DESIGN OF ELASTOMER BASED SHOCK ABSORBER SYSTEM FOR TRANSVERSE DIRECTION

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By

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CANDIDATE DECLARATION

This is to certify that the work carried out in this project report entitled **"DESIGN OF ELASTOMER BASED SHOCK ABSORBER SYSTEM FOR TRANSVERSE DIRECTION"** is presented on behalf of partial fulfilment of the requirements for the award of degree of Master of Technology in Machine Design Engineering and submitted in the Department of Mechanical and Industrial Engineering of the Indian Institute of Technology Roorkee, Roorkee , India, is an authentic record of Dissertation work carried out during a period from August, 2017 to May, 2019 under the supervision of Dr. ANIL KUMAR, Assistant Professor, Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee, India.

I have not submitted the record embodied in this dissertation for the award of any other degree or diploma in any other institute.

(AMIT KUMAR, 17539001)

CERTIFICATE

This is to certify that the above statement made by candidate is correct to the best of my knowledge and belief.

Date: May 9, 2019

Place: IIT Roorkee, Roorkee

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ABSTRACT

Elastomer based shock absorber is designed to absorb shock load due to pressure wave generated when there is underwater explosion near a naval vessel to save the sensitive articles stored in the naval vessel. Modeling an elastomer is really a cumbersome process because of its non-linear nature. Different models were studied to model elastomer material used in our study for this problem. Curve fittings with different models on experimental data were studied to select the best model from different models available in the literature.

In this problem there are three parts namely canister (inside container), container (outer part) and elastomer (filled in between container and canister). Modeling and finite element analysis using Abaqus software was done for this problem in which the whole model was divided into small elements and mesh convergence was done so that our result is independent of our mesh size or number of element. This was done by increasing the number of elements to improve accuracy of analysis but this increases the calculation time and memory used as well so, optimization was done.

Natural rubber, Chloroprene rubber, Hydrogenated nitrile butadiene rubber (HNBR), Neoprene and Santoprene rubber materials were used. Elastomer shock absorber of 110 mm thickness was used in between the canister and container and various analysis were done by changing material, position and number of elastomer and found results for shock load transmitted to the canister (when we apply shock load to container), stress induced in elastomer, velocity response and maximum displacement of the elastomer. Result from various materials has also been optimized by showing trade-off between two constrains (acceleration and displacement). Moreover, it is found that elastomer is one of the preferred choice in the shock absorption of sensitive articles. Small insight of wire rope isolators and high energy rope mounts is also given.

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CHAPTER 1

INTRODUCTION

1.1 General

Shock load is the term used to describe the sudden force exerted when an object suddenly accelerates or decelerates and due to that there can be severe damage to objects subjected to it. Due to shock load vibrations can be induced in the system and any motion that repeats itself after a very small interval of time or high frequency oscillation is called vibration. This vibration can be desirable in many cases like music instruments, loudspeaker, mobile phones etc. but in many cases this vibration is really undesirable, creating undesirable sounds, destructive for sensitive articles and wasting a lot of energy. Most prime movers have vibration problems due to the inherent unbalance in the engines. The wheels of some locomotives can rise more than a centimeter off the track at high speeds due to imbalance. In turbines, vibrations cause spectacular mechanical failures. Most of the heavy duty Machines are subjected to vibration when they are in running state and due to these vibrations these machines can fail. Also there will be excessive wear and tear of the component due to fatigue loading condition.

Similarly in case of naval ships, sometimes blast happens in the vicinity of the ship and due to this blast, pressure waves get generated inside the water that strike to the ship. Due to this, ship gets very high acceleration for very less time (in milliseconds). This shock load can damage many sensitive articles stored on the vessel like articles in the canister which is situated inside the container. Our study is focused to attenuation the impact of this load so that sensitive article can be saved from the shock load in transverse direction. This shock can cause severe damage to sensitive articles. So, there can be severe damage to the sensitive articles if proper design of a system to attenuate this acceleration is not done.

There may be different ways to attenuate this shock but here we restrict our study to use of elastomer based shock absorption system. Here our aim is to do finite element analysis for such shock absorber and to design by varying number of elastomers, material, position and size of the elastomer.

Elastomers behave non-linearly under the applied load, i.e. Young's modulus of an elastomer changes with the applied strain. So, to represent this in analysis for different modes of deformation there are many models. Implementation of best suitable model is must otherwise our analysis may go absurd. Uni-axial, bi-axial, shear and volumetric test data of material are required to represent any hyperelastic behaviour and stress relaxation test data is required to represent the viscoelastic behaviour of material into any finite element analysis software like Ansys and Abaqus

1.2 Problem statement: Shock Absorber System

1.2.1 Objective

Design of Elastomer based shock absorber system for transverse direction.

1.2.2 System Description

As shown in figure below the sensitive article would be mounted inside container in this system, the sensitive article/instrumentation mounted on the naval vessel has to be protected from shock loads arising due to underwater explosion in the vicinity of vessel.

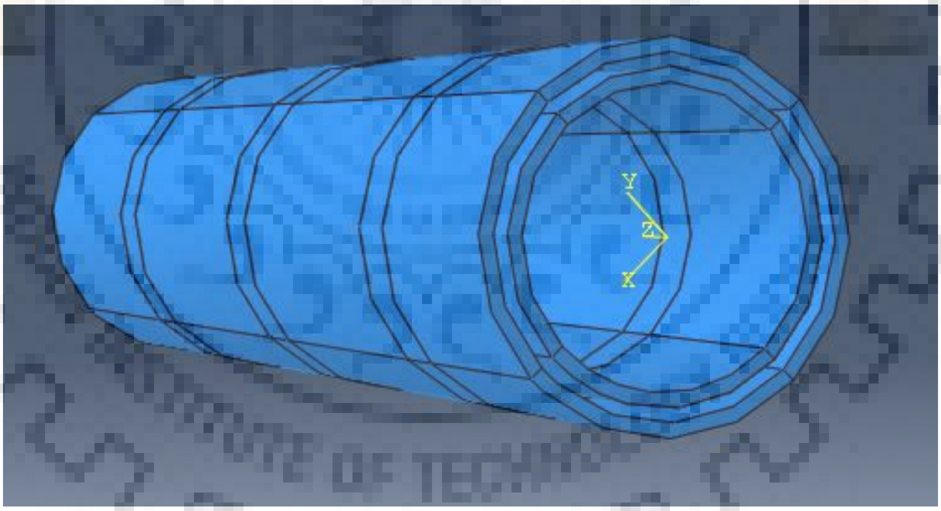


Figure 1.1: Canister inside container assembly

Our motive is to make canister (inner part) safe from the underwater explosion because article is to be mounted inside this canister only which is situated inside the container with radial gap of 110mm. we need to do this job using elastomer which is to be fitting inside this gap and shock to be absorbed by this elastomer.

Canister dimensions: inner diameter and outer diameter are 2.34 m and 2.58 m respectively, length is 13.2 m and having mass of 95 ton.

Container dimensions: inner and outer diameter is 2.8 m and 3.04 m respectively, length is 14m.

1.3 Design inputs

1. Suspended mass of article is 95+/- 3 ton. Design shall be capable of tuning for variation in suspended mass.
2. Shock load data given is as below:

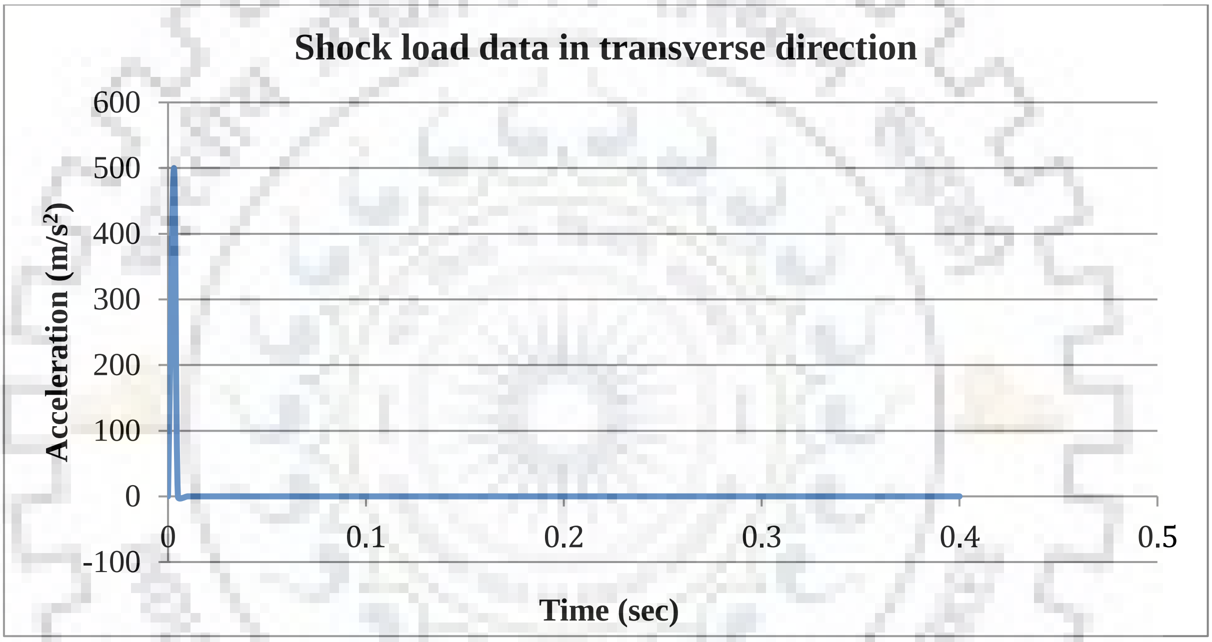


Figure 1.2: Shock load data in transverse direction.

Peak value is 50g (Assumed g = 10 m/s^2)

1.4 Design constraints

The allowable limit of maximum acceleration at the payload is 2g in transverse direction.

1. Maximum allowable displacement is +/- 10 mm for given shock load.
2. The available radial gap is 110 mm. Elastomer shock absorption system shall be designed to accommodate in available gap.

It is clear from the problem that we are not concerned with the deformation in container and canister. So, we can consider them as rigid bodies for our finite element analysis. Here we used Ansys and Abaqus for analysis of this problem.

For this analysis we used neoprene material from Ansys material library and to define a hyperelastic material for analysis, we need to have uni-axial, bi-axial, shear and volumetric test data and then we apply hyperelastic model to represent this experimental behavior in the analysis. For curve fittings we used Ansys and abaqus both and for analysis of this problem, we used Abaqus because in Ansys we are not able to give acceleration boundary condition to individual bodies but this can be given in Abaqus.

1.5 Assumptions to simplify our analysis

1. Deformation in container and canister are not considered. So, these parts are made rigid in our analysis.
2. Behaviour of elastomer is considered to be same throughout the analysis and effect of temperature change on properties of elastomer is not considered.

CHAPTER 2

ELASTOMER

2.1 Introduction to elastomeric materials

Elastomer refers to large variety of synthesized polymers and natural rubber. Elastomers can sustain very large deformation with elasticity that is called hyperelasticity. Also the loading and unloading curve for these materials is different and makes hysteresis which in turn dissipates energy in form of heat and this property is viscoelasticity. In any finite element analysis, hyperelasticity can be incorporated with uni-axial, bi-axial, planar and volumetric test data. And viscoelasticity can be incorporated by creep test data and stress relaxation test data.

Dynamic property of these elastomers is a function of many factors like temperature, strain rate, frequency and preload etc. Other than these factors, there are some environmental factors which affect the working of elastomers like exposure to oil or other fluids, aging etc

Reduction in vibration transmitted or shock transmitted can be either isolation or insulation. When we reduce vibrations being transmitted from any machine to the surroundings, it is called "isolation" and when we reduce vibrations from environment to machine component, it is called "insulation".

Other than this, elastomer dampers have many advantages like these are easy to design, assemble, maintain and these are inexpensive as compared to other dampers. Elastomer dampers are very easy to handle, durable to rough handling and because there is no fluid in it, so there is no leakage problem.

With elastomers there is one problem that these materials dissipate less energy or give less damping at high frequency which is not desirable. And environmental effect can be reduced by proper choice of the elastomer material.

One of the most popular is shear damping by elastomers, in which elastomer layer is added in between two rigid materials and this layer dissipates energy and reduces the vibration or shock being transmitted to the other layer. Currently, elastomer dampers enjoy broad use for control of unidirectional vibrations [1].

The natives of South America got the idea to exploit the latex of the Hevea Brasiliensis rubber tree to produce waterproof footwear, among other products from soaking their feet in the liquid, latex, tapped from the tree. From the Indian word "caa-o-chu" (a weeping tree) are derived the words caoutchouc in English and French, Kautschuk in German, caucho in Spanish and caucciù in Italian. The word rubber originates from the early applications of rubber, i.e. from the property of caoutchouc to rub out pencil writing [1].

In the 18th century, when rubber appeared in Europe, it was used for the fabrication of suspenders and straps. Different kinds of materials were impregnated with rubber to make them waterproof. However, the performance of the rubber articles was quite poor, because rubber was at that time still gummy and fluctuation in temperature caused great changes in products. It was only in the year 1839 that Charles Goodyear discovered nearly by accident the vulcanization of rubber, which made rubber as an elastic material capable of preserving its characteristics over a wide temperature range.

An elastomer is a polymer with hyperelastic nature which means it is not strain rate dependent (viscoelasticity is strain rate dependent and this can be modeled by spring and dashpot in which dashpot is used to show the time dependent behavior) and very weak intermolecular forces, generally having low Young's modulus (E~3MPa) [2] and high failure strain compared with other materials. Elastomers have wide range of application in vibration dissipation due to its capacity of being largely deformed and dissipating energy in form of heat energy.

2.2 Stress relaxation of elastomer

When a constant strain is maintained over a time, then Material experience a initial (maximum) stress and as we keep the strain constant and strain rate is not there. Stress undergoes a gradual reduction to an equilibrium value this characteristic as shown in figure 2.1.

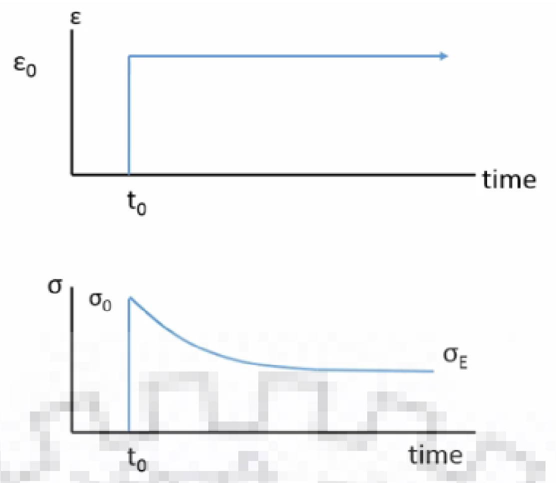


Figure 2.1: Stress relaxation in elastomer [3]

2.3 Non linear behaviour and hysteresis

Non linear behaviour and hysteresis of elastomer or stress strain curve of elastomer is shown in figure 2.2. The area between the load and unload curves represents the hysteresis, which is directly proportional to the damping. As we can see from figure 2.2 loading and unloading curve are different and the area in between these loading and unloading curve represent the energy being dissipated in terms of heat. More the area between loading and unloading curve, more will be the energy dissipated in form of heat.

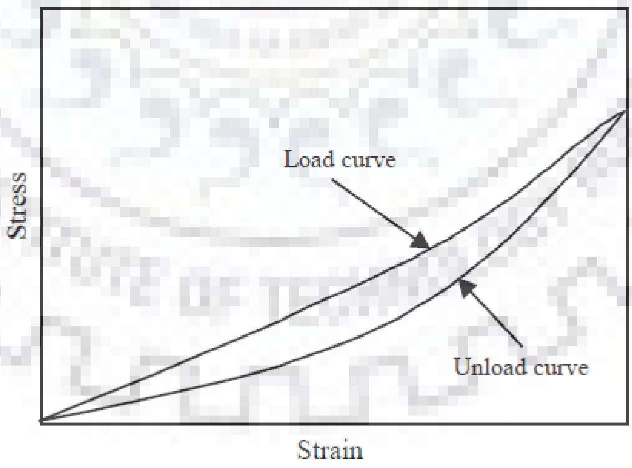


Figure 2.2: Stress- strain curve of elastomer isolator [3]

CHAPTER 3

LITERATURE REVIEW

Elastomer is having rate-independent nonlinear elastic behaviour. Under cyclic load, it shows some other inelastic effects like hysteresis, residual strain and stress relaxation [3]. So, while modeling the hyperelastic materials like elastomer, the most important thing is that the hyperelastic model that we are going to implement in our problem must be capable of considering these effects as well to get the stress strain relationship at different mode of deformations in the material**.**

These models expressed in terms of strain energy density function, i.e. (W). Before finding the functions, it is assumed that the elastomer recovers its initial state completely and W is not dependent on the history of loading but depends only upon the final state of the strain, such a model represents essentially a response that is rate independent and such model works as the main part for a general model that represents other inelastic effects as well [4].

Elastomers fall into the class of highly deformable solids exhibiting large deformation under a comparatively small load. When a solid body is subjected to a large deformation, the relationship of positions in deformed and undeformed configurations is described by a deformation gradient tensor F and $\lambda_1, \lambda_2, \lambda_3$ are stretches in three principal directions where

$$\lambda = 1 + dL/L$$

Where, L is the undeformed length.

I_1, I_2, I_3 are three strain invariants. the strain energy density function W can be expressed in terms of strain invariants (based on the isotropic assumption) [5].

$$W = W(I_1, I_2, I_3)$$

We use some material constants or parameters to represent the behaviour of different materials with these strain invariants. As we know that elastomers are incompressible in nature i.e. change in volume for these materials is close to zero (dv = 0). So, the value of third strain invariant I_3 is unity (I_3=1). Due to this, strain energy density function (W) can be represented solely as a function of I_1 and I_2 [6].

As per the Valanis and Landel hypothesis**,** W can also be represented as a function of principle stretches i.e. λ_1, λ_2, λ_3 [7]. A very complex mathematical calculations are there in Treloar 1975 to show that these both approaches are same and strain energy density function (W) can be represented as a function of strain invariants and principal stretches as well [8].

For elastomer, state of stress is strongly dependent on the state of strain so, to find the strain energy density function (W) that represents the behaviour of material adequately, experiments are required to be done. Such a function will be able to predict the behaviour of elastomer at all the deformation modes that are possible. So, some models are based on strain invariants and some are based on the principal strain. And among the models that are strain invariants based, Mooney-Rivlin model is the oldest one. But this model is not able to predict the hardening behaviour of elastomer at large strain value that is why this model is not good for large strain values. After this, many other hyperelastic models came into existence that could capture the hardening effect of elastomer for large strain values [9].

In 1990, Yeoh noted that Mooney-Rivlin model cannot capture the simple shear deformations in elastomer and then he proposed a cubic function for W that was able to represent the tension and shear behaviour of elastomer as well and this was called Yeoh model. Most of the researches at that time were aimed at predicting the behaviour of elastomer and rubber at large strain values or large deformation but there was one more problem with these models to predict the behaviour of elastomer for small strain or deformation values [10, 11].

There are some models that are based on principal stretch other than the strain invariants like Ogden model and this model is able to represent the large strain behaviour under uni-axial and bi-axial behaviour, also this model predicts the shear load behaviour of the material [12].

While modeling the hyperelastic model, it is really difficult to find out the value of these parameters subjected to different modes of deformation. In modeling the behaviour of elastomers subjected to several deformation modes, a certain amount of ambiguity arises in identifying the parameters of a hyperelastic model. The parameters are generally estimated by using a curve-fitting technique. Hence, they are solely based on their fit to experimental data [13]. Over the years, different researchers have noted that the constitutive parameters of a hyperelasticity model determined from tests at a particular deformation mode are not valid for other modes. To solve this problem, earlier work examined the parameters identified from uniaxial tension, planar tension pure shear, and biaxial tension deformations. These deformations are solely involved in the diagonal elements F_{11}, F_{22}, and F_{33} of the deformation gradient tensor. Charlton et al. 1994 [14] mention that the parameters determined from uniaxial test data fail in predicting biaxial or planar tension pure shear responses. To resolve the problem, Gendy and Saleeb 2000 [15] proposed a nonlinear material parameter estimation scheme. The scheme used a differential form of the Ogden hyperelastic model along with a sensitivity analysis and an optimization procedure to obtain the parameters. The set of parameters determined with this approach by using uniaxial tension, biaxial tension, and planar tension pure shear were found to perform well in these deformation modes.

In order to identify the parameters of the proposed hyperelasticity model, the experimental data obtained in compression and shear regime were used along with a scheme involving the least-square method to minimize the residuals [6].

Elastomers respond nonlinearly to the amplitude of motion, frequency of motion, and temperature. Compared with conventional hydraulic dampers, elastomeric dampers are lighter in weight. Many researchers have focused on the analytical and empirical modeling of the nonlinear behaviour of elastomeric dampers. Recent developments in the area of material science have led to the development of very high loss factor elastomers. The design of elastomeric dampers is hindered by its complex behaviour. The need for accurate modeling of elastomeric materials was recognized early. All elastomers produce a damping output with a high degree of non-linearity. The output is essentially in-phase with the system stress. Elastomers are also subject to environmental degradation, due to age and chemical reagents [16].

