Innovative natural rubber bearing for earthquake isolation

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Abstract. In the paper are presented two seismic isolation systems. One is classic, made out of two rubber plates, with a metallic plate vulcanized between the two. For fastening, the isolator has another two clamping plates vulcanized on it. The proposed model has same components as the classical one, having on top and under, attached to the rubber, two thin plates with bossages. For fastening the insulator there are two plates for clamping, which are not vulcanized to the isolator. The contact between the insulator and the clamping plates is made just by the bossages, the rest of the surface being free. As a result of the simulations done in the SolidWorks software we concluded that, in the case of the proposed model, the rubber has no longer the tendency to detach from the clamping plates. As long as the bossage plates are moving together with the rubber, the whole isolator becomes more elastic and durable in time.

1. Introduction
Given the significant importance of the built environment, solutions have been sought permanently to keep them in good working order. For reinforcement and post-consolidation, various stiffening methods were used using reinforced concrete. Due to the consolidation work, buildings have become stiffer [1]. Accelerations and displacements during earthquakes have not diminished, and damage has increased (Figure 1).

Figure 1. Attempts to strengthen the Canyon Channel Bridge (source: Institute of Earthquake Research 1996)
The solution to these problems is the seismic isolation [2]. A good seismic isolation is achieved by inserting flexible bearings into the structure, between the substructure and the superstructure (Figure 2) [3], [4]. It shifts the vibration period of the system, permit relatively large displacements and provide good energy dissipation [5]. Natural rubber materials are characterized by their capacity to take large amounts of strain with relatively small stress [6]. The following properties of the natural rubber material were imposed from the material library of SolidWorks software: elastic modulus 0.01 N/mm², Poisson’s ratio 0.45, mass density 960 kg/m³, tensile strength 20 N/mm² [7].

![Figure 2](source: nova next tech rubber bearings seismic protection 2013 [4])

2. The geometry of the classic and innovative natural rubber bearing (NRB)

The geometry and dimensions of the classic and innovative NRB are presented in (Figure 3) and (Figure 4). The innovative NRB has two steel plate with label 2, cylindrical bossage and 100 mm diameter. The central steel plate with label 4 has no bossage.

![Figure 3](The geometry of the classic NRB)

![Figure 4](The geometry of the innovative NRB)
3. The FEM simulation of the classic NRB

The FEM simulation of the classic NRB was made in the SolidWorks Simulation software. A nonlinear study was performed on the half of the classic NRB in order to reduce the simulation time.

The following boundary conditions were applied to the classic NRB (Figure 5):

- the **Fixed Geometry** restrain are applied on the bottom face of the base steel clamping plate;
- the **Symmetry** restraints are applied on all faces of the parts included in the symmetry plane;
- the **On flat faces 0 mm** restraint are applied in +X direction on the steel upper plate right face, to block the X movement of this part;
- the vertical **force F=30 N** are applied on -Y direction on the top face of the steel upper plate, which increases linearly from zero to the 30 N nominal value in the first second, after which it remains constant until the 2 second end of the analysis (Figure 6);
- the horizontal **force F=60 N** are applied on +X direction on the right face of the superior steel clamping plate, with null value in the first second, after which increases linearly from zero to the 60 N nominal value until the 2 second end of the analysis (Figure 7);
- the **Bonded** contact are imposed between all parts of the classic NRB, except between the top face of the superior steel clamping plate and the bottom face of the steel upper plate, where **No penetration contact** with friction are imposed, using the following values for the friction coefficient \( C_f \): 0, 0.25, 0.5, 0.75 and 1.

