1. Introduction

1.1 Introduction to problem

In the modern technological environment, large masses moving at great velocities are a common occurrence. The potential hazard of not being able to control these masses, leaves a gap in industry that needs to be filled in terms of an effective, reliable kinetic energy absorbing system capable of harnessing and dissipating such large forces.

A possible beneficiary of such a device would be the mining industry, which extensively involves the transport of vast amounts of personnel, equipment and minerals. Accompanying these activities are the unavoidable risks of accidental over or under-wind situations, involving the cages and their contents. Mining personnel are exposed to these dangerous situations daily, and numerous fatalities and injuries have been sustained as a result. With this in mind, transport safety in underground mining is of utmost importance.

Against this background, a SIMRAC (Safety In Mines Research Advisory Committee) project GAP638 [1], was undertaken by a design team from the University of Pretoria and a deceleration device was identified as a possible solution. In this project, past accidents involving conveyances were investigated and the shortfalls in the systems were addressed. A literature study was conducted to identify the existing safety devices used to safeguard cages. These devices were evaluated and efforts were made to constructively utilise their strong points and develop their weaknesses to increase their effectiveness [1].

This dissertation deals with the development of the deceleration device identified as a viable option in the SIMRAC project GAP638 [1]. The device can also be used universally in industry to produce specific deceleration forces to any moving mass. With GAP638 as a preceding project base history, a mining specific event known as an under-wind condition is used as a point of reference, as a possible area of application for the device, which is under development. An under-wind condition occurs when a cage, during its downward journey, overshoots the landing platform and strikes the bottom of the shaft. The proposed device to be used as an under-wind protection system makes use of a steel strip threaded between inline rollers which, when pulled through the roller set, repeatedly deforms from one roller to the next. The repeated bending action disperses energy in the form of plastic deformation, which generates heat, and thereby decelerates the mass system.

A prominent problem with this highly effective system used for mass retardation, is its sensitivity to deformation rate, and therefore the velocity of the decelerated mass at impact [1,2]. This factor drastically varies the performance of a specific configuration, under a quasi-static condition, and that of a dynamic, real-life situation [3].

The first complication regarding the application of the system is the need to accurately and consistently predict the performance for any configuration and thus, for any conceivable situation. This is important due to the stringent deceleration specifications which humans can be subjected to for limited periods of time [4]. The challenge is to incorporate the parameters of a dynamic deceleration system into a calculation which, when fed the operating conditions, would deliver an accurate performance prediction.

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The next complication is the devices inability to both detect and accommodate for a varying mass to be decelerated. The deceleration force potential of the device would always be constant, and thus for a certain mass to be decelerated, a specifically sized deceleration system would deliver a corresponding deceleration rate (i.e. F = Ma). If, for example, the same system was to be used to decelerate half the mass, (i.e. half full cage) to satisfy the physical description of force, (F) the acceleration (a) would have to be twice as much. To design for conditions allowing for maximum mass deceleration, a worst case scenario, provision has to be made for a means of staying within the specified limit set for the deceleration of a half mass condition, as well as still having the capacity to decelerate a full load condition within the travel distance available. A possible solution to this problem will be discussed in chapter 9.

1.2 Proposed solution

A method selected to fulfil the operational requirements, is an existing system. It is based on the Strain Energy Linear Ductile Arrestor system, (SELDA). [5] The method of energy absorption by means of kinetic to strain conversion was pioneered by Jackson in 1965 [19].

This method of operation involves the absorption of energy through the plastic bending and unbending of material. This system encompasses a metal strip, which is pulled through a set of sequential rollers, between which the strip is threaded (refer: Figure 1, Figure 2).

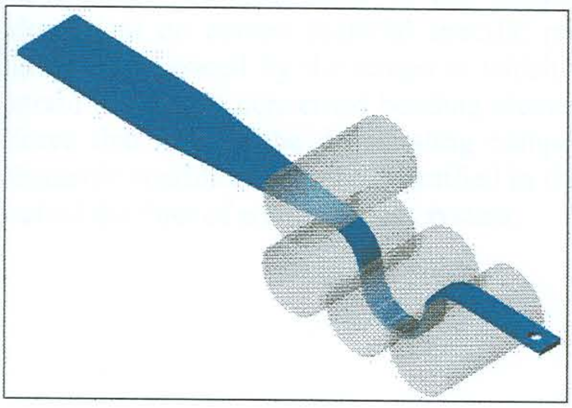

Figure 1 Schematic representation of taper strip energy absorber.

Figure 2 Practical application of wall-mounted, tapered energy absorber.

