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An Elephant Foot Analogy: Design and Development of Landing Gear

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ABSTRACT

The purpose of this study was to investigate, analyze, and develop a landing gear mechanism. To support the analysis, we used an elephant foot analogy. Elephant, especially African elephant, is the largest terrestrial mammals living on the planet. Having enormous size and distinctive weight make them classified as one of the significant surviving species. The project mainly focused on the use of elephant foot analogy for understanding the reduction of asphalt deformation. The deformation was tested by reducing the simulated stresses. The final solution mimics elephant foot stress absorption carrying capacity, in which this can be modeled for the modified landing gearscould demonstrate the use of BIM for bridge rehabilitation.

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1. INTRODUCTION

Transportation is one of the key factors in the country. In transportation, there are many components, and the most important component is road. Road in transportation plays a crucial role. In most parts of the world, trucks, buses, trailers, and heavy vehicles park with the landing gear. This landing gear supports the end of the trailer. When it is disconnected from the towering truck, it is loaded or unloaded the main component. The movement is influenced by the disconnected condition, in which it relates to the loading and unloading. In the back-and-forth direction, generally, the longitudinal length of the trailer causes the condition in the landing gear to raise. Then, the lower part of the trailer allows it to adjust the differences in fifth wheel height. The truck landing gears are used for supporting trailers during static loading and unloading, and indeed it causes asphalt deformation. The phenomena are presented in **Figure 1**. The load applied from the landing gear, due to the contact surface area between asphalt and landing gear, is greater than the carrying capacity of the asphalt that causes asphalt deformation.

The purpose of this study was to investigate, analyze, and develop a landing gear mechanism. To support the analysis, we used an elephant foot analogy. Elephant, especially African elephant, is the largest terrestrial mammals living on the planet. Having enormous size and distinctive weight make them classified as one of the significant surviving species. The project mainly focused on the use of elephant foot analogy for understanding the reduction of asphalt deformation. The deformation was tested by reducing the simulated stresses. The final solution mimics elephant foot stress absorption carrying capacity, in which this can be modeled for the modified landing gears.

2. LITERATURE REVIEW

2.1. Landing Gear

The landing gear is a pair of support, that raises and lowers the trailer according to the applications. The landing gear selection depends on the type of trailer, type of landing gear, and the type of manufacturer. The landing gear should provide optimum performance for the appropriate applications. As an example, the length of landing gear should be selected to ensure the normal height of the trailer for leveled and uneven surfaces.

The landing gears are detachable for trailers and trucks. One of the objectives of his findings was to give a landing gear for detachable trailers that is capable of supporting a full load on soft earth without sinking below operative position for connection to the fifth wheel of the truck, to provide a landing gear rugged in structural strength and yet quick-acting in both raising and lowering operations, to provide a landing gear with such simplicity of design as to be easily built and repaired with readily available materials. The second objective was to provide a landing gear capable to be raised rapidly away from the terrain to provide full road clearance for traversing embankments, ditches, culverts, and other obstructions. In addition, it focuses on providing landing gear shoes with a large surface area that can be rapidly set in place. The landing gear has a secured locking mechanism for locking the gear in raised and lowered positions. And, this is done to prevent any accidents.

Many researchers researched strategies improvements in landing gear for trailers with the double retractable landing gear. The key objective was to develop an operative connection between the rotatable mechanism. Then, telescopically, it is adjusting the leg section and retractable mechanism by raising and lowering the supporting leg about a hinge mounting. Similarly, another important objective was achieved by the particular structural arrangement of the rotating mechanism for causing such telescopic adjustment of the leg sections.

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(a) (b)

Figure 1. Deformed asphalt due to landing gear parked in before (a) and after (b) landing condition.

2.2. Elephant Foot

The African elephant is the largest and heaviest living animal walking on earth with uniquely designed limbs (Weissengruber *et al.,* 2006). The morphological peculiarities are equipped with a large subcutaneous cushion, which plays a crucial role in distributing mechanical forces. The cushion of the captive elephants' feet was investigated and a hindlimb (See **Figure 2**).