![Figure 5. The boundary conditions applied to the classic NRB](image)

(Figure 8) show the mesh of the classic NRB made from 28328 elements and 6132 nodes. The simulation results of the classic NRB (**von Mises** stress, the maximum resultant displacement **\( \delta_{rez \ max} \)**)
and the maximum displacements on X, Y and Z directions - $\delta_{X\text{ max}}$, $\delta_{Y\text{ max}}$, $\delta_{Z\text{ max}}$ - are presented in Table 1 at the end of the 2 seconds simulation time. The classic NRB distribution friction force from the top face of the superior steel clamping plate as a function of time for imposed values of the friction coefficient $C_f$ are shown in (Figure 9). Until the 1 second time the friction force is not present. Between 1 second and the time corresponding to the intersection point the friction force increase linearly from zero to the maximum value, calculated by multiplying the friction coefficient $C_f$ with the value of the vertical force $F=30\ \text{N}$. Finally, until the end of the 2 seconds simulation time the friction force remains constant at maximum value.

Table 1. The simulation results of the classic NRB at the end of the 2 seconds simulation time

| Parameter | UM | Friction coefficient $C_f$ |
|-----------|----|---------------------------|
|           |    | 0 | 0.25 | 0.5 | 0.75 | 1 |
| von Mises | MPa | 0.200955 | 0.176176 | 0.069451 | 0.126389 | 0.101 |
| $\delta_{rez\text{ max}}$ | mm | 36.73 | 31.932 | 26.005 | 22.596 | 18.074 |
| $\delta_{X\text{ max}}$ | mm | 36.711 | 31.932 | 26.005 | 22.596 | 18.074 |
| $\delta_{Y\text{ max}}$ | mm | -3.136/4.415 | -2.908/3.337 | -2.832/2.438 | -2.951/1.945 | -2.863/1.375 |
| $\delta_{Z\text{ max}}$ | mm | -2.152/1.038 | -1.994/0.789 | -1.612/0.698 | -1.580/0.271 | -1.361/0.057 |

The time displacements distribution on X and Y directions - $\delta_X$, $\delta_Y$ are presented in (Figure 10) and (Figure 11), for points A and B (Figure 5). In the absence of horizontal force, until the time corresponding to the intersection point marked in (Figure 9) there is no displacement on X direction, then the $\delta_X$ displacement increase until maximum value simultaneously with the horizontal force. The displacement on Y direction $\delta_Y$ decreases linearly simultaneously with the vertical force until 1 second, remain constant until the time corresponding to the same intersection point, then increase to a maximum value.
4. The FEM simulation of the innovative NRB
The FEM simulation of the innovative NRB was made in the SolidWorks Simulation software. A nonlinear study was performed on the half of the innovative NRB in order to reduce the simulation time. The following boundary conditions were applied to the innovative NRB (Figure 12):

- the Fixed Geometry restrain are applied on the bottom face of the base steel clamping plate;
- the Symmetry restraints are applied on all faces of the parts included in the symmetry plane;
- the On flat faces 0 mm restraint are applied in +X direction on the steel upper plate right face, to block the X movement of this part;
- the same vertical force F=30 N are applied on -Y direction on the top face of the steel upper plate;
- the same horizontal force F=60 N are applied on +X direction on the right face of the superior steel clamping plate;
- the Bonded contact are imposed between 2, 3, 4 parts of the innovative NRB;
- three No penetration contact with friction contacts are imposed, using the following values for the friction coefficient $C_f$: 0, 0.25, 0.5, 0.75 and 1:
  - between the top face of the base steel clamping plate with bossage with label 1 and the bottom face of the inferior steel plate with bossage with label 2, except the cylindrical face of the bossage where Bonded condition is applied;
  - between the bottom face of the superior steel clamping plate with bossage with label 1 and the top face of the superior steel plate with bossage with label 2, except the cylindrical face of the bossage where Bonded condition is applied;
  - between the top face of the superior steel clamping plate with label 1 and the bottom face of the steel upper plate with label 5.

