5. Mathematical Code Evaluation Design Program

5.1 Introduction

A common characteristic, which can be identified in most approximation programs, is the need for a realistically estimated input of the workable solution by the user. The hindrance is usually that the user has no idea of what the expected solution's parameters are going to be, thus has no starting point from which the simulation program can work. For this reason the author decided to use two versions of a prediction program. The first version is spreadsheet based, and has all the permissible ratios of geometry inserted in envelope form (*limit<X<limit*), for the user to simply check whether the chosen values are of correct proportion. This version produces an appropriate force, based on a simplistic calculation, ignoring the change in speed of the mass during the retardation process. The second version of the simulation program, which is MATLAB code based, is then fed the result of the first version, which would be a reasonable estimation of the final outcomes proportion. The second version of the program then delivers an accurate approximation, based on realistic scenario estimations, allowing for the change in speed during the deceleration process.

There are two basic differences between the two versions of the prediction programs. The first difference is the taking into account of the effect which the changing in speed of the mass or conveyance during the retardation process has on the system. In the first spreadsheet version the assumption is made that the deformation rate remains constant throughout the process of deceleration, which is clearly incorrect. This assumption however produces a valuable estimation of the scale of parameters to be expected. The second version of the program, which is automated code executing in MATLAB version 5.3 for students, takes into account the effect of diminishing speed during the retardation process. This diminishing speed greatly affects the performance of the retardation process, causing a transition from dynamic to quasi-static performance. The gradual decrease in arresting force with the decrease in speed is witnessed in the practical experiments, the FEA as well as the analytical program's prediction. This will be mentioned again in chapter 7, where the comparisons between all three methods, namely experiments, FEA and computer generated analytical prediction, are compared.

The second difference is the program's ability to account for the effect of the taper section of the strip, mentioned in section 1.2 (refer: Figure 1). The spreadsheet version of the program cannot account for this and thus assumes a parallel section. The resulting answer, based upon this assumption, is used as the maximum width for the taper in the MATLAB version of the program. The thin section of the strip is determined by calculating the factor of safety upon yielding when subjected to the maximum deceleration force and ensuring that this safety factor is no less than six, which is the acceptable amount based on the Occupational Health and Safety Act and Regulations [21]. The Act is applicable to ropes and cables. In this application the strip could be classified as a structural element, which then requires a design factor of a magnitude consistent with "good engineering practice", which would not need to be as large as the factor required for the ropes and cables. The higher factor specification is still maintained and applied, for total peace of mind.

Through the experimental phase of the project it has been found that the length of this taper section, generally required to fulfil the task of deceleration is between 5 and 10 times the difference in taper width. This implies that a taper of 10mm to 40mm would generally be applied between 150mm and 300mm, as illustrated in Figure 17, depending on the deceleration space available and whether or not the deceleration limit is of application concern. The deceleration magnitude is influenced by the profile of the strip, and can thus be adapted according to specific requirements.

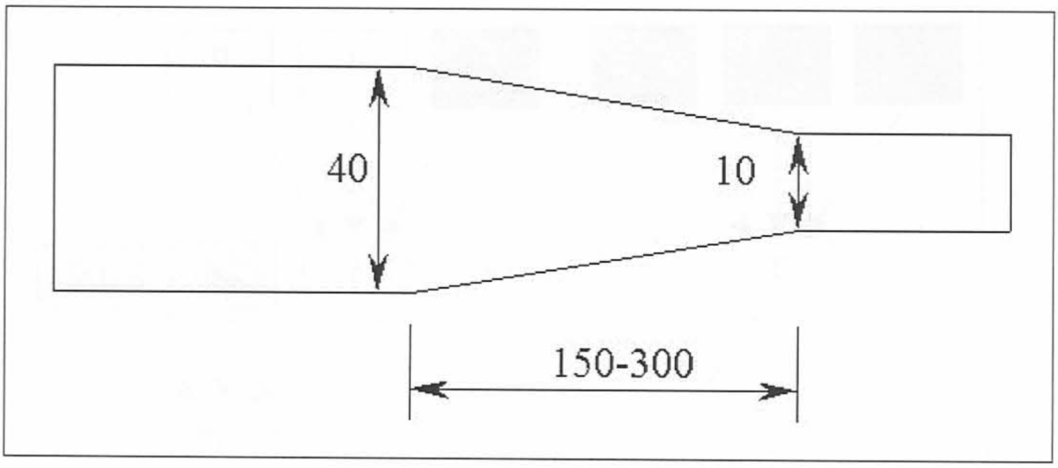

Figure 17 Schematic profile of a typical deceleration strip.

