

# Determination of Energy Absorption on Seat Regions of Footwear for the Obese

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## Abstract

*Ideal footwear with a design configuration is necessitated as a tool of rehabilitation to render therapeutic benefits, especially for obese individuals who are experiencing greater risk during locomotion. Energy absorption is found to depend on variables like heel height, slope angle and load exerted by the body mass index. Statistical analysis was carried out to formulate a predictive equation for absorbed energy. It was found that a heel height of 30 mm offers an optimum base for further design of footwear. A coefficient of determination ( $R^2$ ) with a value of 0.933 indicates that the model fits the experimental data nicely. Hence, 30 mm 20 degree is suggested for designing ideal footwear as it enables load dissipation and energy absorption to render foot-comfort benefits and advantages to the user.*

**Key words:** energy, design configurations, foot, comfort, obese.

## Introduction

It has been commonly noticed that people with heavy-weight exert pressure which is 2 or 3 times more than normal people during locomotion phases. Due to excessive loading in the heel strike phase, obese individuals predominantly experience heel pain symptoms, plantar fascia and pain over lower extremities. Plantar loading of the heel during locomotion can result in high local pressures that need to be relieved in the case of heel pain [1]. There is a need to measure the effectiveness of the range of pressure relieving interventions for the prevention and treatment of diabetic foot ulcers as there is a small amount of poor quality research in this area [2]. Thus an analysis on how much energy is absorbed by footwear for a person is necessary to find a particular design. A proper analysis of energy absorption is one of the important parameters in research to evaluate the functional performance of footwear and its efficacy on the foot-health parameters of end-users.

To overcome specific foot problems due to the heaviness of obese individuals, external design configurations have been employed, particularly in heel-seat regions, to provide remedial solutions for beneficiaries [2]. “Rocker” profiles are the most commonly prescribed external shoe modifications used mainly to offload pressure on the plantar surface of the foot [3]. The “Rocker design” alters the biomechanics of the gait and is said to reduce the load that can be borne under the forefoot area at push-off. The “Rocker design” on the bottom shape of the sole of the shoe influences roll-off of the fore-foot occurring behind

the metatarsophalangeal joint of the foot, and it significantly alters the biomechanics of the gait, thereby reducing the load that can be borne under the forefoot area in the push-off phase of locomotion [4]. Nawoczinski *et al.* showed that certain pivotal and curved rocker bottom shoes are able to reduce plantar pressure particularly on the fore-foot region in normal subjects [5]. Rocker bottom shoes help offload plantar pressure in the fore-foot but are dependent on the placement of the rocker [6, 7]. However, analysis of comfort designs with different heel-seat configurations has not yet been undertaken.

Footwear designed and developed with various external design configurations on the bottom surface profile are mainly to render therapeutic benefits to overweight and obese individuals [8]. Previous studies revealed that design change in shape and sole structure can significantly alter shoe plantar pressure in specific regions of the foot, which could prevent illness and provide improved comfort [9]. The influence of shoe design on the plantar pressure dynamics of patients and the most effective way to offload the effect of plantar pressure were understood through the use of the rocker sole principle [10]. Although the amount of energy absorbed can be known from an Instron Universal testing machine, especially for safety footwear, a similar concept is lacking in the design of comfortable footwear for the obese.

Therapeutic footwear has been used to treat acute problems such as plantar fasciitis or metatarsalgia and as a preventive tool on patients with diabetic neuropathy [11]. Therapeutic footwear is important

for end-users at ease, consequently design innovation in the surface geometric configuration has gained intense interest in shoe – engineering. Designing footwear for a patient’s foot morphology and foot type will assist in preventing injury and discomfort to the beneficiaries [12]. Previous studies revealed that design change in the shape and sole structure can significantly alter shoe plantar pressure in specific regions of the foot, which could prevent illness and provide improved comfort [13]. The reduction of pressure peaks can be achieved by providing special shoes [14]. Footwear outsoles and heels can alter the mechanical load on the lower limbs during the stance phase of the gait [15] and can effect biomechanical function during the various components of the dynamic phases of the gait. De castro *et al* [16] and Mueller *et al* [17] expressed their concern that the mid-foot region of the sole in footwear is important for a reduction of energy absorption to render comfort to end-users. Older obese adults suffer foot pain and foot related functional limitation [18]. Generally, the obese use sports footwear, which provides a wider fit dimension to accommodate the obese foot. However, the energy absorbed by footwear needs to be analysed in designing comfortable footwear, as a dependent-function of the heel-seat angle, heel height and load, which will render therapeutic benefits to the obese.

