18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012
pp. 849–855
Paper #14

THE USE OF RUBBER VIBRO-BASE ISOLATION TO DECREASE STRUCTURE DYNAMIC RESPONSE

D. Makovička*, D. Makovička**

Abstract: *The use of rubber or another elastomer in the foundation structure is an efficient solution to reduce vibrations propagating into the building structure through the subsoil. The principle of vibro-base isolation consists in inserting an elastic layer between the dual foundation plates, with protective hydroisolation against water flooding. The example of reinforced concrete structure of the building is used to show the efficiency of vibro-base isolation, comparing isolated versus non-isolated structures. This efficiency is assessed based on computational prognosis of vibration of the building floors. Non-stationary dynamic load by the measured vibrations due to technical seismicity caused by cars passing near the analyzed structure is used to calculate the building response. technical seismicity, insulation, building, dynamic analysis, response prognosis.*

Keywords: ***technical seismicity, vibro-base isolation, building, dynamic analysis, response.***

1. Introduction

The example of a residential building is used to illustrate the use of vibro-base isolation against the propagation of vibrations (Makovička & Makovička, 2009) from the subsoil to the protected building. The building (ground plan size roughly 90 ×21 m) has three underground storeys and graduated six (north side) up to ten (south side) storeys over the ground. The building is founded on a foundation plate on the level of the 3rd underground storey. Spatial model was chosen for dynamic analysis of the structure. Floor slabs, load-bearing walls, columns and beams were modelled as reinforced concrete monoliths made of concrete C30/37. Load-bearing walls in the longitudinal direction of the storeys over the ground were modelled as built of bricks. Staircase broadsteps and loggia slabs were simulated as precast slabs, hinge-connected to the structure walls.

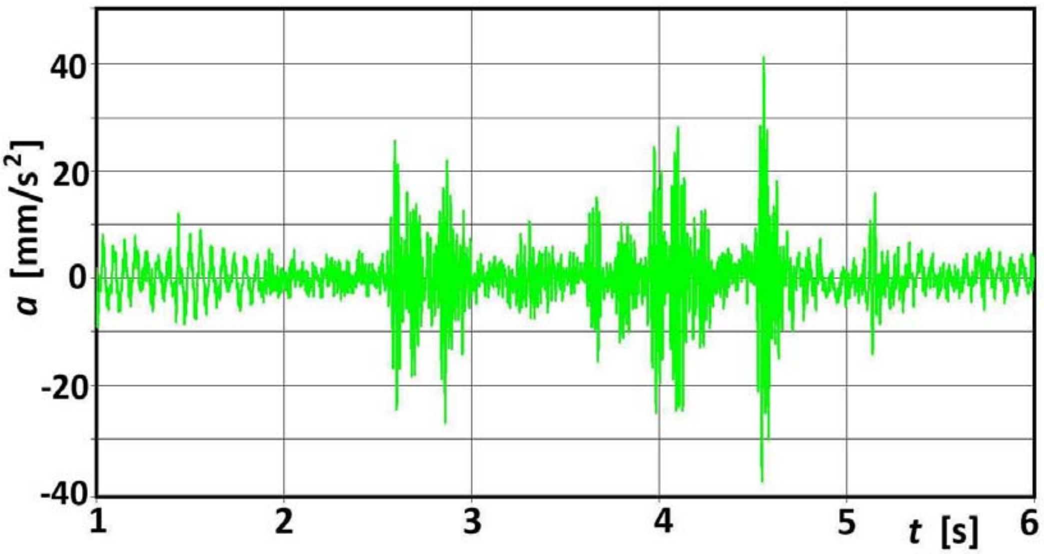

Fig. 1: Measured horizontal acceleration excited by an underground train pass below the building

* Doc. Ing. Daniel Makovička, DrSc.: Klokner Institute, Czech Technical University in Prague, Šolínova 7; 166 08, Prague 6; CZ, e-mail: daniel.makovicka@klok.cvut.cz

** Ing. Daniel Makovička, Jr.: Static and Dynamic Consulting, Šultysova 170; 284 01 Kutná Hora; CZ, e-mail: d.makovicka@makovicka.cz

Rubber antivibration blocks Ekodyn of the company Ekostar were chosen as isolation against vibrations caused by traffic. The rubber layer was designed to be placed underneath the entire ground plan of the building, and also on side walls of the underground storeys. The rubber layer would be laid using Ekodyn plates with the dimensions 500 × 500 × 30 mm for the horizontal isolation layer. Rubber thickness of 25 mm was used for the vertical layer.

