Methodology development for vibration prediction on transportation packages in routine transport conditions using validated CAE method

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Abstract— Road transport plays an important role in routine transportation of passenger and goods. For transport of heavy goods, packages can be used which are secured to the transport vehicles. These packages can be restrained by two basic methods, direct method or indirect method. Direct restraint is when the load is prevented from moving by containing, blocking or attaching it to the vehicle whereas indirect method makes use of tie down ropes to restrain the load. Tie-down is when the load is prevented from moving by friction only. The integrity of the tie-down system is important from the point of view of safeguarding the general public from injury, protecting the transporting vehicle, and preventing any damage to the package and its content. The objective of this research is to develop a validated simulation methodology to model and simulate performance of transportation packages under routine transport conditions by correlating virtual results with the acquired road load data. Correlating virtual simulation results with road load data is challenging task as the complex construction of the transportation package plays a key role in simulation. The methodology developed can be used for vibration analysis of similar kind of packages.

***Keywords*: Road transportation, Tie-down ropes, Transportation methodology, Modal analysis**

I. INTRODUCTION

Road transport plays an important role in routine transportation of passenger and goods. The scenario referred to as "routine conditions of transport" is intended to cover the use and transport of packages under everyday/routine operations (i.e. conditions of transport in which there are no minor mishaps or damaging incidents to the packages). The package retention systems shall be designed such that the package integrity will not be affected under routine conditions of transport.
Numerous schemes have been used to secure the packages to vehicle beds. These schemes are derived from two basic restrain procedures: the rigid or bolted tie-down and the tension member tie-down. In bolted tie-down the base of the package is directly bolted to the bed of a vehicle. From a load carrying point of view, the bolted attachment systems are far superior for larger packages. However it has certain obvious disadvantages unless the package is shipped in the same vehicle routinely. Tie-down with tension members to restraint the package, is the most common form of load restraint and involves the use ofwire ropes. The load is prevented from moving by friction between the load and the vehicle. The wire ropes are tensioned using a turnbuckle, to clamp the load to the vehicle and to prevent the package from moving. The friction force comes from both the load weight and the clamping force of the ropes.
The inertial forces that act on the packages under routine conditions of transport can be derived from:
(a) Uneven road or track;
(b) Vibration;
(c) Linear accelerations and decelerations;
(d) Direction changes;
(e) Road skids in severe weather conditions.
The package, including its internal and external restraint systems, is required to be capable of withstanding the effects of the transport accelerations described in the table 1.1.[1]

Table 1: Acceleration factors for package retention system design.

Sr. No.	*Mode*	*Acceleration Factors*		
		Longitudinal	*Lateral*	*Vertical*
1.	*Road*	*2g*	*1g*	*2g Up,*

				3g Down
2.	*Rail*	*5g*	*2g*	*2g Up,* *2g Down*
3.	*Sea/Water*	*2g*	*2g*	*2g Up,* *3g Down*
4.	*Air*	*1.5g*	*1.5g*	*2g Up,* *6g Down*

II. LITERATURE REVIEW:

This section discusses the literature reviewed related to modal testing, finite element analysis simulations techniques to perform modal analysis and transient modal analysis.

•Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) states the safety regulations for package retention systems during routine transportation [1].

•Joint Service Specification 55555 (JSS 55555) is based on Environmental Testmethods for electronic and electrical equipment was prepared in 1979 which waslater revised on 2000.This specification describes standard proceduresand conditions for Environmental Tests for Service Electronic and ElectricalEquipment.The objective of roadability test is to ensure thatthe system shelter assemblage shall be capable of withstanding the vibrations andother dynamic stresses normally induced during transportation [2].

•Liphg I-hang et al. present a practice of dynamic durability analysis (from model correlation to fatigue life prediction) of a vehicle body structure, demonstrating an effort of efficiently using modal methods to conduct transient dynamic analysis of large structure with long time loads. A vehicle body structure subjected to major damaging road loads is studied utilizing the Finite Element Method. [3]

•Fei Lu et al. carried out a study mainly to analyze the effect of truck speed on vibration and shock levels separately in orderto further clarify the nature of shock and vibration during truck transportation, and to develop laboratory-simulated vibration and shock test methods that can be used to optimize protective packaging[4].

