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EFFECT OF VIBRO-INSULATION ON RESTRICTION OF VIBRATION TRANSFER FROM SUBSOIL INTO THE BUILDING

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Abstract: *The solution of vibration transfer from the subsoil to the structure is demonstrated using the example of a multi-storey reinforced concrete building, founded on a dual foundation plate. An anti-vibration layer of rubber has been designed between the two plates. Two 3-D numerical models of the building take into account the individual storeys, firstly together with the lay-out of the rubber distribution in the foundation part and secondly without this rubber part. For response analysis, the measured time histories in the construction area were selected and then the typical response was used as an input for a dynamic analysis of the structure.*

Keywords: ***Technical seismicity, insulation, building, dynamic analysis, response prognosis.***

1. Introduction

Trains running through underground tunnels produce vibrations which, together with the vibrations from a wide range of constituents of the underground railway, such as ventilation fans and escalator drives, propagate from the source to more distant structures. As a rule, these vibrations propagate into building foundations at the foundations/subsoil interface. Vibrations produced by subsurface traffic usually do not threaten the safety of structures. Nevertheless, they may be significant because of their undesirable impacts on people living or working in the residential or office parts of the building, especially due to their tuning. The applied springing is, consequently, a very efficient instrument for reducing the vibration propagation (Jacquet, 2002).

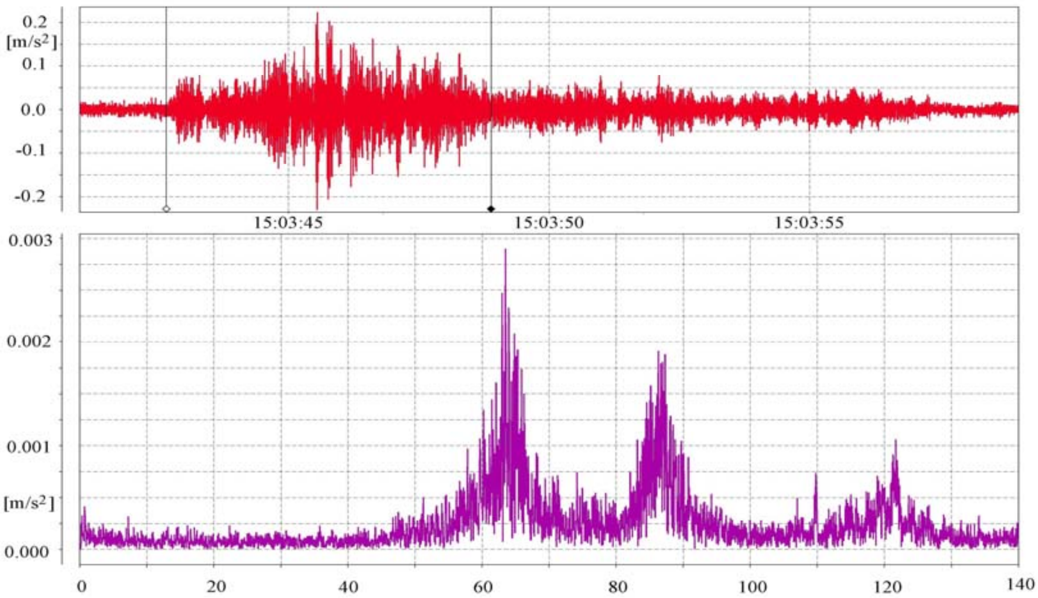

Fig. 1: Measured vertical of the underground station excited by a train pass (the whole course, FFT spectrum).

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2. Technical seismicity effect

The character of vibrations depends on their parameters at their source, i.e. the character of the train motion, the structure and occupancy of the rolling stock, the geometry and characteristics of the permanent way (above all, the fastening of the rails, etc.), the structure of the tunnel or station, the parameters of the equipment of the tunnel or station, etc. The magnitude of the vibrations is influenced not only by the vibration parameters at the source, but also by the composition of the geological environment in the proximity of the underground railway, i.e. the route from the source to the threatened structure. Last but not least, the magnitude of these vibrations may be increased or damped by the actual execution of the structure loaded by them (Makovička, 2005). The measured real characteristics of the vibrations may show considerable mutual differences, because the magnitude of the vibrations and their frequency structure depend not only on the general parameters of source (train characteristics, way, underground structure, etc.) but also on the local parameters on the site (particularly the composition of the geological environment, foundation design, etc.) These measurements produce typical histories of vibrations affecting selected parts of the structure (Fig. 1), which can be considered as the dynamic load of the future or existing structure at its foundation level. This vibration load has a non-stationary character.

