The Comparative Analysis of Methods for Calculation of Buildings With Rubber Bearings

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SUMMARY:

Nowadays rubber bearings are being widely used as a practical method of protecting buildings from earthquake ground shaking. Since rubber bearings has non linear parameters during earthquake, it appears to be very complex to simulate the bearing's influence on building seismic performance while using computer models. This paper provides information about a method which allows designing building structures with installed rubber bearings in the elastic formulation and comparative analyses of the results obtained by this method and by engineering software ANSYS Mechanical.

Keywords: steel-rubber bearing, seismic isolation, spectrum for acceleration.

1. Introduction

Application of steel - rubber bearings is an effective method of seismoisolation. As long as bearings has non linear parameters during earthquake, it appears to be very complicated to simulate the bearing's influence on building seismic performance while using computer models.

The specialists of TsNIISK have developed a method based on using the modified spectra of seismic effects. This method allows designing building structures with installed rubber bearings in the elastic formulation. Therefore hardware requirements reduce dramatically. The main point of this method is that we calculate isolated and non-isolated constriction of a building separately (see Fig. 1). The value of Seismic loads applied to the isolated constructions is found using modified acceleration spectra. Thus we can take into account rubber bearing’s non linear parameters.

Non – isolated constructions are calculated according to Seismic Code of Russian Federation.

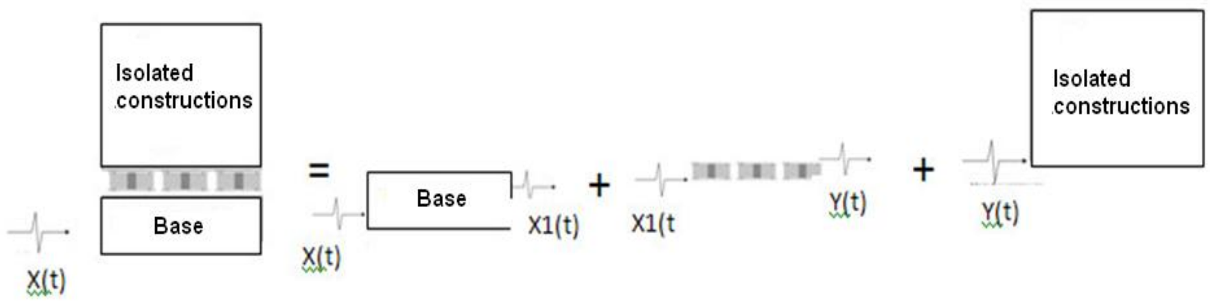


Figure 1. General pattern

2. Modification process

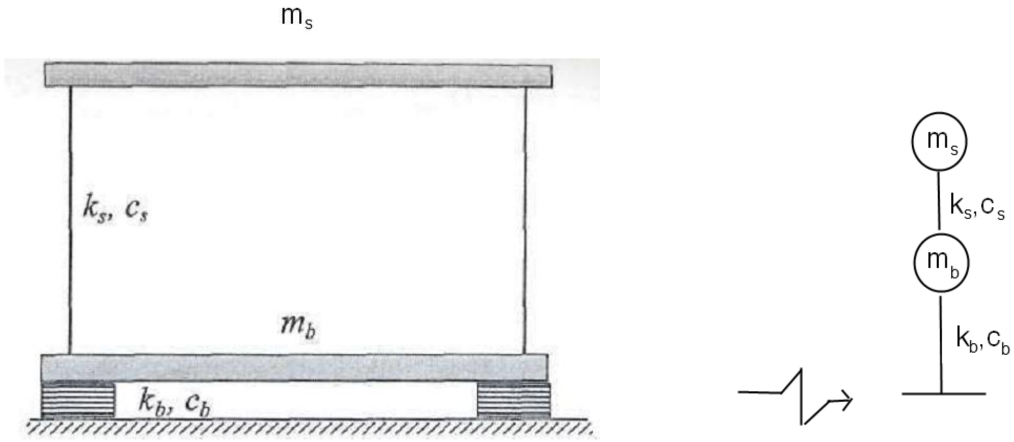
Principle behind the modification process might be described as follows: there is a set of accelerogrammes for each particular construction site. Depending on the level where rubber bearings are installed we choose the motion input which is supposed to be modified. For example, if rubber bearings are installed at the foundation level we modify an accelerogramme itself, in case the bearings are located significantly above the ground level the original motion input fades away due to the damping effect credited to the underlying constructions, therefore it is necessary to conduct preliminary calculation which allows to determine the acceleration value at the level where rubber bearings are installed.

