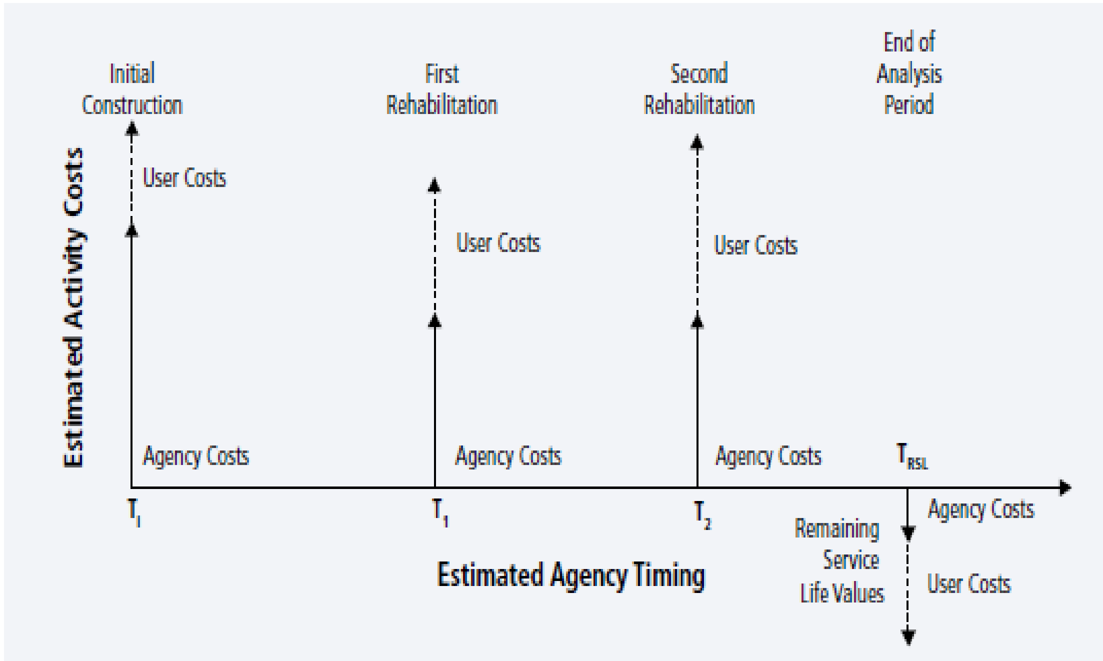


Figure 6.3.2 –Pavement Expenditure Stream Diagram

The LCCA process steps are ordered so that the analysis builds upon information gathered in prior steps. The LCCA steps are:

1. Establish design alternatives
2. Determine activity timing
3. Estimate costs (agency and user)
4. Compute life-cycle costs
5. Analyze the results

This study presents the deterministic approach of the life-cycle cost analysis of one of the alternative presented in the FHWA 2002 LCCA Primer and comparing this given LCCA example to an improved LCCA due to using the Cap device in restoring asphalt core holes.

- Step One: Establish Design Alternatives

  Alternative "A" assumes restoring asphalt core holes as per the USDOT and FHWA specifications or also known as the traditional method of using compactive efforts to restore the fill material inside the core holes. Alternative "B" assumes restoring asphalt core holes using the innovation of the Cap device by applying compactive efforts to restore the fill material inside the core holes. Alternative "B" will assume the enhancement of 4% in the pavement life due to improved core hole restoration method using the Cap device and its cost savings. Alternative "A" is characterized by some construction and rehabilitation activities assuming restoring the asphalt core holes the traditional method and Alternative "B" is characterized by the same construction and rehabilitation activities assuming restoring the asphalt core holes using the innovation of the Cap device.

- Step Two: Determine Activity Timing

  Table 6.3.1 presents the LCCA activating time-table for typical pavement alternatives using the traditional method in restoring asphalt core holes versus using the innovation of a Cap device in restoring asphalt core holes. Both alternatives assume the same initial costs and rehabilitation costs. The value of the alternative at the end of the evaluation period will be impacted by different agency costs between the alternatives.

Year	Alternative "A" Activities (w/o Cap)	Alternative "B" Activities (w/ Cap)
0	Initial construction	Initial construction
12	Rehabilitation one (8-year service life) w/o Cap	Rehabilitation one (8-year service life) w/ Cap
20	Rehabilitation one (8-year service life) w/o Cap	Rehabilitation one (8-year service life) w/ Cap
28	Rehabilitation one (8-year service life) w/o Cap	Rehabilitation one (8-year service life) w/ Cap
35	End of analysis period—residual service life value if applicable.	

Table 6.3.1 – LCCA Activity Timing Table

- Step Three: Estimate Costs (Agency and User)

Agency and user costs for each activity are in constant, base year dollars. User costs are based upon user vehicle operating costs and traveler delay associated with work zone activities. User costs increase for similar work due to the increase in traffic over time. Costs for year 35 reflect the value of remaining service life for each alternative in year 35. The agency costs will be impacted by 4% due to using the Cap device in restoring asphalt core holes. The user costs of discomfort are extremely insignificant to be considered in this study. Table 6.3.2 demonstrates the LCCA agency and user cost estimates for the assumed pavement life span of 35 years.

	Alternative "A" Activities (w/o Cap)		Alternative "B" Activities (w/ Cap)	
Year	Constant Dollar Agency Costs	Constant Dollar User Costs	Constant Dollar Agency Costs	Constant Dollar User Costs
0	$20,000,000.00	$8,000,000.00	$20,000,000.00	$8,000,000.00
12	$6,000,000.00	$10,000,000.00	$5,760,000.00	$10,000,000.00
20	$6,000,000.00	$16,000,000.00	$5,760,000.00	$16,000,000.00
28	$6,000,000.00	$28,000,000.00	$5,760,000.00	$28,000,000.00
35	-$750,000.00	-$3,500,000.00	-$780,000.00	-$3,500,000.00

Table 6.3.2 – LCCA Agency & User Cost Estimates

- Step Four: Compute Life-Cycle Costs

  Step four calculated the present value (PV) for each of the agency and user costs based on a 4% discount rate and 4% improvement for Alternative "B" due to using the innovation of the Cap device in restoring ashphalt core holes.

  Present Value (PV) = Future Value (FV) x 1/ $(1+r)^n$

  r = discount rate

  n = number of years

Year	Discount Factor	Alternative "A" Activities		Alternative "B" Activities	
		Discounted Agency Costs	Discounted User Costs	Discounted Agency Costs	Discounted User Costs
0	1.0000	$20,000,000.00	$8,000,000.00	$20,000,000.00	$8,000,000.00
12	0.6246	$3,747,582.00	$6,245,970.00	$3,597,678.72	$10,000,000.00
20	0.4564	$2,738,322.00	$7,302,191.00	$2,628,789.12	$16,000,000.00
28	0.3335	$2,000,865.00	$9,337,369.00	$1,920,830.40	$28,000,000.00
35	0.2534	-$190,062.00	-$886,954.00	-$197,664.48	-$886,954.00

Table 6.3.3 – LCCA Life Costs

- Step Five: Analyze the Results

  Alternative "A" has the same initial construction costs and same user costs. Alternative "B" has more cost savings than Alternative "A" shown in the agency costs if the Cap device is used to restore asphalt core holes taken at Year "0".

6.4 Time Analysis of Using Cap Device

The estimates in Section 6.1 of this study assumes the use of two (2) Cap devices on site. The Contractor will be using one Cap device to compact restoration material inside asphalt core holes and the other Cap device shall be available as a spare in the event of damaging the first Cap device. Both methods of restoring asphalt core holes involves mobilization and preparatory time, drilling time, removing of asphalt core, clearing the asphalt core hole, filling the asphalt core hole with restoration material, compact the restoration material and clean up the site at the end. The new technique proposing the use of the Cap device involves exactly the same aforementioned steps to restore and compact asphalt core holes with the addition of 2 seconds to physically carry the Cap device and place it on top of the filled asphalt core hole with restoration material.

It is apparent that the difference in time between restoring the asphalt core holes based on the current and regular method using a hammer only versus restoring the asphalt core holes hammer the Cap device is approximately 2 seconds for the whole operation. The time difference is extremely insignificant compared the benefits of using the Cap device in enhancing the compaction ratios of the restored material, protecting the existing pavement structure and improving the aesthetic physical appearance of the whole pavement structure.

CHAPTER 7 - CONCLUSIONS

The main purpose of this research project was to enhance the construction procedures or compacting asphalt restoration material used to restore asphalt core holes in paved roadways. This study presents the development of the core hole Cap device to enhance the compactability of the restoration material in asphalt core holes. The following conclusions can be made based on the design, finite element modeling and field testing of the cap device application in restoring core holes;

- The current asphalt core hole restoration method results in improper and insufficient compaction of the restoration fill material due to lack of enforcement of proper design and construction compaction procedures. This causes settlement of the asphalt fill material used in the restoration process and hence creating voids within the asphalt core hole.

- The current asphalt core hole restoration method results in the disintegration of the top surface of the asphalt core restoration fill material due to impact from weighty vehicles and inclement weather conditions. The exposure, hence, of the edges of the surrounding pavement structures and making it vulnerable to damages, cracks, failures and/or fatigues.

- The current asphalt core hole restoration method results in poor physical appearance of the pavement structure due to the uneven finished compacted restored asphalt material.

- The asphalt Cap device is patented device that proved to improve the compaction ratio of the asphalt restoration material and improve the overall behavior of the restored asphalt in asphalt core holes by reducing the air voids and increasing the compaction ratio to the acceptable range by State's Department of Transportation.

- The Cap device evenly distribute the forces resultant from hammering on the restoration material. The finite element model revealed the even distribution of the forces on the surface of the restoration material body.
- The finite element model also proved the concentration of the compactive efforts in the area of contact with the compaction tool (i.e. hammer) which shows loss of compaction percentage in adjacent areas while evenly compacted areas is mandatory.

- The Cap device provides an even and smooth finished surface that protects the existing asphalt edging without exposing the edges to vehicular pressure. The even finished asphalt surface in the core holes provides more aesthetic physical appearance of the paved structure.

- It is safe to assume a conservative 4% improvement of the density of compacted asphalt restoration material used to retore core holes on 10% of the whole pavement area that has been distressed due to core sampling.

- The Life-Cycle Cost Analysis (LCCA) proved the cost savings in agency costs if the Cap devce is used to restore asphalt core holes.

The study suggests the following enhanced construction procedures to restore core holes in roadways and highways in the United States of America;

“Upon completion of an HMA lot, drill cores at random locations determined by the Engineer. Use drilling equipment with a water-cooled, diamond-tipped, masonry drill bit that shall produce 4-inch or 6-inch nominal diameter cores for the full depth of the pavement. Remove the core from the pavement without damaging it. After removing the core, clean and remove all water from the hole. Place HMA restoration material in maximum lifts of 4 inches in the hole and compact each lift. Place the Cap device on top of the asphalt restoration material and compact each lift by randomly hand-hammering approximately 10 strokes on top of the asphalt restoration material placed inside the core hole to gain initial compaction. Place the Cap device after the initial compaction on top the of the asphalt restoration material and apply additional 15 strokes on Cap device for each lift. Ensure that the final surface is 1/2 inch above the surrounding pavement surface.”

CHAPTER 8 - RECOMMENDATIONS

This research study included the invention of a Cap device to enhance the restoration of asphalt core holes. The information and investigation gathered during this research was utilized to improve the method of compacting the asphalt restoration material in core holes and suggest an update to the current core hole restoration construction practice to state agencies. There is always room for improvement and optimizing the mechanism of restoring asphalt core holes. Recommendations for future research in this area include;

- Optimization of Cap device applications: investigate various applications using the Cap device to enhance the compaction of paved structures. The optimization of using the Cap device to fit the purpose of enhancing the compaction of construction materials in different situation, locations and sizes. The Cap device dimensions in the event of having different core hole sizes or for the use in other compaction applications can be optimized to enhanced performance while used in restoring asphalt core holes.

- The quality of patching material: the two (2) major factors that affect the pavement performance are compaction and the mix design. Improving the quality of patching and restoration material will improve the overall performance of the pavement structure. The methods used does appear to affect the durability of patches placed. The ability to identify good-quality patching materials for use by highway agencies will befit many agencies, from state departments of transportation to county, city, and municipal streets and roads departments (Wilson, 1993).

- LCCA probabilistic analysis could help to capture the effects of uncertainty in estimates of timing or magnitude of costs developed for pavement construction alternative.

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APPENDIX A

Appendix A-1

Cap Device US Patent Application

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

NOTICE OF ALLOWANCE AND FEE(S) DUE

135086 7590 01/17/2017
Changi Wu Law Office
53 Jersey Avenue
Edison, NJ 08820

EXAMINER	
ADDIE, RAYMOND W	
ART UNIT	PAPER NUMBER
3671	

DATE MAILED: 01/17/2017

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
14/836,951	08/26/2015	AHMAD K. ALHALAWANI	CWU720291501AA	1334

TITLE OF INVENTION: CAP FOR RESTORED ASPHALT CORE AND METHODS OF PROTECTING ASPHALT CORE HOLE

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	MICRO	$240	$0	$0	$240	04/17/2017

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PTOL-85 (Rev. 02/11)

US009587357B1

(12) **United States Patent** (10) **Patent No.: US 9,587,357 B1**
Alhalawani (45) **Date of Patent: Mar. 7, 2017**

(54) **CAP FOR RESTORED ASPHALT CORE AND METHODS OF PROTECTING ASPHALT CORE HOLE**

(71) Applicant: **Ahmad K. Alhalawani**, Piscataway, NJ (US)

(72) Inventor: **Ahmad K. Alhalawani**, Piscataway, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/836,951**

(22) Filed: **Aug. 26, 2015**

(51) **Int. Cl.**
E01C 11/00 (2006.01)

(52) **U.S. Cl.**
CPC ***E01C 11/005*** (2013.01)

(58) **Field of Classification Search**
CPC E01C 11/005
USPC 404/9, 12–16, 75
See application file for complete search history.

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* cited by examiner

Primary Examiner — Raymond W Addie
(74) *Attorney, Agent, or Firm* — Changi Wu Law Office; Changi Wu

(57) **ABSTRACT**

A cap device to protect a restored asphalt core hole created from asphalt core test and methods to protect an asphalt core hole.

9 Claims, 4 Drawing Sheets

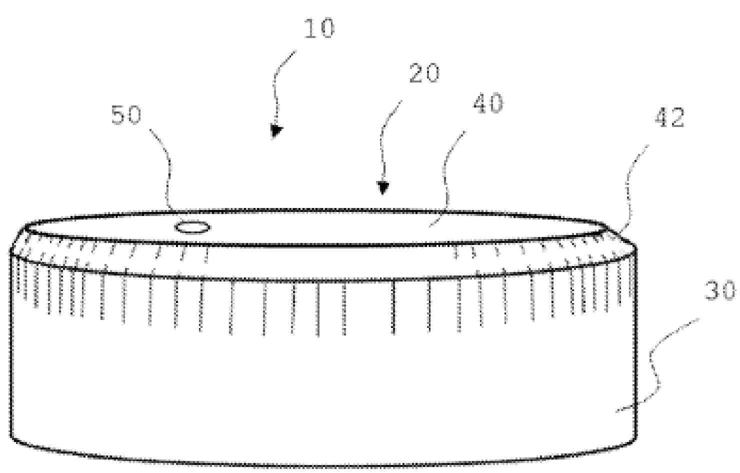


FIG. 1

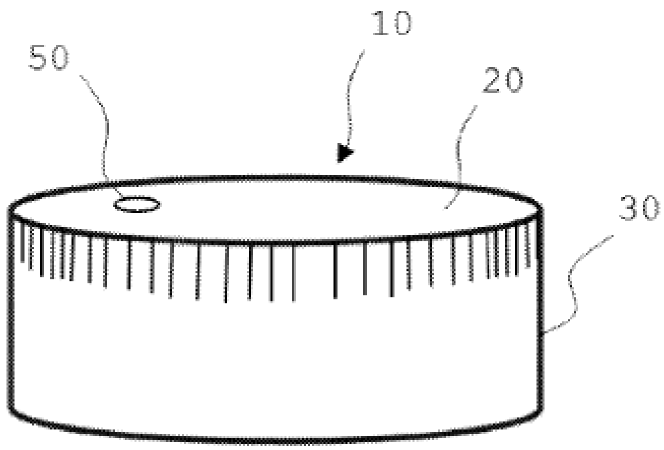


FIG. 2

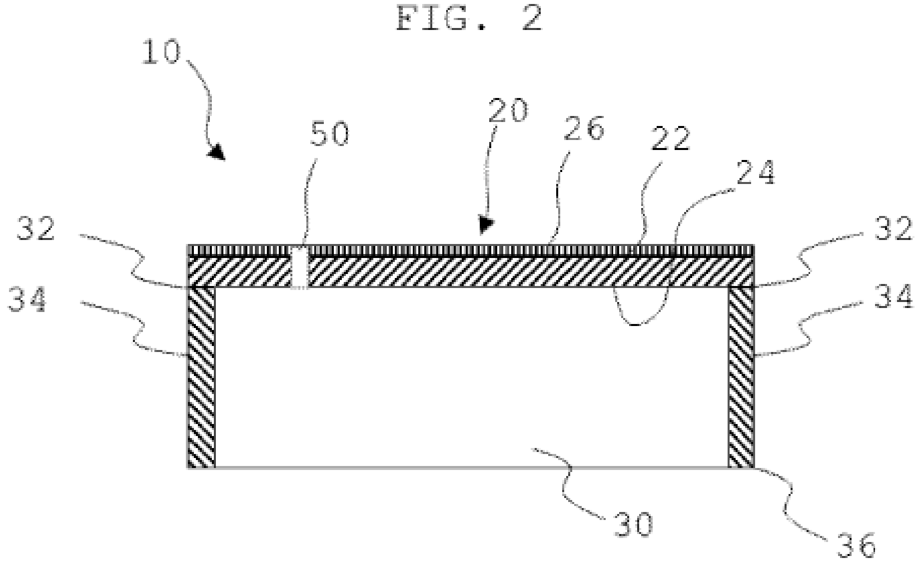


FIG. 3

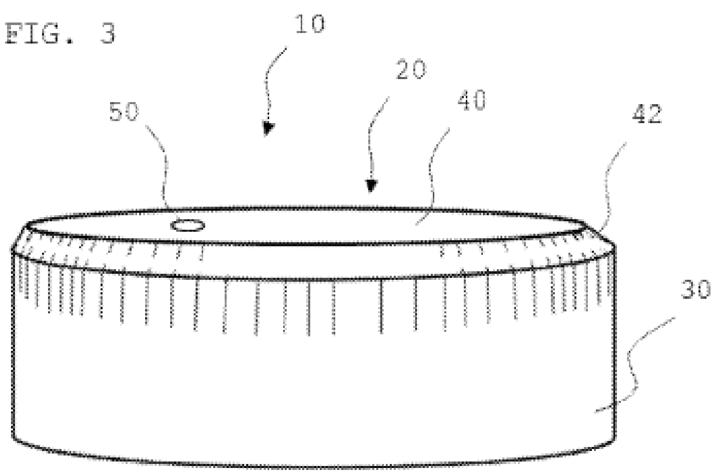


FIG. 4

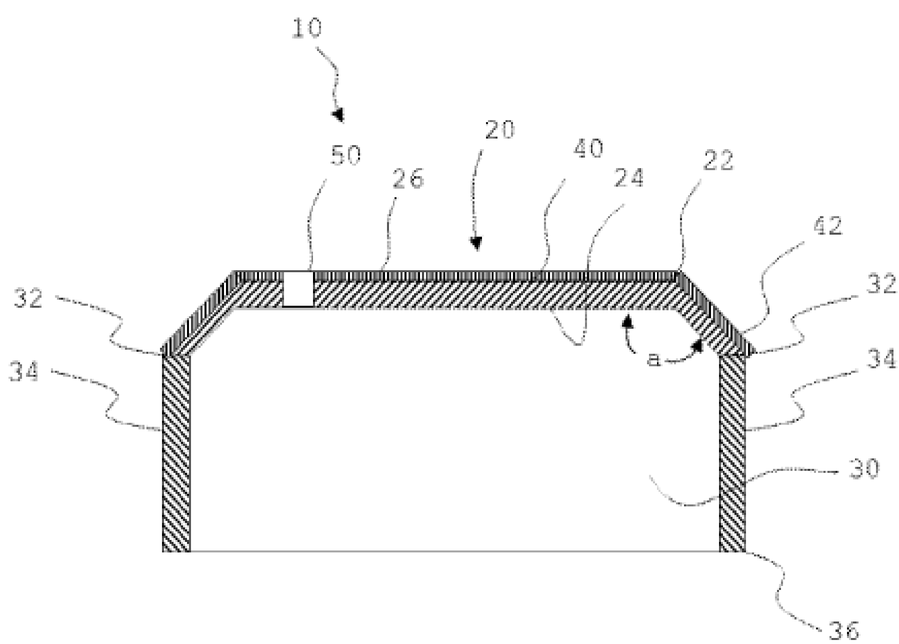


FIG. 5

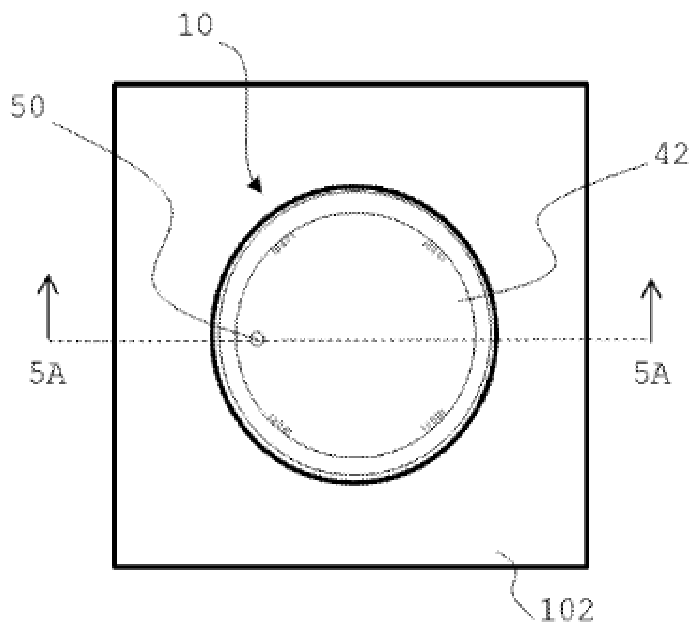


FIG. 5A

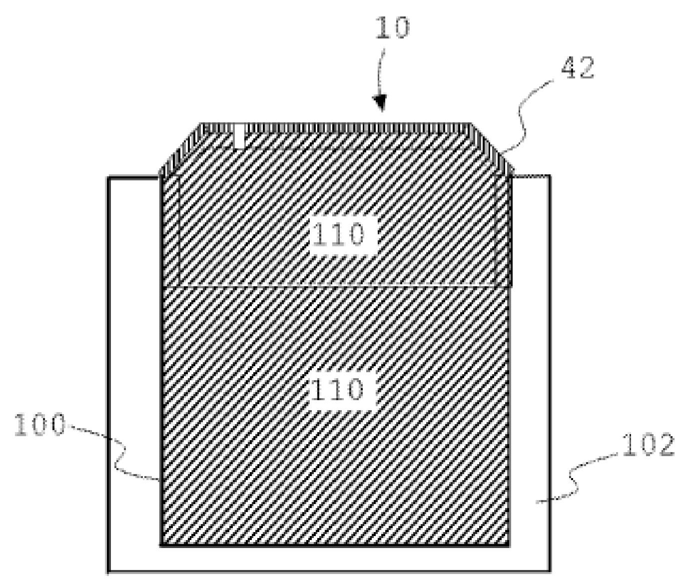


FIG. 6

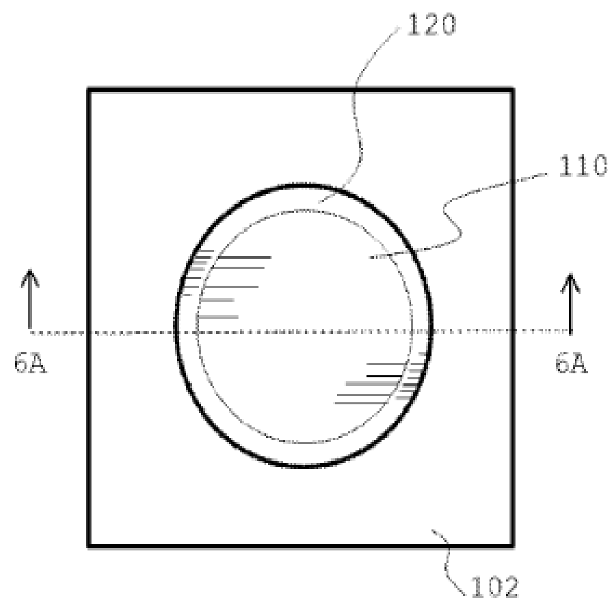
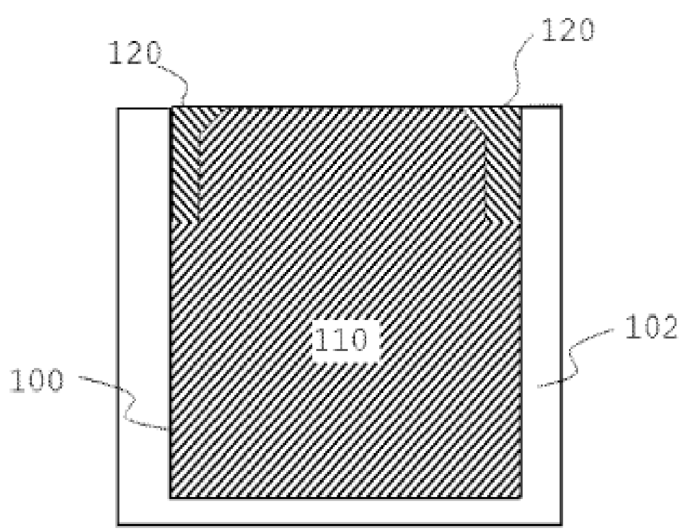


FIG. 6A



CAP FOR RESTORED ASPHALT CORE AND METHODS OF PROTECTING ASPHALT CORE HOLE

CROSS-REFERECE RELATED TO RELATED APPLICATIONS

Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING COMPACT DISK APPENDIX

Not Applicable

BACKGROUND

Pavement maintenance is the key to pavement preservation. Effective pavement preservation programs integrate many maintenance strategies and treatments, such as preventive, corrective and emergency maintenance. However, a common practice in construction, core hole testing, and often leaves newly constructed roadways vulnerable to premature damage that can inhibit effective pavement preservation. There is no doubt that asphalt pavement needs to be tested for evaluation, verification and research purposes, and that core hole testing is a cost-effective and diagnostic method by which to verify asphalt properties, as dictated by the specifications, such as thickness, structural integrity, specific gravity, air void content and percent compaction. Nonetheless, State agencies currently enforce specific procedures for asphalt core hole restoration.

BRIEF SUMMARY OF THE INVENTION

The lack of proper protection of the restored asphalt core holes leads to multiple potential asphalt failures, such as cracking, spalling, potholes, dispersion of top surface of the core hole restoration material which will result to scattering of debris throughout the roadway, disintegration of restoration material from the existing paved structure and poor physical appearance. The need of inventing a new device to improve the core sampling post-construction procedures is crucial. The inventor discerns that the current construction practice for asphalt core hole restoration does not require protection to the top surface of the restoration material and tips and edges of the existing structure resulting from core drilling, proper compaction to the restoration fill material or application of emulsifying asphaltic bonding agent. The invention of a cap device for asphalt core holes should protect asphalt core holes and the restoration material, provide better compaction for the asphalt core restoration material and provide the space for the application of a bonding agent between the core hole fill material and the existing surface. This invention provides a useful cap device to protect the restored asphalt core hole. As resolved by the inventor, a cap for protecting fill material of asphalt core hole comprises a top plate, a hollow tubular member. The tubular member is attached to the top plate, and the tubular member is substantially perpendicular to the top plate. Also, resolved by the inventor is a method to protect a asphalt core hole, which comprises the steps of placing fill materials to

fulfill an asphalt core hole, forming a top of the fill material, placing a circular cap on the top of the fill material, forming a gap between the circular cap and the asphalt core hole, compacting the fill material by putting pressure on the circular cap, filing a bonding agent into the gap, leaving the circular cap in the asphalt core hole at least one day and no more than 3 days, removing the circular cap from the asphalt core hole, creating a void space from the removal of the circular cap, and filing an emulsifying bonding agent into the void space to fulfill the asphalt core hole.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a cap according to some embodiments;

FIG. **2** is section view of a cap according to some embodiments;

FIG. **3** is a perspective view of a cap according to some embodiments;

FIG. **4** is a section view of a cap according to some embodiments;

FIG. **5** is a plan view of an embodiment of the method to protect an asphalt core hole;

FIG. **5**A is a section view of an embodiment of the method to protect an asphalt core hole;

FIG. **6** is another plan view of an embodiment of the method to protect an asphalt core hole;

FIG. **6**A is another section view of an embodiment of the method to protect an asphalt core hole.

DETAILED DESCRIPTION

Before the present invention is described in greater detail, it is to be understood that this invention is not limited to particular embodiments described, and as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting, since the scope of the present invention will be limited only by the appended claims.

Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limits of that range is also specifically disclosed. Each smaller range between any stated value or intervening value in a stated range and any other stated or intervening value in that stated range is encompassed within the invention. The upper and lower limits of these smaller ranges may independently be included or excluded in the range, and each range where either, neither or both limits are included in the smaller ranges is also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included in the invention.

Unless defined otherwise, all terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, some potential and exemplary methods and materials may now be described. Any and all publications mentioned herein are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited. It is understood that the present disclosure supersedes any disclosure of an incorporated publication to the extent there is a contradiction.

It must be noted that as used herein and in the appended claims, the singular forms "a", "an", and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a plate" includes a plurality of such plates and reference to "the peripheral portion" includes reference to one or more peripheral portions, and so forth.

It is further noted that the claims may be drafted to exclude any element that may be optional. As such, this statement is intended to serve as antecedent basis for use of such exclusive terminology as "solely", "only" and the like in connection with the recitation of claim elements, or the use of a "negative" limitation.

As will be apparent to those of skill in the art upon reading this disclosure, each of the individual embodiments described and illustrated herein has discrete components and features which may be readily separated from or combined with the features of any of the other several embodiments without departing from the scope or spirit of the present invention.

Referring to FIG. **1** a cap **10** has a top plate **20** and tubular member **30**. Top plate **20** can be substantially circular, rectangular, or square. Tubular member **30** can be substantially circular, rectangular, or square. Cap **10** is made of material, such as cast iron, steel, high strength aluminum, high strength plastic that can sustain vehicular weight, such as 4-axle trucks, 6-axle trailer or bulldozer. Top plate **20** is attached to tubular member **30** by methods known to the person having the skill of art such as welding, screwing, bolting, adhesion, or forging ways. Top plate **20** and tubular member **30** can be different materials; however, it is also understood that even though the cap comprises two parts, top plate **20** and tubular member **30**, the cap can be made with one piece such as casting or molding.

Referring to FIG. **2** one embodiment of a cap **10** shows a top plate **20** having an upper side **22** and bottom side **24**, a tubular member **30** having a top edge **32**, a tubular body **34**, and bottom edge **36**, where tubular body **34** is substantially axially hollow. Also referring to FIG. **2** one embodiment of a cap **10** shows that upper side **22** of top plate **20** and a opposed bottom side **24** of top plate **20**, where opposed bottom side **24** is connected to top edge **32** of tubular member **30**. And, tubular member **30** is substantially perpendicular to top plate **20**. Also referring to FIG. **2** an optional coating material **26** is attached to upper side **22** of top plate **20**. The coating material **26** can be abrasive material such as rubber, plastic, or combination of two. Also referring to FIG. **2** hole **50** is formed through top plate **20** allowing insert of tools, such as screw driver, pry bar, or steel bar, to remove cap **10** from an asphalt core hole (not shown). Referring to FIG. **3** another embodiment of cap **10**, top plate **20** has a central portion **40** and peripheral portion **42**. Also referring to FIG. **3** an embodiment of cap **10** has a tubular member **30**.

Referring to FIG. **4**, an embodiment of cap **10** shows that central portion **40** and peripheral portion **42** form an angle a between 0 degree to 90 degree, and where the angle a is formed on the bottom side **24** of the top plate **20**. Also referring to FIG. **2** an optional coating material **26** is attached to upper side **22** of top plate **20**. The coating material **26** can be abrasive material such as rubber, plastic, or combination of two. Also referring to FIG. **4** tubular member **30** is substantially hollow where the inner diameter of tubular member **30** is approximately 5.5 inches and the outer diameter of tubular member **30** is approximately 6 inches, and where the length of the tubular member **30** is approximately 2 inches. Also referring to FIG. **4** a hole **50** is formed through the top plate **20** for allowing insert of tools, such as screw driver, pry bar, or steel bar, to remove cap **10** from an asphalt core hole (not shown).

Referring to FIGS. **5** and **5**A a cap **10** is placed inside an asphalt core hole **100** formed in an existing asphalt structure **102**. Referring to FIG. **5**A, fill material **110** has been placed to fulfill the asphalt core hole **100**, and in where cap **10** is placed on top of fill material **110**. Referring to FIG. **5**A fill material **110** is compacted by pressed down cap **10**, and cap **10** is force into asphalt core hole **100** by hammering or other forceful way. Referring to FIGS. **6** and **6**A cap **10** (not shown) is removed from asphalt core hole **100** in asphalt pavement **102**. Referring to FIG. **6**A emulsifying bonding agent **120** is filled between fill material **110** and the existing asphalt structure **102**.

Numerous characteristics, advantages, and embodiments of the invention have been described in detail in the forgoing description with reference to the accompanying drawings. However, the above description and drawings are illustrative only. The invention is not limited to the illustrated embodiments, and all embodiments of the invention need not necessarily achieve all of the advantages or purposes, or possess all characteristics, identified herein. Various changes and modifications may be effected by one skilled in the art without departing from the scope or spirit of the invention. Although example materials and dimensions have been provided, the invention is not limited to such materials and dimensions have been provided, the invention is not limited such materials or dimensions unless specifically required by the language of a claim. The elements and uses of the above-described embodiments can be rearranged and combined in manners other than specifically described above, with any and all permutations within the scope of the inventions.

What is claimed:

1. A cap for protecting fill material of asphalt core hole, comprising

a top plate having a upper side, a bottom side opposed to the upper side; and

a tubular member having a top edge, a tubular body, and a bottom edge, wherein the top edge of the tubular member is attached to the bottom side of the top plate, wherein the tubular body is substantially axially hollow, wherein the tubular member is substantially perpendicular to the top plate, and wherein the tubular member is made of material that can sustain vehicular weight.

2. The cap as recited in claim **1**, wherein the top plate is circular.

3. The cap as recited in claim **1**, wherein the tubular member is circular.

4. The cap as recited in claim **1**, further comprising a central portion and a peripheral portion, wherein the central portion and the peripheral portion forms an angle between zero degree and 90 degree, wherein the angle is formed on the bottom aide of the top plate.

5. The cap as recited in claim **1**, wherein the top plate and the tubular member is substantially made of material that can sustain vehicular weight.

6. The cap as recited in claim **1**, further comprising a coating material attached on the top side of the cap, wherein the coating material consists of rubber, plastic, or a combination of rubber and plastic.

7. The cap as recited in claim 1, wherein at least a hole is formed through the top plate.

8. A cap for protecting fill material of asphalt core hole, comprising a top plate having a upper side, a bottom side opposed to the upper side, wherein the top plate is made of material that can sustain vehicular weight, and wherein at least a hole is formed through the top plate, arid wherein the top plate is circular;

A central portion of the top plate and a peripheral portion of the top plate, wherein the central portion and the peripheral portion forms an angle between zero degree and 90 degree, wherein the angle is formed on the bottom side of the top plate; and

a tubular member having a top edge, a tubular body, and a bottom edge, wherein the top edge of the tubular member is attached to the bottom side of the top plate, wherein the tubular body is substantially axially hollow, and the tubular member is substantially perpendicular to the top plate, wherein the tubular member is made of material that can sustain vehicular weight.

9. A method to protect an asphalt core hole, comprising the steps of

Placing fill materials to fulfill an asphalt core hole formed in an existing asphalt structure,

Forming a top of the fill materials,

Placing a circular cap on the top of the fill materials,

Compacting the fill materials by putting pressure on the circular cap,

Applying force on the circular cap until the circular cap into the asphalt core hole,

Leaving the circular cap in the asphalt core hole at least one day but no more than 3 days,

Removing the circular cap from the asphalt core hole, and

Filing an emulsifying bonding agent between the fill material and the existing asphalt structure.

* * * * *

Appendix A-2

Material Test Certification of Cap Device

Atlas ABC Corp (Atlas Tube Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80701422
Date: 02.01.2016
Customer: 98

MATERIAL TEST REPORT

Sold to

METALS USA-NORTHEAST L
50 CABOT BLVD EAST
LANGHORNE PA 19047
USA

Shipped to

Metals USA - Northeast, L.P
75 Stonewood Road
YORK PA 17402
USA

Material: 6.625x280x21'0"0(7x1)NMHDOMUS   Material No: R06625280   Made in: USA   Melted in: USA

Sales order: 1058483   Purchase Order: YRK 24878

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
D03593	0.190	0.830	0.010	0.007	0.015	0.056	0.020	0.006	0.004	0.010	0.020	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800609828	7	057486 Psi	073499 Psi	33 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 6.625x280x42'0"0(7x1)NMHDOMUS   Material No: R06625280   Made in: USA   Melted in: USA

Sales order: 1058483   Purchase Order: YRK 24878

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
D03593	0.190	0.830	0.010	0.007	0.015	0.056	0.020	0.006	0.004	0.010	0.020	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800609817	7	057486 Psi	073499 Psi	33 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 6.625x280x21'0"0(7x1)NMHDOMUS   Material No: R06625280   Made in: USA   Melted in: USA

Sales order: 1058483   Purchase Order: YRK 24878

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
D03593	0.190	0.830	0.010	0.007	0.015	0.056	0.020	0.006	0.004	0.010	0.020	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800609829	7	057486 Psi	073499 Psi	33 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

METALS USA
CUST. PO # ____________
OUR ORDER # ____________

Authorized by Quality Assurance: *Jason Richard*
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute of North America   Page : 2 Of 3   Metals Service Center Institute

METALS USA
CASTILLO IRON WORKS, INC
Black Plain End Pipe A500 Gr B Structural
8 Sch 40 .280W X 42'
PART NO:
PO: BROOKLYN
POREQ:
HEAT: d03593
Certificate of Mill Test Results
PHI-494159-7
30-Jun-2016
Page 1 of 1

Appendix A-3

Sakrete® All Weather Blacktop Patch Product Data Sheets

ALL WEATHER BLACKTOP PATCH

SAKRETE SINCE 1936

The Pro's Choice Since 1936

Sakrete® All Weather Blacktop Patch is a ready to use asphalt repair product designed for the permanent repair of potholes, large cracks and other defects in asphalt surfaces. Repairs can be opened to traffic immediately after proper compaction. The unique design provides an environmentally friendly low VOC product.

Maximum repair area is not to exceed 2' x 2' x 4" (0.6 m x 0.6 m x103 mm).

Features:

- Environmentally preferable - VOC compliant
- Easy to use - does not require heating
- Fast and permanent
- Minimum 2-year shelf life

Use For:

- Patch and repair potholes in blacktop walks, driveways and parking lots

Yield/Coverage:

Per 60 lb (27.2 kg) bag:

Area in ft² (m²)	3 (0.3)	4 (0.4)
1" (25 mm) deep	1	1
2" (51 mm) deep	2	2
3" (75 mm) deep	2	3
4" (102 mm) deep	3	4

Color:

Black

Preparation:

- Chisel out loose blacktop. Try to avoid a bird bath shaped hole. Sweep clean removing all debris. A hose can be used to wash out loose material.
- Pour a 2" (51 mm) layer of All Weather Blacktop Patch into the pot hole. Compact into a 1" (25 mm) layer using a tamper or 4" x 4" (103 x 103 mm) post. Place and compact additional layers until the hole is filled.
- Finished repair should be mounded slightly higher than the surrounding asphalt surface.
- Very high summer temperatures can cause freshly applied material to track. Placing sand on the repair will minimize tracking.

Placement and Compaction:

Pour a 2" (51 mm) layer of loose All Weather Blacktop Patch into the area to be patched. Level the loose material and then compact to a 1" (51 mm) layer. Compact with a tamper or a 4" x 4" (103 x 103 mm) post. PLACE AND COMPACT additional layers until desired thickness is achieved. Riding over the patch with a car will not provide sufficient compaction. Compaction must be sufficient to cause the stone in the blacktop to lock together and minimize voids in each layer. If the blacktop is not completely compacted, the patch will remain soft and the material may not stay in place. Properly compacted All Weather Blacktop Patch will continue to harden over time.

Tips for use:

All Weather Blacktop Patch may be opened to traffic immediately after being thoroughly compacted. Under certain conditions the surface may remain tacky for a short period of time. If this occurs, a light layer of sand may be helpful. Do not apply driveway sealer to the patched area for a period of 60-90 days of warm weather.

NOTE: Proper application and installation of all Sakrete products are the responsibility of the end user.

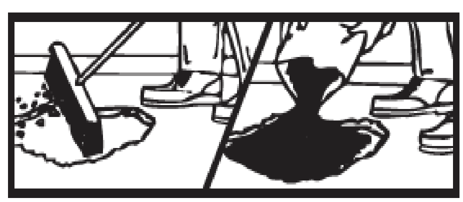
Safety:

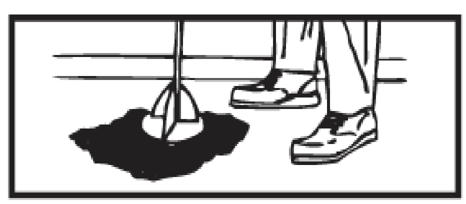
READ and UNDERSTAND the Safety Data Sheet (SDS) before using this product. WARNING: Wear protective clothing and equipment. For emergency information, call CHEMTREC at 800-424-9300 or 703-527-3887 (outside USA).

