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# IMPACT VIBRATIONS GENERATED BY NON-SEISMIC SOURCES ON STRUCTURAL SAFETY, FUNCTIONALITY AND COMFORT

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***Abstract***

*In most cases, most of the vibration energy source with the dynamic flux propagation Rayleigh waves propagated near the surface of the ground may cause movement of the ground and a high level of efforts that transmit vibrations from underground to the supported structures and adjacent structures. The permanent negative effects of these major vibrations on foundations cause structural damage to adjacent buildings, especially those supported by deposits of soil/soft soil. This type of vibration can cause adverse effects in the nearby areas and inside buildings to sensitive electronic equipment and to devices/facilities measuring and alike can have a major impact on occupant comfort. The literature shows that the best assessing criterion is the maximum speed of oscillation of the particle soil - PPV (Peak Particle Velocity).*
*The paper aims to present a case study on determining the effects of vibration levels generated by non-seismic sources on structures. A criterion for assessing the vibration at internationally level is considered and also some existing solutions in the literature to reduce the level of vibration are presented. The proposed systems were evaluated and compared using particle displacements reductions obtained in soil through intensive study of parameters. All proposed filled barrier systems performed well in order to reduce surface waves and effectiveness shielding, but in most cases a variable protection in the presence of structure was provided.*

***Key words:*** *non-seismic sources, vibration, assessing criteria, structural safety, systems for vibrations mitigation.*

## INTRODUCTION

In-situ vibration can be characterized in any point by the following seismic parameters: period or frequency, displacement, velocity or acceleration of the particle of soil at that point. From these parameters, secondary quantities as relative energy, the strength of vibration expressed in vibrating can be also estimated.
Evaluation criteria can be related to one of the dynamic parameters listed above. In terms of mediation in time of the kinematic quantities, they can be instantaneous maximum values, mean or RMS spectral values resulting from a third octave analysis.
Descriptions of allowable values for different types of kinematic values are specified in national technical rules and in the literature.
Technical standards referred to in this report are:
Romanian rules:
- SR 12025-2-Vibration effects on buildings or parts of buildings. Permissible limits;
- P 121 -89 - Technical instructions for the design of noise protection measures and anti-vibration to industrial buildings;

German norm:
- DIN 4150-3/1999 - Vibration in buildings - Effect on structures;

Swiss norm:
- Standard for the effect of explosions on buildings;

Norm in Washington - USA:
- WAC 266-52-67065 - Vibration and damage control

The literature shows that the best criterion for assessing is the maximum velocity of oscillation of the particle of soil - PPV (Peak

Particle Velocity). The following theoretical and experimental justification comes to support the choice of velocity criterion as the most reliable criterion for assessing the effects of vibration:

- the particle velocity take into account both frequency and displacement and give a valid indication for any frequency vibration;
- good statistical correlation of degradation data with velocity;
- the velocity of oscillation depends in large measure of soil properties, except those saturated with water, compared to displacement or acceleration.

Velocity criteria as defined in various standards or studies generally refer to buildings with structures designed according to the technical rules. Different thresholds with allowable limits are defined for structural types based on height, number of openings; constituting material for the structural elements, possible degradation of structural and non-structural elements; distance; vulnerable/non-vulnerable buildings (refer also to historical monuments).

Assessment criteria refer to the velocity of oscillation at ground level or structural oscillation velocity.

## MATERIALS AND METHODS

Determining the level of vibrations produced by ambient vibration is in an area comprising an inside, outside and the perimeter of the industrial hall, the location of technological equipment (industrial presses), the driveway and the road surface limit, in the residential neighbourhood and in the subway station, Figure 1.


Figure 1. The area for which the vibration measurements are carried out

**Materials-Equipment.** In order to achieve the instrumental recordings, the following equipments were used: the digital triaxial accelerometers Kinemetrics (ETNA), triaxial accelerometer GSM-18 GEOSIG, broadband multichannel stations GeoDAS – Japan for vibration monitoring, Figure 2.