An original design accelerogram or accelerogram obtained by preliminary calculation are “filtrated” by specially developed software, in order to take into account rubber bearing’s non linear parameters and considerable damping effect.

As result of modification process we have a modified accelerations and spectrum for modified accelerations which we use to determine seismic loads value.

3. Principles behind filter

Consider the principles behind “filter” through the example of two – mass system (fig. 2). This system describes a bearing with dead load applied to it. The value of the dead load is equal to compression capacity of a steel - rubber bearing.



a) b)

Figure 2. Two - mass isolated system: a) general pattern; b) console model.

Basic equation of motion of the two-mass system are:

$$(m_s + m_b)\ddot{u}_b + m_s\ddot{u}_s + c_b\dot{u}_b + k_b u_b = -(m_s + m_b)\ddot{u}_g$$
$$m_s\ddot{u}_b + m_s\ddot{u}_s + c_s\dot{u}_s + k_s u_s = -m_s\ddot{u}_g \qquad (3.1)$$

Which can be written in matrix notation as:

$$\begin{bmatrix} M & m_s \\ m_s & m_s \end{bmatrix}\begin{Bmatrix} \ddot{u}_b \\ \ddot{u}_s \end{Bmatrix} + \begin{bmatrix} c_b & 0 \\ 0 & c_s \end{bmatrix}\begin{Bmatrix} \dot{u}_b \\ \dot{u}_s \end{Bmatrix} + \begin{bmatrix} k_b & 0 \\ 0 & k_s \end{bmatrix}\begin{Bmatrix} u_b \\ u_s \end{Bmatrix} = \begin{bmatrix} M & m_s \\ m_s & m_s \end{bmatrix}\begin{Bmatrix} 1 \\ 0 \end{Bmatrix}\ddot{u}_g \qquad (3.2)$$

Here: u_g– application point displacement; u_b – displacement of m_b; u_s – displacement of m_s;
k_b - bearing horizontal stiffness; k_s - construction element horizontal stiffness

We define a mass ratio as:

$$\gamma = \frac{m_s}{m_s + m_b} = \frac{\mathrm{m_s}}{\mathrm{M}} \qquad (3.3)$$

Natural frequencies given by:

$$\omega_b^2 = \frac{k_b}{m_s+m_b}; \ \omega_s^2 = \frac{k_s}{m_s} \tag{3.4}$$

Damping factors are given by:

$$\omega_b \varepsilon_b = \frac{c_b}{m_s+m_b}; \ 2\omega_s \varepsilon_s = \frac{c_s}{m_s} \tag{3.5}$$

Here: ε – equivalent damping factor

In terms of these quantities, the basic equation of motion become:

$$\begin{aligned} \gamma \ddot{u}_b + \ddot{u}_s + 2\omega_b \varepsilon_b \dot{u}_b + \omega_b^2 u_b &= -\ddot{u}_g \\ \ddot{u}_b + \ddot{u}_s + 2\omega_s \varepsilon_s \dot{u}_s + \omega_s^2 u_s &= -\ddot{u}_g \end{aligned} \tag{3.6}$$

We solve these equations according to force- displacement diagram of a rubber bearing (fig. 3).