When the strip is bent and unbent around the rollers, the kinetic energy is absorbed and transformed into low-level heat. The maximum amount of energy that can possibly be absorbed by these means would be a constant force at the maximum specified level for the duration of the deceleration stroke. This, in concept, can be achieved by making use of a strip of constant width, threaded through the rollers, delivering maximum permissible deceleration force.

deceleration profile resulting from the plastic deformation of the strip moving between the rollers, has to be accounted for. This thesis concerns itself with that very investigation.

To alleviate the initial impact effect, the strip or deceleration element, is cut in the profile of a taper, which facilitates a smooth decelerating action, by means of gradual application of the decelerating force (refer: Figure 2). The tapered profile masks the prominent influence of the inertial effect on the deceleration levels experienced by the decelerated body. By these means, the requirement for the primary designed, inline damper system is also eliminated, further simplifying the deceleration system (refer: Appendix C). The narrowest section of the strip, the neck, is designed to have a safety factor of six for static yielding while under application of the maximum expected dynamic load. A design factor of six is acceptable practice according to the Occupational Health and Safety Act and Regulations specifications for all driven machinery [21]. The section of the act is applicable to cables and ropes, and since this application could be classified as a structural member, good engineering principles are required and should be applied. A safety factor of six is more than adequate.

The tapered metal element can only contribute to the decelerating force, once the tapered section enters the roller system. The absorption of kinetic energy takes place during the deformation action of forcing the element to conform to the roller radius. This event occurs once the section of the element leaves the roller radius it had travelled over, and moves to the next radius, bending from one arc to conform to the next. This event is repeated, as many times as there are rollers in the series. The bending and straightening of the element under tension causes slight elongation. This effect has been identified and quantified in past research. It is magnified by specific geometrical and system properties but the effect is still negligible in the current application [6]. The force of the element resisting travel through the rollers is dependant on certain material specific properties. The performance properties are greatly influenced by the tempo at which the process takes place, and therefore the strain rate of the concerned bending element [7]. The element's resisting force is the force that acts as the decelerating component. The performance characteristic for dynamic conditions is to be quantified in this dissertation, which could then be used to retard the "out of control" mass system.

In the proposed application of the deceleration system [1], sets of rollers loaded with deformable strips can be anchored either side of the shaft to the walls, connected by means of pulleys and cables strung across the width of the shaft. When the cage travels past the shaft bottom limit, contact with the cable strung across the path of travel of the cage is made. The cable, which is attached on either of its ends to a deformable strip, would then pull the deformable element through the roller sets, resulting in a decelerating force (refer: Figure 3, Figure 4).

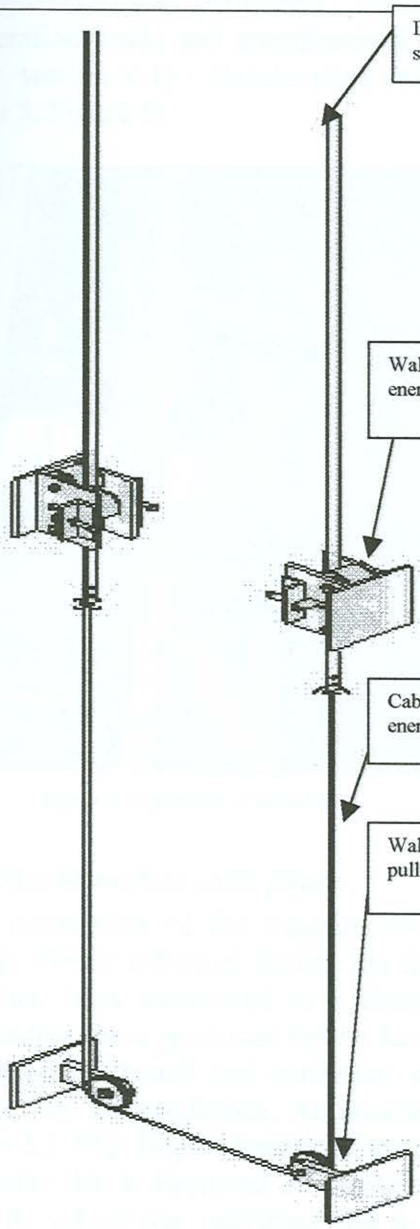

Figure 3 Schematic of retardation system.