From the literature survey above, it is understood that obese individuals do not have a choice in the selection of appropriate footwear to accommodate their foot characteristics for fit and comfort. Sports footwear is their only preferred choice due to the wider space inside the shoe fa-

cilitating fit to their feet. Sports footwear turns to a disadvantage for the obese in places of formal attire. This footwear is meant for informal use but not for maintaining self-esteem in society. Hence, footwear with a formal design to maintain comfort with dignity is warranted for obese individuals. Obese people generally exert a higher impact at heel strike due to heaviness as well as the body mass index, the impact of which induces discomfort in the lower limb regions and causes pain in the ankle, knee and thigh areas of the feet of obese people. A literature survey revealed that the surface geometry on the bottom sole of footwear aids in the dissipation of forces exerted by people and that it is helpful for off-loading purposes in walking. In order to overcome these discomfort consequences, the design features on footwear have been mooted to develop comfortable footwear for the well-being of obese people. The importance of research on the “design of footwear with optimum angle configuration” exclusively for obese individuals is extremely great in the present context. Thus the primary objective of this research is to design footwear with external surface modifications for easing pressure off-loading to improve the well-being of end-users. The rest of the paper is organised as follows: Section 2 discusses materials and methods; experimental apparatus is explained in section 3; results and discussion are presented in section 4, and statistical analysis in support of the experiment and observations has also been presented in this section. At the end a conclusion is drawn.

## Materials and methods

It is important to investigate the efficacy of design configurations and their significance for the comfort parameters of users using scientific and research interventions in the domain of footwear. In the line of this research, shoes with

**Table 1.** Specification of microcellular rubber sole.

Property	Experimental results	Parameter requirements	Producer and country of origin of the equipment used
Hardness, IRHD	42-45	Min. 40	SATRA, UK
Density, g/cc	0.48	Max 0.5	Sartorius, Germany
Tensile stress, N/mm <sup>2</sup>	2.7	Min 2.5	Instron, USA
Elongation at break, %	190	Min 175	SATRA, UK
Compression set, %	18	Max 20	SATRA, UK
Abrasion resistance, mm <sup>3</sup> Volume loss	650	Max 700	Instron, USA

a 30mm heel height and heel curve angles ranging from standard design to varied design angles such as 5 & 10 degrees and 15 & 20 degrees, respectively, were developed, with a total number of five samples for determination of energy absorption in the seat regions of footwear especially for obese individuals. Materials for the development of this footwear were procured from a local market.

Externally heel configured shoes were designed of different angles, with the seat-line as the basis, using Microcellular rubber (MCR) soling materials (as given in **Table 1**) for the bottom part of the shoes for obese individuals. Three types of MCR soling materials were sourced from the local market, and their characteristics were investigated for bottom applications in this study. Physical characteristics such as hardness, density, tensile strength, elongation at break, compression set and abrasion resistance were evaluated, and it was observed that one of the MCR materials possessed requisite parameters, chosen on the basis of its merits, and used in the preparation of the bottom sole of footwear for obese individuals, as presented in **Table 1**.

SATRA test methods were carried out to evaluate the physical characteristics of the materials in this study.

The main purpose of choosing MCR material is due to its accessibility and availability at the local market. This material

is primarily suitable in research and development applications and was easier to use in making prototypes for scientific analysis in the study. The method “Determination of energy absorption in seat regions of footwear” was identified for experimentation on the developed footwear designed with external design configurations for the obese.

**Figure 1.a** shows footwear designed with 20° slope angle and 30 mm heel height. A line sketch for the above design is shown in **Figure 1.b**. The slope angle was varied from 0 to 20° with an interval of 5°, keeping in mind the stability, energy absorption, load dissipation and foot-comfort of the obese while walking. While walking, in every such case, experiments were carried out to find a foot-comfort solution for obese individuals.