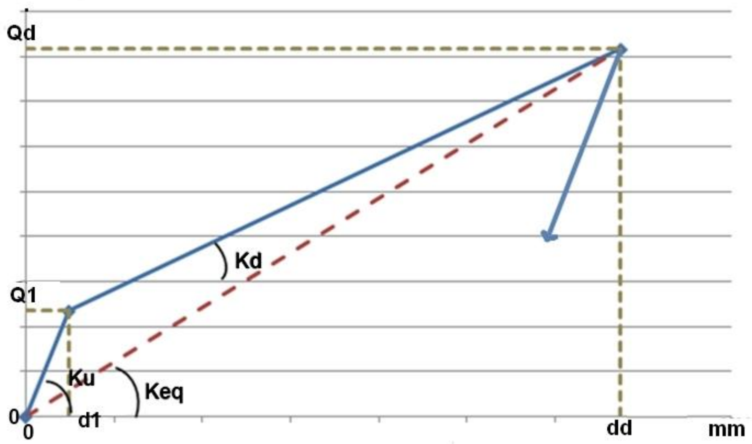


Figure 3. Force- displacement diagram of a rubber bearing

The natural periods given by:

$$T_{b1} = 2\pi\sqrt{\frac{W}{gk_{b1}}}; \ T_{b2} = 2\pi\sqrt{\frac{W}{gk_{b2}}} \tag{3.7}$$

Here: T_{b1} and T_{b2} – natural periods of a rubber bearing before yield and after yield respectively; W – weight of a building (designed compression capacity of a bearing); $k_{b1} = k_u$ - horizontal stiffness before yield, $k_{b2} = k_d$ - horizontal stiffness after yield.

In terms of these quantaties natural frequencies defined as:

$$\omega_{b1/2} = \begin{cases} 2\pi/T_{b1} & if \ \ddot{u}_b \le RY \\ 2\pi/T_{b2} & if \ \ddot{u}_b > RY \end{cases} \tag{3.8}$$

Modified (filtrated) accelerations defined as:

$$R(t) = \begin{cases} \omega_{b1}^2 \cdot u_b(t) & if \ \ddot{u}_b(t) \le RY \\ RY + \omega_{b2}^2 \cdot (u_b(t) - d_1) & if \ \ddot{u}_b(t) > RY \end{cases} \tag{3.9}$$

In order to obtain an appropriate modified spectrum for acceleration we must take into account the following conditions:

- a center of mass of a building might be located at different levels in relation to rubber bearings.
- for different construction we take into consideration variable amount of natural mode shapes, consequently the response is variable as well.

Therefore the question arises about the limits of validity of models that allow simplification to a sufficient degree to obtain more accurate results.
In this work we researched one-mass, two-mass and seven-mass console models in order to obtain the following results:

- determination of the acceleration value at the top of rubber bearings, using one-mass model
- determination of the acceleration value at the top of rubber bearings and at the level of center of massl, using two-mass model
- determination of the acceleration value at the top of rubber bearings and at the center of mass level, using seven-mass model

The comparative analysis of the acceleration values was aimed at defining the range of applicability for different models, which might be used in the field of design of earthquake resistant constructions.

4. Results

The results obtained by “filter” software were compared with the results obtained by ANSYS Mechanical. For this purposes, finite element models of isolated one-mass, two-mass and seven-mass systems were created. The seismic isolation was represented by a steel-rubber bearing GZY300V5A produced by “Vibro – Tech Industrial and Development Co Ltd” (China). The bearing technical data are summarized in table 1.

Table 1. Technical data.