2. Computational model and load

A 3D model of the whole structure was designed for the structure analysis, including underground storeys and the vibroisolation rubber layer. On the level of the floor of the 3rd underground storey, the computational model is placed on a multiple-layer subsoil structure. The foundation plate with the thickness 500 mm (upper foundation plate) is placed on the vibroisolation layer made of Ekodyn rubber blocks. Bottom concrete with the thickness 150 mm (lower foundation plate) is placed under the rubber layer, which is laid on the layer of the original subsoil formed by healthy slate (class R3). The footing bottom is below the underground water level. The relative structure damping value was chosen as 5% of the critical damping value.

Modelled rubber stiffness in the computational model respects the selected rubber type. The stiffness of the rubber blocks in their rotation around the vertical axis of the sample and stiffness of bend compression of the rubber around horizontal axes was neglected compared to the vertical and horizontal stiffness of the rubber samples.

The antivibration layer of the rubber plates was designed so that (a) its response to permanent and long-term loads in deflections is approximately uniform and does not exceed 10% to 15% of the rubber thickness, and so that (b) the dynamic response of the whole system fulfils the criteria of optimal vibration reduction compared to vibration of the base (Makovička, & Makovička, 2011, a,b).

As for the dynamic analysis of the structure, non-bearing parts of the structure were incorporated in the mass of the load-bearing elements as mean “blurred“ value of load caused by thin partition walls, floorings, etc. Similarly, the magnitude of the long-term live load components were incorporated in the mass of ceiling structures in the value of 50%.