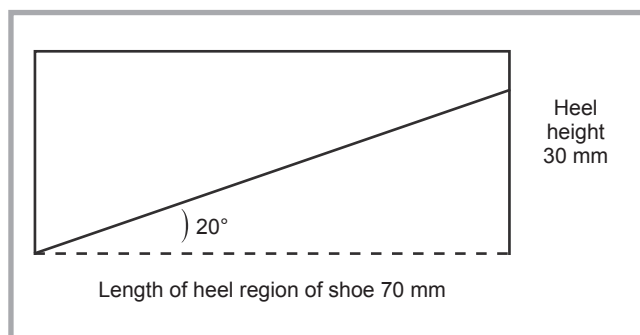
A universal testing machine (Model 3369) was employed for energy studies on the externally modified footwear exclusively engineered for the obese.

## Experimental apparatus

The Universal testing machine (Model 3369) was fitted with a compression cage comprising of two parallel plates made of hardened stainless steel. Experimental data were displayed on a computer interfaced with the UTM. This machine is user-friendly and gives better accuracy on outcome. It is connected to a computer as a graphical interface for display



**Figure 1.a.** Shoe for obese with extra upper volume and sole modification with 30 mm heel height and 20° slope angle.



**Figure 1.b.** Cross sectional view of 30 mm heel height shoe illustrated with 20° slope angle.



**Figure 2.** Schematic of Instron Universal Testing Machine (Model 3369).

of energy absorbed and the compressive distance during application.

A method (Indian Standard 15298: 2011) was employed in this research for determination of energy absorption behaviors on shoes developed especially for obese individuals. The footwear configured with a heel height of 30 mm were designed with different slope angle degrees: 0, 5, 10, 15 and 20 and experimented upon using this machine under different loading: 700, 800, 900 and 1000 N, respectively. The footwear was placed on the steel base of the UTM. The test punch, a component of the UTM, being the back part of a standardised shoe last,

is made up of polyethylene. The shoe last was sectioned on a plane vertical to the feather edge and at 90° to the axis of the back part. The shoes developed with a heel height of 30 mm with external design angles ranging from 0 to 20 degrees were used (experimented) on this equipment. The test punch was pressed against various design configured shoes at the centre of the heel area at a test rate of  $10 \pm 3$  mm/min until a force of 700 to 1000 N is obtained.

The load and compression curve drawn for each test is plotted, and subsequently the energy absorption  $E$  in joules is determined using the equation:

$$E = F ds \quad (1)$$

where,  $F$  is the compressive force applied in Newtons, and  $s$  is the distance in mm.

The energy absorption and extension values of footwear with standard and externally modified configurations appear on the display of the UTM, from which the readings are observed.

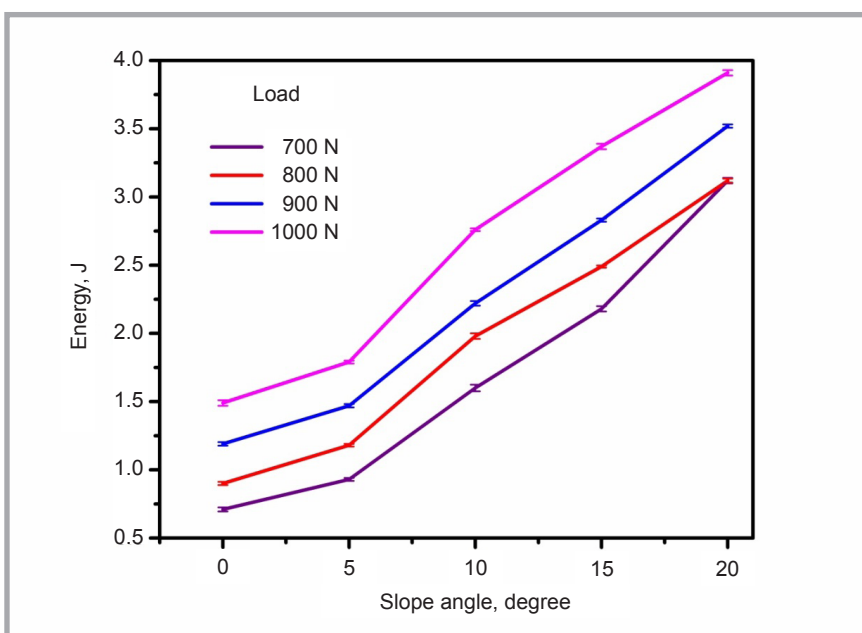
## Results and discussion

The footwear designed with a standard model and other externally designed angles of 5, 10, 15 and 20 degrees were subjected to energy absorption studies using the Instron Universal Testing Machine. The study includes determination of energy absorption behaviours and compressive distance values under the follow-