5.1.1 First version of prediction program

The flow diagram Figure 18 illustrates the method of execution of the spreadsheet version prediction program. This illustrated process is converted into the examples shown in Table 3 and Table 4. The selection choices and implications thereof are discussed in the following text, with reference to the shown example.

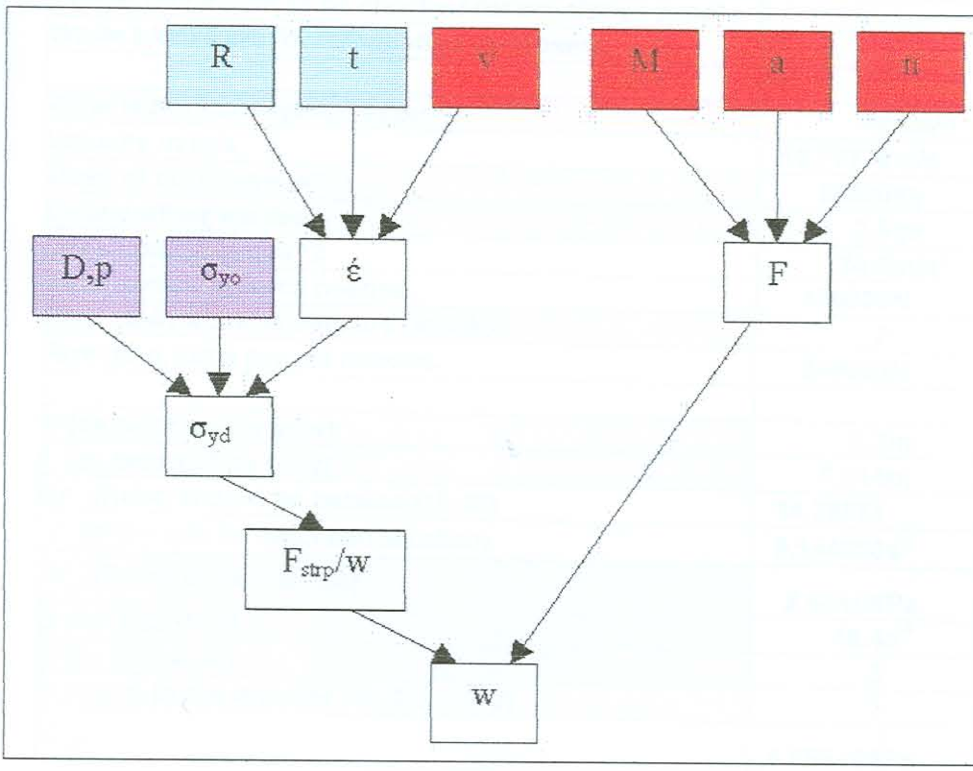

Figure 18 Flow chart of spread sheet program.

Design Process.	
Red blocks are the design variables for the user to specify, based on expected scenario!!	
Blue blocks are the arrester design variables for the user to specify!	
Purple blocks are the material variables!	
Yellow blocks are to be checked for envelopes spec!	
White blocks are for information purposes!	
What is the conveyance speed?	46km/h
Velocity in m/s	12.77778m/s
Mass of conveyance?	20000kg
Deceleration wanted!	2.5gs
Deceleration in m/s^2	24.5m/s^2
Total arresting force needed.	490000N
How many arrester sets are needed?	2
Arresting force per set needed.	245000N
R (as selected by user)	0.2m
t (as selected by user)	0.014m
R/t (Ratio should be between15-25)	14.28571
ε' (strain rate for described situation)	5.144033s^{-1}
σ_{yd} (Dynamic yield stress)	2.8E+08Pa
D (for mild steel)	40.4s^{-1}
p (for mild steel)	5
n rollers in the arrester set (Usually 3)	3
σ_{yd}	4.65E+08Pa

Table 3 User input variables for spread sheet prediction program.

Table 3 illustrates the actual view of the spread sheet, set up to guide the user to a reasonable base decision. The user describing the problem scenario to which the deceleration systems are to be applied, fills in the red blocks. Following that, the two blue blocks referring to the radius of the roller and the thickness of the strip are chosen. This is done in such a way that the R/t ratio is within the ranges specified. This ratio controls the geometric aspect in terms of having a thick strip bending around a small radius and thus creating the opportunity for extremely high strain rates or surface tearing due to excessive surface straining (refer: section 4.2). The information block indicating strain rate (ε') is for the current application at the points of bending, and is the solution of Equation 5. The purple blocks allow for the material characteristics of the material chosen for the strip. The variables (D) and (p) are the specific strain rate sensitive qualities of 300W mild steel. These variables allow for the evaluation of Equation 6, which is the magnitude of the dynamic yield stress (σ_{yd}) of the material.

