Computational Mechanics Tools

Course Project (Elasticity)

Ye Mao

Zichen Ding

mao.ye@estudiant.upc.edu

zichen.ding@estudiant.upc.edu

Master of Numerical methods on engineering - Universitat Politècnica de Catalunya

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1. Introduction

Nowadays, track bed structures need to be elastic to minimize the forces applied to support the train's pass over. In rail track where no ballast is added, high elastic material components are placed between the rail and the sleeper (or baseplate) to absorb the loads. However, on ballast beds, these rail pad (elastomeric mats) are also used to reduce high-frequency vibrations. These vibrations are channeled into the ballast bed throughout the rail. So, reducing this high-frequency vibration can guarantee the safety of the ballast.

Modern rail fastening system with such elastomeric mats allow rails to counter sink while using the load-transferring effect in rails and dispersing vertical forces. These components also provide insulation against more than possible vibrations and structure borne sound produced by any kind of irregularities in the wheels or in the track. By the way, they ensure these vibrations are not transmitted into the ground and minimize the secondary air-borne sound extend to the adjacent buildings.

Aforementioned noise generated at discontinuities or duet to sever features in the track and wheel, such as crossings, rail joints, welds or wheel flats.

In this report, we study assesses of the efficiency of some elastomeric mats designs through the analysis of their stiffness.

Our simulation environment is:

Software: ABAQUS/CAE 2019 student revision

Hardware: inter core i7 8750H, RAM: 16GB DDR4 2666HZ

2. Problem statement

2.1 Static massive case

This problem statement is given by some data which is already obtained.

Testing mat sample placed between two rigid plate that applied the stress uniformly.

Area:$300 \times 300\ mm^2$

Static load: the weight of the superstructure: $\sigma_0 = 0.02\ N/mm^2$

Dynamic load from the train passage: $\sigma_d = 0.01\ N/mm^2$

The amplification factor (for a train speed of 80 km/h): $\gamma = 1.4$

Frequency of excitation: $F = 5\ Hz$f

The study is carried out by different models. Firstly, it is calculated analytically the static stiffness of a massive mat considering the static case only. The features of this mat are:

Young modulus: $= 1.3\ GPa$

Poisson's ratio: $= 0$

H: $= 25mm$

Density: $800\ kg/mm^3$

A metallic plate where the force is applied with the following:

Young modulus: $= 210\ GPa$

Poisson's ratio: $= 0.3$

H: $= 25mm$

Density: $7800\ kg/mm^3$

	ELASTOMERIC MAT	STEEL PLATE
Young modulus	$1.3 \times 10^3\ MPa$	$2.1 \times 10^5\ MPa$
Poisson's ratio	0	0.3
Density	$8 \times 10^{-7} kg/mm^3$	$7.8 \times 10^{-6} kg/mm^3$

Table 2.1 Material basic property

To model the contact between the mat and the plate, different c constrains are taken into account. Then, the models are generated by Abaqus following FEM to proof the results.

2.2 Two new designs of static case

Secondly, two designs are proposed with the aim of optimizing material efficiency. Comparing with the fist massive case, these two new proposals are evaluated in terms of stiffness efficiency. These designs can be seen in the following subsections.

2.3 Dynamic massive case

Thirdly, an analysis of the dynamic performs the response of the massive mate.

2.4 Improved design

Finally, two improvement of the two previous design is made. Not both of them have good results from evaluation. We will take them in following subsections.

3. Methodology

3.1 Volume determination

In order to compare new designs of the elastomeric mat, we evaluate the mats by their stiffness which is defined as the stress applied divided by the resulting displacement. Since we have the same static load, we can get the comparing with the same volume. Then, we can only focus the value of displacement. The displacement is larger the stiffness value is smaller, which means the structure is more safety. Also, we can set the same stiffness, and only focus on the volume, the less volume means the more economy. In this report, we choose the 1st way, checking the value of stiffness with the same volume.

Calculate all the dimensions of the section in different designs.

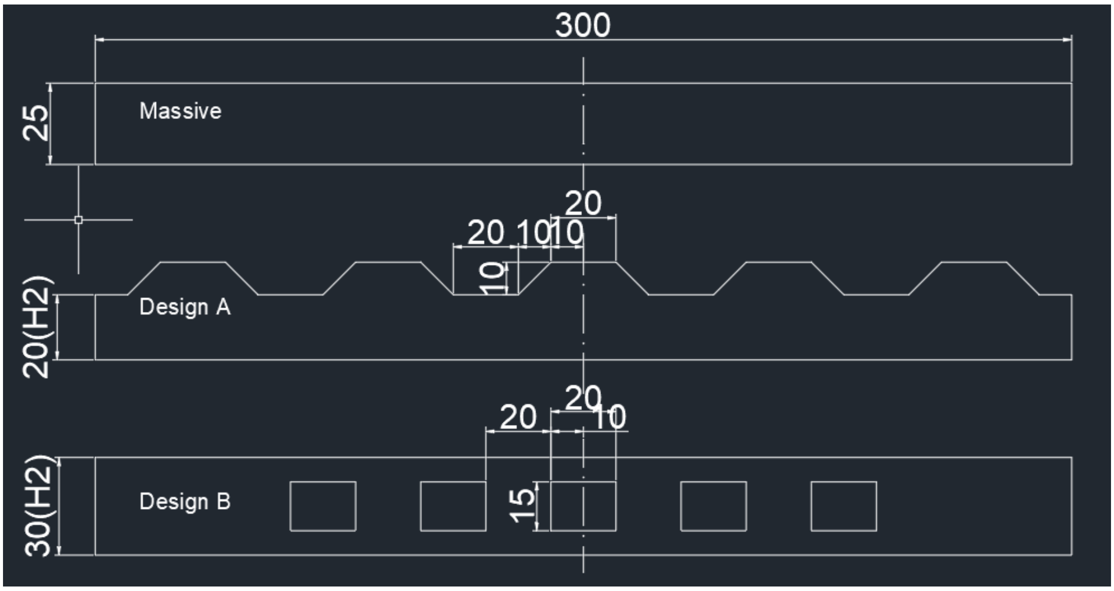


Figure 3.1 Section of volume of Massive, Design A and Design B

It is easy to calculate the H_2, the thickness of mat, by hand calculation or by the Auto CAD. We keep all the section area equal to $300 \times 25 = 7500\,mm^2$