KEEP OUT OF REACH OF CHILDREN.

Limited Product Warranty:

The manufacturer warrants that this product shall be of merchantable quality when used or applied in accordance with the manufacturer's instructions. This product is not warranted as suitable for any purpose other than the general purpose for which it is intended. This warranty runs for one (1) year from the dates the product is purchased. ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ON THIS PRODUCT IS LIMITED TO THE DURATION OF THIS WARRANTY. Liability under this warranty is limited to replacement or defective products or, at the manufacturer's option, refund of the purchase price. CONSEQUENTIAL AND INCIDENTAL DAMAGES ARE NOT RECOVERABLE UNDER THIS WARRANTY.





Appendix A-4

QPR No VOC Repair Material Product Data Sheets

QUALITY PAVEMENT REPAIR

Asphalt Repair Products

SAFETY DATA SHEET
(Complies with OSHA 29 CFR 1910.1200)

SECTION I: PRODUCT IDENTIFICATION

QPR
One Securities Centre
3490 Piedmont Road, Suite 1300
Atlanta, GA 30305

Emergency Telephone Number
(800) 282-5828
Information Telephone Number
(800) 388-4338

Revision: Jun-15

Permanent Blacktop Repair

Product Use: Construction Material

SECTION II - HAZARD IDENTIFICATION

Classification of the substance or mixture

- **Skin Irritation – Category 2**
- **Eye Irritation – Category 2**
- **Carcinogenicity – Category 2**
- **Acute Toxicity – Oral – Category 4**
- **Acute Toxicity – Inhalation – Category 4**
- **Specific Target Organ Toxicity – Repeated Exposure – Category 2**

Signal word DANGER

Hazard pictograms

Hazard-determining components of labeling: Asphalt

Hazard Statements
Suspected of causing cancer through prolonged or repeated exposure.
Causes skin irritation.
Causes eye irritation.
Harmful if swallowed.

Harmful if inhaled.
May cause respiratory irritation

Do not handle until all safety precautions have been read and understood.
Wear impervious gloves, such as nitrile. Wear eye protection, and protective clothing.
Do not eat, drink or smoke when using this product.
Wash thoroughly after handling.
Use only in a well-ventilated area.
Do not breathe fumes.

If swallowed: Rinse mouth. Do NOT induce vomiting.
If inhaled: Remove person to fresh air and keep comfortable for breathing.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
If on skin (or hair): Remove immediately all contaminated clothing and wash before re-use. Rinse skin or hair with water.
If significant skin irritation or rash occurs: get medical advice or attention.

Immediately seek medical advice or attention if symptoms are significant or persist.

Store in a well-ventilated place. Keep container tightly closed.
Dispose of contents/containers in accordance with all regulations.

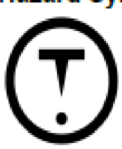
2.3 Additional Information

2.3a HNOC – Hazards not otherwise classified: Not applicable

2.3b Unknown Acute Toxicity: None
2.3C WHMIS Classification

Class D2B – Skin/Eye Irritant
Class D2A – Chronic Toxic Effects – Carcinogen

2.3d Label Elements According To WHMIS
Hazard Symbols



Signal Word
DANGER!

QUALITY PAVEMENT REPAIR

SECTION III - HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Components	CAS No.	% by Weight
Asphalt Cement	8052-42-4	1-5
Diesel Fuel	68476-34-6	1-5
Sand, Silica, Quartz	14808-60-7	95-100

*The concentrations ranges are provided due to batch-to-batch variability.

SECTION IV – FIRST AID MEASURES

General information:
Immediately remove any clothing soiled by the product. In case of unconsciousness place patient stably in side position for transportation. Never give anything by mouth to an unconscious person.
After inhalation: Vapor may cause nose, throat or lung irritation depending on the degree of exposure. Remove to fresh air. If breathing is irregular or stopped, administer artificial respiration. Seek medical attention immediately.
After skin contact: Contact with hot product will cause severe thermal burns. Cool skin rapidly with cold water after contact. Do NOT ATTEMPT TO REMOVE PRODUCT. Seek medical attention immediately.
After eye contact: Cool with cold water and seek medical attention immediately.
After ingestion: Immediately call a doctor. Do NOT induce vomiting unless advised to by medical professionals. Drink copious amounts of water and provide fresh air.
Acute/Delayed Symptoms: None known

SECTION V - FIRE FIGHTING MEASURES

Suitable extinguishing agents: Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.
Special hazards arising from the substance or mixture: No further relevant information available.
Protective equipment: Firefighters should wear NIOSH/MSHA approved self-contained breathing apparatus and full protective clothing.
Flammability of the Product: HMIS Rating - 1
Flash Points: Cleveland Open Cup (ASTM D92) >300°F (>149°C)
Products of Combustion: Carbon monoxide, carbon dioxide and potentially hydrogen sulfide gas.
Fire Hazards in Presence of Various Substances: Non-flammable.
Explosion Hazards in Presence of Various Substances: Non-explosive in presence of shocks
Special Remarks on Fire Hazards: Black, dense, hazy smoke forms during burning. Keep sparks away from concentrated fumes.

QUALITY PAVEMENT REPAIR

SECTION VI – ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures: Wear protective equipment (See section 8). Keep unprotected persons away and remove or secure all ignition sources.
Environmental precautions: Do not allow to enter sewers/ surface or ground water.
Methods and material for containment and cleaning up:
Allow material to cool to a solid form, cover with earth to reduce adhesiveness, place in appropriate containers for transport. Dispose contaminated material as waste according to section 13. Ensure adequate ventilation.
Reference to other sections
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND STORAGE

Handling
Precautions for safe handling: Ensure good ventilation/exhaustion at the workplace. Wear appropriate PPE (See section 8).
Information about protection against explosions and fires: No special measures required.
Storage
Requirements to be met by storerooms and receptacles: No special requirements.
Information about storage in one common storage facility: Not required.
Further information about storage conditions: Keep receptacle tightly sealed.
Specific end use(s): No further relevant information available

SECTION VIII – EXPOSURE CONTROL MEASURES / PERSONAL PROTECTION

Components with limit values that require monitoring at the workplace:

List	Component	CAS No.	Type	Value
ACGIH	Asphalt	8052-42-4	TWA	0.5 mg/m^3
ACGIH	Silica Sand, crystalline	14808-60-7	TWA	0.025 mg/m^3 (resp)

Additional information: The lists that were valid during the creation were used as basis.

General protective and hygienic measures: Keep away from foodstuffs, beverages and feed. Immediately remove all soiled and contaminated clothing. Wash hands before breaks and at the end of work. DO NOT use gasoline, kerosene, solvents or harsh abrasive skin cleaners to clean skin. Avoid contact with the eyes and skin. Use a full-body heat resistant or internally cooled suit when work conditions dictate.

QUALITY PAVEMENT REPAIR

Personal Protective Equipment

Protection of hands:
Wear leather or heat-resistant gloves of adequate length if handling heated material. With product at ambient temperatures, use chemical resistant gloves such as heavy nitrile.

Eye protection:
Use a full-face shield and chemical safety goggles. With product at ambient temperatures, safety glasses equipped with side shields are recommended.

Respiratory protection:
Contaminant air concentrations determine the level of respiratory protection required. Use only NIOSH-approved respiratory equipment within the limits of the protection factors for that equipment. Use supplied air respirators when H_2S concentrations are expected to exceed applicable workplace exposure levels. Do not use air purifying respiratory equipment when considering elevated H_2S concentrations. Respiratory equipment must be selected on the basis of the maximum expected air concentration.

SECTION IX - PHYSICAL/CHEMICAL CHARACTERISTICS

General Information

Appearance	Form: Solid at 25°C / Liquid above 135°C Color: Black Odor: Asphaltic
Boiling point/Boiling range:	NA
Flash point:	>300°F (>149°C)
Auto igniting:	NA
Relative Density at 25°C (77°F)	1.0 - 1.3
Solubility in / Miscibility with Water:	Insoluble
VOC content:	0 g/L VOC

SECTION X – STABILITY AND REACTIVITY

Thermal decomposition / conditions to be avoided: No decomposition if used according to specifications.
Incompatible materials: Strong oxidizing agents
Hazardous decomposition products: When heated, may liberate hydrogen sulfide. Combustion may produce various oxides of carbon (CO, CO_2...)

SECTION XI – TOXICOLOGICAL INFORMATION

QUALITY PAVEMENT REPAIR

Inhalation: No significant adverse health effects are expected to occur upon short-term exposure to this product at ambient temperatures. Asphalt fumes have been associated with irritation of eyes nose and throat. Also, lower respiratory effects have been reported. Hydrogen sulfide (H_2S) can evolve when this product is stored or handled at elevated temperatures. H_2S can cause respiratory irritation and hypoxia. At low concentrations, H_2S has an odor of rotten eggs. At higher concentrations, H_2S odor is not apparent. DO NOT use odor as an indicator of exposure to H_2S. Inhalation of high concentrations of H_2S may be fatal.

Skin irritation: Heated asphalt can cause burns to the skin. May cause skin irritation with redness, an itching or burning feeling, and swelling of the skin. Exposure to sunlight and to asphalt vapors may amplify tendency for sunburns.

Eye irritation: Heated asphalt can cause burns to the eyes. Mists, vapors or fumes from this material can cause eye irritation with tearing, redness, or a stinging or burning feeling.

Ingestion: Contact with heated asphalt may cause bums. If asphalt at ambient temperatures is swallowed, no significant adverse health effects are anticipated. If swallowed in large quantities, asphalt can obstruct the intestine.

Further information: Heated asphalt could release hydrogen sulfide gas. Toxic amounts H_2S could accumulate inside vessels containing heated asphalt.

Component	**CAS No.**	
Asphalt	8052-42-4	Acute oral toxicity: LD50 rat Dose: 5,001 mg/kg Acute dermal toxicity: LD50 rat Dose: 2,001 mg/kg

Component	
NTP	This product, Asphalt (CAS-No.: 8052-42-4), may contain trace amounts of benzene a chemical known to cause cancer.
IARC	Asphalt (Bitumen) (CAS-No.: 8052-42-4) Group 2B possibly carcinogenic to humans
OSHA	This product, Asphalt (CAS-No.: 8052-42-4), may contain trace amounts of benzene a chemical known to cause cancer.

SECTION XII – ECOLOGICAL INFORMATION

Aquatic toxicity: No further relevant information available.
Persistence and degradability: No further relevant information available.
Behavior in environmental systems:
Bioaccumulative potential: No further relevant information available.
Additional ecological information:
General notes:

QUALITY PAVEMENT REPAIR

Analysis for ecological effects has not been conducted on this product. Do not allow undiluted product or large quantities of it to reach ground water, water course or sewage system. Spills into waterways may be harmful to organisms and bottom feeders.

SECTION XIII – DISPOSAL CONSIDERATIONS

Waste treatment methods
Recommendation:
Do not allow product to reach waterways or storm sewers. Disposal must be made in accordance with local, state and federal regulations (see 40CFR 260 through 40 CFR 271).
Uncleaned packaging
Recommendation: Disposal must be made in accordance with local, state and federal regulations.

SECTION XIV – TRANSPORT INFORMATION

CFR

Proper shipping name: Elevated temperature liquid, n.o.s. (Asphalt)
UN-No. : 3257
Class: 9
Packing group: III
Hazard inducer: (Asphalt)

TDG

Proper shipping name: Elevated temperature liquid, n.o.s. (Asphalt)
UN-No. : 3257
Class: 9
Packing group: III
Hazard inducer: (Asphalt)

IMDG-Code

UN-No. : 3257
Description of the goods: Elevated temperature liquid, n.o.s. (Asphalt)
Class: 9
Packaging group: III
IMDG-Labels: 9
EmS Number: F-A S-P
Marine pollutant: No

SECTION XV – OTHER REGULATORY INFORMATION

UNITED STATES (FEDERAL AND STATE)
TSCA Status: Appears on the EPA TSCA inventory

SARA 302/311/312/313 Components: Acute Health Hazard: Asphalt (CAS No. 8052-42-4)

California Prop. 65 Components
This product contains chemicals known to State of California to cause cancer and birth defects or other reproductive harm.

CANADA
DSL Status
All components of this product are on the Canadian DSL list.

WHMIS Classification: Not regulated by the Controlled Products Regulations (CPR) or Health Canada's Workplace Hazardous Material Information (WHMIS). This document complies with the WHMIS requirements of the Hazardous Products Act (HPA) and the CPR.

SECTION XVI – OTHER INFORMATION

Abbreviations and acronyms:
ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
CAS: Chemical Abstract Service
RID: Regalement international concem ant le transport des marchandises dangereuses par chemin de fer (Regulations Concerning the International Transport of Dangerous Goods by Rail)
IMDG: International Maritime Code for Dangerous Goods
IATA: International Air Transport Association
ICAO: International Civil Aviation Organization
ACGIH: American Conference of Governmental Industrial Hygienists
NFPA: National Fire Protection Association (USA)
HMIS: Hazardous Materials Identification System (USA)
VOC: Volatile Organic Compounds (USA, EU)
CERCLA: Comprehensive Environmental Response, Compensation and Liability Act
CFR: Code of Federal Regulations
CPR: Controlled Products Regulations (Canada)
DOT: Department of Transportation
IARC: International Agency for Research
NIOSH: National Institute for Occupational Safety and Health
NTP: National Toxicity Program
OSHA: Occupational Safety and Health Administration
PEL: Permissible Exposure Limit
RCRA: Resource Conservation and Recovery Act
SARA: Superfund Amendments and Reauthorization Act
TLV: Threshold Limit Value
TWA: Time-weighted Average
WHMIS: Workplace Hazardous Material Information System

QUALITY PAVEMENT REPAIR

Last Updated: June 1, 2015

NOTE: The information and recommendations contained herein are based upon data believed to be correct. However, no guarantee or warranty of any kind, express or implied, is made with respect to the information contained herein. We accept no responsibility and disclaim all liability for any harmful effects which may be caused by exposure to silica contained in our products. End of SDS.

High Performance Permanent Pavement Repair Material Material Specification

QPR No VOC Repair Material

DESCRIPTION

This material shall be a plant or pug mill mixed, high performance pavement patching material capable of storage in an uncovered outdoor stockpile for a maximum of 12 months. It shall be composed of laboratory approved mineral aggregates and modified bituminous QPR® No VOC Liquid Blend capable of coating wet aggregates (up to 4% moisture) without stripping and have stripping resistance of retained coating of not less than 95%. The permanent asphalt repair shall be uniform, remain flexible and cohesive to -15°F and be capable of retaining adhesive qualities in wet applications. The patching materials shall be able to repair asphalt, concrete, surface treated roads and shall not require removal and replacement if ever the pavement is overlaid.

ENVIRONMENTAL IMPACT

The modified bituminous asphalt repair must have an independent test conducted by a certified laboratory as to toxicology results in a Static Acute Bio Assay Procedures for Hazardous Materials which determines effect of run-off into waterways, lakes, ponds, and ground water. Furthermore, results of analysis for the toxicity should indicate a 0% mortality rate of Daphnia magna at 100% effluent concentration. Further, the repair material must be classified as non-hazardous, and biologically non-toxic. QPR® No VOC Repair Material conforms to ASTM D402 requirements. Independent laboratory results are available for review.

MATERIALS

A) Aggregate

The aggregate shall consist of 100% crushed stone or a laboratory approved equivalent under ASTM C-136. All aggregate is to be from approved sources, and representative samples of both fine and coarse aggregate shall be from the plant site and laboratory tested. Sampling and testing methods shall be in accordance with accepted local practice.

Gradation analysis to comply with all local requirements. Recommended gradation analysis is as follows:

SCREEN SIZES	PERCENTAGE PASSING
3/8" (9.5mm)	100
#4 (4.75mm)	20 - 85
#8 (2.36mm)	2 - 30
#16 (1.18mm)	0 - 10
#50 (0.75mm)	0 - 6
#200	0 - 2

All aggregate percentages are based on the total weight of aggregate.

ASTM	C-88	Soundness Loss	12.0% Max.
ASTM	C-131	Los Angeles Abrasion	40.0% Max.
ASTM	C-117-200	-200 Sieve (by wash)	2.0% Max.
ASTM	C-127, 127	Absorption	1.0 - 2.0% Max.
ASTM	C-127, 128	Specific Gravity	2.55 - 2.75% Max
ASTM	C-122	Soft Aggregates	3.0% Max.

Aggregate Acceptance

Aggregate compatibility approval must be obtained from the QPR Quality Control Facility in Charleston, South Carolina prior to material mixing at any mixing plant.

B) *Bituminous Material*

The modified bituminous liquid blend shall be QPR® No VOC Liquid which meets the following requirements:

ASTM D-1310	Flashpoint (TOC):		400°F (204°C) Min.
ASTM D-2170	Kinematic Viscosity at 140°F (60°C):		300-4000
ASTM D-95	Water		0.2% Max.
ASTM D-402	Distillate Test (volume of original sample):		
	To 437°F (225°C)		0%
	To 500°F (260°C)		0%
	To 600°F (315°C)		0%
	Residue from distillate at 680°F (360°C)		0.62%
Residue Tests			
ASTM D-2171	ABS. Viscosity at 140°F (60°C):	125-425	Poises
ASTM D-5	Penetration:	200	Min.
ASTM D-113	Ductility at 39°F (4°C) 0.4 in./Min:	100	Min.
ASTM D-2042	Solubility in Trichloroethylene:	99%	Min.

QPR® No VOC Liquid Blend shall be shipped from authorized blending terminal locations. Liquid shall be completely blended at terminal under supervision of authorized Quality Control personnel. No additives, modifiers, or extra ingredients are to be introduced into the liquid blend at any time after shipment from terminal. A copy of bill of lading and material certification shall accompany every shipment. QPR® No VOC Liquid Blend shall be shipped in insulated tankers to maintain oil temperature during transportation.

PLANT MIX

The finished material shall consist of aggregates meeting material as specified in Section A) Aggregate, and the bituminous liquid blend meeting material specified in section B) QPR® No VOC Bituminous Material as indicated in the proposed job mix formula. QPR® No VOC Bituminous Material shall be accepted at the supplier's source and at the plant site on the basis of a supplier material certification.

The preferred mixing ratio shall be 4.0% to 6.0% liquid blend per finished metric ton (2,000 lbs.) of mixed material. Continuous on-site testing will determine exact final mixing ratio which will be identified in the final job mix formula. All aggregate percentages are based on the total weight of the aggregate. The QPR® No VOC Liquid Blend content is based on the total weight of the mix.
The job mix formula information shall provide:

- Aggregate gradation band and aggregate type.
- QPR® No VOC Liquid Blend - amount and type including any additives used.
- Temperature ranges for material preparation.

MANUFACTURING PREPARATION & OPERATION

Asphalt Plant Production

The mixture is to be produced through a conventional hot asphalt plant only under the direct supervision of a qualified QPR sales representative and finished product will not exceed 180°F (82°C). The QPR® No VOC Liquid Blend shall not be heated above 200°F. The final mixture must be tested in accordance with QPR on-site quality control requirements.

Pug Mill Production

The mixture can be produced through a cold manufacturing process (PUGMILL). The QPR® No VOC

Liquid Blend shall be heated between 220°F (104°C) to 260°F (126°C). The QPR® No VOC Liquid Blend temperature is elevated to help with the adhesion process between the bituminous liquid and the aggregate. The finished mix will not exceed 180°F when produced through the pugmill. The final mixture must be tested in accordance with the QPR on-site quality control requirements.

Stockpile Inspection

Prior to production, the stockpile site is to be inspected for any contaminant such as dirt, sand or debris that may affect the quality of the QPR® No VOC Repair Material. The stockpile area should be a hard surface, preferably paved with concrete, or a bituminous surface. Six (6) month shelf life. QPR® No VOC Repair Material may be stockpiled up to 6 months in an uncovered outdoor stockpile

Specification Sampling

A one quart sample of the QPR® No VOC Liquid Blend will be retained at the asphalt depot prior to shipping. On delivery of the tank truck, an additional one-quart sample will be taken by the QPR sales representative and is to be retained by the customer/producer for a period of one year, or until the stockpile is depleted

QPR® Quality Control

On each load, a Quality Control Report will be prepared by the QPR Quality Control Technician. All phases of production of the plant operation and the material testing on each 150 tons of production will be prepared and entered accordingly in each category. Site tests will be completed which include Spot Test, Strip Resistance, Coating Observation and Roll Test.

Heating of Finished Product

QPR No VOC Material should not be heated above 70°F (21°C) when utilizing a hot box.

Training of Installation Crews

QPR will make available a complete training program for all road crews to ensure correct patching methods, along with updates on this subject.

QPR No VOC High Performance Pavement Repair, when applied according to our directions to deteriorated concrete or bituminous pavement surfaces, is guaranteed to adhere permanently to the repaired area for the life of the repair or until the surrounding pavement area fails. QPR will replace actual volumes of QPR No VOC at no charge for any QPR No VOC High Performance Pavement Repair that should ever ravel or release from a properly repaired area.

Appendix A-5

Latexite® Super Patch Product Data Sheets

DALTON ENTERPRISES, INC.

TECHNICAL DATA SHEET
Latex•ite® SUPER PATCH™
Manufacturer Product#: 11916
UPC#: 090932119161

Dalton Driveway latex•ite

PHYSICAL PROPERTIES & PERFORMANCE

Appearance: Black Viscous Fluid with sand and stone	**Maximum VOC:** Less than 10 g/l
Application Temperature: n/a	**Specific Gravity:** 1.3-1.5
Viscosity: n/a	**Weight Per Gallon:** 10.8-11.6 lbs. per gallon
Color: Black	**Consistency:** Solid
Boiling Point: 900° F	**Cure Time (50% relative humidity, 70° F):** Immediate once compacted
Freeze ability: n/a	**Container Size & Weight:** 3.5 gallons, approx. 40 lbs.

FEATURES

Latex•ite® SUPER PATCH™ is a stone asphalt patch for driveways and pavements. It is recommended for **POTHOLES**, large cracks and joints. It can be used on both asphalt and concrete and is designed to be used year-round. Latex•ite® SUPER PATCH™ contains asphalastic binders which give it maximum adhesion and longer life. .

- **Black, stone aggregate formula.**
- **For potholes, joints and large cracks.**
- **Contains asphalastic binders for maximum adhesion to sidewalls.**
- **Just pour and tamp ... traffic ready immediately.**
- **Year-round formula.**

SURFACE PREPARATION

Latex•ite® SUPER PATCH™ is easy to use. It is important to remember that Latex•ite® SUPER PATCH™ works on compaction and must have sidewalls to work properly. If it is put in a depression with no sidewalls, it will not work. We recommend square cutting the vertical sides of the crack or hole wing a chisel and remove all loose debris. Next sweep or blow out the pothole. Allow to dry.

APPLICATION

Fill the hole with Latex•ite® SUPER PATCH™ to a height of ½" above the area. Compact the hole using a tamper or heavy, flat item such as a cinderblock. You may also put a piece of plywood over the area and drive over it with your car for maximum

Dalton Enterprises, Inc., 131 Willow Street, Cheshire, CT 06410
Phone 800-851-5606 • Fax (203) 271-3396 • www.latexite.com
Revised 1/26/09

compaction. It is ready for traffic once it's been fully compacted. If you plan to seal over the repaired area, we recommend you wait 2 weeks prior to sealing. There are oils in the product and you can help speed up the cure rate by sprinkling sand or Portland cement over the repair. Remember, if the repaired area is not setting up, it's most likely because it has not been compacted enough. For deep repairs, tamp the bottom 3 inches, fill, tamp next 3 inches, etc. working your way up to the surface.

PRECAUTIONS

Allow all repaired surfaces to cure 2 weeks prior to sealing. When transporting this product, ensure that the container is secured and the lid is secure. Do not allow the container to tumble as this may loosen the lid and allow leakage to occur. Do not transport on passenger seats or inside the passenger compartment of any vehicle. Protective clothing and eyewear should be used during application.

CLEAN UP & STORAGE

Wash tools with soap and warm water.

!!!CAUTION!!!

Latex•ite® SUPER PATCH™ is for exterior use only. Keep out of reach of children. Keep container capped when not in use. Non-flammable. This product contains chemicals known to the state of California to cause cancer and birth defects or other reproductive harm.

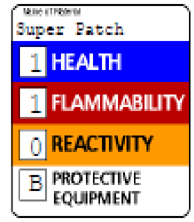
Emergency & First Aid Procedures:

Eyes: Immediately flush with clean water for 15 minutes while holding eyelids open; consult a physician.
Inhalation: If overcome by mist or vapor, remove from exposure immediately; call a physician. If breathing is stopped or irregular, start resuscitation, administer oxygen.
Skin: Remove any contaminated clothing and wash skin with soap and warm water.
Ingestion: DO NOT INDUCE VOMITING even though vomiting may occur. If vomiting occurs, keep head below hips to prevent aspiration of liquid into the lungs. Get immediate medical attention.

WARRANTY AND DISCLAIMER

There are no express warranties which extend beyond the description on the face hereof. MANUFACTURER DISCLAIMS ANY IMPLIED WARRANTIES OF MERCHANTIBILITY, OR OF FITNESS FOR ANY PARTICULAR PURPOSE. Since seller cannot control the manner of use of its products after their sale, seller will not be responsible for any consequential of indirect damages. Rather, seller will, at its options, either replace the goods sold or refund the purchase price. No warranties will apply if the goods are in any way altered or modified after delivery by seller.

SAFETY DATA SHEET



Section I – PRODUCT AND COMPANY IDENTIFICATION

Product Name: Latexite® Super Patch (Stone Patch)
Manufacturer Name: Dalton Enterprises, Inc.
UPC #: 1 gal: 090932319165; **3.5 gal:** 090932119161 **Pallet:** 090932399501
Address: 131 Willow Street Cheshire, CT 06410
Package Size: Container size 1 gal or 3.5 gal
Telephone Number: (203) 272-3221
24 Hour Emergency Number: (203) 272-3221
U.S. And Canada: (203) 272-3221
Trade Names and Synonyms: Asphalt Patch Materials
Recommended Use and Restrictions: Filler / Patch for asphalt pavement

Section II – HAZARDS IDENTIFICATION

Classification

Skin Corrosion/Irritation	Category 2
Serious Eye Damage, Eye Irritation	Category 2
Carcinogenicity	1A

Label Elements

Signal Word: Warning
Hazard Statements:
Harmful if swallowed
May cause skin irritation
May cause cancer

GHS Pictogram: 

Precautionary Statements – Prevention
Obtain special instructions before use
Do not handle until all safety precautions have been read and understood
Use personal protective equipment as required
Wash face, hands and any exposed skin thoroughly after handling
Do not eat, drink or smoke when using this product
Use only outdoors or in a well-ventilated area

Eyes: Contact may cause irritation.
Skin: Prolonged or repeated contact may cause irritation.
Ingestion: May cause nausea, vomiting and diarrhea.
Inhalation: May cause irritation

Precautionary Statements - Storage
Store locked up
Precautionary Statements - Disposal
Dispose of contents/container in accordance with local regulations.
Hazards not otherwise classified (HNOC)
Not applicable
Unknown Toxicity
0% of the mixture consists of ingredient(s) of unknown toxicity
Other information
No information available
Interactions with Other Chemicals
No information available.

Section III – COMPOSITION

CAS#	Component	% Composition
8052-42-4	Petroleum Asphalt	20-55
14808-60-7	Processed Sand	10-20
1317-65-3	Crushed Stone	70-90

Section IV – FIRST-AID MEASURES

Emergency and First Aid Procedures

General Advice: Present this safety data sheet to the physician in attendance.
Eye Contact: Flush thoroughly with water. If irritation persists, see a physician.
Skin Contact: Clean exposed area thoroughly with soap and water. If irritation persists see a physician.
Ingestion: If swallowed do NOT induce vomiting. Seek medical attention if symptoms develop.
Inhalation: Move to fresh air if symptoms develop. If irritation persists see a physician.
Most Important Symptoms: Possibility of minor eye and skin irritation.
Indication of Immediate Medical Attention and Special Treatment Needed: Treat Symptomatically

Section V – FIRE-FIGHTING MEASURES

Suitable Extinguishing Media: CO_2, dry chemical, foam, sand.

Unsuitable Extinguishing Media: N/A
Specific Hazards arising From the Chemical: Combustion may yield fumes, smoke, carbon monoxide and carbon dioxide.
Special Protective Equipment and Precautions for Firefighters: Wear full protective clothing, including self-contained breathing apparatus (Positive Pressure/Pressure Demand), helmet, and face mask.

Section VI – ACCIDENTAL RELEASE MEASURES

Personal Precautions, Protective Equipment and Emergency Procedures: Avoid skin and eye contact, use proper protective equipment recommended in section 8.
Methods and Materials for Containment and Cleanup: Contain spill and dike with inert material (sand, sawdust, dirt, etc.). Place in closed container for proper disposal. Avoid runoff to waterways and sewers. Dispose of in accordance with local regulations.

Section VII – HANDLING AND STORAGE

Precautions for Safe Handling: Store in a dry area, avoid eye contact and wash thoroughly after handling
Conditions for Safe Storage, Including Incompatibilities: Keep container closed and upright to prevent leakage. Store in a cool, dry, ventilated area. Avoid freezing. Keep container upright to prevent leakage.

Section VIII – EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Guidelines

Component	ACGIH TWA (mg/m^3)	OSHA PEL (TWA) (mg/m3)
Petroleum Asphalt	0.5 mg/m^3	-
Processed Sand	0.025 mg/m^3	(30)/(%SiO2 + 2) mg/m3 TWA, total dust (250)/(%SiO2 + 5) mppcf TWA, respirable fraction (10)/(%SiO2 + 2) mg/m3 TWA, respirable fraction
Crushed Stone	-	15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)

Engineering Controls: Ensure adequate ventilation

Individual Protection Measures

Eyes/Face: Safety goggles
Skin: Gloves
Respiratory: None required if good ventilation is maintained. This product is an emulsified, encapsulated mixture which greatly reduces the likelihood of exposure to hazardous particles.

Hygienic controls: Wash thoroughly with soap and water before eating or drinking. Wash contaminated clothing.

Section IX – PHYSICAL AND CHEMICAL PROPERTIES

Appearance: Sand/Stone mixed with black fluid
Physical State: Solid
Upper Explosive Limit: N/A
Lower Explosive Limit: N/A

Odor: Asphaltic odor
Odor Threshold: N/A
pH: N/A
Melting Point: N/A
Boiling Point: 900F
Flash Point: N/A
Evaporation Rate: N/A
Flammability: N/A
Vapor Pressure: Nearly equal to water
Vapor Density: Heavier than air
Specific Gravity: 1.3
Solubility In Water: Negligible
Partition Coefficient (n-octanol/water): N/A
Auto Ignition Temperature: N/A
Decomposition Temperature: N/A
Max Voc: < 10g/L

Section X – STABILITY AND REACTIVITY

Reactivity: None known under normal conditions
Stability: Stable
Hazardous Reactions: None known under normal conditions
Conditions to avoid: Keep from freezing and extreme heat
Incompatibility: Strong oxidizers
Hazardous Decomposition Products: Combustion may yield fumes, smoke, carbon monoxide and carbon dioxide.

Section XI – TOXICOLOGICAL INFORMATION

Health Effects
Eye Contact: Minor irritation may result
Skin Contact: Minor irritation may result
Ingestion: Minor irritation may result
Inhalation: Minor irritation may result
Toxicological Effects

Component	CAS #	Acute oral toxicity LD50	Acute dermal toxicity LD50
Petroleum Asphalt	8052-42-4	5,001 mg/kg (rat)	2,001 mg/kg (rat)
Processed Sand	14808-60-7	1,300 mg/kg (rat)	no data available

Delayed and immediate effects as well as chronic effects from short and long-term exposure
Sensitization: Product not known to cause sensitization
Mutagenic Effects: None known
Carcinogenicity: May cause cancer

Component	CAS #	IARC	NTP	OSHA
Petroleum Asphalt	8052-42-4	2B	Suspected	
Processed Sand	14808-60-7	Group 1	Known	

Reproductive Toxicity: No toxicity known
STOT – Single Exposure: None Known
STOT – Repeated Exposure: None Known

Chronic Toxicity: No Known Effect
Target Organ Effects: Eyes, Skin.
Aspiration Hazard: Based on available data, the classification criteria are not met.

Numerical Measures of Toxicity
No data available

Section XII – ECOLOGICAL INFORMATION

Ecological Fate:	No data available
Persistence/Degradability	No data available
Bioaccumulation Potential:	No data available
Mobility in Soil:	No data available
Other Adverse Effects:	No data available

Analysis for ecological effects has not been conducted.

Section XIII – DISPOSAL CONSIDERATIONS

Waste Disposal Information: Dispose of in accordance with federal, state, and local regulations.

Section XIV – TRANSPORT INFORMATION

DOT
Proper Shipping Name: Not regulated
UN Number: N/A
Hazard Class: N/A

Section XV – REGULATORY INFORMATION

International Inventories
TSCA: Complies

US Federal Regulations
SARA 313: This product contains no chemicals subject to Annual Release Reporting Requirements under SARA Title III, Section 313 (40 CFR 372)

SARA Hazard Category (311/312): Non Hazardous

CWA (Clean Water Act): This product contains no chemicals regulated by the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42)

CERCLA: This product contains no substances regulated by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302)

US State Regulations

Component Name	CAS	State Right to Know		
		MA	NJ	PA
Petroleum Asphalt	8052-42-4	yes	yes	yes
Processed Sand	14808-60-7	yes	yes	yes
Crushed Stone	1317-65-3	yes	yes	yes

International Regulations
WHMIS: Non Hazardous

Section XV – OTHER INFORMATION

Other precautions:
Keep out of reach of children.
Always read label plus precautions and follow directions carefully.
Do not breathe vapor or spray mist.
Use only with adequate ventilation.
Do not take internally.
Avoid contact with eyes and skin.
Wash thoroughly after using.

NFPA Rating: Health 1; Fire 1; Reactivity 0

Revision Date: 04/03/15
Supersedes: 06/09/09
Prepared by: RL

Disclaimer/Statement of Liability:
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Appendix A-6

Drive-Patch Blacktop Crack & Hole Repair Product Data Sheets

Black Jack

6460

DRIVE-PATCH BLACKTOP CRACK & HOLE REPAIR Data Sheet

- Heavy Duty Sand/Asphalt Mix
- Smooth Finish
- Ideal for Larger Cracks or Small Holes

DESCRIPTION: **Drive-Patch Blacktop Crack & Hole Repair** is a ready to use cement textured patching compound. It is a latex fortified and provides a long lasting durable patch that resists gas, oil and chemical deterioration. Use **Drive-Patch Blacktop Crack & Hole Repair** to repair small holes and cracks (up to 3" deep) or to smooth out surfaces that are damaged by gasoline and oil spillage. Dries black.

PREPARATION: Use **Driveway Kleen™** prior to applying driveway patches and coating to surface to remove dirt, and light oil stains. This degreaser will allow for much improved adhesion of driveway sealers. On heavier oil stains, apply liberally and scrub area for best results. Rinses thoroughly with water leaving no puddles. Remove any loose and flaking material from area prior to application.

APPLICATION: Apply product on a clear, warm, sunny day when surface temperature is at least 65°F and rising. Mix contents to a uniform consistency and apply to dampened surface. Do not apply to cracks or holes which have water puddles. Use trowel or putty knife to apply **Drive-Patch** to problem areas, ending with a smooth surface finish. For repairs or depths greater than 1", it is recommended that the compound be applied in layers. This will assure proper drying and strength. Area is ready to be sealcoated in approximately 24 hours.

DO NOT APPLY AT TEMPERATURES BELOW 50°F
DO NOT ALLOW STORED PRODUCT TO FREEZE.

COVERAGE RATE: Approximately 10 lbs. will patch an area 10 sq. ft. x 1/8 inch deep.

CLEAN-UP: Clean tools with soap and water when wet, or an orange citrus cleaner when cured.

PRECAUTIONS: When transporting this product, ensure that lid is tight and pail secure and upright. Do not allow pail to tumble as this may cause lid to loosen and leakage to occur. Do not transport on passenger seats or inside the passenger compartment of any vehicle. Store product in the cargo area of vehicle, and secure over protective cloths to prevent damage due to accidental spills.

TYPICAL PHYSICAL & PERFORMANCE CHARACTERISTICS

Weight Per Gallon, lbs.	15.5 lbs.
Residue by Evaporation, %	90 min.
Combustible Solvents	None
Consistency	Trowel
Cure Time (at recommended coverage)	24 hours
Application Temperatures	65°F and rising
Flammability (Flash point, °F solvent)	N/A
Clean-up Tools	Soap and water when wet Orange citrus cleaner when cured

Approx. Shipping Weights: (Note: All approx. weights include container.)

1 gal. pail	10 lbs. (4.5 kg)

CAUTION! HARMFUL OR FATAL IF SWALLOWED

For exterior use only. Contains petroleum based products. Keep away from heat, sparks and open flame. Use only with adequate ventilation. Eye and skin irritant. Persons with skin or respiratory sensitivity should not use product without sufficient protection. Avoid contact with skin and breathing vapor. If swallowed, do not induce vomiting. Call physician immediately. Seal container when not in use. Do not use in drinking water or food systems.

CAUTION! EYE, SKIN AND RESPIRATORY IRRITANT - DO NOT INGEST
KEEP OUT OF REACH OF CHILDREN.

CALIF. PROP. 65 • CHEMICAL WARNING (CALIFORNIA HEALTH AND SAFETY CODE #25249.5 ET SEQ). WARNING: This product contains chemicals known to the State of California to cause cancer, birth defects or reproductive harm. Use proper protection and adequate ventilation, when using product.

VOC/VOS = 10g/l

CLAY C.A.S.#1332-58-7
SAND C.A.S.#14808-60-7
ASPHALT C.A.S.#8052-42-4

Product is asbestos free

PATENT PENDING

Manufactured by Gardner Asphalt, P.O. Box 5449, Tampa, FL 33675

WARRANTY AND DISCLAIMER:
Gardner Asphalt Co., warranties this product to give satisfactory results when our directions are followed in its use and application, for a period of 12 months from the date of purchase. In no event however shall the manufacturer be liable for an amount in excess of the purchase price of the product used. If not completely satisfied, return to place of purchase for a refund.