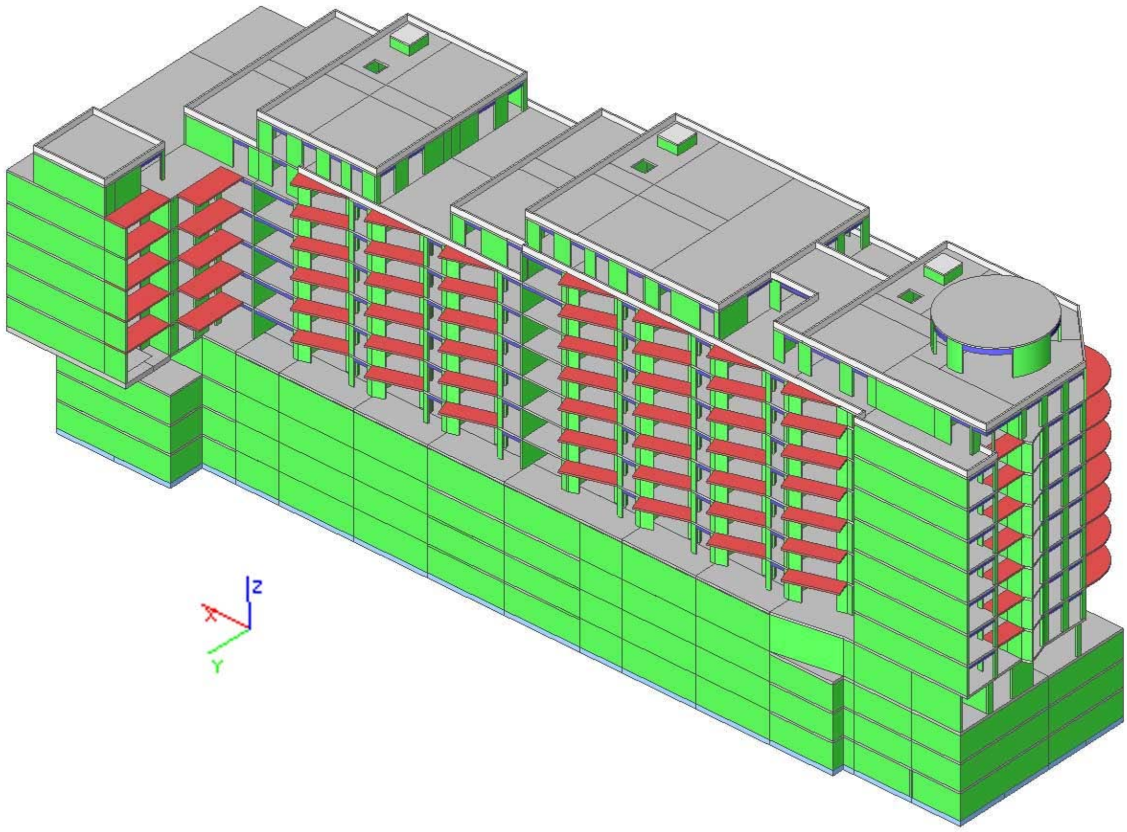

Fig. 2: Calculation model ... South-West view

Nonstationary dynamic excitation (Fig. 1) due to traffic was introduced to the model at selected points of the structure, in an approximately regular grid of points on the level of the foundation plate. Attenuation of dynamic excitation along the distance from the source was introduced to the structure model in steps, using bands of the approximate width of 10 m, graduated based on measured vibrations. Dynamic load was introduced to the structure at the same moment and with the same phase. Part of the measured acceleration record, incorporating the effect of B line metro passage in the duration of 1 s, was used for the dynamic calculation. This selected 1 s of the record includes several maximum non-stationary values of the measured acceleration of the vibrations and corresponds to the maximum excited vibration on a test foundation block inside the area of construction (free-field measurement).

The purpose of the calculation was to determine the relative response of individual building storeys compared to excitation on the foundation base level, at the place of rubber placement. For this reason, the response results were normalized.

3. Natural vibration

The calculation of natural vibration of the residential building was done for the model of the whole structure laid on the elastic vibroisolation layer.

In terms of dynamic response of the building to the effects of dynamic load caused by external sources (traffic), the lowest possible tuning of the building structure is decisive. This is manifested by flexural vibration of the building on the rubber on one hand, and by vertical and horizontal translative vibration of the building as a whole on the rubber or by torsional vibration of the whole structure or its parts.

Besides basic modes of natural vibration of the structure as a whole, natural vibration frequencies of floor slabs of individual storeys, inside walls and console of floor slabs (balconies) appear in the calculation results, which cause that the building response is slightly different on every storey and/or with loops at other stations.

For an illustration, the six lowest natural vibration modes are arranged in Tab. 1 including comments to these modes. The first 75 natural modes were used for the dynamic calculation of forced vibration.

Tab. 1: Natural vibration frequencies of the building and description of natural modes

Mode number	*Natural frequency [Hz]*	*Description of natural mode*
1	*2.28*	*Rotation of the whole building around axis x*
2	*3.54*	*Rotation of the building around axis x and twisting around axis z*
3	*4.25*	*Rotation of the building around axis y and twisting around axis z*
4	*5.83*	*Bending of the building in the direction y, bending of floor slabs*
5	*7.41*	*Bending of the building around axis x, bending of floor slabs*
6	*8.00*	*Bending of the building around axis x, bending of floor slabs, higher mode*

4. Vibration transfer through the foundation structure

The calculation of vibration transfer from the lower to the upper part of the foundation plate of the building was done for the model of the structure part laid on the elastic vibroisolation layer, lower foundation plate (base concrete), and subsoil layer (slate R3).

The interaction at the rubber and reinforced concrete foundation structure interface has an effect on vibration transmission to the building structure itself. Characteristics of this interaction depend on (a) intensity and frequency composition of dynamic load, (b) properties of the foundation structure and subsoil under foundation level, (c) properties of the rubber used, and (d) the upper part of the modelled structure of the whole building.

The same type of rubber is exposed to different types of stress (static load and deformation) in different parts of the foundation structure. In terms of evaluation of the concrete and rubber interaction, the average (most frequent) stress value (and resulting compression) for individual used rubber types must be determined. However, the resulting values are only average values, as well, and may show different behaviour in other conditions.