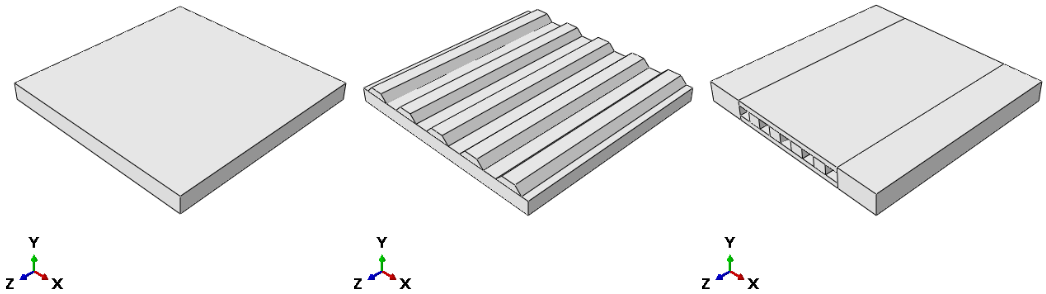


Figure 3.2 Geometry of Massive, Design A and Design B

3.2 Contact and interface models

3.2.1 The constraint behavior

In the figure below, different meshes have been used for the elastomeric mat and steel plate. These two meshes are dissimilar following the fact that when the master and slave regions have different mesh densities, more elements on the slave region means that more contract element are created. This will produce a more accurate solution.

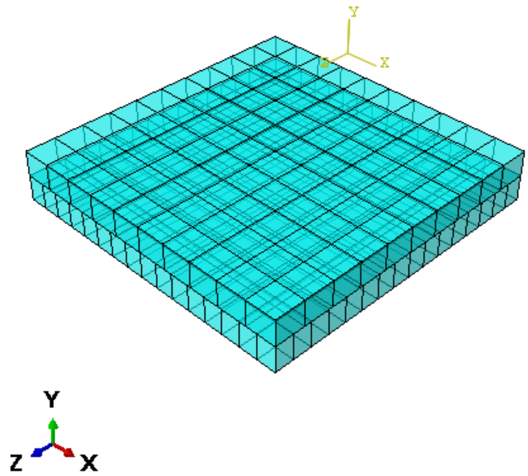


Figure 3.3 Mesh of massive model

It is important to understand how contact element are created when selecting which region will be the master and which one will be the slave, since the two can be interchangeable. The solver projects vector normal from the master region to the slave region. It then creates contact elements when these normal intersect in the slave region and are within the search distance criteria for the contact pair. This means that when the two regions of a pair do not have corresponding one-to-one elements, the number of contact elements that the solver creates can be changed depending on which region it projects the elements from and which the region it projects to.

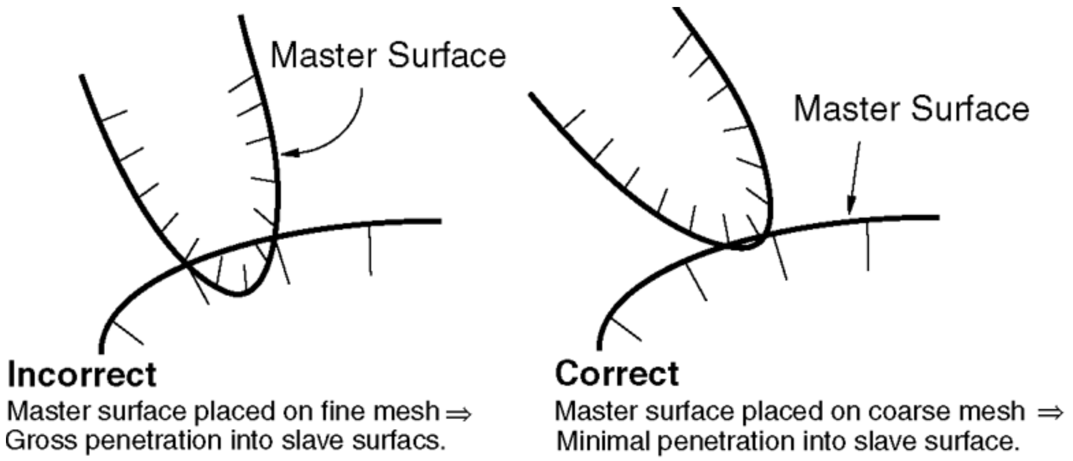


Figure 3.4 Theoretical to choose Master Surface and Slave surface.

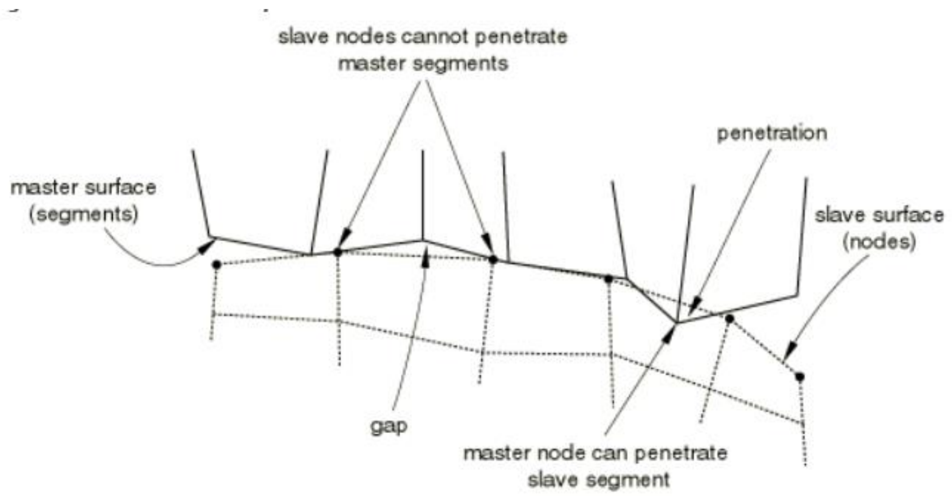


Figure 3.5 Master surface penetrations into the slave surface due to a coarse mesh of the slave surface for node-to-surface contact