(Figure 13) show the mesh of the innovative NRB made from 31258 elements and 7672 nodes. The simulation results of the innovative NRB (von Mises stress, the maximum resultant displacement $\delta_{rez max}$ and the maximum displacements on X, Y and Z directions - $\delta_X max$, $\delta_Y max$, $\delta_Z max$) are presented in Table 2 at the end of the 2 seconds simulation time. The innovative NRB distribution friction force on the top face of the superior steel clamping plate as a function of time for imposed values of the friction coefficient $C_f$ are identical with the curves of the classic NRB, presented in (Figure 9). Small friction forces with values smaller than 1.3 N appear on the other contact surfaces where No penetration contacts were applied. (Figure 14) exemplify the friction force for the $C_f=0.5$ value of the friction coefficient on the exploded view of the innovative NRB.

![Figure 12. The boundary conditions applied to the innovative NRB](image-url)
Table 2. The simulation results of the innovative NRB at the end of the 2 seconds simulation time

| Parameter | UM | Friction coefficient $C_f$ | 0   | 0.25 | 0.5  | 0.75 | 1   |
|-----------|----|-----------------------------|-----|------|------|------|-----|
| von Mises | MPa| 0.227                       | 0.185 | 0.146 | 0.107 | 0.075 |
| $\delta_{rez \ max}$ | mm | 35.754                       | 31.082 | 26.505 | 22.009 | 17.586 |
| $\delta_{X \ max}$ | mm | 35.734                       | 31.08 | 26.503 | 21.99 | 17.531 |
| $\delta_{Y \ max}$ | mm | -3.004/4.555                 | -2.788/3.460 | -2.788/2.531 | -2.790/1.937 | -2.716/1.377 |
| $\delta_{Z \ max}$ | mm | -1.673/1.801                 | -1.352/1.69 | -0.040/1.583 | -0.738/1.479 | -0.446/1.38 |

Figure 13. The mesh of the innovative NRB

Figure 14. The friction force for $C_f=0.5$

The time displacements distribution on X and Y directions - $\delta_X$, $\delta_Y$ for the innovative NRB are presented in (Figure 15) and (Figure 16). The curves present the same allure as those in (Figure 10) and (Figure 11) respectively with small differences of numerical values between X/Y displacements of the classic and innovative NRB.

Figure 15. The time distribution of the innovative NRB displacements on X direction

Figure 16. The time distribution of the innovative NRB displacements on Y direction
5. The innovative NRB behaviour
Although the stress, displacements and friction forces are relatively close for the two geometry variants, a remarkable and important difference compared to classic NRB, is the appearance of the two detachments of the bossage plate from the clamping plate shown in (Figure 17).

![Figure 17. The upper and down detachments of the bossage plate from the clamping plate](image)

(Figure 18) exemplify the detachments of the steel plate with bossage with label 2 from the base steel clamping plate with bossage and label 1 at the 2 second end of the analysis, for the value of the friction coefficient $C_f=1$. The values of the upper and down detachments are presented numerically in Table 3 and graphically in (Figure 19) and (Figure 20). For both detachments the values increases as the friction coefficient decreases, while the down values are bigger then upper values.

6. Conclusions
The possibilities of adjusting the dynamic response of constructions that contain isolation systems are limited, due to the small number of control parameters. The innovative isolation system allows for the proper combination of component parts and optimal elastic characteristics for a broad band of exciting earthquake frequencies.

At the new innovative NRB, the phenomenon of detachment of the bossage plate from the clamping plate, offer to the seismic system an increased durability.

| Friction coefficient $C_f$ | Upper [mm] | Down [mm] |
|---------------------------|------------|-----------|
| 1                         | 0.000002   | 0.000215  |
| 0.75                      | 0.000003   | 0.000527  |
| 0.5                       | 0.000005   | 0.000867  |
| 0.25                      | 0.000007   | 0.001215  |
| 0                         | 0.000008   | 0.001567  |

![Figure 18. The detachments of the steel plate with bossage from the base steel clamping plate for friction coefficient $C_f=1$](image)
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