# Analysis of Vibro-Isolated Building Excited by the Technical Seismicity of Traffic Effects

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***Abstract***— *By location of a building in the vicinity of underground tube structure the effect of train operation excites the groundborne vibration. The solution of vibration transfer from the subsoil environment to the building structure is demonstrated using the example of a multistorey reinforced concrete building. The application of an elastic layer at foundation base level is used in order to eliminate excessive vibrations of these technical seismicity effects. The building is loaded by the non-stationary history of vibrations in accelerations. The measured time histories in acceleration were selected and then the typical history was used as an input for a dynamic analysis of the structure. Two 3-D numerical models of the building take into account the individual storeys, firstly modelled with vibro-isolation of building and secondly without this elastic part. The elastic layer was considered as the elastic subsoil of the Winkler-Pasternak model below the whole area of the upper part of the dual foundation plate and as the elastic support for columns and walls above the piles on the upper foundation plate level. The response prediction for vibro-isolated and non-isolated structure is compared and discussed. In the conclusion, the methodology of vibro-base isolation is evaluated.*

***Keywords— Analysis, building, validation, vibro-isolation.***

## I. INTRODUCTION

A calculation model (Fig. 1) of an entire structure was designed for an analysis of the structure, including the underground storeys and the vibro-isolation rubber layer. The computational model is placed on a multiple-layer subsoil structure, on the level of the floor of the 3$^{rd}$ underground storey.

The character of the vibrations generated by transport depends particularly on vehicle weight, driving speed, how the vehicles move and in what way and direction [1, 3, 4]. Another parameter is the "evenness" of the vehicle trajectory, in terms of whether it concerns the quality of the pavement surface or the horizontal and vertical railway alignment, the way in which the rails are fastened, the composition of the pavement courses, etc. The magnitude of the vibrations is influenced not only by the vibration parameters at the source but also by the composition of the environment on the way from the source to the threatened building structure, in particular the composition of the geological environment and its mechanical properties, i.e. stiffness, wave propagation velocity, distance-dependent damping, etc. Last but not least, the magnitude of the vibration may be amplified or damped by the building structure itself and by its foundations, in particular the frequency tuning of the threatened structure [2].

As far as safety is concerned, this level of vibrations generated by standard traffic is of no significance for current buildings, with the exception of historical or decrepit structures. Major cracks may originate due to the passage of very heavy vehicles or the operation of construction plant (such as vibration rollers) on new construction sites in the proximity of existing buildings.

Before transport-generated vibrations begin to cause damage to threatened structures a more serious problem may arise, i.e., the impact of vibrations on the people dwelling within these structures. Vibrations of this type usually exceed the safety limits specified by hygienic standards well before cracks and fissures originate in the structure.

## II. STRUCTURE MODEL

The building (ground plan size roughly 90 ×21 m) has three underground storeys and six (north side) up to ten (south side) graduated storeys above the ground. The building is founded on a foundation plate on the level of the 3$^{rd}$ underground storey. A 3D model (Fig. 1) was chosen for dynamic analysis of the structure. Floor slabs, load-bearing walls, columns and beams were modeled as reinforced concrete monoliths made of concrete C30/37. The load-bearing walls in the longitudinal direction of the storeys above the ground were modeled as built of bricks. Staircase broadsteps and loggia slabs were simulated as precast slabs, hinge-connected to the walls of the structure. The mass of the floor and the foundation plates includes the masses of the non-loadbearing components (thin partitions, floorings, etc.) as well as the equivalent of the live loads of the floors, roof and terraces. The relative structure damping value was chosen as 5% of the critical damping value.

The foundation plate 500 mm in thickness (upper foundation plate) is placed on a vibro-isolation layer made of Ekodyn rubber blocks [4, 9]. The anti-vibration layer of the rubber plates was designed in such a way 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 [5, 6, 8]. 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 rubber stiffness in the theoretical model takes into account the results of experimental tests on these materials. The bottom concrete 150 mm in thickness (lower foundation plate) is placed below the rubber layer, which is laid on a layer of the original healthy slate subsoil (class R3). The footing bottom is below the underground water level.