The metacarpal unit of the cushion is smaller as compared to the size of the entire foot, indicating that the toes bear the weight. The horizontal orientation of the phalanges indicates that they have higher bending loads than their counterparts. The cushion presumably helps to distribute the animal's weight over the entire foot, which exhibits similarities to humans, camels, and rhinoceroses' feet. The foot in an Asian elephant shows a very similar pattern to that of African elephants. Cushions in the feet of African elephants are a natural solution for pain-free load-bearing and walking for the largest terrestrial animal (Weissengruber *et al.,* 2006). The cushion acts as a damper that compresses and expands during the gait cycle; therefore, it makes elephant feet a more dynamic structure.

The foot cushion occupies the spaces between tarsal, metapodial, and digital bones that cover the bones under the skin (Neuville, 1927). The cartilaginous rods support the metacarpal or metatarsal compartment with the cushions. The cushions have layers of fibrous connective tissue forming larger metacarpal and compartments with smaller chambers which were filled with adipose tissue (Weissengruber & Forstenpointer, 2004). The structural mechanics of elephant foot becomes more interesting because they face extreme biomechanical constraints to support their weight and walk. As the elephant walks the foot pressure changes and redistributes on the viscoelastic material (Panagiotopoulo *et al*., 2012). The elephant's foot cushions work as a viscoelastic material similar to a damper. Thus the foot pressure reduction is achieved by increased surface area with damping thus causing lesser stresses and damage to the contact area.

Three hypotheses assess the foot dynamics of a walking elephant (Miller *et al*., 2008).

(i) Hypothesis 1 – ontogenetic scaling of foot structure is correlated with pressure differences.

(ii) Hypothesis 2 – peak pressure is the limbs (manus and pes) are maintained at a roughly constant level with increasing size.

(iii) Hypothesis 3 – reduction of pressure is not only due to viscoelastic behavior but a complex dynamic interaction manifested with the center of pressure.

The layers of the cushions themselves form septate internal pads like the gel pads that can be used as shock absorbers (Weissengruber *et al*., 2006).

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a) b)

Figure 2: Sagittal section showing distal hindlimb of an African elephant. Figures (a) and (b) are the bone structure and the analysis of organs, respectively. Figures were adopted from Weissengruber *et al*., (2006)

2.3. Asphalt Deformation

Rutting is recognized as major distress in pavements as a result of increased tire pressures as well as increased loads and weathering. Rutting is caused by the accumulation of permanent deformation in layers of the pavement. The accumulation of permanent deformation in the surface is factorized as a major component of rutting flexible pavements. The permanent deformation leads to stress concentration that initiates pavement distress, leading to cracking. The permanent deformation under a given load and temperature conditions is highly influenced by the properties and proportions of the constituent materials and the degree of compaction or voids. A triaxial test was conducted on asphalt concrete specimens with varying levels of the void. It is indicated that a significant portion of the permanent deformation is caused by compaction.

Properties of asphalt concrete mixtures change with the composition, temperature, and level, and frequency of loading. At low temperatures, low load levels, and in high temperatures, slow loading levels, and high loads and the behavior of the material tend to be nonlinear that is viscoelastic. In response to loading, both static and cyclic, asphalt concrete develops permanent deformation, which accumulates with loading cycles over a period of time. This accumulated permanent deformation is the cause of rutting in asphalt pavements.

3. METHODOLOGY

The methodology is classified into software design and simulations, material selection, and physical testing.

3.1. Software Selection

CATIA V5R20 is used for designing the foot model using the necessary design constraints and geometry. The stress analysis of flexible and rigid pavements using KENPAVE is used for simulation and it needs to input geometric properties of the pavement, material properties, axle load, and pressure, and coordinates at which the analysis will simulate. A Four layered Flexible pavement is shown in **Figure 3** with basic data of the four layers of the pavement that are, Asphalt concrete, Base course, Sub-base, and sub-grade with parameters like young's modulus and Poisson's ratio of each layer is computed and the stress plots and displacement data is calculated.

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3.2. Material Selection

Elastomers are materials having a high molecular weight and are generally composed of one or more monomers polymerized. The viscoelastic properties are seen in elastomers, thus making them very useful for the project. Rubber is an elastomer having large chains, entanglement, and cross-links.