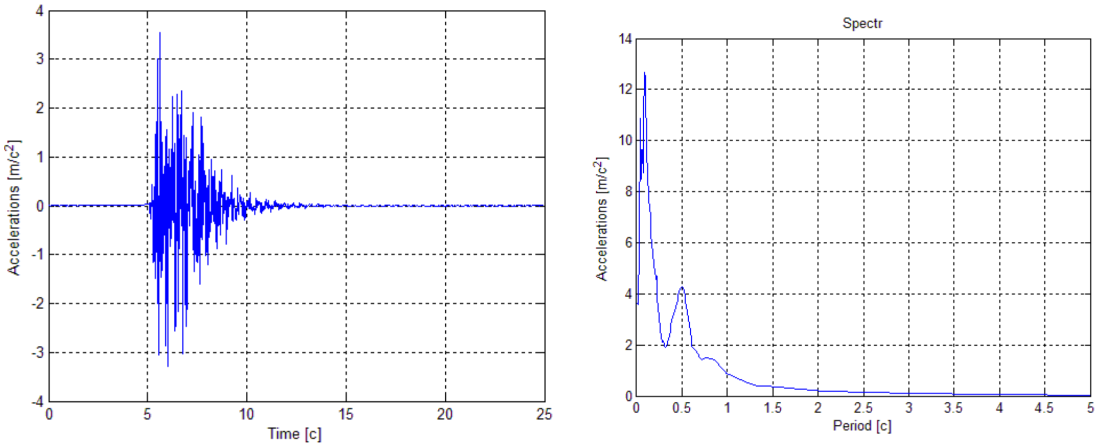
Parameter	Value
k_u, N/m	$6.01 \cdot 10^6$
k_d, N/m	$0.755 \cdot 10^6$
k_e, N/m	$1.11 \cdot 10^6$
Q_1, kN	24
Q_d, kN	64.5
d_1, mm	4
d_d, mm	58
ε	0.2
W, kN	1000

Here: ε – equivalent damping factor, W – bearing compression capacity.
ANSYS Mechanical allows taking damping effect into account using construction damping factor – β defined as:

$$\beta = \frac{\varepsilon}{\pi f_i} \tag{4.1}$$

Here:
f_i – natural dominant frequency

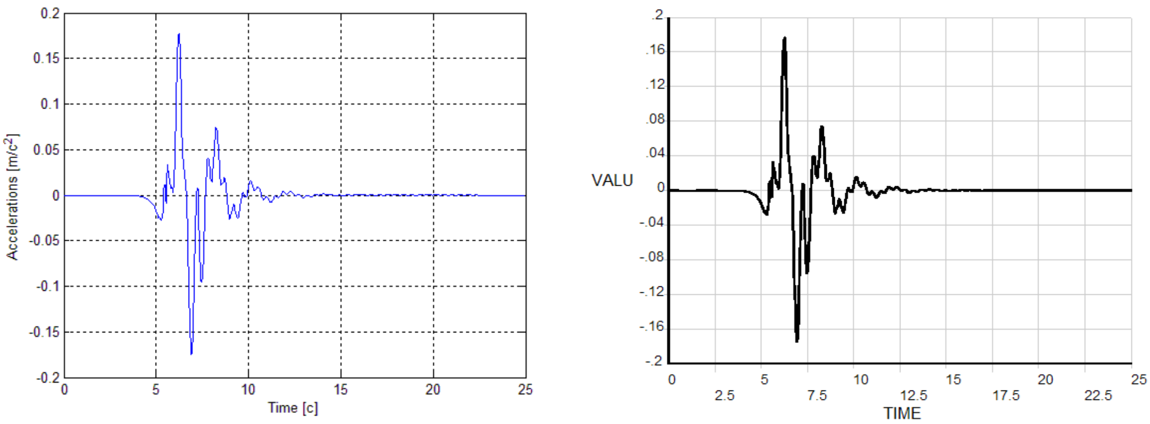
Input motion was the same for all models, see Figure 4.



a) b)