See MSDS for more info

MADE IN THE USA

Gardner-Gibson, Inc. • P.O. Box 5449 • Tampa, Florida 33675-5449
Phone: (813) 248-2101 • Fax (813) 248-6768 • www.gardnerasphalt.com

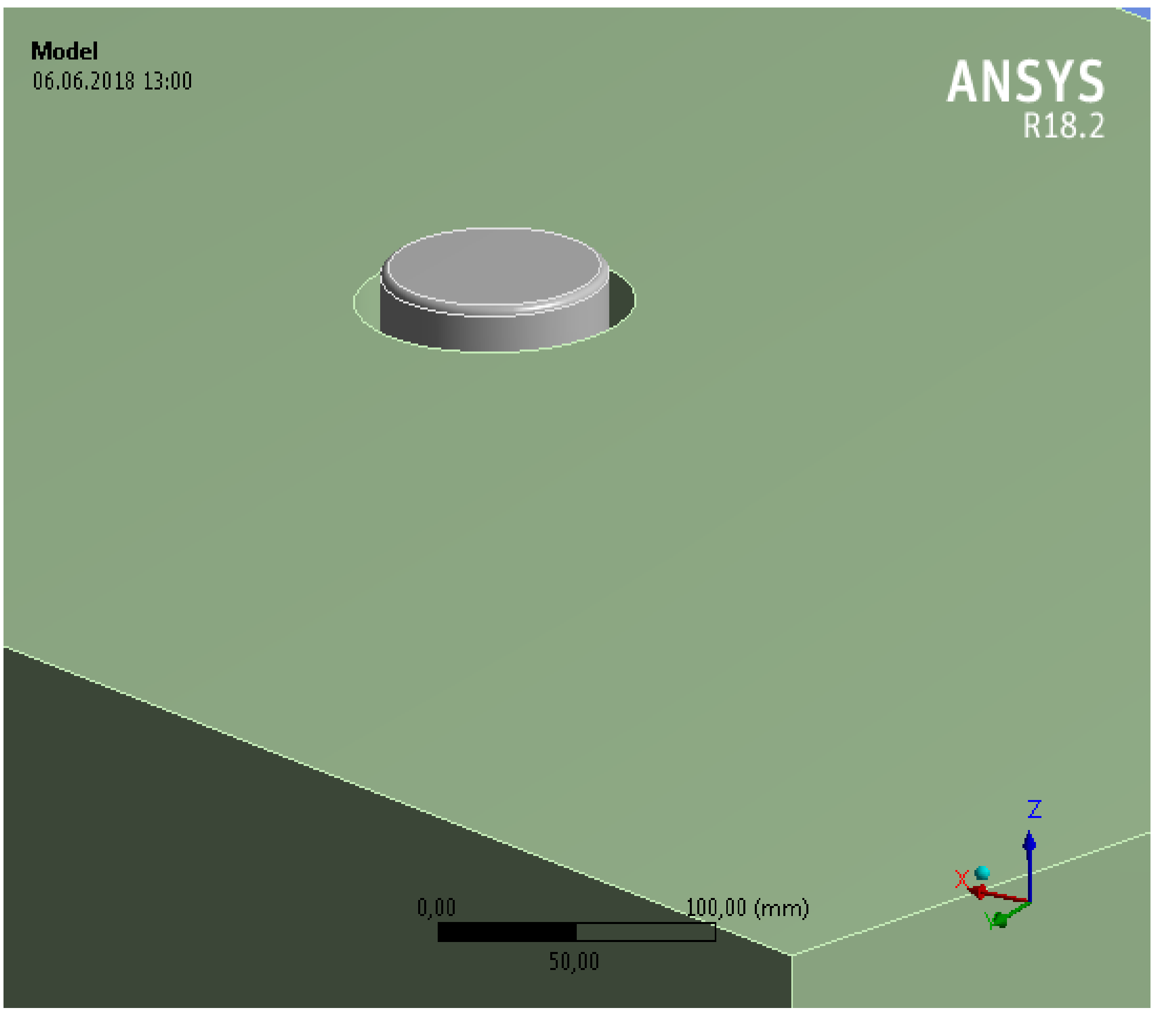
APPENDIX B

Appendix B-1

Finite Element Model No. 1 ANSYS Report

Project

First Saved	Thursday, May 31, 2018
Last Saved	Tuesday, June 05, 2018
Product Version	18.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (B4)

Geometry

TABLE 2
Model (B4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	F:\Hammer\10_strokers_files\dp0\SYS-1\DM\SYS-1.agdb
Type	DesignModeler
Length Unit	Meters
Display Style	Body Color
Bounding Box	

Length X	1262,4 mm
Length Y	1000,1 mm
Length Z	412,73 mm
Properties	
Volume	1,4104e+008 mm³
Mass	1102,9 kg
Scale Factor Value	1,
Statistics	
Bodies	4
Active Bodies	4
Nodes	23693
Elements	112486
Mesh Metric	None
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (B4) > Geometry > Body Groups

Object Name	*Part*
State	Meshed
Graphics Properties	
Visible	Yes
Definition	
Suppressed	No
Assignment	Multiple Materials
Coordinate System	Default Coordinate System
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	139,7 mm
Properties	
Volume	8,9849e+005 mm³

Mass	2,8193 kg
Centroid X	-0,76666 mm
Centroid Y	49,721 mm
Centroid Z	20,211 mm
Moment of Inertia Ip1	6035,1 kg·mm²
Moment of Inertia Ip2	6035,1 kg·mm²
Moment of Inertia Ip3	3465,3 kg·mm²
Statistics	
Nodes	12079
Elements	62364
Mesh Metric	None
CAD Attributes	
DMBodyGroup	4

TABLE 4
Model (B4) > Geometry > Part > Parts

Object Name	*cap*	*core*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Assignment		
Bounding Box		
Length X	82,55 mm	101,6 mm
Length Y	82,55 mm	101,6 mm
Length Z	38,1 mm	101,6 mm
Properties		
Volume	74783 mm³	8,237e+005 mm³
Mass	0,58705 kg	2,2322 kg
Centroid X	-0,76666 mm	
Centroid Y	49,721 mm	
Centroid Z	75,516 mm	5,6661 mm
Moment of Inertia Ip1	431,22 kg·mm²	3336,1 kg·mm²
Moment of Inertia Ip2	431,22 kg·mm²	3336,1 kg·mm²
Moment of Inertia Ip3	614,14 kg·mm²	2851,2 kg·mm²
Statistics		
Nodes	1706	10603
Elements	5516	56848
Mesh Metric	None	

TABLE 5
Model (B4) > Geometry > Parts

Object Name	*floor*	*hammer*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	Rigid
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	1262,4 mm	31,615 mm
Length Y	1000,1 mm	31,365 mm
Length Z	181, mm	119,02 mm
Properties		
Volume	1,4011e+008 mm³	33746 mm³
Mass	1099,9 kg	0,2649 kg
Centroid X	-0,76666 mm	-0,1293 mm
Centroid Y	49,721 mm	50,514 mm
Centroid Z	-8,8313 mm	238,88 mm
Moment of Inertia Ip1	4,912e+007 kg·mm²	200,04 kg·mm²
Moment of Inertia Ip2	1,154e+008 kg·mm²	203,61 kg·mm²
Moment of Inertia Ip3	1,585e+008 kg·mm²	22,428 kg·mm²
Statistics		
Nodes	1821	9793
Elements	8279	41843
Mesh Metric	None	

Coordinate Systems

TABLE 6
Model (B4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Origin	
Origin X	0, mm
Origin Y	0, mm
Origin Z	0, mm
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 7
Model (B4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 8
Model (B4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	4,1564 mm
Use Range	No
Face/Face	Yes
Face Overlap Tolerance	Off
Cylindrical Faces	Include
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	2
Active Connections	2

TABLE 9
Model (B4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region 2*	*Contact Region 3*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Contact	1 Face	2 Faces
Target	1 Face	2 Faces
Contact Bodies	cap	core
Target Bodies	core	floor
Definition		
Type	Bonded	

Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	4,1564 mm
Maximum Offset	1,e-004 mm
Breakable	No
Suppressed	No

TABLE 10
Model (B4) > Connections > Body Interactions

Object Name	*Body Interactions*
State	Fully Defined
Advanced	
Contact Detection	Trajectory
Formulation	Penalty
Sliding Contact	Discrete Surface
Body Self Contact	Program Controlled
Element Self Contact	Program Controlled
Tolerance	0,2

TABLE 11
Model (B4) > Connections > Body Interactions > Body Interaction

Object Name	*Body Interaction*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Frictionless
Suppressed	No

Mesh

TABLE 12
Model (B4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Explicit
Relevance	0
Element Order	Linear
Sizing	
Size Function	Proximity and Curvature
Relevance Center	Coarse
Max Face Size	Default (82,8690 mm)
Mesh Defeaturing	Yes
Defeature Size	Default (0,414340 mm)

Transition	Fast
Growth Rate	Default (1,850)
Span Angle Center	Coarse
Min Size	Default (0,828690 mm)
Max Tet Size	Default (165,740 mm)
Curvature Normal Angle	Default (70,3950 °)
Proximity Min Size	Default (0,828690 mm)
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Bounding Box Diagonal	1662,60 mm
Minimum Edge Length	1,0485e-003 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Number of Retries	0
Rigid Body Behavior	Full Mesh
Rigid Face Mesh Type	Quad/Tri
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Default (0,745820 mm)
Generate Pinch on Refresh	No
Statistics	
Nodes	23693
Elements	112486

TABLE 13
Model (B4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Suppressed	No
Type	Element Size

Element Size	5,0 mm
Advanced	
Defeature Size	Default (0,41434 mm)
Size Function	Uniform
Behavior	Soft
Growth Rate	Default (1,85)

Explicit Dynamics (B5)

TABLE 14
Model (B4) > Analysis

Object Name	*Explicit Dynamics (B5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Explicit Dynamics
Solver Target	AUTODYN
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 15
Model (B4) > Explicit Dynamics (B5) > Initial Conditions

Object Name	*Initial Conditions*
State	Fully Defined

TABLE 16
Model (B4) > Explicit Dynamics (B5) > Initial Conditions > Initial Condition

Object Name	*Pre-Stress (None)*
State	Fully Defined
Definition	
Pre-Stress Environment	None
Pressure Initialization	From Deformed State

TABLE 17
Model (B4) > Explicit Dynamics (B5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Analysis Settings Preference	
Type	Program Controlled
Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	2,e-003 s
Maximum Energy Error	0,1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled

Maximum Time Step	Program Controlled
Time Step Safety Factor	0,9
Characteristic Dimension	Diagonals
Automatic Mass Scaling	No
Solver Controls	
Solve Units	mm, mg, ms
Beam Solution Type	Bending
Beam Time Step Safety Factor	0,5
Hex Integration Type	Exact
Shell Sublayers	3
Shell Shear Correction Factor	0,8333
Shell BWC Warp Correction	Yes
Shell Thickness Update	Nodal
Tet Integration	Average Nodal Pressure
Shell Inertia Update	Recompute
Density Update	Program Controlled
Minimum Velocity	1,e-003 mm s^-1
Maximum Velocity	1,e+013 mm s^-1
Radius Cutoff	1,e-003
Minimum Strain Rate Cutoff	1,e-010
Euler Domain Controls	
Domain Size Definition	Program Controlled
Display Euler Domain	Yes
Scope	All Bodies
X Scale factor	1,2
Y Scale factor	1,2
Z Scale factor	1,2
Domain Resolution Definition	Total Cells
Total Cells	2,5e+05
Lower X Face	Flow Out
Lower Y Face	Flow Out
Lower Z Face	Flow Out
Upper X Face	Flow Out
Upper Y Face	Flow Out
Upper Z Face	Flow Out
Euler Tracking	By Body
Damping Controls	
Linear Artificial Viscosity	0,2
Quadratic Artificial Viscosity	1,
Linear Viscosity in Expansion	No
Artificial Viscosity For Shells	Yes
Hourglass Damping	AUTODYN Standard
Viscous Coefficient	0,1
Static Damping	0,
Erosion Controls	
On Geometric Strain Limit	Yes
Geometric Strain Limit	1,5
On Material Failure	No

On Minimum Element Time Step	No
Retain Inertia of Eroded Material	Yes
Output Controls	
Save Results on	Equally Spaced Points
Result Number Of Points	20
Save Restart Files on	Equally Spaced Points
Restart Number Of Points	5
Save Result Tracker Data on	Cycles
Tracker Cycles	1
Output Contact Forces	Off
Analysis Data Management	
Solver Files Directory	F:\Hammer\10_strokers_files\dp0\SYS-1\MECH\
Scratch Solver Files Directory	

TABLE 18
Model (B4) > Explicit Dynamics (B5) > Accelerations

Object Name	*Standard Earth Gravity*
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Global Coordinate System
X Component	0, mm/s²
Y Component	0, mm/s²
Z Component	-9806,6 mm/s²
Suppressed	No
Direction	-Z Direction

FIGURE 1
Model (B4) > Explicit Dynamics (B5) > Standard Earth Gravity

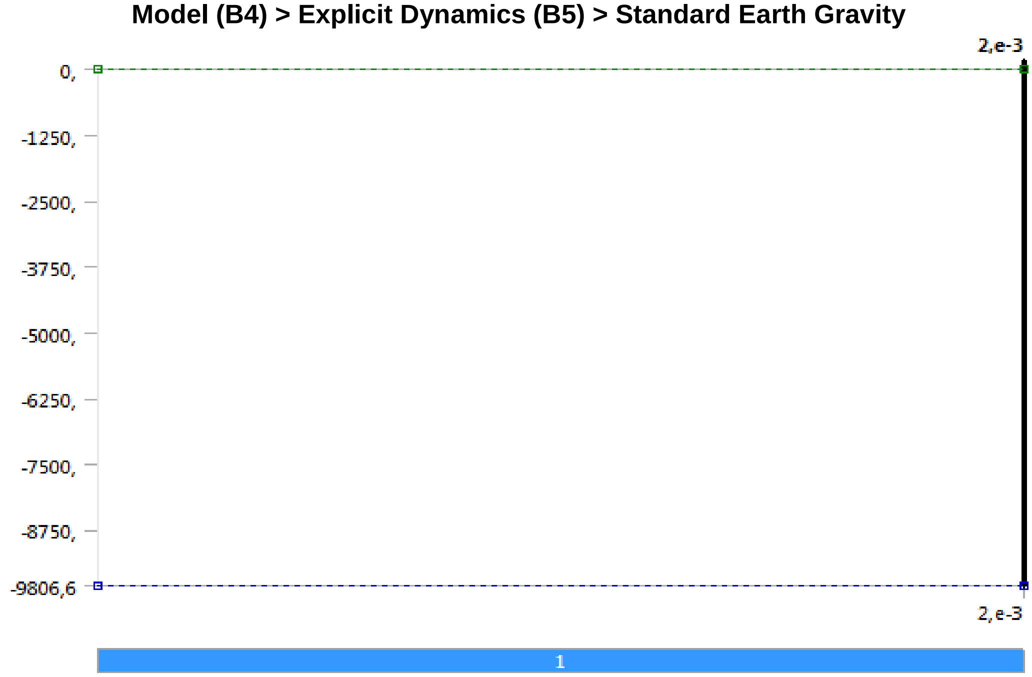


TABLE 19
Model (B4) > Explicit Dynamics (B5) > Loads

Object Name	*Fixed Support*	*Displacement*
State	Suppressed	Fully Defined
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	1 Body
Definition		
Type	Fixed Support	Displacement
Suppressed	Yes	No
Define By		Components
Coordinate System		Global Coordinate System
X Component		Free
Y Component		Free
Z Component		Tabular Data
Tabular Data		
Independent Variable		Time

FIGURE 2
Model (B4) > Explicit Dynamics (B5) > Displacement

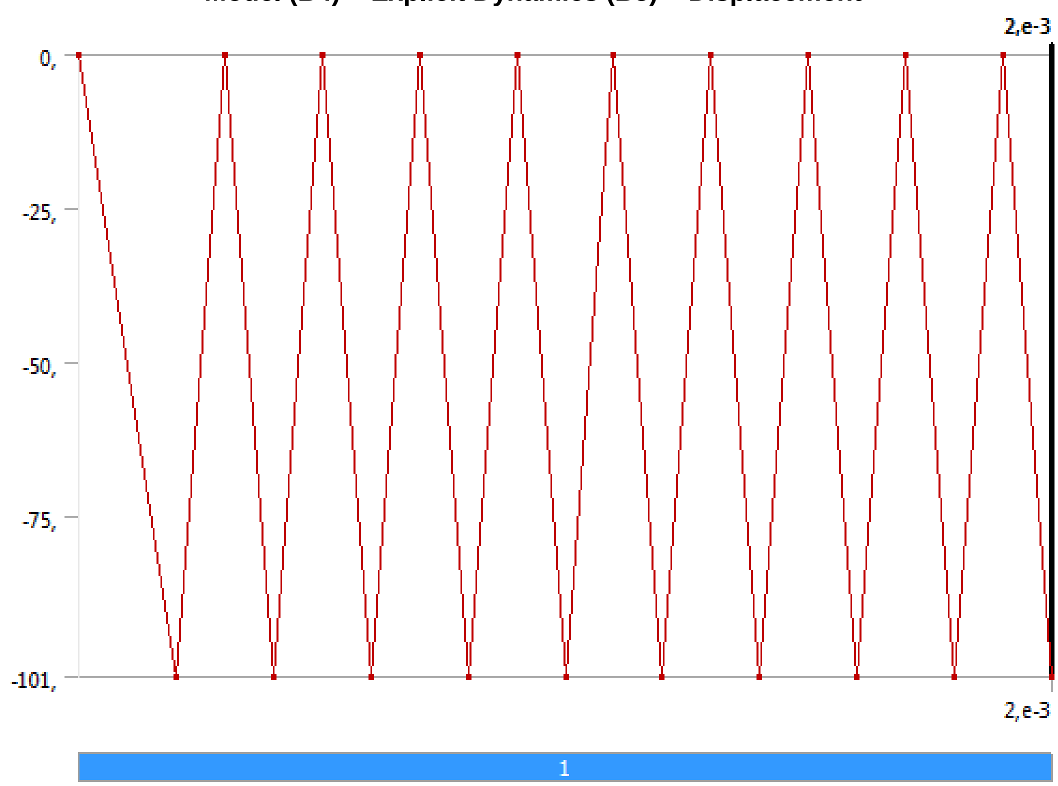


TABLE 20
Model (B4) > Explicit Dynamics (B5) > Displacement

Steps	Time [s]	Z [mm]
1	0,	0,
	2,e-004	-101,
	3,e-004	0,
	4,e-004	-101,
	5,e-004	0,
	6,e-004	-101,
	7,e-004	0,
	8,e-004	-101,
	9,e-004	0,
	1,e-003	-101,
	1,1e-003	0,
	1,2e-003	-101,
	1,3e-003	0,
	1,4e-003	-101,
	1,5e-003	0,
	1,6e-003	-101,
	1,7e-003	0,
	1,8e-003	-101,
	1,9e-003	0,
	2,e-003	-101,
N/A	1,e-002	0,

Solution (B6)

TABLE 21
Model (B4) > Explicit Dynamics (B5) > Solution

Object Name	*Solution (B6)*
State	Solved
Information	
Status	Done
Post Processing	
Beam Section Results	No

TABLE 22
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Update Interval	2,5 s
Display Points	All
Display Filter During Solve	Yes

TABLE 23
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Results

Object Name	*Total Deformation*	*Directional Acceleration*	*Total Deformation 2*	*Total Deformation 3*	*Equivalent Elastic Strain*	*Total Deformation 4*	*Normal Elastic Strain*	*Directional Deformation*	*Total Deformation 5*	*Total Deformation 6*	*Equivalent Stress*
State	Solved										
Scope											
Scoping Method	Geometry Selection										
Geometry	All Bodies			1 Body	All Bodies	1 Body	3 Bodies				2 Bodies
Definition											
Type	Total Deformation	Directional Acceleration	Total Deformation		Equivalent Elastic Strain	Total Deformation	Normal Elastic Strain	Directional Deformation	Total Deformation		Equivalent (von-Mises) Stress
By	Time										
Display Time	Last			1,4e-003 s	Last	1,9e-003 s	Last			1,8002e-003 s	1,3002e-003 s
Calculate Time History	Yes										
Identifier											
Suppressed	No										
Orientation		X Axis					X Axis	Z Axis			
Coord. System		Global Coordinate System					Global Coordinate System				
Results											
Minimum	5,583e-002 mm	-4,8277e+011 mm/s²	5,583e-002 mm	0,36289 mm	0, mm/mm	5,5814e-002 mm	-0,82465 mm/mm	-101,1 mm	9,9578e-002 mm	1,1266e-002 mm	17,529 MPa
Maximum	101,1 mm	1,3752e+011 mm/s²	101,1 mm	12,731 mm	1,6551 mm/mm	1,4871 mm	2,5479e-002 mm/mm	0,41539 mm	101,1 mm	100,93 mm	1,7236e+005 MPa
Minimum Occurs On	floor	cap	floor	cap	hammer	core	cap	hammer	core		
Maximum Occurs On	hammer	cap	hammer	cap		core	cap		hammer		cap
Minimum Value Over Time											
Minimum	0, mm	-1,6996e+012 mm/s²	0, mm		0, mm/mm	0, mm	-0,84056 mm/mm	-101,23 mm	0, mm		0, MPa
Maximum	5,583e-002 mm	0, mm/s²	5,583e-002 mm	0,64122 mm	0, mm/mm	9,9578e-002 mm	0, mm/mm	0, mm	9,9578e-002 mm		19,508 MPa
Maximum Value Over Time											
Minimum	0, mm	0, mm/s²	0, mm		0, mm/mm	0, mm	0, mm/mm	-9,5658e-002 mm	0, mm		0, MPa
Maximum	101,23 mm	2,9827e+012 mm/s²	101,23 mm	12,731 mm	1,6551 mm/mm	2,0684 mm	9,0291e-002 mm/mm	2,7873 mm	101,23 mm		1,885e+005 MPa
Information											
Time	2,0001e-003 s			1,4e-003 s	2,0001e-003 s	1,9e-003 s	2,0001e-003 s			1,8002e-003 s	1,3002e-003 s
Set	21			15	21	20	21			19	14
Cycle Number	11124			7801	11124	10570	11124			10017	7248
Integration Point Results											
Display Option					Averaged		Averaged				Averaged
Average Across Bodies					No		No				No

FIGURE 3
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation

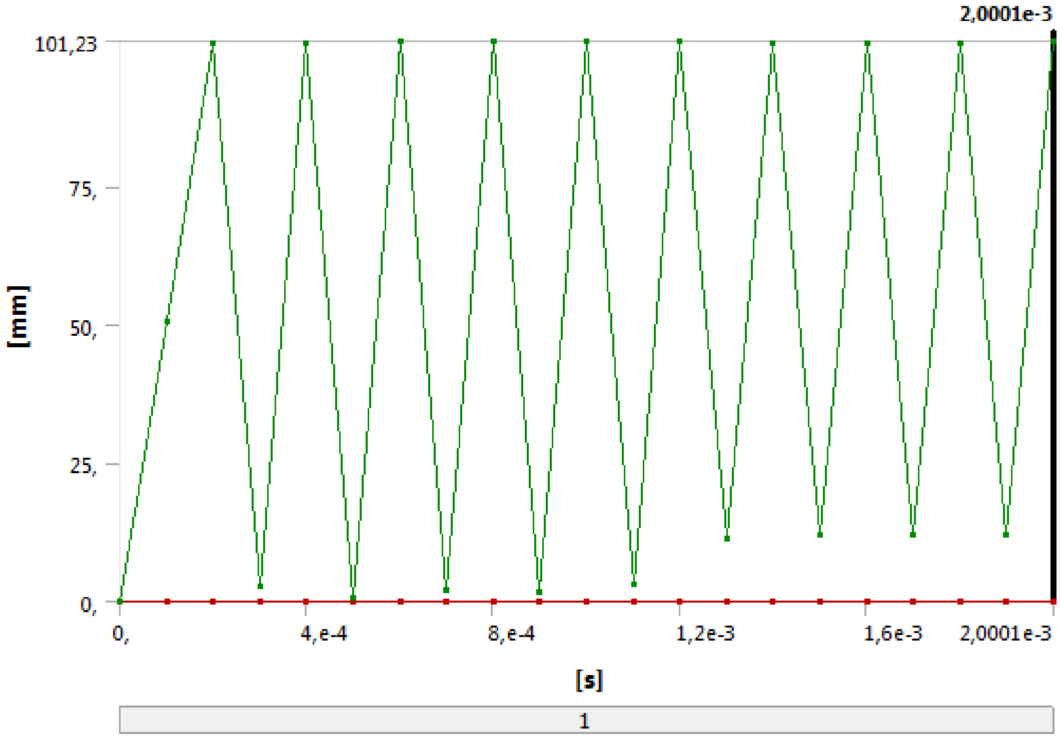


TABLE 24
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	50,576
2,0008e-004	1,072e-004	101,04
3,0011e-004	3,1877e-004	2,7884
4,0013e-004	3,6081e-004	101,04
5,0004e-004	9,7808e-004	0,6342
6,0001e-004	5,7005e-004	101,11
7,0007e-004	1,1072e-003	2,1642
8,0013e-004	4,839e-004	101,1
9,0001e-004	5,1727e-004	1,8268
1,e-003	2,566e-003	101,23
1,1002e-003	1,8949e-003	2,9468
1,2002e-003	1,0834e-003	101,07
1,3002e-003	1,3566e-003	11,496
1,4e-003	2,6071e-004	100,94
1,5001e-003	6,2552e-003	12,022
1,6001e-003	1,1214e-002	100,93
1,7001e-003	2,2828e-002	12,063
1,8002e-003	1,1266e-002	100,93
1,9e-003	5,5814e-002	11,903
2,0001e-003	5,583e-002	101,1

FIGURE 4
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Directional Acceleration

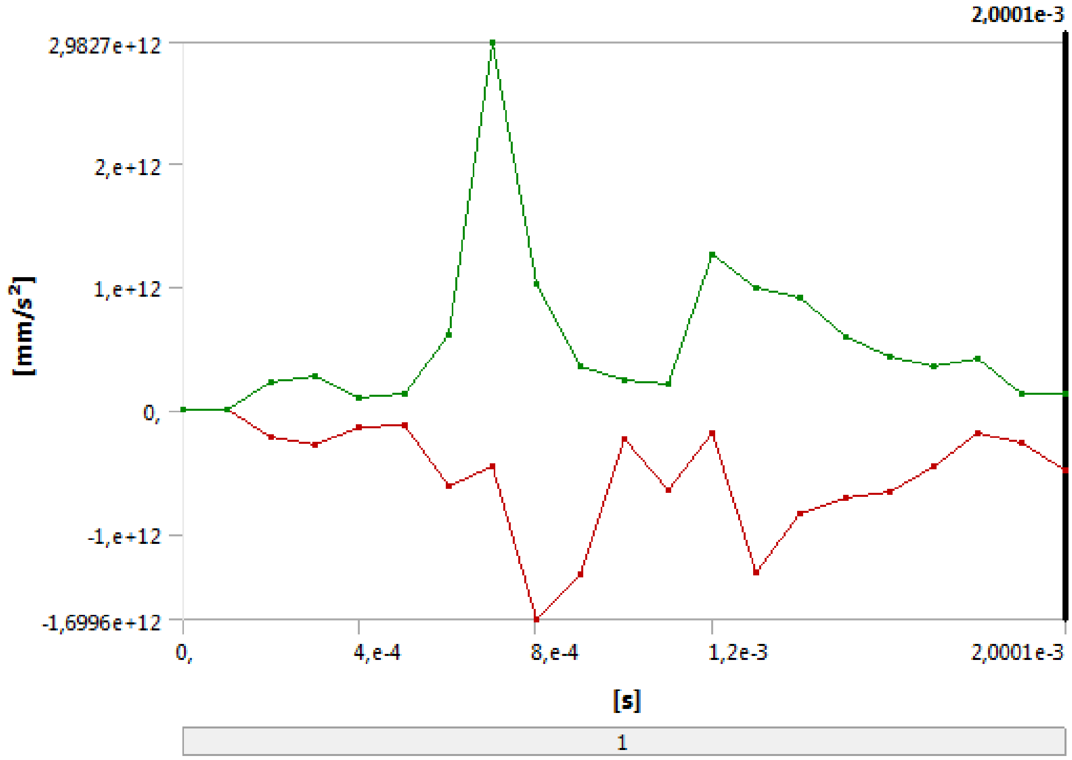


TABLE 25
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Directional Acceleration

Time [s]	Minimum [mm/s²]	Maximum [mm/s²]
1,1755e-038	0,	0,
1,0015e-004		
2,0008e-004	-2,1202e+011	2,281e+011
3,0011e-004	-2,8416e+011	2,6843e+011
4,0013e-004	-1,3477e+011	9,3958e+010
5,0004e-004	-1,2647e+011	1,2939e+011
6,0001e-004	-6,1309e+011	6,0922e+011
7,0007e-004	-4,6007e+011	2,9827e+012
8,0013e-004	-1,6996e+012	1,0176e+012
9,0001e-004	-1,3373e+012	3,4962e+011
1,e-003	-2,3712e+011	2,3691e+011
1,1002e-003	-6,4893e+011	2,091e+011
1,2002e-003	-1,8318e+011	1,2629e+012
1,3002e-003	-1,3159e+012	9,9105e+011
1,4e-003	-8,3184e+011	9,0968e+011
1,5001e-003	-7,0434e+011	5,8886e+011
1,6001e-003	-6,699e+011	4,3169e+011
1,7001e-003	-4,5287e+011	3,5278e+011
1,8002e-003	-1,7884e+011	4,242e+011
1,9e-003	-2,7182e+011	1,2488e+011
2,0001e-003	-4,8277e+011	1,3752e+011

FIGURE 5
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 2

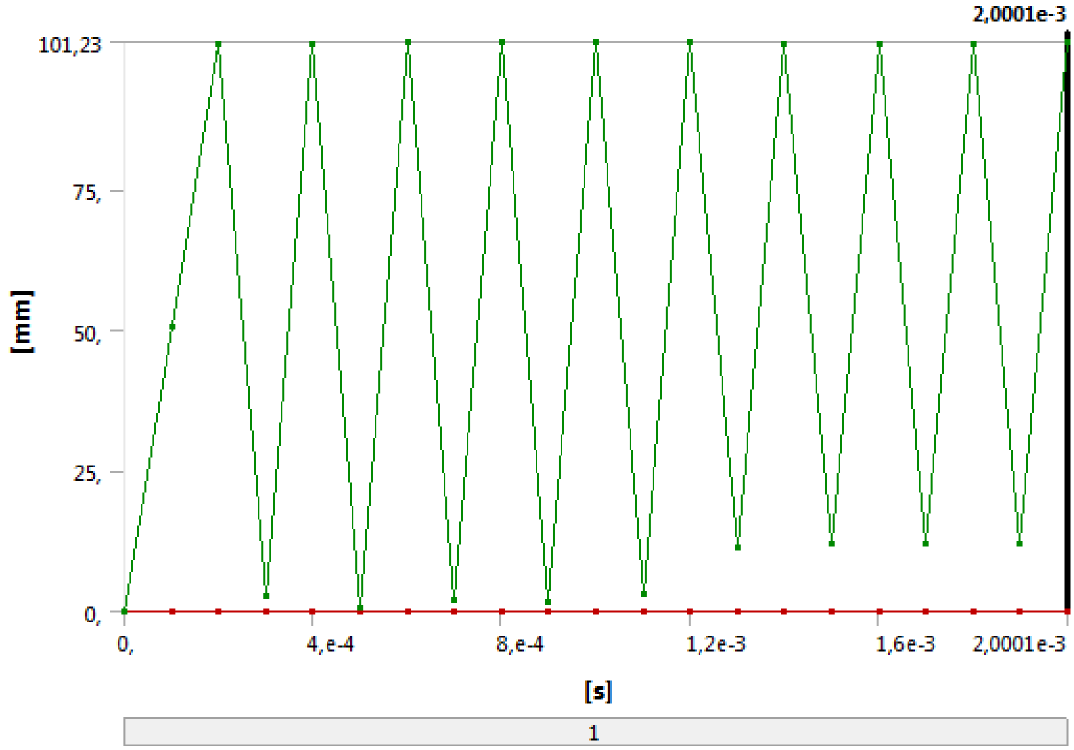


TABLE 26
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	50,576
2,0008e-004	1,072e-004	101,04
3,0011e-004	3,1877e-004	2,7884
4,0013e-004	3,6081e-004	101,04
5,0004e-004	9,7808e-004	0,6342
6,0001e-004	5,7005e-004	101,11
7,0007e-004	1,1072e-003	2,1642
8,0013e-004	4,839e-004	101,1
9,0001e-004	5,1727e-004	1,8268
1,e-003	2,566e-003	101,23
1,1002e-003	1,8949e-003	2,9468
1,2002e-003	1,0834e-003	101,07
1,3002e-003	1,3566e-003	11,496
1,4e-003	2,6071e-004	100,94
1,5001e-003	6,2552e-003	12,022
1,6001e-003	1,1214e-002	100,93
1,7001e-003	2,2828e-002	12,063
1,8002e-003	1,1266e-002	100,93
1,9e-003	5,5814e-002	11,903
2,0001e-003	5,583e-002	101,1

FIGURE 6
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 3

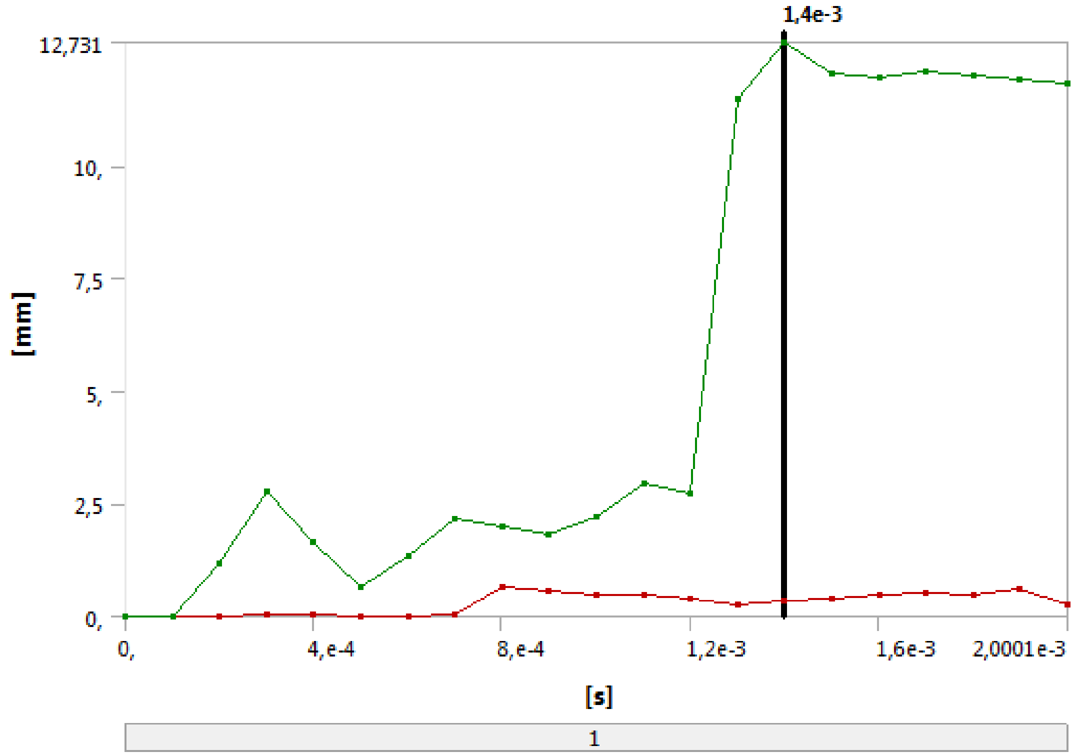


TABLE 27
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 3

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	4,9133e-005
2,0008e-004	1,072e-004	1,1534
3,0011e-004	2,5198e-002	2,7884
4,0013e-004	2,5113e-002	1,6366
5,0004e-004	1,2872e-002	0,6342
6,0001e-004	2,7536e-003	1,3501
7,0007e-004	3,2307e-002	2,1642
8,0013e-004	0,64122	1,9915
9,0001e-004	0,55878	1,8268
1,e-003	0,45477	2,2204
1,1002e-003	0,49587	2,9468
1,2002e-003	0,37665	2,7463
1,3002e-003	0,2811	11,496
1,4e-003	0,36289	12,731
1,5001e-003	0,40321	12,022
1,6001e-003	0,47907	11,954
1,7001e-003	0,50735	12,063
1,8002e-003	0,45604	12,016
1,9e-003	0,59987	11,903
2,0001e-003	0,25202	11,809

FIGURE 7
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Equivalent Elastic Strain

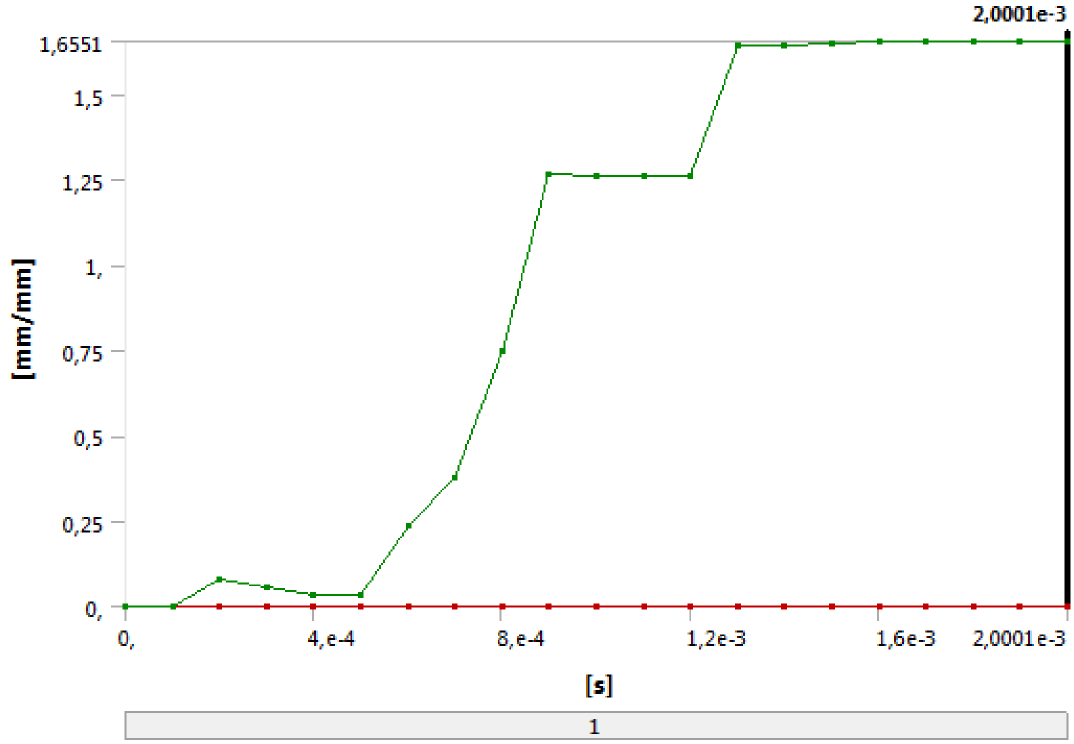


TABLE 28
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,0015e-004		
2,0008e-004		8,0641e-002
3,0011e-004		5,7113e-002
4,0013e-004		3,348e-002
5,0004e-004		3,2635e-002
6,0001e-004		0,23597
7,0007e-004		0,37439
8,0013e-004		0,74616
9,0001e-004		1,2643
1,e-003		1,263
1,1002e-003		
1,2002e-003		1,2598
1,3002e-003		1,6416
1,4e-003		1,6424
1,5001e-003		1,651
1,6001e-003		1,655
1,7001e-003		1,6524
1,8002e-003		1,6549
1,9e-003		1,6547
2,0001e-003		1,6551

FIGURE 8
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 4

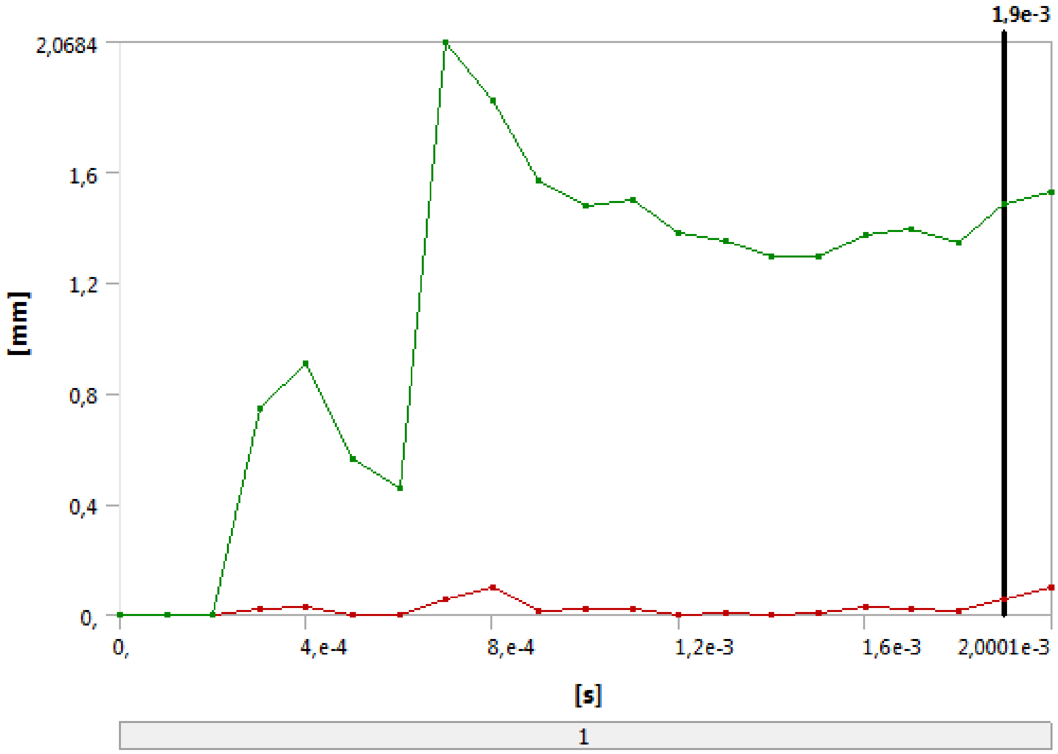


TABLE 29
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 4

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	4,9133e-005
2,0008e-004	1,962e-004	1,962e-004
3,0011e-004	1,9887e-002	0,74563
4,0013e-004	2,8819e-002	0,91092
5,0004e-004	9,7808e-004	0,56191
6,0001e-004	1,1234e-003	0,45969
7,0007e-004	5,677e-002	2,0684
8,0013e-004	9,606e-002	1,8607
9,0001e-004	1,6715e-002	1,5659
1,e-003	1,8833e-002	1,4744
1,1002e-003	2,3535e-002	1,4973
1,2002e-003	1,0834e-003	1,3763
1,3002e-003	3,6394e-003	1,3477
1,4e-003	2,6071e-004	1,2964
1,5001e-003	6,2552e-003	1,2911
1,6001e-003	2,6399e-002	1,3685
1,7001e-003	2,2828e-002	1,3927
1,8002e-003	1,1266e-002	1,3469
1,9e-003	5,5814e-002	1,4871
2,0001e-003	9,9578e-002	1,5242

FIGURE 9
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Normal Elastic Strain

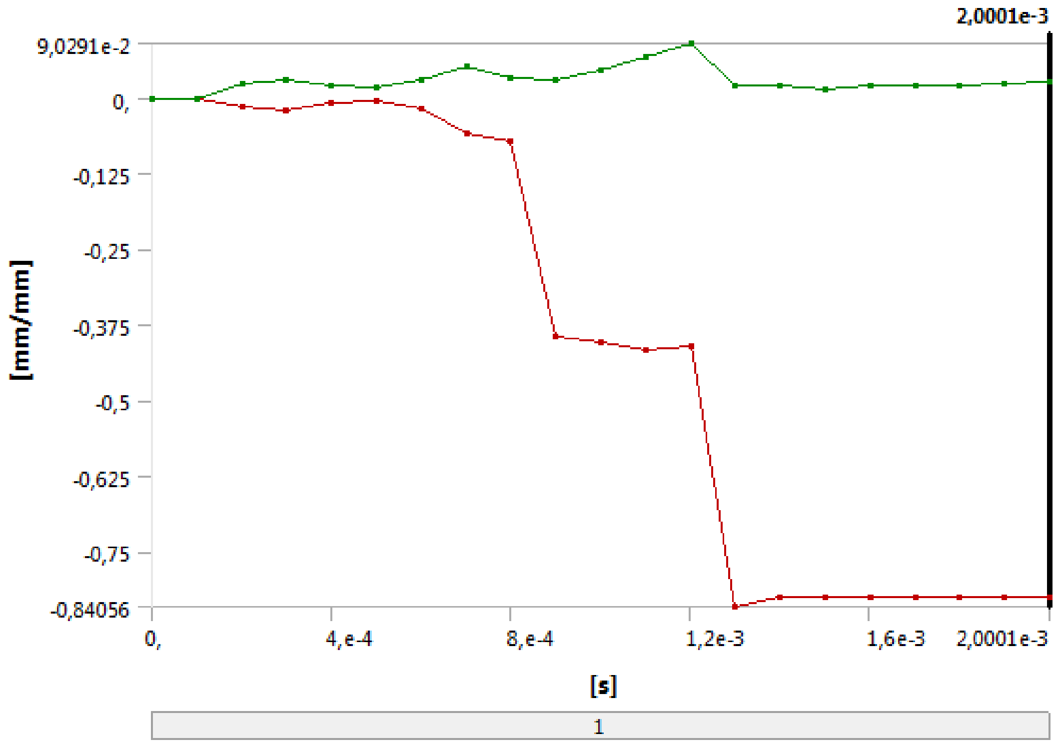


TABLE 30
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Normal Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,0015e-004		
2,0008e-004	-1,4284e-002	2,4142e-002
3,0011e-004	-2,0721e-002	3,0429e-002
4,0013e-004	-8,1976e-003	2,0456e-002
5,0004e-004	-4,3863e-003	1,6319e-002
6,0001e-004	-1,8104e-002	3,1379e-002
7,0007e-004	-5,8844e-002	5,2954e-002
8,0013e-004	-7,2152e-002	3,4388e-002
9,0001e-004	-0,39401	3,0988e-002
1,e-003	-0,404	4,4475e-002
1,1002e-003	-0,41611	6,7305e-002
1,2002e-003	-0,41038	9,0291e-002
1,3002e-003	-0,84056	2,0682e-002
1,4e-003	-0,8235	2,0551e-002
1,5001e-003	-0,82497	1,4861e-002
1,6001e-003	-0,82522	2,0436e-002
1,7001e-003	-0,82352	1,945e-002
1,8002e-003	-0,8239	1,9381e-002
1,9e-003	-0,82423	2,3188e-002
2,0001e-003	-0,82465	2,5479e-002