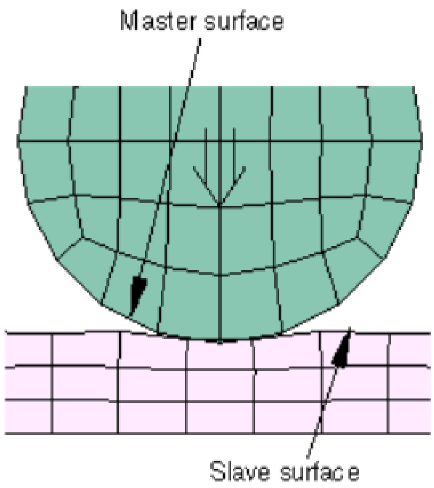


Figure 3.6 The master surface contacts the slave surface at a single element face

3.2.2 Tie constraint model

Totally constrained contact is defined using tie constraints. The tie constraint ties two separate surfaces together so that there is no relative motion between them. In this model, we neglect the friction in Tangential behavior. Surface-based constraint using a master-slave formulation and the constraint prevents slave nodes from separating or sliding to the master surface.

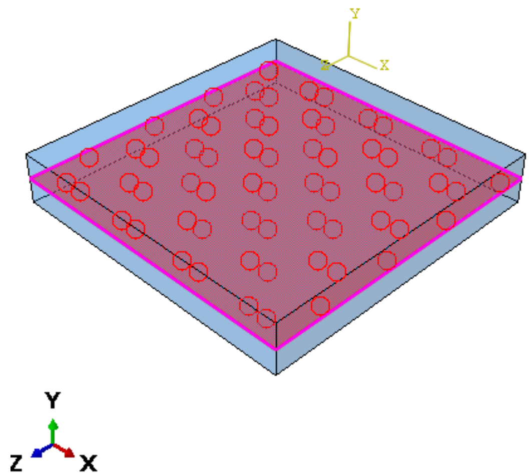
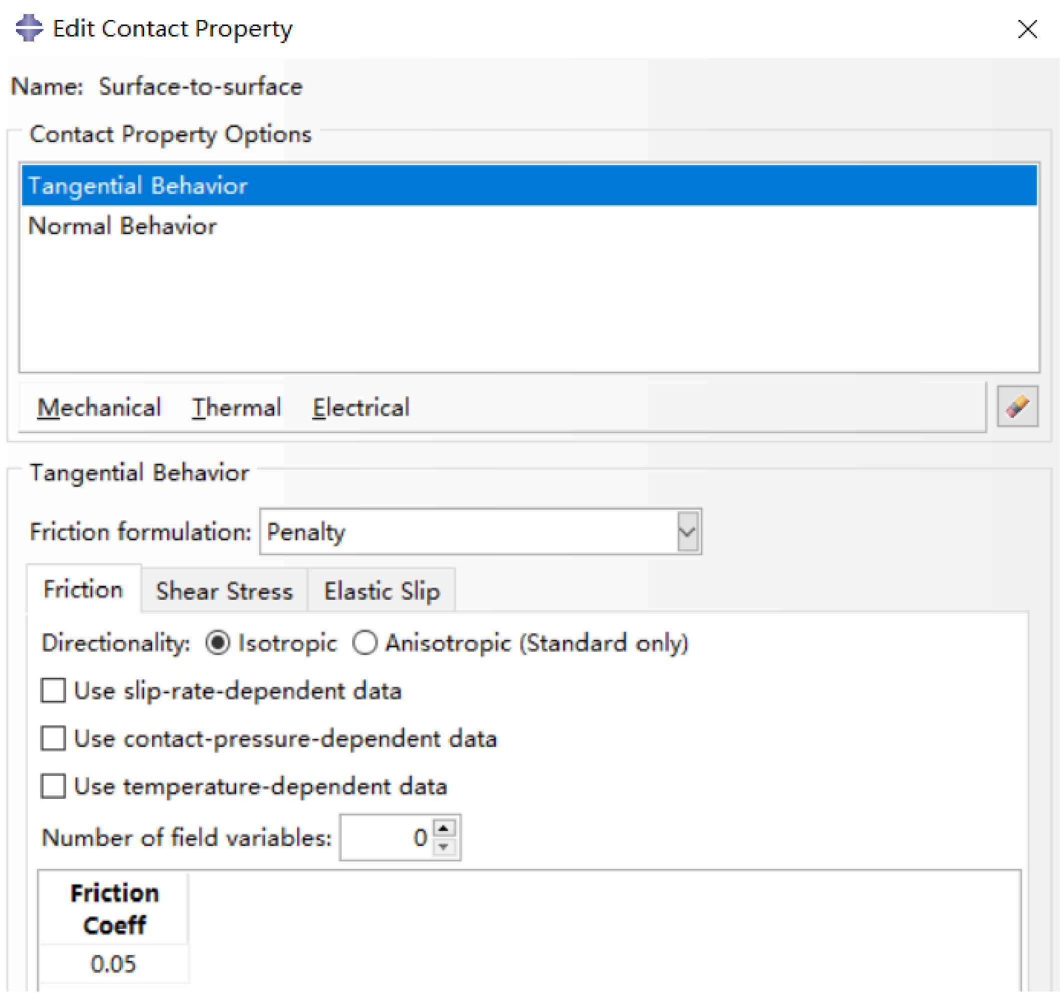


Figure 3.7 Constraints of Tie massive model

3.2.3 Surface to surface contact model

This kind of mesh are used to obtain more realistic results. In this context, friction effect and no penetration conditions are considered.