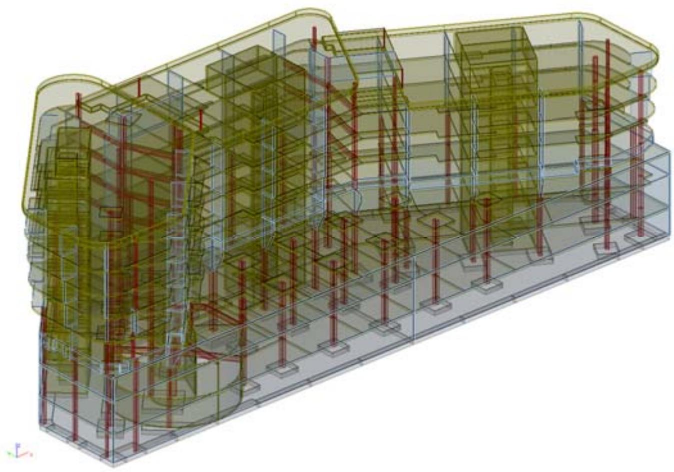

Fig. 2: Calculation model North-West view.

3. Structure analysis

The multistorey reinforced concrete building (Fig. 2) is founded on the base plate. On top of this plate an antivibration layer of rubber has been designed. Above the rubber there is an upper foundation plate in which the cast-in-place skeleton building structure is constrained. The rubber 500×500×30 mm (slabs) are butt-jointed (not interlocked) in a single layer with 3 – 5 mm joints enabling the rubber to buckle, thus assuring identical conditions of deformability and, consequently, stiffness corresponding to the conditions at the foundation base. The principle involves consistent separation of the upper part of the structure from the foundation structure by an elastic layer (Makovička, 2009). The advantage of rubber layers is that they provide sufficient damping to reduce the resonance peaks of the vibrations of the elastic supported structure.

The calculation model takes into account the individual storeys, broken down into the floor, foundation and roof slabs, columns, load-bearing walls and peripheral and interior girders. The layer of rubber was considered as the elastic subsoil of the Winkler-Pasternak model below the whole area of the upper part of the foundation plate. The mass of the floor and the foundation plates includes the masses of the non-load-bearing components (thin partitions, floorings, etc.) as well as the equivalent of the live loads of floors, roof and terraces (Makovička, 2005).

The dynamic load, i.e., the vibrations (Fig. 1), was introduced into the model as a normalized load and with the identical phase all over the foundation plate. The vibrations of the building produced by underground traffic were predicted by the response analysis of the whole system. The time histories for selected points on all the floors located on the chosen vertical line on the margin of the left highest structure part on its rear side are shown in Fig. 3. The most intensive vibrations can be observed in the proximity of columns, balconies, terraces and structural parts situated on the underground side. With increasing height, this excitation mode will manifest itself by vibrations of the building in one of the natural frequencies of the structure. More significant influence of vibration is in most cases limited to the lowest two or three storeys. In the higher storeys, the time characteristic of the vibrations is divided into lower frequencies.