Figure 2. Location of GEODAS 12USB stations (left) and ETNA (right)

In accordance with STAS 12025/1-81, the level of vibration strength encountered in the literature that the relative intensity of the vibration is determined by the relationship:

$$S = 10\lg\frac{A}{A_0}$$

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in which:
*A* is the strength (intensity) of vibration, defined by the relation:

$$A = \frac{a^2}{f} \ [cm^2 / s^3]$$

*a* is the amplitude of vibration acceleration at frequency f, in [cm/s$^2$];
f considered frequency, in Hz;
$A_0$ – strength (intensity) of reference, with the given value:

$$A_0 = 0{,}1 \ [cm^2 / s^3]$$

SR 12025/2-94 sets allowable limits for normal operation of residential, social and cultural buildings subjected to vibration action produced by aggregates located in or outside the buildings and of road traffic vibration, after propagation through the structure of the path or road bed, acting on buildings or parts of buildings. For the comfort of the building, the limit values of the vibration are different in the case of vibrations acting in the longitudinal direction or transverse direction.
For a number of materials commonly used in construction, SR 12025/2-94 shows the material degradation curves. According Norms on acoustics in buildings and urban areas, indicative C 125 - 2013, Part IV - Protective measures against noise in urban areas, indicative C 125/4 - 2013 Annex 1 List of parameters and performance levels corresponding requirement "Protection against noise in urban ensembles, "published in official Gazette No. 812 bis., on 20/12/2013, parameter 9: allowable vibration level of specified velocities on structure in terms of the frequency is maximum 8mm / s.

## RESULTS AND DISCUSSIONS

Results are acceleration, velocity fields, with the response spectra in the hazardous frequency domain for buildings (0÷40Hz). Description of allowable values for different types of kinematic values is specified in the national technical rules and in the literature presented mentioned above.
Processing records can led to determining the maximum instantaneous velocity and acceleration records and expressed in velocity and acceleration and getting the velocity and displacement through calculation (ETNA, GSM-18), determining the maximum instantaneous of records expressed in velocity (GEODAS stations), the spectral analysis of records in velocity and acceleration, Figure 3 and Figure 4.

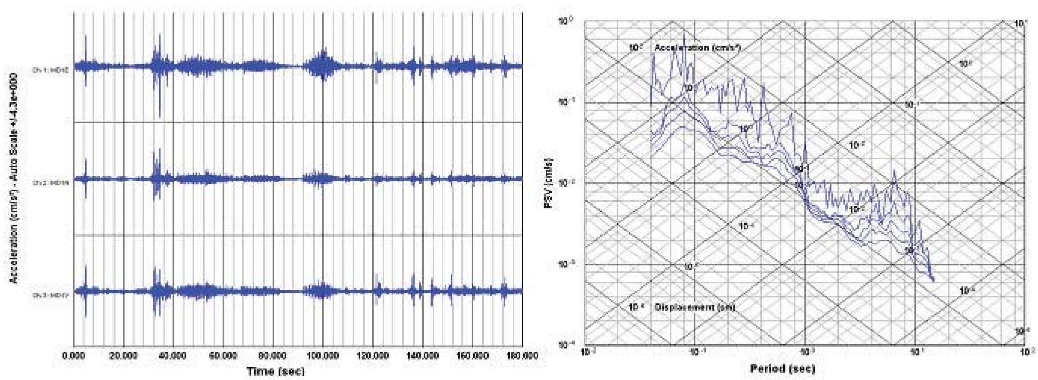


Figure 3. Example of registration in terms of acceleration (left) and results obtained after processing in form of tripartite spectra (right)

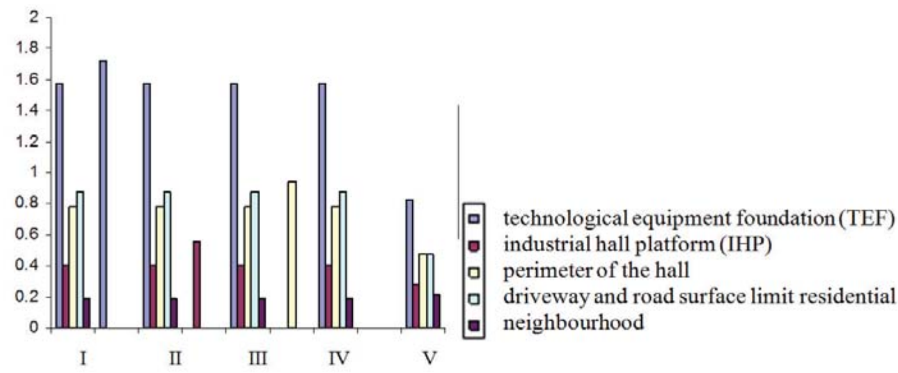


Figure 4. Graphical representation of the maximum velocity (mm/s) in the studied area (Dragomir et al., 2015)