Fstrpdyn/w (Model 4, Alexander)	763501.7	N/m	
w	0.32089	m	(Arresting force needed/Fstrpdyn/m)
w/t (Should be 15-25)	22.92071		
Fstrpdyn/w (Model 1, Rosslee Bending)	661211.9	N/m	
w	0.370532	m	(Arresting force needed/Fstrpdyn/m)
w/t (Check for ratio 15-25)	26.46655		
Fstrpdyn/w (Model 2, Rosslee Energy)	763322.4	N/m	
w	0.320965	m	(Arresting force needed/Fstrpdyn/m)
w/t (Should be 15-25)	22.92609		
Fstrpdyn/w (Model 3, Mamalis and Johnson)	661022.8	N/m	
w	0.370638	m	(Arresting force needed/Fstrpdyn/m)
w/t (Should be 15-25)	26.47413		

Table 4 Second part of spreadsheet program.

Table 4 summarises the force prediction results produced by the deceleration systems specified by the user in this example. The four models which have been adapted and selected for dynamic prediction, as described in section 4.3.2, have been utilised. The dynamic force per strip width indicator, (Fstrpdyn/w) describes the force per unit width (N/m). This is a convenient result, since when planning to retard a moving mass (M) at a specific rate (g), the magnitude of required force is then F = Mg. This is the combined deceleration force required, and is divided between the number of arrestor sets, of which there are two in this case. If the required deceleration force is divided by the force per unit width capability of the strip, the remaining value is the width of strip required to retard the mass at the desired deceleration rate. This describes the method followed to arrive at the strip width (w). The width over thickness ratio (w/t) is again a geometrical constraint check, prohibiting the development of a situation where the strip is paper thin and many meters wide or vice versa, narrow and extremely thick. The limits set are guide lines to be considered by the user. To change the ratio, the thickness of the strip must be altered, influencing the R/t ratio, which should also be evaluated again for position in the prescribed envelope.

The following figures depict the relationship between three fundamental variables of the deceleration systems, namely the roller radius (R), the strip thickness (t), and the resulting predicted retarding force the system would deliver, relative to the width of the strip (w).