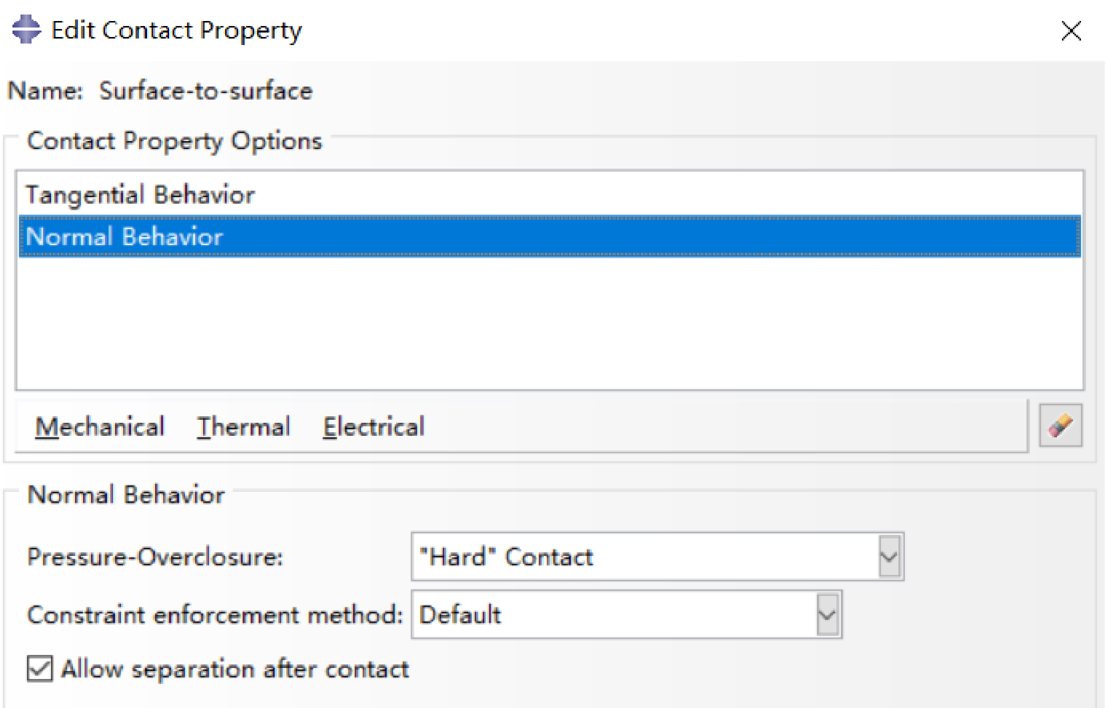


Figure 3.8 Surface-to-surface Contact Property

3.3 Dynamic load

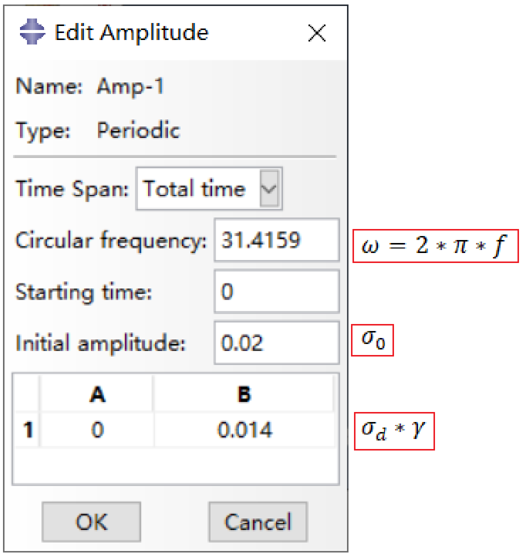
In order to analyze the dynamic repose of the mat, a dynamic load was applied. The mathematician expression of it is:

$$\sigma(t) = \sigma_0 + \sigma_d * \gamma * \sin(\omega * t)$$

Where $\omega = 2 * \pi * f$ and σ_0 is the static load.

$$\sigma_d = 0.01\, N/mm^2, \gamma = 1.4, f = 5\, Hz$$

The input details of dynamic load are showed in following:



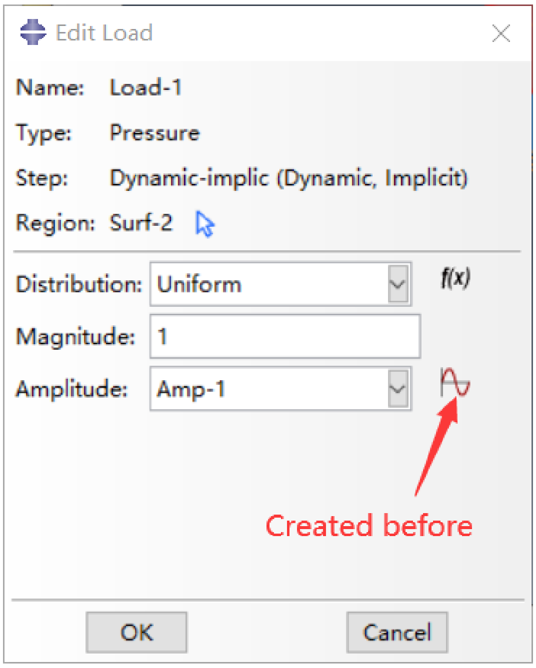


Figure 3.9 Dynamic load input

3.4 Analysis

In order to compute the stiffness of mat and dynamic response, two analysis types are considered. First, to compute the mat stiffness, a static linear analysis was performed. And then, to compute the dynamic response, a dynamic implicit analysis was carried out. Non-linear effects are not considered.

For the dynamic response, small time increments were taken into account for an accurate representation of the displacement-time graphic. The input of dynamic step can be observed in figure below.