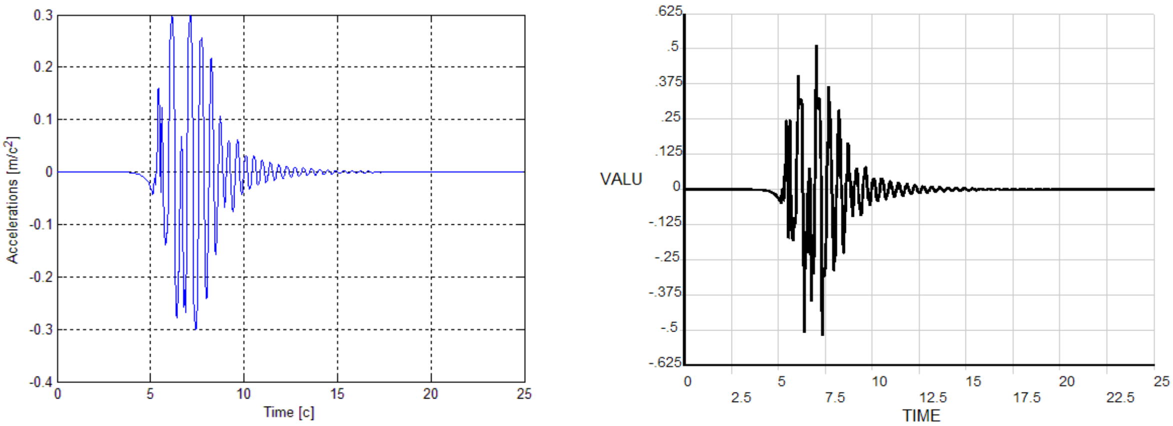
Figure 4. Input motion: a) accelerogram; b) spectrum for acceleration of input motion.

The calculations of the models, mentioned above gave the following results:



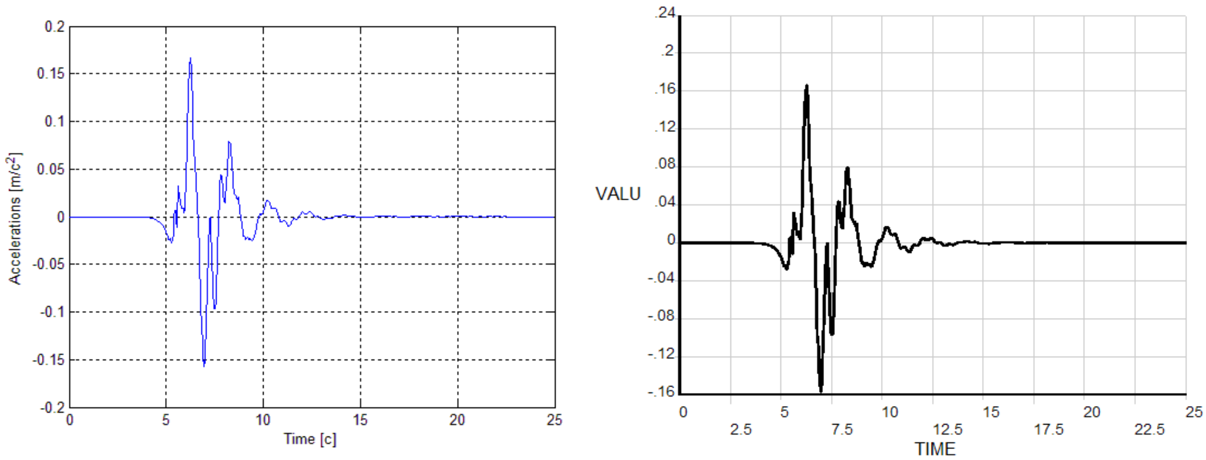
a) b)

Figure 5. Modified accelerations (linear formulation, one-mass system): a) obtained by “filter” software; b) obtained by ANSYS Mechanical