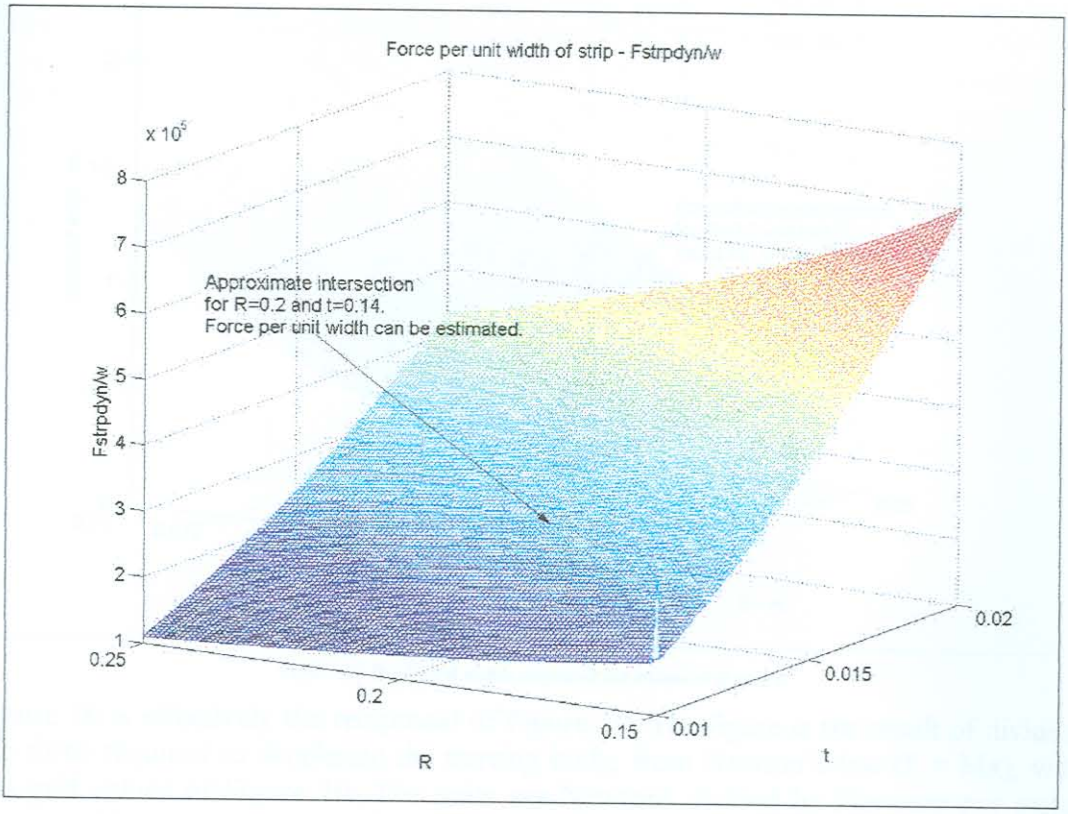

Figure 19 Predicted force per unit width for ratios of R and t.

With reference to Figure 19, the predicted performance of the strip and roller deceleration systems follows a logical trend. The vertical axis recording $F_{strpdyn}/w$, which is the retarding force per unit width of the strip, increases to the corner where the roller radius decreases and the strip thickness increases. This is a logical trend since a sharper angle, or smaller roller radius, will increase the force required to draw the strip over the roller. The effect of a thicker section of material having a larger resistance to bending than a thin section also follows logic. This would lead to the conclusion that the position of the peak for the expected maximum force per unit width is correct.

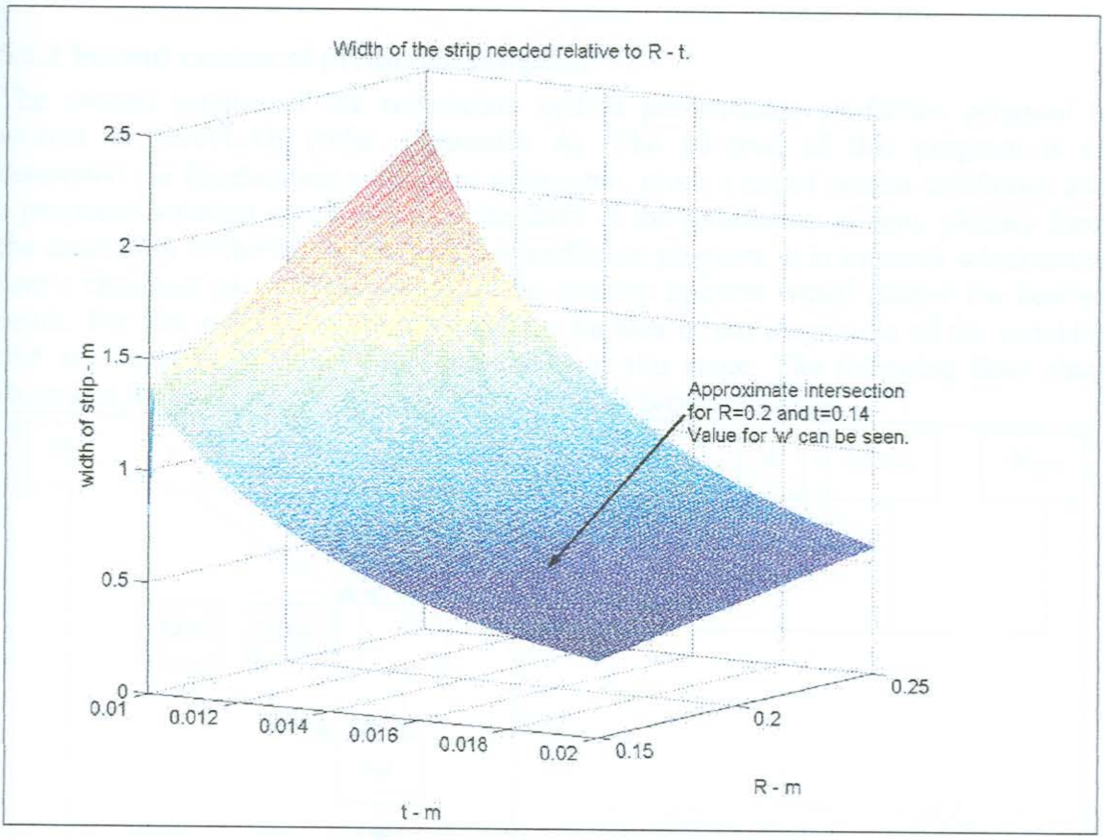

Figure 20 Predicted width required for ratios of R and t.