Vibration of the lower part of the (unsprung) foundation structure was normalized to the maximum value 1.0 (100%); the intensity of vertical and horizontal vibration of the upper part of the isolated foundation structure does not exceed 40%. Conservatively, vibrations of the lower foundation plate, due to passing through the rubber layer and thanks to interaction at the contact point between individual parts of the foundation structure, can be considered to become reduced approximately by 50%. Another positive consequence of using the rubber layer consists in changed intensities of individual dominant frequencies corresponding to natural frequencies of the system. The calculation results show very well that vibrations at frequencies of the order over 30 Hz become significantly attenuated and/or filtered off (Makovička & Makovička, 2011, b).

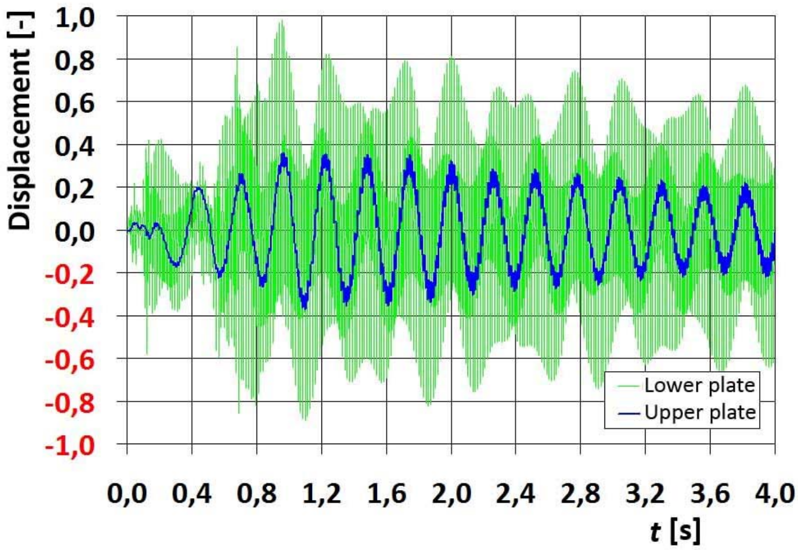

Fig. 3: Time histories of vertical vibration within the vibration transfer through foundation structure.

5. Forced vibration of the whole building

Calculations of forced vibration of the residential building were done for the model of the whole structure laid on the elastic vibroisolation layer, or as a variant, on the original slate R3 subsoil. Calculation of forced vibration of the structure was done using the method of dynamic excitation decomposition to the spectrum of natural vibration modes. The calculation determined the dynamic response of the structure, while the overall duration of the calculation was 1.000 s, and the calculation was done with the step of 0.005 s. The calculated values (displacements of the foundation plate and floor slabs) were normalized so that the maximum displacement value in the foundation plate was equal to 1. Maximum calculated response values are shown in Tab. 2. Normalized displacements of the structure make it possible to perform a simple comparison of the increased or decreased response of the structure.

Comparing the calculated response on the level of the foundation plate (at the place where the structure is laid on the rubber and at places where dynamic excitation is introduced) to the response on individual higher storeys, this ratio can be used to estimate the magnitude of vibration changes on individual storeys. This ratio depends on the structure tuning, thus on the effect of the building geometry, chosen cross-sections and thickness and load values, including the permanent component of live loads. This procedure is considerably conservative and on the safety side.

For the sake of comparison, the structure response to dynamic load was calculated also for the nonisolated building (without any inserted rubber); the resulting normalized values in displacements caused by vertical and horizontal excitation are shown in Tab. 2.