**Studies on mitigation/reduction of vibrations**

For effective protection of buildings from structural failure due to dynamic loads generated by human activities such as drilling, blasting in construction of roads, foundations subjected to vibration in industrial, heavy and dense traffic caused by the development of interconnections residential areas etc., there are multiple possibilities for shielding the vibration caused by all these sources. In particular the development of rapid transport and increased of weight of fast trains have as effects vibration in soil and structures along transport routes and in the immediate vicinity of loads, especially in densely populated urban areas (Orehov et al, 2012).

Reducing the structural response can be achieved by: Adjusting the frequency content of the excitation; Change the location and direction of vibration sources; changing the dissipation of waves near the ground surface; Interrupt partial waves spread in structure or by providing a damping attenuation structure by various means such as additional damping systems or other base isolation systems. It is also possible to change the dynamic behaviour of transmitted locally underground waves by way of a complex mechanism of reflection waves and changing the source of vibration isolation by building a barrier between the waves and dynamic load affected structures such structures will be protected. When insulating barrier is positioned near the vibrating source, such application is known as "active isolation" (near field). If the barrier is located far from the source but around the structure to be protected from Rayleigh waves so far containment field is known as "passive isolation".

As an open trench and a solid barrier such as a ditch filled with suitable materials may be useful as anti-vibration measures. There is a wide range of types of construction that can be considered as the basic insulating barrier, ranging from concrete walls or piles arranged in series to the gas highly flexible mats or barrier which prevents the waves, when the latter is based on the cut-off frequency of a rigid layer soil on the bedrock. Due to effective shielding, easy and low-cost implementation, both open and the filled trenches are most commonly used in engineering as isolation measures.

Numerous studies have had as main objective the development of new numerical techniques as a tool to analyse the influence of different parameters in order to shield vibration through trench barriers compared with the few experimental studies in which tests are conducted at real scale and laboratory models only for particular cases.

The effect of stratification of soil on wave shielding efficiency by vibration isolation systems under plane deformation are also investigated using frequency domain formulation of numerical analysis.

Shielding effectiveness depends on accurate assessment of stiffness material used as a barrier. This requires a series of experiments to understand the characteristics of wave propagation.

For testing are required an excitatory, two concrete blocks, a wave barrier and two measuring points. Electro-dynamic stirrer, which induces a sinusoidal motion, as shown in Figure 5, is used as a source of vibration to produce a stationary vertical harmonic force of 250 N maximum amplitude in a frequency range of practical importance of 10 Hz÷95 Hz. Adjacent accelerometers are used to obtain values generated that are stored on computer. Excitation frequency is increased gradually in steps of $\Delta f = 5$ Hz. The noise of the signals recorded during the test was removed by digital signal processing by filtering with a band pass filter (Orehov et al, 2012).

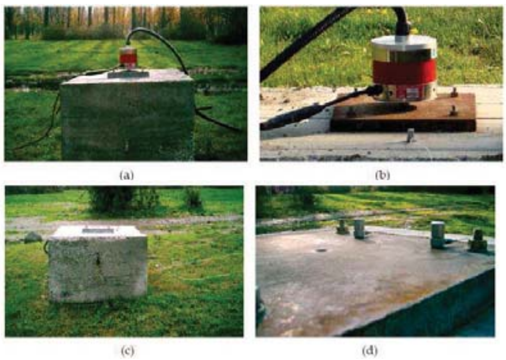

Figure 5. Electrodynamic shaker and accelerometer rests on a foundation: a) electrodynamic shaker placed on foundation; b) electrodynamic shaker and accelerator positioned on the foundation, c) Measurements made on the basis of the Foundation, d) Accelerometer rests on the foundation.

