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ANALYTICAL METHODS AND ENGINEERING ANALYSIS OF PROSTHETIC FOOT

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Abstract:-
Natural disasters are occurring everyday across the globe, these claim the lives and livelihood of many individuals and families, especially in poorer regions of the world where if there is access to necessary medical care it is difficult to afford. Because of this there are many who have suffered a lower limb amputation and thus have had their ability to provide for themselves and their families greatly reduced or taken away. In the testing, analysis, and design of a low-cost prosthetic toe that would allow lower knee amputees who are unable to afford a high level prosthesis to regain a significant portion of their lost mobility, In developed countries like the United States, most people are able to obtain prosthetics with relative ease. Additionally, technology has become so advanced that below the knee prosthetics have begun to provide nearly natural form and function to someone who has lost a part of their leg.

Introduction:

Inhabitants of developing countries suffer from amputations arising from tragic accidents or illnesses at relatively high rates; civil wars, poor health care, and a high frequency of traffic accidents result in a large number of amputees. In an economy where most occupations require physical labor, the loss of a leg can have catastrophic effects on a person's life (Ellis et al 2010).The acquisition and maintenance of prosthetics takes a tremendous amount of resources not available to most people in such countries.

To accurately communicate information regarding the prescription, fabrication, and evaluation of prosthetic devices, one must appreciate the disparities that can arise because of differences in adopted terminology. This section of the course highlights potential areas for confusion in the terminology related to gait that warrant consideration, specifically clinical terminology, gait analysis, and the terminology of clinical biomechanics

DESIGN PROCESS OF PROSTHETIC FOOT

Process Flow Chart for Foot Design Process

The following flow chart exhibits an overview of the method used to carry out the design of the prosthetic foot.

Evaluation of Existing Feet:Analyticiterations based on previous teams' findings, professional knowledge, and experimental data provided our team with an understanding of the project.

Generation of Alternatives:Provided with a list of improvements given by the last team, alternatives were made to address the weak points of the previous design in one or more ways. Drawings of new components with some dimensions and description of the innovation incorporated were made by each team member on engineering paper.

Design of Foot Envelope:Developing the envelope for the prosthetic foot was carried out by casting a plaster mold of the inside of a size 9 tennis shoe. After the plaster hardened, measurements of the base and profile provided a proper envelope.

Engineering Analysis Steps:

1. First, a rough model was made in AutoCAD for the best alternatives.The first test that it must pass is the envelope test. If the alternative does not fit inside of the envelope, then the alternative must be adjusted in a way to allow it to fit the envelope.
2. AutoCAD drawings were input into ANSYS, which tested the foot alternative for stress and deflection under a given max load. If the stress or deflection is too high, then the design must change to lower the stress/deflection.
3. Parameters, such as the dimensions of the steel cross-sections, length of toe bar or deflection under loading were calculated using an Excel table applying mechanics of materials analysis to cantilever beams.
4. Weaknesses in modeling a cantilever beam are offset by creating a control element shaped to the alternative's specifications which is then tested on an Instron© machine for its stress vs. deflection.

Looping of Analysis: The empirical data from the Instron test provides a control and performance estimate for the Excel table to allow us to select materials and dimensions suited to our needs. The parameters for this chosen steel (dimensions deliberated upon during static loading analysis) are then plugged into ANSYS (and AutoCAD, if dimensions are to be changed) and a new and more valid simulation can be run. This process continues and restarts until we decide we have optimized every aspect we can under our particular scope.

Early exploration of AutoCAD designs and Brainstorming Alternatives:

At the beginning,different prototypes were generated on paper and drawn in AutoCAD, mainly as early exploration of AutoCAD. The goal was to alter at least one of the components, such as the toe or heel, in order to acquire the skills associated with prototype development and assessment.

Below is a table showing the different designs that were drawn up early in the design process and the conclusions made on each design by the team. Although we generated many different feet, these prototypes are more helpful in learning how to incorporate designs into AutoCAD and ANSYS software as most of these designs do not meet our design constraints.

The following bullets address some attractive qualities as well as future considerations:

- Incorporation of a heel that would deflect to the next piece of steel and stop, which provides energy return and bend during heel-strike.
- Bracing the top of the prosthesis to ensure that it will not collapse under loading.

Future considerations:

- Sizing was an issue, it could not fit into a shoe.
- Another thing that was not done with this foot was to consider uneven terrain, since the toe was not split.