3.3. Hot Mix Asphalt Test

Hot Mixture asphalt was used as a composition of Aggregate and Bitumen. Therefore, the most important task in this analysis is to mix aggregate with the optimum selection of bitumen. The quality of the aggregate used from the May-keah query was checked in a central laboratory in Addis Ababa. Quality and frequency tests have also been conducted from the time of production to the final product. The project used one Asphalt plant, one impact crusher, and one cone crusher to produce the required 0-5, 5-10, and 10-20 mm required aggregates size. The Bitumen grade used as a binder in the project was Asphalt cement AC 60/70. The quality of the bitumen has been checked based on a test carried out in the Construction design and share company (CDSCo, Ethiopia). The bitumen grade is suitable for the specified road design standard and climate conditions in the project. The temperature of the mixed and blended aggregate and bitumen was 135-160 and 135-175°C and with compaction temperature respectively as specified in ERA (Ethiopian Road authority manual) 2002 specification. Detailed information is shown in **Table 1**.

Table 1. Summary of the mix properties and specifications.

Sr No	Test Performed	Standard test Method	Properties for 5.0% design Bitumen content	Accepted criteria
1	Job mix formula (JMF)	AASHTO 164, MS-2	5.0	
2	Design Bitumen content (%)	AASHTO	10.2	=<5.5
3	Marshal Stability (KN)	AASHTO	2.6	>=8.0
4	Flow (mm)	AASHTO	4.0	2 – 3.5
5	Air Void in the mix (%)	AASHTO	15.3	3 - 5
6	Voids in minerals aggregate VMA (%)	AASHTO	73	>=14.0
7	Voids filled with asphalt	AASHTO	3.2	65 - 75
8	Marshal refusal density air voids (%)	AASHTO	1.2	>=2.5
9	Filler to binder ratio	AASHTO	2.4404	=<1.6
10	Bulk specific gravity of the mix	AASHTO		

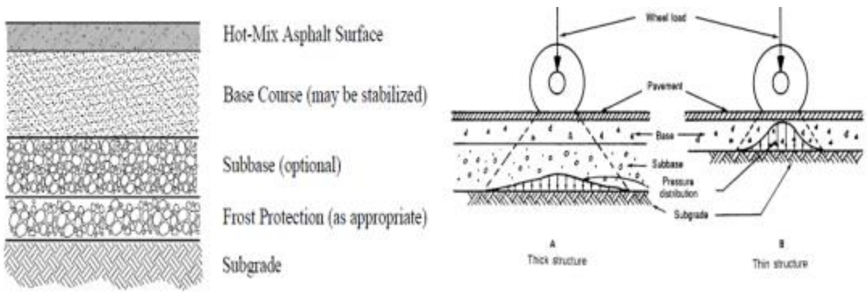

Figure 3. Representations of four-layered flexible pavement (a) and the way how they contact with the load.

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4. RESULTS

The result section is divided into two different test inferences viz., physical compressive strength test for asphalt concrete with & without rubber for marshal mix (Asphalt concrete) and simulated Kenpave analysis for flexible pavement design model with and without rubber was tested.

A compressive physical test was done for three samples modeled in marshal mix (Asphalt concrete) that shows average stress of 1.133 MPa. Secondly, three marshal composite mix samples (Asphalt concrete) with Rubber, was tested under compressive loading. The second test concluded the same inference similar to the elephant foot analogy of viscoelastic materials. Thus, viscoelastic material for landing gear foot can reduce the amount of stress or pressure and absorb around 0.559 MPa that will reduce the deformation by 49.34%.

Computer simulated Kenpave pavement Design and Analysis tool was used with simulated pressure in vertical, radial, and tangential stress components in their respective 3 coordinates to verify the above results with contact pressure for non-rubber and with rubber sample. **Figure 4** shows LGRAPH for landing gear with the non-rubber model. Another, test sample using rubber was modeled as shown in **Figure 5**.