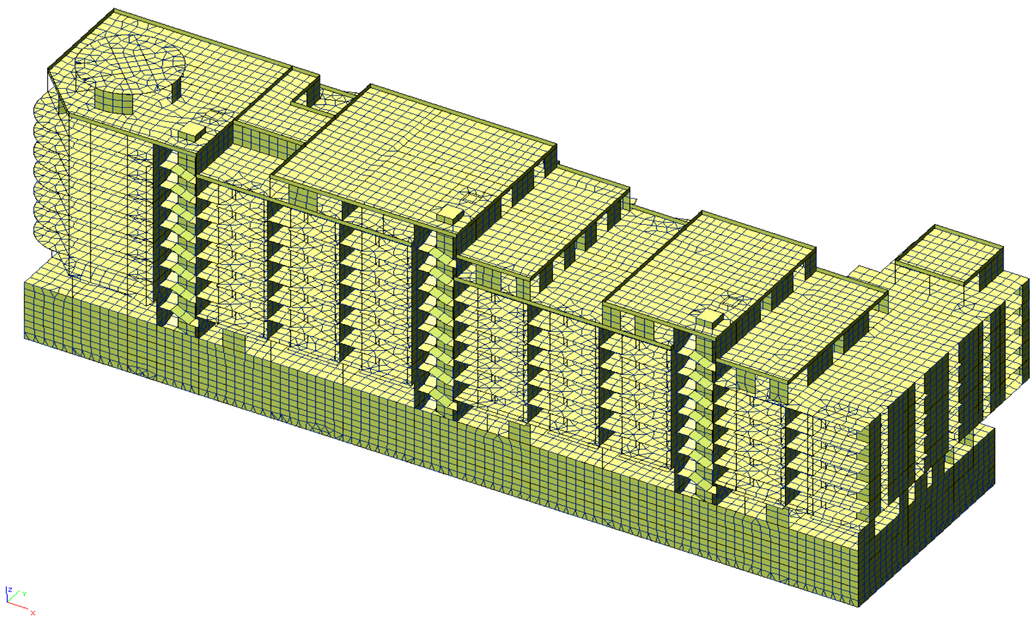

**FIGURE 1: CALCULATION MODEL OF THE BUILDING (NORTH-EAST VIEW)**

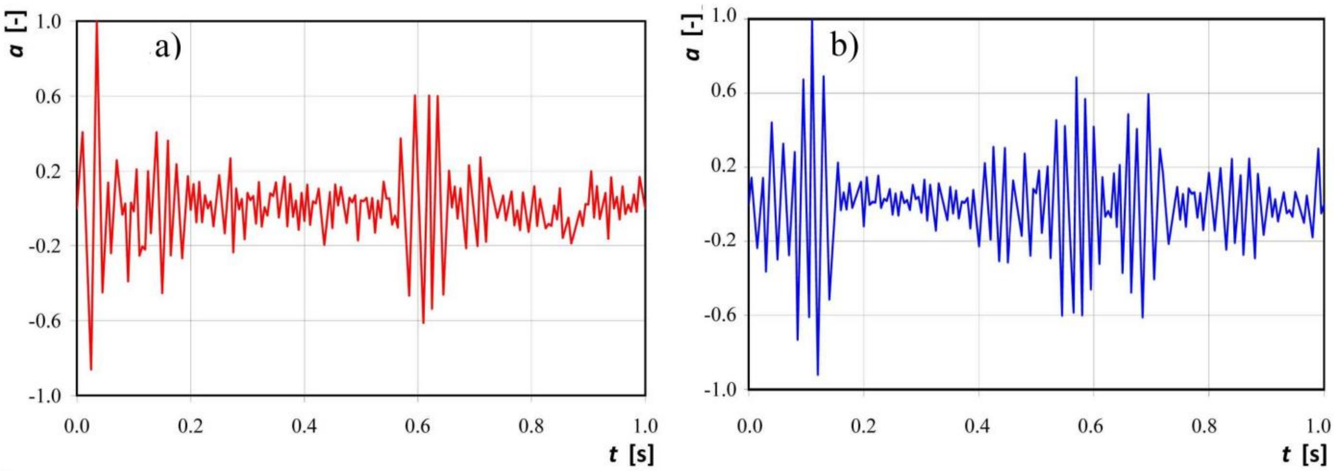


**FIGURE 2: SELECTED PARTS OF THE NORMALIZED VIBRATION EXCITATION, A) VERTICAL, B) HORIZONTAL**

## III. LOAD

Nonstationary normalized dynamic excitation (Fig. 2) due to traffic was introduced to the model at selected points of the structure, in a mesh 3 × 3 m of points on the level of the foundation plate. 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 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).

## IV. STRUCTURE ANALYSIS

The calculation model (Fig. 1) takes into account the individual storeys, broken down into the floor, foundation and roof slabs, columns, load-bearing walls and peripheral and interior girders [6, 7, 9]. 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 [10]. The rubber stiffness in the theoretical model takes into account the results of experimental tests on these materials. 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.

The natural vibrations were computed for the analyzed building structure. For the dynamic response to the effects of external actions (traffic), the lowest possible tuning of the rubber-mounted structure is decisive. This manifests itself, on the one hand, by flexural vibrations of the vibro-isolated building in the environs of 1.75 Hz, and, on the other hand, by vertical and horizontal translative vibrations of the building as a whole or by torsional vibrations. The difference between the calculated natural frequencies for the structure with and without vibro-isolation is very small.

**TABLE 1**
**EFFECT OF VIBRO-ISOLATION ON NATURAL FREQUENCY VALUES**

| Natural frequency [Hz] | | Character of natural mode |
|---|---|---|
| with | without | |
| vibro-isolation | | |
| 1.75 | 1.91 | Bending of the whole structure in perpendicular direction |
| 2.33 | 2.53 | Bending of floor plates and bending of the whole structure in longitudinal direction |
| 2.43 | 2.54 | Rotation of the whole structure round the vertical axis |
| 4.46 | 4.56 | Rotation of the whole structure round the vertical axis and floor slab bending of the higher storeys |
| 5.32 | 5.53 | Higher modes of floor slab bending |
| 5.35 | 5.57 | Bending of some floor plates of the lower storeys and roof |
| 5.43 | 5.76 | Bending of some floor plates of the middle storey |
| 5.56 | 5.82 | Higher modes of floor slab bending |
| 5.87 | 6.00 | |
| 5.99 | 6.19 | |

The vibrations of the building produced by underground traffic were predicted by the response analysis of the whole system. Extremes of relative displacements in all the storeys are shown in the Table 2. 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. Another element reducing the vibration level in the individual storeys may be the non-load-bearing partitions, floating floors, carpet floorings, etc.

The forced vibration of the structure was calculated using the method of decomposing the dynamic excitation 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 made with a step of 0.005 s.