From this prototype design, the team will improve different elements and use the design as a starting point for our project.

1. ANALYTICAL METHODS AND ENGINEERING ANALYSIS

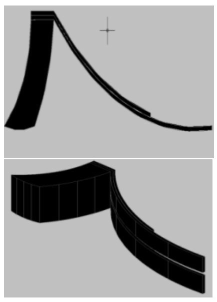
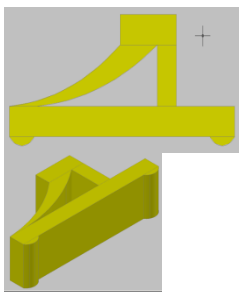
Enveloping the Foot:

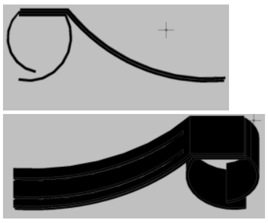
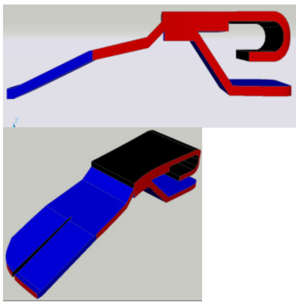
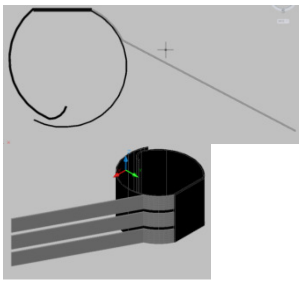
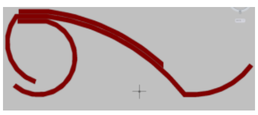
Developing an envelope around the human foot is imperative to scaling / sizing the optimized prototype to fit different individual's foot size. The envelope was designed by measuring a size 9 running shoe. To accomplish this task, plaster was poured into a plastic shopping bag, which was then inserted into the shoe and allowed to harden overnight. After 24 hours, the plaster hardened and was able to be modeled and dimensioned using AutoCAD. This envelope gave the team an overall understanding of the shape of the foot inside a shoe, as well as constraining dimensions in centimeters for our prosthetic.

The following figures below show the envelope that was designed from the plaster technique that has been described.

Figure 3 shows the dimensions of the plaster that were obtained when the plaster was removed from the size 9 shoe after it had hardened. This envelope gave the team an understanding of critical dimensions, such as the foot arch, heel depth/ length, and toe length of a size 9 foot. Based on this figure and the following figures of the envelope, different sized feet will be temporarily dimensioned into a table for use in scaling feet sized from 8-12 shoe size. The different sizes are merely a guesstimation at this point in the design project. The following figure shows the dimensions of the bottom of the foot from the size 9 running shoe plaster: The total length of the size 9 shoe was 26 centimeters long.

Table 1 : Alternative Exploration and Evaluation

Alternative	Conclusions
 Alternative 1: A-type	Pros • Simple design similar to look of human foot • Split toe incorporated for compliance on uneven terrain • Support plate for increased toe stability • Strong heel support Cons • Compliance at heel inadequate • Possible weakness at heel toe connection
 Prototype 2: Z- Type	Pros • Ease of manufacture • Rubber stoppers for heel and toe rollover • Basic Design Cons • Does not have many characteristics of a foot

	• Little or NO compliance
 Prototype 3: Skelasticdesign	Pros • Three toe design (split toe), greater compliance on uneven terrain • Heel from 2010's foot for good compliance • Toe lever of thicker steel for greater strength • Three separate components for ease of manufacturing Cons • Possible weaknesses at connections of components
 Prototype 4: T-Type design	Pros • Three piece design • Similar heel from 2010's foot • Good deflection possible in toe and heel Cons • Sharp corners tend to concentrate stress
 Prototype 5: Three split toe design	Pros • Three toe design similar to skelastic design • Thinner steel elements • Different attachment points Cons • More parts than skelastic design • Thin steel may provide too much compiliance
	Pros • Designed with shoe as intended envelope • Similar