ing load conditions: 700, 800, 900 and 1000 N. For each experimental point, 5 samples were tested for energy absorption study. Trends of energy behaviours for 30 mm heel height footwear with standard and external design configurations under different loading conditions ranging from 700 to 1000 N are illustrated in the **Figure 3**.

The energy behaviours with respect to various design configurations under different loading conditions are shown in **Figure 3**. It can be observed from the graph in **Figure 3** that there are linear positive trends from standard footwear to the series of externally designed footwear ranging from 0 to 20 degrees. The design configuration plays significant roles in energy-absorption characteristics under the different load conditions. In all cases of graphical presentation, the energy absorption trend is lower in the case of 700 N, while it is higher in case of 1000 N. It is evident that the design configurations developed on footwear with significant energy absorption characteristics impart promising benefits to end-users. The heel surface curvature aids in dissipating the pressure generated during locomotion, which greatly influences the offloading pressure, thereby enhancing/rendering comfort as well as therapeutic benefits, ideally to the obese. From the study, it may be observed that the standard footwear or 0 degree footwear exhibited lower energy absorbed values and lower compressive distances than other the slope angle footwear. It is evident from **Figure 3** that the graph progresses linearly upwards from standard footwear to 20 degree footwear under various loading conditions ranging from 700 to 1000 N.

In an earlier study, it was found that a 30 mm heel height with a 20 degree angle provides an optimal design for the heel region of footwear. **Table 2** shows data of the various design angle footwear and the design configurations of the heel region in respect of the slope area, slope distance and volume at the end. The energy absorption parameters were obtained from the experiments carried out on the footwear using the UTM Machine. The energy absorbed per unit volume was estimated by the area under the curve with the compressive distance travelled during experimentation analysis.



**Figure 3.** Trends of energy behaviours for 30 mm heel height footwear with standard and external design configurations under different loading conditions ranging from 700 to 1000 N.

Calculation of the volume is based on the following formula:

$$\begin{aligned} \text{Volume of rectangular prism} &= \\ &= L \times H \times W \end{aligned} \quad (2)$$

where,  $L$  is the length,  $H$  the for height and  $W$  the width.

$$\begin{aligned} \text{Volume of triangular prism} &= \\ &= \text{area of cross section} \times \\ &\times \text{length } (\frac{1}{2} bh \times l), \end{aligned} \quad (3)$$

where,  $b$  is the base,  $h$  the height, and  $l$  the length.

The heel regions of the footwear were configured with slope angles such as 5, 10, 15 and 20 degrees in this study. The shape of the heel region designed is the composition of two geometric shapes, namely a rectangular and triangular prism. The volume of the rectangular and triangular prism was calculated mathematically and added to arrive at the total volume of the different slope angles of the heel region.

The emphasis on the concept of design configurations in footwear is to ease load dissipation exerted or off-loading on the heel region of footwear at the heel strike phase. In locomotion, the heel strike phase is the initial contact of the foot on the ground surface, and the entire load of the person hits or strikes at this phase. As the heel strike contact of the foot is vulnerable to developing pain in the ankle, knee and thigh regions, the remedial solution is the off-loading technique through design configurations. The slope design of the heel aids propulsion in locomotion, and simultaneously the velocity increases to improve the physical fitness of the beneficiaries. The design angle helps in increasing the swing phase, meaning the foot off the ground in locomotion, and increases the propulsive impulse during gait phases. The design angle footwear would encourage users to acquire comfort advantages with a high degree of confidence during usage.