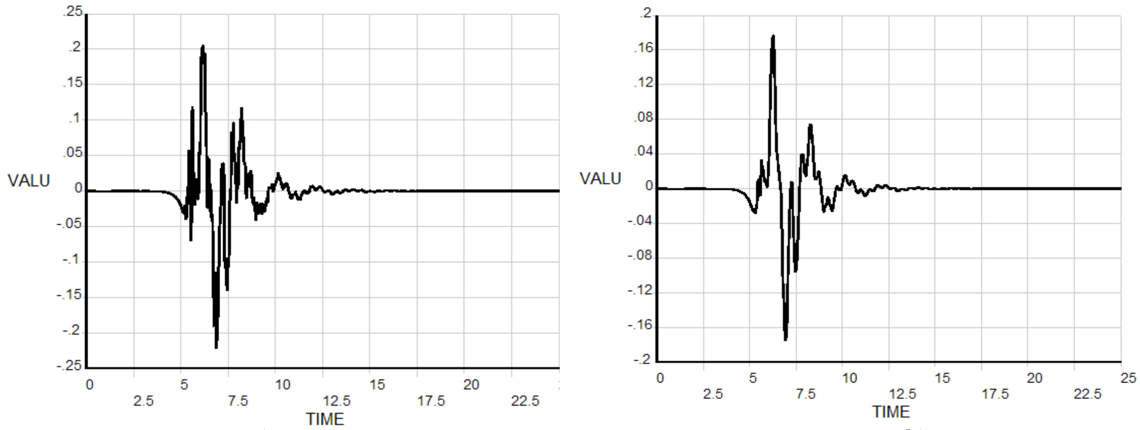
a) b)

Figure 6. Modified accelerations (non-linear formulation, one-mass system): a) obtained by “filter” software; b) obtained by ANSYS Mechanical



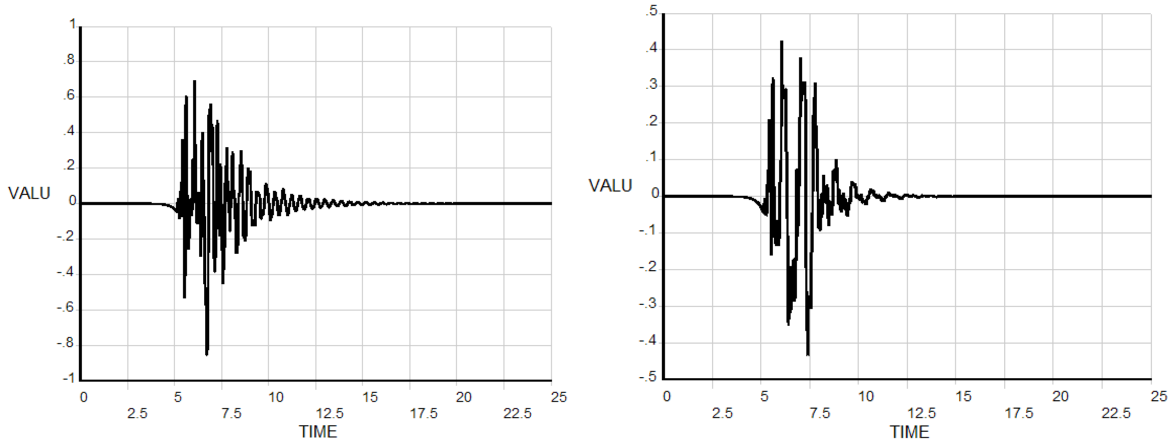
a) b)

Figure 7. Modified accelerations at the top of the bearing (linear formulation, two-mass system): a) obtained by “filter” software; b) obtained by ANSYS Mechanical



a) b)

Figure 8. Modified accelerations, m/s^2 (linear formulation): a) at the level of center of mass (two-mass system); b) one-mass system



a) b)

Figure 9. Modified accelerations, m/s^2 (non-linear formulation, two-mass system): a) at the top of the bearing; b) at the level of center of mass