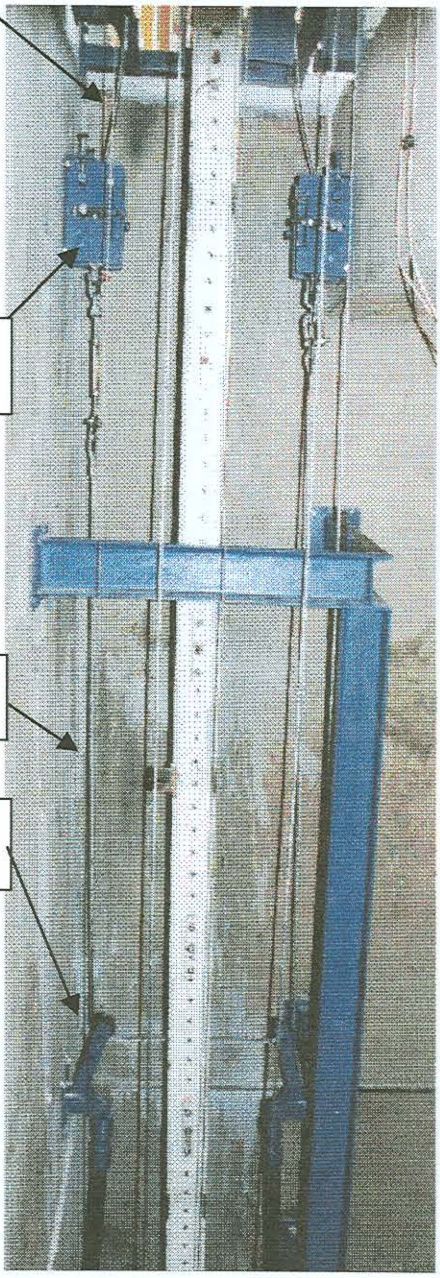

Figure 4 Image showing model retardation system.

1.3 Problem solution approach

1.3.1 Scale model phase

A tenth scale model of a mineshaft, constructed at the University of Pretoria, has been used to implement and evaluate the proposed under-wind protection system. This model was also used for the test work for the SIMRAC project GAP638 [1]. Experiments were performed, decelerating the model cage within the desired deceleration limits and specifications, which were established in the literature study (refer: section 2.1). Deceleration data was recorded during the experiments (refer: Figure 5, Figure 6).

Figure 5 Top section of model shaft.

Figure 6 Lower section of model shaft.

1.3.2 Mathematical code phase

Upon completion of the experiments, mathematical code was developed based on existing theory collected during the literature study (refer: section 4.) [3], [7]. This code has been automated in a design program to predict the magnitude of the deceleration force produced by the simulated geometry. Various geometries were then experimentally tested and compared with the design program's output to verify the accuracy of the prediction. An accuracy of between 75%-99% was obtained (refer: section 8.). The largest deviations were obtained with the small force simulations. The reason for this is discussed in chapter 9. The extent of which the experimental set-up could be varied was restricted due to the space constraints in the scale shaft (refer: section 6.2). These restricting factors, i.e. roller radius and drop height, which would vary in industrial applications, required to be investigated by other means of testing to verify that the prediction program delivers accurate information, and to further ascertain its accuracy domain. During the course of the study it has been noted that the developed design program's output only significantly deviates from the true situations once the inertia factors reach a significant size. This is when the combined mass of the strips used to perform the retardation, are within 10% of the mass being decelerated. This is in an extreme situation that will be discussed at a later stage (refer: section 8.).

1.3.3 Dynamic finite element analysis phase

Further testing has been achieved by means of a dynamic Finite Element Analysis (FEA) simulation, making use of MSC Patran and MSC Dytran. Firstly a model was created similar to the scale experiments already performed, and the results were compared to the captured experimental data. This is considered to be the benchmarking phase. The predictions of the design program also compared well with the experimental data captured (refer: section 8.). Having gone through this process of calibrating the FEA, it could be accepted that the Finite Element Model (FEM), was delivering sound information. The correlation between the FEM and the experimentally recorded data was between 75%-99% (refer: section 8.). This is an acceptable degree of accuracy considering the finite element program only delivers a velocity output, which had to be filtered and differentiated to obtain an acceleration figure. Some degree of inaccuracy would this be expected.

The restrictions of the experimental model mentioned in the above paragraph, could thus be changed and tested in the FEM, where space and velocity have no limits. The simulation can be performed, and the output can be used as a reference or yardstick, since the quality of the FEM predication has been established as being of an acceptable standard, allowing for the design program to be further explored and quantified.

Various possible real life conditions have been simulated by means of the FEM. The outputs of the simulated conditions were compared to the output of the design program to determine the deviation of the prediction from the true conditions obtained from the FEM (refer: section 8).

1.4 Conclusion

This dissertation describes the development and testing of a reliable design tool, in the form of mathematical code, which predicts the performance of the dynamic strain energy converting deceleration system under various dynamic conditions, and in various forms. This project is thus an extension of the preceding SIMRAC project, GAP638 [1], which investigated the possibility of utilising the proposed deceleration system for application in the mining industry.