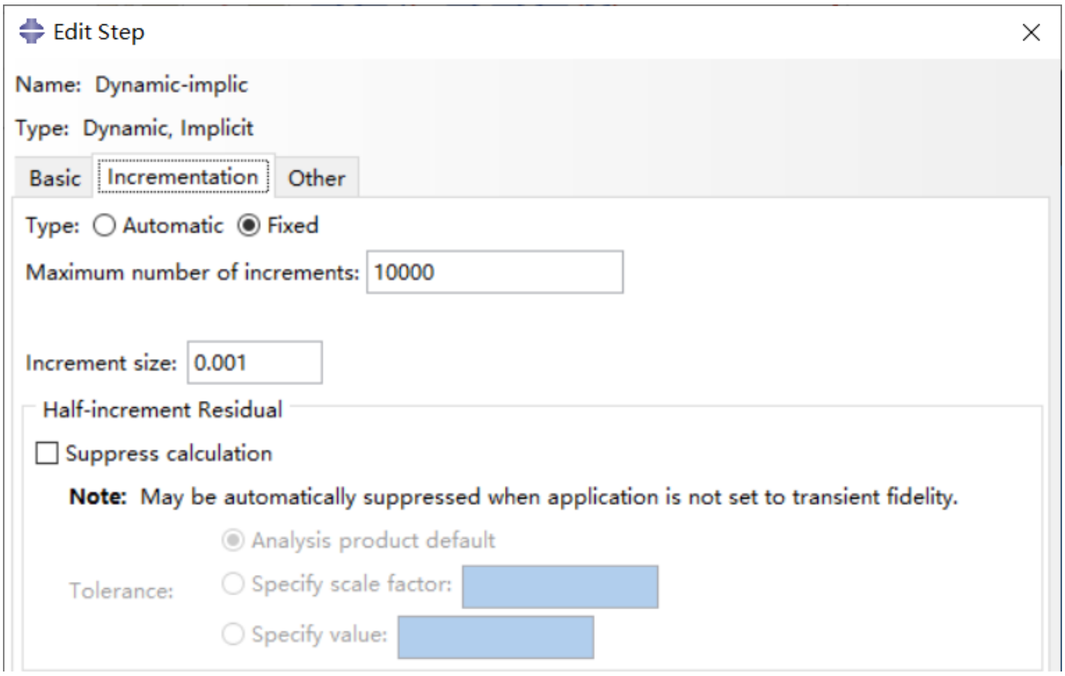


Figure 3.10 Dynamic step input

4. Result and discussion

In this section, the obtained result will be shown and discussed for each model and analysis performed. We correlate the results and models to obtain the physical meaning.

4.1 Results of massive mat model and linear static analysis

4.1.1 Theoretical calculation of stiffness

The mat stiffness was calculated according elasticity theory in infinitesimal strains.

$$\boldsymbol{\sigma} = \boldsymbol{\varepsilon} : C$$

We note that the Poisson ratio equal to zero. So, only the displacement controls the stiffness under the same pressure. Then, 1D elastic equation can be used:

$$\sigma_{yy} = E \cdot \boldsymbol{\varepsilon}_{yy}$$

$$\frac{\sigma_{yy}}{E} = \boldsymbol{\varepsilon}_{yy}$$

$$\int_0^h \frac{\sigma_{yy}}{E} dy = \int_0^h \frac{\sigma_0}{E} dy = \frac{\sigma_0}{E} h$$

$$\boldsymbol{\varepsilon}_{yy} = \frac{dv}{dy}$$

$$dv = \boldsymbol{\varepsilon}_{yy} dy$$

$$v = \int_0^h \boldsymbol{\varepsilon}_{yy}\, dy = \int_0^h \frac{\sigma_{yy}}{E} dy = \frac{\sigma_0}{E} h = \frac{0.02}{1300} \cdot 25 = 3.85E - 04\, mm$$

Where $\sigma_0 = 0.02\, N/mm^2$ （static load） and $E = 1300\, MPa$

Then the stiffness is:

$$S_{theor} = \frac{\sigma_0}{v} = \frac{E}{h} = \frac{1300}{25} = 52\, N/mm^3 = 0.052\, KN/mm^3$$

4.1.2 The stiffness of Surface to surface contact model

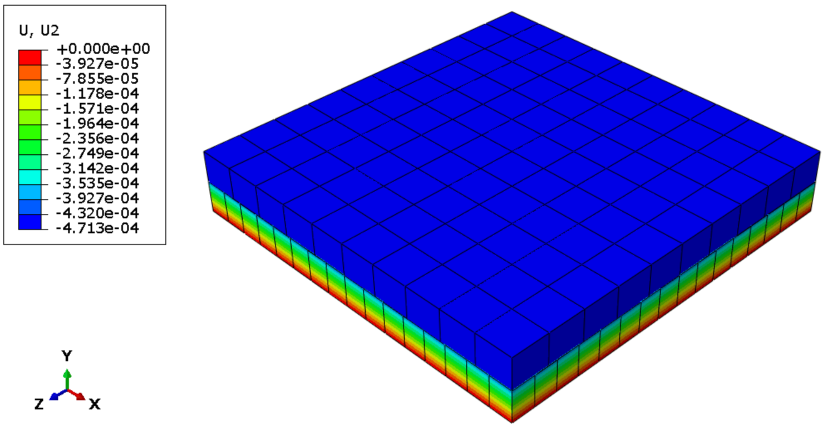


Figure 4.1 Displacement of instance under surface to surface contact model

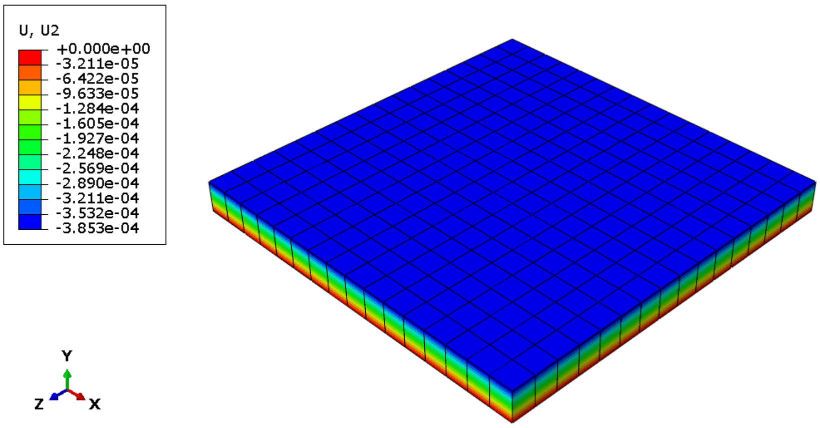


Figure 4.2 Displacement of mat under surface to surface contact model

We obtain the maximum vertical displacement $v = -3.853E - 04\,mm$

$$S_{sur\ to\ sur} = \frac{\sigma_0}{v} = \frac{0.02}{3.853E - 04} = 51.90\ N/mm^3 = 0.052\ KN/mm^3$$