•S. P. Singh et al. provides a brief overview of the road and rail transportation environment in India. It also provides the results of a study that measured and analyzed truck and rail transport vibration for the major freight distribution routes between New Delhi, Bangalore, Mumbai, Chennai, Hyderabad and Kolkata [5].

•J. H. Evans states analytical techniques developed to evaluate the more common types of tie-down used to secure a shipping cask to a vehicle bed during transport are presented in this report. These frequently encountered types include the rigid or bolted tie-down of casks with rectangular and circular bases and the tension member tie-down with four-member [6].

•MSC Nastran Dynamic Analysis Users Guide is a guide to the proper use of MSC Nastran for solving various dynamic analysis problems. The basic types of dynamic analysis capabilities available in MSC Nastran are described in this guide. These common dynamic analysis capabilities include normal modes analysis, transient response analysis, frequency response analysis, and enforced motion.[7]

III. METHODOLOGY:

The following activities are to be carried out to develop the transportation methodology.

- **3D model generation from the drawings of the transportation package.**

This is done using 3D modeling software ProE. Individual components were modeled using various commands like sweep, extrude, revolve, etc. and then assembled to generate final 3D model**.**

- **Building of Finite Element (FE) model.**Proper selection of elements enhances the computational performance. The accuracy of solution and time convergence depends on the meshing of the component.

- **Determination of natural frequency and mode shapes of the package using simulation.**The first step in performing a dynamic analysis is determining the natural frequencies and mode shapes of the structure. These results characterize the basic dynamic behavior of the structure and are an indication of how the structure will respond to dynamic loading.

- **Experimental modal testing to validate the FE model.**

Modal correlation is used to validate the mass and stiffness of the FE model. The validated FE model is used for further dynamic analysis.

- **Road load data acquisition (RLDA).** Dynamic data acquisition is carried out on instrumented vehicles with the package on test tracks and public roads. This acquired data serves as an input for FE simulation.

- **Dynamic FE simulation using measured road load data**.

This analysis is the most general method for computing forced dynamic response. The purpose of a transient response analysis is to compute the behavior of a structure subjected to time-varying excitation.

- **Correlation of the virtual results with the experimental results so as to develop a validated methodology for transportation.**

The FEA simulation methodology is shown in the figure below:

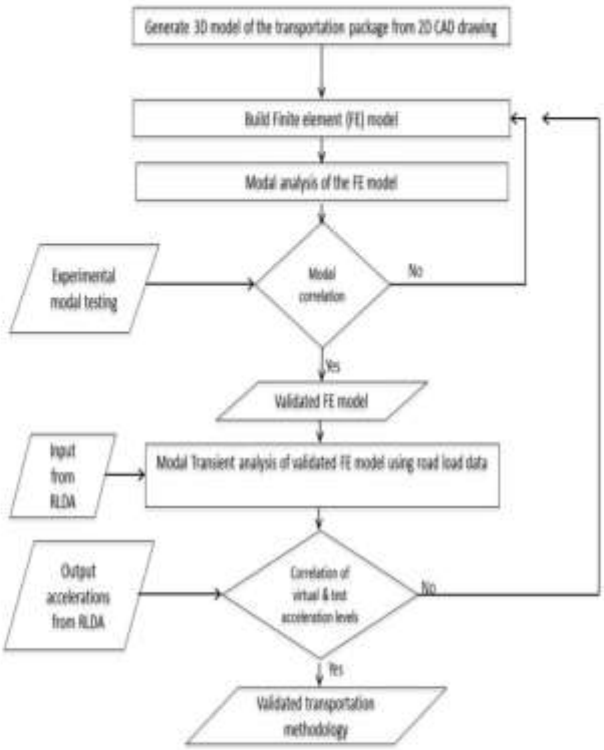

Figure 1: Virtual simulation methodology flowchart

IV. FINITE ELEMENT ANALYSIS.

The FE analysis was carried out to determine natural frequencies and corresponding mode shapes of the package.

4.1 Meshing of model:

The model was meshed using a combination of solid and shell elements. All the solid elements were modeled using tetrahedral elements while the shell elements were modeled using quad and tria elements.