Jia J H, Hua H X compared the performance of the elastomer damper and the hydraulic damper where the hydraulic damper shows the linear damping behaviour whereas the elastomer damper shows the non linear damping behaviour. In numerical simulation analysis the behavior of both the dampers was plotted for the unit impulse. The work performance of the elastomer damper is analyzed and compared both numerically and experimentally **[17]** with the hydraulic damper, in order to introduce the elastomer damper into piping protection to improve the safety reliability of Nuclear power plant. The numerical results show that the system with the elastomer damper can attenuate much more quickly than the system with the hydraulic damper. Moreover, the shock mitigation process of the elastomer damper is more smoothly and shorter than that of the hydraulic damper.

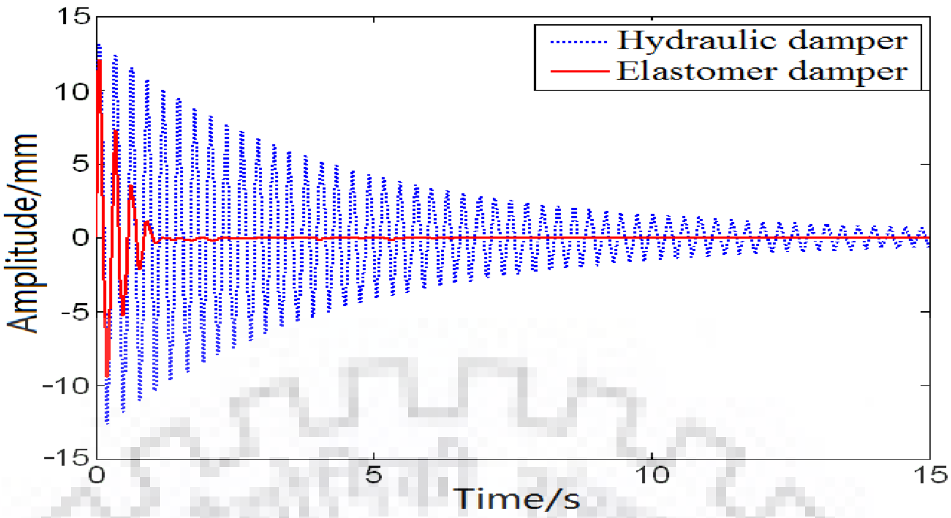


Figure 3.1: Response comparison of the SDOF system excited by a unit impulse [17]

M.K. Kim et. al. 2008 evaluated the effectiveness of a coil spring-viscous damper system as a vibration and seismic isolation system for an EDG (emergency diesel generator). The seismic effectiveness of a coil spring-viscous damper system was evaluated by seismic tests with a scaled model of a base-isolated EDG on a shaking table. The scaled model was designed to represent the seismic behavior of a prototype of an EDG set. The seismic responses of the base-isolated EDG model obtained by the shaking table tests showed that the spring-viscous damper system could reduce the seismic force transmitted to the EDG by up to 70 percent [18].

Vibration is a key factor to induce failure of the piping in nuclear power plants (NPPs). In order to keep the safety of important pipes, mechanical absorbers and hydraulic dampers are widely used. However, aging and leakage problems of the hydraulic oil happen frequently. And for the mechanical absorbers, the absorbing rate is too low. Therefore, improvement and replacement of the absorbers are becoming more and more important in keeping safety of NPPs [19]. In recent years, the elastomer damper can be effectively employed in order to achieve desired levels of passive control and absorb almost all of the disturbing energy, leaving the structure intact and ready for immediate use [17]. It has been successfully applied in transportation and military equipments [20, 21].

When the elastomer layer in between two rigid layers gets deformed, this attenuates the vibration and this is the shear damping

First publication in this are was by Oberst, he studied the bending vibrational effects of an elastic plate coated on one side with a layer of viscoelastic material [22]. Oberst found that not only is the damping of the composite structure dependent upon the loss factor of the viscoelastic material, but that damping is also dependent on the stiffness and thickness of the viscoelastic material.

Another pioneer in this field was Kerwin who is generally acknowledged as being first to provide an analysis of the shear damping mechanism of a constrained viscoelastic layer (constrained between the thin elastic constraining layer and the basic elastic structure). Kerwin [23] establishes a complex stiffness relationship, demonstrates that the neutral axis of the composite system is frequency dependent, and also demonstrates that the normal force in the viscoelastic layer may be neglected, since the magnitude of the modulus for the viscoelastic material is generally at least an order of magnitude smaller than the modulus of the elastis layers.

Many other authors have extended the state of analytical and experimental investigation to multilayered and other variations of the basic three-layered configuration. For example, Derby, Ruzicka, Schubert and Pepi [24, 25) have presented comprehensive experimental data relating to he viscoelastic shear damped characteristics of composite structures.

Reference 24 provides a review of the design equations including the governing design parameters for various shear damped configurations. Derby et a1 [24] also provides extensive experimental results for L-shaped, T-shaped, circular, tubular, and rectangular composite material cross-section beams. The iterative scheme for design implementation presented in [24] was improved upon by the latter publication [25] to provide a more direct utilization of design data.

An excellent review of the state of the act in viscoelastic structural damping is contained in the work of Nakra [26]. Recent application are provided in papers presented at a conferenczon viscoelastic damping [27]. Payne and Scott [28] discussed a number of geometric considerations for unidirectional loading, such as a compression specimen shape factor. They also provided a general design guide for elastomeric mounts.

CHAPTER 4

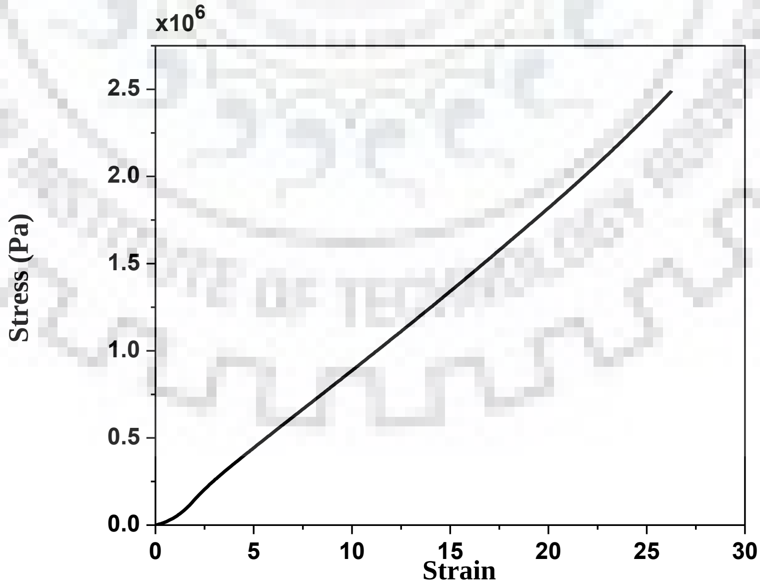
MATERIAL PROPERTIES

For our analysis we needed some materials that are suitable for heavy duty shock absorption system, so, we emailed to many companies and requested them to provide us with the hyperelastic and viscoelastic properties or the test data like uniaxial, biaxial, planar and stress relaxation test data and ultimately we got the required properties from Indian rubber manufacturing Indian Rubber Manufacturers Research Association (IRMRA), Ministry of Commerce & Industry, Govt. of India in form of test data.

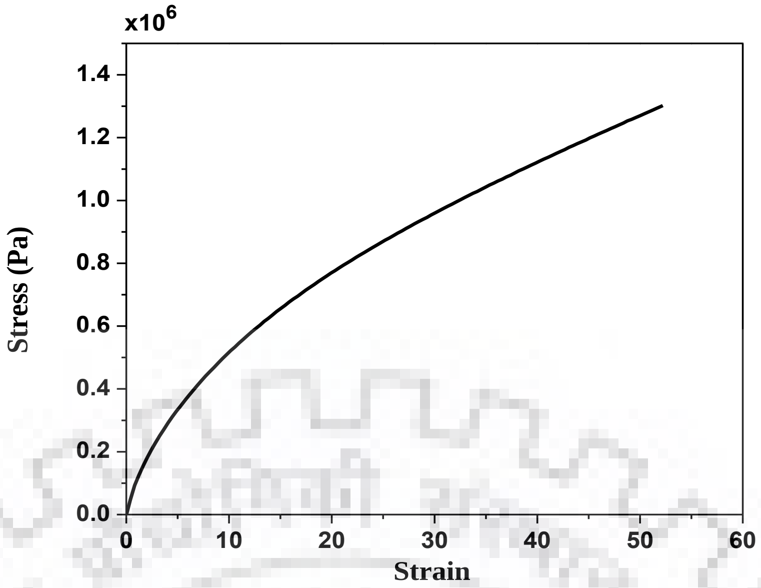
We are having test data for Natural rubber, Chloroprene rubber and Hydrogenated nitrile butadiene rubber (HNBR) [29] which are shown below in graphical form.

1. Natural rubber

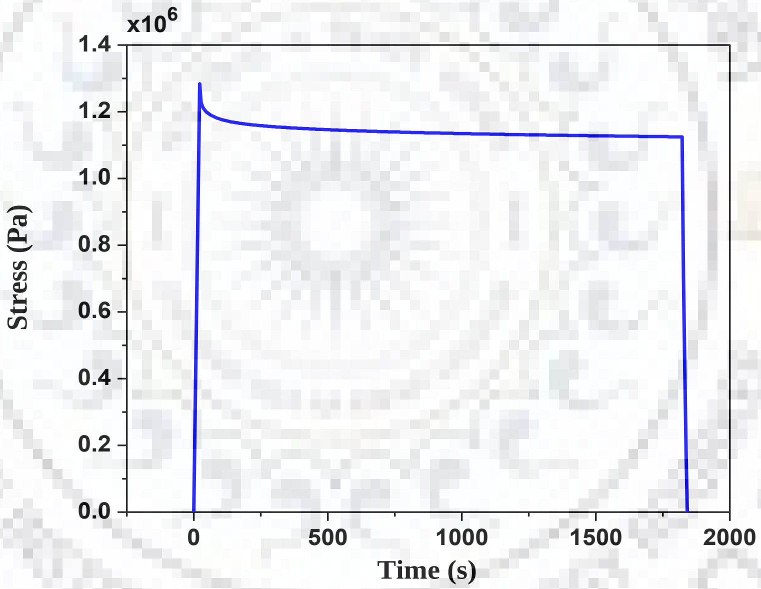
Uniaxial test data, planar test data, planar test data , stress relaxation test data and the hysteresis effect for natural rubber are shown below in the graphical form:



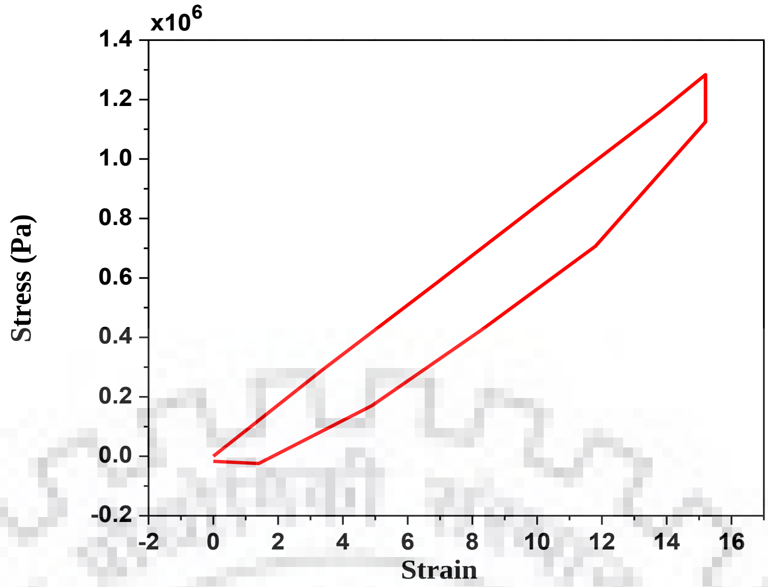
(a) Uni-axial compression test data



(b) Planar test data



(c) Stress relaxation test data

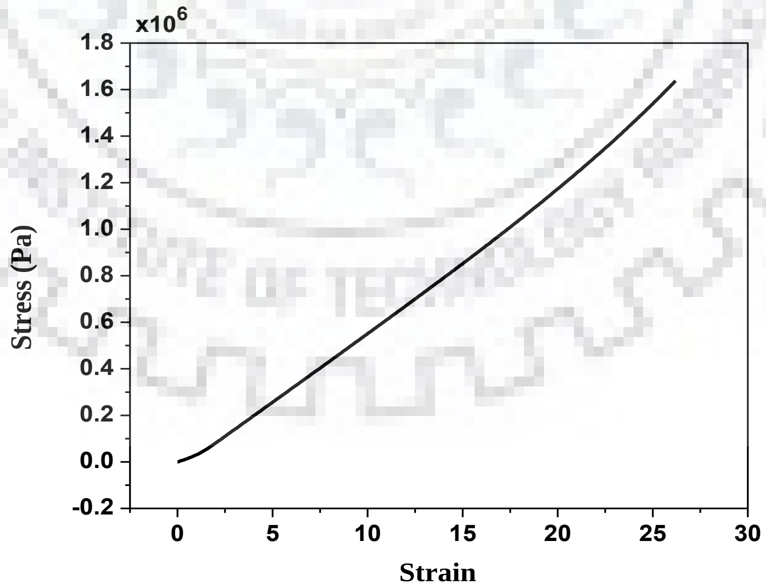


(d) Hysteresis effect

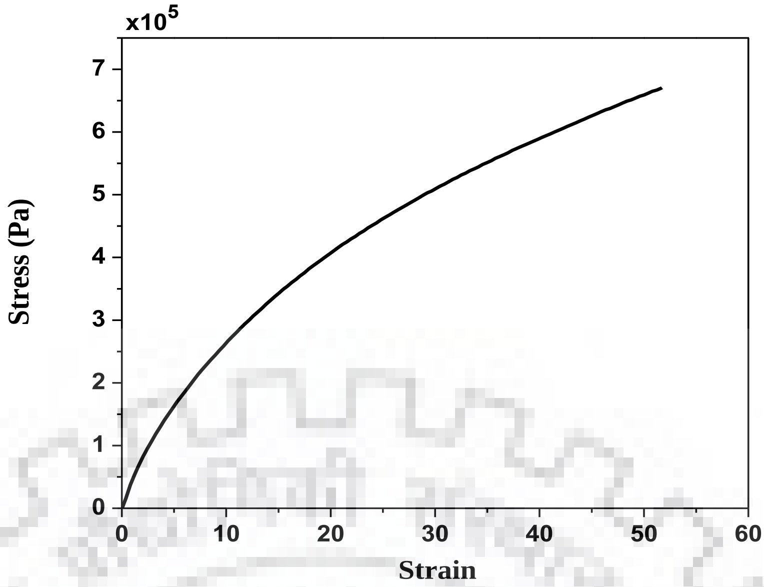
Figure 4.1: (a) Uniaxial test data, (b) Planar test data (c) Stress relaxation test data and (d) Hysteresis effect for natural rubber.

2. Chloroprene rubber

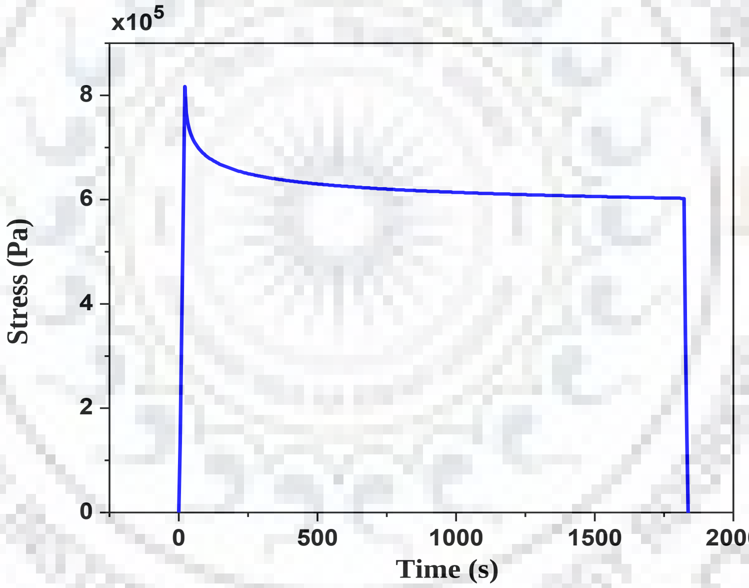
Uniaxial test data, planar test data, planar test data , stress relaxation test data and the hysteresis effect for chloroprene rubber are shown below in the graphical form:



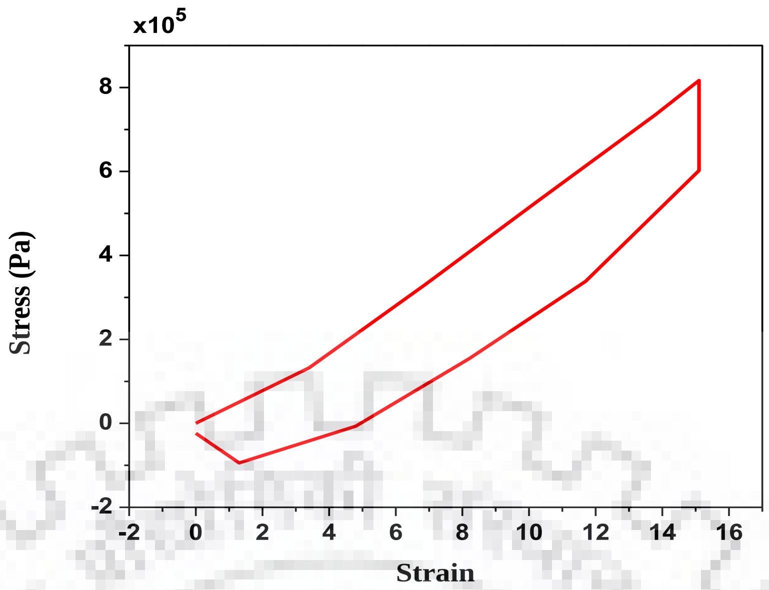
(a) Uni-axial compression test



(b) Planar test data



(c) Stress relaxation test data

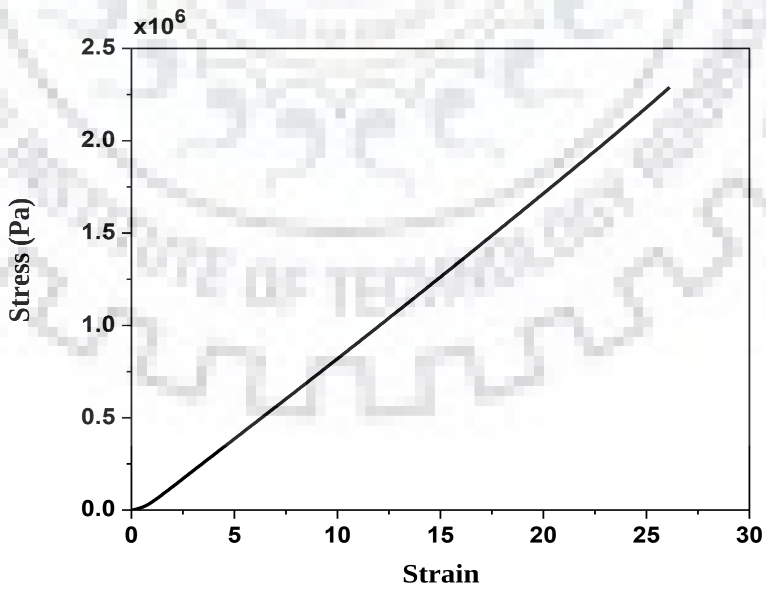


(d) Hysteresis effect

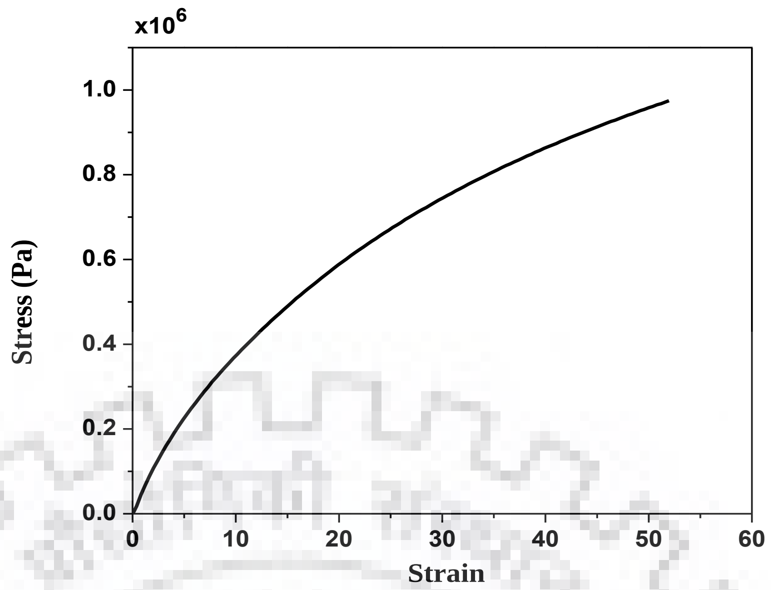
Figure 4.2: (a) Uniaxial test data, (b) Planar test data (c) Stress relaxation test data and (d) Hysteresis effect for chloroprene rubber.