From **Table 2**, it is clearly understood that while the design angle increases, the slope distance and slope area consistently increase, but the volume decreases accordingly. The primary reason for increased energy absorption characters is mainly due to the increased slope length and slope area on the externally designed configurations. The decrease in volume on all externally modified designs are compared with the standard design, and it

**Table 2.** Mathematical calculation on various external design configurations.

S. No	Heel height, mm	Design angle, degree	Slope distance, mm	Slope area, mm <sup>2</sup>	Volume, mm <sup>3</sup>
1	30	0	70	4591.3	137.70
2		5	72	4739.3	134.80
3		10	73	4813.3	124.90
4		15	75	4961.3	117.20
5		20	81	5405.3	109.20

**Table 3.** Statistical analysis with standard deviations for energy absorbed under different loads.

S. No	Sample angle, degree	Energy absorption, J (SD) under			
		700 N	800 N	900 N	1000 N
1	0	0.66 (0.18)	0.84 (0.29)	1.10 (0.38)	1.38 (0.48)
2	5	0.90 (0.34)	1.02 (0.34)	1.35 (0.51)	1.61 (0.52)
3	10	1.42 (0.41)	1.62 (0.45)	1.88 (0.46)	2.37 (0.44)
4	15	2.16 (0.02)	2.51 (0.03)	3.04 (0.29)	3.69 (0.46)
5	20	3.04 (0.11)	2.94 (0.25)	3.37 (0.21)	4.16 (0.35)

**Table 4.** Statistical significance of energy absorbed with heel-height, angle and load.

Predictors	B	Std. error	t	p-value
Constant	-3.158	0.362	-8.723	0.000
Angle, degree	0.118	0.006	20.698	
Load, N	0.003	0.000	9.161	
Heel_thickness	0.036	0.006	6.203	

can be seen that there are substantial benefits to the end-users with a decrease in the weight of the heel. The lesser weight of the heel would render an improved level of comfort to the user, specifically the obese.

#### Statistical analysis – multivariate linear regression model

Experimental observations of absorbed energy for all the obese designs along with the different degrees of inclination for the footwear were subjected to statistical analysis to formulate a predictive equation for energy. The independent variables in this case are the angle, heel height and load exerted by the obese, while the dependent variable is the energy absorbed. The coefficient of determination ( $R^2$ ) was found to be 0.933, which indicates that the model fits the experimental data nicely. The R value was observed to be 0.966, while the adjusted R square was 0.929. The statistical analysis, followed by statistical data of absorbed energy with the heel-height, angle and load are presented in **Table 3**. This table shows energy absorbed values for 5 different samples under different load conditions. Each observation (sample) was made five times, whose standard deviation is shown inside the bracket.

The significance of independent variables for the dependent variables (energy absorbed) can be observed from **Table 4**. It can be found that the angle contributes more significantly (0.118) than the other parameters to the energy absorbed using predictor B.

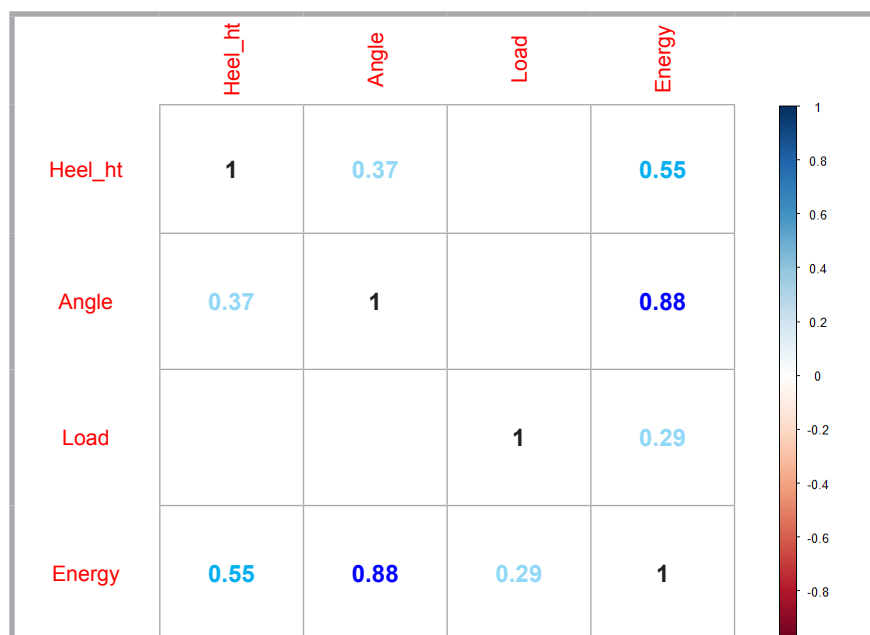
#### Predictive model equation

$$\begin{aligned} \text{Energy} &= -3.158 + 0.118 \times \text{angle} + \\ &+ 0.003 \times \text{load} + 0.036 \times \text{heel thickness} \end{aligned}$$