The total no of nodes and elements are as shown in the table below.

Table 2: Mesh details

Sr. No.	***Parameter***	
1.	*No. of Nodes*	*102844*
2.	*No. of Elements*	*383846*

The meshed model and the materials used are as shown below:

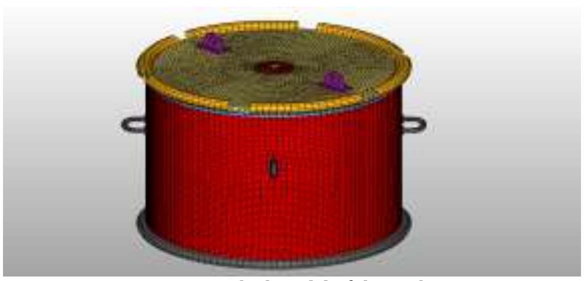
Figure 2: Meshed model of the package.

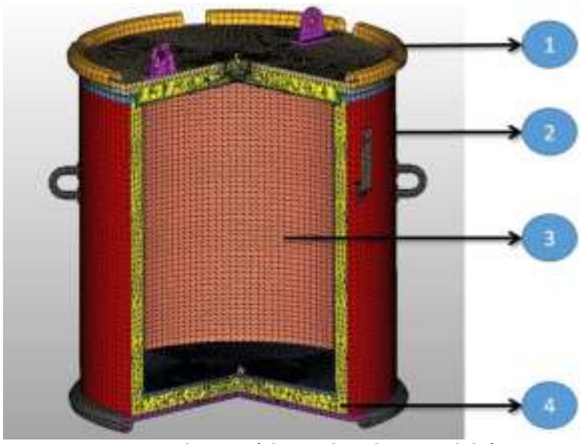

Figure 3: Sectional view of the mesh with material definition.

4.2Material and properties:

The package is made using the following material as shown in the table below:

Table 3: Material and Properties

Sr. No.	*Material*	*Young's modulus (MPa)*	*Density (Ton/m3)*	*Poiss-ons ratio*
1.	*A106GrB*	*2.1e+05*	*7.9e-09*	*0.3*
2.	*IS2062GrB*	*2.1e+05*	*7.9e-09*	*0.3*
3.	*SA240Typ304L*	*2.1e+05*	*7.9e-09*	*0.3*
4.	*LEAD_S27/ ASTM_B29*	*1.7e+04*	*1.1e-08*	*0.4*

4.3 Modeling contacts:

The package consists of different metals in contact having different material properties. The lead and steel components in the package form a non-homogeneous contact. [8] To obtain accuracy of the FE results, the modeling of contacts between mating parts is very important. The contacts between the steel and lead were modeled using spring elements. The effect of spring stiffness on natural frequency and mode shapes of the package i.e. the results of modal analysis was studied. The value of the spring stiffness is finalized after experimental modal testing. Thus the FE modal may have to be fine-tuned using iterative methods by varying spring stiffness to obtain modal correlation. [9]

4.4 Design of package retention components:

The package retention system should be capable of withstanding acceleration factors as given in table 1. Thus, for road transportation, the retention system should withstand a maximum of 2g force in the longitudinal direction. The weight of the package is approximately 5 tons. A tie down arrangement is used to secure the package to the vehicle. Tie-down ropes are used to help restrain a load using friction. The ropes must be correctly pre-tensioned. If the ropes loosen below the minimum required pre-tension during transportation, the friction forces are reduced and the package could shift from its location. Tie-down ropes are most effective if they are vertical and tight. [10] The more a rope is angled from the vertical, the less is the clamping force. The clamping force is very small when the rope is near horizontal. Although the tie down is most effective when the ropes are vertical, due to geometric constraints of the package and its fixture, the wire ropes are used at an optimum angle of 72 degrees with respect to horizontal.

The designs of the components of package retentions system are as follows.