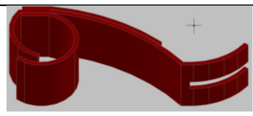
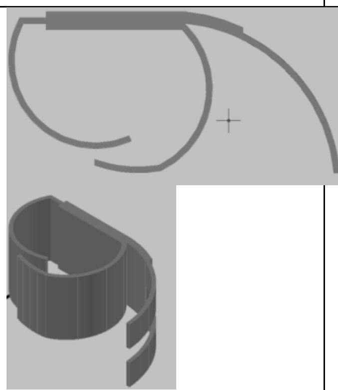
 Prototype 6: Shoe Design	features like upturned toe for good roll off • Heel dimensions similar to human heel • 3 piece design Cons • Concentrated stress at split toe – sharp corner • Compliance at toe may be undesirable
 Prototype 7: Downward split-toe	Pros • Heel is based on the previous designs • Downward toe might provide a new effect to rollover and toe off Cons • Downward toe may cause unwanted wear in cosmesis or shoe

Table 2 : Analysis of Critical dimensions of foot envelope

Shoe Size	Heel length(cm)	Arch Depth(cm)	Arch Length(cm)	Toe length(cm)
8	6.5	6.57	11.91	6.48
9	6.5	7.4	13.4	7.3
10	6.5	8.2	14.88	8.1
11	6.5	9.04	16.37	8.92
12	6.5	9.86	17.86	9.73

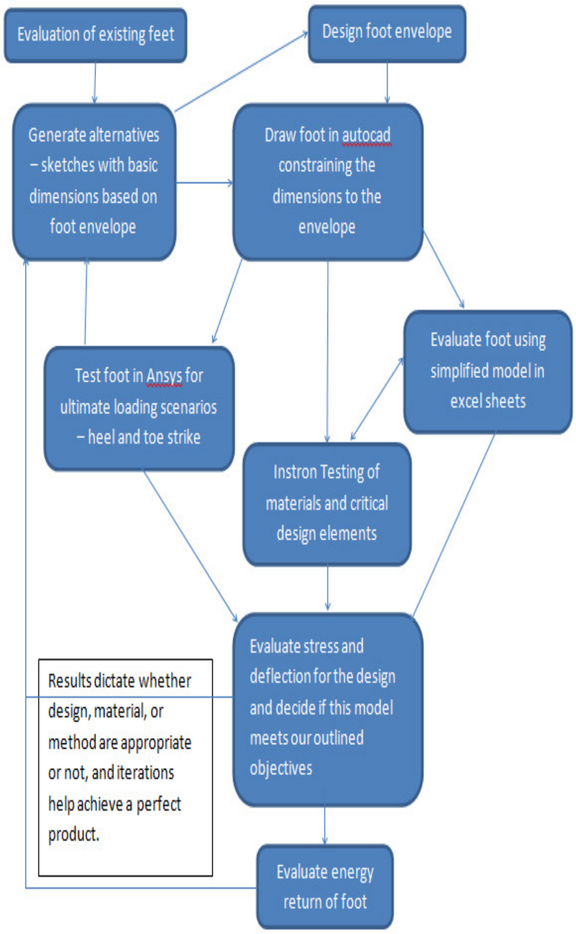


Figure 1: Process Flow Chart

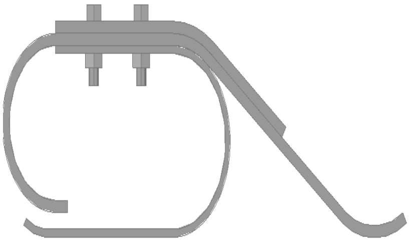


Figure 2 : Final Design

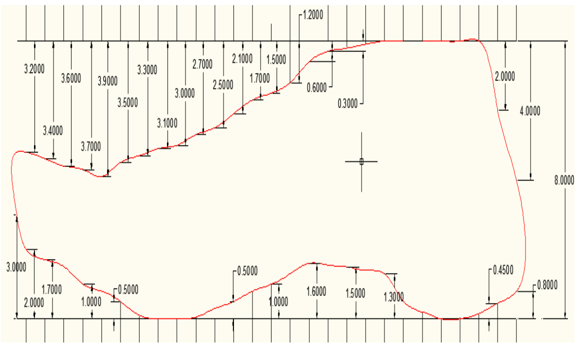


Figure 3 : Dimensions of side view of plaster foot inside of size 9 shoe (in 1 cm increments)