Figure 20 is effectively the reciprocal of Figure 19. The figure is the result of dividing the force required to decelerate the moving body, from Newton's law (F = Ma), with the grid values of Figure 19. The units are Newtons divided by Newtons per meter thus resulting in meters, which is the width of the strip required to decelerate the moving mass (M) moving at a velocity (v), at a specific deceleration rate (g). The strip width (w) is displayed on the vertical axis, relative to the roller radius (R) and strip thickness (t) on the horizontal axes. Similar to Figure 19, the displayed graphical result of Figure 20 is a logical conclusion. The width of strip needed to decelerate the mass reaches a maximum where the thickness of the strip (t) is the least, and the roller radius (R) is the largest. In this position the thin strip has a large bending radius and would have the minimum resulting resistive force, thus requiring a wide section to accommodate the required deceleration.

5.1.2 Second version of prediction program

The second version of the retardation system performance prediction program is written in MATLAB (refer: Appendix A). The purpose of this program is to determine the deceleration conditions achievable, given a set of system conditions and a proposed solution specification in the form of the retardation system, gleaned from the estimation of the first version of the prediction program. It is to verify whether the user's choice of geometrical values of the arrestor systems would deliver the desired result. For this reason the user should have an idea of the magnitude of the variables that are expected to fulfil the requirements at this stage. The following flow chart illustrates the route of execution of the MATLAB program's code.

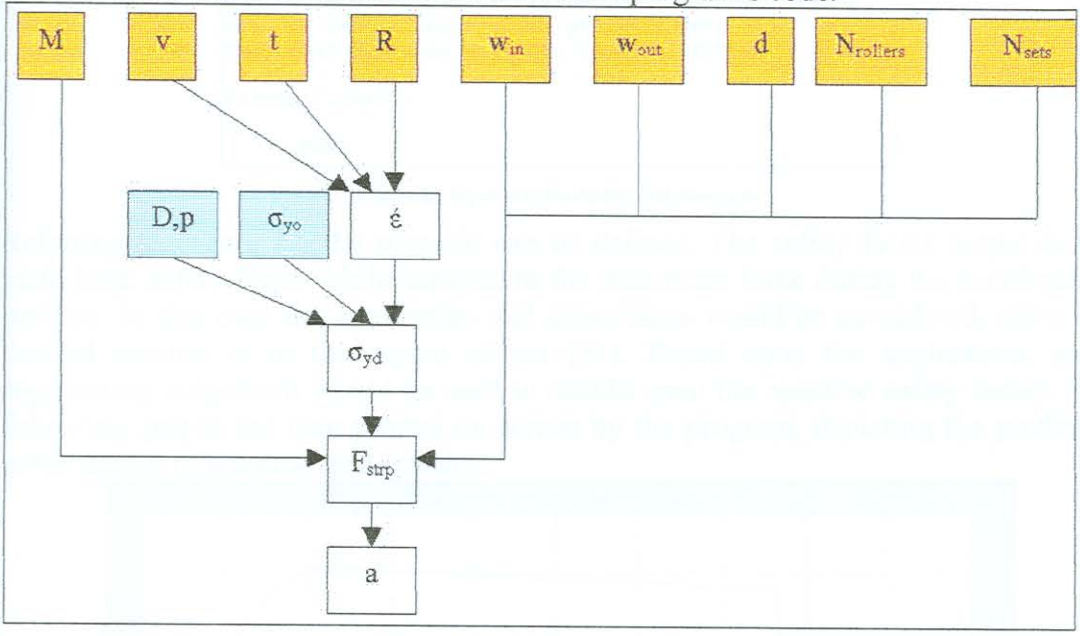

Figure 21 Flow chart of the Matlab program.

When comparing the two flow diagrams Figure 18 and Figure 21, the difference between the first and second versions of the prediction program is evident. Referring to Figure 18, the outcome of the first version can be seen to be a geometrical output, namely the width of the strip and in Figure 21 the result can be seen to be a performance parameter, namely acceleration. In the second version prediction program certain geometrical variables are entered by the user: the strip thickness (t) roller radius (R), the widths of the taper and the distance over which it occurs, as well as the number of rollers in the arrestor set ($N_{rollers}$) and the number of arrestor sets themselves (N_{sets}). The final outcome is then the resulting deceleration of the mass or conveyance, and all the other parameters can also be determined such as distance travelled during the retardation process and the velocity profile. These results can be scrutinised to see whether the chosen set-up conforms to the desired deceleration requirements. The entire process is discussed in the following section.