**TABLE 2**
**EXTREMES OF RELATIVE FLOOR DISPLACEMENTS**

| Floor level | With isolation | | | | Without isolation | | | |
|---|---|---|---|---|---|---|---|---|
| | vertical | | horizontal | | vertical | | horizontal | |
| | $u_z$ | | $u_y$ | | $u_z$ | | $u_y$ | |
| | max | min | max | min | max | min | max | min |
| –3rd | +1.00 | –0.76 | +1.00 | –0.83 | +1.00 | –1.00 | +1.00 | –1.00 |
| –2nd | +1.22 | –1.29 | +0.96 | –1.07 | +1.43 | –1.00 | +1.28 | –1.89 |
| –1st | +1.24 | –0.97 | +0.89 | –0.89 | +1.00 | –1.00 | +1.12 | –1.23 |
| +1st | +0.87 | –0.92 | +0.70 | –0.59 | +0.85 | –0.82 | +1.18 | –1.49 |
| +2nd | +0.74 | –0.64 | +1.00 | –1.02 | +0.70 | –0.53 | +0.85 | –0.91 |
| +3rd | +0.70 | –0.69 | +0.85 | –0.76 | +0.54 | –0.72 | +0.91 | –0.95 |
| +4th | +0.73 | –0.72 | +1.80 | –1.13 | +0.63 | –0.51 | +0.81 | –1.04 |
| +5th | +0.66 | –0.66 | +1.80 | –0.93 | +0.63 | –0.56 | +0.81 | –1.19 |
| +6th | +0.69 | –0.71 | +0.85 | –1.04 | +0.52 | –0.47 | +1.90 | –1.32 |