The vibrator is mounted on a thin metal plate and located above the central square shock rigid concrete, in order to cause only vertical vibrations. Two surface concrete foundations size 1.0 m×1.0 m×0.5 m, at a distance from one another by LF = 25 m are used. For research purposes, is built a long rectangular trench (an open channel) with $\Delta t = 3$ m, symmetrical about the centre line of these foundations. The first foundation is used to produce a harmonic load accelerometers and one for recording and vice versa. Source measurement on concrete pedestal is at a distance of 4 m from the gutter to isolate active research at a distance Lt = 20 m for measuring passive isolation. Vertical components of harmonic vibrations are recorded with accelerometers placed on these foundations and corresponding to a time interval Dt = 0.0005 sec.

Shielding performance of trench material stiffness in relation to soil and excitation frequency range is investigated by performing a series of field tests on transmitter and receiver isolation barriers, namely active and passive.
In order to achieve the best results in vibration control, are using four types of ditch barriers. For trenches filled with water as shown in Figure 6, the backfill material compared to soil is considered as water, bentonite as a material softer and the concrete as more rigid material instead of open trenches. For stability reasons the trench/ditch walls slope has been reinforced with 0.15 m thick reinforced concrete.

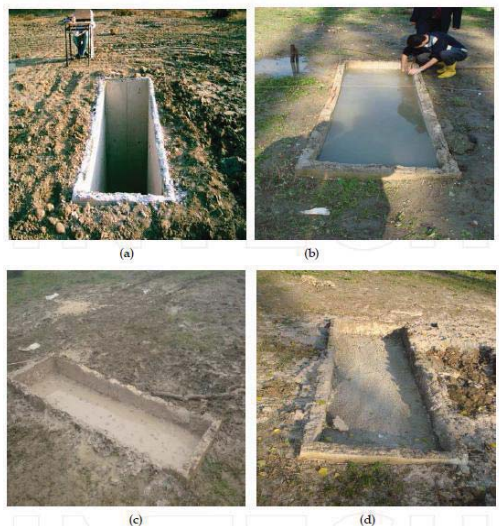

Figure 6. Trench-type insulating barriers: a) open trench, b) pre-filled trench with water, c) trench filled with bentonite, d) concrete ditch

## CONCLUSIONS

Measurements to determine the level of vibration were non-seismic sequence and were made with type Geodas stations, Japan, broadband and high sensitivity (10-6 m/s) with 12 channels equipped with four triaxial transducers, and that 3-channel transmitter equipped with one triaxial, ETNA accelerographs GeoSIG Kinemetrics and GSM-18, triaxial, with automatic and manual release.
The analysis of all data recorded in the industrial equipment, and in its vicinity, during the recordings were made, there were no vibrations that exceed permissible levels set by

the standards and regulations, which are almost ten times below their limits.

According Norms on acoustics in buildings and urban areas allowable vibration level specified for structures is up to 8 mm/s.

Regarding the study of active and passive insulation against vibration was put to demonstrate the effectiveness of different system configurations barrier protection as ditches filled. Proposed systems were evaluated and compared using particle displacements reductions obtained in soil through intensive study of parameters. Following previous discussions and analysis results, we can draw the following conclusions: All filled barrier proposed systems perform well to reduce surface waves and shielding effectiveness. Moreover, in most cases provide protection in the presence of variable structure. Continuous monolithic wall system is an economical solution as a passive isolation system, since it requires less material.

In the presence of structure, where open ditches and some filled, the barrier acting normal and the movement of the particle behind the barrier went up, but if no structure was observed that the measurements are expected trend in terms of amplitude versus distance for all distances. This may be due to two reasons: first, the vibration of the structure under dynamic loading can affect the vibration of the ground surface particles. Waves produced by the structure to the ground, passing through the soil-structure interface, in-phase or out of phase are; The second reason, the amplitude of vibration is negligible even without barrier, and any variation of the response rate is a major change.

It is noted that in many instances it is necessary to conduct a more thorough investigation on the structure of soil-insulating barrier (ditch/channel) used simultaneously, as performed in this study.

## ACKNOWLEDGEMENTS

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