Tab. 2: Extremes of relative floor displacements under vertical and horizontal excitation

Floor level	Isolated structure				Nonisolated structure			
	Vertical		Horizontal		Vertical		Horizontal	
	u_z		u_y		u_z		u_y	
	Max	Min	Max	Min	Max	Min	Max	Min
-3rd Floor	1.00	-0.76	1.00	-0.83	1.00	-1.00	1.00	-1.00
-2nd Floor	1.22	-1.29	0.96	-1.07	1.43	-1.00	1.28	-1.89
-1st Floor	1.24	-0.97	0.89	-0.89	1.00	-1.00	1.12	-1.23
+1st Floor	0.87	-0.92	0.70	-0.59	0.85	-0.82	1.18	-1.49
+2nd Floor	0.74	-0.64	1.00	-1.02	0.70	-0.53	0.85	-0.91
+3rd Floor	0.70	-0.69	0.85	-0.76	0.54	-0.72	0.91	-0.95
+4th Floor	0.73	-0.72	1.08	-1.13	0.63	-0.51	0.81	-1.04
+5th Floor	0.66	-0.66	1.08	-0.93	0.63	-0.56	0.81	-1.19
+6th Floor	0.69	-0.71	0.85	-1.04	0.52	-0.47	1.09	-1.32

Tab. 3: Response comparison of isolated and nonisolated structure in frequency interval 1 to 20 Hz

Floor level	Isolated structure			Nonisolated structure		
	Tuning effect	Transfer through foundation	Effective acceleration	Tuning effect	Transfer through foundation	Effective acceleration
	[–]	[–]	[mm/s^2]	[–]	[–]	[mm/s^2]
Horizontal vibration						
-3rd to 1st FL, North part	1.00	0.5	1.01	2.66	1	9.71
2nd to 9th FL, North part	0.69	0.5	0.7	2.91	1	10.61
-3rd to 1st FL, South part	0.78	0.5	0.79	1.31	1	4.79
2nd to 9th FL, South part	0.52	0.5	0.53	1.76	1	6.43
Roof	1.34	0.5	1.35	2.89	1	10.55
Balconies	0.71	0.5	0.72	2.62	1	9.55
Vertical vibration						
-3rd to 1st FL, North part	2.54	0.5	2.79	1.90	1	6.77
2nd to 9th FL, North part	2.60	0.5	2.86	1.75	1	6.24
-3rd to 1st FL, South part	2.03	0.5	2.23	1.62	1	5.77
2nd to 9th FL, South part	2.67	0.5	2.94	1.36	1	4.83
Roof	3.44	0.5	3.78	4.26	1	15.15
Balconies	4.44	0.5	4.88	3.67	1	13.08

Comparison of both analyses indicates that the isolated structure shows significantly lower vibrations in acceleration (Tab. 3) than structures without any isolation (Makovička & Makovička, 2011, c).

Time courses of the response, or dominant frequencies of this response, respectively, provide another effect that plays an important role in dynamic response assessment. Time courses of forced vibration in the vertical direction with horizontal excitation were calculated for selected points within an axis, located over each other (Fig. 4). Thanks to springing of the building structure by the inserted rubber layer, the frequency signal of the response would be redistributed in the area of low frequencies, approximately on the level between 1 Hz to 15 Hz, 20 Hz at the maximum (Jacquet. & Heiland, 2002 and Roško & Králik, 2009). Higher frequency components of excitation are markedly damped and are be transmitted to the building by negligibly small vibration amplitudes compared to the low frequency components.

In the structure without any rubber layer, no redistribution of the frequency signal and attenuation of vibrations occur and/or they occur in a considerably lower extent. Individual parts of the structure then start vibrating at some of the dominant excitation frequencies that correspond to or approach the natural frequency (or higher harmonic frequencies) of the appropriate part of the structure.