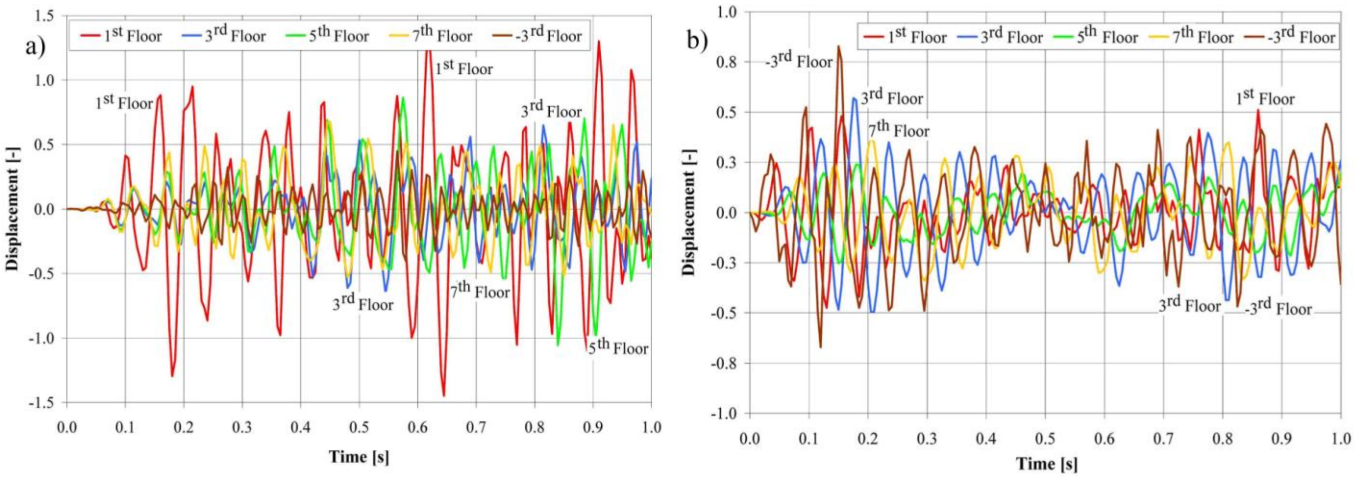


**FIGURE 3: TIME HISTORIES OF RELATIVE DISPLACEMENTS OF ISOLATED STRUCTURE, A) VERTICAL, B) HORIZONTAL**

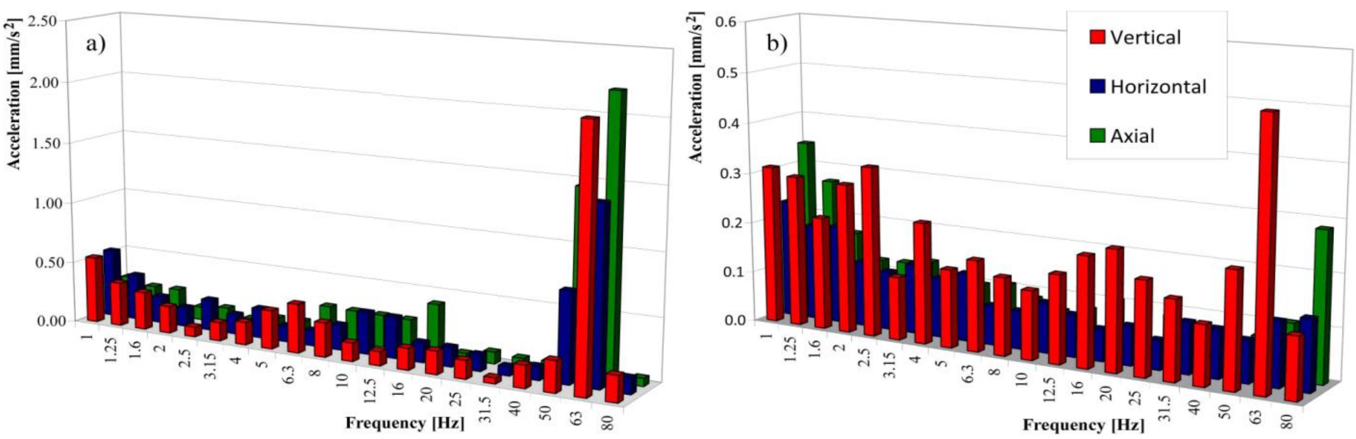


**FIGURE 4: ONE-THIRD-OCTAVE FREQUENCY SPECTRA BEFORE (A) AND AFTER (B) CONSTRUCTION OF BUILDING**

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. For comparison, the response of the structure to dynamic load was also calculated for the isolated and non-isolated structure; the resulting normalized values in the displacements caused by vertical and horizontal excitation are shown in Tab. 2.

In the case of nonisolated foundation of the building, the vibrations would propagate from the subsoil directly into the RC building structure, practically without decreasing.

Fig. 3 shows the resulting time histories of the calculated response for selected points within a vertical axis located in the central part of the building almost above the underground tube structure in the vicinity of the west corner of the building. The most intensively vibrating points are found near the underground floors and in the lowest one or two aboveground storeys in parts of the structure that are spatially situated toward the side of the underground tube. With rising height of the building, the dynamic response on particular floor levels decreases in cases where the mass and stiffness of the higher storeys are comparable. This effect manifests mainly on the lowest natural vibration modes, because the inertia of a substantial part of the structure is relative high, and the compliance of this part of the building at lower frequencies is low.