4.1.3 The stiffness of tied constraint model

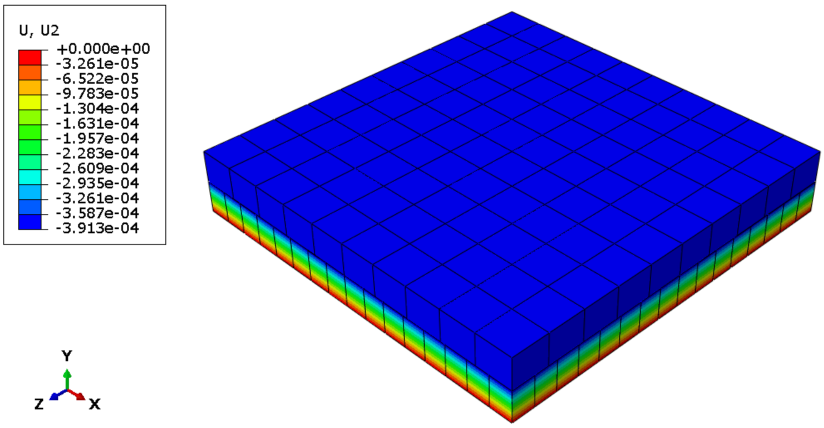


Figure 4.3 Displacement of instance under tied constraint model

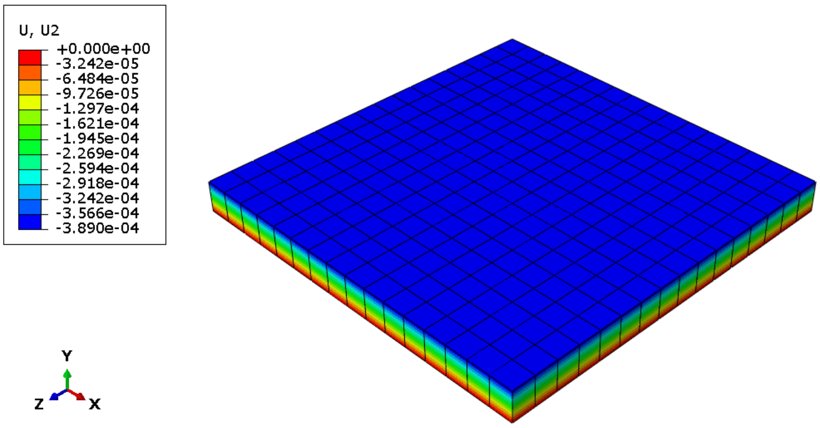


Figure 4.4 Displacement of mat under tied constraint model

We obtain the maximum vertical displacement $v = -3.89E - 04\,mm$

$$S_{tied} = \frac{\sigma_0}{v} = \frac{0.02}{3.89E-04} = 51.41\ N/mm^3 = 0.051\ KN/mm^3$$

Comparing the stiffness of massive mat surface-to-surface model and tied constraint model, the surface-to-surface model's result is more closed to the theorical result. However, both of the model can get good simulation result. The surface to surface model has more accuracy, while the tied constraint model is cheaper.

SURFACE TO SURFACE MODEL	TIED CONSTRAINT MODEL
JOB TIME SUMMARY USER TIME (SEC) = 93.400 SYSTEM TIME (SEC) = 6.7000 TOTAL CPU TIME (SEC)= 100.10 WALLCLOCK TIME (SEC)= 101	JOB TIME SUMMARY USER TIME (SEC) = 62.70 SYSTEM TIME (SEC) = 7.0000 TOTAL CPU TIME (SEC)= 69.70 WALLCLOCK TIME (SEC)= 76

Table 4.1 Cost between surface-to-surface model and tied constraint model

4.2 Results of Design A, B and linear static analysis

Since the surface to surface model is more closed to the realistic. We can apply it in the left models of this report. But, to speed up calculation, we neglect the steel plate and apply the harmonic pressure directly on the mat.

In the following figure, we can see the displacement of two new design.

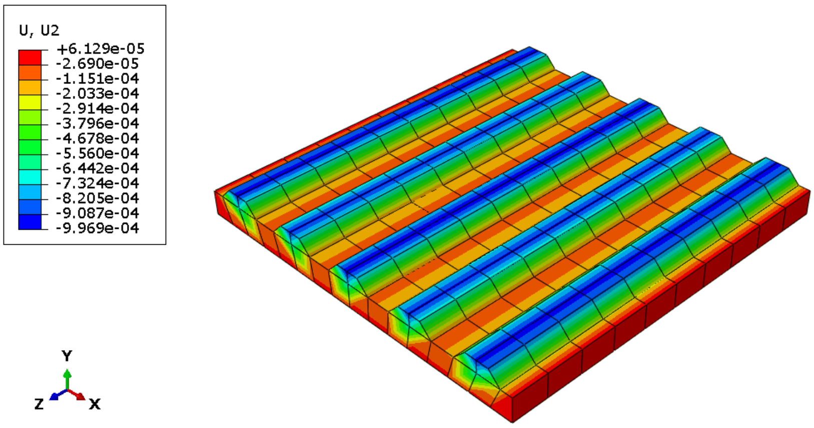


Figure 4.5 Displacement of mat under Design A

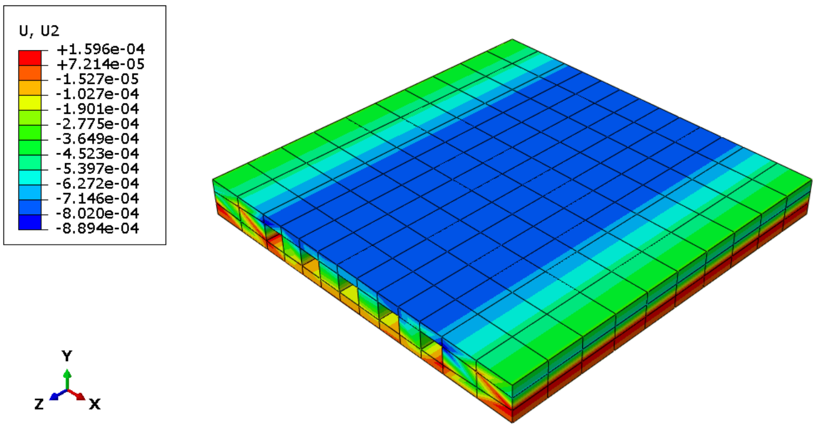


Figure 4.6 Displacement of mat under Design B

Both of the results are similar. The maximum vertical displacement of design A equal to $v = -9.969E - 04\ mm$, while the one design B equal to $v = -8.894E - 04\ mm$

Design A stiffness:

$$S_{D\_A} = \frac{\sigma_0}{v} = \frac{0.02}{9.969E - 04} = 20.06\ N/mm^3 = 0.02\ KN/mm^3$$

Design B stiffness:

$$S_{D\_B} = \frac{\sigma_0}{v} = \frac{0.02}{8.894E - 04} = 22.49\, N/mm^3 = 0.022\ KN/mm^3$$

Also, comparing the stiffness, both designs show similar results. So, their mechanical behavior will be similar. Both of them are better than the massive structure in the same volume.