3. Hydrogenated nitrile butadiene rubber (HNBR)

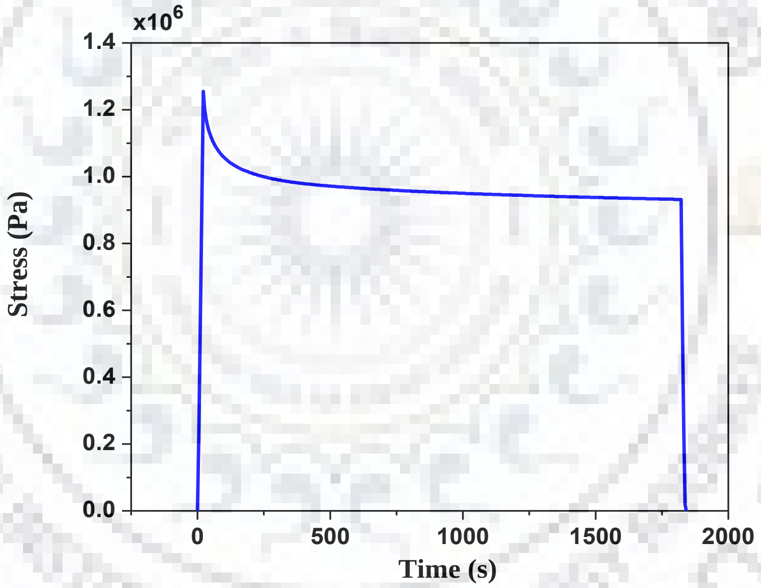
Uni-axial test data, planar test data, planar test data, stress relaxation test data and the hysteresis effect for HNBR are shown below in the graphical form:



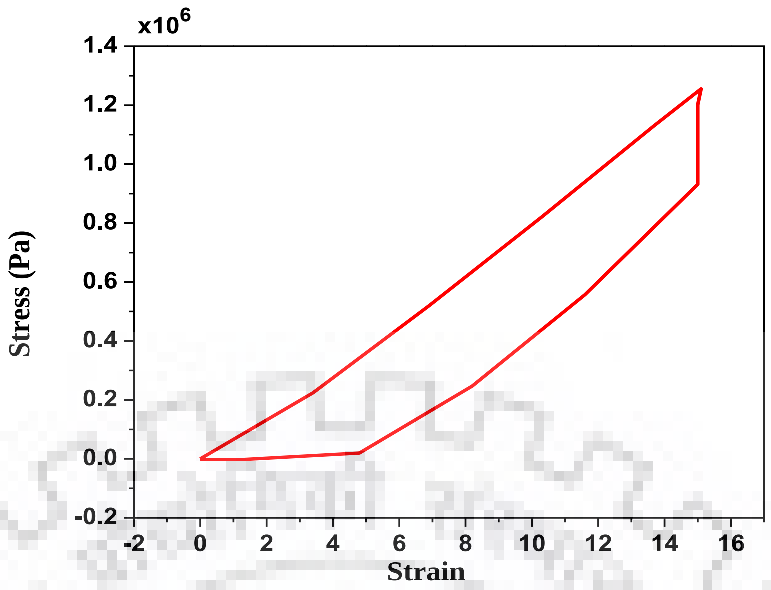
(a) Uni-axial compression test data



(b) Planar test data



(c) Stress relaxation test data



(d) Hystersis effect

Figure 4.3: (a) Uniaxial test data, (b) Planar test data (c) stress relaxation test data and (d)Hysteresis effect for HNBR.

CHAPTER 5

MODEL SELECTION

Linear elastic models do not describe the actual material behaviour of elastomer materials because of the non linear behaviour of elastomers. Stress-strain behaviour of elastomeric materials can be described by hyperelasticity [30]. These materials show both the hyperelastic as well as viscoelastic behaviour. To check which hyperelastic material fits best for our material, we have uni-axial test data and planar test data which we need to fill in material properties and then evaluate to see which material model does best curve fittings and then we can find the hyperelastic model parameters by evaluating it in abaqus. Filled elastomers and biological tissues are also often modeled via the hyperelastic idealization [31, 32].

To predict the behaviour of different materials for finite element analysis, it is really important to check which model fits best as per the experimental data or say which model is able to represent the behaviour of material under given loading condition.

To check which material model fits best for the material used in our analysis, i.e. natural rubber, chloroprene and HNBR. We took the experimental data like uniaxial test data, planar test data and stress relaxation test data. For hyperelastic materials we cannot give properties like young's modulus directly as with the application of load, stress-strain behaviour is non-linear. Hence the value of young's modulus changes with respect to the different stress and strain value. So, we need test data to represent the actual behaviour of material in the computer for finite element analysis.

For this, we took different models like Neo-Hookean [33], Mooney-Rivlin [9,10], Ogden [12] and Yeoh [10] model and analyzed the curve fittings given by different models and found that Mooney-Rivlin model is not stable for this curve fitting but Neo-Hookean, Ogden and Yeoh models are stable for this as shown in figure:

But as we have observed in literature that Ogden model is widely used. So, we used Ogden model in our analysis.

(Here, our motive is not to study these models in detail as this is really a vast area and if someone is interested in going through detail of these hyperelastic models, he can refer to detailed models in references. Here, we need to check that which material model fits best for our material by curve fittings, so that we can get good accuracy in our finite element analysis)

Ogden model

Ogden model [12] is different from the other model (Neo-Hookean model, Mooney-Rivlin model which are expressed by strain invariants) which is expressed in terms of principal stretches. In addition, it has the advantages that the test data can be directly used and it shows good agreement with the test data up to 700% of the tensile test results [34].

Using Ogden model in our analysis and evaluating, we found values of different coefficients as shown below:

```
HYPERELASTICITY - OGDEN STRAIN ENERGY FUNCTION WITH N =   1

                  I           MU_I            ALPHA_I             D_I

                  1         33373.6313       2.07513338       1.206594990E-06


                  STABILITY LIMIT INFORMATION


   UNIAXIAL TENSION:          STABLE FOR ALL STRAINS
   UNIAXIAL COMPRESSION:      STABLE FOR ALL STRAINS
   BIAXIAL TENSION:           STABLE FOR ALL STRAINS
   BIAXIAL COMPRESSION:       STABLE FOR ALL STRAINS
   PLANAR TENSION:            STABLE FOR ALL STRAINS
   PLANAR COMPRESSION:        STABLE FOR ALL STRAINS
   VOLUMETRIC TENSION:        STABLE FOR ALL VOLUME RATIOS
   VOLUMETRIC COMPRESSION:    STABLE FOR ALL VOLUME RATIOS
```

(a) For natural rubber

```
HYPERELASTICITY - OGDEN STRAIN ENERGY FUNCTION WITH N =    1

                 I          MU_I           ALPHA_I           D_I

                 1       25640.0166       1.95018187      1.570531600E-06


                  STABILITY LIMIT INFORMATION

   UNIAXIAL TENSION:          STABLE FOR ALL STRAINS
   UNIAXIAL COMPRESSION:      STABLE FOR ALL STRAINS
   BIAXIAL TENSION:           STABLE FOR ALL STRAINS
   BIAXIAL COMPRESSION:       STABLE FOR ALL STRAINS
   PLANAR TENSION:            STABLE FOR ALL STRAINS
   PLANAR COMPRESSION:        STABLE FOR ALL STRAINS
   VOLUMETRIC TENSION:        STABLE FOR ALL VOLUME RATIOS
   VOLUMETRIC COMPRESSION:    STABLE FOR ALL VOLUME RATIOS
```

(b) For chloroprene rubber

```
HYPERELASTICITY - OGDEN STRAIN ENERGY FUNCTION WITH N =    1

                 I          MU_I           ALPHA_I           D_I

                 1       24217.8755       2.08998399      1.662757591E-06


                  STABILITY LIMIT INFORMATION

   UNIAXIAL TENSION:          STABLE FOR ALL STRAINS
   UNIAXIAL COMPRESSION:      STABLE FOR ALL STRAINS
   BIAXIAL TENSION:           STABLE FOR ALL STRAINS
   BIAXIAL COMPRESSION:       STABLE FOR ALL STRAINS
   PLANAR TENSION:            STABLE FOR ALL STRAINS
   PLANAR COMPRESSION:        STABLE FOR ALL STRAINS
   VOLUMETRIC TENSION:        STABLE FOR ALL VOLUME RATIOS
   VOLUMETRIC COMPRESSION:    STABLE FOR ALL VOLUME RATIOS
```

(c) For HNBR

Figure 5.1: Evaluation of material test data for (a) Natural rubber (b) Chloroprene rubber (c) HNBR using Ogden model

CHAPTER 6

MESH CONVERGENCE

We know that we have a system or parts that deforms continuously, i.e. at each and every point and there are infinite number of points in our part or system. So, to solve such problem, we have infinite number of degree of freedom and hence infinite number of equations to be solved. So to simplify this, to bring this system from infinite number of degree of freedom to finite number of degree of freedom, we do meshing. In meshing, we divide our domain into sub domains called elements and hence we can solve them individually by using finite element method and then we can assemble them to get to the full domain result. That is why we need to do meshing.

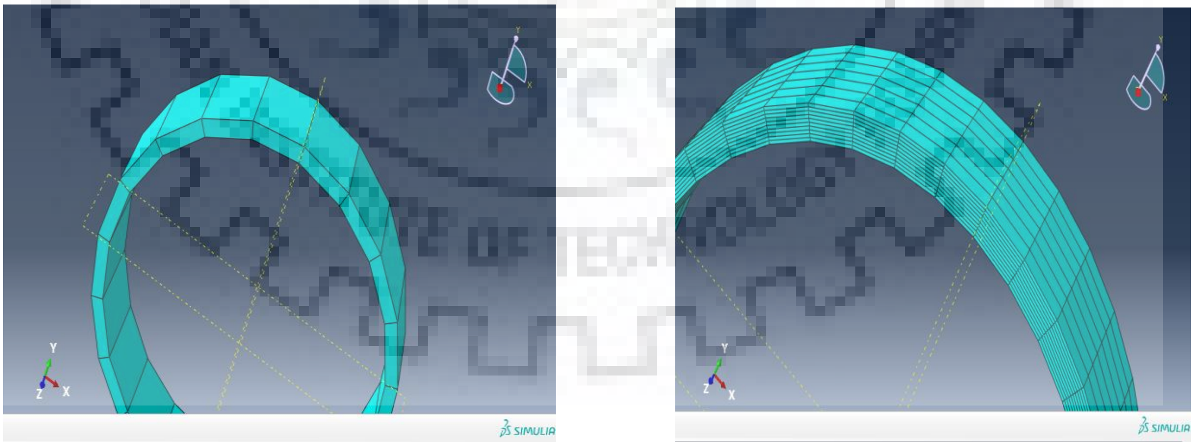
In this chapter we will look the factor that affects the accuracy in finite element analysis called “mesh convergence”. This refers to the minimum number of elements required to be in our model so that accuracy is not compromised or number of elements after which if we increase the number of elements, accuracy of our analysis does not change but time taken in the analysis drastically increases.

This chapter is really important for our analysis. The issue of mesh size is important in all analysis. All the analysis results are dependent on the element size in the beginning. But as we reduce the size of the elements of our FEA model, we reach to the more accurate solution. This implies that more the number of elements the better will be the solution given by our finite element analysis. But there is one more factor that comes into picture as we increase the number of elements and that is the calculation time and the memory used by the analysis in computer.

As the number of elements increases, solution will be more and more accurate, but the time taken by the system to solve this problem increases tremendously so, the memory used by the system. Initially, to increase the accuracy, time increased is less but as we keep on increasing the elements, near the convergence, to improve the accuracy up to 1%, time to solve the problem can increase even more than 100%. So, we need to optimize this as the time taken is proportional to the cost to the analyst. Doing this is generally termed as mesh convergence or the stress convergence.

To reduce the time of calculation, instead of increasing the number of elements in whole model, we can increase the number of elements in the critical part only. As in our model, container and canister are rigid parts (as we are not concerned about the deformations and stress values in these parts) and elastomers are deformable parts. So, here elastomer is the critical part as it is being compressed because of the acceleration coming on the container. Thus, instead of increasing the number of elements in the whole model we can increase the number of elements in the elastomer only. This will improve the accuracy and calculation time will not be increased much. But number of elements in the elastomer also needs to be converged.

In this model, we started with the 20 elements in the elastomer and then gradually increased the number of elements up to 2800 elements and found that in 110 mm thickness of elastomer, if we keep only one element in thickness as shown in figure 5.1, gives much error than that of the model in which we increase the number of elements in the thickness. This can be seen in the acceleration convergence curve. In this curve, we can see that initially the acceleration given by one element in thickness (number of elements 20, 48, 96,160) is much more than the converged value and comes near convergence as we increase the number of elements in the thickness



(a) (b)

Figure 6.1: (a) One element in thickness and one element in width of elastomer.

(b) Seven elements in thickness and ten elements in width of elastomer

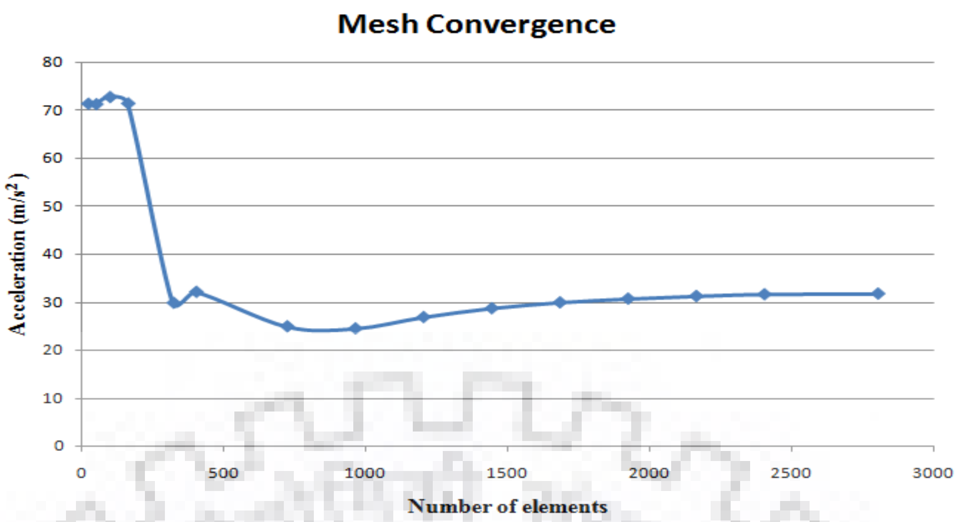


Figure 6.2: Acceleration v/s Number of elements.

As it is clear from this graph that near convergence, increasing the number of elements from 2400 to 2800 time of calculation increased by 30.4% but the accuracy increased by only 0.3914%. Thus this is not economical to keep on increasing the number of elements.

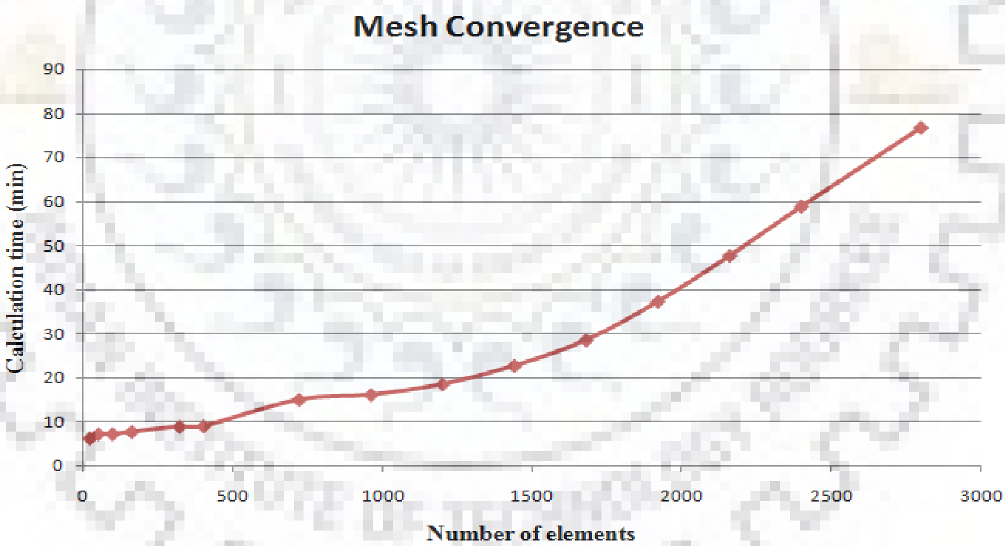


Figure 6.3: Calculation time v/s No. of elements.

It is clear from this analysis that initially as we increase the number of elements, time of calculation does not increase much. But for more number of elements, the time for calculation increases exponentially.

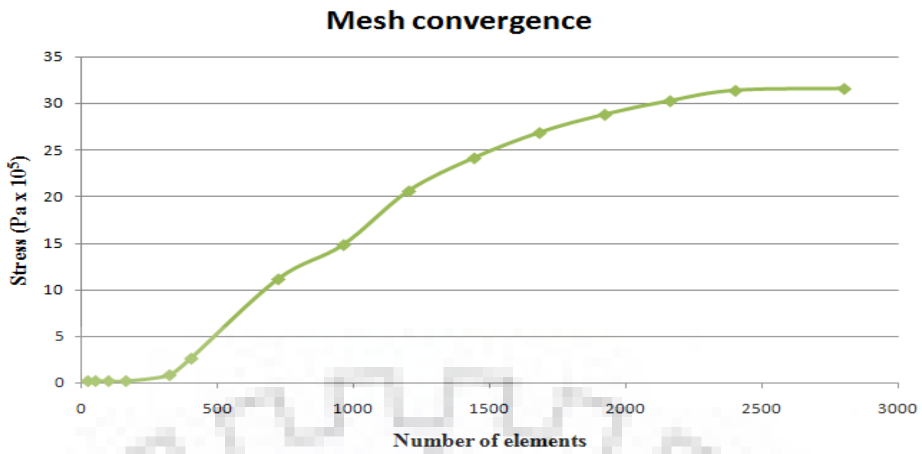


Figure 6.4: Mesh convergence by stress convergence.

As we can see that as we keep on increasing the number of elements, graph of stress versus number of elements converges and this is said to be the stress convergence. It is clear from the graph that further increasing the number of elements will increase the time of calculation tremendously but its effect on stress will be negligible. Thus we can say that now our solution is independent of the mesh size and hence mesh is converged.

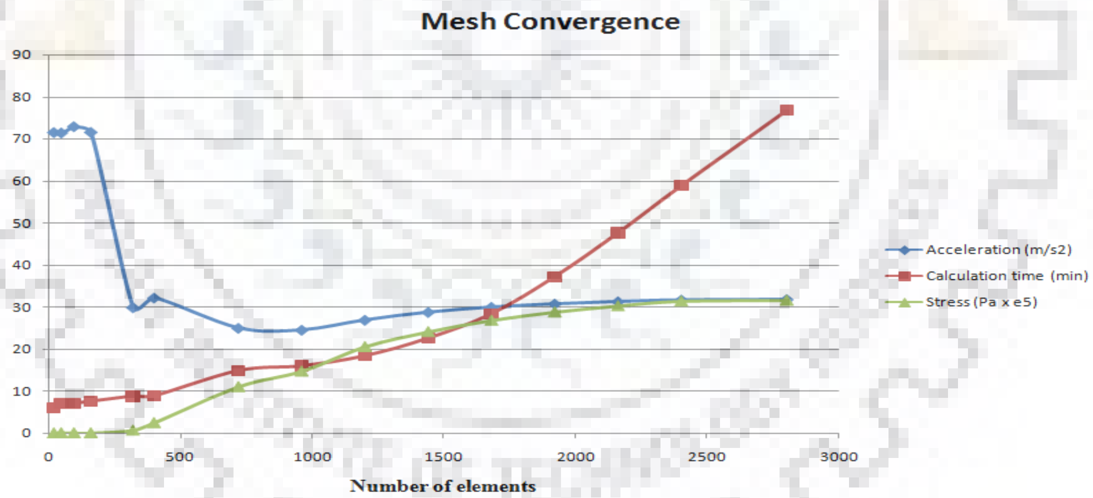


Figure 6.5: Acceleration, calculation time and stress v/s number of elements.

Table 1: Total number of elements after mesh convergence

S. no.	Part	No. of elements
1	container	6216
2	canister	6640
3	elastomer	2400

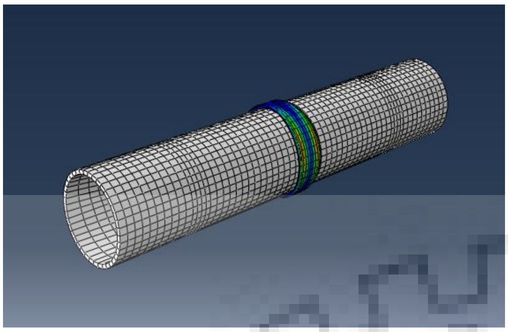
CHAPTER 7

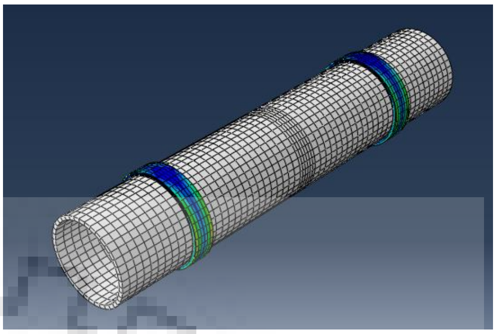
RESULTS

Container and canister assembly with elastomer was made as per the data provided. First this was tried with ansys software, but it is not possible to provide acceleration to the individual parts in the ansys. So, for this analysis we used Abaqus software in which it is possible to give acceleration to the individual parts. As we are only interested in deformation elastomer and the acceleration of container and canister is to be checked. So, container and canister were made rigid bodies and acceleration shock load was given to the container on its reference point(on the centre of gravity of container) which was coupled with the container body and the response of canister reference point(on the centre of gravity of canister) was checked for acceleration and deformation of the elastomer. We did the simulation using different number of elastomers. (Numbering is such that top one is first, on mid position of canister is second and at the bottom is third. Beginning with one elastomer in the mid of canister and then using two on the either side of the mid of canister and then going for three and five elastomers as shown in figure 6.1) and different materials so as to find the optimum result from it. Material properties (hyperelastic and viscoelastic) were provided by the Indian Rubber Manufacturers Research Association, Ministry of Commerce & Industry, Govt. of India.