The effect of guide rail friction in the system is also accommodated in the MATLAB code. During experimentation it has been noted that a maximum of 0.8Gs is reached during free-fall and is thus defined as such in the MATLAB program (refer: section 8.1.1).

5.1.2.1 Second version prediction program output

An example of the MATLAB program is shown in Figure 22. The same values used in the first version of the prediction program will be used here for comparison purposes in order to demonstrate how the two programs are to be used as a combination.

```
>> case2
What is the mass of the conveyance? kg - 20000
How many roller sets are needed? - 2
How many rollers in each set ?  - 3
Speed of conveyance, at impact? km/h - 46
Enter the choice of roller radius. m - 0.2
Enter the choice of strip thickness. m - 0.014
What is the thinnest width of the taper? m  - 0.22
What is the thickest width of the taper? m  -  0.37
Over what distance does the taper occur? m  -  1.5

Safety_Factor =

    4.8422
```

Figure 22 Input text for MATLAB program.

Referring to Figure 22, the scenario can be defined. The safety factor output is the yield limit safety factor while exposed to the maximum force during the deceleration process. In this case the application and importance would be considered, since the desired amount is in the region of six [21]. Based upon the application, good engineering judgement would be used to decide upon the required safety factor. The following graphs are then printed on screen by the program, depicting the predicted performance of the proposed system.

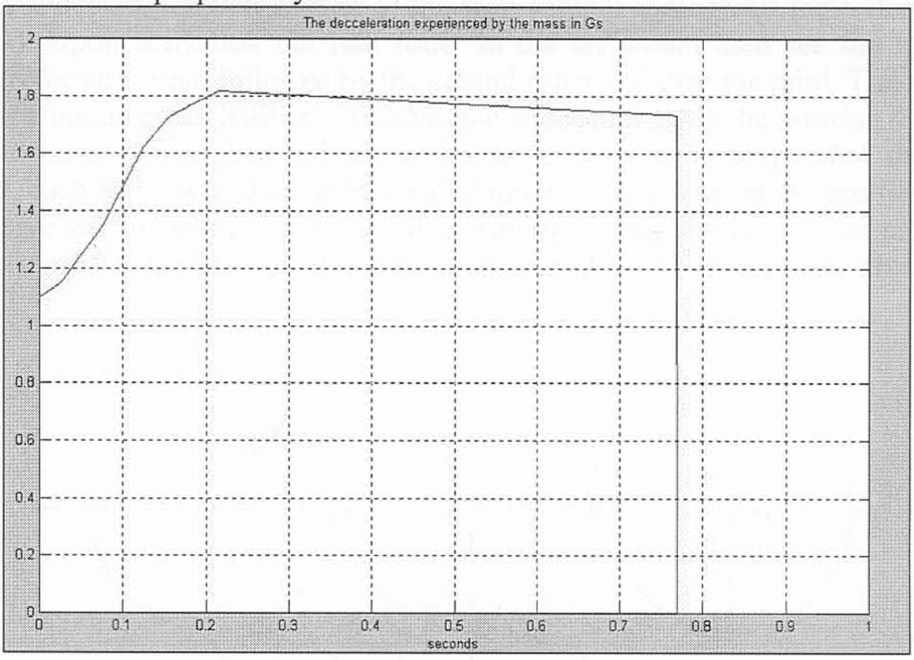

Figure 23 Predicted deceleration of the mass/conveyance.

In Figure 23 the diminishing deceleration effect can clearly be seen. This effect is due to the strain rate decreasing during the slower deformation of the material as the mass is retarded. From this the influence of strain rate on the system's performance can be identified. This phenomenon will be compared again to the experimental results in chapter 8. The predicted deceleration level is less than that predicted by the spread sheet version of the program (refer: Table 3). The discrepancy is due to the slowing of the mass or conveyance during the transition on the taper section of the strip. By the time the main section is reached, considerable speed has been lost (refer: Figure 27).