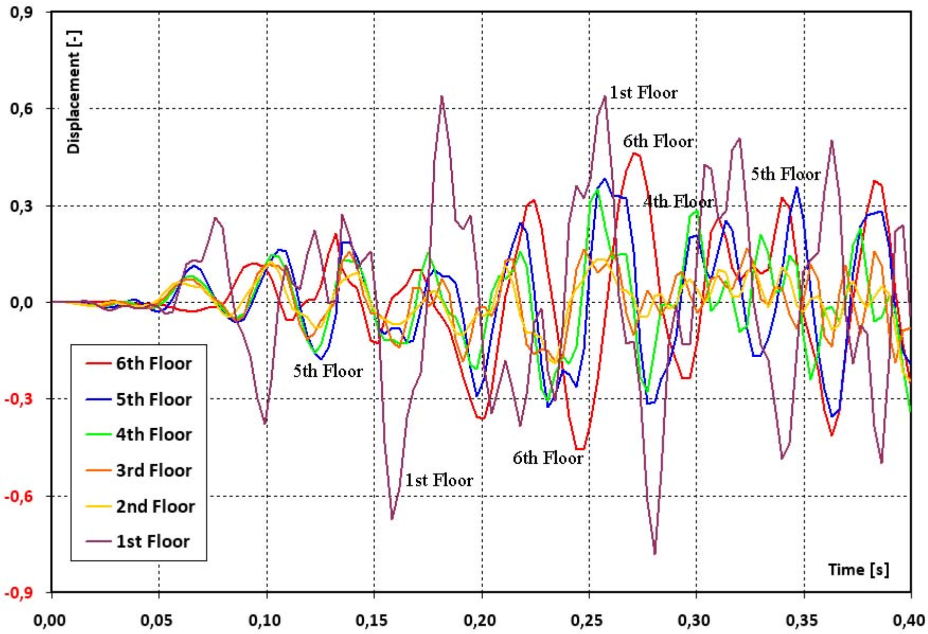

Fig. 3: Time histories of relative displacements on line B for vertical excitation.

Tab. 1: Extremes of relative floor displacements under vertical and horizontal excitation.

Floor level	*Insulated structure*				*Noninsulated 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*

4. An assessment of the effectiveness of springing

An assessment of the effectiveness of the sprung system can be based on a comparison between the measured vibrations (Fig. 1) and the vibration level of the individual storeys in the sprung building (Fig. 3) and vibration of insulated and noninsulated structure (Tab. 1). The measured dominant excitation frequencies of underground train traffic are 63 Hz and 87 Hz on the frequency peaks. The measured dominant excitation frequencies of underground train traffic are 63 Hz and 87 Hz on the frequency peaks. The springing of the building will shift its dominant vibrations into the range of the lowest natural frequencies (from 1.7 Hz to about 20 Hz, see Fig. 3) of the sliding or flexural vibrations of the building as a whole. For frequencies of up to 20 Hz, this maximum response acceleration value corresponds approximately to the effective acceleration a_{RMS} according to Tab. 2.

Tab. 2: Prognosis of maximum floor vibration

Excitation a_{RMS} [mm/s^2]	***Vertical excitation***		***Horizontal excitation***	
	Middle part of floors	*Balconies*	*Middle part of floors*	*Balconies*
	Response a_{RMS} [mm/s^2]			
0.80-0.84	*0.736-0.773*	*1.152-1.210*		
0.22-0.24			*0.238-0.259*	*0.235-0.257*

The above results show that the influence of springing will manifest itself by redistribution of the dominant vibrations into the low frequency range of the springing and by the practically negligible amplitude range of the vibration level in comparison with the initially dominant excitation frequencies (Fig. 1).

5. Conclusion

This paper deals with the application of an elastic antivibration layer at foundation base level in order to eliminate excessive vibrations propagating to the assessed building through the geological environment from an underground railway structure. When the train is in motion, the dominant vibrations are transferred to the environs in the form of non-stationary vibrations produced by the pass of the train and of the tunnel station structure vibration (in our case).

The histories of the measured vibrations were used as loads applied to a modelled building structure at the foundation base of which, as an alternative, a separating elastic rubber layer had been designed. The response of the vibroinsulated structure is compared with the non-isolated structure. The computed vibration histories reveal that the vibrations of the sprung structure are decreased in almost all the above-ground storeys. The effectiveness of the springing is determined by the frequency tuning of the sprung structure. The lower the tuning of the structure based on springs (the lower the dominant natural frequencies), the greater the decrease in the higher vibration frequencies and acoustic frequency effects propagating into the structure from its geological environment.

More significant influence of vibration is in most cases limited to the lowest two or three storeys. The predicted vibrations in the individual storeys were shown for a model with and without insulation, and were compared with the level of excitation vibrations at the foundation base. In the case of hard inelastic placing of the building on subsoil without springing, the vibrations would propagate from the subsoil in the whole frequency interval directly into the building structure, practically without decreasing. The applied springing is, consequently, a very efficient instrument for reducing the transfer of vibration from the soil to the interior parts of the building.

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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., Jr. (2005) Structure insulation exposed to excessive vibration of underground traffic (in Czech), Stavební obzor, 14, 1.

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