As shown in **Figure 6**, the results plot compares stress stimulated on the landing gear, due to loading for both with and without rubber models. Thus showing, viscoelastic material has absorbed a high amount of stress or load causing very low stress in the asphalt concrete relative to without rubber model. Finally comparing the stress for the non-rubber and rubber model, the amount of the actual stress stimulated by the landing gear in trailers decreases with rubber-based models. Considering the above test results, the following observations were drawing as shown in **Figure 6**.

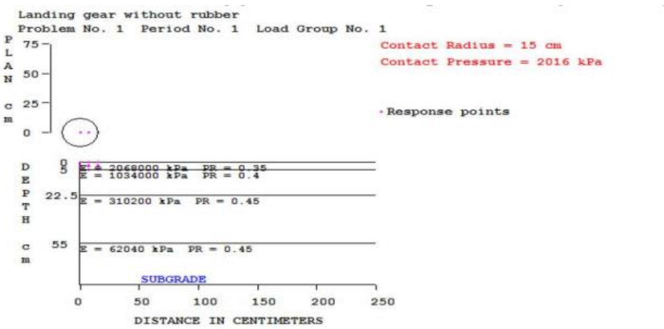

Figure 4. LGRAPH for landing gear without rubber Kenpave pavement design and analysis model.

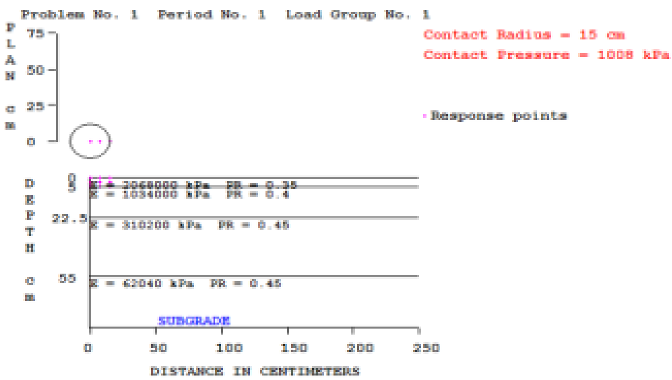

Figure 5. LGRAPH for landing gear with rubber Kenpave pavement design and analysis model.

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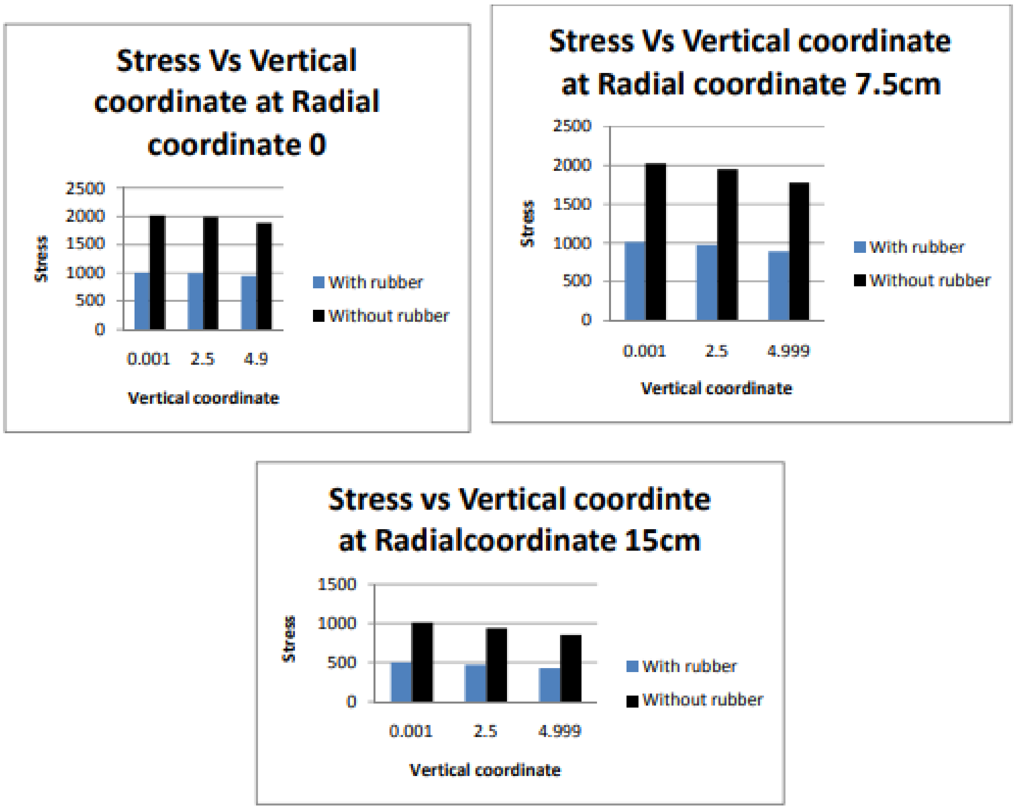