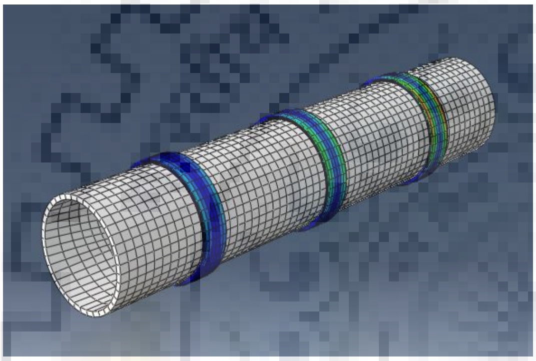
In case of elastomeric materials in which the poisons ratio is near 0.5, there is problem of volumetric locking, which can produce error in our simulation. Because of which, we chose C3DQ8R element (An 8-node linear brick, reduced integration, hourglass control).

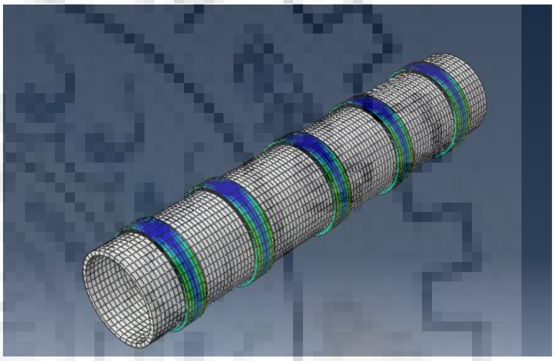
As we know that in our finite element problems, we use gauss integration rule and sometimes it estimates excessive stiffness value and because of which there is error in problem solving because of locking. That is why we use reduced integration method in which we reduce the number of gauss points, because of which it estimates less stiffness value. But sometimes it reduce the stiffness value very rapidly and because of this, element cannot sustain any load or say it cannot store any strain energy. To solve this issue, we use hourglass control, in which artificial strain energy is provided to the element to guide us whether we need to control it or not. User can control it by checking the artificial strain energy plot and total strain energy plot. If at any point, the artificial strain energy exceeds 5% of total kinetic energy, it means we need to control the hourglass effect by changing some settings in hourglass control.





(a) (b)





(c)

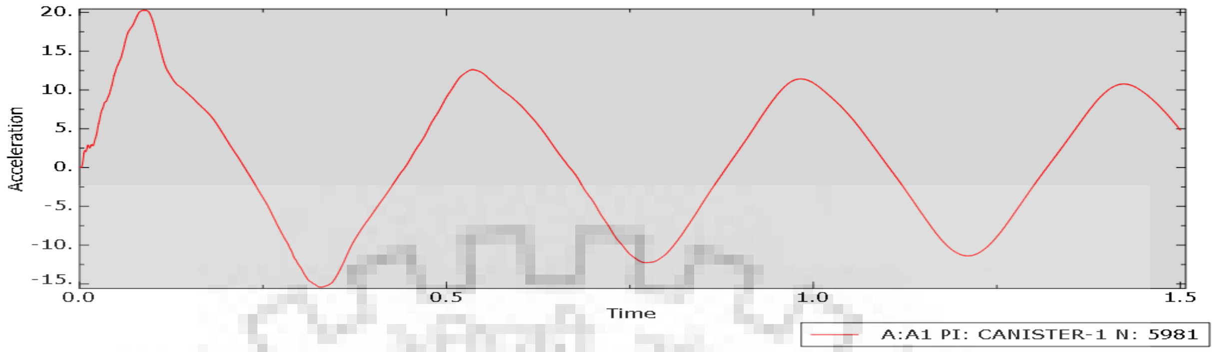
Figure 7.1: Assembly with (a) One elastomer (b) Two elastomers (c) Three elastomers (d)Five elastomers (after deformation).

7.1 Using Natural rubber

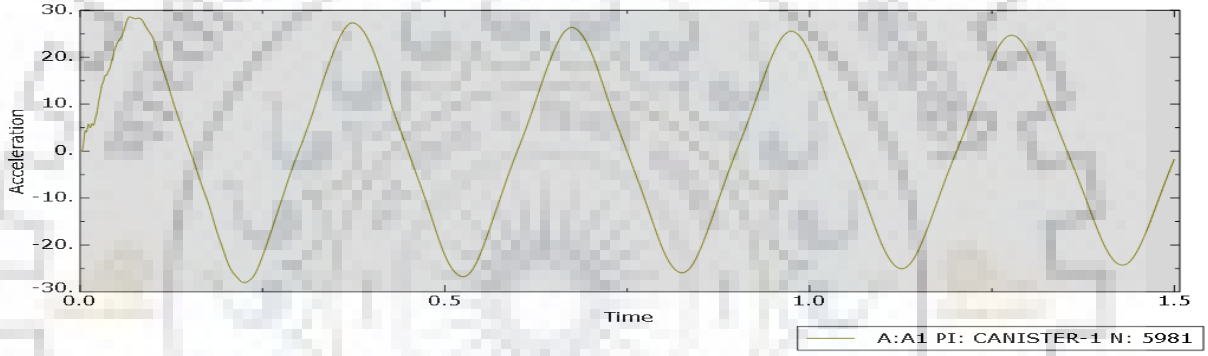
7.1.1 Acceleration of canister with 50g to container

By using natural rubber we did simulation using different number of elastomers at different location. Here we are showing the results that are found to be good as per the constraint and as per balancing. From the analysis, we could found that the best result using the natural rubber is that we could bring the acceleration from 500m/s^2 to 20.2m/s^2 (by using one elastomer on the centre of gravity of the canister) which fulfill our requirement to bring the acceleration from 500m/s^2 to 20m/s^2. But the problem with this is that there is large deformation (71mm) in the elastomer which is not required.

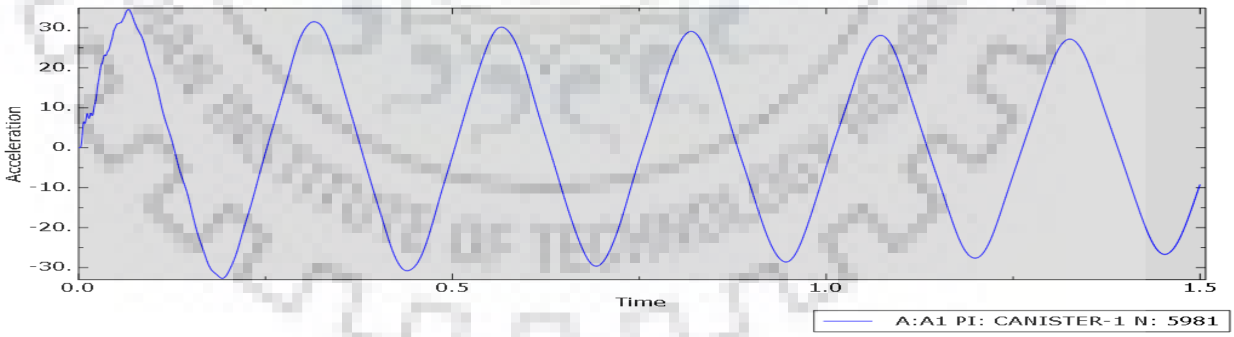
Analysis results (acceleration of canister) using different number of elastomer is shown below:



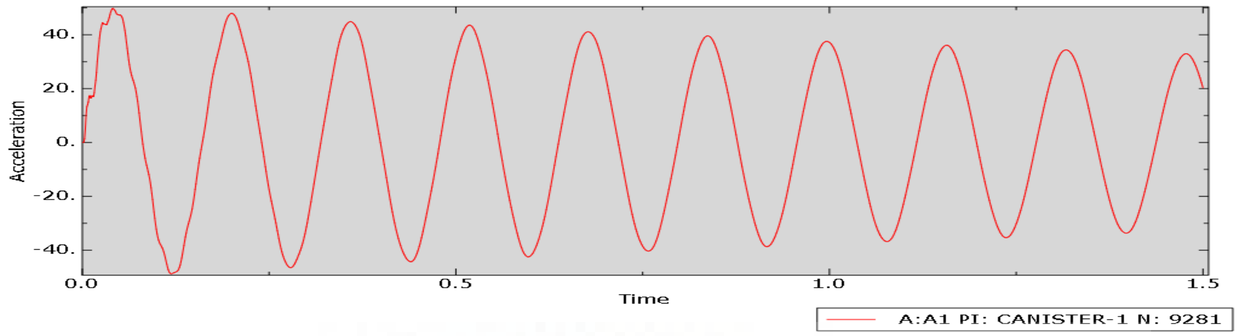
(a)



(b)



(c)



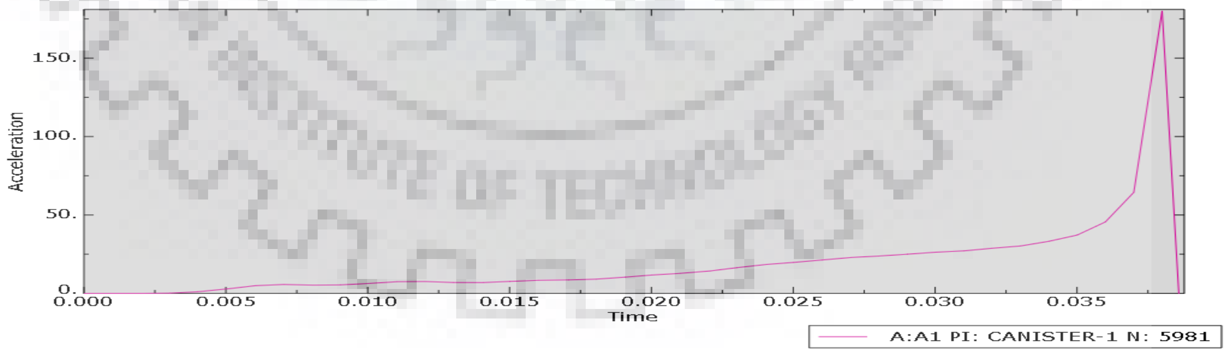
(d)

Figure 7.2: Acceleration of canister (when 50g is given to container) using natural rubber with (a) One elastomer, (b) Two elastomers (c) Three elastomers and (d) Five elastomers

From acceleration result data we found that maximum acceleration in the canister by using one, two and three elastomer is 20.2 m/s^2, 28.6 m/s^2 and 34.8 m/s^2 and 49.8 m/s^2 respectively. Here, we can see a sharp shoot in case when using only one elastomer, because this elastomer is being compressed to a very high value, i.e. 71mm.

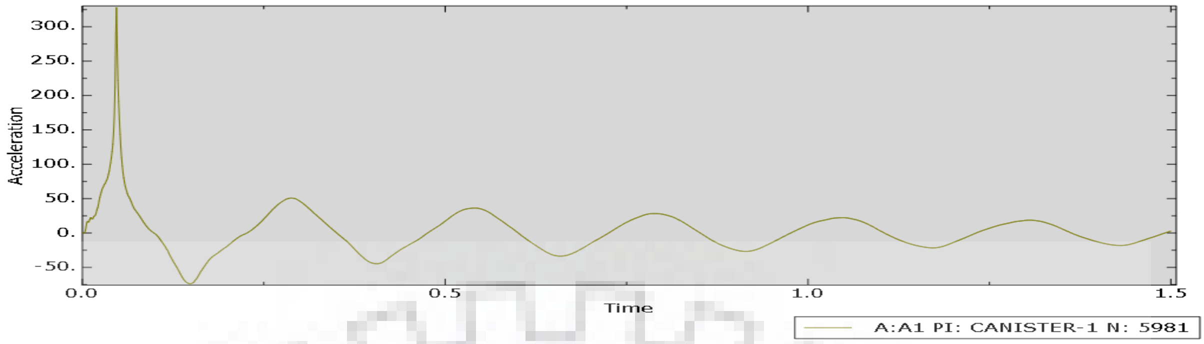
Other than this 50g acceleration shock load, we had to do this to attenuate 130g shock load. So, for this, we did the same analysis for 130g as well. Acceleration result when natural rubber was used for this analysis is given below:

7.1.2 Acceleration of canister with 130g to container



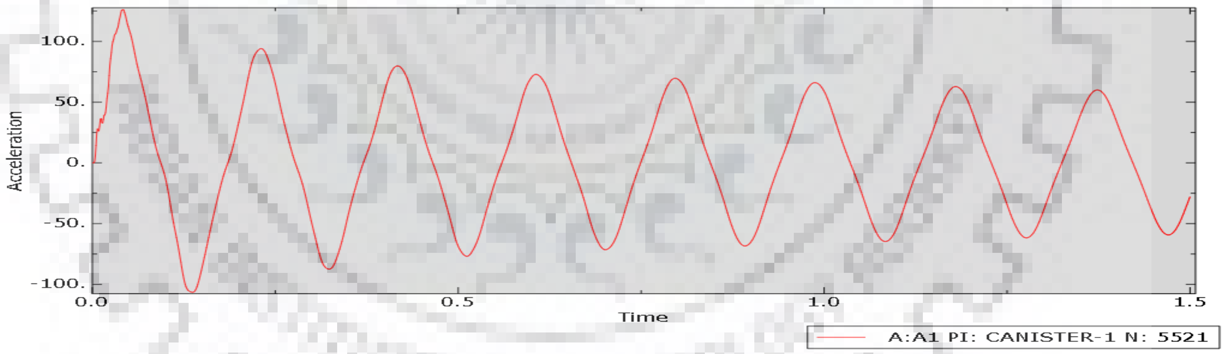
(a) Using one elastomer

From this analysis we can see that after some time, elements of the elastomer are being extremely distorted and container touches to the canister. Due to this, analysis was aborted after some time. Thus, one elastomer could not sustain such a heavy shock load, i.e. 130g.



(b) Using three elastomers

We did same simulation using two elastomers, but two elastomers also could not sustain 130g acceleration given to the container. Then we did simulation using three elastomers and we saw that three elastomers could sustain this 130g acceleration and it could bring this acceleration upto 360m/s^2 to the canister but with maximum displacement of 91mm, which is quite high. And because of this much deformation of the elastomer, we can see sharp shoot in the acceleration of the canister. Here, damping effect of the elastomer was diminished after being extremely distorted as this started behaving like a material of very high density.



(c) Using five elastomers

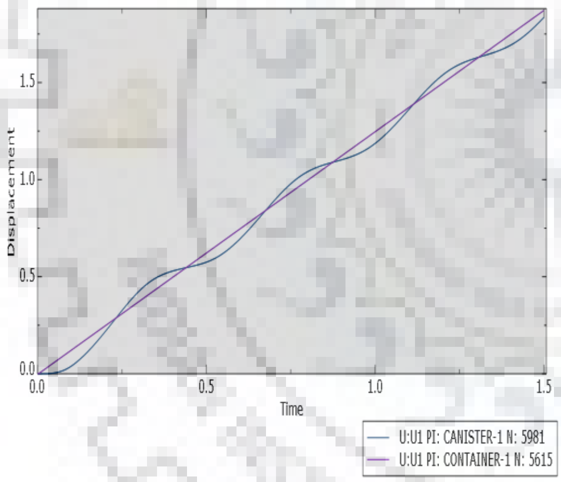
Figure 7.3: Acceleration of canister (when 130g is given to container) using natural rubber with (a) One elastomer, (b) Three elastomers and (c) Five elastomers

Using five elastomers, we could see that acceleration transmitted to the canister was reduced upto 126.5m/s^2 from 1300m/s^2 which is quite impressive but with the maximum displacement of 83mm. Here, we can see contradiction in our result because if we see in results with

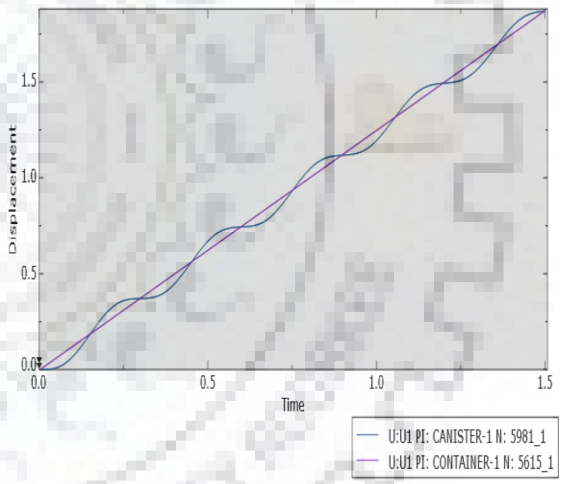
500m/s^2, as we were increasing the number of elastomers, the acceleration transmitted to the canister was being increased and the maximum displacement was being reduced. But here, acceleration being transmitted to the canister and maximum displacement of the canister both are decreasing. The reason behind this is that in case of 50g (g = 10m/s^2) acceleration, elastomer material was not being very extremely distorted as compared to when we used 130g acceleration and because of that, in case of 130g acceleration to the container, there is sharp shoot in the acceleration of the canister which is not present in case of the 50g simulation.

7.1.3. Maximum displacement of canister

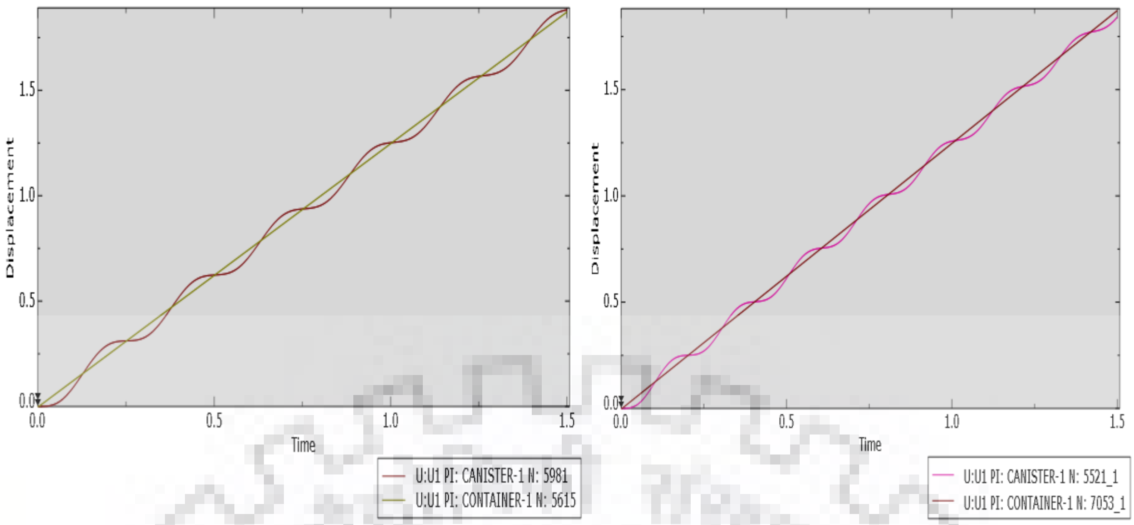
From this analysis we found acceleration plot of canister and deformation in the elastomer by knowing the displacement of canister inside the container and stress value inside the elastomer. Various plots with different number of elastomers using natural rubber material are shown:



(a)



(b)



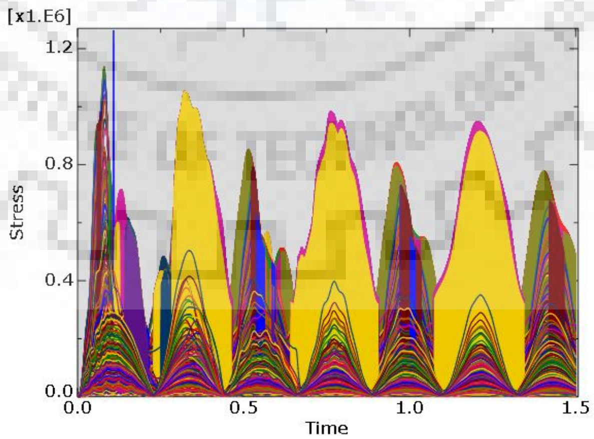
(c) (d)

Figure 7.4: Maximum displacement of canister inside container using (a) One elastomer, (b)Two elastomers (c) Three elastomers and (d) Five elastomers using natural rubber.