In an earlier separate study, a 30 mm heel height was found to be optimal for the development of footwear for the obese. Besides this, in the earlier research, separate energy studies were preliminarily carried out with a 20 mm and 40 mm heel height in footwear, and the research findings revealed were not important with respect to foot-comfort benefits for those concerned. Hence, 30 mm heel height footwear was chosen for the study.

Footwear configured with slope angles such as 5, 10, 15 and 20 degrees is a part of the design innovation in the study. The load applied is 700, 800, 900 and 1000 N, respectively. a heel height of 30 mm is constant for all the footwear considered for this study. The variables are slope angles and loads applied along with the heel-height, using a UTM machine for determination of the energy absorbed in the study.

**Table 5.** Correlation plot of energy absorption with dependent parameters.



A heel height of 30 mm has the constraint of a maximum diagonal angle up to about 22 degrees. Five samples, each spaced by 5 degrees, were chosen to carry out the experiment. Hence the study limits the selection of the angle to 20 degrees at maximum. In another study (Table 5) using multivariate regression involving the heel height, angle and load as independent variables and energy as a dependent variable, it was found that the variable angle is the most significant (0.88) for energy absorption. The significance of other variables is found to be the heel height (0.55) and then the load (0.29). The objective of the correlation analysis is to ascertain the primary factor associated with the energy absorbed in the footwear. This analysis reveals that the design of the slope angle is important for energy absorption, indicating that the excessive load exerted by the obese is dissipated in the footwear to render foot-comfort benefits.

In the footwear developed for scientific analysis, the standard footwear possesses a 30 mm heel height, whereas others have different slope angles with a heel height of 30 mm. Furthermore, it is confirmed that a heel height of 30 mm is common for all footwear, but standard footwear is distinct from the others. In standard footwear, a heel height of 30 mm is maintained over the entire heel region, whereas it is not the case for other slope angle footwear.

The main objective of this study was to scientifically investigate the efficacy of

design configured footwear for energy absorption characteristics and to confirm that the rocker bottom profile of footwear is helpful and beneficial to rehabilitate people in need. It is observed (Table 5) that the most significant factor to predict energy absorption is the angle, displaying a coefficient correlation value of (0.88), followed by the heel height, while the least significant factor is the load. It can also be inferred that a 30 mm heel height with 20 degree footwear displays a higher energy absorption value than all other categories. The highest value of slope distance and slope area affects the highest energy absorption in the case of 30 mm 20 degree footwear. Higher energy absorption results in lowering the impact of the body weight or load on the ground. A design configuration of 30 mm 20 degree footwear aids in the dissipation of load across the sole, thereby improving foot-comfort that adds advantages for those overweight and obese.

### Conclusions

Energy absorption by the heel of footwear for the obese is important for foot comfort to get therapeutic benefits. The present study analysed designs based on their parameters (angle, heel-height etc.) to find the best design for the obese. In order to achieve this, experimental and theoretical analyses were performed in this study. A Universal Instron Testing Device was employed on footwear designed with external configurations, revealing the effectiveness of energy absorption characteristics. The statistical analysis

evidenced that the efficacy of design angles is significant. Under the various design angles experimented upon in this research work, the 30 mm 20 degree angle is best in terms of energy absorption behaviour, which would bring enhanced therapeutic advantages for the beneficiaries. Hence 30 mm 20 degree footwear is suggested as ideal comfort solution footwear for obese individuals. The statistical analysis of experimental samples yielded the formulation of a predictive equation for energy-absorption with a coefficient of determination of 0.933. The study also revealed that the energy absorbed is influenced by the parameter 'angle', displaying a coefficient correlation value of (0.88), followed by the 'heel height' as a moderate factor, with the load as the least significant.

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