4.3 Design C

In this section, we will study another model to improve the Design A and B. Now, the first model is similar as Design B. The only difference is that we add two rectangular channels than Design B. Then, to keep the same volume, we add the area on the top and bottom of this mat. This module can be called as Design C.

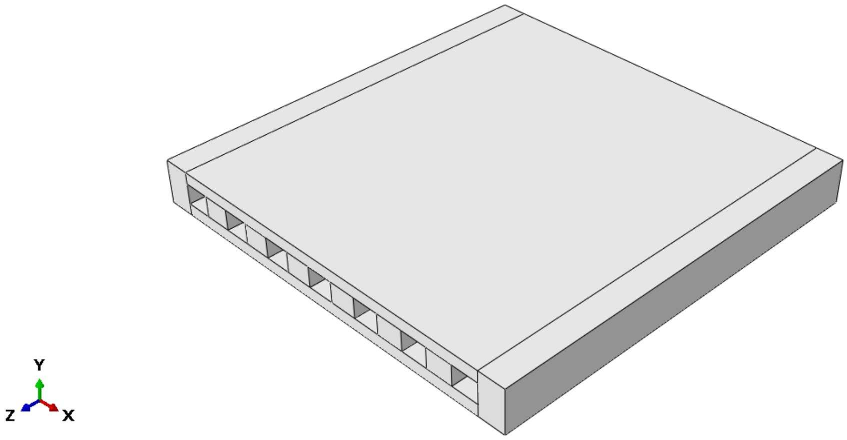


Figure 4.7 Geometry of Design C

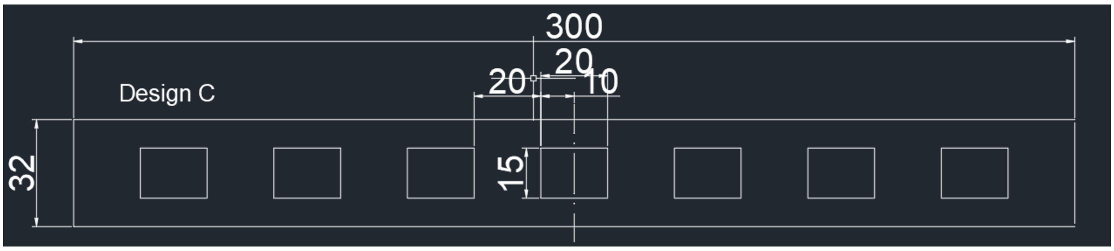


Figure 4.8 Section of volume of Design C

From the section, we could see the detail of dimensions. Comparing the thickness of Design B, it increases to 32 mm.

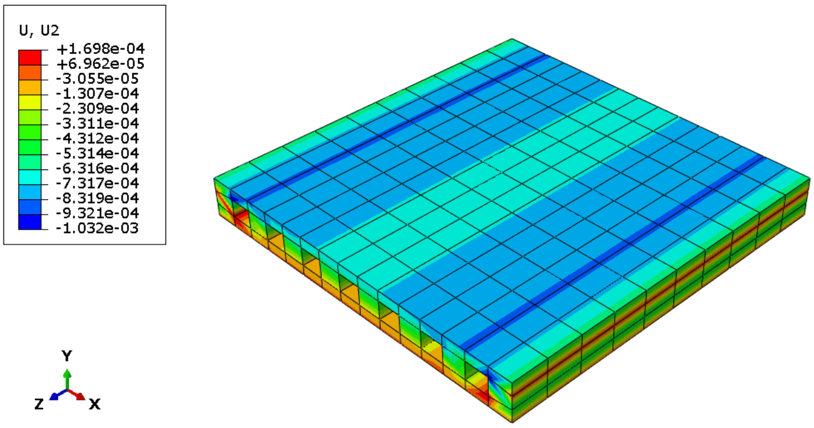


Figure 4.9 Displacement of mat under Design C

The maximum vertical displacement of design A equal to $v = -1.032E - 03\ mm$

Design C stiffness:

$$S_{D\_C} = \frac{\sigma_0}{v} = \frac{0.02}{1.032E-03} = 19.38\,N/mm^3 = 0.019\ KN/mm^3$$

Obviously, the stiffness of Design C is the best in all the modules. This module decreases the strong part area and add it to the weak part of the mat. This modification is a strengthening behavior for the structure.

4.4 Design D

This structure is widely used in steel structure. Actually, the M type structure is very classic. But, in our simulation, it does not show the superiority then other modules. The mainly reason is the nodes limited by the student revision of ABAQUS. The 1000 nodes work bad for this complicated structure, although we have taken so much work such as adding partitions and local mesh. Finally, for this module, the mesh is still too coarse.