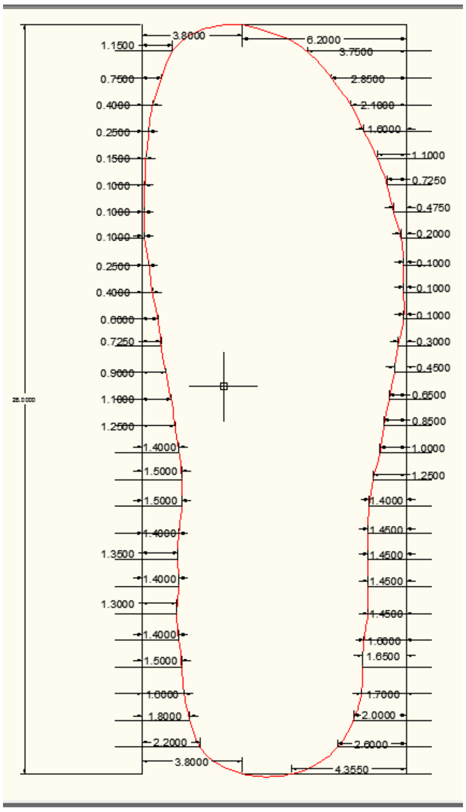
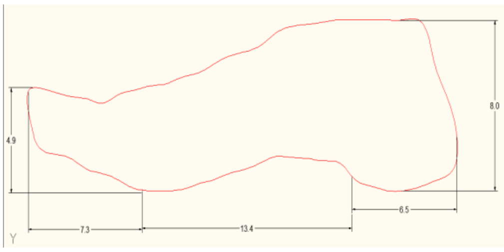


Figure 4 : Dimensions of bottom of plaster foot in one inch increments(26 cm length)

After dimensioning the bottom of the plaster foot, the next step was to dimension the elevation and critical dimensions of the plaster envelope.



Arch depth Heel Length

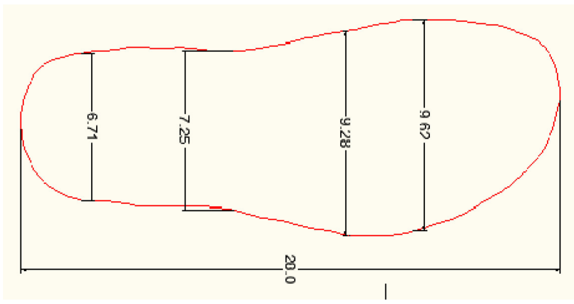


Figure 5 : Important Foot Dimensions (in centimeters) and Bottom of Foot Dimensions for Size 9 Shoe

Conclusion

Table below was constructed as a preliminary table to show the possible critical dimensions for shoe sizes 8-12. This was done by using an equation that may not be entirely accurate. In the future design process, envelopes will be constructed in similar fashion for each shoe size for sizes 8-12.

Table shows the different dimensions for a foot envelope for different shoe sizes. Since feet have different dimensions depending on the size, different lengths must be scaled accordingly. To be able to accommodate for different sizes of feet, this envelope table will help determine which parts of the prosthesis can be scaled to fit inside of a normal running shoe of a specified size. The heel length is the length from the beginning of the heel (back of foot) to the start of the arch in the bottom of the foot. The arch depth is the measure of the height of the arch at 4 centimeters from the end of the heel. Arch depth ensures that the proper slope of the prosthesis is constructed to allow the prosthesis to fit inside of the shoe. Arch length is the measured length from the ankle of the foot to the beginning of the toes. Toe length is the beginning to the end of the toes. These dimensions will allow for proper scaling to be done if our client wants to create the desired prosthesis for different shoe sizes. Since only a size 9 shoe was done using the plaster technique, the other sizes were scaled by setting up an equation for conversion:

As stated earlier, this equation is not entirely accurate, since it is relying on a linear relationship to determine different shoe envelope sizes.

$$\left(\frac{\textit{Arch depth Size 9 shoe}}{\textit{size shoe}}\right) = \left(\frac{\textit{Arch depth x Size shoe}}{\textit{x size shoe}}\right)$$

From this equation, the unknown dimensions for each shoe size were solved for and the dimensions of different shoes were scaled from the size 9 shoe envelope. This equation assumes that there is a direct correlation for each dimension of different shoe sizes comparable to size 9 shoe size. For simplicity of sizing different feet sizes and being able to manufacture the design more simply and effectively, the heel size will always remain at 6.5 cm in length. The other dimensions will change based on shoe size by using the above equation.

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