FIGURE 10
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Directional Deformation

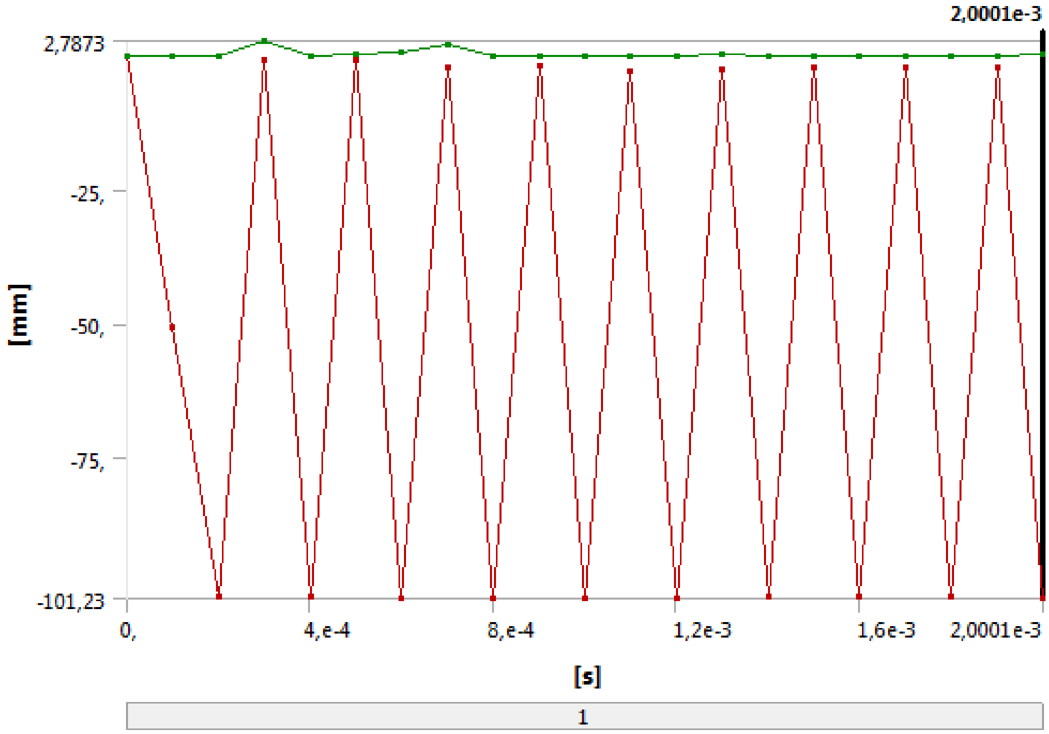


TABLE 31
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	-50,576	-4,9133e-005
2,0008e-004	-101,04	3,882e-002
3,0011e-004	-0,76119	2,7873
4,0013e-004	-101,04	2,5815e-003
5,0004e-004	-0,63069	0,31284
6,0001e-004	-101,11	0,59119
7,0007e-004	-2,1592	2,1216
8,0013e-004	-101,1	-9,5658e-002
9,0001e-004	-1,739	-1,6077e-002
1,e-003	-101,23	7,857e-002
1,1002e-003	-2,9433	-2,002e-003
1,2002e-003	-101,07	0,1114
1,3002e-003	-2,6756	0,18251
1,4e-003	-100,93	0,12978
1,5001e-003	-2,0138	0,11396
1,6001e-003	-100,93	7,6313e-002
1,7001e-003	-2,2665	0,10963
1,8002e-003	-100,92	8,3184e-002
1,9e-003	-1,9982	-4,2961e-002
2,0001e-003	-101,1	0,41539

FIGURE 11
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 5

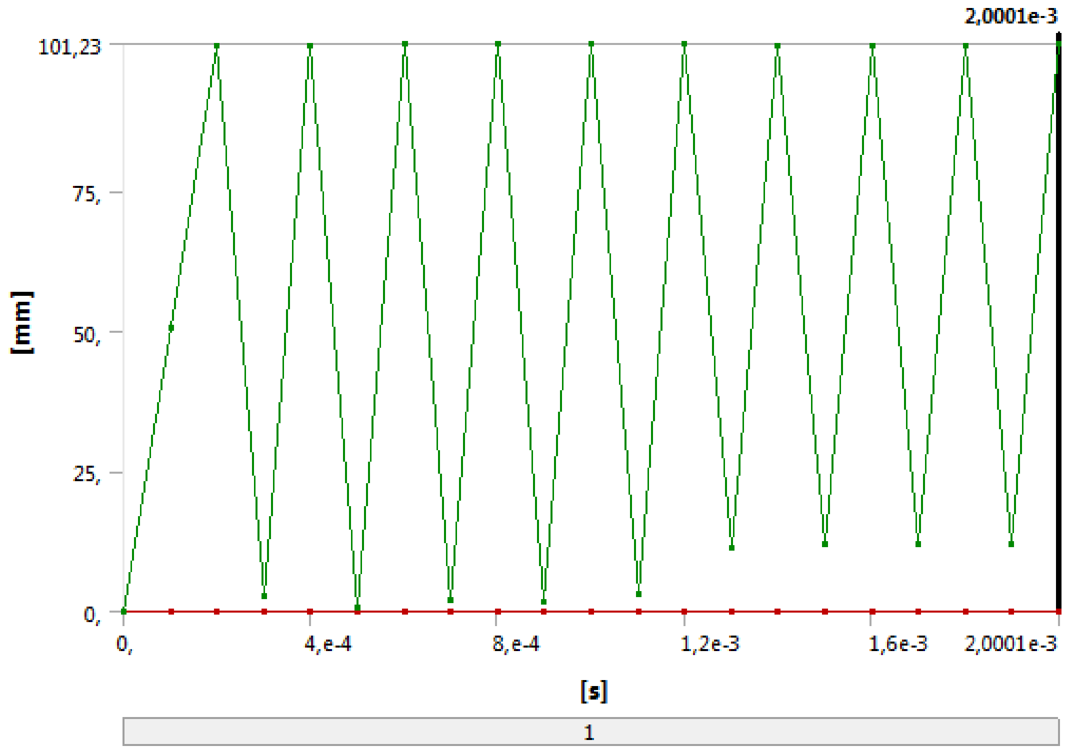


TABLE 32
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 5

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	50,576
2,0008e-004	1,072e-004	101,04
3,0011e-004	1,9887e-002	2,7884
4,0013e-004	2,5113e-002	101,04
5,0004e-004	9,7808e-004	0,6342
6,0001e-004	1,1234e-003	101,11
7,0007e-004	3,2307e-002	2,1642
8,0013e-004	9,606e-002	101,1
9,0001e-004	1,6715e-002	1,8268
1,e-003	1,8833e-002	101,23
1,1002e-003	2,3535e-002	2,9468
1,2002e-003	1,0834e-003	101,07
1,3002e-003	3,6394e-003	11,496
1,4e-003	2,6071e-004	100,94
1,5001e-003	6,2552e-003	12,022
1,6001e-003	2,6399e-002	100,93
1,7001e-003	2,2828e-002	12,063
1,8002e-003	1,1266e-002	100,93
1,9e-003	5,5814e-002	11,903
2,0001e-003	9,9578e-002	101,1

FIGURE 12
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 6

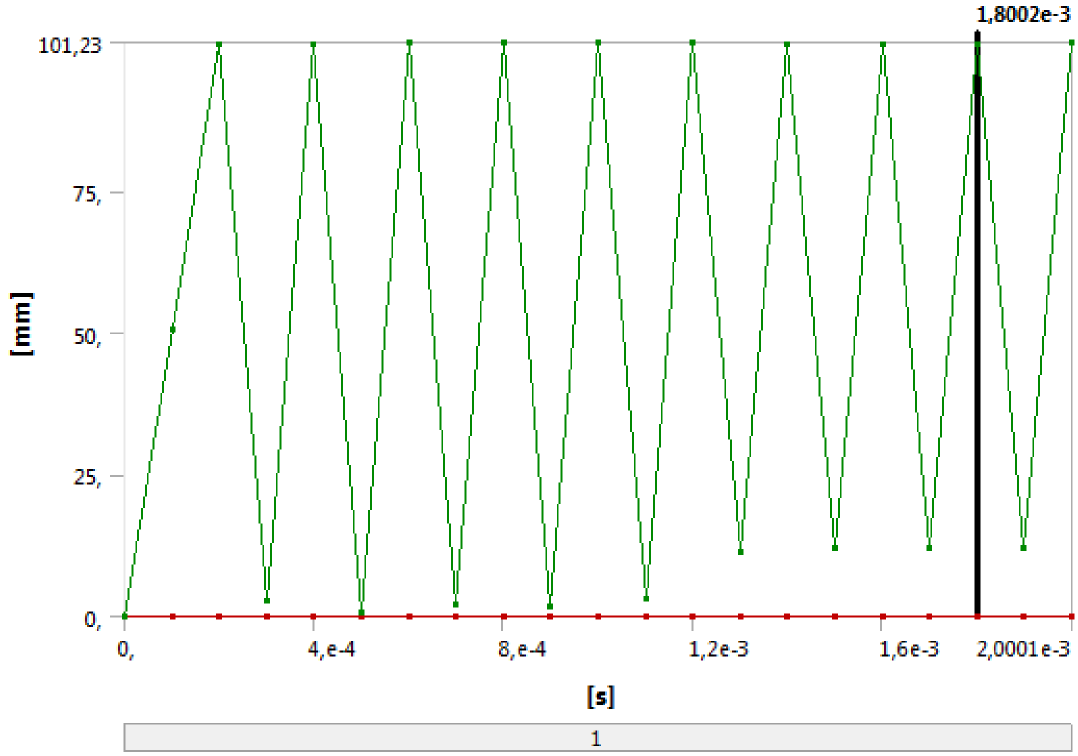


TABLE 33
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Total Deformation 6

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0015e-004	4,9133e-005	50,576
2,0008e-004	1,072e-004	101,04
3,0011e-004	1,9887e-002	2,7884
4,0013e-004	2,5113e-002	101,04
5,0004e-004	9,7808e-004	0,6342
6,0001e-004	1,1234e-003	101,11
7,0007e-004	3,2307e-002	2,1642
8,0013e-004	9,606e-002	101,1
9,0001e-004	1,6715e-002	1,8268
1,e-003	1,8833e-002	101,23
1,1002e-003	2,3535e-002	2,9468
1,2002e-003	1,0834e-003	101,07
1,3002e-003	3,6394e-003	11,496
1,4e-003	2,6071e-004	100,94
1,5001e-003	6,2552e-003	12,022
1,6001e-003	2,6399e-002	100,93
1,7001e-003	2,2828e-002	12,063
1,8002e-003	1,1266e-002	100,93
1,9e-003	5,5814e-002	11,903
2,0001e-003	9,9578e-002	101,1

FIGURE 13
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Equivalent Stress

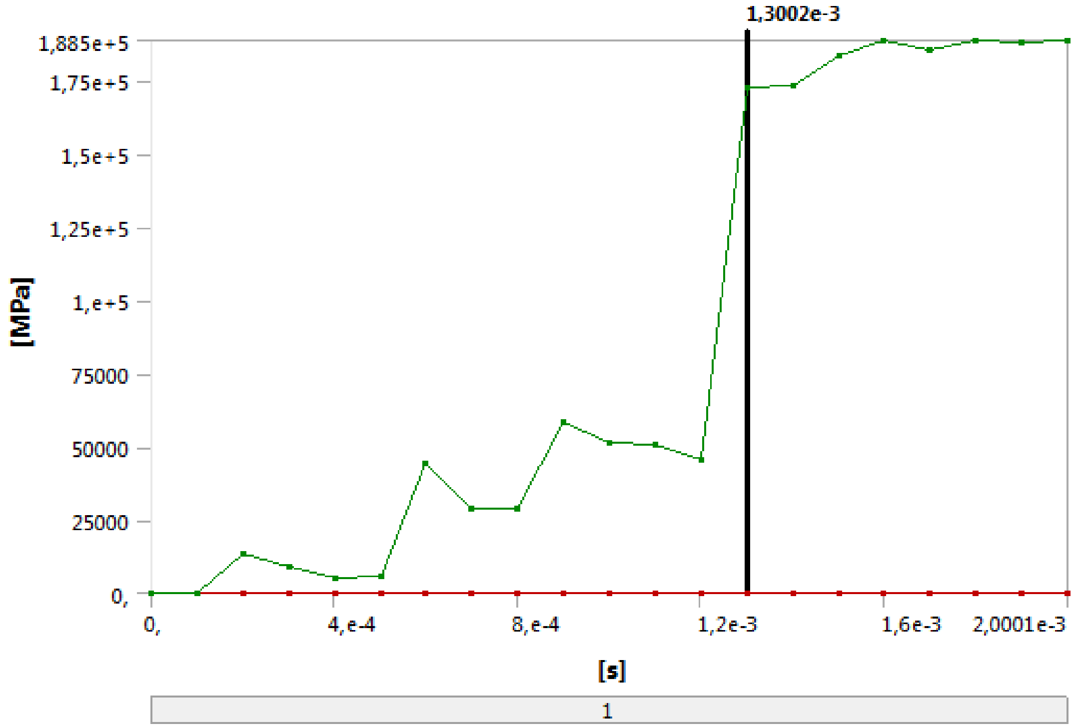


TABLE 34
Model (B4) > Explicit Dynamics (B5) > Solution (B6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,1755e-038	0,	0,
1,0015e-004		
2,0008e-004		13265
3,0011e-004	9,4856	9052,7
4,0013e-004	11,072	5227,9
5,0004e-004	5,3603	5556,7
6,0001e-004	8,9558	44242
7,0007e-004	12,102	29123
8,0013e-004	12,669	29122
9,0001e-004	19,508	58344
1,e-003	10,359	51182
1,1002e-003	10,588	50967
1,2002e-003	10,668	45563
1,3002e-003	17,529	1,7236e+005
1,4e-003	11,103	1,7333e+005
1,5001e-003	12,612	1,8363e+005
1,6001e-003	11,866	1,8838e+005
1,7001e-003	8,8998	1,853e+005
1,8002e-003	11,341	1,8829e+005
1,9e-003	9,4304	1,8806e+005
2,0001e-003	9,7322	1,885e+005

Material Data

Structural Steel

TABLE 35
Structural Steel > Constants

Density	7,85e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat Constant Pressure	4,34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Isotropic Resistivity	1,7e-004 ohm mm

TABLE 36
Structural Steel > Appearance

Red	Green	Blue
132,	139,	179,

TABLE 37
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0,

TABLE 38
Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
250,

TABLE 39
Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
250,

TABLE 40
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
460,

TABLE 41
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22,

TABLE 42
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 43
Structural Steel > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 44
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 45
Structural Steel > Isotropic Relative Permeability

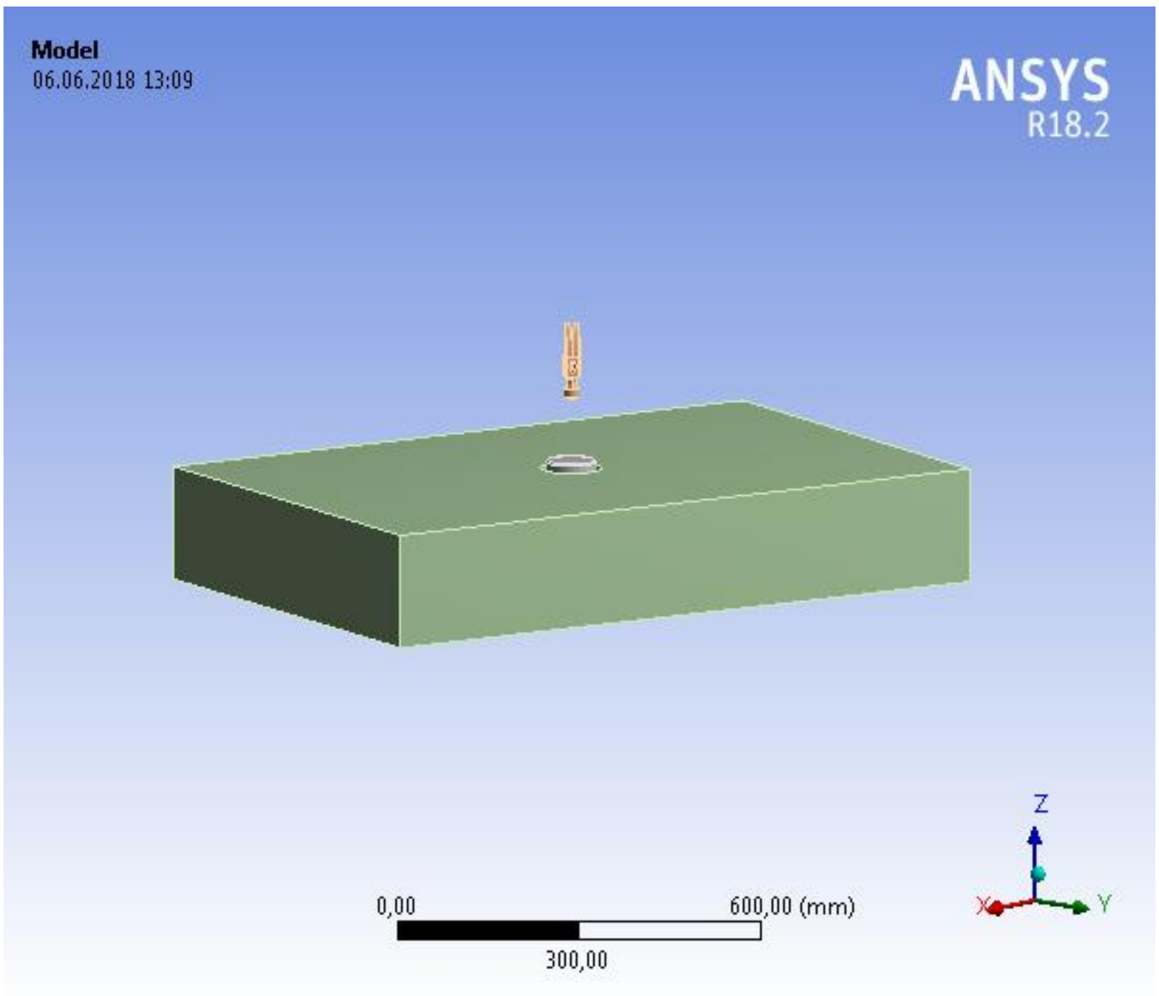
Relative Permeability
10000

Appendix B-2

Finite Element Model No. 2 ANSYS Report

Project

First Saved	Thursday, May 31, 2018
Last Saved	Tuesday, June 05, 2018
Product Version	18.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (C4)

Geometry

TABLE 2
Model (C4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	F:\Hammer\10_strokers_files\dp0\SYS-2\DM\SYS-2.agdb
Type	DesignModeler
Length Unit	Meters
Display Style	Body Color
Bounding Box	

Length X	1262,4 mm
Length Y	1000,1 mm
Length Z	412,73 mm
Properties	
Volume	1,4104e+008 mm³
Mass	1102,9 kg
Scale Factor Value	1,
Statistics	
Bodies	4
Active Bodies	4
Nodes	13484
Elements	58664
Mesh Metric	None
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (C4) > Geometry > Body Groups

Object Name	*Part*
State	Meshed
Graphics Properties	
Visible	Yes
Definition	
Suppressed	No
Assignment	Multiple Materials
Coordinate System	Default Coordinate System
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	139,7 mm
Properties	
Volume	8,9849e+005 mm³

Mass	2,8193 kg
Centroid X	-0,76666 mm
Centroid Y	49,721 mm
Centroid Z	20,211 mm
Moment of Inertia Ip1	6035,1 kg·mm²
Moment of Inertia Ip2	6035,1 kg·mm²
Moment of Inertia Ip3	3465,3 kg·mm²
Statistics	
Nodes	1870
Elements	8542
Mesh Metric	None
CAD Attributes	
DMBodyGroup	4

TABLE 4
Model (C4) > Geometry > Part > Parts

Object Name	*cap*	*core*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Bounding Box		
Length X	82,55 mm	101,6 mm
Length Y	82,55 mm	101,6 mm
Length Z	38,1 mm	101,6 mm
Properties		
Volume	74783 mm³	8,237e+005 mm³
Mass	0,58705 kg	2,2322 kg
Centroid X	-0,76666 mm	
Centroid Y	49,721 mm	
Centroid Z	75,516 mm	5,6661 mm
Moment of Inertia Ip1	431,22 kg·mm²	3336,1 kg·mm²
Moment of Inertia Ip2	431,22 kg·mm²	3336,1 kg·mm²
Moment of Inertia Ip3	614,14 kg·mm²	2851,2 kg·mm²
Statistics		
Nodes	423	1502
Elements	1259	7283
Mesh Metric	None	

TABLE 5
Model (C4) > Geometry > Parts

Object Name	*floor*	*hammer*
State	Meshed	

Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	Rigid
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	1262,4 mm	31,615 mm
Length Y	1000,1 mm	31,365 mm
Length Z	181, mm	119,02 mm
Properties		
Volume	1,4011e+008 mm³	33746 mm³
Mass	1099,9 kg	0,2649 kg
Centroid X	-0,76666 mm	-0,1293 mm
Centroid Y	49,721 mm	50,514 mm
Centroid Z	-8,8313 mm	238,88 mm
Moment of Inertia Ip1	4,912e+007 kg·mm²	200,04 kg·mm²
Moment of Inertia Ip2	1,154e+008 kg·mm²	203,61 kg·mm²
Moment of Inertia Ip3	1,585e+008 kg·mm²	22,428 kg·mm²
Statistics		
Nodes	1821	9793
Elements	8279	41843
Mesh Metric	None	

Coordinate Systems

TABLE 6
Model (C4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Origin	
Origin X	0, mm
Origin Y	0, mm
Origin Z	0, mm
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 7
Model (C4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 8
Model (C4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	4,1564 mm
Use Range	No
Face/Face	Yes
Face Overlap Tolerance	Off
Cylindrical Faces	Include
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	2
Active Connections	2

TABLE 9
Model (C4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region 2*	*Contact Region 3*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Contact	1 Face	2 Faces
Target	1 Face	2 Faces
Contact Bodies	cap	core
Target Bodies	core	floor
Definition		
Type	Bonded	
Scope Mode	Automatic	
Behavior	Program Controlled	

Trim Contact	Program Controlled
Trim Tolerance	4,1564 mm
Maximum Offset	1,e-004 mm
Breakable	No
Suppressed	No

TABLE 10
Model (C4) > Connections > Body Interactions

Object Name	*Body Interactions*
State	Fully Defined
Advanced	
Contact Detection	Trajectory
Formulation	Penalty
Sliding Contact	Discrete Surface
Body Self Contact	Program Controlled
Element Self Contact	Program Controlled
Tolerance	0,2

TABLE 11
Model (C4) > Connections > Body Interactions > Body Interaction

Object Name	*Body Interaction*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Frictionless
Suppressed	No

Mesh

TABLE 12
Model (C4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Explicit
Relevance	0
Element Order	Linear
Sizing	
Size Function	Proximity and Curvature
Relevance Center	Coarse
Max Face Size	Default (82,8690 mm)
Mesh Defeaturing	Yes
Defeature Size	Default (0,414340 mm)
Transition	Fast
Growth Rate	Default (1,850)

Span Angle Center	Coarse
Min Size	Default (0,828690 mm)
Max Tet Size	Default (165,740 mm)
Curvature Normal Angle	Default (70,3950 °)
Proximity Min Size	Default (0,828690 mm)
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Bounding Box Diagonal	1662,60 mm
Minimum Edge Length	1,0485e-003 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Number of Retries	0
Rigid Body Behavior	Full Mesh
Rigid Face Mesh Type	Quad/Tri
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Default (0,745820 mm)
Generate Pinch on Refresh	No
Statistics	
Nodes	13484
Elements	58664

TABLE 13
Model (C4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	2 Bodies
Definition	
Suppressed	No
Type	Element Size
Element Size	10,0 mm
Advanced	

Defeature Size	Default (0,41434 mm)
Size Function	Uniform
Behavior	Soft
Growth Rate	Default (1,85)

Explicit Dynamics (C5)

TABLE 14
Model (C4) > Analysis

Object Name	*Explicit Dynamics (C5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Explicit Dynamics
Solver Target	AUTODYN
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 15
Model (C4) > Explicit Dynamics (C5) > Initial Conditions

Object Name	*Initial Conditions*
State	Fully Defined

TABLE 16
Model (C4) > Explicit Dynamics (C5) > Initial Conditions > Initial Condition

Object Name	*Pre-Stress (None)*
State	Fully Defined
Definition	
Pre-Stress Environment	None
Pressure Initialization	From Deformed State

TABLE 17
Model (C4) > Explicit Dynamics (C5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Analysis Settings Preference	
Type	Program Controlled
Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	2,55e-003 s
Maximum Energy Error	0,1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	0,9

Characteristic Dimension	Diagonals
Automatic Mass Scaling	No
Solver Controls	
Solve Units	mm, mg, ms
Beam Solution Type	Bending
Beam Time Step Safety Factor	0,5
Hex Integration Type	Exact
Shell Sublayers	3
Shell Shear Correction Factor	0,8333
Shell BWC Warp Correction	Yes
Shell Thickness Update	Nodal
Tet Integration	Average Nodal Pressure
Shell Inertia Update	Recompute
Density Update	Program Controlled
Minimum Velocity	1,e-003 mm s^-1
Maximum Velocity	1,e+013 mm s^-1
Radius Cutoff	1,e-003
Minimum Strain Rate Cutoff	1,e-010
Euler Domain Controls	
Domain Size Definition	Program Controlled
Display Euler Domain	Yes
Scope	All Bodies
X Scale factor	1,2
Y Scale factor	1,2
Z Scale factor	1,2
Domain Resolution Definition	Total Cells
Total Cells	2,5e+05
Lower X Face	Flow Out
Lower Y Face	Flow Out
Lower Z Face	Flow Out
Upper X Face	Flow Out
Upper Y Face	Flow Out
Upper Z Face	Flow Out
Euler Tracking	By Body
Damping Controls	
Linear Artificial Viscosity	0,2
Quadratic Artificial Viscosity	1,
Linear Viscosity in Expansion	No
Artificial Viscosity For Shells	Yes
Hourglass Damping	AUTODYN Standard
Viscous Coefficient	0,1
Static Damping	0,
Erosion Controls	
On Geometric Strain Limit	Yes
Geometric Strain Limit	1,5
On Material Failure	No
On Minimum Element Time Step	No
Retain Inertia of Eroded Material	Yes

Output Controls	
Save Results on	Equally Spaced Points
Result Number Of Points	20
Save Restart Files on	Equally Spaced Points
Restart Number Of Points	5
Save Result Tracker Data on	Cycles
Tracker Cycles	1
Output Contact Forces	Off
Analysis Data Management	
Solver Files Directory	F:\Hammer\10_strokers_files\dp0\SYS-2\MECH\
Scratch Solver Files Directory	

TABLE 18
Model (C4) > Explicit Dynamics (C5) > Accelerations

Object Name	*Standard Earth Gravity*
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Global Coordinate System
X Component	0, mm/s²
Y Component	0, mm/s²
Z Component	-9806,6 mm/s²
Suppressed	No
Direction	-Z Direction

FIGURE 1
Model (C4) > Explicit Dynamics (C5) > Standard Earth Gravity

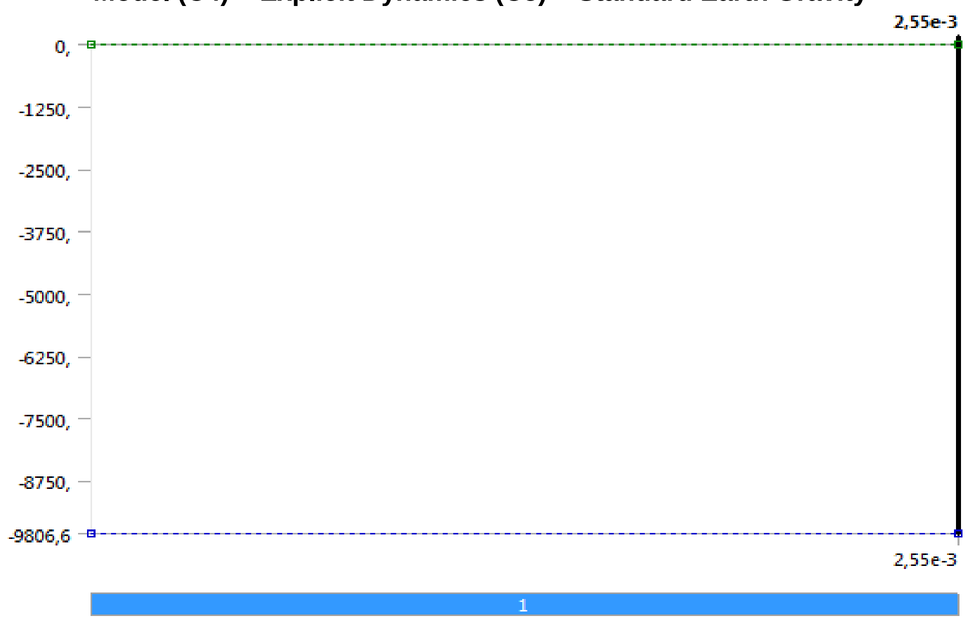


TABLE 19
Model (C4) > Explicit Dynamics (C5) > Loads

Object Name	*Fixed Support*	*Displacement*
State	Suppressed	Fully Defined
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	1 Body
Definition		
Type	Fixed Support	Displacement
Suppressed	Yes	No
Define By		Components
Coordinate System		Global Coordinate System
X Component		Free
Y Component		Free
Z Component		Tabular Data
Tabular Data		
Independent Variable		Time

FIGURE 2
Model (C4) > Explicit Dynamics (C5) > Displacement

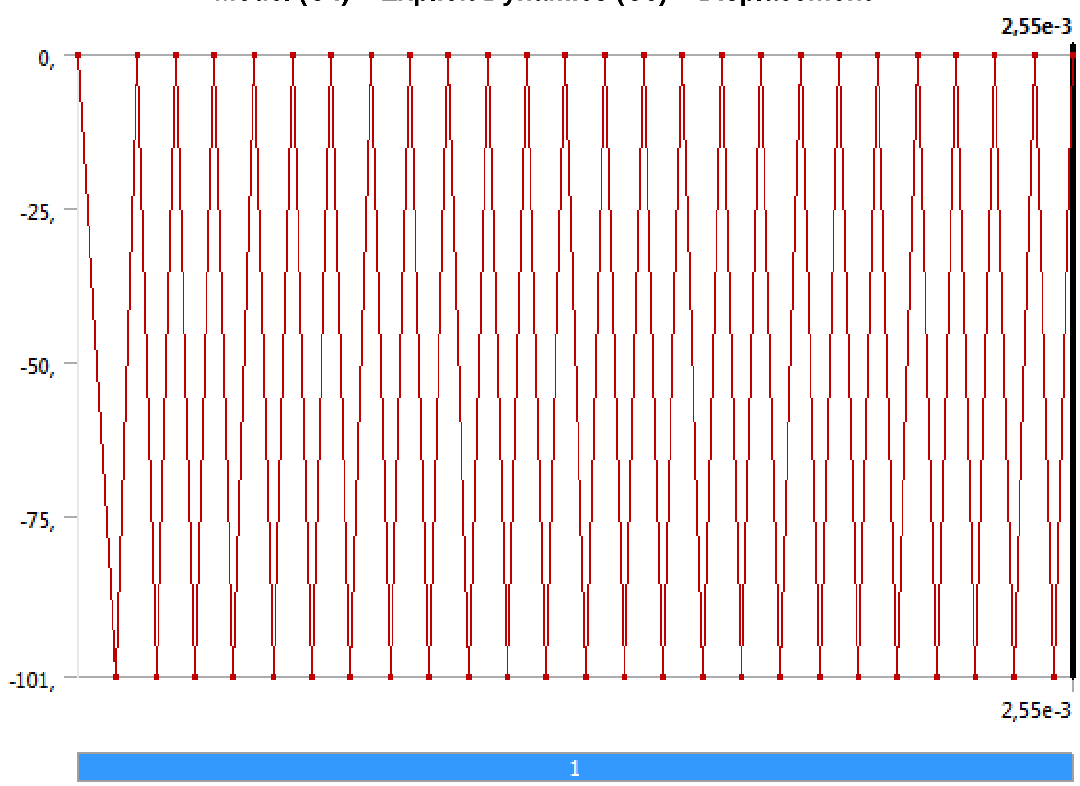


TABLE 20
Model (C4) > Explicit Dynamics (C5) > Displacement

Steps	Time [s]	Z [mm]
1	0,	0,
	1,e-004	-101,
	1,5e-004	0,
	2,e-004	-101,
	2,5e-004	0,
	3,e-004	-101,
	3,5e-004	0,
	4,e-004	-101,
	4,5e-004	0,
	5,e-004	-101,
	5,5e-004	0,
	6,e-004	-101,
	6,5e-004	0,
	7,e-004	-101,
	7,5e-004	0,
	8,e-004	-101,
	8,5e-004	0,
	9,e-004	-101,
	9,5e-004	0,
	1,e-003	-101,
	1,05e-003	0,
	1,1e-003	-101,
	1,15e-003	0,
	1,2e-003	-101,
	1,25e-003	0,
	1,3e-003	-101,
	1,35e-003	0,
	1,4e-003	-101,
	1,45e-003	0,
	1,5e-003	-101,
	1,55e-003	0,
	1,6e-003	-101,
	1,65e-003	0,
	1,7e-003	-101,
	1,75e-003	0,
	1,8e-003	-101,
	1,85e-003	0,
	1,9e-003	-101,
	1,95e-003	0,
	2,e-003	-101,
	2,05e-003	0,
	2,1e-003	-101,
	2,15e-003	0,
	2,2e-003	-101,
	2,25e-003	0,
	2,3e-003	-101,

	2,35e-003	0,
	2,4e-003	-101,
	2,45e-003	0,
	2,5e-003	-101,
	2,55e-003	0,

Solution (C6)

TABLE 21
Model (C4) > Explicit Dynamics (C5) > Solution

Object Name	*Solution (C6)*
State	Obsolete
Information	
Status	Post-processing Required
Post Processing	
Beam Section Results	No

TABLE 22
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Update Interval	2,5 s
Display Points	All
Display Filter During Solve	Yes

TABLE 23
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Results

Object Name	*Total Deformation*	*Directional Acceleration*	*Total Deformation 2*	*Total Deformation 3*	*Equivalent Elastic Strain*	*Total Deformation 4*	*Normal Elastic Strain*	*Directional Deformation*	*Total Deformation 5*	*Total Deformation 6*	*Equivalent Stress*
State	Solved							Obsolete	Solved		Obsolete
Scope											
Scoping Method	Geometry Selection							Geometry Selection	Geometry Selection		Geometry Selection
Geometry	All Bodies			1 Body	All Bodies	1 Body	3 Bodies	3 Bodies	3 Bodies		2 Bodies
Definition											
Type	Total Deformation	Directional Acceleration	Total Deformation		Equivalent Elastic Strain	Total Deformation	Normal Elastic Strain	Directional Deformation	Total Deformation		Equivalent (von-Mises) Stress
By	Time							Time	Time		Time
Display Time	Last			1,4e-003 s	Last	1,9e-003 s	Last	9,6489e-005 s	Last	1,8002e-003 s	1,275e-004 s
Calculate Time History	Yes							Yes	Yes		Yes
Identifier											
Suppressed	No							No	No		No
Orientation		X Axis					X Axis	Z Axis			
Coordinate System		Global Coordinate System					Global Coordinate System	Global Coordinate System			
Results											
Minimum	0,12924 mm	-1,1229e+010 mm/s²	0,12924 mm	1,2612 mm	0, mm/mm	0,14121 mm	-1,718e-002 mm/mm	-2,1578 mm	0,20095 mm	0,16542 mm	12,922 MPa
Maximum	2,1606 mm	8,6516e+009 mm/s²	2,1606 mm	2,0717 mm	7,1379e-002 mm/mm	2,0139 mm	1,0366e-002 mm/mm	0,40959 mm	2,1606 mm	70,139 mm	5587,9 MPa
Minimum Occurs On	floor	cap	floor	cap	hammer	core	cap	cap	core		core
Maximum Occurs On	cap					core		hammer	cap	hammer	cap
Minimum Value Over Time											
Minimum	0, mm	-1,7361e+011 mm/s²	0, mm		0, mm/mm	0, mm	-2,0613e-002 mm/mm	-95,507 mm	0, mm		0, MPa
Maximum	0,12924 mm	0, mm/s²	0,12924 mm	1,3376 mm	0, mm/mm	0,23891 mm	0, mm/mm	0, mm	0,23891 mm		19,29 MPa
Maximum Value Over Time											
Minimum	0, mm	0, mm/s²	0, mm		0, mm/mm	0, mm	0, mm/mm	-0,23857 mm	0, mm		0, MPa
Maximum	95,509 mm	1,6631e+011 mm/s²	95,509 mm	9,1776 mm	0,1035 mm/mm	2,2477 mm	3,2344e-002 mm/mm	0,63265 mm	95,509 mm		11325 MPa
Information											
Time	2,5501e-003 s			1,4026e-003 s	2,5501e-003 s	1,9127e-003 s	2,5501e-003 s	2,5501e-003 s	2,5501e-003 s	1,7851e-003 s	1,2752e-003 s
Set	21			12	21	16	21	21	21	15	11
Cycle Number	9591			5273	9591	7192	9591	9591	9591	6712	4794
Integration Point Results											
Display Option					Averaged		Averaged				Averaged
Average Across Bodies					No		No				No

FIGURE 3
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation

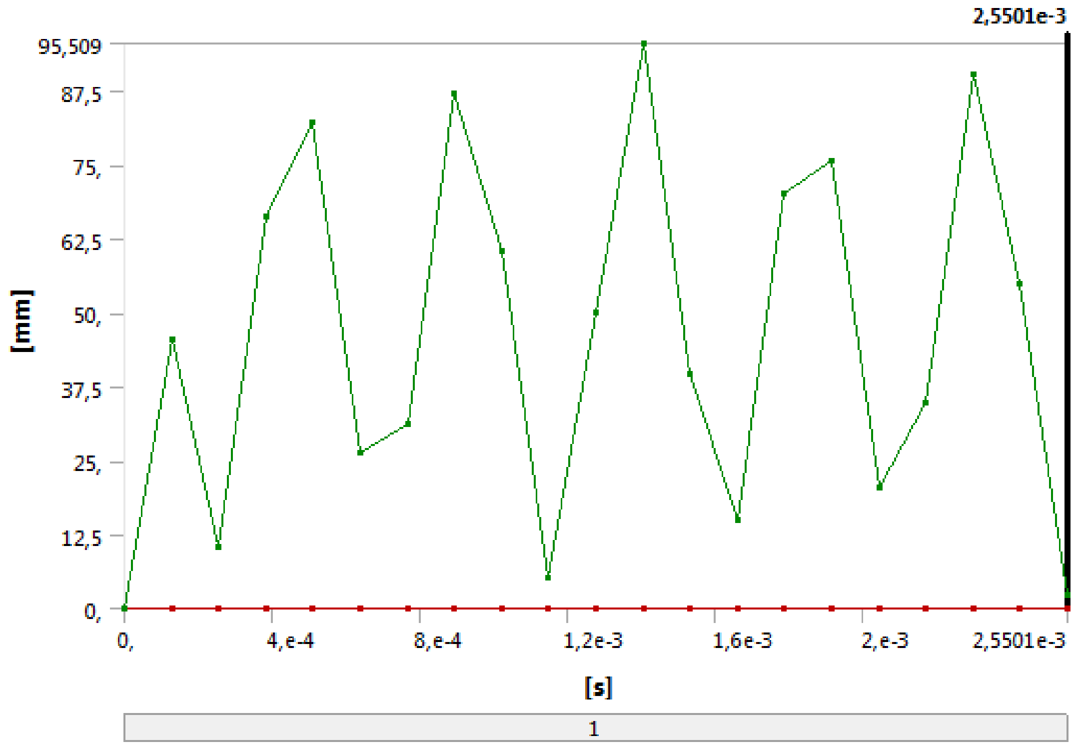


TABLE 24
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	6,2551e-006	45,578
2,5509e-004	1,24e-004	10,381
3,8255e-004	8,4156e-004	66,185
5,1007e-004	1,1327e-003	82,1
6,3774e-004	1,0265e-003	26,207
7,6506e-004	3,3551e-003	31,124
8,9258e-004	2,6882e-003	86,987
1,0202e-003	2,3469e-003	60,385
1,1476e-003	1,1393e-002	5,0936
1,2752e-003	2,3016e-002	50,071
1,4026e-003	2,5501e-002	95,509
1,5302e-003	2,7473e-002	39,565
1,6577e-003	5,1063e-002	14,904
1,7851e-003	6,6004e-002	70,139
1,9127e-003	7,3936e-002	75,698
2,0401e-003	7,434e-002	20,432
2,1677e-003	9,1121e-002	34,81
2,295e-003	8,1524e-002	90,455
2,4228e-003	0,11164	54,924
2,5501e-003	0,12924	2,1606