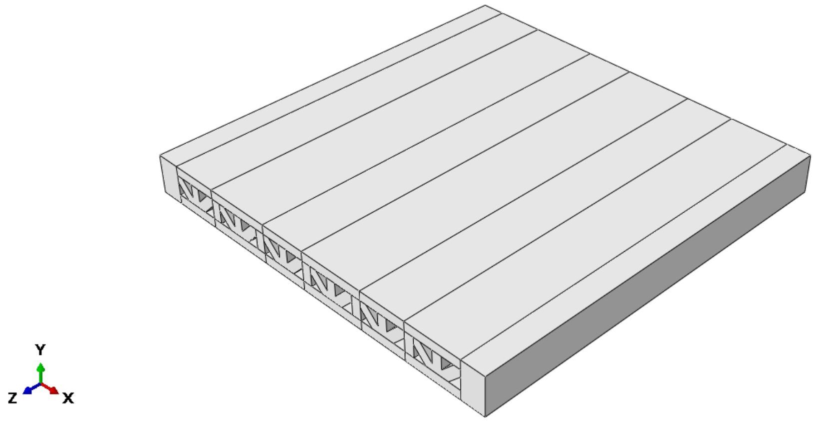


Figure 4.10 Geometry of Design D

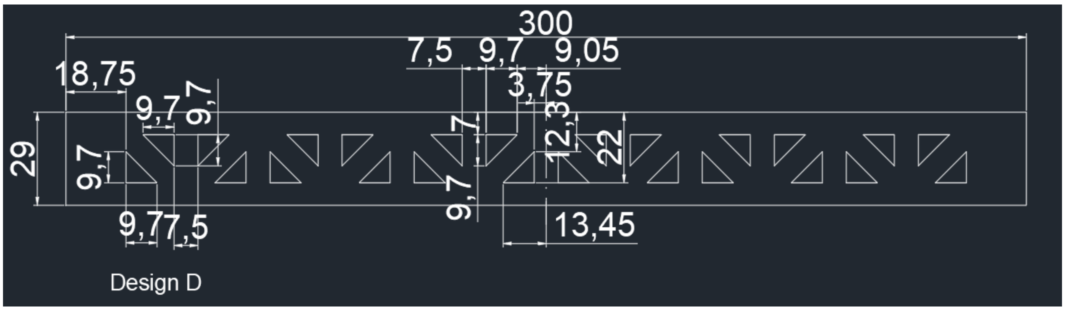


Figure 4.11 Section of volume of Design D

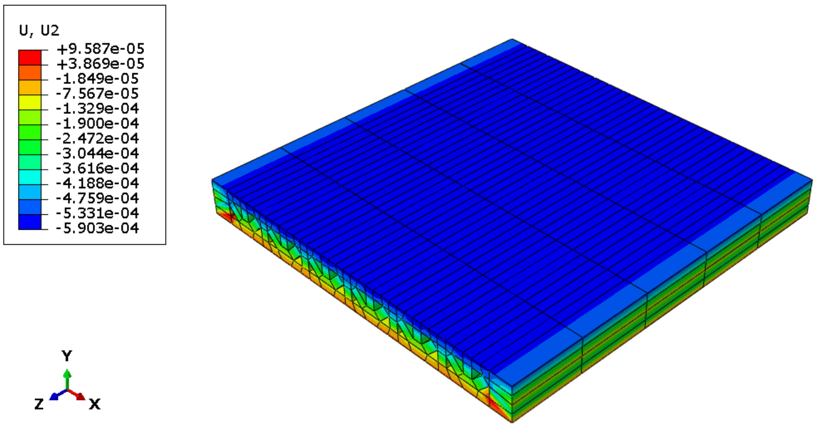


Figure 4.12 Displacement of mat under Design D

The maximum vertical displacement of design A equal to $v = -5.903E-04\ mm$

Design C stiffness:

$$S_{D\_D} = \frac{\sigma_0}{v} = \frac{0.02}{5.903E-04} = 33.88\, N/mm^3 = 0.034\ KN/mm^3$$

In this simulation, the stiffness of this structure is worse than Design A, B and C. We could do more study on it with a non-limited ABAQUS in future.

4.5 Dynamic response results of massive mat

According what we mentioned in previous sections, the massive mat was analyzed in static load. Now we consider the dynamic load on it, and discuss the response. This sort of analysis is carried out due to the fact that this type of material and geometries are usually undergone to a dynamic load. This one is closed to the condition for the train speed of $v = 80\ km/h$.

In the figure bellow, we can observe the vertical displacement vs time for a given central mesh node. As expected, the plot conserves the harmonic shape.

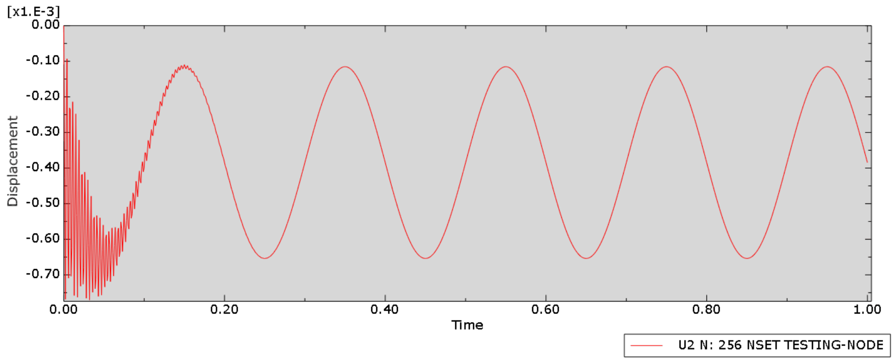


Figure 4.13 Dynamic response: Displacement at function of time

Finally, it can be observed in vertical displacement that theoretically speaking at time $t = 0$. The static stress should be applied and obtained results like the static one. However, at time $t = 0$ the static load can not be applied instantaneously, and the vertical displacement decrease abruptly with some oscillation. This phenomenon would be associated to the fact that the solver has to make some iteration until certain stability is reached. In order to avoid these spurious results, a refinement in term of time can be performed or enlarge the total time.

5. Conclusion

In conclusion, the mat design has been studied in different modules and different ways. Such as different interface models, loads and geometries. We focus on the stiffness of different modules with same volume for the elastomeric mat. We have finally determined that the best performance is belong to Design C in static load.

We also find that the ABAQUS Student Version has a node limitation of 1000. That is a problem in the development of the project since most of the models created and meshed automatically exceeded this number by far. The solution in this case was reducing the elements in longitudinal direction. Following this behavior, we avoided the reduction of elements in the thickness direction which is more important for the results.

Another issues we find it is necessary to comment is the isotropic or orthotropic characteristic of elastomeric material. In this work, we just consider the isotropic condition of material. It can be studied in future for the orthotropic material in this case. We can expect there would be some different results.

Finally, the elastomeric mat is one of the key features when it comes to reducing the vibration noise in the railway. However, there are other ways of reducing the vibration of it. Such as the concrete used in the construction.

Reference

[1] Calenberg Ingenieure: Elastomeric bearings - Anti-vibration bearings for building construction and track construction - Noise protection.

http://www.calenberg-ingenieure.com

[2] Adrian Jansen. *Linear contact analysis: demystified* . White Peper, Predictive Engineering 2010.

[3] ABAQUS/CAE 2019, help documents.

Appendix

Mr. Zichen Ding and me work on this subject individually at the beginning, then in the last week, we discussed what we got and combined our solution together.