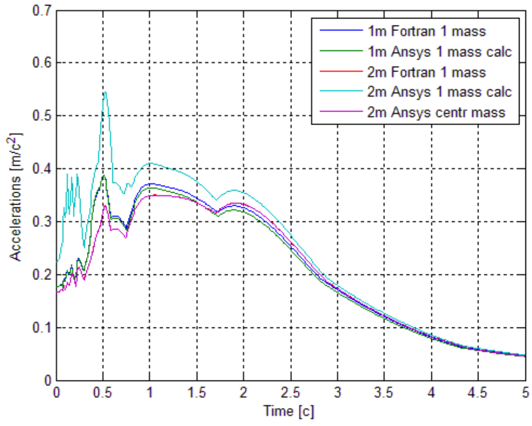


Figure 10. Spectrum for modified accelerations (linear formulation): 1m fortran 1 mass – “filter” software, one-mass system; 1m Ansys 1mass calc - ANSYS Mechanical, one-mass system; 2m fortran 1 mass - “filter” software (at the top of the bearing, two-mass system); 2m Ansys 1mass calc – ANSYS Mechanical (at the top of the bearing, two-mass system); Ansys centr mass - ANSYS Mechanical (at the level of center of mass, two-mass system)

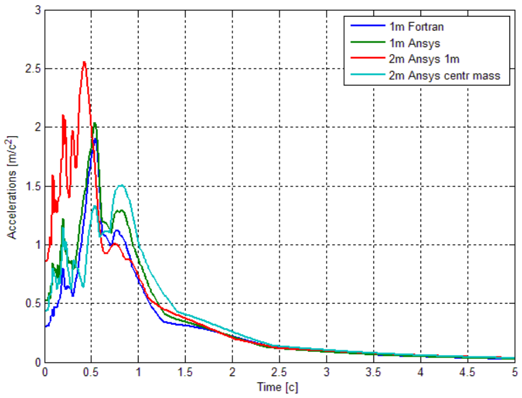
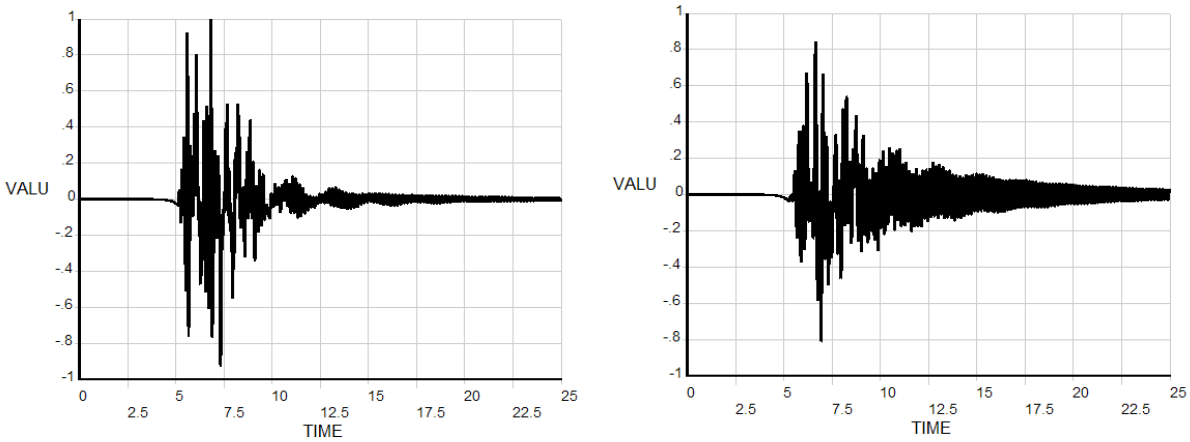
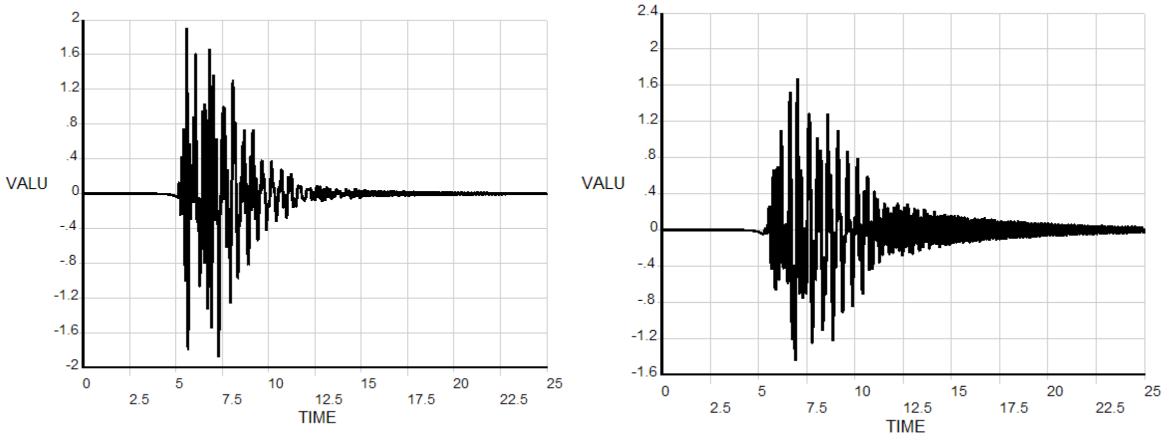