FIGURE 4
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Directional Acceleration

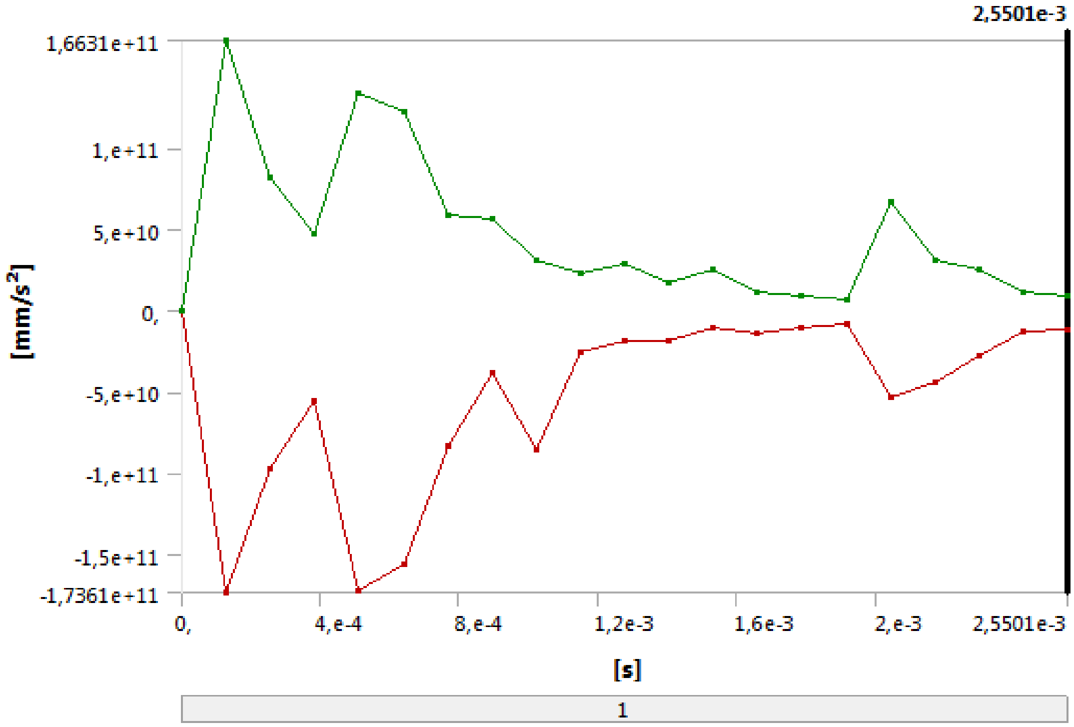


TABLE 25
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Directional Acceleration

Time [s]	Minimum [mm/s²]	Maximum [mm/s²]
1,1755e-038	0,	0,
1,275e-004	-1,7361e+011	1,6631e+011
2,5509e-004	-9,7237e+010	8,2066e+010
3,8255e-004	-5,5186e+010	4,7395e+010
5,1007e-004	-1,7285e+011	1,3406e+011
6,3774e-004	-1,5584e+011	1,2279e+011
7,6506e-004	-8,365e+010	5,8985e+010
8,9258e-004	-3,8176e+010	5,6061e+010
1,0202e-003	-8,5931e+010	3,151e+010
1,1476e-003	-2,5057e+010	2,2502e+010
1,2752e-003	-1,9179e+010	2,877e+010
1,4026e-003	-1,8185e+010	1,7112e+010
1,5302e-003	-1,0886e+010	2,4796e+010
1,6577e-003	-1,4121e+010	1,0902e+010
1,7851e-003	-1,1055e+010	8,681e+009
1,9127e-003	-8,2612e+009	6,7726e+009
2,0401e-003	-5,3486e+010	6,6425e+010
2,1677e-003	-4,3995e+010	3,0757e+010
2,295e-003	-2,7823e+010	2,5363e+010
2,4228e-003	-1,3015e+010	1,1641e+010
2,5501e-003	-1,1229e+010	8,6516e+009

FIGURE 5
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 2

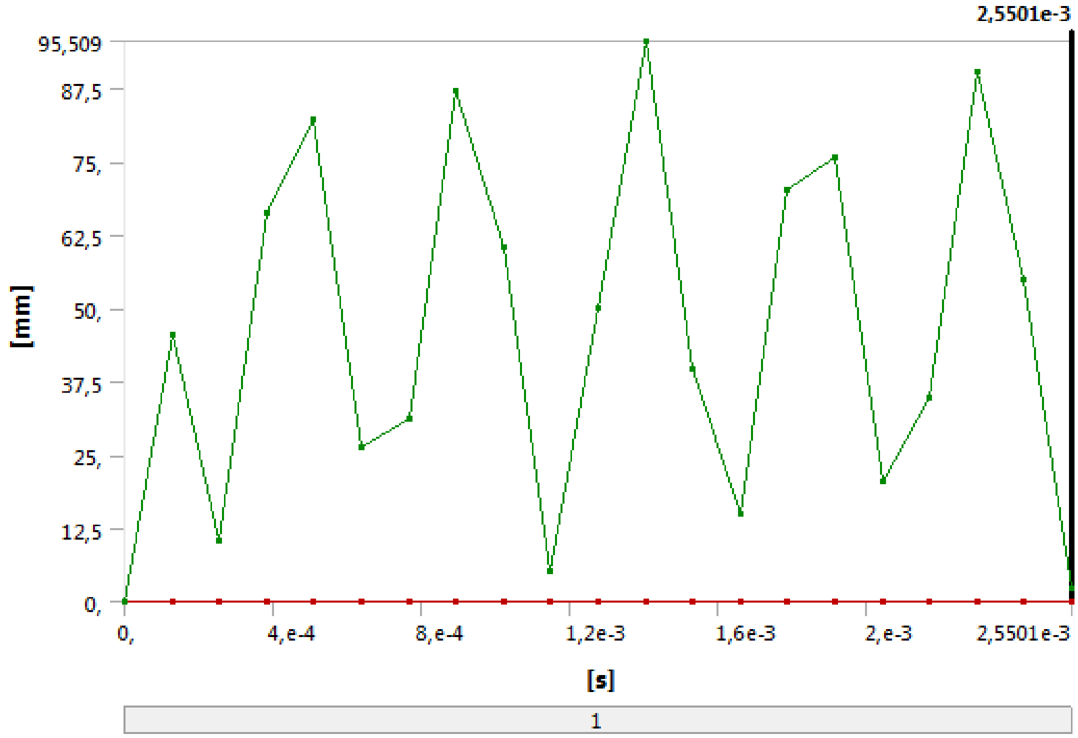


TABLE 26
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	6,2551e-006	45,578
2,5509e-004	1,24e-004	10,381
3,8255e-004	8,4156e-004	66,185
5,1007e-004	1,1327e-003	82,1
6,3774e-004	1,0265e-003	26,207
7,6506e-004	3,3551e-003	31,124
8,9258e-004	2,6882e-003	86,987
1,0202e-003	2,3469e-003	60,385
1,1476e-003	1,1393e-002	5,0936
1,2752e-003	2,3016e-002	50,071
1,4026e-003	2,5501e-002	95,509
1,5302e-003	2,7473e-002	39,565
1,6577e-003	5,1063e-002	14,904
1,7851e-003	6,6004e-002	70,139
1,9127e-003	7,3936e-002	75,698
2,0401e-003	7,434e-002	20,432
2,1677e-003	9,1121e-002	34,81
2,295e-003	8,1524e-002	90,455
2,4228e-003	0,11164	54,924
2,5501e-003	0,12924	2,1606

FIGURE 6
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 3

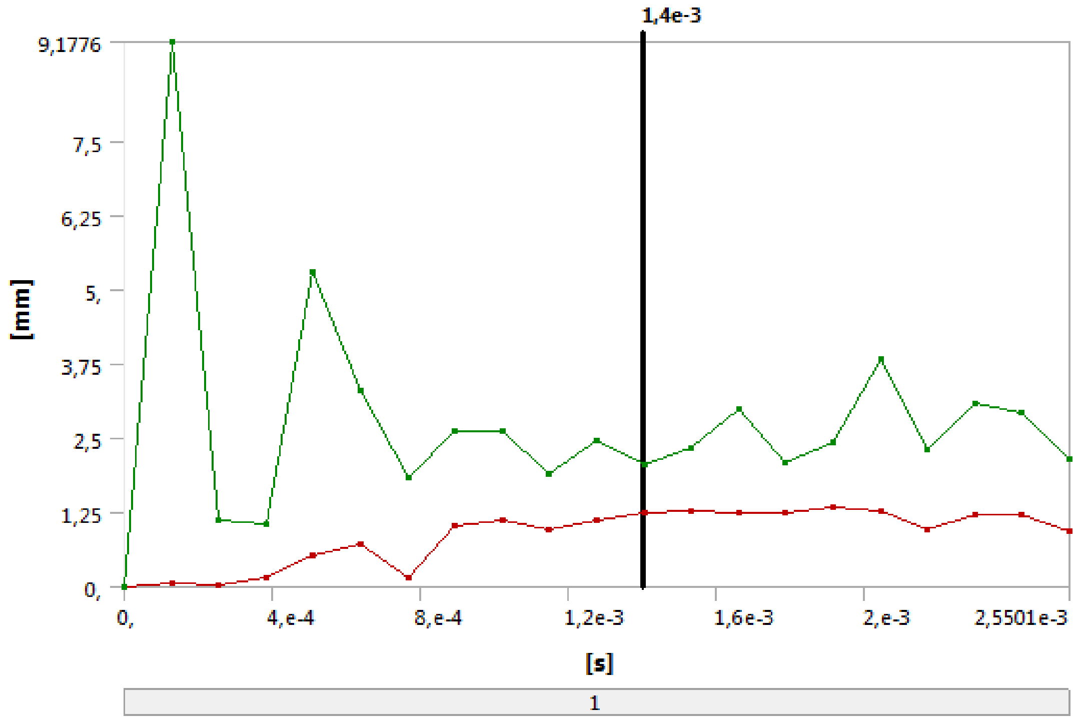


TABLE 27
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 3

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	7,4731e-002	9,1776
2,5509e-004	1,9121e-002	1,1382
3,8255e-004	0,15922	1,0626
5,1007e-004	0,53516	5,3023
6,3774e-004	0,71397	3,3206
7,6506e-004	0,1659	1,8358
8,9258e-004	1,0273	2,6149
1,0202e-003	1,1365	2,6352
1,1476e-003	0,96959	1,9168
1,2752e-003	1,132	2,4594
1,4026e-003	1,2612	2,0717
1,5302e-003	1,2667	2,3328
1,6577e-003	1,2384	2,9835
1,7851e-003	1,2545	2,0981
1,9127e-003	1,3376	2,4411
2,0401e-003	1,2774	3,8257
2,1677e-003	0,96136	2,2974
2,295e-003	1,2225	3,0814
2,4228e-003	1,2315	2,9216
2,5501e-003	0,92181	2,1606

FIGURE 7
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Equivalent Elastic Strain

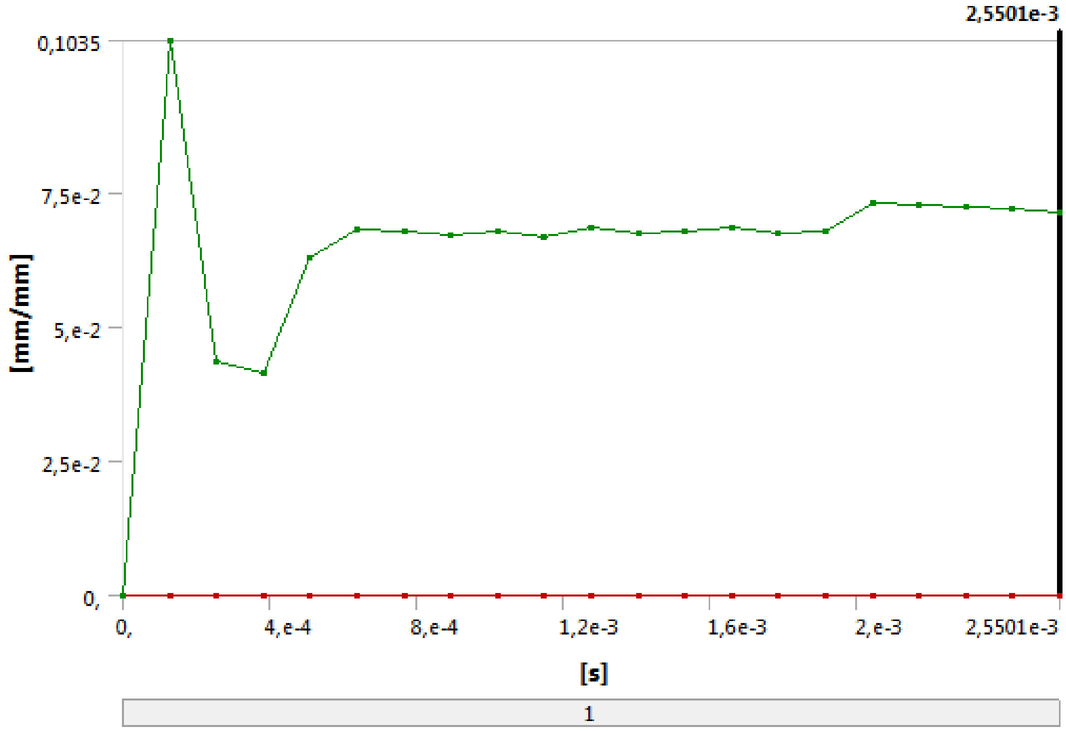


TABLE 28
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,275e-004		0,1035
2,5509e-004		4,3698e-002
3,8255e-004		4,1637e-002
5,1007e-004		6,3053e-002
6,3774e-004		6,8461e-002
7,6506e-004		6,7958e-002
8,9258e-004		6,737e-002
1,0202e-003		6,7993e-002
1,1476e-003		6,697e-002
1,2752e-003		6,8537e-002
1,4026e-003		6,7671e-002
1,5302e-003		6,7929e-002
1,6577e-003		6,879e-002
1,7851e-003		6,7461e-002
1,9127e-003		6,8079e-002
2,0401e-003		7,311e-002
2,1677e-003		7,283e-002
2,295e-003		7,2605e-002
2,4228e-003		7,2283e-002
2,5501e-003		7,1379e-002

FIGURE 8
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 4

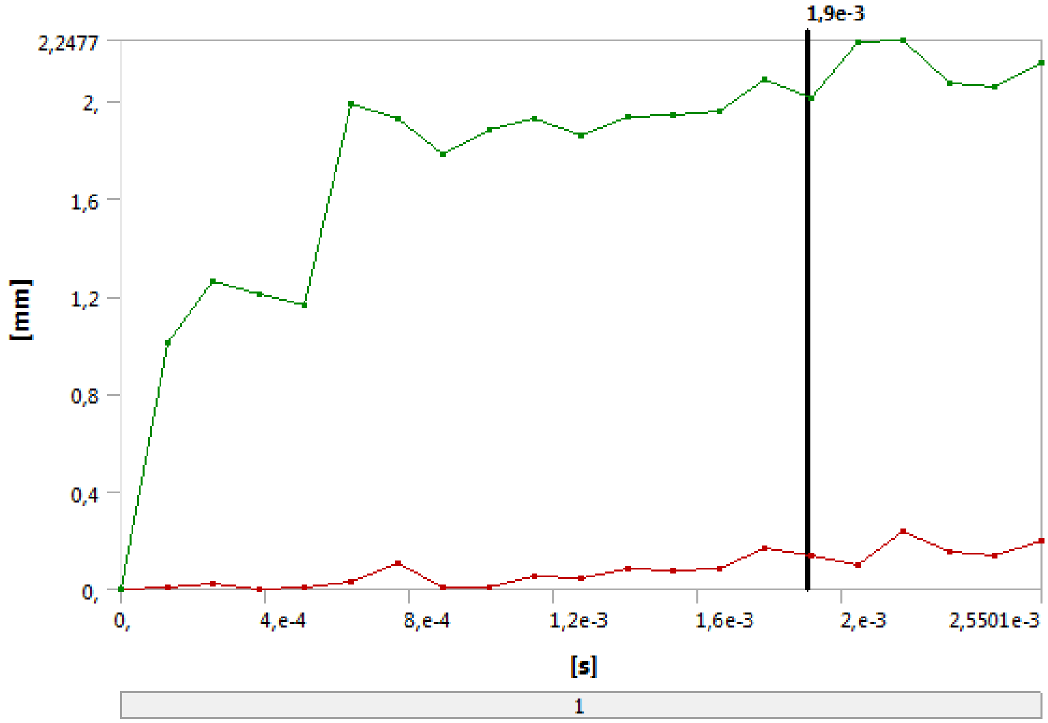


TABLE 29
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 4

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	4,4213e-003	1,0083
2,5509e-004	2,2104e-002	1,2637
3,8255e-004	1,7455e-003	1,206
5,1007e-004	7,7503e-003	1,1607
6,3774e-004	2,837e-002	1,9909
7,6506e-004	0,10472	1,9304
8,9258e-004	5,2853e-003	1,7845
1,0202e-003	1,0612e-002	1,8845
1,1476e-003	5,2139e-002	1,9286
1,2752e-003	4,237e-002	1,8569
1,4026e-003	8,16e-002	1,932
1,5302e-003	7,5291e-002	1,9425
1,6577e-003	8,7011e-002	1,9568
1,7851e-003	0,16542	2,087
1,9127e-003	0,14121	2,0139
2,0401e-003	9,7544e-002	2,2395
2,1677e-003	0,23891	2,2477
2,295e-003	0,15122	2,0722
2,4228e-003	0,13621	2,057
2,5501e-003	0,20095	2,1553

FIGURE 9
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Normal Elastic Strain

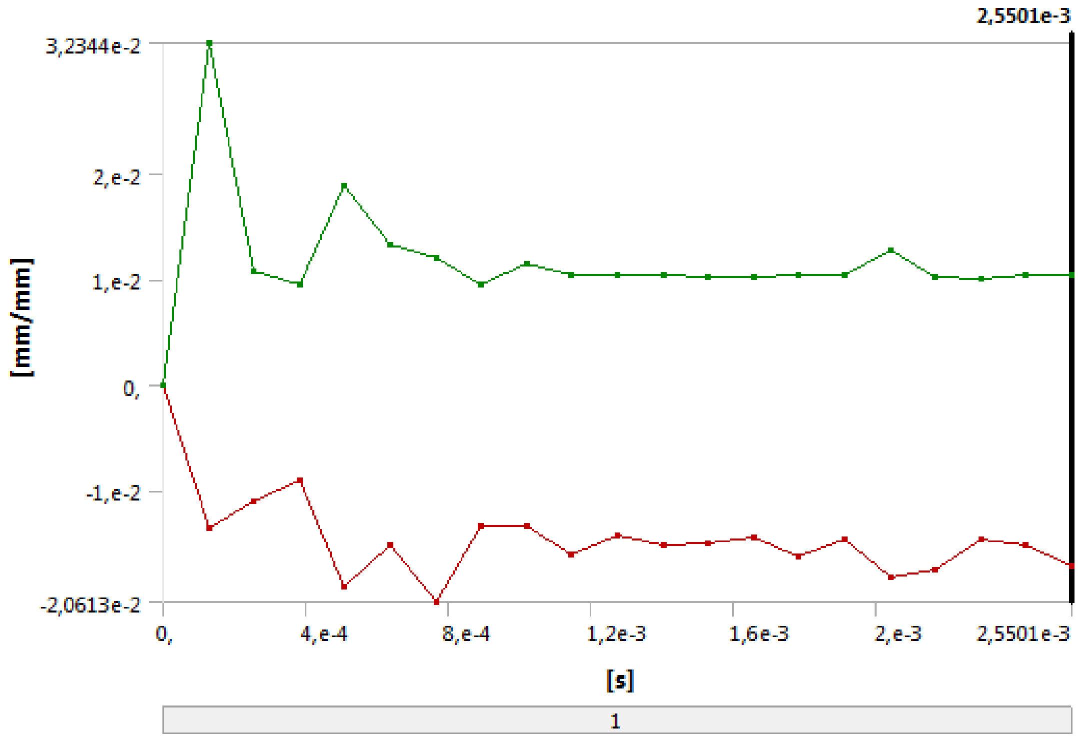


TABLE 30
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Normal Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,275e-004	-1,3664e-002	3,2344e-002
2,5509e-004	-1,1036e-002	1,0742e-002
3,8255e-004	-9,0655e-003	9,4319e-003
5,1007e-004	-1,9193e-002	1,8865e-002
6,3774e-004	-1,5169e-002	1,3192e-002
7,6506e-004	-2,0613e-002	1,1928e-002
8,9258e-004	-1,347e-002	9,502e-003
1,0202e-003	-1,3341e-002	1,1363e-002
1,1476e-003	-1,614e-002	1,0433e-002
1,2752e-003	-1,4304e-002	1,0401e-002
1,4026e-003	-1,5171e-002	1,036e-002
1,5302e-003	-1,5098e-002	1,0187e-002
1,6577e-003	-1,4562e-002	1,0211e-002
1,7851e-003	-1,6378e-002	1,0369e-002
1,9127e-003	-1,4679e-002	1,0406e-002
2,0401e-003	-1,8265e-002	1,2714e-002
2,1677e-003	-1,748e-002	1,0113e-002
2,295e-003	-1,4598e-002	1,0074e-002
2,4228e-003	-1,513e-002	1,0408e-002
2,5501e-003	-1,718e-002	1,0366e-002

FIGURE 10
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Directional Deformation

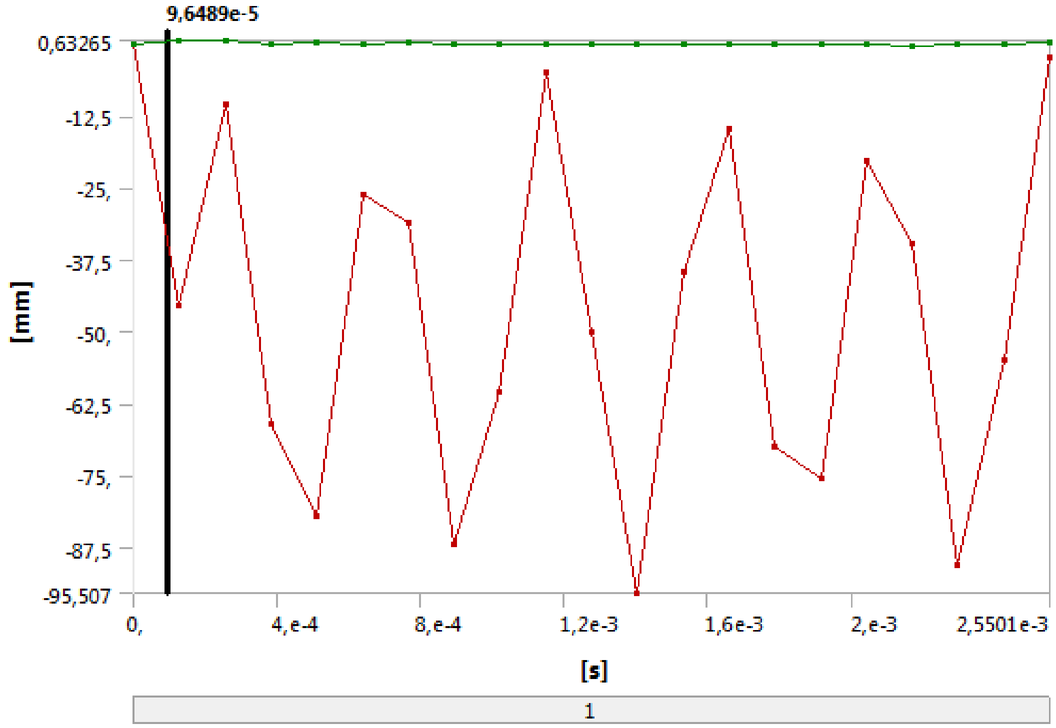


TABLE 31
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	-45,578	0,63265
2,5509e-004	-10,381	0,47363
3,8255e-004	-66,184	7,7602e-002
5,1007e-004	-82,099	0,19385
6,3774e-004	-26,205	8,7582e-002
7,6506e-004	-31,123	0,40042
8,9258e-004	-86,987	2,6347e-002
1,0202e-003	-60,384	-7,9575e-003
1,1476e-003	-5,0777	-5,0327e-002
1,2752e-003	-50,068	-4,0582e-002
1,4026e-003	-95,507	-8,1467e-002
1,5302e-003	-39,557	-7,5004e-002
1,6577e-003	-14,875	-8,6573e-002
1,7851e-003	-70,131	-0,16528
1,9127e-003	-75,688	-0,14108
2,0401e-003	-20,389	-9,5474e-002
2,1677e-003	-34,777	-0,23857
2,295e-003	-90,439	-0,15087
2,4228e-003	-54,892	-0,13619
2,5501e-003	-2,1578	0,40959

FIGURE 11
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 5

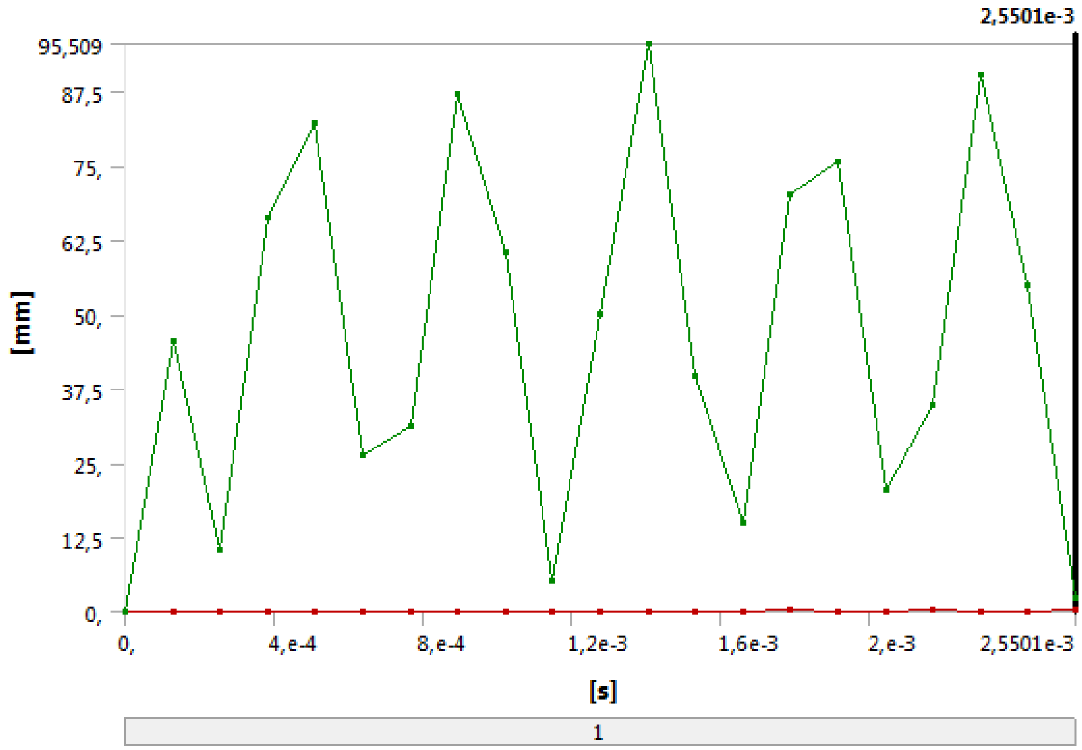


TABLE 32
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 5

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	4,4213e-003	45,578
2,5509e-004	1,9121e-002	10,381
3,8255e-004	1,7455e-003	66,185
5,1007e-004	7,7503e-003	82,1
6,3774e-004	2,837e-002	26,207
7,6506e-004	0,10472	31,124
8,9258e-004	5,2853e-003	86,987
1,0202e-003	1,0612e-002	60,385
1,1476e-003	5,2139e-002	5,0936
1,2752e-003	4,237e-002	50,071
1,4026e-003	8,16e-002	95,509
1,5302e-003	7,5291e-002	39,565
1,6577e-003	8,7011e-002	14,904
1,7851e-003	0,16542	70,139
1,9127e-003	0,14121	75,698
2,0401e-003	9,7544e-002	20,432
2,1677e-003	0,23891	34,81
2,295e-003	0,15122	90,455
2,4228e-003	0,13621	54,924
2,5501e-003	0,20095	2,1606

FIGURE 12
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 6

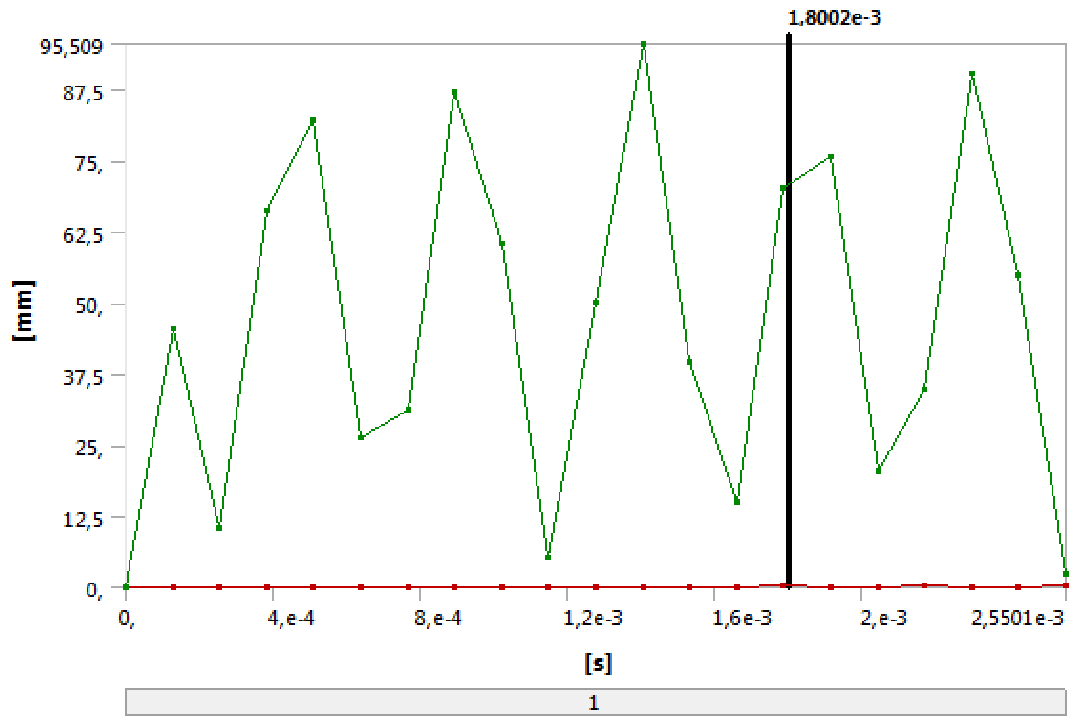


TABLE 33
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Total Deformation 6

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,275e-004	4,4213e-003	45,578
2,5509e-004	1,9121e-002	10,381
3,8255e-004	1,7455e-003	66,185
5,1007e-004	7,7503e-003	82,1
6,3774e-004	2,837e-002	26,207
7,6506e-004	0,10472	31,124
8,9258e-004	5,2853e-003	86,987
1,0202e-003	1,0612e-002	60,385
1,1476e-003	5,2139e-002	5,0936
1,2752e-003	4,237e-002	50,071
1,4026e-003	8,16e-002	95,509
1,5302e-003	7,5291e-002	39,565
1,6577e-003	8,7011e-002	14,904
1,7851e-003	0,16542	70,139
1,9127e-003	0,14121	75,698
2,0401e-003	9,7544e-002	20,432
2,1677e-003	0,23891	34,81
2,295e-003	0,15122	90,455
2,4228e-003	0,13621	54,924
2,5501e-003	0,20095	2,1606

FIGURE 13
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Equivalent Stress

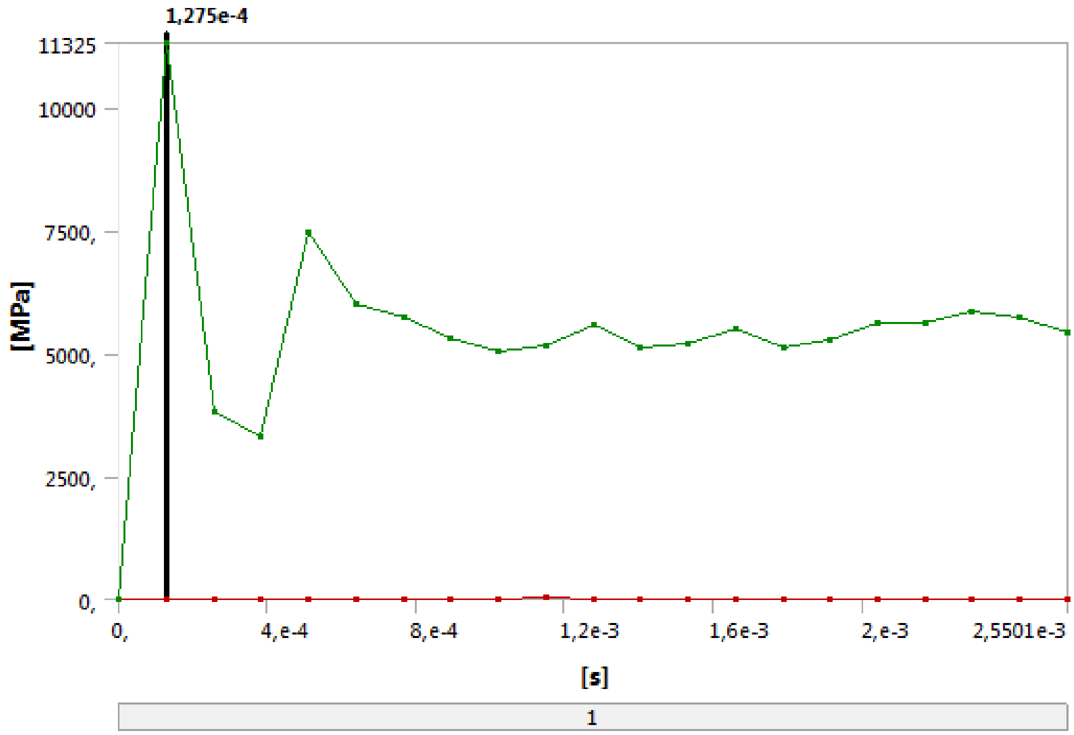


TABLE 34
Model (C4) > Explicit Dynamics (C5) > Solution (C6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,1755e-038	0,	0,
1,275e-004	16,69	11325
2,5509e-004	17,013	3816,3
3,8255e-004	13,345	3328,2
5,1007e-004	17,116	7470,5
6,3774e-004	14,425	5996,
7,6506e-004	15,513	5754,4
8,9258e-004	17,141	5304,1
1,0202e-003	13,083	5043,1
1,1476e-003	19,29	5160,9
1,2752e-003	12,922	5587,9
1,4026e-003	12,497	5129,
1,5302e-003	11,02	5206,
1,6577e-003	7,7273	5499,4
1,7851e-003	13,943	5110,
1,9127e-003	7,4332	5294,5
2,0401e-003	13,481	5608,2
2,1677e-003	17,608	5606,
2,295e-003	13,352	5848,6
2,4228e-003	9,7015	5741,8
2,5501e-003	17,712	5445,

Material Data

Structural Steel

TABLE 35
Structural Steel > Constants

Density	7,85e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat Constant Pressure	4,34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Isotropic Resistivity	1,7e-004 ohm mm

TABLE 36
Structural Steel > Appearance

Red	Green	Blue
132,	139,	179,

TABLE 37
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0,

TABLE 38
Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
250,

TABLE 39
Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
250,

TABLE 40
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
460,

TABLE 41
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22,

TABLE 42
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 43
Structural Steel > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 44
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 45
Structural Steel > Isotropic Relative Permeability

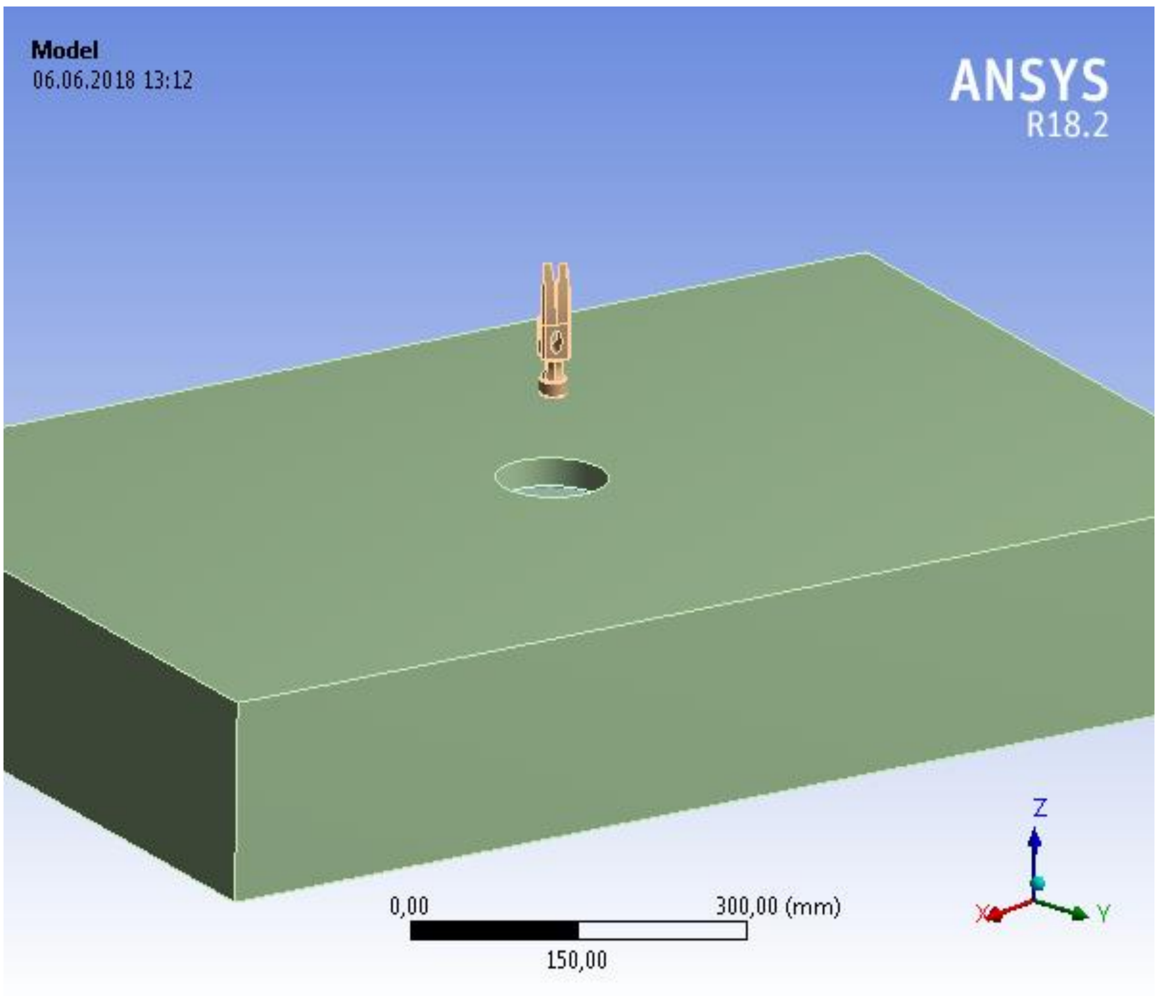
Relative Permeability
10000

Appendix B-3

Finite Element Model No. 3 ANSYS Report

Project

First Saved	Thursday, May 31, 2018
Last Saved	Sunday, June 03, 2018
Product Version	18.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (D4)

Geometry

TABLE 2
Model (D4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	F:\Hammer\10_strokers_files\dp0\SYS-3\DM\SYS-3.agdb
Type	DesignModeler

Length Unit	Meters
Display Style	Body Color
Bounding Box	
Length X	1262,4 mm
Length Y	1000,1 mm
Length Z	375,62 mm
Properties	
Volume	1,4097e+008 mm³
Mass	1102,4 kg
Scale Factor Value	1,
Statistics	
Bodies	3
Active Bodies	3
Nodes	14391
Elements	53268
Mesh Metric	None
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (D4) > Geometry > Body Groups

Object Name	*Part*
State	Meshed
Graphics Properties	
Visible	Yes
Definition	
Suppressed	No
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	101,6 mm
Properties	

Volume	8,237e+005 mm³
Mass	2,2322 kg
Centroid X	-0,76666 mm
Centroid Y	49,721 mm
Centroid Z	5,6661 mm
Moment of Inertia Ip1	3336,1 kg·mm²
Moment of Inertia Ip2	3336,1 kg·mm²
Moment of Inertia Ip3	2851,2 kg·mm²
Statistics	
Nodes	2568
Elements	2178
Mesh Metric	None
CAD Attributes	
DMBodyGroup	4

TABLE 4
Model (D4) > Geometry > Part > Parts

Object Name	*core*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Reference Frame	Lagrangian
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	101,6 mm
Properties	
Volume	8,237e+005 mm³
Mass	2,2322 kg
Centroid X	-0,76666 mm
Centroid Y	49,721 mm
Centroid Z	5,6661 mm
Moment of Inertia Ip1	3336,1 kg·mm²
Moment of Inertia Ip2	3336,1 kg·mm²
Moment of Inertia Ip3	2851,2 kg·mm²
Statistics	
Nodes	2568
Elements	2178
Mesh Metric	None