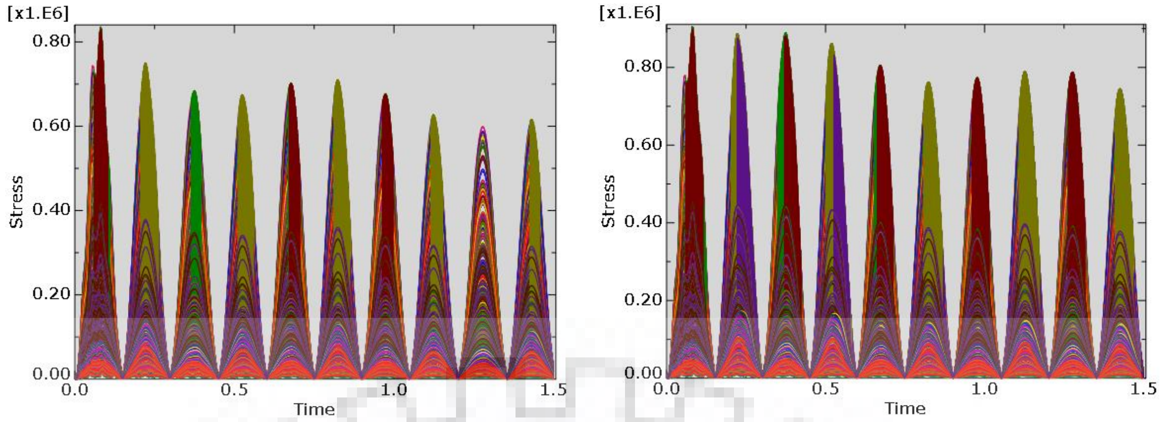
From the analysis result data, we found that the best result for the deformation in the elastomer is 27 mm using natural rubber and the worst is 71mm but here we have both the constraints (acceleration and deformation) to be fulfilled. So we need to optimize our results

Results show that Maximum deformation in elastomer using one, two, three and five elastomers is 71mm, 57mm, 44 mm and 27m respectively.

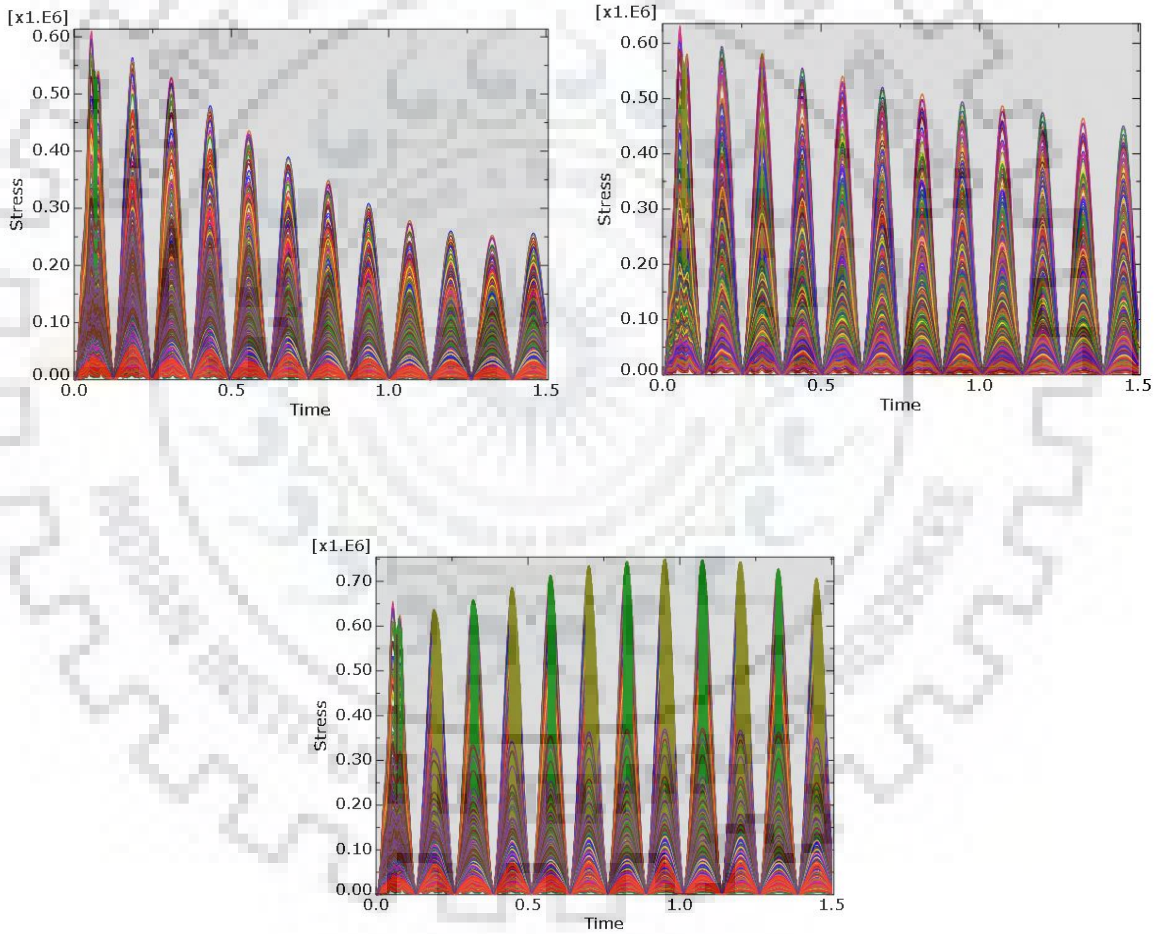
7.1.4. Stress behaviour



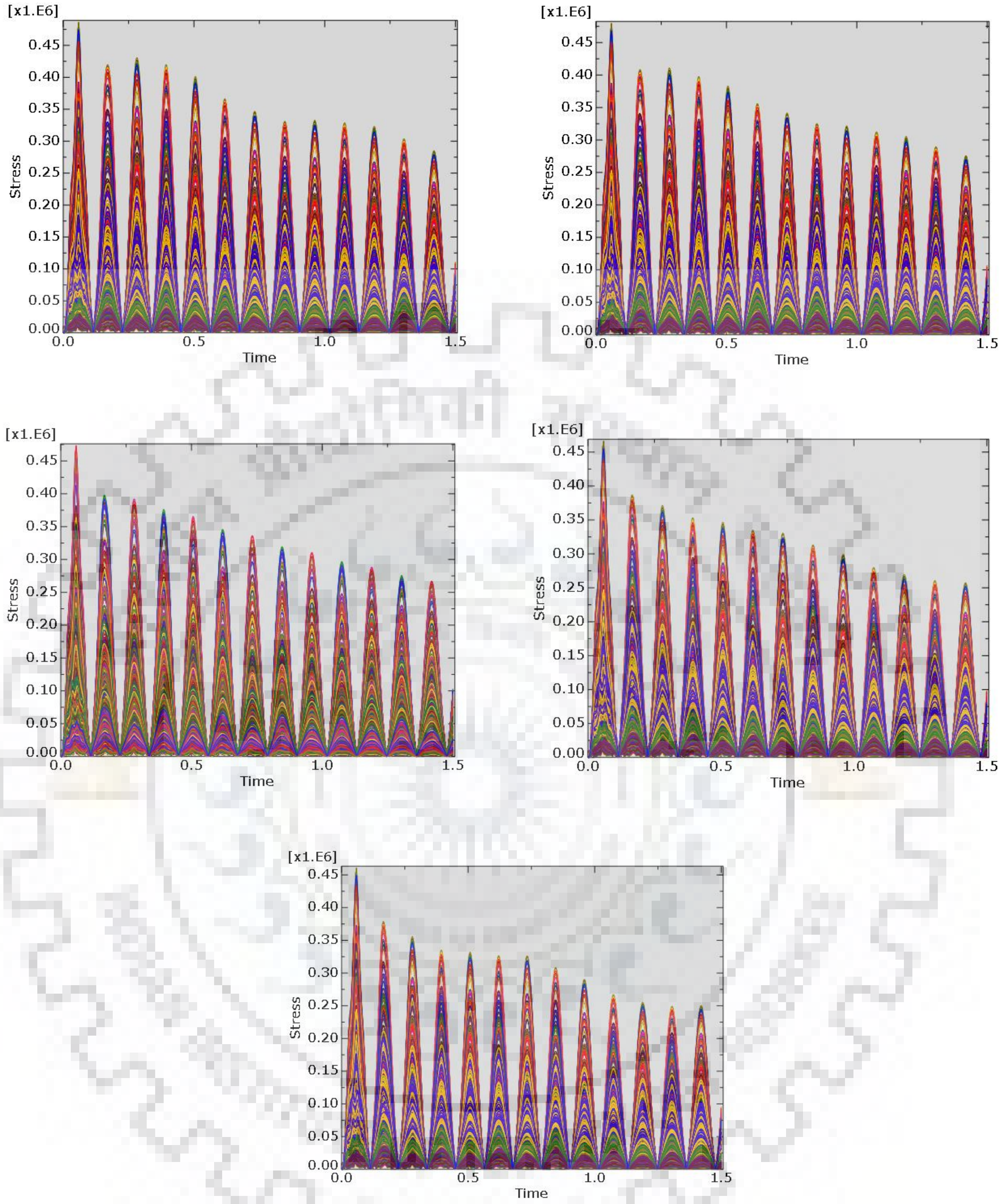
(a) Using one elastomer



(b) Using 2 elastomers



(c) Using 3 elastomers



(d) Using 5 elastomers

Figure7.5: Stress plots (von mises) with chloroprene rubber using (a) One elastomer, (b) Two elastomers, (c) Three elastomers and (d) Five elastomers.

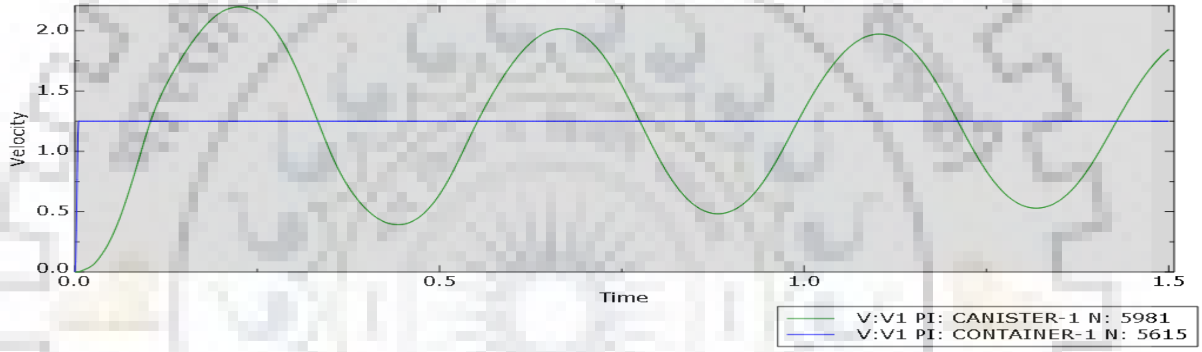
7.1.5 Velocity behaviour

Velocity response shows that as we increase the number of elastomers the number of cycles per unit time increases and thus it can attenuate it faster than the less number of elastomers.

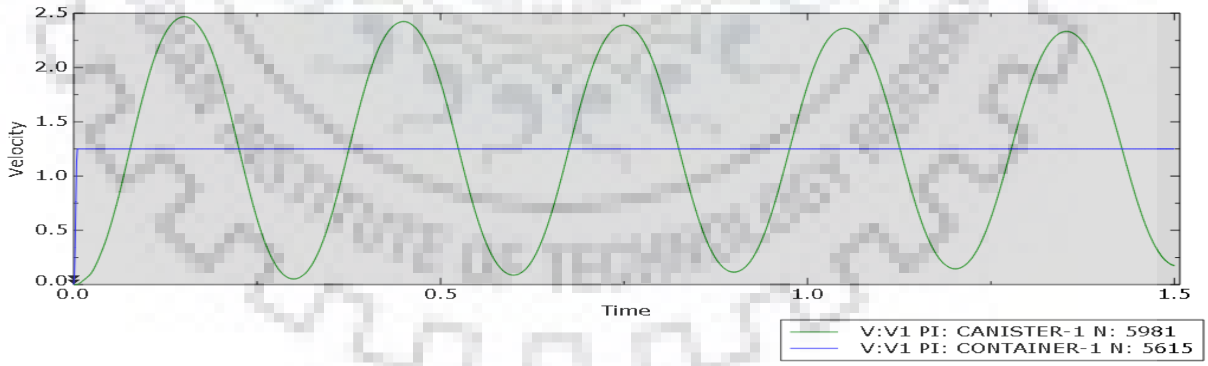
From this velocity response, we can say that our results are approximately near to the analytical result. As we know that the area under the acceleration curve gives the value of velocity which can be calculated as:

From acceleration curve which is having a triangular area having height of $500 m/s^2$ and base of 0.005sec.

So, area under this acceleration curve is (500 x 0.005)/2 = 1.25m/s

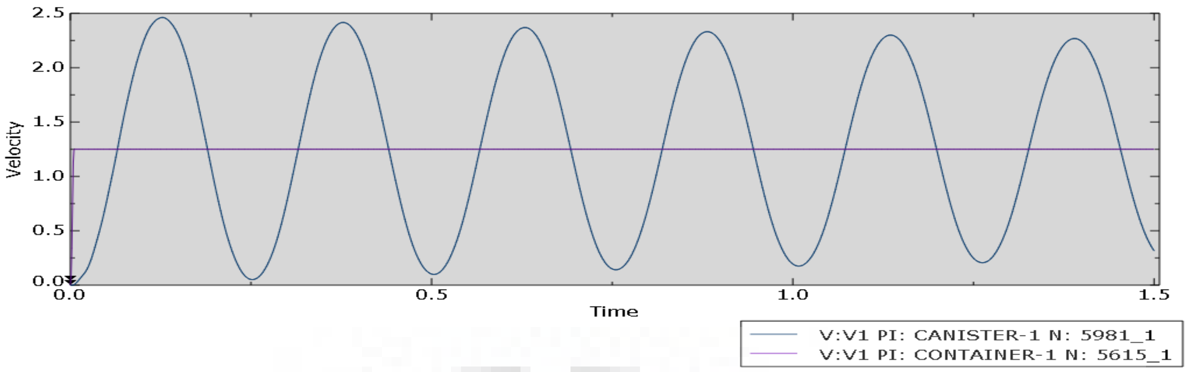


(a)

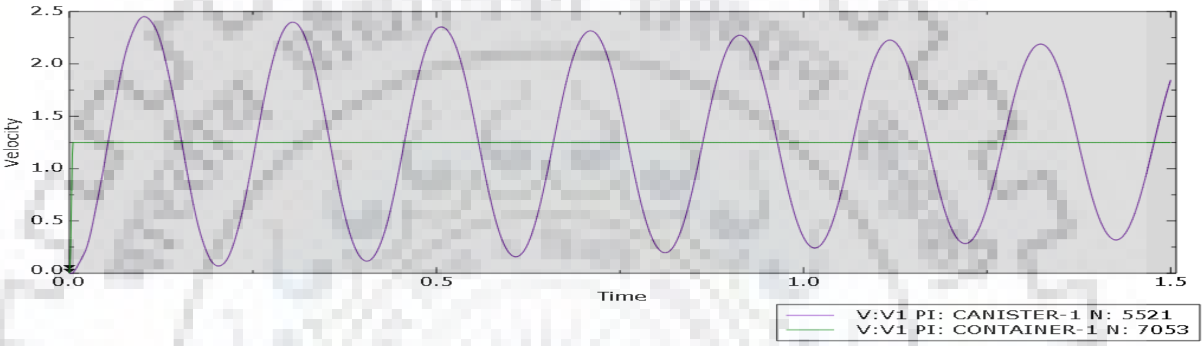


(b)

From this response, we can see that the velocity of container is same as the analytical result. As we are increasing the number of elastomer, we can see there are more number of cycles in the same time.



(c)



(d)

Figure 7.6: Velocity response of container and canister with natural rubber using (a) One elastomer, (b) Two elastomer, (c) Three elastomer and (d) Five elastomers.

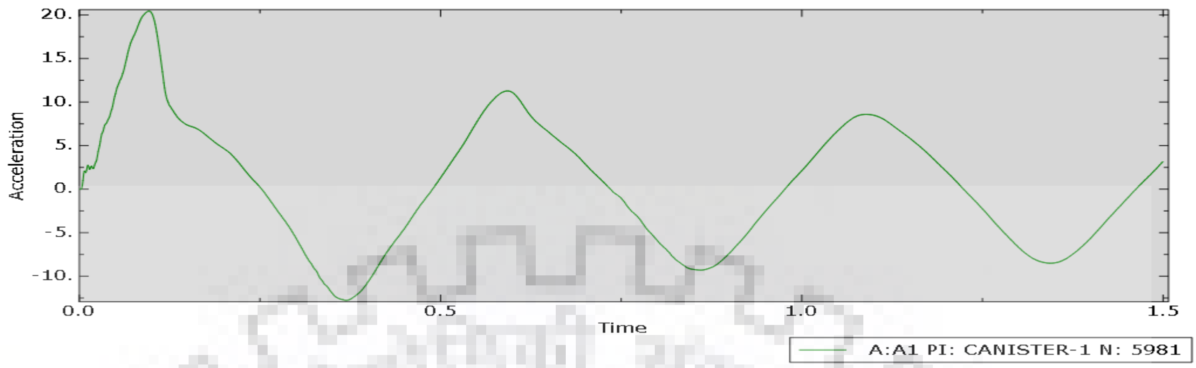
7.2 Using Chloroprene Rubber

7.2.1 Acceleration of canister with 50g to container

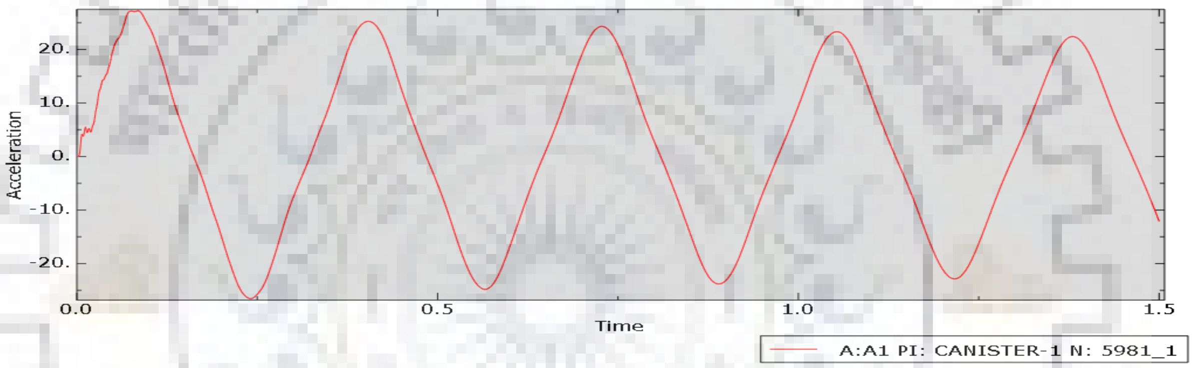
Chloroprene rubber is very effective material when it comes to heavy duty damping. From our analysis, we found that it is a suitable material for such application.

By using one elastomer on the centre of gravity of canister, we found that it could bring the shock load acceleration from 500m/s^2 to 20.44m/s^2 which is really a good result. But as we increase the number of elastomers, the acceleration transmitted to the canister is increased because of the elastomers being added parallel increase the stiffness value, which in return decrease the deformation value, but increase the value of acceleration being transmitted to the canister.