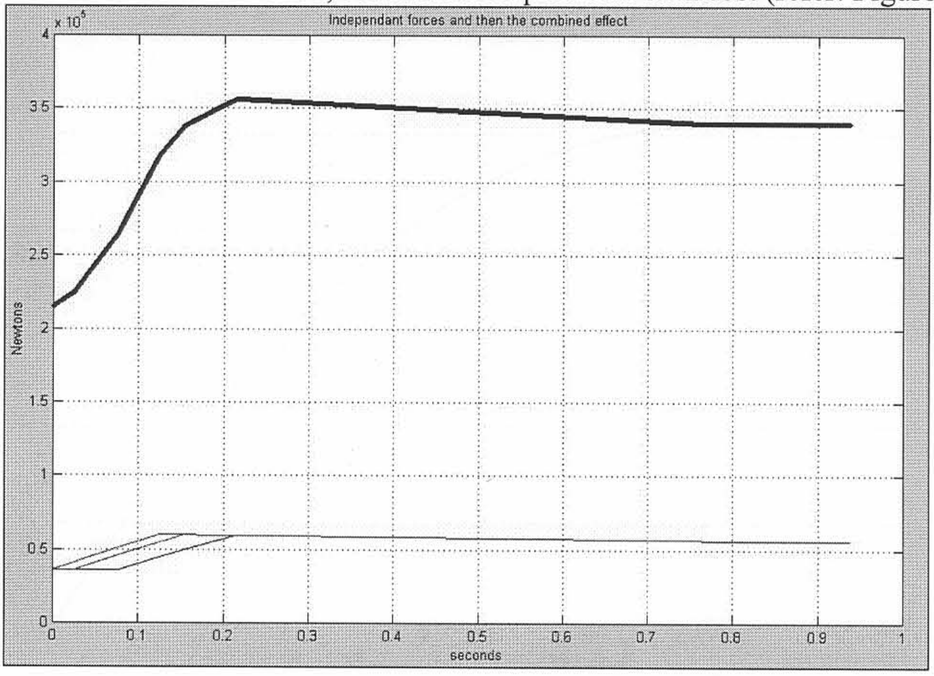

Figure 24 Predicted force delivery from rollers.

Figure 24 shows the force components applied to the mass or conveyance by the individual rollers and then the roller set as a unit. Initially, before the arresting device has been activated, the thin section of the strip extends through all the rollers (refer: Figure 1). Upon activation the first roller in the set would then see the widening section of the strip first, followed by the second roller and then the third. The resistive force contribution of each roller is thus unique, depending upon the position in the set. Once the taper section has left the roller set entirely and the parallel section is threaded, each roller would contribute equal force. For this reason the position of the strip's taper has to be tracked in the programming, during the retardation process to accurately predict the individual contribution of each roller to the total deceleration force.

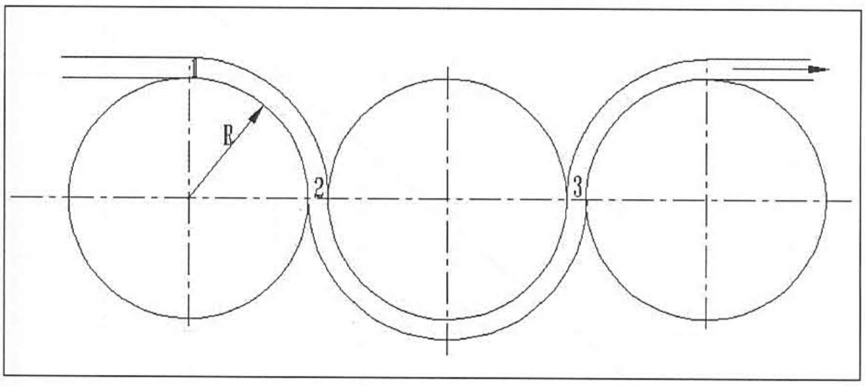

Figure 25 Bending positions of strip element.

In Figure 25 the bending positions of the strip can be seen. Position 1 and 2 can be seen to be only 90° apart, and then position 2 and 3 are separated by 180°. The individual roller force contribution shown in Figure 24 confirm this, since the interval between the increase in force of roller 1 and roller 2, is half the duration of the interval between roller 2 and roller 3. The bold blue line shows the sum total of the resistive force created by the arrestor set. The initial input can be seen to be gradual which is favourable when decelerating living cargo, for any application.