TABLE 5
Model (D4) > Geometry > Parts

Object Name	*floor*	*hammer*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	Rigid
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	1262,4 mm	31,615 mm
Length Y	1000,1 mm	31,365 mm
Length Z	181, mm	119,02 mm
Properties		
Volume	1,4011e+008 mm³	33746 mm³
Mass	1099,9 kg	0,2649 kg
Centroid X	-0,76666 mm	-0,1293 mm
Centroid Y	49,721 mm	50,514 mm
Centroid Z	-8,8313 mm	201,77 mm
Moment of Inertia Ip1	4,912e+007 kg·mm²	200,04 kg·mm²
Moment of Inertia Ip2	1,154e+008 kg·mm²	203,61 kg·mm²
Moment of Inertia Ip3	1,585e+008 kg·mm²	22,428 kg·mm²
Statistics		
Nodes	1819	10004
Elements	8259	42831
Mesh Metric	None	

Coordinate Systems

TABLE 6
Model (D4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Origin	
Origin X	0, mm
Origin Y	0, mm
Origin Z	0, mm
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 7
Model (D4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 8
Model (D4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	4,1344 mm
Use Range	No
Face/Face	Yes
Face Overlap Tolerance	Off
Cylindrical Faces	Include
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	1
Active Connections	1

TABLE 9
Model (D4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region 2*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	2 Faces
Target	2 Faces
Contact Bodies	core
Target Bodies	floor
Definition	
Type	Bonded

Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	4,1344 mm
Maximum Offset	1,e-004 mm
Breakable	No
Suppressed	No

TABLE 10
Model (D4) > Connections > Body Interactions

Object Name	*Body Interactions*
State	Fully Defined
Advanced	
Contact Detection	Trajectory
Formulation	Penalty
Sliding Contact	Discrete Surface
Body Self Contact	Program Controlled
Element Self Contact	Program Controlled
Tolerance	0,2

TABLE 11
Model (D4) > Connections > Body Interactions > Body Interaction

Object Name	*Body Interaction*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Frictionless
Suppressed	No

Mesh

TABLE 12
Model (D4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Explicit
Relevance	0
Element Order	Linear
Sizing	
Size Function	Proximity and Curvature
Relevance Center	Coarse
Max Face Size	Default (82,4290 mm)
Mesh Defeaturing	Yes
Defeature Size	Default (0,412140 mm)

Transition	Fast
Growth Rate	Default (1,850)
Span Angle Center	Coarse
Min Size	Default (0,824290 mm)
Max Tet Size	Default (164,860 mm)
Curvature Normal Angle	Default (70,3950 °)
Proximity Min Size	Default (0,824290 mm)
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Bounding Box Diagonal	1653,70 mm
Minimum Edge Length	1,0485e-003 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Number of Retries	0
Rigid Body Behavior	Full Mesh
Rigid Face Mesh Type	Quad/Tri
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Default (0,741860 mm)
Generate Pinch on Refresh	No
Statistics	
Nodes	14391
Elements	53268

TABLE 13
Model (D4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size

Element Size	10,0 mm
Advanced	
Defeature Size	Default (0,41214 mm)
Size Function	Uniform
Behavior	Soft
Growth Rate	Default (1,85)

Explicit Dynamics (D5)

TABLE 14
Model (D4) > Analysis

Object Name	*Explicit Dynamics (D5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Explicit Dynamics
Solver Target	AUTODYN
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 15
Model (D4) > Explicit Dynamics (D5) > Initial Conditions

Object Name	*Initial Conditions*
State	Fully Defined

TABLE 16
Model (D4) > Explicit Dynamics (D5) > Initial Conditions > Initial Condition

Object Name	*Pre-Stress (None)*
State	Fully Defined
Definition	
Pre-Stress Environment	None
Pressure Initialization	From Deformed State

TABLE 17
Model (D4) > Explicit Dynamics (D5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Analysis Settings Preference	
Type	Program Controlled
Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	2,55e-003 s
Maximum Energy Error	0,1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled

Maximum Time Step	Program Controlled
Time Step Safety Factor	0,9
Characteristic Dimension	Diagonals
Automatic Mass Scaling	No
Solver Controls	
Solve Units	mm, mg, ms
Beam Solution Type	Bending
Beam Time Step Safety Factor	0,5
Hex Integration Type	Exact
Shell Sublayers	3
Shell Shear Correction Factor	0,8333
Shell BWC Warp Correction	Yes
Shell Thickness Update	Nodal
Tet Integration	Average Nodal Pressure
Shell Inertia Update	Recompute
Density Update	Program Controlled
Minimum Velocity	1,e-003 mm s^-1
Maximum Velocity	1,e+013 mm s^-1
Radius Cutoff	1,e-003
Minimum Strain Rate Cutoff	1,e-010
Euler Domain Controls	
Domain Size Definition	Program Controlled
Display Euler Domain	Yes
Scope	All Bodies
X Scale factor	1,2
Y Scale factor	1,2
Z Scale factor	1,2
Domain Resolution Definition	Total Cells
Total Cells	2,5e+05
Lower X Face	Flow Out
Lower Y Face	Flow Out
Lower Z Face	Flow Out
Upper X Face	Flow Out
Upper Y Face	Flow Out
Upper Z Face	Flow Out
Euler Tracking	By Body
Damping Controls	
Linear Artificial Viscosity	0,2
Quadratic Artificial Viscosity	1,
Linear Viscosity in Expansion	No
Artificial Viscosity For Shells	Yes
Hourglass Damping	AUTODYN Standard
Viscous Coefficient	0,1
Static Damping	0,
Erosion Controls	
On Geometric Strain Limit	Yes
Geometric Strain Limit	1,5
On Material Failure	No

On Minimum Element Time Step	No
Retain Inertia of Eroded Material	Yes
Output Controls	
Save Results on	Equally Spaced Points
Result Number Of Points	20
Save Restart Files on	Equally Spaced Points
Restart Number Of Points	5
Save Result Tracker Data on	Cycles
Tracker Cycles	1
Output Contact Forces	Off
Analysis Data Management	
Solver Files Directory	F:\Hammer\10_strokers_files\dp0\SYS-3\MECH\
Scratch Solver Files Directory	

TABLE 18
Model (D4) > Explicit Dynamics (D5) > Accelerations

Object Name	*Standard Earth Gravity*
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Global Coordinate System
X Component	0, mm/s²
Y Component	0, mm/s²
Z Component	-9806,6 mm/s²
Suppressed	No
Direction	-Z Direction

FIGURE 1
Model (D4) > Explicit Dynamics (D5) > Standard Earth Gravity

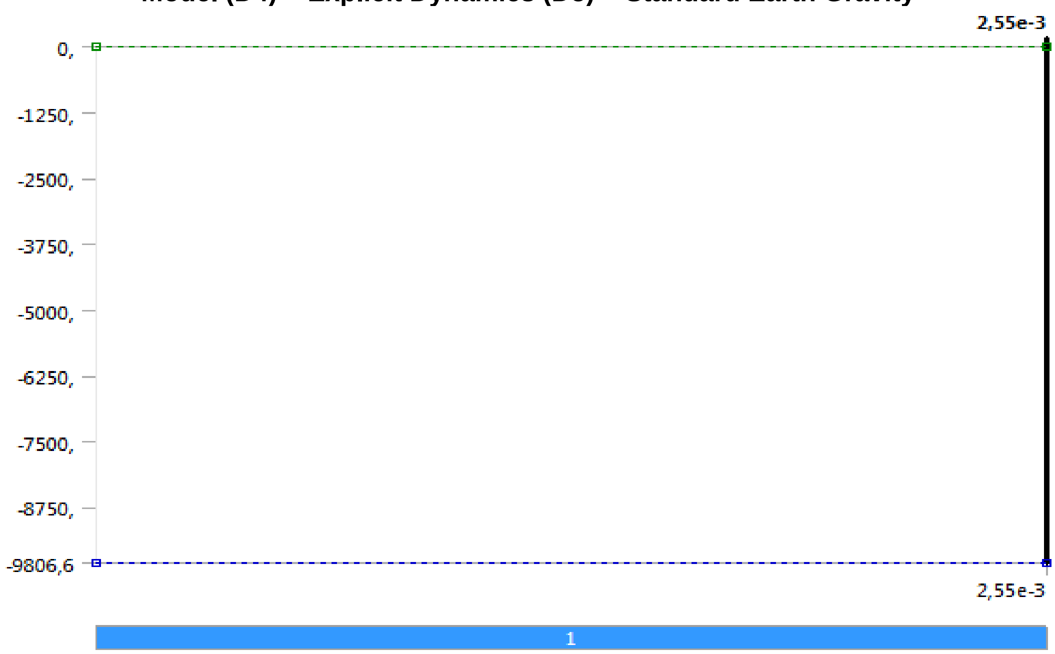


TABLE 19
Model (D4) > Explicit Dynamics (D5) > Loads

Object Name	*Fixed Support*	*Displacement*
State	Suppressed	Fully Defined
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	1 Body
Definition		
Type	Fixed Support	Displacement
Suppressed	Yes	No
Define By		Components
Coordinate System		Global Coordinate System
X Component		Free
Y Component		Free
Z Component		Tabular Data
Tabular Data		
Independent Variable		Time

FIGURE 2
Model (D4) > Explicit Dynamics (D5) > Displacement

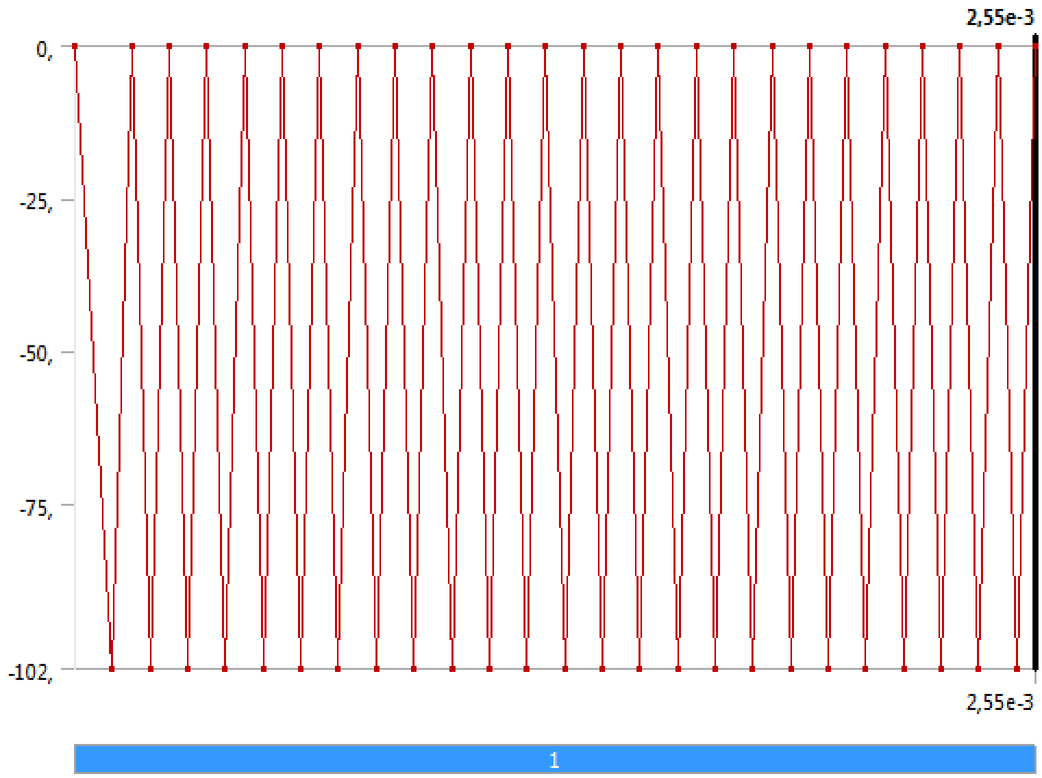


TABLE 20
Model (D4) > Explicit Dynamics (D5) > Displacement

Steps	Time [s]	Z [mm]
1	0,	0,
	1,e-004	-102,
	1,5e-004	0,
	2,e-004	-102,
	2,5e-004	0,
	3,e-004	-102,
	3,5e-004	0,
	4,e-004	-102,
	4,5e-004	0,
	5,e-004	-102,
	5,5e-004	0,
	6,e-004	-102,
	6,5e-004	0,
	7,e-004	-102,
	7,5e-004	0,
	8,e-004	-102,
	8,5e-004	0,
	9,e-004	-102,
	9,5e-004	0,
	1,e-003	-102,
	1,05e-003	0,
	1,1e-003	-102,
	1,15e-003	0,
	1,2e-003	-102,
	1,25e-003	0,
	1,3e-003	-102,
	1,35e-003	0,
	1,4e-003	-102,
	1,45e-003	0,
	1,5e-003	-102,
	1,55e-003	0,
	1,6e-003	-102,
	1,65e-003	0,
	1,7e-003	-102,
	1,75e-003	0,
	1,8e-003	-102,
	1,85e-003	0,
	1,9e-003	-102,
	1,95e-003	0,
	2,e-003	-102,
	2,05e-003	0,
	2,1e-003	-102,
	2,15e-003	0,
	2,2e-003	-102,
	2,25e-003	0,
	2,3e-003	-102,

	2,35e-003	0,
	2,4e-003	-102,
	2,45e-003	0,
	2,5e-003	-102,
	2,55e-003	0,

Solution (D6)

TABLE 21
Model (D4) > Explicit Dynamics (D5) > Solution

Object Name	*Solution (D6)*
State	Solved
Information	
Status	Done
Post Processing	
Beam Section Results	No

TABLE 22
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Update Interval	2,5 s
Display Points	All
Display Filter During Solve	Yes

TABLE 23
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Results

Object Name	*Total Deformation*	*Directional Acceleration*	*Total Deformation 2*	*Total Deformation 3*	*Equivalent Elastic Strain*	*Total Deformation 4*	*Normal Elastic Strain*	*Directional Deformation*	*Total Deformation 5*	*Total Deformation 6*	*Equivalent Stress*
State	Solved										
Scope											
Scoping Method	Geometry Selection										
Geometry	All Bodies					1 Body	2 Bodies				1 Body
Definition											
Type	Total Deformation	Directional Acceleration	Total Deformation		Equivalent Elastic Strain	Total Deformation	Normal Elastic Strain	Directional Deformation	Total Deformation		Equivalent (von-Mises) Stress
By	Time										
Display Time	Last			1,4e-003 s	Last	1,9e-003 s	Last			1,8002e-003 s	1,3002e-003 s
Calculate Time History	Yes										
Identifier											
Suppressed	No										
Orientation		X Axis					X Axis	Z Axis			
Coordinate System		Global Coordinate System					Global Coordinate System				
Results											
Minimum	4,1053e-002 mm	-2,0439e+008 mm/s²	4,1053e-002 mm	6,6893e-003 mm	0, mm/mm	8,962e-003 mm	-5,8413e-002 mm/mm	-6,0593 mm	4,1053e-002 mm	5,4339e-003 mm	7,4301 MPa
Maximum	6,2531 mm	1,4979e+008 mm/s²	6,2531 mm	99,968 mm	0,10854 mm/mm	6,2217 mm	3,0863e-003 mm/mm	0,96023 mm	6,2531 mm	75,401 mm	210,49 MPa
Minimum Occurs On	core	floor	core		hammer	core					
Maximum Occurs On	core	floor	core	hammer	core					hammer	core
Minimum Value Over Time											
Minimum	0, mm	-2,3933e+010 mm/s²	0, mm		0, mm/mm	0, mm	-5,8977e-002 mm/mm	-99,967 mm	0, mm		0, MPa
Maximum	4,1053e-002 mm	0, mm/s²	4,1053e-002 mm		0, mm/mm	4,1053e-002 mm	0, mm/mm	0, mm	4,1053e-002 mm		15,334 MPa
Maximum Value Over Time											
Minimum	0, mm	0, mm/s²	0, mm		0, mm/mm	0, mm	0, mm/mm	0, mm			0, MPa
Maximum	99,968 mm	2,3865e+010 mm/s²	99,968 mm		0,1094 mm/mm	6,2547 mm	3,6046e-003 mm/mm	0,99977 mm	99,968 mm		288,91 MPa
Information											
Time	2,5502e-003 s			1,4026e-003 s	2,5502e-003 s	1,9127e-003 s	2,5502e-003 s			1,7851e-003 s	1,275e-003 s
Set	21			12	21	16	21			15	11
Cycle Number	9311			4721	9311	6742	9311			6228	4250
Integration Point Results											
Display Option					Averaged		Averaged				Averaged
Average Across Bodies					No		No				No

FIGURE 3
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation

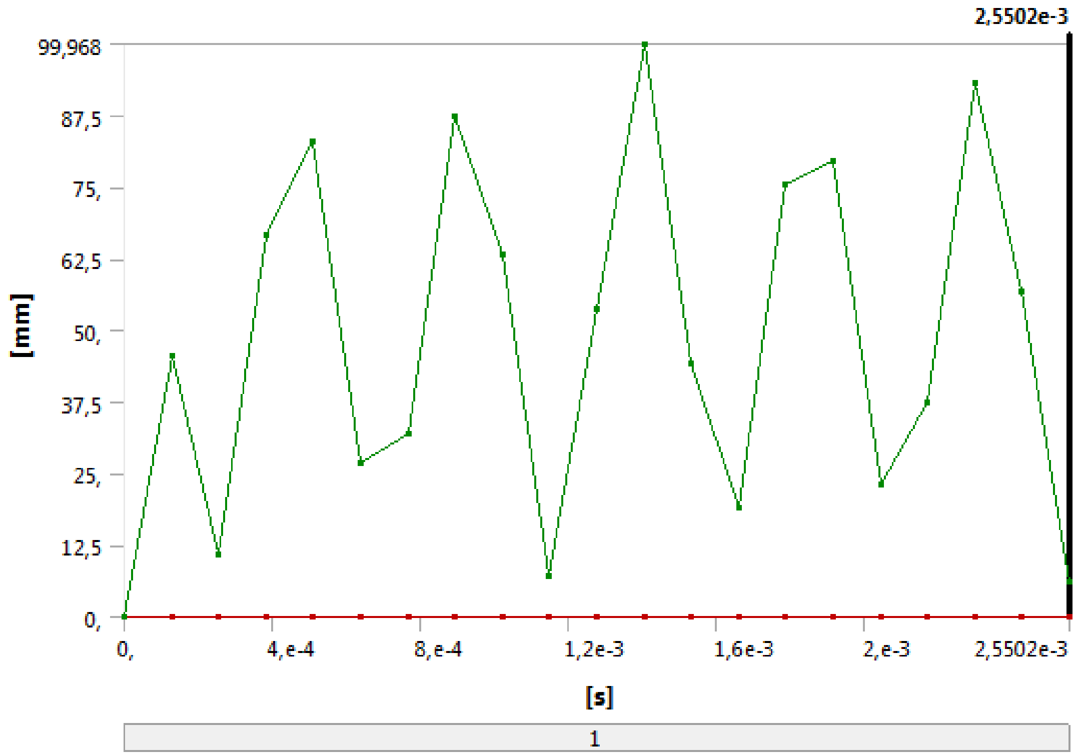


TABLE 24
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	2,092e-005	45,565
2,5514e-004	8,938e-005	10,804
3,8257e-004	1,7958e-004	66,509
5,1e-004	3,1117e-004	83,008
6,3773e-004	1,8296e-004	26,72
7,6514e-004	4,8915e-004	31,974
8,9254e-004	3,1399e-004	87,372
1,0202e-003	3,294e-004	63,185
1,1477e-003	8,9377e-004	6,9731
1,275e-003	7,4288e-004	53,888
1,4026e-003	6,6893e-003	99,968
1,5302e-003	1,8251e-002	44,309
1,6576e-003	2,0216e-002	19,023
1,7851e-003	5,4339e-003	75,401
1,9127e-003	8,962e-003	79,463
2,04e-003	1,6855e-002	23,275
2,1676e-003	1,3365e-002	37,464
2,2951e-003	2,5788e-002	93,151
2,4227e-003	3,5884e-002	56,704
2,5502e-003	4,1053e-002	6,2531

FIGURE 4
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Directional Acceleration

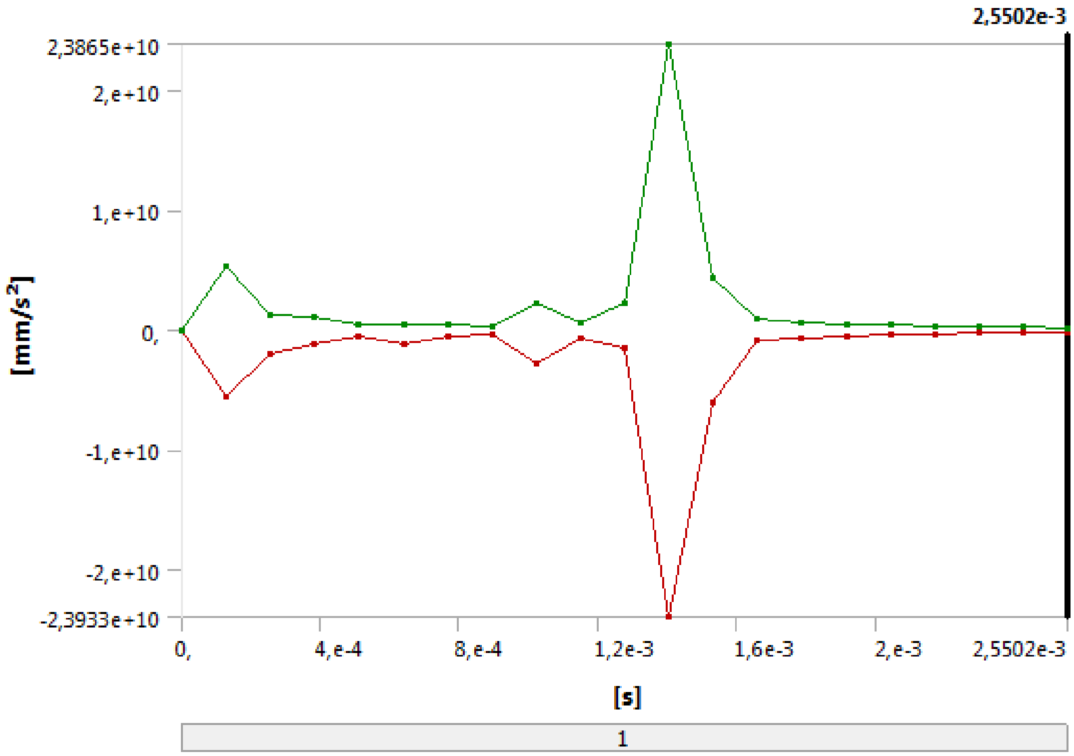


TABLE 25
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Directional Acceleration

Time [s]	Minimum [mm/s²]	Maximum [mm/s²]
1,1755e-038	0,	0,
1,2774e-004	-5,4849e+009	5,338e+009
2,5514e-004	-2,0647e+009	1,2983e+009
3,8257e-004	-1,1007e+009	1,0483e+009
5,1e-004	-5,2055e+008	5,3421e+008
6,3773e-004	-1,1303e+009	4,6191e+008
7,6514e-004	-4,4143e+008	4,8323e+008
8,9254e-004	-3,2385e+008	3,6028e+008
1,0202e-003	-2,7782e+009	2,2144e+009
1,1477e-003	-7,4811e+008	6,2206e+008
1,275e-003	-1,5545e+009	2,2076e+009
1,4026e-003	-2,3933e+010	2,3865e+010
1,5302e-003	-6,1089e+009	4,3257e+009
1,6576e-003	-8,184e+008	9,8046e+008
1,7851e-003	-7,3534e+008	6,2902e+008
1,9127e-003	-5,3476e+008	3,7422e+008
2,04e-003	-4,0276e+008	3,9538e+008
2,1676e-003	-2,8493e+008	2,901e+008
2,2951e-003	-2,5531e+008	3,709e+008
2,4227e-003	-2,1142e+008	2,2015e+008
2,5502e-003	-2,0439e+008	1,4979e+008

FIGURE 5
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 2

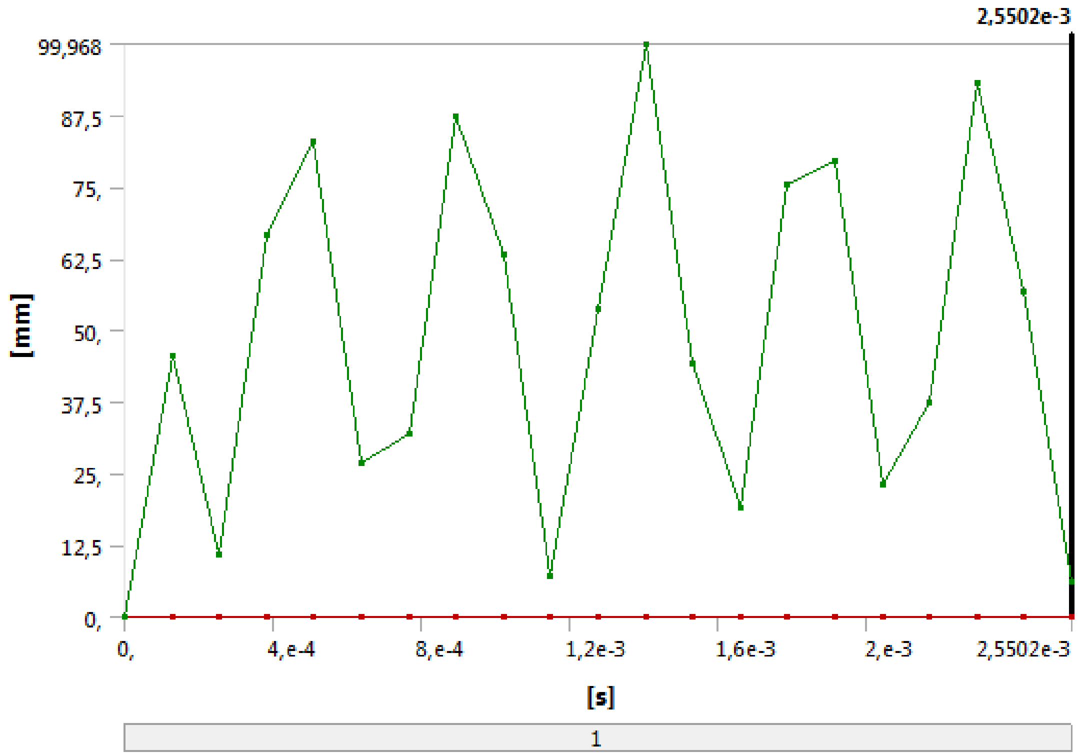


TABLE 26
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	2,092e-005	45,565
2,5514e-004	8,938e-005	10,804
3,8257e-004	1,7958e-004	66,509
5,1e-004	3,1117e-004	83,008
6,3773e-004	1,8296e-004	26,72
7,6514e-004	4,8915e-004	31,974
8,9254e-004	3,1399e-004	87,372
1,0202e-003	3,294e-004	63,185
1,1477e-003	8,9377e-004	6,9731
1,275e-003	7,4288e-004	53,888
1,4026e-003	6,6893e-003	99,968
1,5302e-003	1,8251e-002	44,309
1,6576e-003	2,0216e-002	19,023
1,7851e-003	5,4339e-003	75,401
1,9127e-003	8,962e-003	79,463
2,04e-003	1,6855e-002	23,275
2,1676e-003	1,3365e-002	37,464
2,2951e-003	2,5788e-002	93,151
2,4227e-003	3,5884e-002	56,704
2,5502e-003	4,1053e-002	6,2531

FIGURE 6
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 3

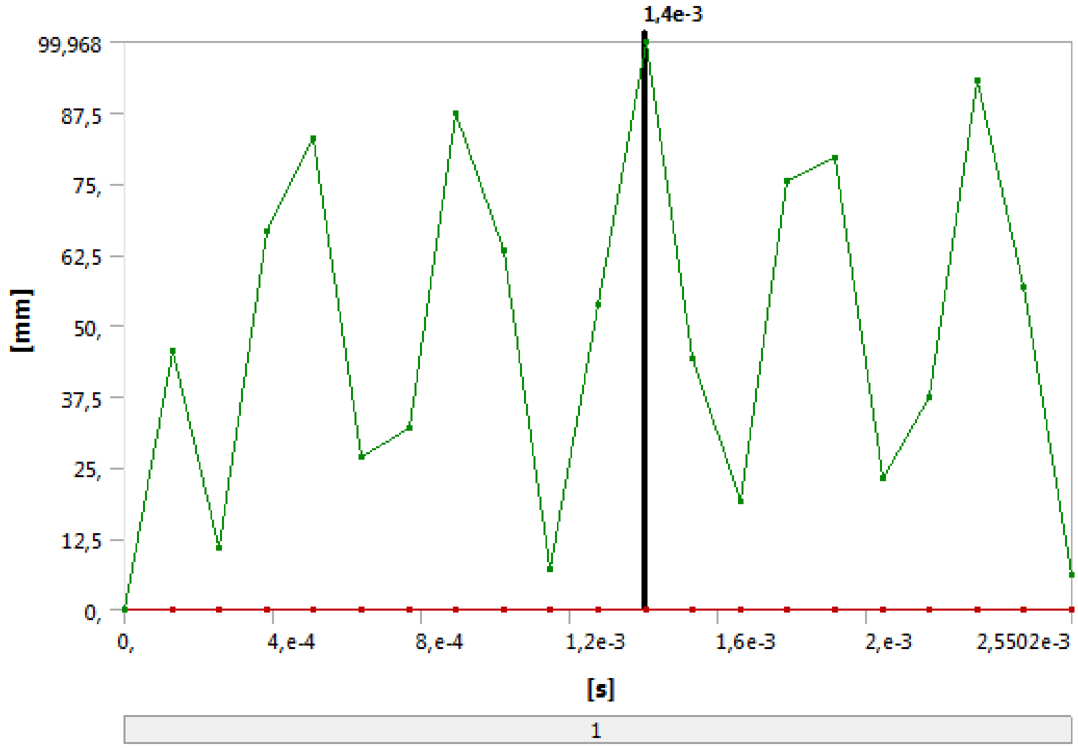


TABLE 27
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 3

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	2,092e-005	45,565
2,5514e-004	8,938e-005	10,804
3,8257e-004	1,7958e-004	66,509
5,1e-004	3,1117e-004	83,008
6,3773e-004	1,8296e-004	26,72
7,6514e-004	4,8915e-004	31,974
8,9254e-004	3,1399e-004	87,372
1,0202e-003	3,294e-004	63,185
1,1477e-003	8,9377e-004	6,9731
1,275e-003	7,4288e-004	53,888
1,4026e-003	6,6893e-003	99,968
1,5302e-003	1,8251e-002	44,309
1,6576e-003	2,0216e-002	19,023
1,7851e-003	5,4339e-003	75,401
1,9127e-003	8,962e-003	79,463
2,04e-003	1,6855e-002	23,275
2,1676e-003	1,3365e-002	37,464
2,2951e-003	2,5788e-002	93,151
2,4227e-003	3,5884e-002	56,704
2,5502e-003	4,1053e-002	6,2531

FIGURE 7
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Equivalent Elastic Strain

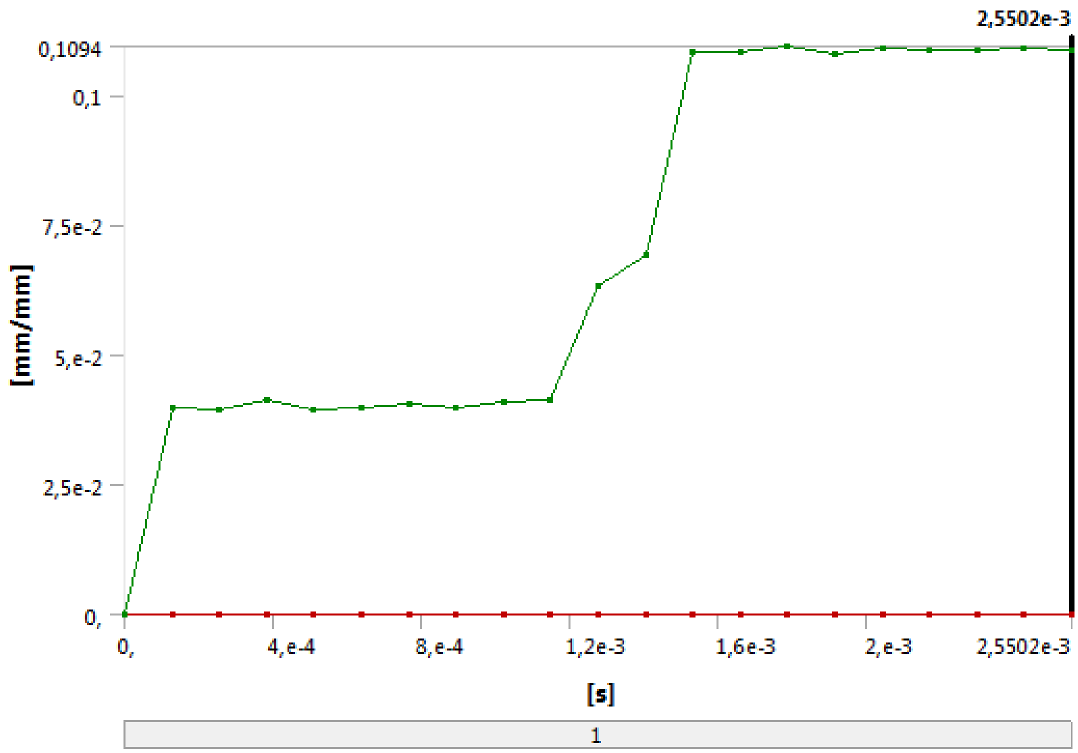


TABLE 28
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,2774e-004		3,9927e-002
2,5514e-004		3,9363e-002
3,8257e-004		4,1332e-002
5,1e-004		3,9545e-002
6,3773e-004		3,9909e-002
7,6514e-004		4,0648e-002
8,9254e-004		3,9684e-002
1,0202e-003		4,0767e-002
1,1477e-003		4,1322e-002
1,275e-003		6,3199e-002
1,4026e-003		6,9324e-002
1,5302e-003		0,10831
1,6576e-003		0,10822
1,7851e-003		0,1094
1,9127e-003		0,10809
2,04e-003		0,10898
2,1676e-003		0,10872
2,2951e-003		0,10848
2,4227e-003		0,10889
2,5502e-003		0,10854

FIGURE 8
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 4

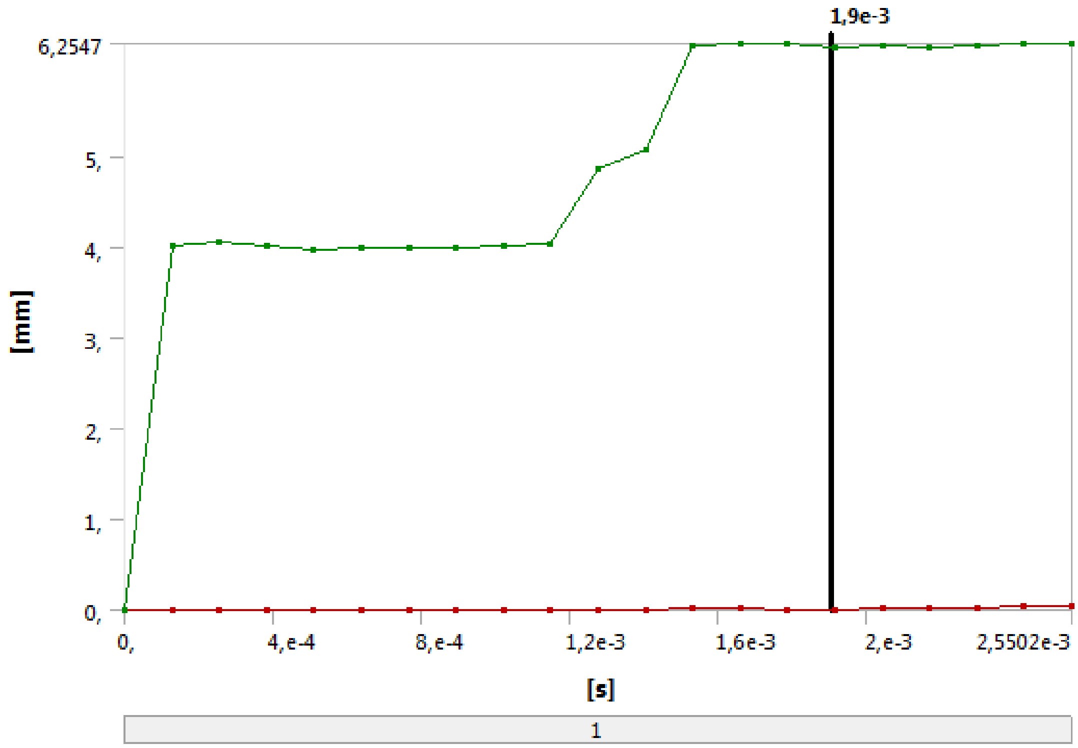


TABLE 29
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 4

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	5,0987e-004	4,026
2,5514e-004	1,6071e-003	4,0705
3,8257e-004	9,883e-004	4,0216
5,1e-004	1,2625e-003	3,9764
6,3773e-004	1,8296e-004	3,9918
7,6514e-004	4,8915e-004	4,0076
8,9254e-004	3,1399e-004	3,9993
1,0202e-003	3,294e-004	4,0141
1,1477e-003	8,9377e-004	4,0332
1,275e-003	7,4288e-004	4,8767
1,4026e-003	6,6893e-003	5,0759
1,5302e-003	3,1854e-002	6,2368
1,6576e-003	3,0057e-002	6,2491
1,7851e-003	5,4339e-003	6,247
1,9127e-003	8,962e-003	6,2217
2,04e-003	1,6855e-002	6,2241
2,1676e-003	1,3365e-002	6,2204
2,2951e-003	2,5788e-002	6,2378
2,4227e-003	3,5884e-002	6,2547
2,5502e-003	4,1053e-002	6,2531

FIGURE 9
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Normal Elastic Strain

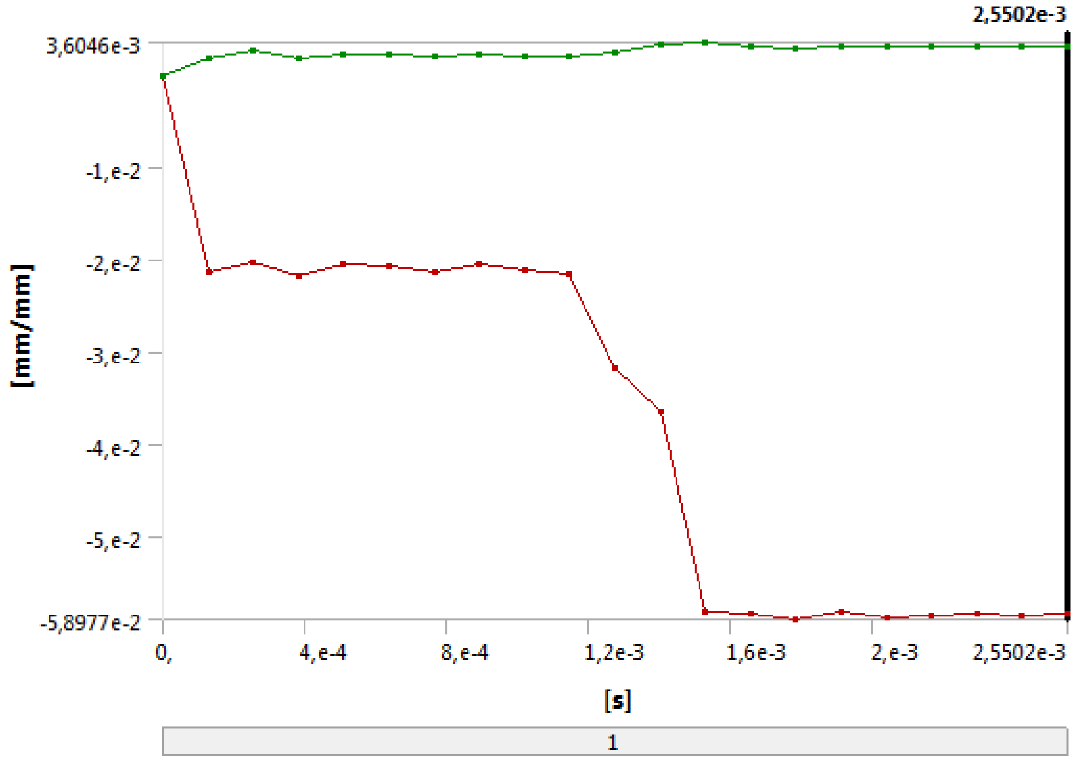


TABLE 30
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Normal Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,2774e-004	-2,1375e-002	1,8383e-003
2,5514e-004	-2,0322e-002	2,7543e-003
3,8257e-004	-2,1771e-002	1,8415e-003
5,1e-004	-2,0408e-002	2,2366e-003
6,3773e-004	-2,0673e-002	2,2212e-003
7,6514e-004	-2,1365e-002	2,0458e-003
8,9254e-004	-2,0552e-002	2,3814e-003
1,0202e-003	-2,1161e-002	2,2192e-003
1,1477e-003	-2,1468e-002	2,1879e-003
1,275e-003	-3,1791e-002	2,6233e-003
1,4026e-003	-3,6353e-002	3,3808e-003
1,5302e-003	-5,8091e-002	3,6046e-003
1,6576e-003	-5,8364e-002	3,2706e-003
1,7851e-003	-5,8977e-002	2,9095e-003
1,9127e-003	-5,8138e-002	3,2636e-003
2,04e-003	-5,8702e-002	3,1417e-003
2,1676e-003	-5,8517e-002	3,139e-003
2,2951e-003	-5,8437e-002	3,1853e-003
2,4227e-003	-5,8588e-002	3,0886e-003
2,5502e-003	-5,8413e-002	3,0863e-003

FIGURE 10
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Directional Deformation