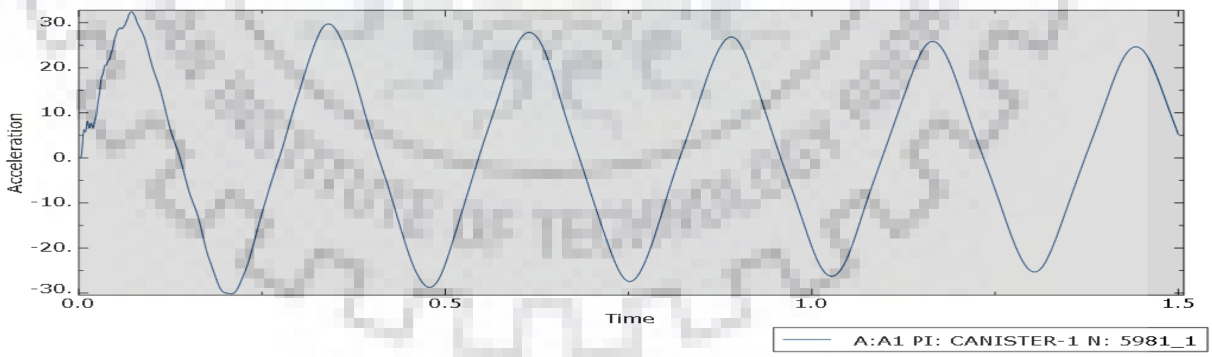
Acceleration plots of canister using chloroprene rubber with different number of elastomers at different location are shown below:



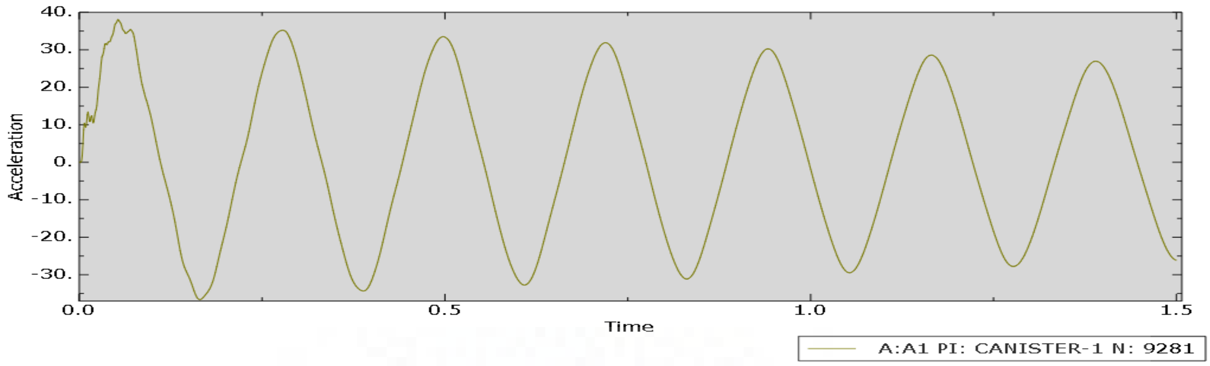
(a)



(b)



(c)

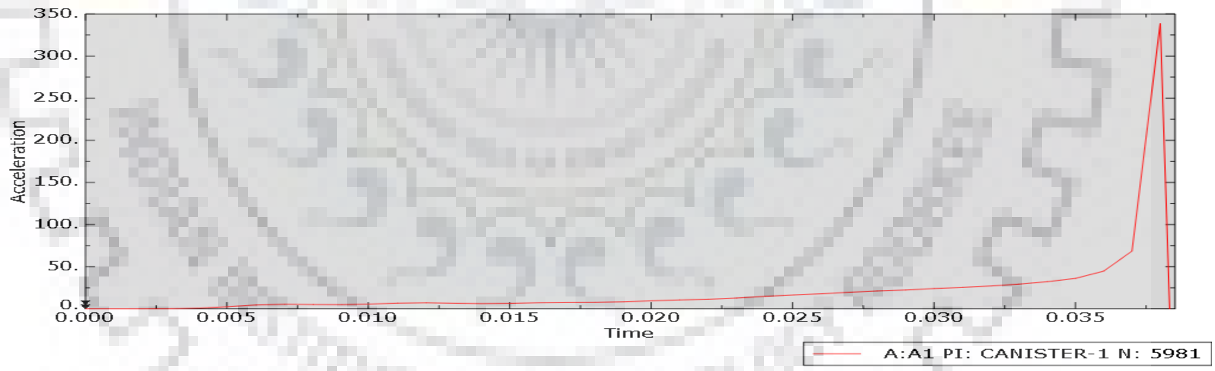


(d)

Figure 7.7: Acceleration of canister (when 50g is given to container) using chloroprene rubber with (a) One elastomer, (b) Two elastomers (c) Three elastomers and (d) Five elastomers

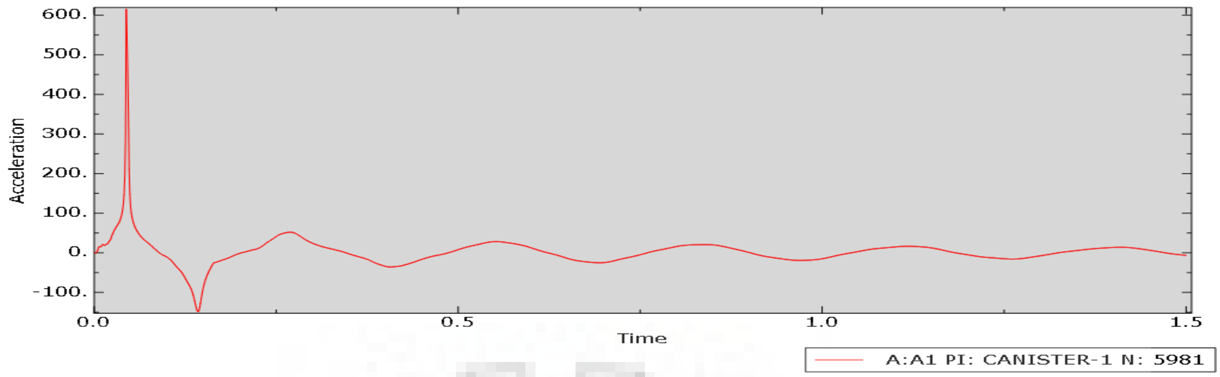
From acceleration result data we found that maximum acceleration in the canister by using one, two and three elastomer is 20.44 m/s^2, 27.23 m/s^2 and 33.1 m/s^2 and 38.1 m/s^2 respectively.

7.2.2 Acceleration of canister with 130g to container



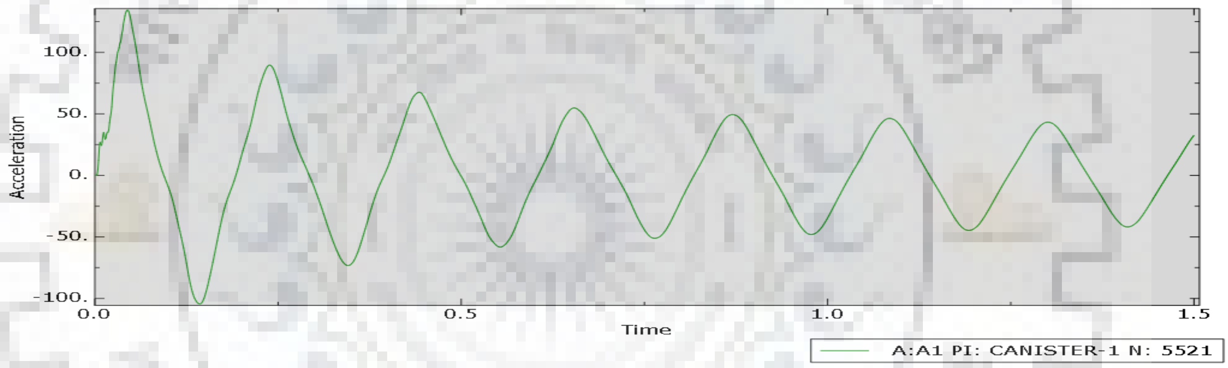
(a) Using one elastomer

As discussed earlier in case of natural rubber, similar trend can be seen here as well and we found that one and two elastomer (using chloroprene rubber) could not sustain such a high shock load and analysis gets aborted after some time.



(b) Using three elastomers

Here, we can see that using three elastomers, we could bring shock load upto 62g which is quite high and with the deformation of 96mm. As this deformation is quite high in this case, that is why there is sharp peak in the acceleration value transmitted to the canister.



(c) Using five elastomers

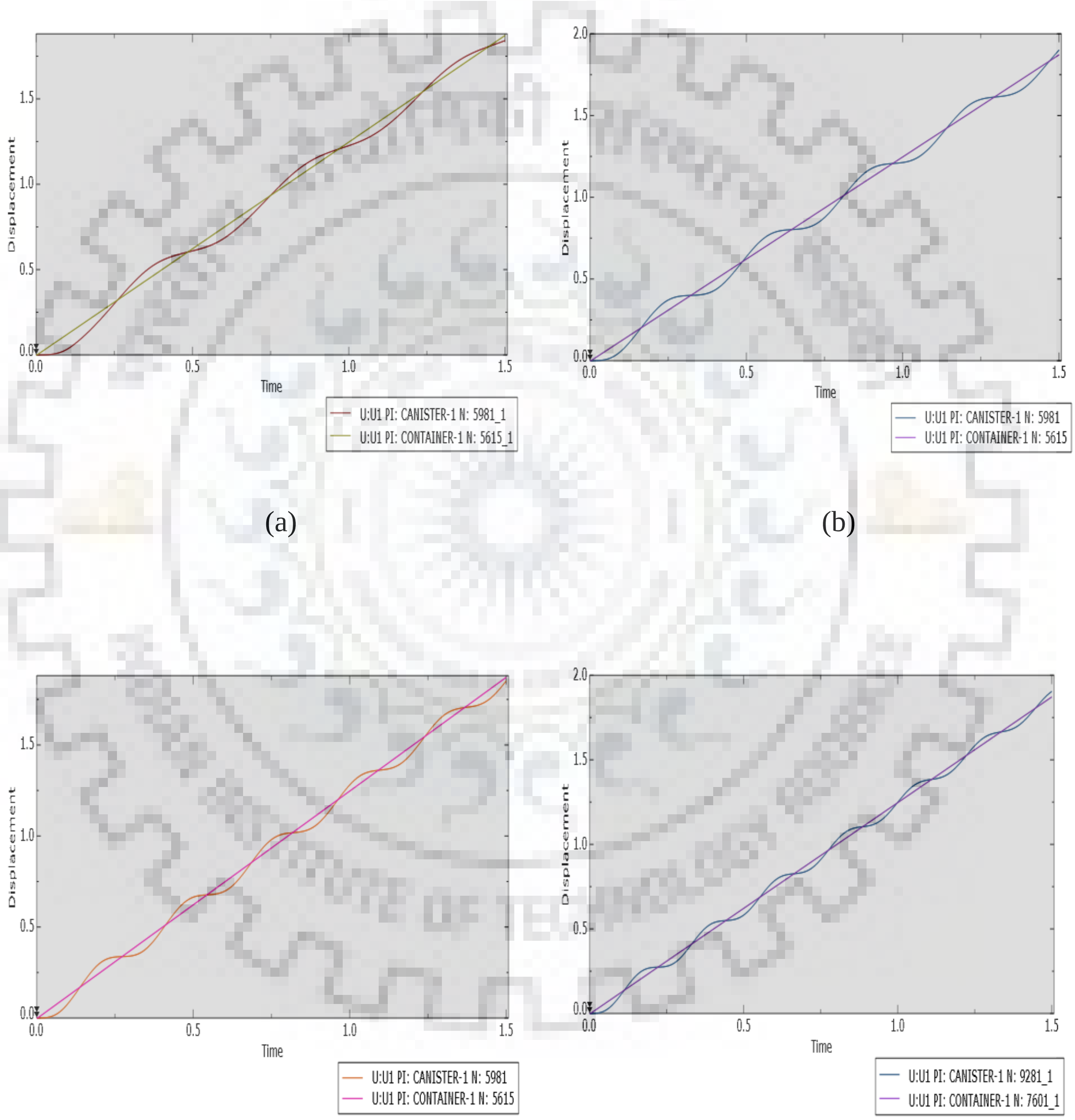
Figure 7.8: Acceleration of canister (when 130g is given to container) using chloroprene rubber with (a) One elastomer, (b) Three elastomers and (c) Five elastomers

By using five elastomers, we found that maximum acceleration transmitted to the canister is 13.44g with maximum displacement of 86mm in the canister.

7.2.3 Maximum displacement of canister

From the simulation results, it can be seen that the deformation in the elastomer is decreasing with the increase in number of elastomers because the stiffness value of elastomer is increasing.

By using chloroprene rubber material, we found that the best result for deformation is by using five elastomers as this gives 31mm deformation in the elastomer but at the same time, the acceleration value being transmitted to the canister is increased which is not good for our application. Deformation plots by using chloroprene rubber material with different number of elastomers at different location are shown below:

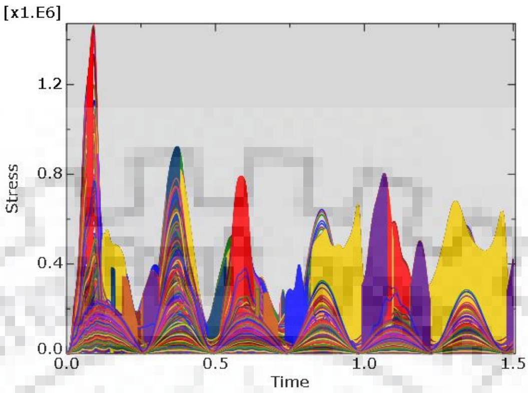


(c) (d)

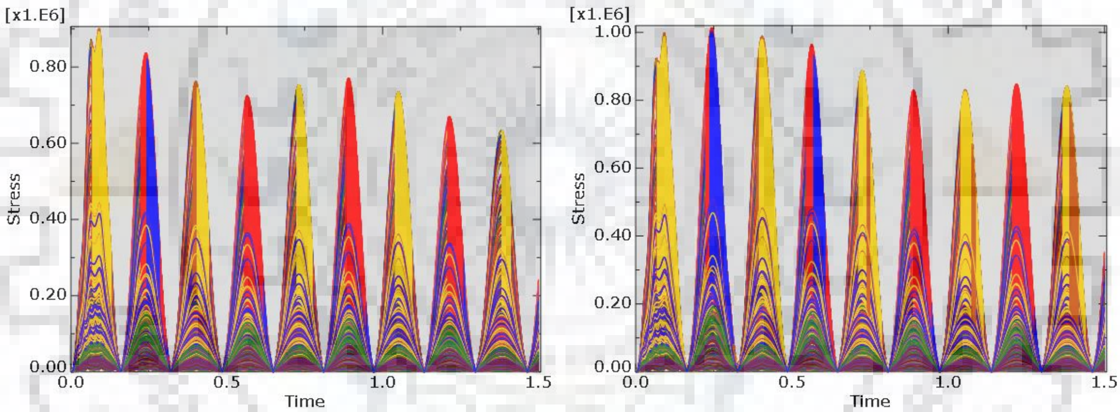
Figure 7.9: Maximum displacement of canister inside container using (a) One elastomer, (b)Two elastomers (c) Three elastomers and (d) Five elastomers using chloroprene rubber.

From our analysis we found that the deformation in the elastomer using one, two, three and five elastomers is 77mm, 59mm, 52mm and 31mm, respectively.

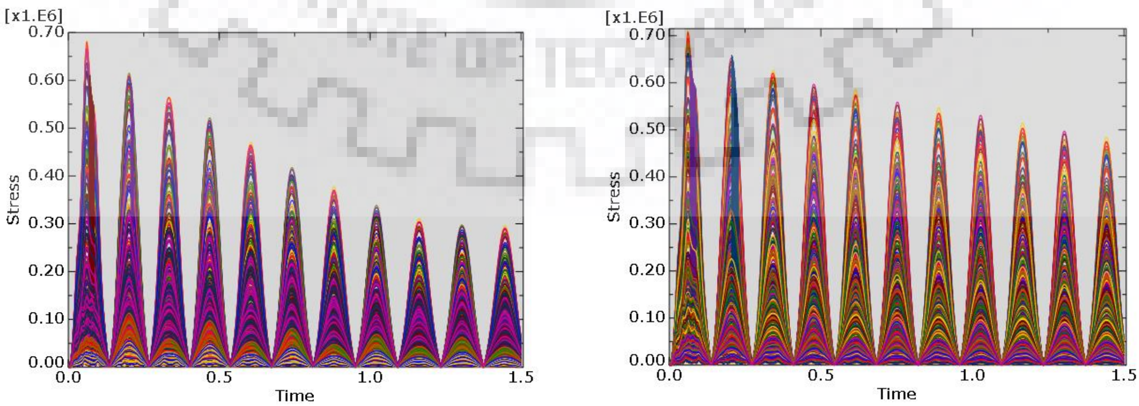
7.2.4 Stress behaviour

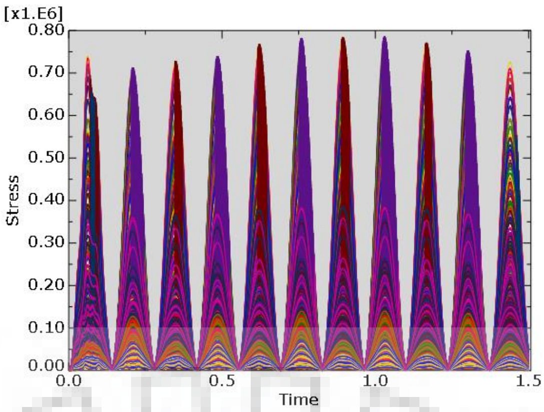


(a) Using one elastomer

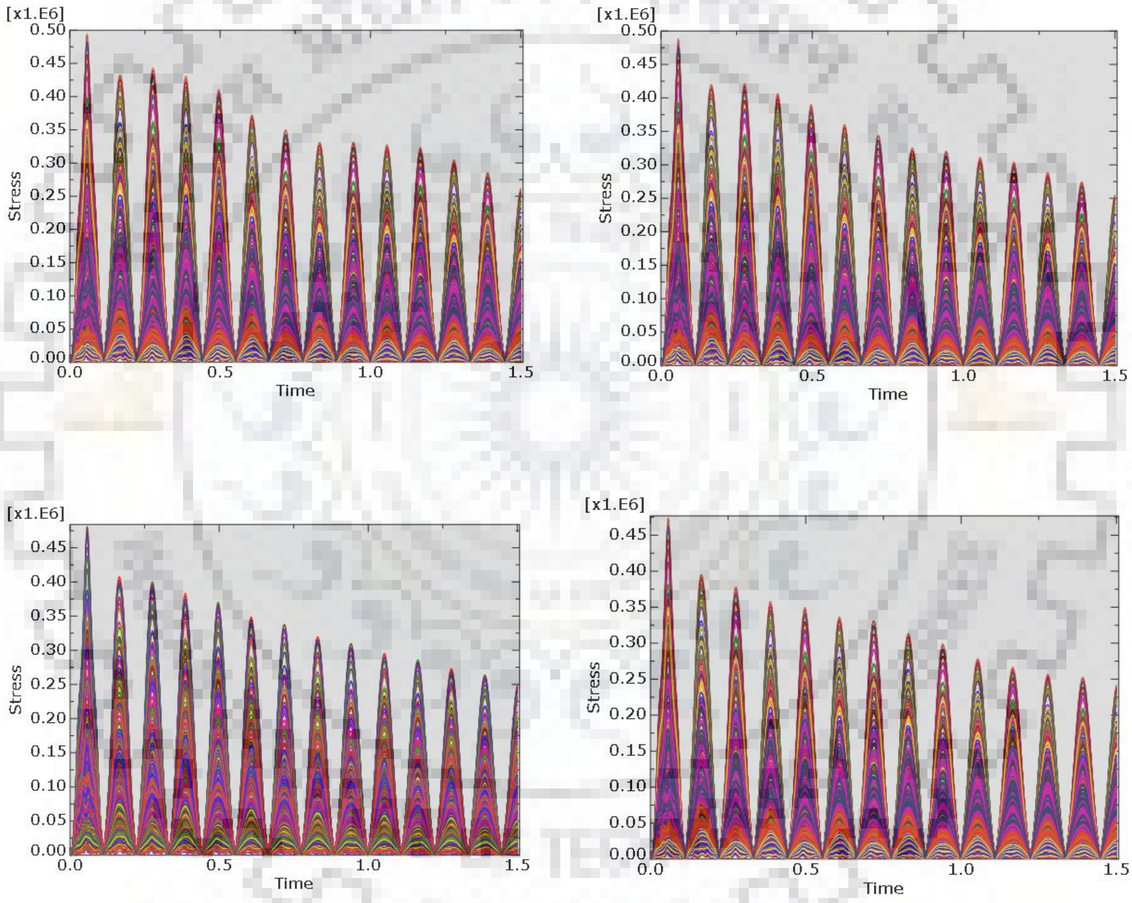


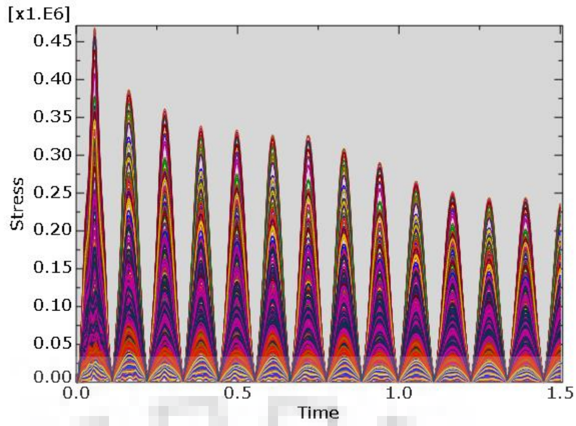
(b) Using two elastomers





(c) Using three elastomers



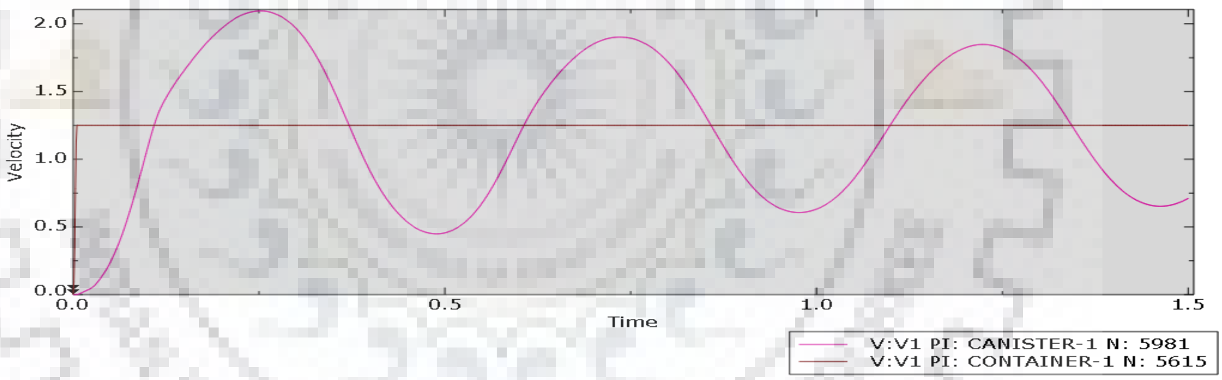


(d) Using five elastomers

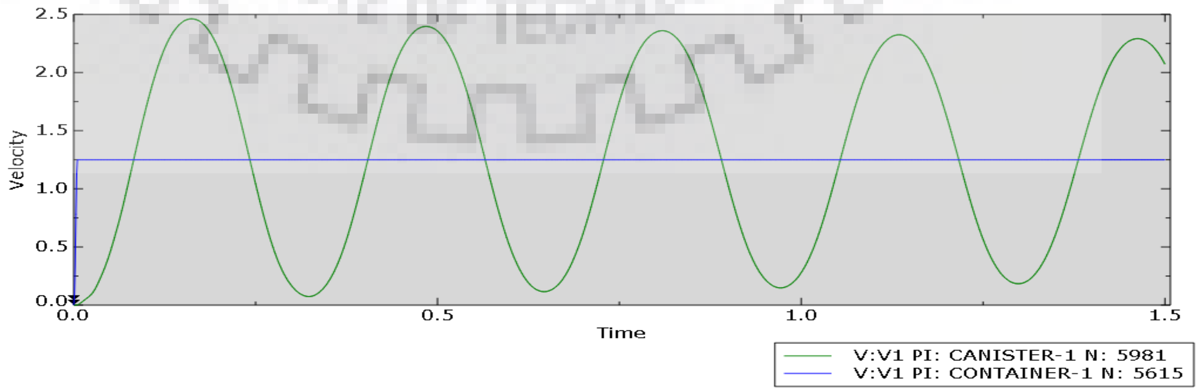
Figure 7.10: Stress plots (von mises) with chloroprene rubber using (a) One elastomer, (b)Two elastomers, (c) Three elastomers and (d) Five elastomers.

