Basement vibration isolation efficiency investigation

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Abstract. The article deals with experimental investigation of insertion loss estimation for a building elastic shielding vibration isolation system. Precision mechatronics production facility is located inside it with VC-D requirements for their foundation vibration level. A road with double tram lines lays 23 m off the exterior building’s walls producing reasonable vibration background noise. In order to reduce surface wave amplitudes elastic layer of Sylomer® polyurethane pads are glued to the underground exterior walls of the building. The vibration measurements were conducted before and after the elastic shield installation and the insertion loss was estimated using these results. Moreover, simultaneous dual channel analysis of vibration transfer through the wall structure was evaluated. Measured vibration isolation efficiency reaches 14 dB in octave band 31.5 Hz in vertical and from 9 to 15 dB in horizontal direction. For higher frequencies vibration isolation efficiency reduces due to wave effects in the isolators.

1. Introduction
In recent years, vibration has become increasingly important factor to consider during design of precision mechatronics production facilities. As the demand for higher precision tools increases, the importance of vibration control also increases [1]. Many processes involved in advanced technology applications are highly sensitive to vibrations. Among these processes are precision metrology, high-energy physics, long-beam path laser applications, biotechnology research, and the R&D and production of semiconductors [2]. In fact, at the present time, many aspects of structure/foundation design are controlled by vibration considerations rather than the traditional needs for load-carrying capacity.

This study deals with experimental analysis of vibration mitigation measures applied at precision mechatronics production facility (PMPF). PMPF occupies ground floor of a 9 floor commercial building, that is located in 23 m off the road. The road characterizes by heavy automobile traffic (in rush hours) and double tram lines. The arrangement of the building and the road is shown in Fig. 1.

PMPF is supposed to produce high-precision linear drives, so its equipped with both precision production equipment as well as high-accuracy metrology equipment. Due to design project, permissible vibration level at the base of equipment falls to VC-D vibration curve [3–5] with maximum acceptable RMS vibration velocity of 6 µm/s in third-octave frequency band from 0 to 100 Hz. Close location of PMPF to the road and the tram line poses the most serious issue: vibrations from the road can affect the precision equipment performance. Vibration affects different processes in
different ways. In some cases, it can cause differential motion within instruments, distorting images; it can also lead to misalignment in processes that occur over extended periods of time, such as time-lapse imaging or photolithography [6].

Figure 1. Location of the test site.

Adjacency of tram lines to vibration-sensitive facility is a sticky issue, but not without precedent in the design of advanced technology facilities. There exist a plenty of different methods used for vibration isolation of precision equipment discussed in [6–10]. The concept and general layout of a facility greatly determines its vibration levels, as well as the cost to achieve them. For example, vibration control is usually easier to achieve with slab-on-grade floors than with those suspended floors supported on columns [6]. The stiffness or rigidity of a floor is paramount to determining its ability to absorb impacts or shocks without propagating vibration [11]. However, the most economical way to reduce vibration level is to understand its primary source, its path and vibration spectra.

Vibrations propagate from the upper track structure and the road through the ground to a vibration-sensitive receiver predominantly by means of Rayleigh (surface) waves and secondarily by body (shear and compressional) wave [2]. Moreover, vibration amplitude decreases with depth. These facts charted a course for a surface wave barrier in order to satisfy VC-D requirements inside the facility.

2. Site survey
In order to understand the properties of vibration source, site survey was performed. Vibrations of ground surface as well as vibration at the bottom of foundation pit inside the building were measured with a highly sensitive low-noise ICP accelerometers with the sensitivity of 1000 mV/g placed on a stake driven into the ground. Measurement locations are depicted in Fig. 1. The measurements were taken at three directions X, Y and Z simultaneously at each point. The duration of each measurement was not less than 30 minutes at point. Data was discretized at 25600 Hz using 24-bit 8-channel LMS Scadas mobile-I acquisition system. Measurement data analysis was performed using LMS TestLab software or manually written codes in MATLAB software using statistical and spectral analysis algorithms using [12–15].