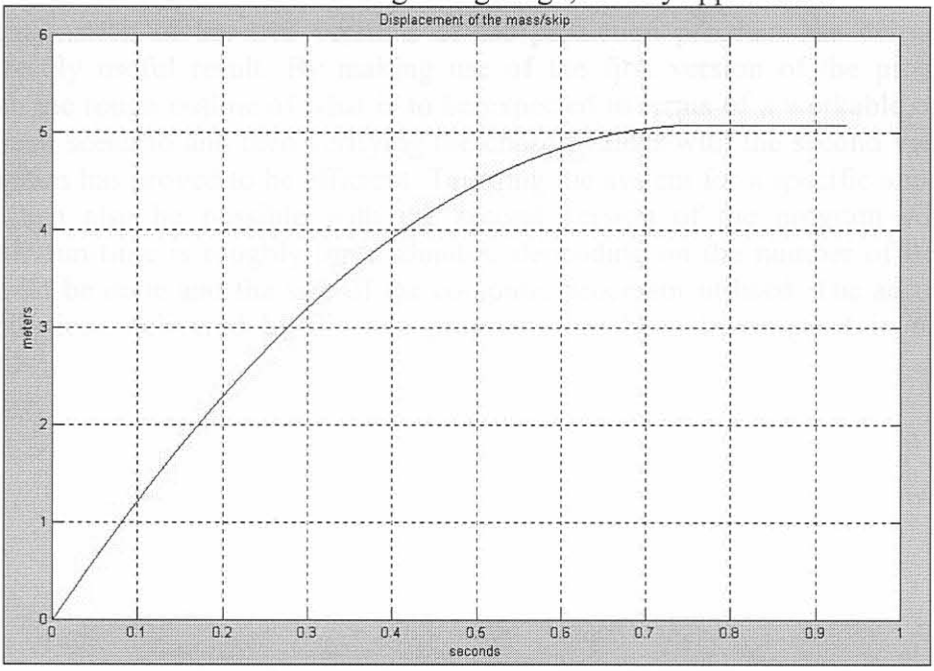

Figure 26 Predicted displacement of mass or conveyance.

In Figure 26 the projected distance travelled by the mass or conveyance during the deceleration can be seen. From Figure 24, the taper takes approximately 0.15 seconds to travel through all three rollers and the corresponding displacement is 1.5 meters which is the specified taper length (refer: Figure 22).

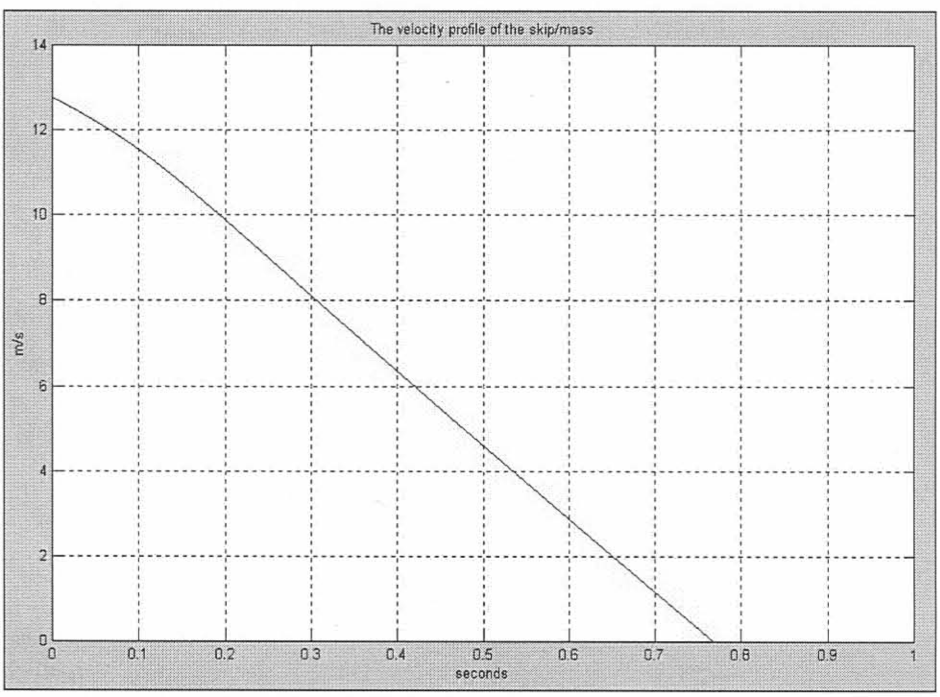

Figure 27 Predicted velocity profile of mass/conveyance.

Figure 27 projects the velocity profile of the mass or conveyance during the retardation process. The taper section takes roughly 0.15 seconds to move past all three rollers, by which time 2m/s or 15% of the initial velocity has already been decelerated.

5.2 Conclusion

The combination of the two versions of the prediction program has delivered an operationally useful result. By making use of the first version of the program to establish the rough outline of what is to be expected in terms of a workable outcome for a given scenario and then verifying the chosen values with the second version of the program has proved to be efficient. Tailoring the system for a specific application would then also be possible with the second version of the program since the computer run-time is roughly three minutes, depending on the number of iterations that would be done and the size of the computer processor utilised. The accuracy of the predictions delivered by the two programs has been investigated in detail in chapter 8.