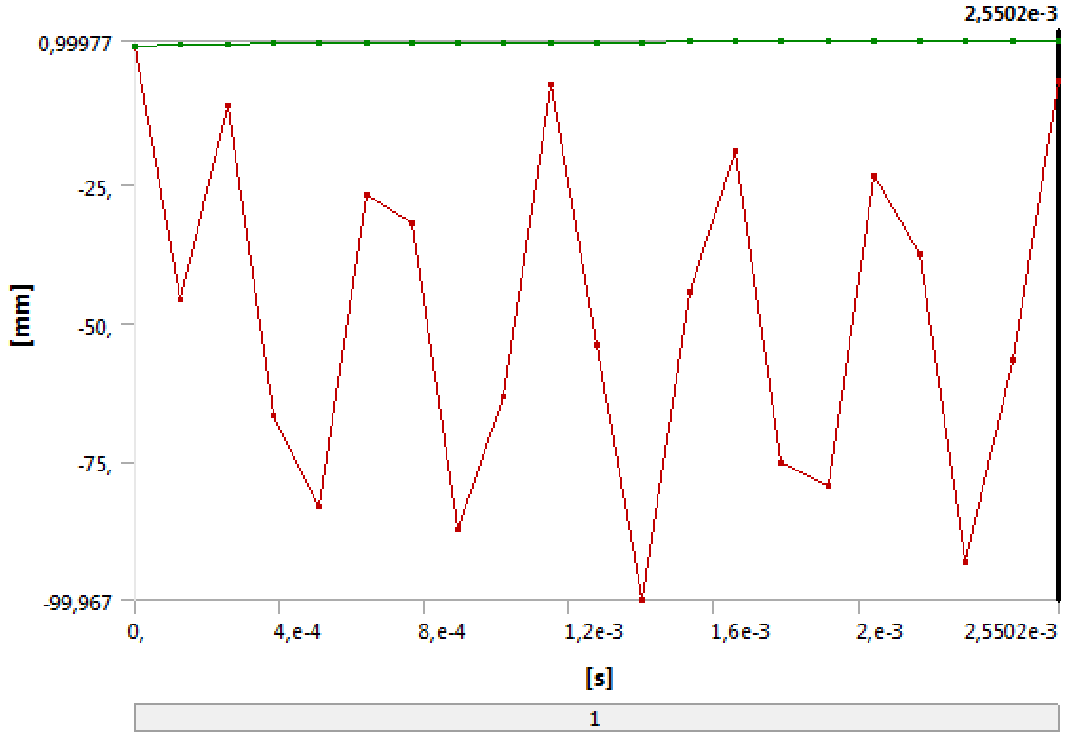


TABLE 31
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	-45,565	0,47687
2,5514e-004	-10,804	0,44348
3,8257e-004	-66,509	0,51183
5,1e-004	-83,008	0,53413
6,3773e-004	-26,72	0,52672
7,6514e-004	-31,973	0,51445
8,9254e-004	-87,372	0,51556
1,0202e-003	-63,185	0,50068
1,1477e-003	-6,9676	0,50527
1,275e-003	-53,887	0,76133
1,4026e-003	-99,967	0,79047
1,5302e-003	-44,307	0,99773
1,6576e-003	-19,019	0,96827
1,7851e-003	-75,4	0,97584
1,9127e-003	-79,461	0,99363
2,04e-003	-23,266	0,99663
2,1676e-003	-37,455	0,99977
2,2951e-003	-93,146	0,97954
2,4227e-003	-56,693	0,96119
2,5502e-003	-6,0593	0,96023

FIGURE 11
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 5

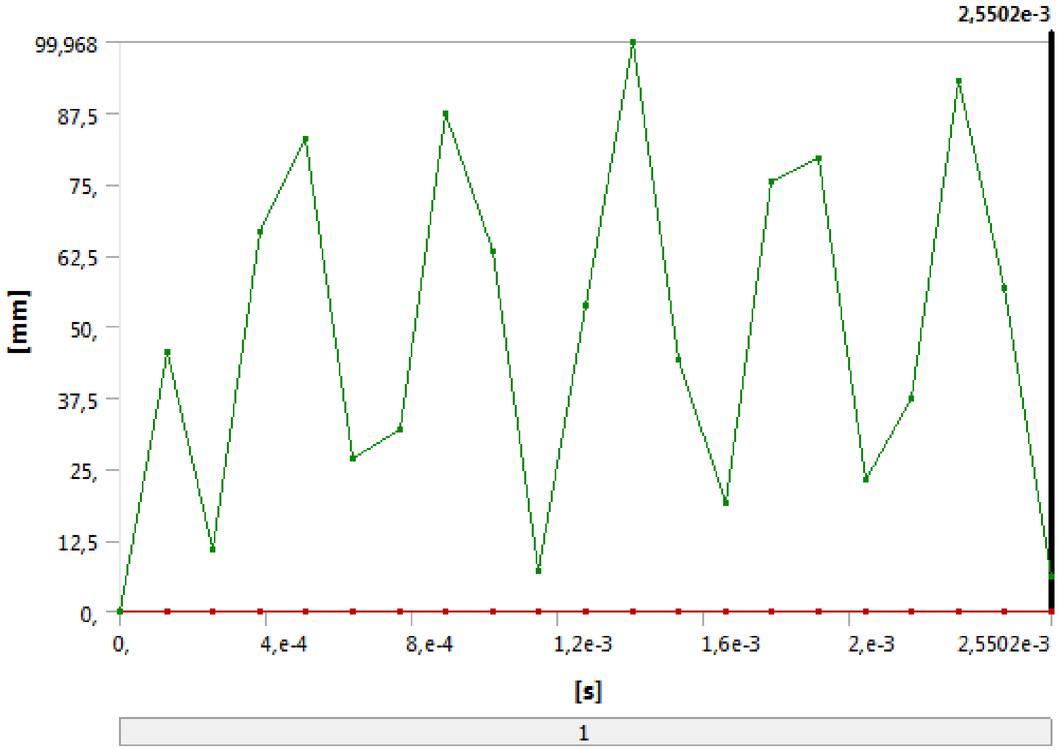


TABLE 32
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 5

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	5,0987e-004	45,565
2,5514e-004	1,6071e-003	10,804
3,8257e-004	9,883e-004	66,509
5,1e-004	1,2625e-003	83,008
6,3773e-004	1,8296e-004	26,72
7,6514e-004	4,8915e-004	31,974
8,9254e-004	3,1399e-004	87,372
1,0202e-003	3,294e-004	63,185
1,1477e-003	8,9377e-004	6,9731
1,275e-003	7,4288e-004	53,888
1,4026e-003	6,6893e-003	99,968
1,5302e-003	3,1854e-002	44,309
1,6576e-003	3,0057e-002	19,023
1,7851e-003	5,4339e-003	75,401
1,9127e-003	8,962e-003	79,463
2,04e-003	1,6855e-002	23,275
2,1676e-003	1,3365e-002	37,464
2,2951e-003	2,5788e-002	93,151
2,4227e-003	3,5884e-002	56,704
2,5502e-003	4,1053e-002	6,2531

FIGURE 12
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 6

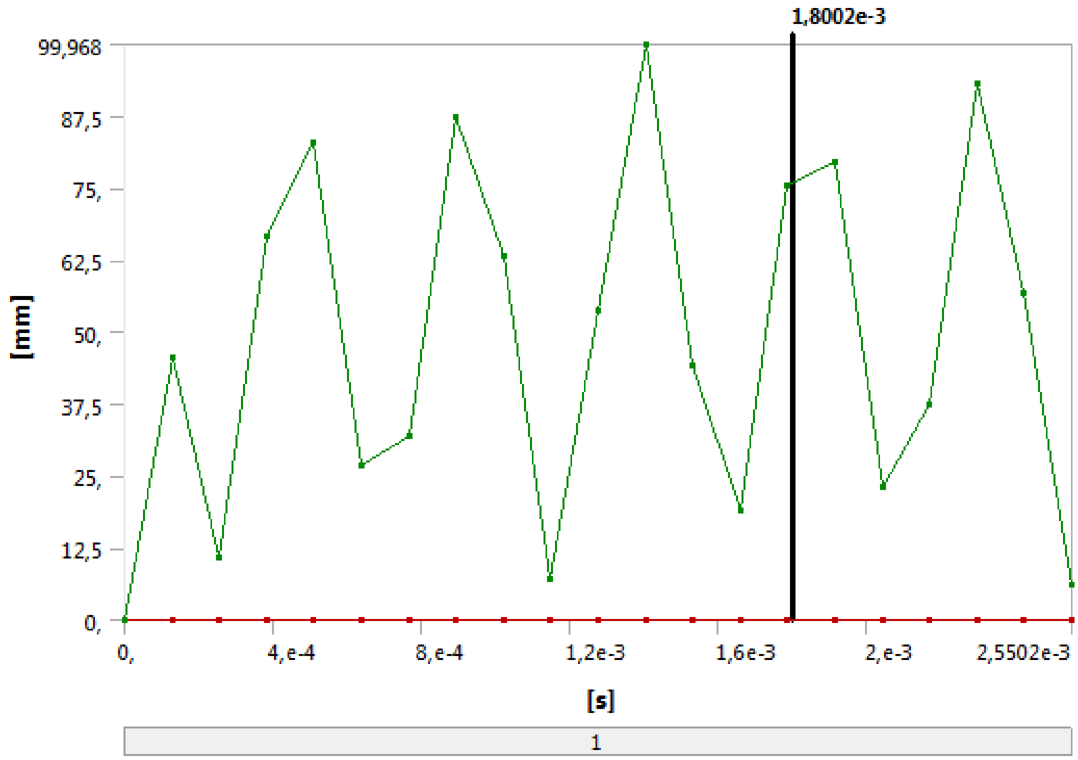


TABLE 33
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Total Deformation 6

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,2774e-004	5,0987e-004	45,565
2,5514e-004	1,6071e-003	10,804
3,8257e-004	9,883e-004	66,509
5,1e-004	1,2625e-003	83,008
6,3773e-004	1,8296e-004	26,72
7,6514e-004	4,8915e-004	31,974
8,9254e-004	3,1399e-004	87,372
1,0202e-003	3,294e-004	63,185
1,1477e-003	8,9377e-004	6,9731
1,275e-003	7,4288e-004	53,888
1,4026e-003	6,6893e-003	99,968
1,5302e-003	3,1854e-002	44,309
1,6576e-003	3,0057e-002	19,023
1,7851e-003	5,4339e-003	75,401
1,9127e-003	8,962e-003	79,463
2,04e-003	1,6855e-002	23,275
2,1676e-003	1,3365e-002	37,464
2,2951e-003	2,5788e-002	93,151
2,4227e-003	3,5884e-002	56,704
2,5502e-003	4,1053e-002	6,2531

FIGURE 13
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Equivalent Stress

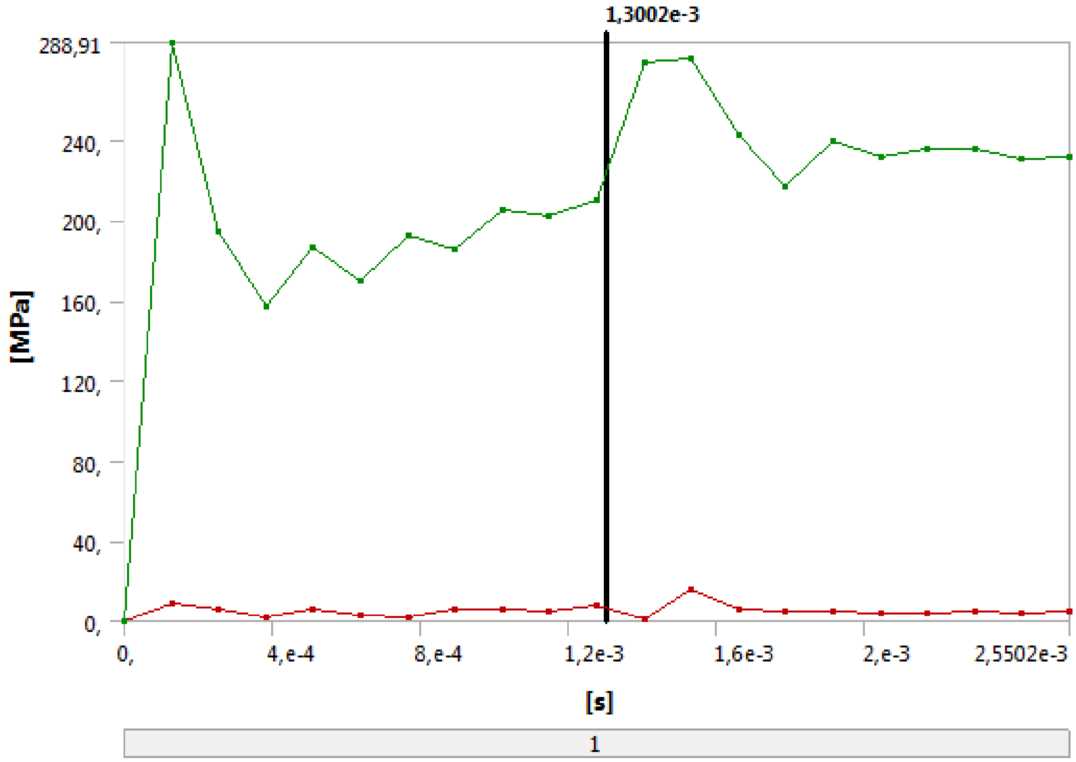


TABLE 34
Model (D4) > Explicit Dynamics (D5) > Solution (D6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,1755e-038	0,	0,
1,2774e-004	8,6218	288,91
2,5514e-004	6,1703	194,81
3,8257e-004	1,9636	157,69
5,1e-004	6,1467	186,36
6,3773e-004	2,6937	169,89
7,6514e-004	2,4249	192,32
8,9254e-004	5,4947	185,5
1,0202e-003	6,3869	205,28
1,1477e-003	4,8357	202,55
1,275e-003	7,4301	210,49
1,4026e-003	1,4049	279,21
1,5302e-003	15,334	281,33
1,6576e-003	5,7042	242,98
1,7851e-003	5,3083	217,57
1,9127e-003	4,7797	239,92
2,04e-003	3,6652	231,58
2,1676e-003	4,1001	235,83
2,2951e-003	4,6337	235,49
2,4227e-003	3,8173	230,73
2,5502e-003	4,5253	231,48

Material Data

Structural Steel

TABLE 40
Structural Steel > Constants

Density	7,85e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat Constant Pressure	4,34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Isotropic Resistivity	1,7e-004 ohm mm

TABLE 41
Structural Steel > Appearance

Red	Green	Blue
132,	139,	179,

TABLE 42
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0,

TABLE 43
Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
250,

TABLE 44
Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
250,

TABLE 45
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
460,

TABLE 46
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22,

TABLE 47
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 48
Structural Steel > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 49
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 50
Structural Steel > Isotropic Relative Permeability

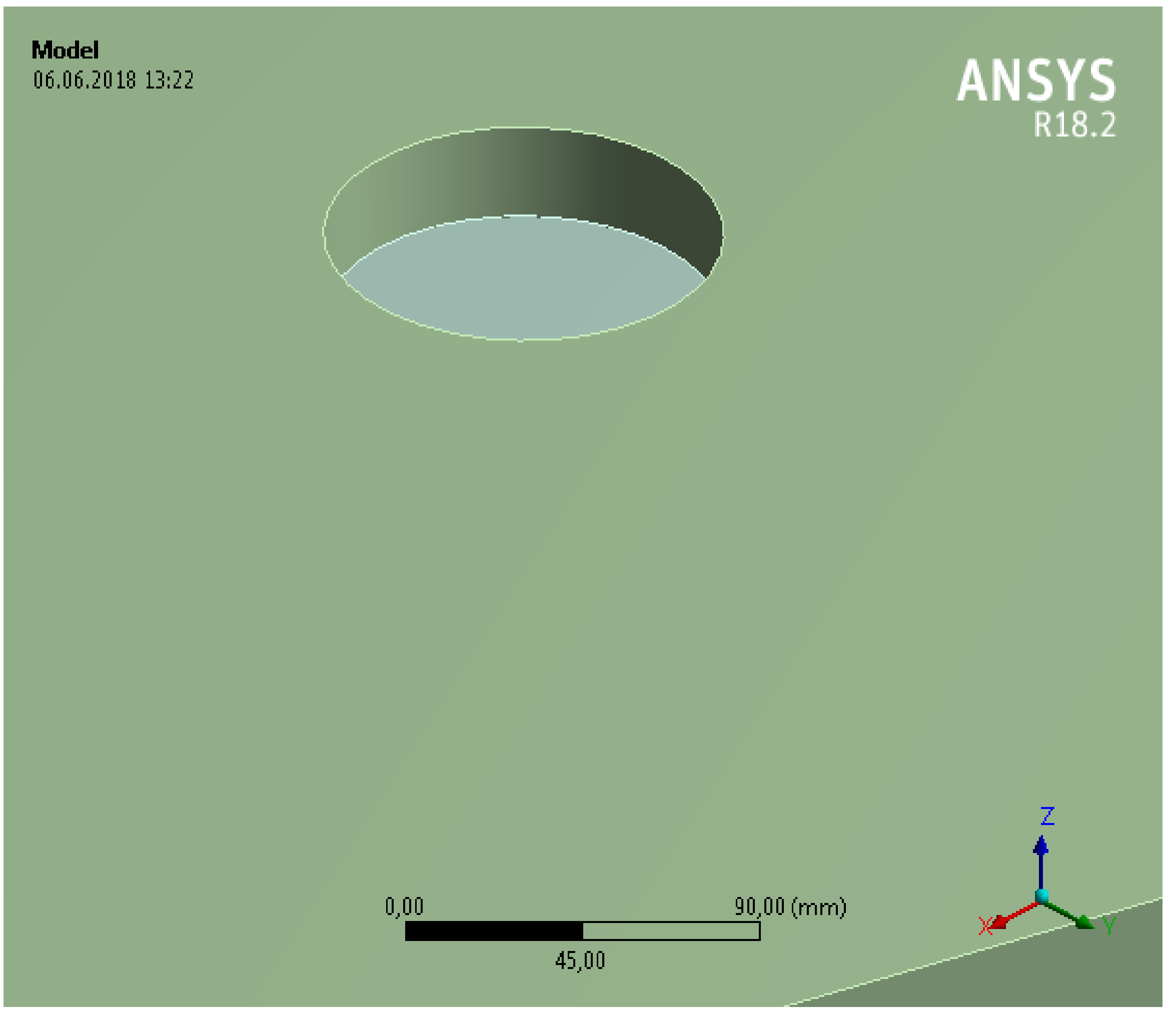
Relative Permeability
10000

Appendix B-4

Finite Element Model No. 4 ANSYS Report

Project

First Saved	Thursday, May 31, 2018
Last Saved	Tuesday, June 05, 2018
Product Version	18.2 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

Units

TABLE 1

Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (E4)

Geometry

TABLE 2
Model (E4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	F:\Hammer\10_strokers_files\dp0\SYS-4\DM\SYS-4.agdb
Type	DesignModeler
Length Unit	Meters
Display Style	Body Color
Bounding Box	

Length X	1262,4 mm
Length Y	1000,1 mm
Length Z	375,62 mm
Properties	
Volume	1,4097e+008 mm³
Mass	1102,4 kg
Scale Factor Value	1,
Statistics	
Bodies	3
Active Bodies	3
Nodes	14391
Elements	53268
Mesh Metric	None
Basic Geometry Options	
Parameters	Independent
Parameter Key	
Attributes	Yes
Attribute Key	
Named Selections	Yes
Named Selection Key	
Material Properties	Yes
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	Yes
Coordinate System Key	
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	Yes
Compare Parts On Update	No
Analysis Type	3-D
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (E4) > Geometry > Body Groups

Object Name	*Part*
State	Meshed
Graphics Properties	
Visible	Yes
Definition	
Suppressed	No
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	101,6 mm
Properties	
Volume	8,237e+005 mm³
Mass	2,2322 kg
Centroid X	-0,76666 mm

Centroid Y	49,721 mm
Centroid Z	5,6661 mm
Moment of Inertia Ip1	3336,1 kg·mm²
Moment of Inertia Ip2	3336,1 kg·mm²
Moment of Inertia Ip3	2851,2 kg·mm²
Statistics	
Nodes	2568
Elements	2178
Mesh Metric	None
CAD Attributes	
DMBodyGroup	4

TABLE 4
Model (E4) > Geometry > Part > Parts

Object Name	*core*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Reference Frame	Lagrangian
Material	
Bounding Box	
Length X	101,6 mm
Length Y	101,6 mm
Length Z	101,6 mm
Properties	
Volume	8,237e+005 mm³
Mass	2,2322 kg
Centroid X	-0,76666 mm
Centroid Y	49,721 mm
Centroid Z	5,6661 mm
Moment of Inertia Ip1	3336,1 kg·mm²
Moment of Inertia Ip2	3336,1 kg·mm²
Moment of Inertia Ip3	2851,2 kg·mm²
Statistics	
Nodes	2568
Elements	2178
Mesh Metric	None

TABLE 5
Model (E4) > Geometry > Parts

Object Name	*floor*	*hammer*
State	Meshed	
Graphics Properties		

Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	Rigid
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Reference Frame	Lagrangian	
Material		
Assignment	Structural Steel	
Bounding Box		
Length X	1262,4 mm	31,615 mm
Length Y	1000,1 mm	31,365 mm
Length Z	181, mm	119,02 mm
Properties		
Volume	1,4011e+008 mm³	33746 mm³
Mass	1099,9 kg	0,2649 kg
Centroid X	-0,76666 mm	-0,1293 mm
Centroid Y	49,721 mm	50,514 mm
Centroid Z	-8,8313 mm	201,77 mm
Moment of Inertia Ip1	4,912e+007 kg·mm²	200,04 kg·mm²
Moment of Inertia Ip2	1,154e+008 kg·mm²	203,61 kg·mm²
Moment of Inertia Ip3	1,585e+008 kg·mm²	22,428 kg·mm²
Statistics		
Nodes	1819	10004
Elements	8259	42831
Mesh Metric	None	

Coordinate Systems

TABLE 6
Model (E4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Origin	
Origin X	0, mm
Origin Y	0, mm
Origin Z	0, mm
Directional Vectors	
X Axis Data	[1, 0, 0,]
Y Axis Data	[0, 1, 0,]
Z Axis Data	[0, 0, 1,]

Connections

TABLE 7
Model (E4) > Connections

Object Name	*Connections*
State	Fully Defined
Auto Detection	
Generate Automatic Connection On Refresh	Yes
Transparency	
Enabled	Yes

TABLE 8
Model (E4) > Connections > Contacts

Object Name	*Contacts*
State	Fully Defined
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	4,1344 mm
Use Range	No
Face/Face	Yes
Face Overlap Tolerance	Off
Cylindrical Faces	Include
Face/Edge	No
Edge/Edge	No
Priority	Include All
Group By	Bodies
Search Across	Bodies
Statistics	
Connections	1
Active Connections	1

TABLE 9
Model (E4) > Connections > Contacts > Contact Regions

Object Name	*Contact Region 2*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Contact	2 Faces
Target	2 Faces
Contact Bodies	core
Target Bodies	floor
Definition	
Type	Bonded

Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	4,1344 mm
Maximum Offset	1,e-004 mm
Breakable	No
Suppressed	No

TABLE 10
Model (E4) > Connections > Body Interactions

Object Name	*Body Interactions*
State	Fully Defined
Advanced	
Contact Detection	Trajectory
Formulation	Penalty
Sliding Contact	Discrete Surface
Body Self Contact	Program Controlled
Element Self Contact	Program Controlled
Tolerance	0,2

TABLE 11
Model (E4) > Connections > Body Interactions > Body Interaction

Object Name	*Body Interaction*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Frictionless
Suppressed	No

Mesh

TABLE 12
Model (E4) > Mesh

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Explicit
Relevance	0
Element Order	Linear
Sizing	
Size Function	Proximity and Curvature
Relevance Center	Coarse
Max Face Size	Default (82,4290 mm)
Mesh Defeaturing	Yes
Defeature Size	Default (0,412140 mm)

Transition	Fast
Growth Rate	Default (1,850)
Span Angle Center	Coarse
Min Size	Default (0,824290 mm)
Max Tet Size	Default (164,860 mm)
Curvature Normal Angle	Default (70,3950 °)
Proximity Min Size	Default (0,824290 mm)
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Faces and Edges
Bounding Box Diagonal	1653,70 mm
Minimum Edge Length	1,0485e-003 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Quality	Default (0.050000)
Smoothing	High
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0,272
Maximum Layers	5
Growth Rate	1,2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Number of Retries	0
Rigid Body Behavior	Full Mesh
Rigid Face Mesh Type	Quad/Tri
Mesh Morphing	Disabled
Triangle Surface Mesher	Program Controlled
Topology Checking	No
Pinch Tolerance	Default (0,741860 mm)
Generate Pinch on Refresh	No
Statistics	
Nodes	14391
Elements	53268

TABLE 13
Model (E4) > Mesh > Mesh Controls

Object Name	*Body Sizing*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size

Element Size	10,0 mm
Advanced	
Defeature Size	Default (0,41214 mm)
Size Function	Uniform
Behavior	Soft
Growth Rate	Default (1,85)

Explicit Dynamics (E5)

TABLE 14
Model (E4) > Analysis

Object Name	*Explicit Dynamics (E5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Explicit Dynamics
Solver Target	AUTODYN
Options	
Environment Temperature	22, °C
Generate Input Only	No

TABLE 15
Model (E4) > Explicit Dynamics (E5) > Initial Conditions

Object Name	*Initial Conditions*
State	Fully Defined

TABLE 16
Model (E4) > Explicit Dynamics (E5) > Initial Conditions > Initial Condition

Object Name	*Pre-Stress (None)*
State	Fully Defined
Definition	
Pre-Stress Environment	None
Pressure Initialization	From Deformed State

TABLE 17
Model (E4) > Explicit Dynamics (E5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Analysis Settings Preference	
Type	Program Controlled
Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	2,e-003 s
Maximum Energy Error	0,1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled

Maximum Time Step	Program Controlled
Time Step Safety Factor	0,9
Characteristic Dimension	Diagonals
Automatic Mass Scaling	No
Solver Controls	
Solve Units	mm, mg, ms
Beam Solution Type	Bending
Beam Time Step Safety Factor	0,5
Hex Integration Type	Exact
Shell Sublayers	3
Shell Shear Correction Factor	0,8333
Shell BWC Warp Correction	Yes
Shell Thickness Update	Nodal
Tet Integration	Average Nodal Pressure
Shell Inertia Update	Recompute
Density Update	Program Controlled
Minimum Velocity	1,e-003 mm s^-1
Maximum Velocity	1,e+013 mm s^-1
Radius Cutoff	1,e-003
Minimum Strain Rate Cutoff	1,e-010
Euler Domain Controls	
Domain Size Definition	Program Controlled
Display Euler Domain	Yes
Scope	All Bodies
X Scale factor	1,2
Y Scale factor	1,2
Z Scale factor	1,2
Domain Resolution Definition	Total Cells
Total Cells	2,5e+05
Lower X Face	Flow Out
Lower Y Face	Flow Out
Lower Z Face	Flow Out
Upper X Face	Flow Out
Upper Y Face	Flow Out
Upper Z Face	Flow Out
Euler Tracking	By Body
Damping Controls	
Linear Artificial Viscosity	0,2
Quadratic Artificial Viscosity	1,
Linear Viscosity in Expansion	No
Artificial Viscosity For Shells	Yes
Hourglass Damping	AUTODYN Standard
Viscous Coefficient	0,1
Static Damping	0,
Erosion Controls	
On Geometric Strain Limit	Yes
Geometric Strain Limit	1,5
On Material Failure	No

On Minimum Element Time Step	No
Retain Inertia of Eroded Material	Yes
Output Controls	
Save Results on	Equally Spaced Points
Result Number Of Points	20
Save Restart Files on	Equally Spaced Points
Restart Number Of Points	5
Save Result Tracker Data on	Cycles
Tracker Cycles	1
Output Contact Forces	Off
Analysis Data Management	
Solver Files Directory	F:\Hammer\10_strokers_files\dp0\SYS-4\MECH\
Scratch Solver Files Directory	

TABLE 18
Model (E4) > Explicit Dynamics (E5) > Accelerations

Object Name	*Standard Earth Gravity*
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Global Coordinate System
X Component	0, mm/s²
Y Component	0, mm/s²
Z Component	-9806,6 mm/s²
Suppressed	No
Direction	-Z Direction

FIGURE 1
Model (E4) > Explicit Dynamics (E5) > Standard Earth Gravity

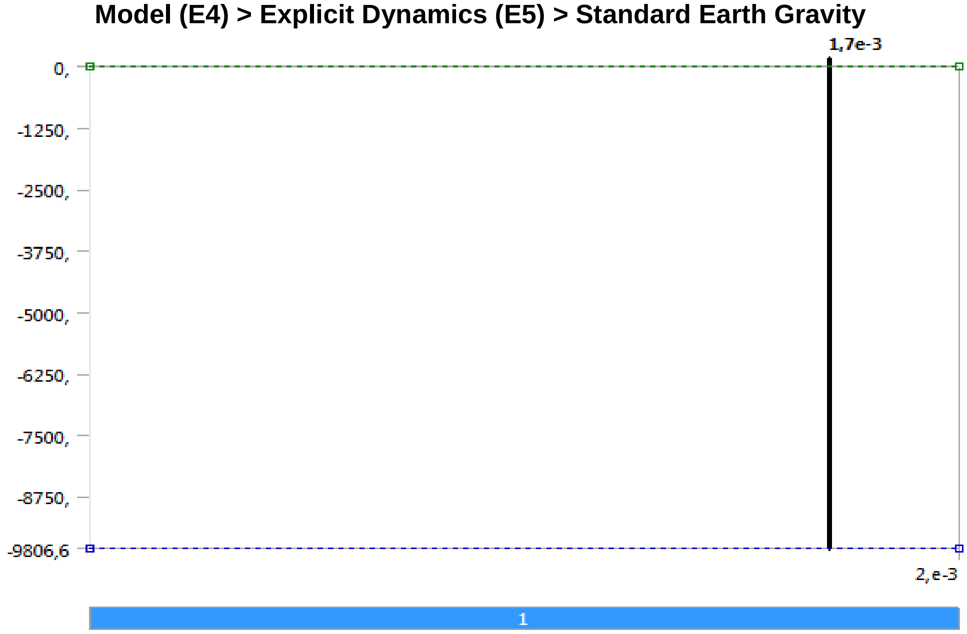


TABLE 19
Model (E4) > Explicit Dynamics (E5) > Loads

Object Name	*Fixed Support*	*Displacement*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	1 Body
Definition		
Type	Fixed Support	Displacement
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		Free
Y Component		Free
Z Component		Tabular Data
Tabular Data		
Independent Variable		Time

FIGURE 2
Model (E4) > Explicit Dynamics (E5) > Displacement

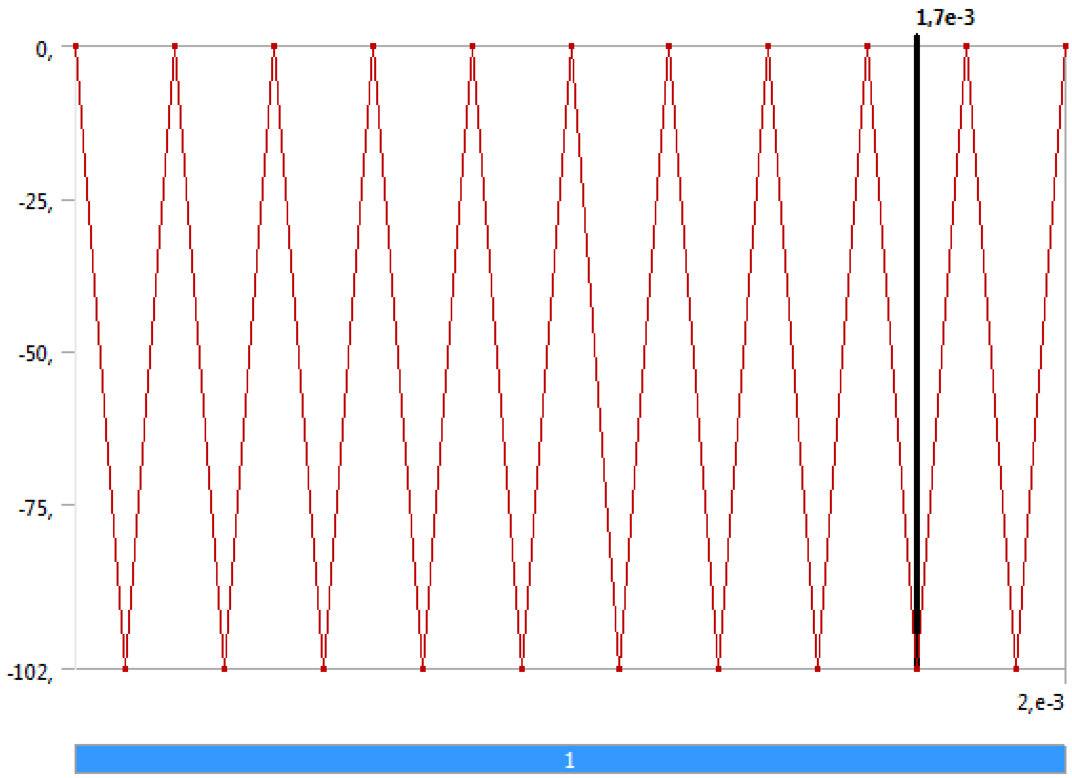


TABLE 20
Model (E4) > Explicit Dynamics (E5) > Displacement

Steps	Time [s]	Z [mm]
1	0,	0,
	1,e-004	-102,
	2,e-004	0,
	3,e-004	-102,
	4,e-004	0,
	5,e-004	-102,
	6,e-004	0,
	7,e-004	-102,
	8,e-004	0,
	9,e-004	-102,
	1,e-003	0,
	1,1e-003	-102,
	1,2e-003	0,
	1,3e-003	-102,
	1,4e-003	0,
	1,5e-003	-102,
	1,6e-003	0,
	1,7e-003	-102,
	1,8e-003	0,
	1,9e-003	-102,
	2,e-003	0,

Solution (E6)

TABLE 21
Model (E4) > Explicit Dynamics (E5) > Solution

Object Name	*Solution (E6)*
State	Solved
Information	
Status	Done
Post Processing	
Beam Section Results	No

TABLE 22
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Update Interval	2,5 s
Display Points	All
Display Filter During Solve	Yes

TABLE 23
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Results

Object Name	*Total Deformation*	*Directional Acceleration*	*Total Deformation 2*	*Total Deformation 3*	*Equivalent Elastic Strain*	*Total Deformation 4*	*Normal Elastic Strain*	*Directional Deformation*	*Total Deformation 5*	*Total Deformation 6*	*Equivalent Stress*
State	Solved										
Scope											
Scoping Method	Geometry Selection										
Geometry	All Bodies					1 Body	2 Bodies				1 Body
Definition											
Type	Total Deformation	Directional Acceleration	Total Deformation		Equivalent Elastic Strain	Total Deformation	Normal Elastic Strain	Directional Deformation	Total Deformation		Equivalent (von-Mises) Stress
By	Time										
Display Time	Last			1,4e-003 s	Last	1,9e-003 s	Last	1,9406e-003 s	Last	1,8002e-003 s	1,3002e-003 s
Calculate Time History	Yes										
Identifier											
Suppressed	No										
Orientation		X Axis					X Axis	Z Axis			
Coordinate System		Global Coordinate System					Global Coordinate System				
Results											
Minimum	0, mm	-1,3487e+008 mm/s²	0, mm		0, mm/mm	1,5123e-003 mm	-2,0555e-002 mm/mm	-99,2 mm	1,2188e-003 mm	1,0124e-003 mm	4,9142 MPa
Maximum	3,9678 mm	1,4797e+008 mm/s²	3,9678 mm	3,9985 mm	3,9723e-002 mm/mm	3,9671 mm	2,1733e-003 mm/mm	0,54535 mm	3,9678 mm	3,972 mm	166,37 MPa
Minimum Occurs On	floor	core	floor		hammer	core		hammer	core		
Maximum Occurs On	core										
Minimum Value Over Time											
Minimum	0, mm	-1,9099e+011 mm/s²	0, mm		0, mm/mm	0, mm	-2,1449e-002 mm/mm	-102,05 mm	0, mm		0, MPa
Maximum	0, mm	0, mm/s²	0, mm		0, mm/mm	7,2988e-003 mm	0, mm/mm	0, mm	7,2988e-003 mm		19,563 MPa
Maximum Value Over Time											
Minimum	0, mm	0, mm/s²	0, mm		0, mm/mm	0, mm	0, mm/mm	0, mm			0, MPa
Maximum	102,05 mm	2,1157e+011 mm/s²	102,05 mm		4,0887e-002 mm/mm	4,0563 mm	3,2848e-003 mm/mm	2,9536 mm	102,05 mm		283,48 MPa
Information											
Time	2,0002e-003 s			1,4002e-003 s	2,0002e-003 s	1,9001e-003 s	2,0002e-003 s	1,9001e-003 s	2,0002e-003 s	1,8002e-003 s	1,3001e-003 s
Set	21			15	21	20	21	20	21	19	14
Cycle Number	6632			4631	6632	6298	6632	6298	6632	5965	4297
Integration Point Results											
Display Option					Averaged		Averaged				Averaged
Average Across Bodies					No		No				No

FIGURE 3
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation

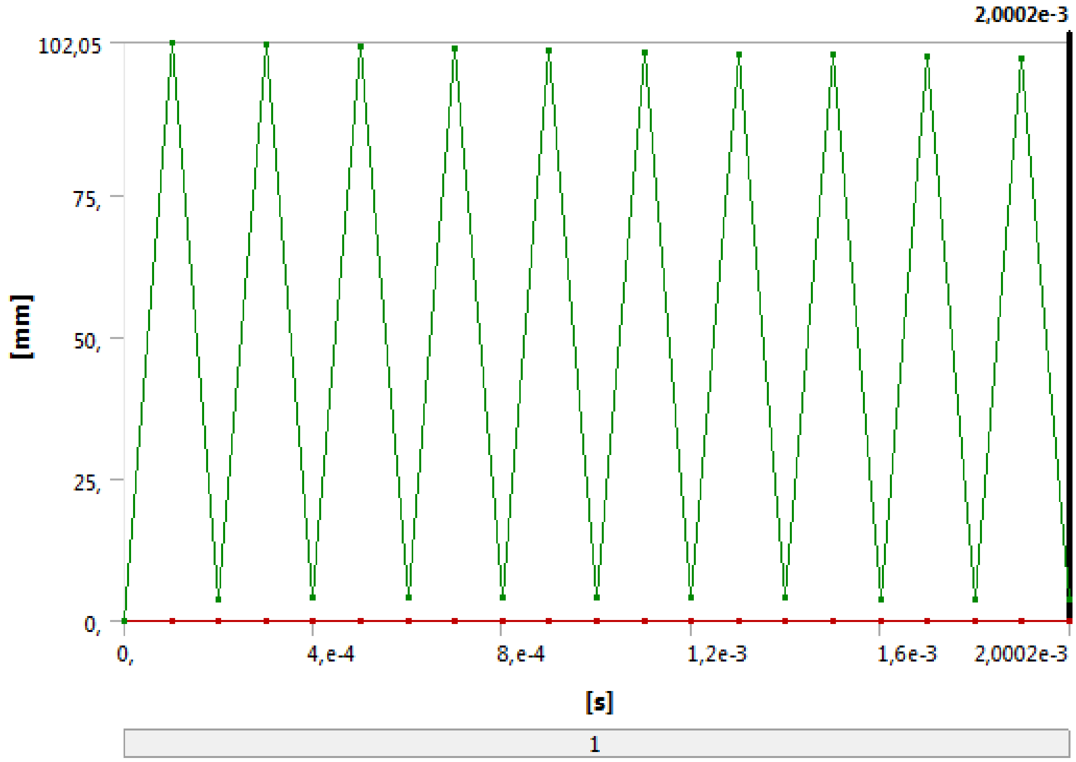


TABLE 24
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004		102,05
2,0028e-004		3,9535
3,0011e-004		101,64
4,0024e-004		4,0032
5,0008e-004		101,34
6,0023e-004		4,0393
7,0008e-004		101,04
8,0023e-004		4,0515
9,0008e-004		100,73
1,0002e-003		4,037
1,1001e-003		100,42
1,2002e-003		4,0121
1,3001e-003		100,12
1,4002e-003		3,9985
1,5001e-003		99,813
1,6002e-003		3,9857
1,7001e-003		99,507
1,8002e-003		3,972
1,9001e-003		99,201
2,0002e-003		3,9678

FIGURE 4
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Directional Acceleration

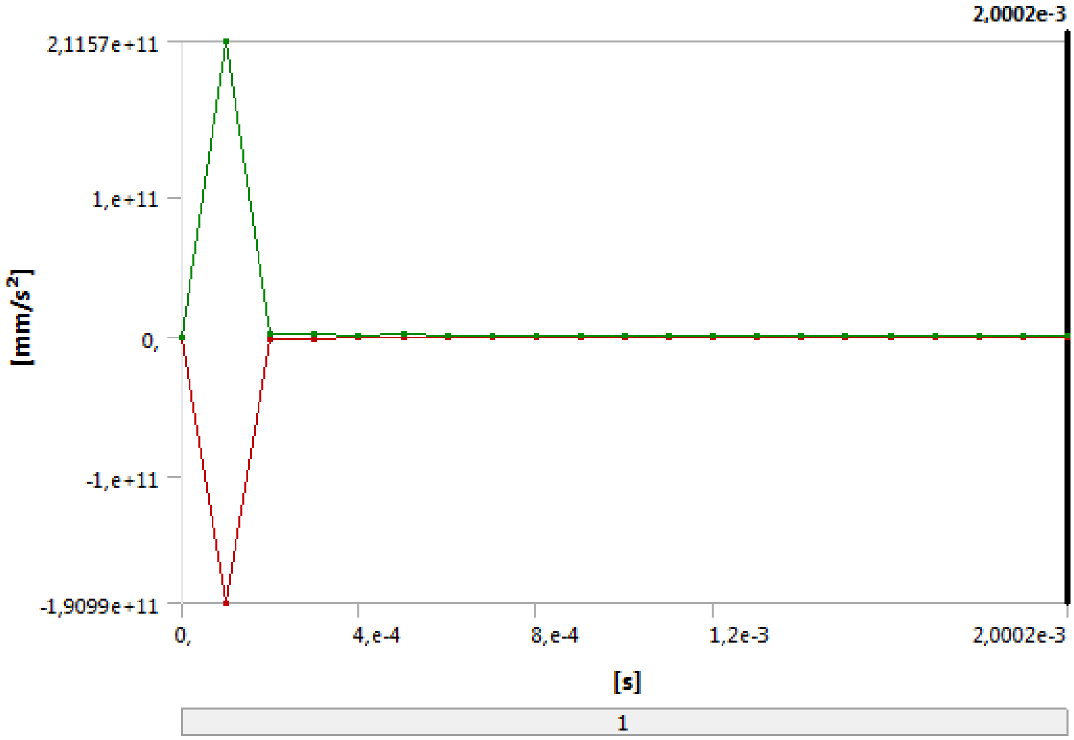


TABLE 25
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Directional Acceleration