Figure 11. Spectrum for modified accelerations (non-linear formulation): 1m fortran – “filter” software, one-mass system; 1m Ansys - ANSYS Mechanical, one-mass system; 2m Ansys 1m – ANSYS Mechanical (at the top of the bearing, two-mass system); 2m Ansys centr mass - ANSYS Mechanical (at the level of center of mass, two-mass system)



a) b)

Figure 12. Modified accelerations, m/s^2 (linear formulation, seven-mass system): a) at the top of the bearing; b) at the level of center of mass ;



a) b)

Figure 13. Modified accelerations, m/s^2 (non-linear formulation, seven-mass system):
a) at the top of the bearing; b) at the level of center of mass ;

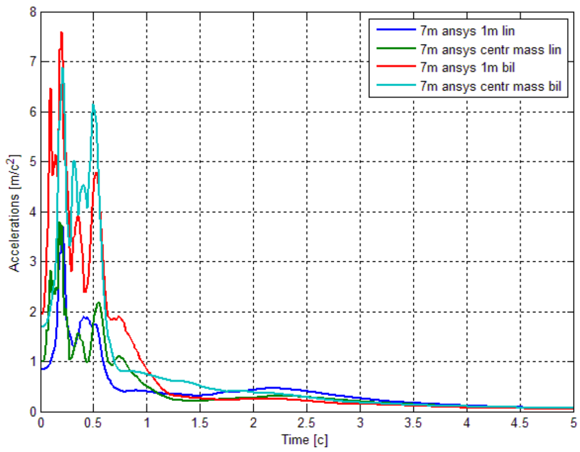


Figure 14. Spectrum for modified accelerations obtained by ANSYS Mechanical (seven-mass system) : 7m Ansys 1m lin – at the top of the bearing, (linear formulation); 7m Ansys centr mass lin - at the level of center of mass (linear formulation); 7m Ansys 1m bil - at the top of the bearing, (non - linear formulation); 7m Ansys centr mass bil - at the level of center of mass (non-linear formulation);

CONCLUSION

A method based on using modified spectrums for accelerations is presented. This method allows designing building structures with installed steel - rubber bearings in the elastic formulation. Therefore hardware requirements reduce dramatically. To modify source accelerogrames special “filter” software was developed.

The comparative analyses of the results obtained by “filter” software and ANSYS Mechanical showed that for console models with up to two masses there is no big discrepancy. It means that we can use the method given in this paper, at least to conduct preliminary calculations of constructions with steel – rubber bearings.

On the other hand the results of the calculation of the seven – mass console model showed that the method needs to be improved regarding to adjustment in parameters of models. This problem is a part of further research work.

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