From these von mises stress plots, we can find that stress value is more in the beginning and it is reducing with time because energy is being absorbed by the elastomer in each cycle

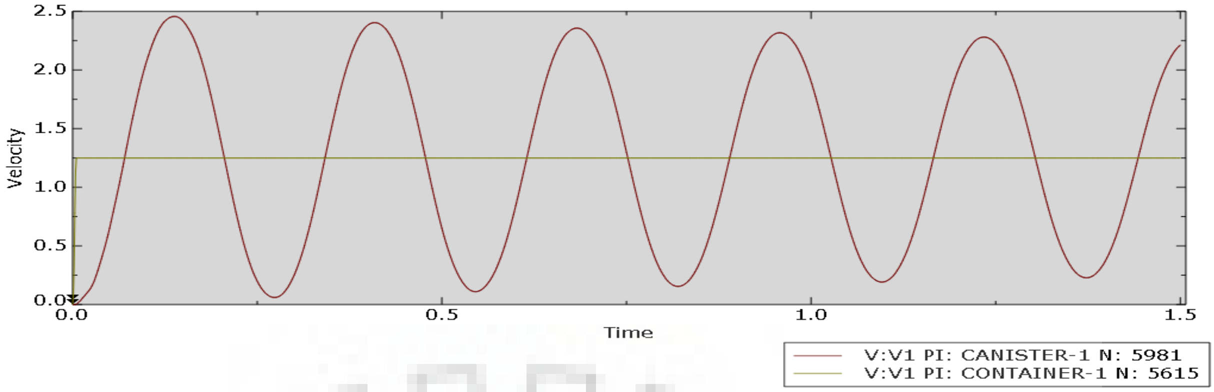
7.2.5 Velocity response



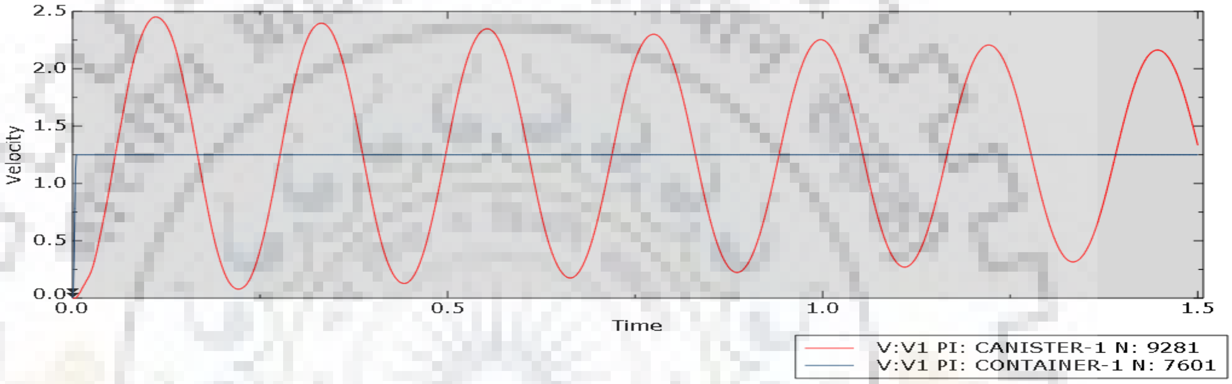
(a)



(b)



(c)



(d)

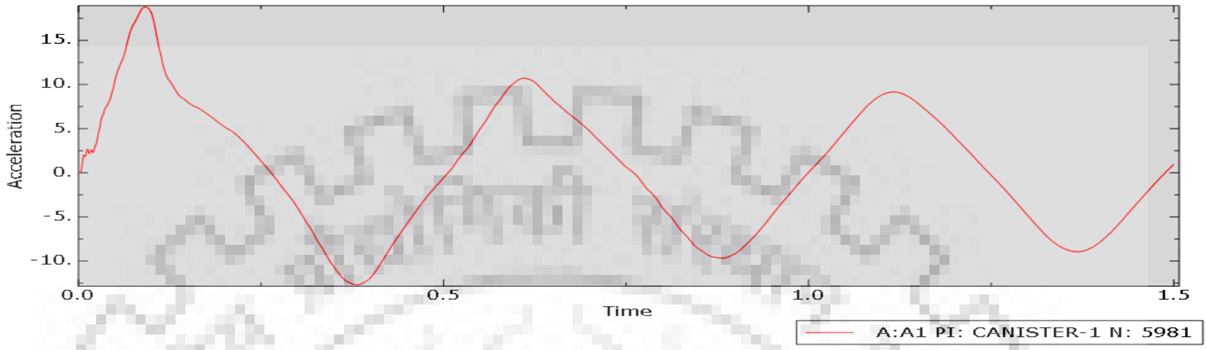
Figure 7.11: Velocity response (for both container and canister) with Chloroprene rubber using (a) One elastomer, (b) Two elastomer, (c) Three elastomers and (d) Five elastomers.

7.3 Using HNBR rubber

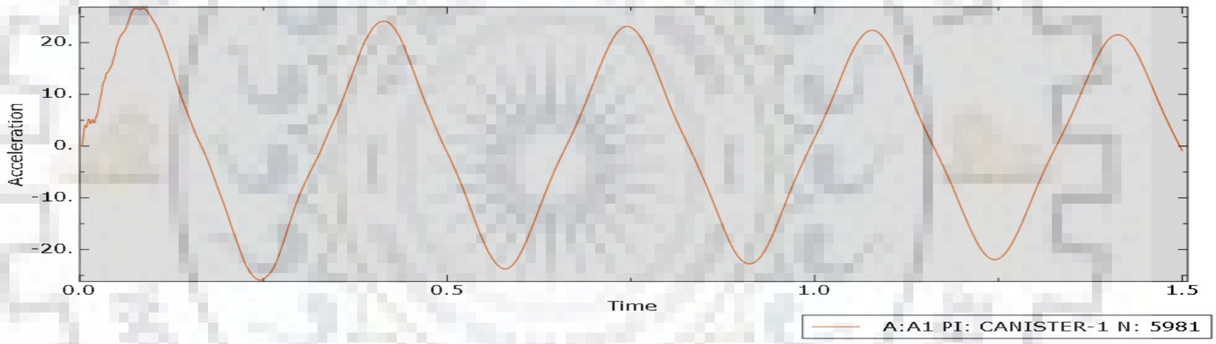
7.3.1 Acceleration of canister with 50g to container

Hydrogenated nitrile butadiene rubber (HNBR) is a heavy duty rubber widely used for the shock attenuation. From our analysis results, this material is showing the best damping among all the materials used. By using HNBR we could bring the acceleration shock from 500m/s^2 to 18.77m/s^2 which is really impressive result. But the problem with the application is that more the damping by any material, more is the deformation in that material. One more this is observed that by using single elastomer in our analysis, it is attenuating it faster, because of the hysteresis effect. The more is the deformation in the elastomer, more is the strain value and hence more energy is being dissipated in the form of heat.

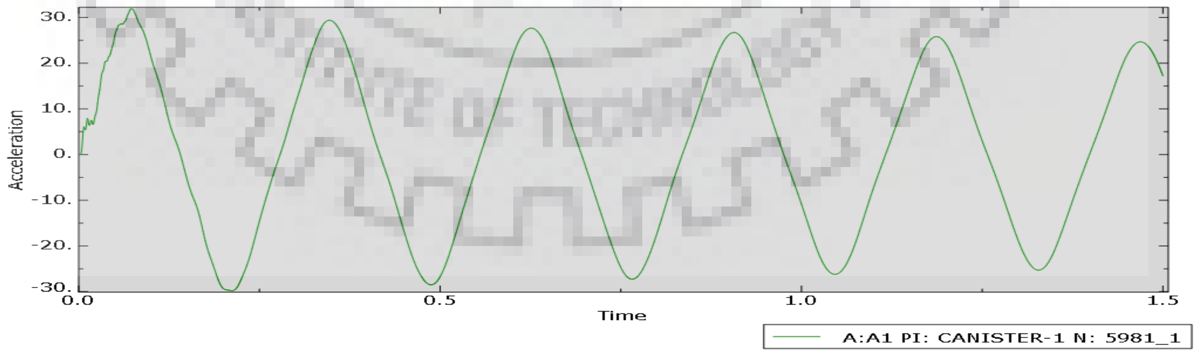
Acceleration plots using HNBR material with different number of elastomers at different location are shown below:



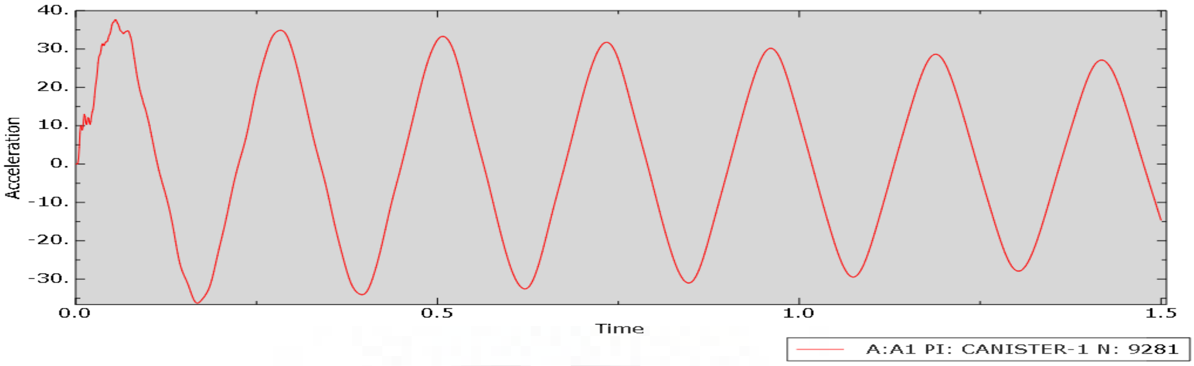
(a)



(b)



(c)

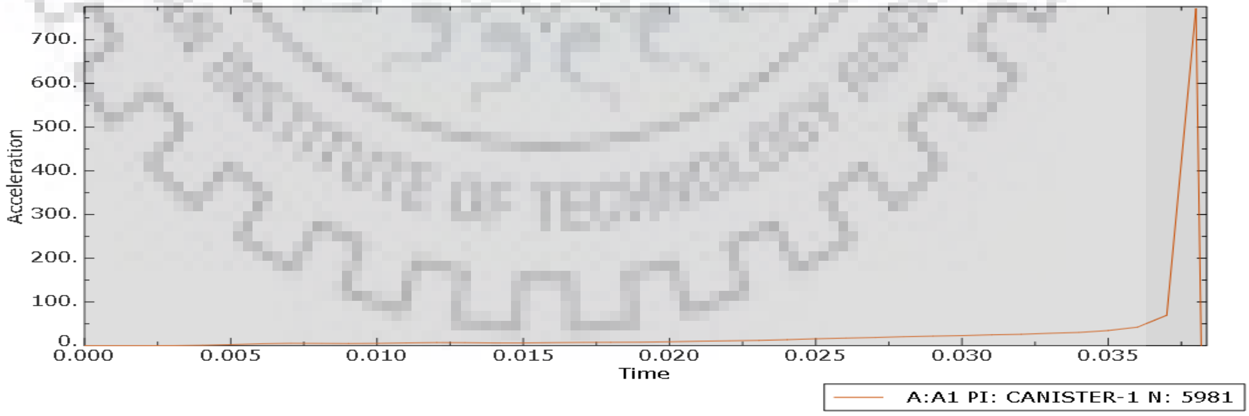


(d)

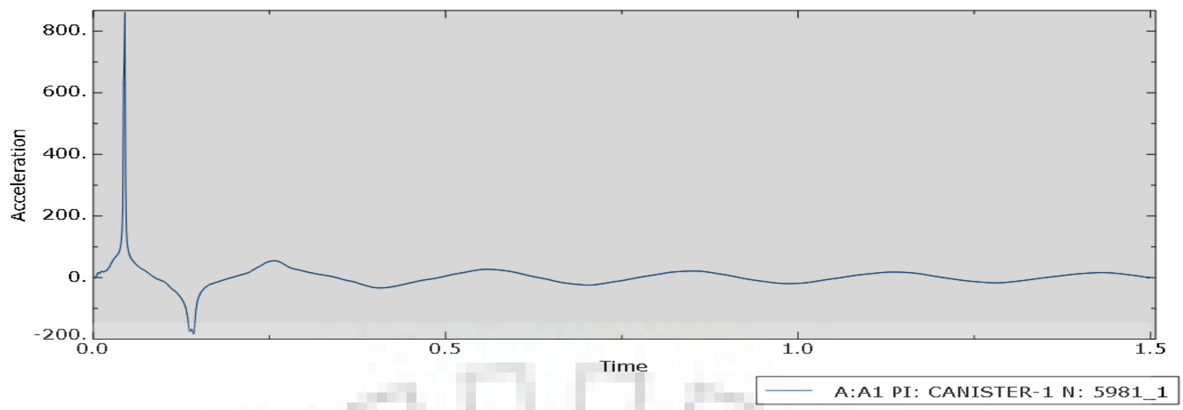
Figure 7.12: Acceleration of canister (when 50g is given to container) using chloroprene rubber with (a) One elastomer, (b) Two elastomers (c) Three elastomers and (d) Five elastomers

Form the simulation result, we found that the acceleration transmitted to the canister using one, two, three and five elastomers is 18.77m/s^2, 26.61m/s^2, 31.9m/s^2 and 37.705m/s^2 respectively. Here, we can see that acceleration of the canister is 18.77m/s^2 which is the best result till now but with large deformation in the elastomer and having maximum displacement of 81mm to the canister.

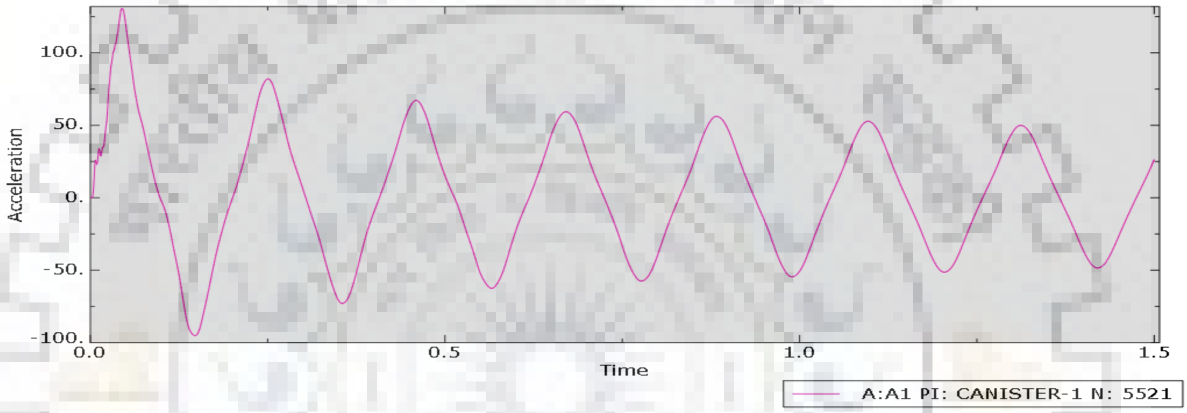
7.3.2 Acceleration of canister with 130g to container



(a)



(b)



(c)

Figure 7.13: Acceleration of canister (when 130g is given to container) using HNBR rubber with (a) One elastomer, (b) Three elastomers and (c) Five elastomers.

It is clear from this analysis using HNBR rubber material, that, one and two elastomers could not sustain this much high shock load and analysis was aborted. But three elastomers could sustain it but it could bring acceleration upto 81.2g with massive distortion in the elastomer and maximum displacement of 98mm of the canister. But when we used five elastomers, it could attenuate it to 13.083g with maximum displacement of 85mm in the canister.

7.3.3 Maximum displacement of canister

Displacement curves of canister with respect to the container are shown below:

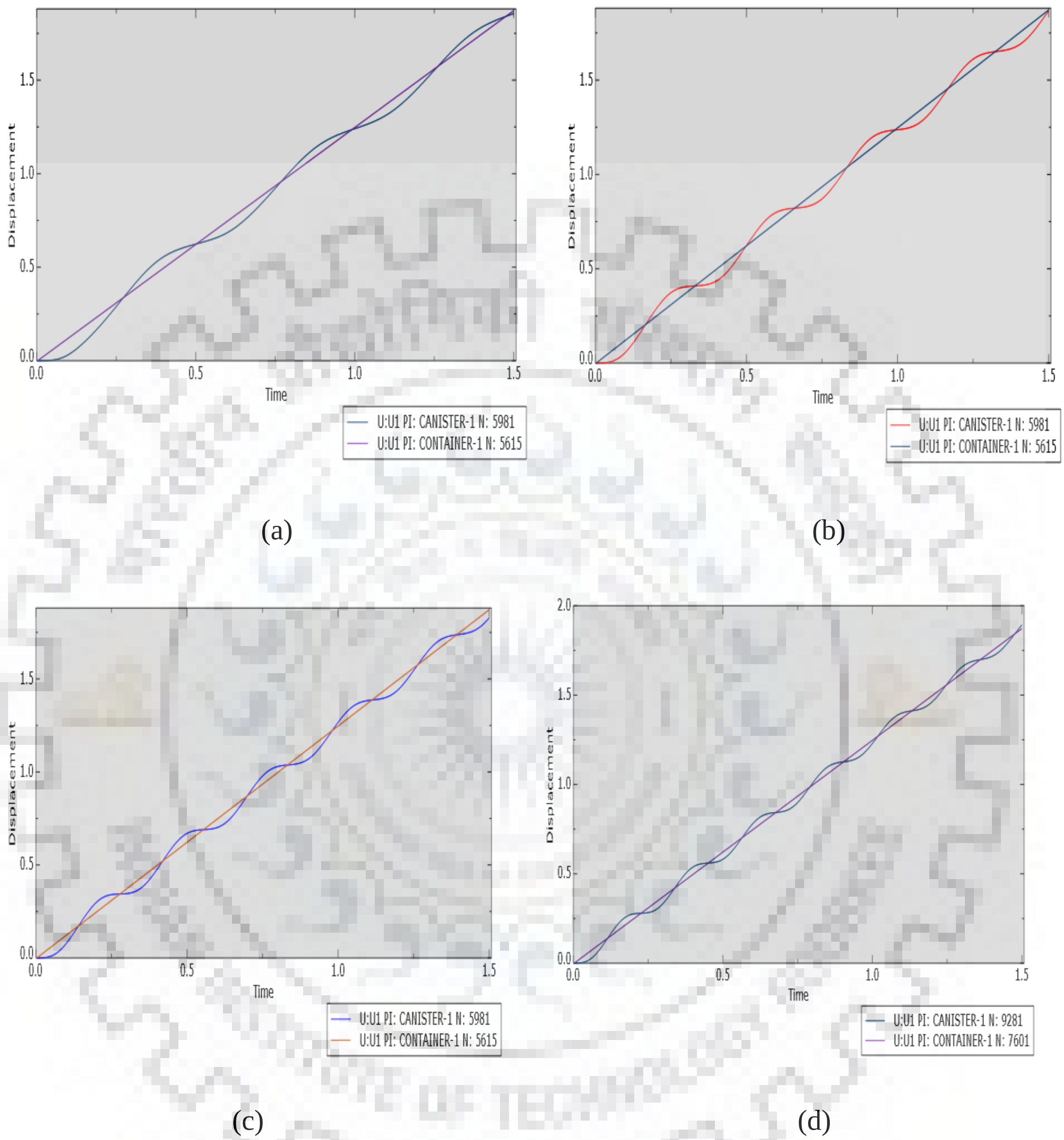
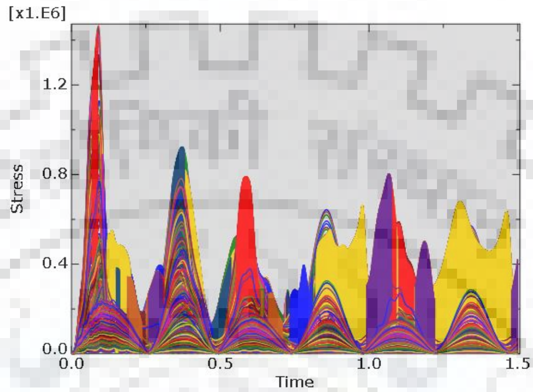


Figure 7.14: Maximum displacement of canister inside container using (a) One elastomer, (b)Two elastomers (c) Three elastomers and (d) Five elastomers using HNBR rubber.