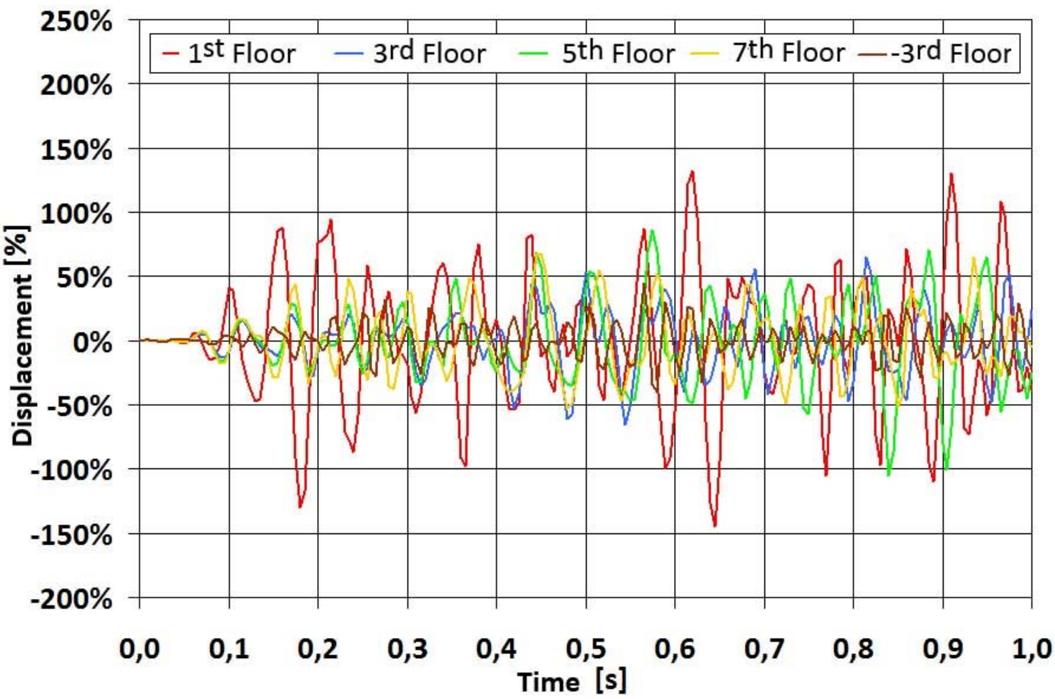

Fig. 4: Time courses for selected points of vertical vibration under horizontal excitation.

6. Conclusion

The aim of this paper is to assess the effect of building vibroisolation on the transfer of vibrations due to traffic from the subsoil environment. When metro trains pass in the tunnel in immediate vicinity of the building, dominant vibrations are propagated to the surroundings in the form of transient vibration.

Maximum measured intensities of vibrations at the construction site were used as non-periodic load of the building by technical seismicity caused by traffic effects. Based on calculation of static and dynamic response of the building, optimum distribution of the rubber in the foundation structure was designed. Furthermore, the calculation was used to predict floor vibration on individual storeys, and time courses of vibration at selected points were determined.

This paper compares calculated responses for an isolated and nonisolated building (Tab. 3). Comparison of the results clearly indicates the advantages of implementing vibroisolation in the foundation part of the building.

Acknowledgement

This research was supported as a part of the research projects in GAČR P105/11/1580 Transient response of structure under short-term dynamic or impact load due to seismic effects and explosions, for which the authors would like to thank the Agency.

References

Makovička, D. & Makovička, D., Jr. (2009) Response analysis and vibroinsulation of buildings subject to technical seismicity, in: *Earthquake Resistant Engineering Structures VII*, WIT Press, Southampton, UK, pp. 197-205.

Makovička, D. & Makovička, D. (2011, a) Vibrobase insulation of a building excited by the technical seismicity effect of tube railway operation, in: *Earthquake Resistant Engineering Structures VIII* (C.A.Brebbia & M.Maugeri eds), WIT Press, Southampton, UK, pp. 79-88.

Makovička, D. & Makovička, D. (2011, b) Springing of building structure in order to eliminate traffic vibrations, in: *EURODYN 2011: Proceedings of the 8th International Conference on Structural Dynamics*, Leuven, pp. 922-927

Makovička, D. & Makovička, D. (2011, c) Effect of vibro-insulation on restriction of vibration transfer from subsoil into the building, in: Fuis, Vladimír: *Engineering Mechanics 2011, 17th International Conference* (V.Fuis ed), Institute of Thermomechanics, Academy of Sciences of the Czech Republic, v.v.i. - Brno, pp.375-378

Jacquet, T. & Heiland, D. (2002) *Tieffrequente Bauwerken-Kopplungen als Schutz gegen Erschütterungen*, Gerb Berlin.

Roško, P. & Králik, J. (2009) Energy-based analysis and design of structures under seismic loading. in: Papadrakakis, M., Lagaros, N.D., Fragiadakis, M: *COMPDYN 2009: Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering* (M.Papadrakakis, N.D.Lagaros, M.Fragiadakis eds), Rhodes.