Fig. 4 presents the one-third-octave frequency spectra in acceleration for two records. The first spectrum (Fig. 4a) corresponds to one measurement record in free-field conditions, and the second spectrum (Fig. 4b) corresponds to the record at a stage when the building is almost finished. The frequency spectrum (Fig. 4b) clearly indicates that the dominant vibrations of the building are found in the area of low frequencies, and correspond to the building tuned as a whole on rubber vibro-isolation.

## V. CONCLUSION

In this paper we set out to assess the effect of building vibro-isolation on the transfer of vibrations due to traffic from the subsoil environment. The maximum measured intensities of the vibrations at the construction site were used as a non-periodic load of the building by technical seismicity caused by traffic effects. Optimum distribution of the vibro-isolation in the foundation structure was designed on the basis of a calculation of the static and dynamic response of the building. The calculation was also used to predict the floor vibration on individual storeys, and the time courses of the vibration at selected points were determined.

The paper has compared the calculated responses for an isolated building and a non-isolated building. The computed vibration histories of the examined building reveal that the vibrations of the isolated structure are decreased in all the above-ground storeys. The effectiveness of the vibro-isolation is determined by the frequency tuning of the isolated structure.

The calculated vibration forecast was compared with the final measurement results after the building was constructed (Fig. 4). This measurement indicated good agreement between prognosis and final observations. The frequency spectra show clearly that the main reason for the reduction in vibration is the shift of the excitation frequencies in the soil medium to the lower interval of frequencies of the vibration response due to the vibro-base isolation of the whole building.

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