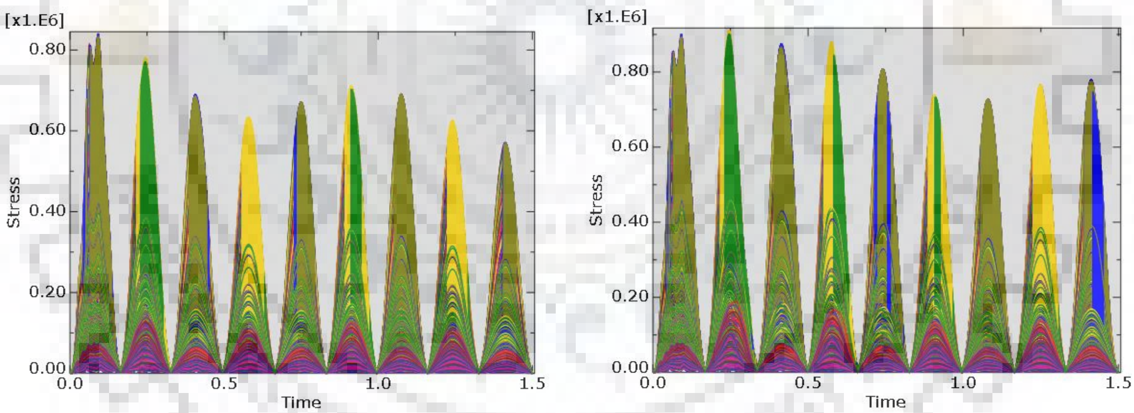
HNBR material is showing the best damping among all these materials used. But the problem is that being the softer material, it is showing more deformation when subjected to the shock load. As it can be seen from the analysis in abaqus that the deformation in the HNBR elastomer (using single elastomer) when subjected to the $500m/s^2$ acceleration is 81mm, which is pretty much high as compared to the required.

Maximum displacement of canister using one, two, three and five elastomers is 81mm, 63mm, 52mm and 42mm respectively.

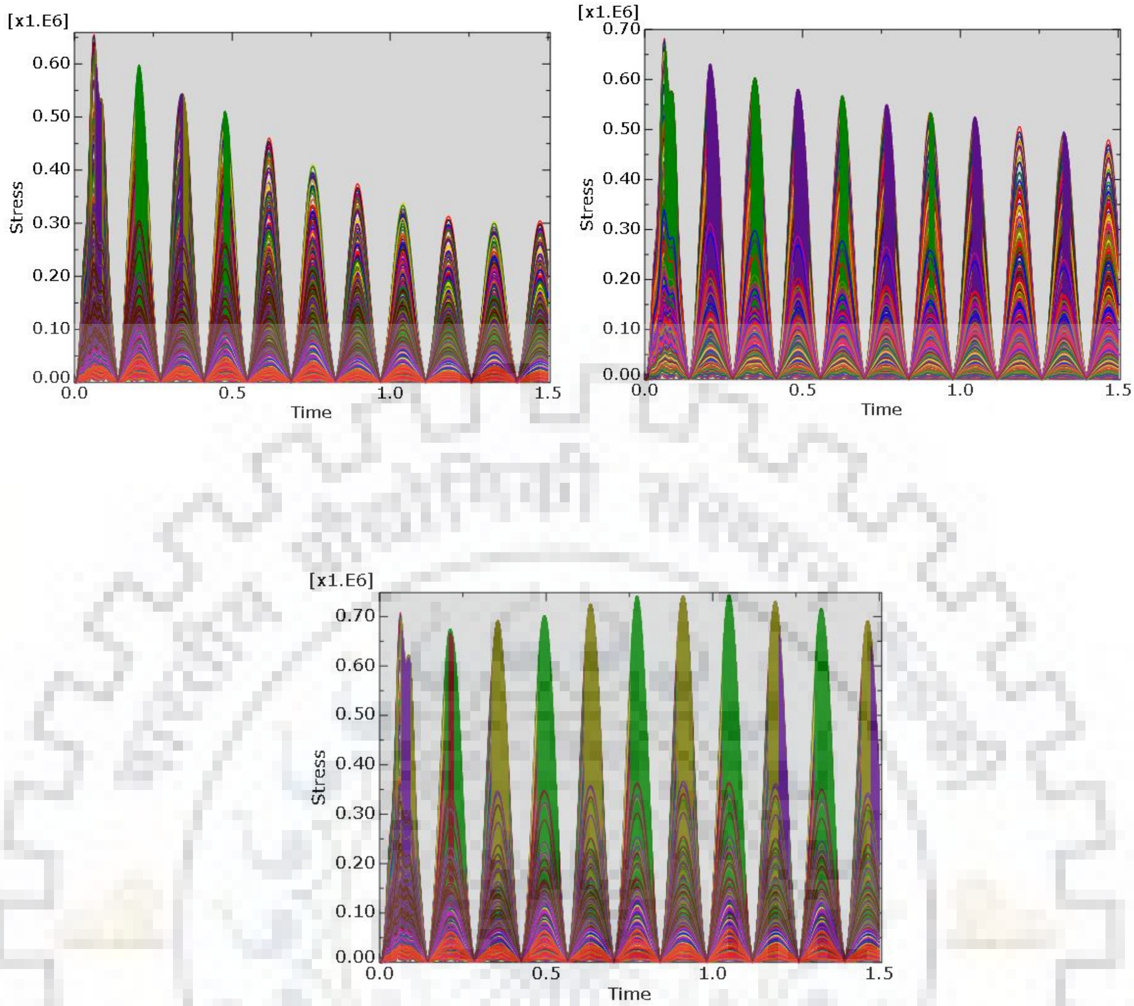
7.3.4 Stress behaviour



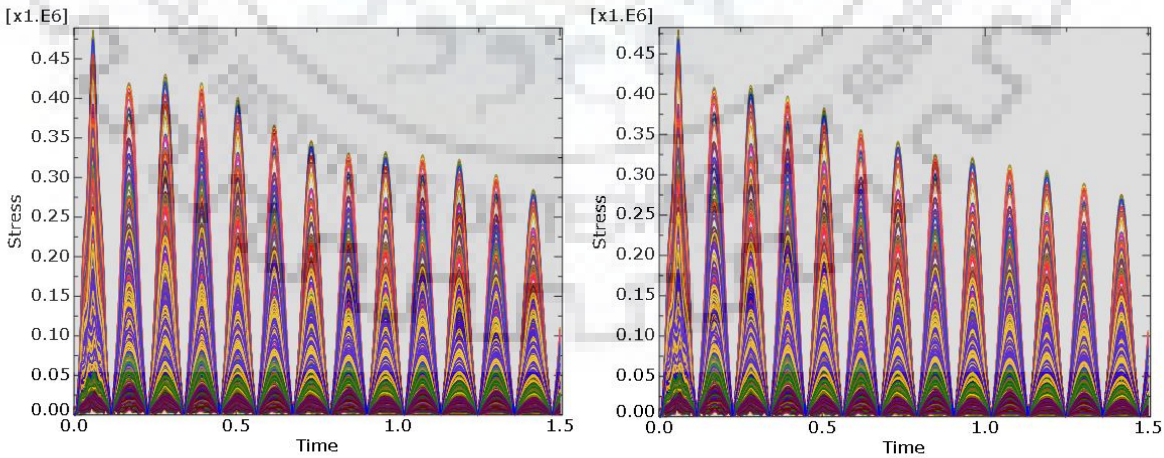
(a) Using one elastomer

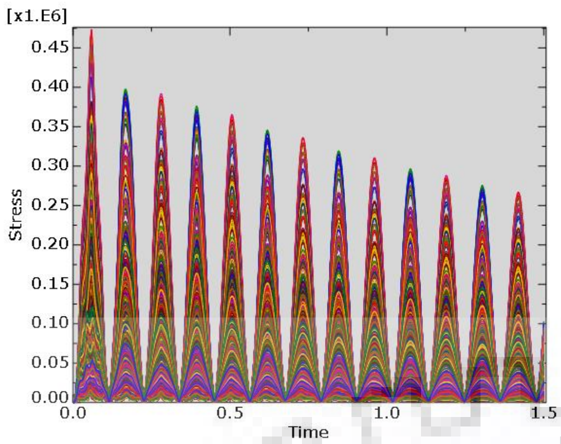


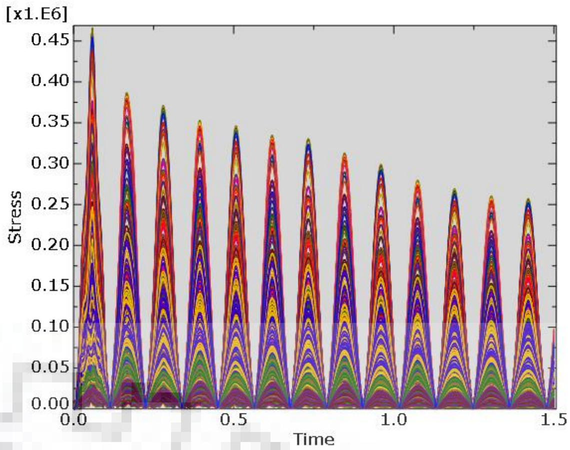
(b) Using two elastomers

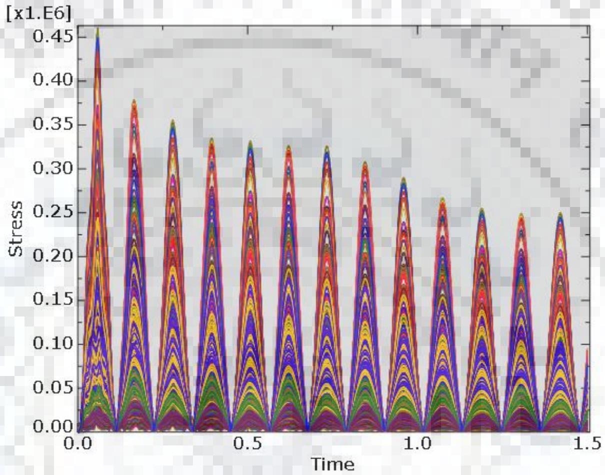


(c) Using three elastomers









(d) Using five elastomers

Figure 7.15: Stress plots (von mises) with chloroprene rubber using (a) One elastomer, (b) Two elastomers, (c) Three elastomers and (d) Five elastomers.

Here, we can see the similar trend in the stress values in the elastomer, i.e. as we are increasing the number of elastomers, maximum stress value in each of the elastomer is decreasing because of the shock load being distributed between the different number of elastomers. Also, stress value is decreasing with the time because of energy being absorbed in each cycle.

7.4 Neoprene Rubber and santoprene rubber

Neoprene rubber is also a heavy duty rubber which can be used for our purpose, but, we could find its hyperelastic properties from ansys material library [35] and we did the simulation using its hyperelastic properties only. From acceleration result data we found that maximum acceleration in the canister by using one, two and three elastomer is 36.39 m/s^2, 38.25 m/s^2 and 39.74 m/s^2, respectively. with Maximum deformation in elastomer using one, two and three elastomers is 57mm, 46mm and 39 mm respectively.

Santoprene rubber [36] is a very soft rubber material so, it could not sustain the shock load given to it and it was deformed extensively and because of that, analysis was aborted. thus, these two materials can not sustain such high shock load.

CHAPTER 8

CONCLUDING REMARKS

After doing simulation with different number of elastomers at different location, we choose some of the best results that are shown in the results.

Now, from these results, we need to find out the optimized result to satisfy both the constraints, i.e. to minimize the acceleration shock being transmitted to the canister and the deformation value in the elastomer (or say the maximum displacement of canister with respect to the container). For this, we need to plot graphs for acceleration in canister and deformation in elastomer values versus the the number of elastomers being used with different material properties.

8.1 Natural rubber

Acceleration of canister and deformation in elastomer versus number of elastomers for natural rubber material is shown below in tabular as well as graphical form.

No. of Elastomer	Acceleration (m/s^2)	Maximum deflection (mm)
1	20.2	71
2	28.6	57
3	34.8	44
5	49.8	27

Table 2: Acceleration (m/s^2) and maximum deflection (mm) using different number of elastomers of Natural rubber

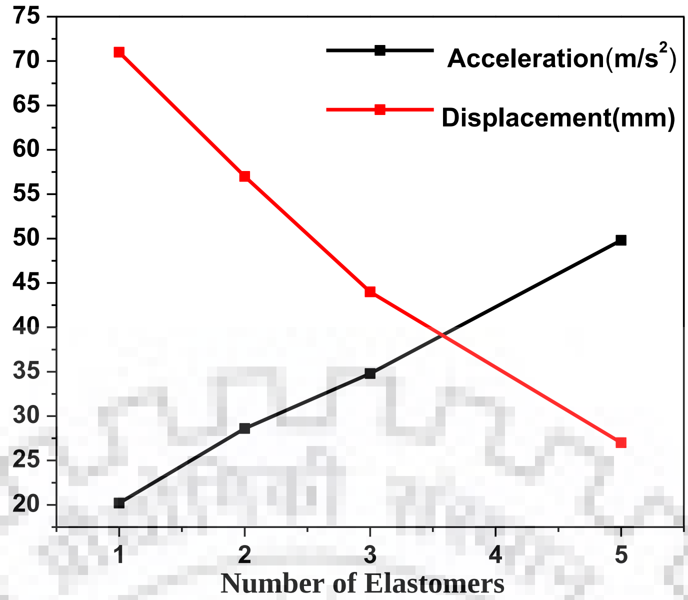


Figure 8.1: Acceleration (m/s^2) and displacement (mm) v/s number of elastomer plot using Natural rubber

From this plot, we can conclude that the as the acceleration value decreases, deformation in the elastomer increases. But we need to trade off this situation because we need to minimize both the conditions. So from the plot we can see that acceleration and deformation plots are intersecting at 39 value. So we can say that acceleration can be brought up to 39m/s^2 with maximum deformation of 39mm in the elastomer.

8.2 Chloroprene rubber

Acceleration of canister and deformation in elastomer versus number of elastomers for natural rubber material is shown below in tabular as well as graphical form.

No. of Elastomer	Acceleration (m/s^2)	Maximum deflection (mm)
1	20.44	77
2	27.23	59
3	33.1	52
5	38.1	31

Table 3: Acceleration (m/s^2) and maximum deflection (mm) using different number of elastomers of Chloroprene rubber

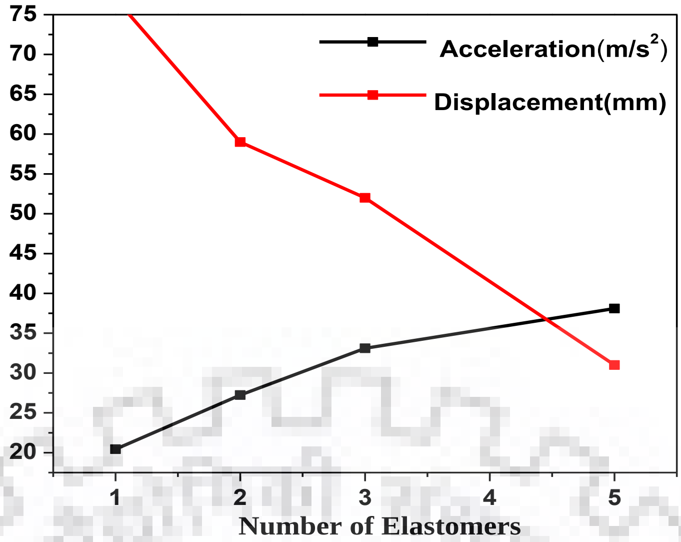


Figure 8.2: Acceleration (m/s^2) and displacement (mm) v/s number of elastomer plot using Chloroprene rubber

Similar trend can be observed here as, i.e. by increasing the number of elastomers, acceleration transmitted to the canister is increasing but the displacement value is increasing. To optimize both the constraints, we plot Acceleration (m/s^2) and displacement (mm) v/s number of elastomer plot using Chloroprene and which intersect at (37.2, 4.39), which means it can bring shock load from 50g to 3.72g with 37.2mm displacement, using 4.39 (~5) elastomers.

8.3 HNBR rubber

Acceleration of canister and deformation in elastomer versus number of elastomers for natural rubber material is shown below in tabular as well as graphical form.

No. of Elastomer	Acceleration (m/s^2)	Maximum deflection(mm)
1	18.77	81
2	26.61	63
3	31.9	52
5	37.705	42

Table 4: Acceleration (m/s^2) and maximum deflection (mm) using different number of elastomers of HNBR

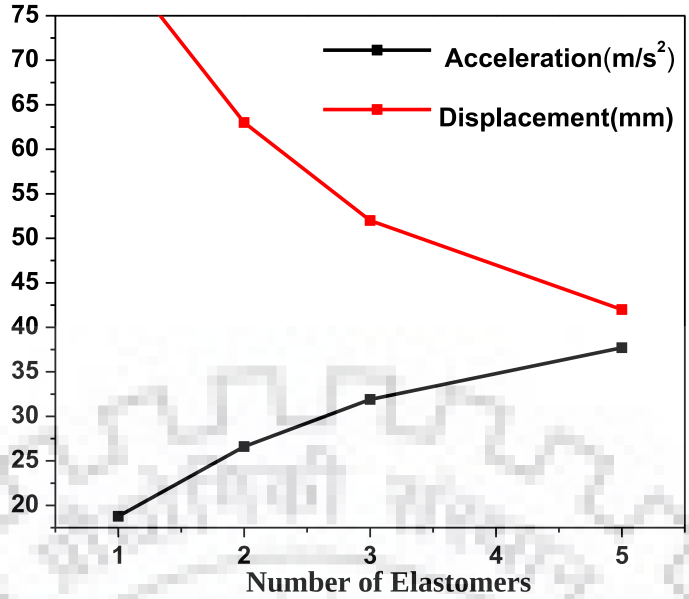


Figure 8.3: Acceleration (m/s^2) and displacement (mm) v/s number of elastomer plot using HNBR

Here, we can observe that these curves are going to intersect at 40 (approximately), which means that it can bring 50 g acceleration to 4 g using more than 5 elastomers.

Thus from this trade off, we can see that

- As we increase the number of elastomers, the acceleration being transmitted to the canister is being increased because number of medium is increasing for shock load to transmit from container to the canister.
- With increase in the number of elastomer, maximum displacement of canister is being decreased as shock load is being distributed among different elastomers.
- We could bring shock load from 500m/s^2 to 18.77m/s^2 but maximum displacement of canister was 84mm which is quite high.
- From trade off of different rubber materials, we found that natural rubber can attenuate this shock load upto 39m/s^2 with 39mm maximum displacement of canister using four elastomers.
- By using these materials, we found that our constraints can not be satisfied completely. So, we need some other means of energy absorber to attenuate it to the required level which are discussed in future work.

CHAPTER 9

FUTURE WORK

In future, there are following things that we are going to do:

- First of all we are going to develop a distributed mass modal to make our modal more realistic.
- Damping acceleration shock load from 50g to 2g with maximum displacement of +/-10mm seems difficult alone with elastomer. In future, we are going to analyse this using wire rope isolators and high energy rope mounts shown further

Figure 9.1: Wire rope isolators [37]

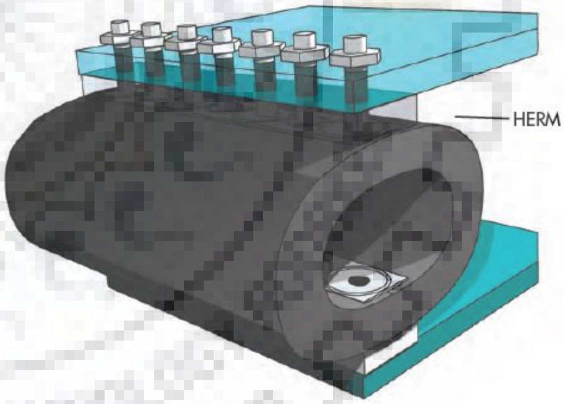


Figure:9.2: High energy rope mounts [37]

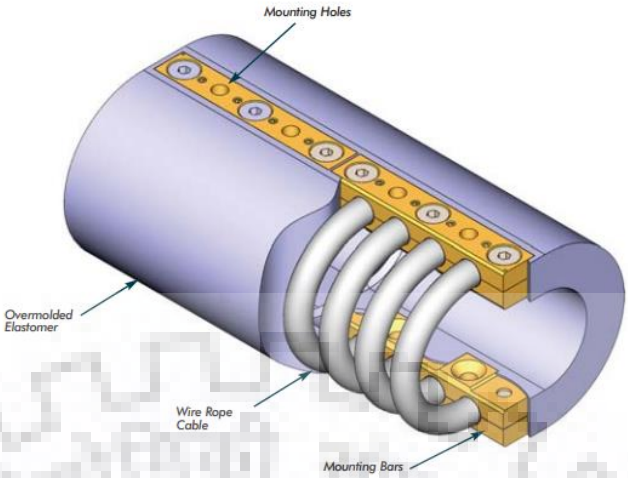


Figure 9.3: High energy rope mounts (sectional view) [37]

- If still there is some modification required, we can check using the viscous fluid damper.

- We are going to optimize the Ogden model parameters for the required constraints and see if these Ogden parameters are feasible or not. Then we can select a material with somewhat similar Ogden model parameters for better results.

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