Time [s]	Minimum [mm/s²]	Maximum [mm/s²]
1,1755e-038	0,	0,
1,0005e-004	-1,9099e+011	2,1157e+011
2,0028e-004	-1,5011e+009	1,4996e+009
3,0011e-004	-2,41e+009	2,2934e+009
4,0024e-004	-9,1034e+008	7,7157e+008
5,0008e-004	-4,3513e+008	2,261e+009
6,0023e-004	-3,534e+008	4,1317e+008
7,0008e-004	-7,1514e+008	7,9527e+008
8,0023e-004	-7,3727e+008	7,3653e+008
9,0008e-004	-2,2167e+008	3,5194e+008
1,0002e-003	-1,7303e+008	4,0896e+008
1,1001e-003	-7,6092e+008	4,1086e+008
1,2002e-003	-3,8369e+008	3,9971e+008
1,3001e-003	-5,2961e+008	2,6172e+008
1,4002e-003	-7,7998e+007	7,3587e+007
1,5001e-003	-2,7826e+008	2,3121e+008
1,6002e-003	-2,2861e+008	2,3474e+008
1,7001e-003	-1,2615e+008	1,6405e+008
1,8002e-003	-7,5529e+007	5,7075e+007
1,9001e-003	-1,5991e+008	1,5679e+008
2,0002e-003	-1,3487e+008	1,4797e+008

FIGURE 5
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 2

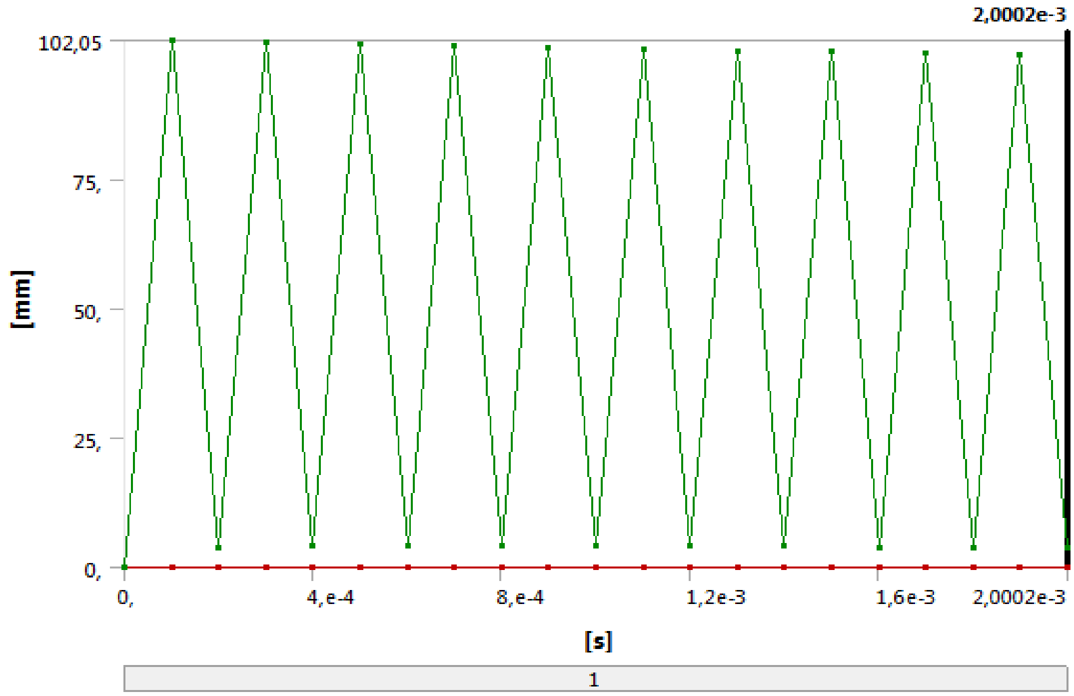


TABLE 26
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 2

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004		102,05
2,0028e-004		3,9535
3,0011e-004		101,64
4,0024e-004		4,0032
5,0008e-004		101,34
6,0023e-004		4,0393
7,0008e-004		101,04
8,0023e-004		4,0515
9,0008e-004		100,73
1,0002e-003		4,037
1,1001e-003		100,42
1,2002e-003		4,0121
1,3001e-003		100,12
1,4002e-003		3,9985
1,5001e-003		99,813
1,6002e-003		3,9857
1,7001e-003		99,507
1,8002e-003		3,972
1,9001e-003		99,201
2,0002e-003		3,9678

FIGURE 6
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 3

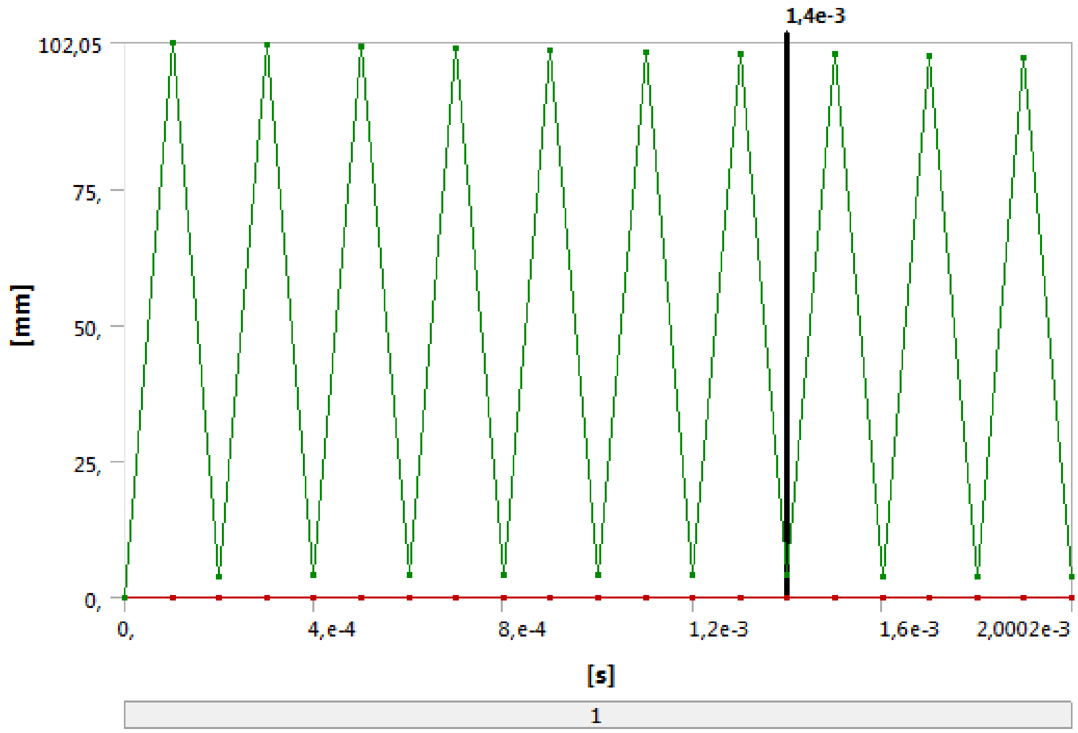


TABLE 27
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 3

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038		0,
1,0005e-004		102,05
2,0028e-004		3,9535
3,0011e-004		101,64
4,0024e-004		4,0032
5,0008e-004		101,34
6,0023e-004		4,0393
7,0008e-004		101,04
8,0023e-004		4,0515
9,0008e-004		100,73
1,0002e-003	0,	4,037
1,1001e-003		100,42
1,2002e-003		4,0121
1,3001e-003		100,12
1,4002e-003		3,9985
1,5001e-003		99,813
1,6002e-003		3,9857
1,7001e-003		99,507
1,8002e-003		3,972
1,9001e-003		99,201
2,0002e-003		3,9678

FIGURE 7
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Equivalent Elastic Strain

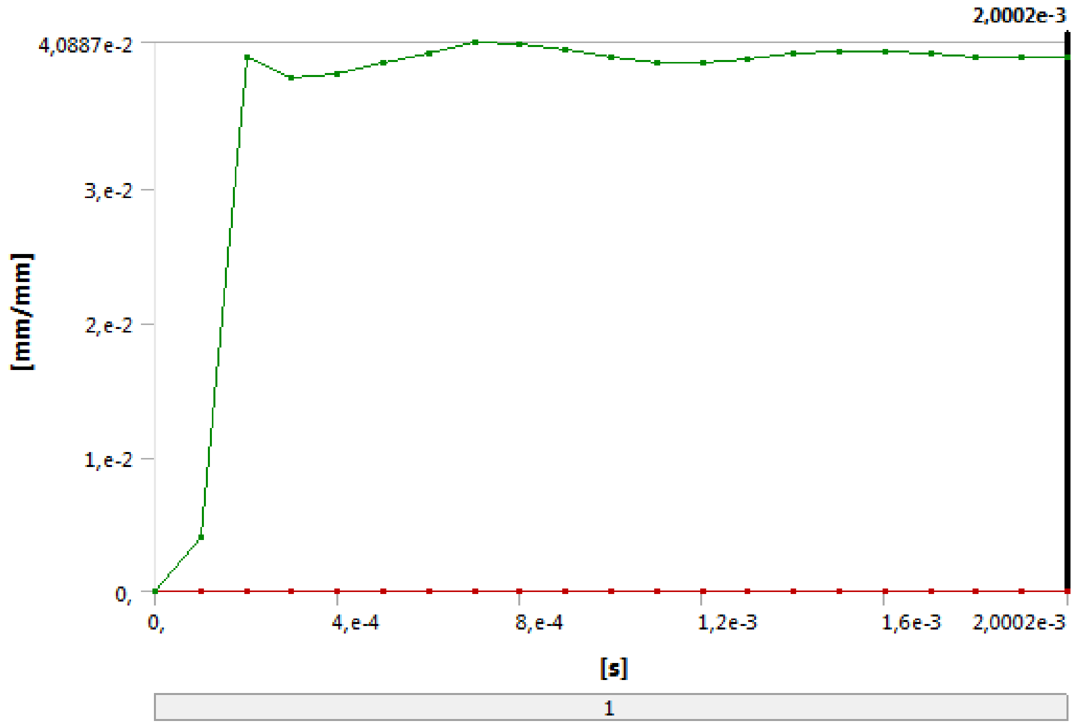


TABLE 28
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,0005e-004		4,0047e-003
2,0028e-004		3,9768e-002
3,0011e-004		3,8294e-002
4,0024e-004		3,8508e-002
5,0008e-004		3,9304e-002
6,0023e-004		4,0078e-002
7,0008e-004		4,0887e-002
8,0023e-004		4,0759e-002
9,0008e-004		4,0312e-002
1,0002e-003		3,9769e-002
1,1001e-003		3,9328e-002
1,2002e-003		3,9386e-002
1,3001e-003		3,9655e-002
1,4002e-003		4,0012e-002
1,5001e-003		4,0247e-002
1,6002e-003		4,0242e-002
1,7001e-003		4,0078e-002
1,8002e-003		3,984e-002
1,9001e-003		3,9709e-002
2,0002e-003		3,9723e-002

FIGURE 8
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 4

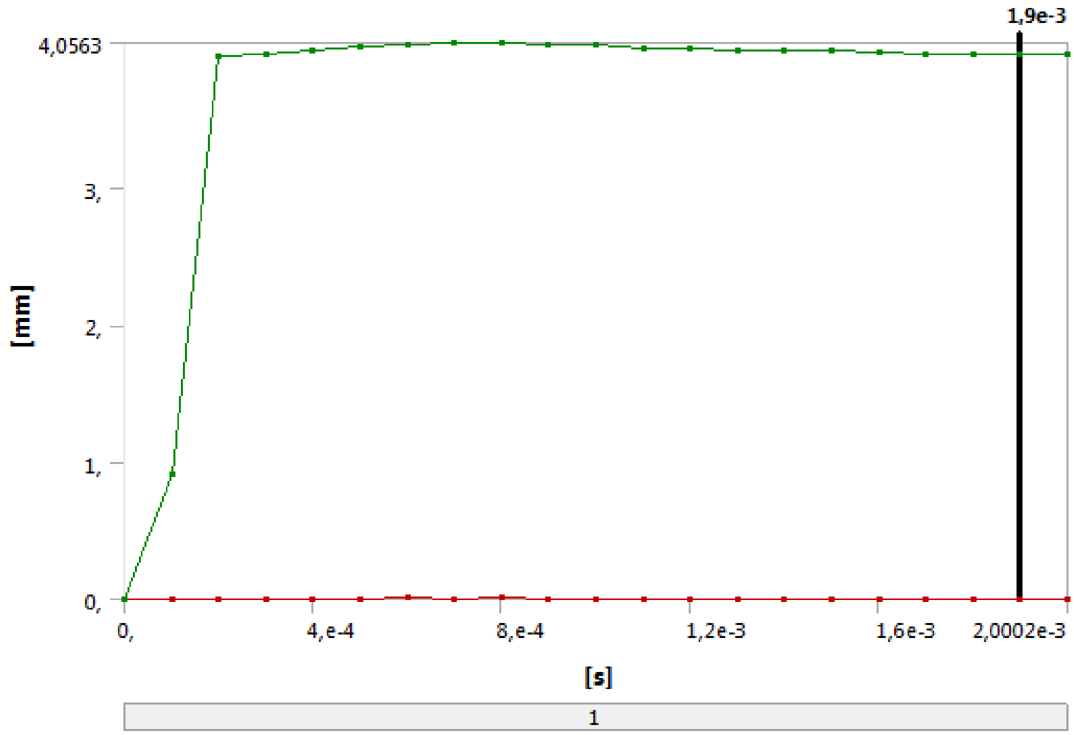


TABLE 29
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 4

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004	6,4566e-007	0,90585
2,0028e-004	1,8538e-003	3,9535
3,0011e-004	3,4349e-004	3,9779
4,0024e-004	9,1214e-004	4,0032
5,0008e-004	1,901e-003	4,0309
6,0023e-004	7,2988e-003	4,0393
7,0008e-004	4,2996e-003	4,0563
8,0023e-004	7,0616e-003	4,0515
9,0008e-004	5,6846e-003	4,0477
1,0002e-003	2,0978e-003	4,037
1,1001e-003	1,369e-003	4,0187
1,2002e-003	4,8166e-004	4,0121
1,3001e-003	3,1748e-004	4,0021
1,4002e-003	1,4272e-004	3,9985
1,5001e-003	3,272e-004	3,9954
1,6002e-003	4,3104e-004	3,9857
1,7001e-003	1,1914e-003	3,9804
1,8002e-003	1,0124e-003	3,972
1,9001e-003	1,5123e-003	3,9671
2,0002e-003	1,2188e-003	3,9678

FIGURE 9
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Normal Elastic Strain

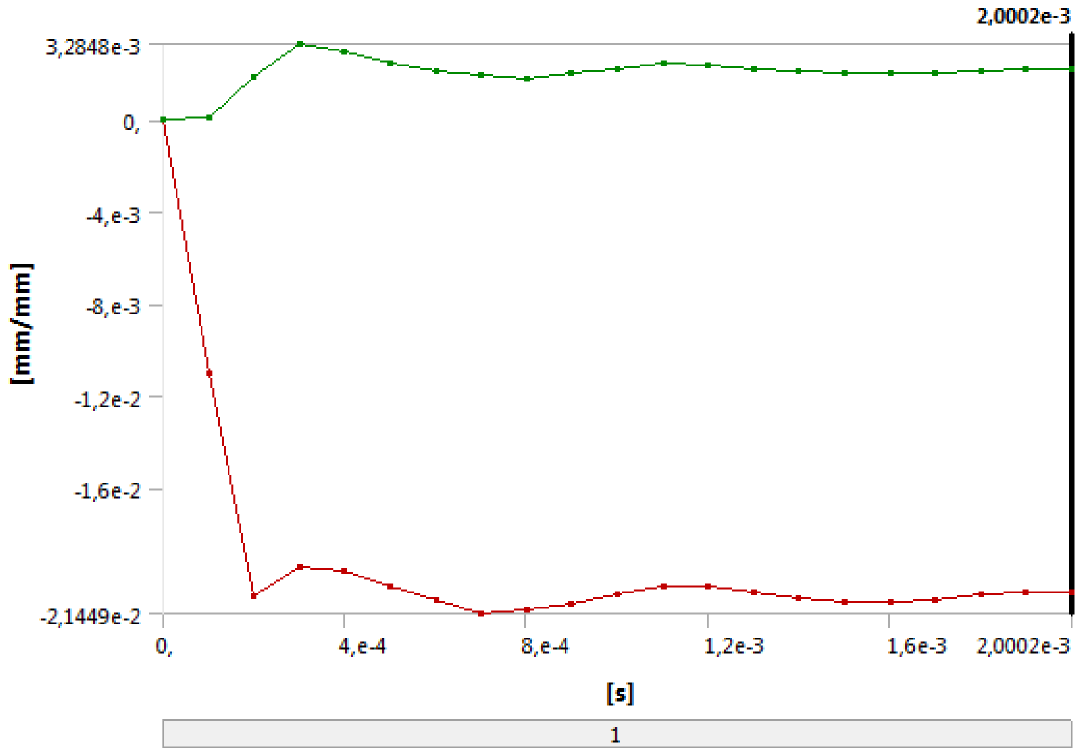


TABLE 30
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Normal Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1,1755e-038	0,	0,
1,0005e-004	-1,0998e-002	8,9762e-005
2,0028e-004	-2,0719e-002	1,8722e-003
3,0011e-004	-1,9405e-002	3,2848e-003
4,0024e-004	-1,9619e-002	2,9805e-003
5,0008e-004	-2,0301e-002	2,4752e-003
6,0023e-004	-2,0848e-002	2,1415e-003
7,0008e-004	-2,1449e-002	1,9297e-003
8,0023e-004	-2,1305e-002	1,7952e-003
9,0008e-004	-2,1012e-002	2,0316e-003
1,0002e-003	-2,0605e-002	2,2054e-003
1,1001e-003	-2,024e-002	2,4097e-003
1,2002e-003	-2,0309e-002	2,3757e-003
1,3001e-003	-2,0492e-002	2,2006e-003
1,4002e-003	-2,076e-002	2,0907e-003
1,5001e-003	-2,0952e-002	1,9918e-003
1,6002e-003	-2,0951e-002	2,022e-003
1,7001e-003	-2,0822e-002	2,0337e-003
1,8002e-003	-2,063e-002	2,1206e-003
1,9001e-003	-2,0533e-002	2,1721e-003
2,0002e-003	-2,0555e-002	2,1733e-003

FIGURE 10
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Directional Deformation

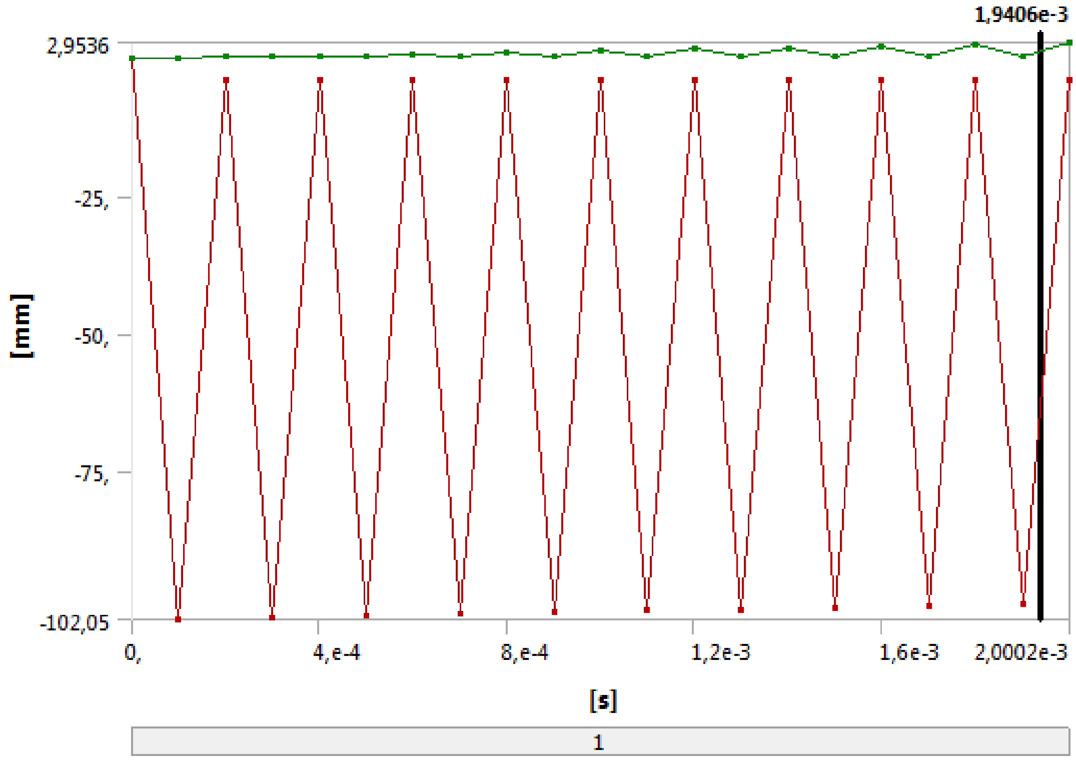


TABLE 31
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Directional Deformation

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004	-102,05	5,5652e-003
2,0028e-004	-3,8763	0,54609
3,0011e-004	-101,64	0,52047
4,0024e-004	-3,9259	0,49845
5,0008e-004	-101,34	0,475
6,0023e-004	-3,9671	0,81104
7,0008e-004	-101,04	0,46779
8,0023e-004	-3,9805	1,1187
9,0008e-004	-100,73	0,47222
1,0002e-003	-3,9629	1,4233
1,1001e-003	-100,42	0,48899
1,2002e-003	-3,9364	1,729
1,3001e-003	-100,12	0,51067
1,4002e-003	-3,9246	2,0366
1,5001e-003	-99,813	0,52406
1,6002e-003	-3,9126	2,3429
1,7001e-003	-99,507	0,53643
1,8002e-003	-3,8975	2,6478
1,9001e-003	-99,2	0,54535
2,0002e-003	-3,8926	2,9536

FIGURE 11
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 5

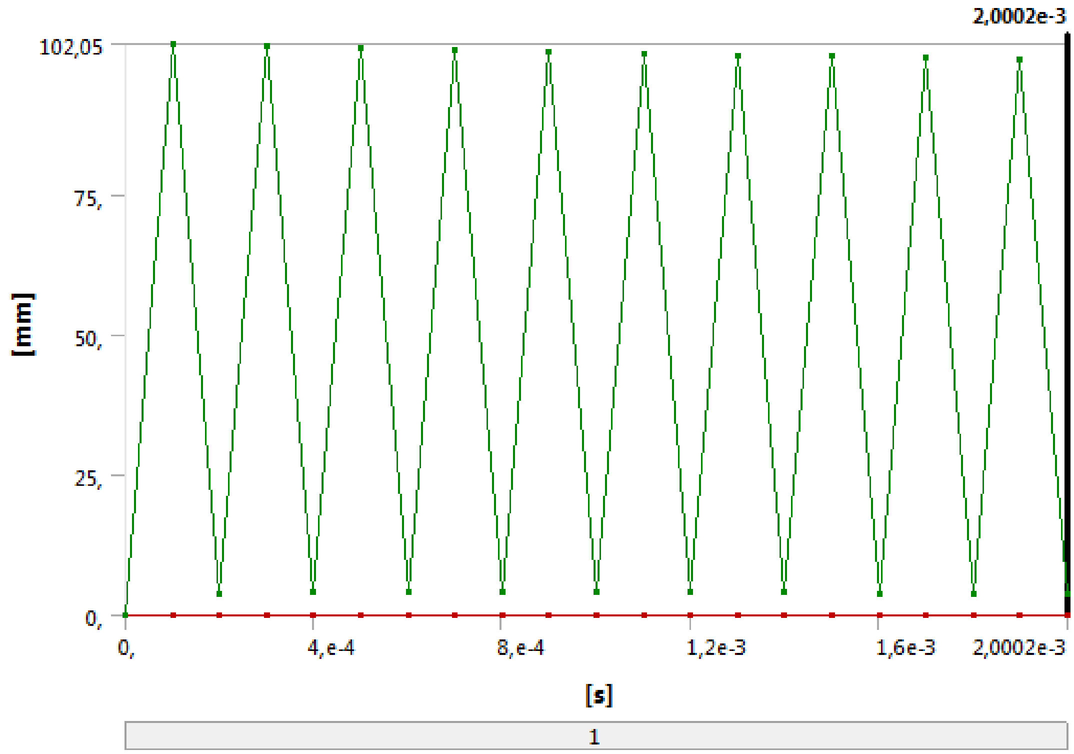


TABLE 32
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 5

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004	6,4566e-007	102,05
2,0028e-004	1,8538e-003	3,9535
3,0011e-004	3,4349e-004	101,64
4,0024e-004	9,1214e-004	4,0032
5,0008e-004	1,901e-003	101,34
6,0023e-004	7,2988e-003	4,0393
7,0008e-004	4,2996e-003	101,04
8,0023e-004	7,0616e-003	4,0515
9,0008e-004	5,6846e-003	100,73
1,0002e-003	2,0978e-003	4,037
1,1001e-003	1,369e-003	100,42
1,2002e-003	4,8166e-004	4,0121
1,3001e-003	3,1748e-004	100,12
1,4002e-003	1,4272e-004	3,9985
1,5001e-003	3,272e-004	99,813
1,6002e-003	4,3104e-004	3,9857
1,7001e-003	1,1914e-003	99,507
1,8002e-003	1,0124e-003	3,972
1,9001e-003	1,5123e-003	99,201
2,0002e-003	1,2188e-003	3,9678

FIGURE 12
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 6

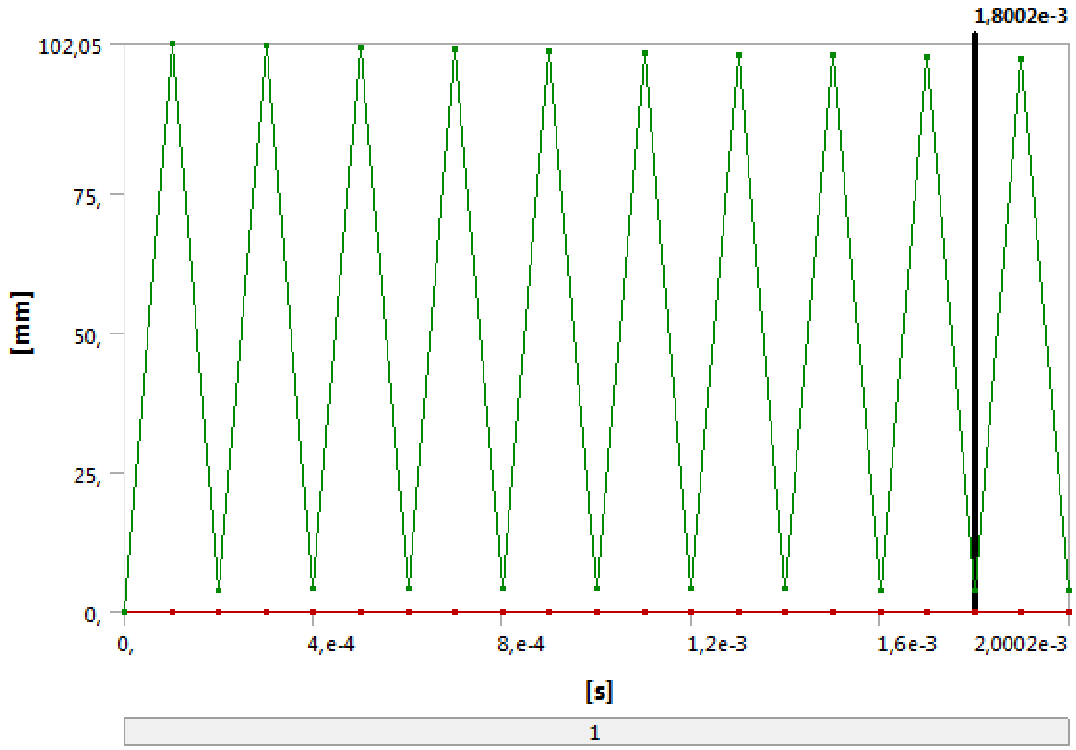


TABLE 33
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 6

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004	6,4566e-007	102,05
2,0028e-004	1,8538e-003	3,9535
3,0011e-004	3,4349e-004	101,64
4,0024e-004	9,1214e-004	4,0032
5,0008e-004	1,901e-003	101,34
6,0023e-004	7,2988e-003	4,0393
7,0008e-004	4,2996e-003	101,04
8,0023e-004	7,0616e-003	4,0515
9,0008e-004	5,6846e-003	100,73
1,0002e-003	2,0978e-003	4,037
1,1001e-003	1,369e-003	100,42
1,2002e-003	4,8166e-004	4,0121
1,3001e-003	3,1748e-004	100,12
1,4002e-003	1,4272e-004	3,9985
1,5001e-003	3,272e-004	99,813
1,6002e-003	4,3104e-004	3,9857
1,7001e-003	1,1914e-003	99,507
1,8002e-003	1,0124e-003	3,972
1,9001e-003	1,5123e-003	99,201
2,0002e-003	1,2188e-003	3,9678

FIGURE 13
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Equivalent Stress

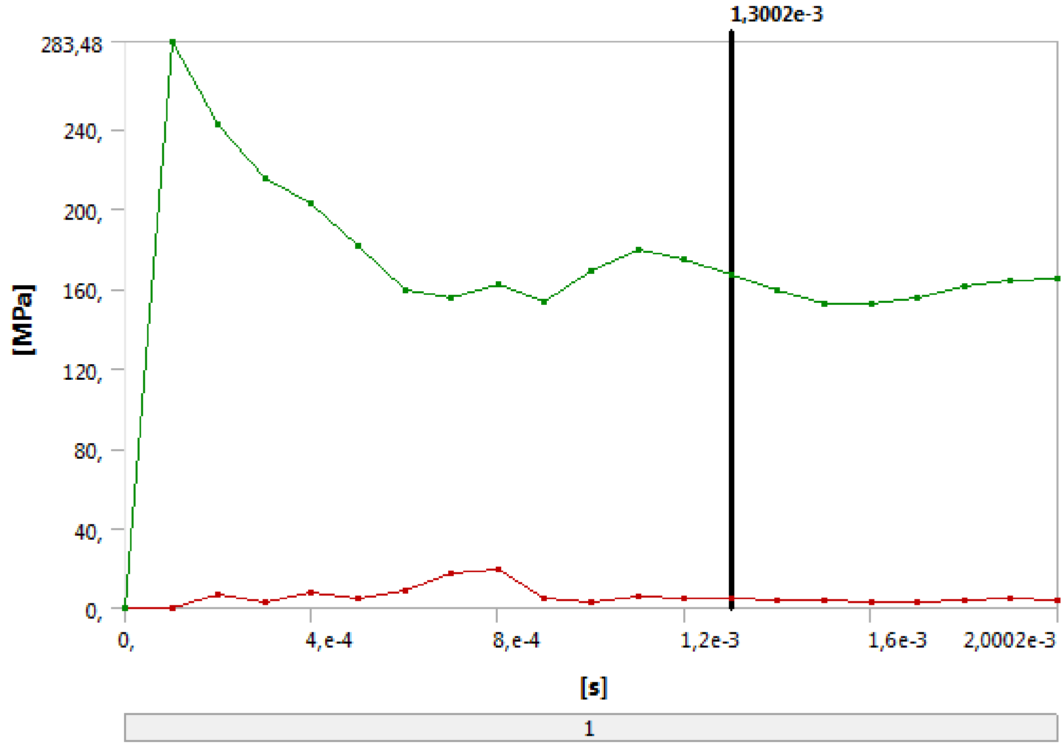


TABLE 34
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Equivalent Stress

Time [s]	Minimum [MPa]	Maximum [MPa]
1,1755e-038	0,	0,
1,0005e-004	3,2322e-005	283,48
2,0028e-004	6,7778	241,87
3,0011e-004	3,1863	214,7
4,0024e-004	7,8044	202,72
5,0008e-004	4,5361	181,72
6,0023e-004	8,8312	158,77
7,0008e-004	17,383	154,81
8,0023e-004	19,563	162,16
9,0008e-004	4,9085	152,84
1,0002e-003	3,2527	168,5
1,1001e-003	6,0079	179,02
1,2002e-003	5,0472	174,89
1,3001e-003	4,9142	166,37
1,4002e-003	4,172	159,3
1,5001e-003	3,7262	152,11
1,6002e-003	3,1498	152,36
1,7001e-003	3,2703	155,31
1,8002e-003	4,0532	160,83
1,9001e-003	4,8466	163,56
2,0002e-003	3,9242	164,95

TABLE 35
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Results

Object Name	*Total Deformation 7*	*Total Deformation 8*
State	Solved	
Scope		
Scoping Method	Geometry Selection	
Geometry	All Bodies	1 Body
Definition		
Type	Total Deformation	
By	Time	
Display Time	Last	
Calculate Time History	Yes	
Identifier		
Suppressed	No	
Results		
Minimum	0, mm	1,2188e-003 mm
Maximum	3,9678 mm	
Minimum Occurs On	floor	core
Maximum Occurs On	core	
Minimum Value Over Time		
Minimum	0, mm	
Maximum	0, mm	7,2988e-003 mm
Maximum Value Over Time		
Minimum	0, mm	
Maximum	102,05 mm	4,0563 mm
Information		
Time	2,0002e-003 s	
Set	21	
Cycle Number	6632	

FIGURE 14
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 7

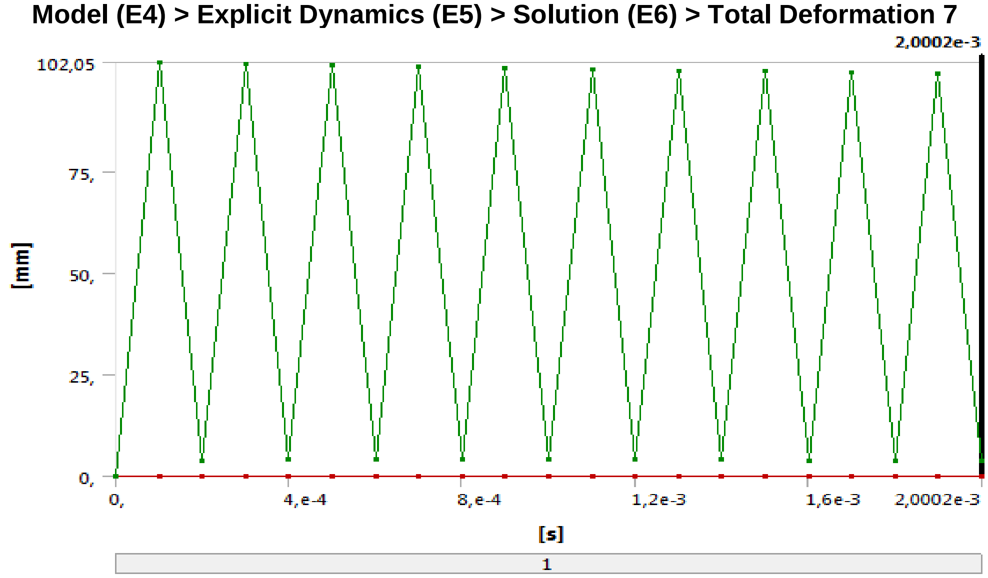


TABLE 36
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 7

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004		102,05
2,0028e-004		3,9535
3,0011e-004		101,64
4,0024e-004		4,0032
5,0008e-004		101,34
6,0023e-004		4,0393
7,0008e-004		101,04
8,0023e-004		4,0515
9,0008e-004		100,73
1,0002e-003		4,037
1,1001e-003		100,42
1,2002e-003		4,0121
1,3001e-003		100,12
1,4002e-003		3,9985
1,5001e-003		99,813
1,6002e-003		3,9857
1,7001e-003		99,507
1,8002e-003		3,972
1,9001e-003		99,201
2,0002e-003		3,9678

FIGURE 15
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 8

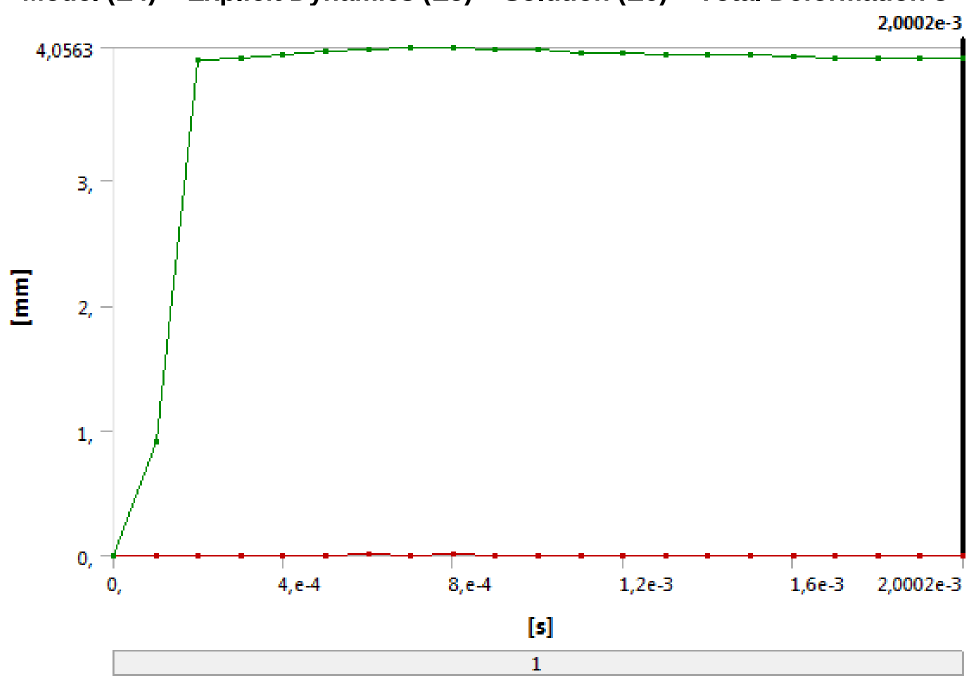


TABLE 37
Model (E4) > Explicit Dynamics (E5) > Solution (E6) > Total Deformation 8

Time [s]	Minimum [mm]	Maximum [mm]
1,1755e-038	0,	0,
1,0005e-004	6,4566e-007	0,90585
2,0028e-004	1,8538e-003	3,9535
3,0011e-004	3,4349e-004	3,9779
4,0024e-004	9,1214e-004	4,0032
5,0008e-004	1,901e-003	4,0309
6,0023e-004	7,2988e-003	4,0393
7,0008e-004	4,2996e-003	4,0563
8,0023e-004	7,0616e-003	4,0515
9,0008e-004	5,6846e-003	4,0477
1,0002e-003	2,0978e-003	4,037
1,1001e-003	1,369e-003	4,0187
1,2002e-003	4,8166e-004	4,0121
1,3001e-003	3,1748e-004	4,0021
1,4002e-003	1,4272e-004	3,9985
1,5001e-003	3,272e-004	3,9954
1,6002e-003	4,3104e-004	3,9857
1,7001e-003	1,1914e-003	3,9804
1,8002e-003	1,0124e-003	3,972
1,9001e-003	1,5123e-003	3,9671
2,0002e-003	1,2188e-003	3,9678

Material Data

Structural Steel

TABLE 43
Structural Steel > Constants

Density	7,85e-006 kg mm^-3
Isotropic Secant Coefficient of Thermal Expansion	1,2e-005 C^-1
Specific Heat Constant Pressure	4,34e+005 mJ kg^-1 C^-1
Isotropic Thermal Conductivity	6,05e-002 W mm^-1 C^-1
Isotropic Resistivity	1,7e-004 ohm mm

TABLE 44
Structural Steel > Appearance

Red	Green	Blue
132,	139,	179,

TABLE 45
Structural Steel > Compressive Ultimate Strength

Compressive Ultimate Strength MPa
0,

TABLE 46
Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
250,

TABLE 47
Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
250,

TABLE 48
Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
460,

TABLE 49
Structural Steel > Isotropic Secant Coefficient of Thermal Expansion

Zero-Thermal-Strain Reference Temperature C
22,

TABLE 50
Structural Steel > Alternating Stress Mean Stress

Alternating Stress MPa	Cycles	Mean Stress MPa
3999,	10,	0,
2827,	20,	0,
1896,	50,	0,
1413,	100,	0,
1069,	200,	0,
441,	2000,	0,
262,	10000	0,
214,	20000	0,
138,	1,e+005	0,
114,	2,e+005	0,
86,2	1,e+006	0,

TABLE 51
Structural Steel > Strain-Life Parameters

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920,	-0,106	0,213	-0,47	1000,	0,2

TABLE 52
Structural Steel > Isotropic Elasticity

Temperature C	Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
	2,e+005	0,3	1,6667e+005	76923

TABLE 53
Structural Steel > Isotropic Relative Permeability

Relative Permeability
10000