Spectrogram of measured signal outside the building at point 1 for vertical direction is depicted in Fig. 2.
The spectrogram at Fig. 2 clearly shows at least six passes of trams by nearest track along the street and at least five by distant one, as well as the passage of trucks and public transport. From the results of Fig. 2 it can be noted that the passage of a tram excites in the ground oscillations with the largest amplitudes in the frequency range from 10 to 100 Hz with peaks in the frequency range from 10 to 37 Hz and from 60 to 85 Hz. Vibrational impact is continuous – each tram pass takes about 25 – 30 s. Unlike trams, the passage of vehicles causes vibrations in the ground with the largest amplitudes in the frequency range 5 – 40 Hz. For vehicles, a significant spread in the frequency, amplitude and exposure time is evident which depends on a large number of parameters – speed, mass of the vehicle and suspension type.

The data obtained using high sensitive accelerometers show that pedestrian activity, which occurs mainly at low frequencies (1 – 5 Hz), will also have an effect on the vibrational background in the building. According to the results of the measurements, it can be noted that in a comfortable environment the speed of human flow is about 60 – 90 m / min, which with a human step length of 0.6 – 0.8 m gives about 0.8 - 2.3 foot touches per second. Thus, in an elastic medium, vibrations in a frequency range from 0.8 to 2.3 Hz are excited.

Comparison between RMS vibration level on the bottom of foundation pit with VC-D & VC-E curves is depicted in Fig. 3. It is evident that VC-D vibration requirement are not satisfied in the frequency range from 1 – 40 Hz and vibration isolation is necessary.

It was proposed to use a dual stage vibration isolation system. The first stage is the building elastic shielding used to reduce surface waves travelling from the road. It is well-known solution applied for historical buildings located near tram lines [16]. On the second stage, local foundation vibration isolation is proposed using rubber resilient elements to withstand VC-D or even VC-E criteria depending on equipment requirements.
Building elastic shielding was made on the underground part of exterior walls facing the street. It consists of an elastic layer made of Sylomer® SR28 foamed polyurethane pad 25 mm thick, protected from external environmental perturbations with 10 mm thick asbestos boards and double layered torch-welded waterproofing. The required dynamic stiffness of the elastic layer and its thickness was calculated due to soil and pavement set-on weights and maximum permissible deflection of 5 mm required to maintain waterproof layer continuity. Sylomer® materials were selected due to their quality, lot compliance and excellent long-term behavior tested both in laboratory and on-site [17,18].

3. Insertion loss estimation
Insertion loss estimation was managed on the basis of simultaneous measurements performed on the ground surface in front and after the elastic shield layer. The difference between the vibration levels is shown in Fig. 4 for each of measurement directions for maximum and equivalent vibration acceleration level in dB.

Results shows that vibration levels inside the elastic shield are lower than in front of it due to reduction of surface wave amplitudes. The valuable vibration reduction occurs in frequency band of 31.5 Hz: 14 dB for vertical direction and from 9 to 15 dB in horizontal one. Vibration isolation efficiency reduces with octave band frequency increase and result in negative values at 250 Hz, which is due to wave effects in the elastic layer [19,20]. Negative efficiency values in low octave bands from 8 to 16 Hz are due to resonance on elastic layer’s eigenfrequency.

The application of elastic shielding has also reduced vibration levels on the bottom of the foundation pit – as it can be seen from comparison 1/3 – octave band spectrum before and after shielding installation on Fig. 3. With a little increase of vibration level in octave band 20 Hz, great reduction in octave band range 1.6 – 12.5 Hz and 31.5 – 100 Hz is obtained, that also complies with VC-D requirements. Residual vibration level increase in octave band 20 Hz can be easily suppressed by conventional vibration isolated foundation with linear or nonlinear resilient mounts like discussed in [8,21,22].
Figure 4. Insertion loss estimation

Conclusion
Adjacent location of vibration sensitive facilities with road and railway lines reveals a sticky issue that has to be dealt with on the design stage or during renovation of existing facilities.

Proposed elastic shielding vibration isolation solution effectively reduces unwanted surface waves traveling from the road and railway track both in horizontal and vertical directions. Measured vibration isolation efficiency reaches 14 dB in octave band 31.5 Hz in vertical and from 9 to 15 dB in horizontal direction. For higher frequencies vibration isolation efficiency reduces due to wave effects in the isolators.

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