Figure 6. Stresses plot for both with and without rubber models at three different radial co-ordinates.

5. DISCUSSION

Using the above results, a landing gear shoe is modeled in CatiaV5R20 using viscoelastic material properties for landing gear footage. The main function is to distribute the load, so that deformation will be minimized. The reduction of asphalt deformation caused by landing gear for trailers now has design modifications that cause very low asphalt deformation due to viscoelastic shoe design (see **Figure 7**). The shoe can be customized and assembled for any design of landing gear with minimum cost impact and better support.

Thus, by providing a landing gear that is simple and durable in construction, easy to install and economical to manufacture, and which is easily and quickly operated by anyone without requiring any complicated instructions is made available for commercial use.

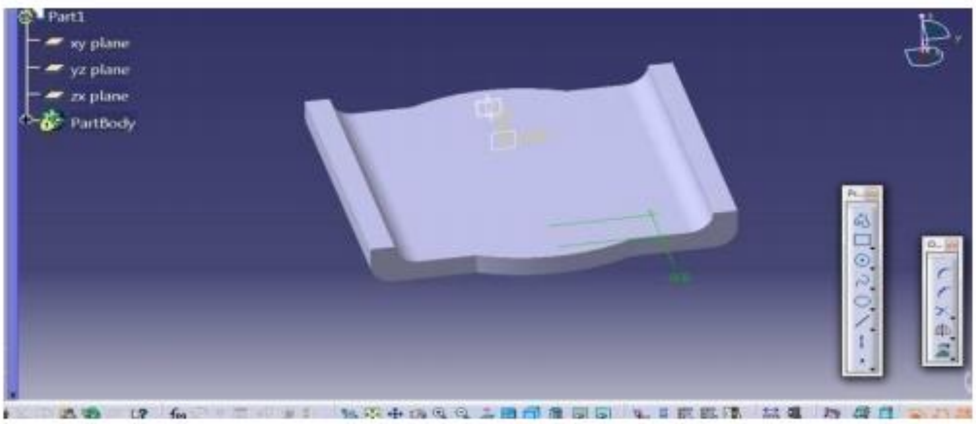

Figure 7. Customised 3D model for Holland Mark V series.

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6. CONCLUSION

The research study can be concluded by studying the asphalt deformation that is most of the time caused due to high stresses which affect the elasticity of the asphalt layers that causes deformation. Considering the elephant foot as a reference to see how they distribute their heavy loads can work due to their fat pad that existing at the bottom of their foot. This fat pad has a viscoelastic property which serves as means of distributing its load to the ground. So, this could be considered as a reference for land gear foot design. Viscoelastic materials as their name indicate have the property of distributing load slowly (in a vicious way) and returning to their original shape during unloading (elastic). From tests conducted during this study both physically and computational; it is found that Rubber (RTV940) has a good property of distributing the load. And redesigning landing gear foot is selected as a solution to minimize asphalt deformation. This has reduced the stimulated stress 2.16MPa to 0.41Mpa. Thus, when it comes to asphalt deformations, it can help in increasing the load distribution time which can reduce the asphalt deformation. The elephant foot analogy developed from the elephant foot study, about the viscoelastic material surrounding the bones to reduce stresses is used in the design of landing gear. Thus, maximum stress occurring at the edge of the landing gear foot shears the asphalt; So if we model the landing gear having more viscoelastic material thickness around the edges; it can reduce the shear.

7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. The authors confirmed that the data and the paper are free of plagiarism.

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