1. *Wire ropes:*

The tension force in the tie down ropes can be found out using the following equation:

$$Ft = \frac{Fz.(A-\mu)}{n.\mu.\sin\alpha}$$

Where, Ft = tension force in the rope,

Fz = weight (Normal force)

A = Longitudinal acceleration factor

μ= Coefficient of friction

n = No of ropes

α= Angle of the rope

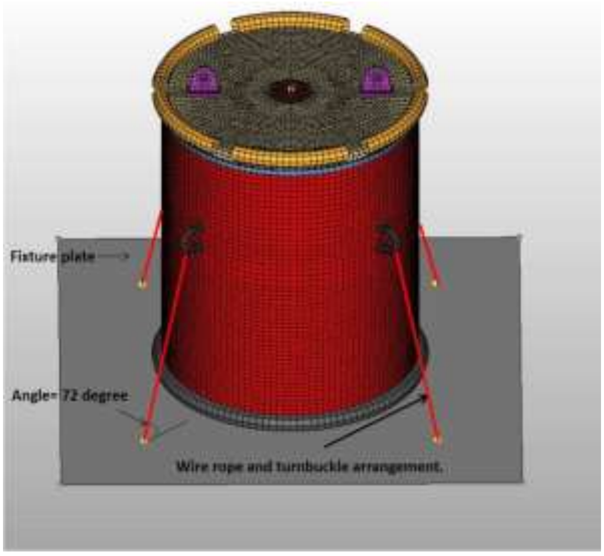

Figure 4: Package retention system

The package weighs approximately 5 tons, and its retention system should withstand acceleration up to 2g with the help of 4 wire ropes. Assuming the coefficient of friction between the package and its fixture to be 0.3, the tension force in each rope is calculated to be 73KN.

2. *Eye bolts:*

Eye bolts are used for securing the package to the base plate i.e. fixture during transportation. Each eye bolt should be able to withstand a force of 73KN applied at an angle of 72 degree with respect to horizontal.

Thus designing the bolt using maximum shear stress theory,

$$\tau permissible = \sqrt{(\sigma/2)^2 + \tau^2}$$

Thus M42 size eye bolts was selected.

3. *Turnbuckle:*

A turnbuckle is used to apply tension to the wire rope which helps to retain the package during transportation.

Figure 5: Turnbuckle for adjusting tension in wire rope.

4. *Stud bolts:*

Stud bolts are used to clamp the package retention system to the vehicle. The fixture is clamped to the chassis frame of the vehicle with the help of stud bolts. Designing the stud bolts using maximum shear stress theory, eight number of M20 stud bolts were selected.

5. *Fixture Plate*

The dimensions of the fixture base plate are 1700mmX1700mmX40mm. The plate dimensions are selected considering the transportation vehicle load body and the package dimensions. The fixture used is as shown below

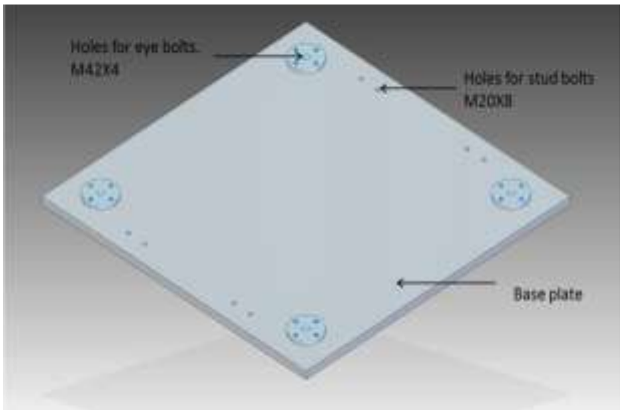

Figure 6: Fixture for mounting the package

V. RESULTS AND DISCUSSION

As a first step in performing a dynamic analysis, modal analysis was carried out to validate the FE model. Modal analyses are usually divided into two types based on the constraints. If the model is unconstrained it is referred to as a free-free analysis. The other type of modal analysis is carried out on a constrained system.

When a modal analysis is carried out on a free-free system, there will be six zero-frequency rigid body modes (or mechanism modes) found in addition to the elastic modes. These modes represent the free translation and rotation of the system in the six directions of motion and will be extracted as modes one through six. Mode seven is then referred to as the first flexible mode and will not be a zero energy mode.

An unconstraint or free-free modal analysis is always a good parameter to check the mesh model and ensure that the model is not internally constrained. [11] Thus, modal analysis is carried out on the unconstrained model usingFE software MSC Nastran to compute first 10 modes. Also to study the effect of spring elements, which are used to model the contact between lead and steel, varying spring stiffness are used to compute the corresponding natural frequencies and mode shapes.

The mode shape obtained for spring stiffness of 1500 N/mm is as shown below.

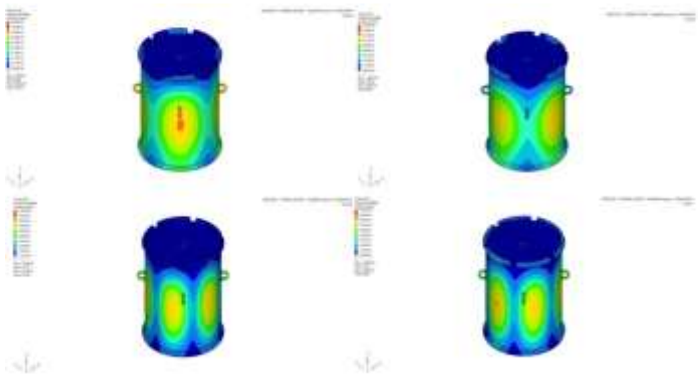

Figure 7: Mode shapes for spring stiffness of 1500 N/mm

The details of modal analysis with spring stiffness 1500N/mm are as shown in the table below:

Table 4: Modal analysis results for spring stiffness 1500 N/mm.

Mode No.	*Natural Frequency (Hz)*	*Type of Mode*
1.	*2.7831E-04*	*Rigid body modes*
2.	*1.5151E-04*	
3.	*3.8969E-04*	
4.	*4.4676E-04*	
5.	*6.4036E-04*	
6.	*7.0487E-04*	
7.	*249.15*	*Elastic modes*
8.	*250.03*	
9.	*283.02*	
10.	*284.26*	

The spring stiffness was varied to understand its effect on natural frequency and mode shapes.
The results for spring stiffness 1300 N/mm and 1E+08 are shown in the table below. First 6 modes were rigid body modes.

Table 5: Modal analysis results for varying spring stiffness.

Sr. No.	*Mode No.*	*Natural frequency (Hz)*	
		K = 1300 N/mm	*K=1E+08 N/mm*
1	*7*	*276.5*	*319.0*
2.	*8*	*276.8*	*319.1*
3.	*9*	*317.1*	*349.4*
4.	*10*	*350.3*	*404.2*

VI. CONCLUSION

- It was observed that there are no modeling errors in the mesh model of the package i.e. the model is not internally constrainedThus the mesh model can be used for further dynamic analysis.
- Also it is observed that the spring stiffness has a considerable effect on the natural frequency and mode shape of the package.
- The model has to be fine-tuned by varying the spring stiffness to obtain modal correlation with the experimental results of modal testing.

REFERENCES

[1] “Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)”. IAEA Safety Standards, 2012.

[2] Joint Services Specification on Environmental test methods for electronic and electricalequipment. Ministry of Defence, India, 2000.

[3]Liphg I-hang, HariAgrawal, “Durability analysis of a vehicle body structure using modal transient methods”.

[4] Packaging Technology and Science, ch. Effect of Vehicle Speed on Shock and VibrationLevels in Truck Transport. Wiley InterScience, 2010.

[5] S.P.Singh, A.P.S.Sandhu and E.Joneson, “Measurement and analysis of truckand rail shipping environment in india,” PACKAGING TECHNOLOGYAND SCIENCE, 2007.

[6] J.H.Evans, “Structural analysis of shipping cask, Cask tie-down design manual”.

[8] SivaramanGuruswamy, “Engineering Properties and Application of Lead Alloys”, CRC Press.

[9] S.S.Pachpore, J.M.Paranjape and Dr.S.S.Salunkhe, “Simulation of routine road load condition of transportation cask to assess tie-down arrangement”, technical paper.

[10]“Load restraint guide”, Guidelines and Performance Standards for the Safe Carriage of Loads on Road Vehicles, national transport commission & Road & traffic authority, NSW.

[11] Mathematical Overview of Normal Modes Analysis, MSC Nastran Dynamic Analysis User’s Guide.

