ANNOYANCE AND DAMAGE IN BUILDINGS CAUSED BY VIBRATIONS. CONSIDERATIONS FOR A VIBRATION CONTROL GOOD PRACTICE

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RESUMO:
As pessoas atribuem a vibrações as fendas nos estuques e rebocos e outros danos cosméticos de que se apercebem nas suas casas, vibrações essas que sentiram anteriormente, e que, em regra, não foram medidas nem controladas, tais como as devidas a explosões (em escavações com desmonte de rochas com explosivos), ou vibrações ainda ocorrentes, tais como as provocadas por equipamentos motorizados próximos (mais correntemente passagem de combóios); muitas reclamações referem que os danos apareceram após a ocorrência das vibrações. Em processos judiciais os Juízes requerem ao LNEC perícias no sentido de se averiguar se vibrações passadas podem ter sido responsáveis por incómodos e danos nos edifícios.

Em regra os valores medidos são muito inferiores aos limiares de danos referidos na normalização nacional e internacional, bem como nos critérios de danos usados pelo LNEC. É difícil avaliar os efeitos de vibrações anteriores não medidas, e fórmulas utilizáveis dão previsões com grande incerteza.

Os danos cosméticos são geralmente devidos à retracção de estuques e rebocos, a variações e diferenças de temperatura e humidade diárias e anuais, e entre as duas faces dos elementos dos edifícios, e a deformações dos elementos dos edifícios e a assentamentos diferenciais das suas fundações; em que medida as vibrações agravam fendas já existentes?

Listam-se algumas regras básicas para o planeamento ou exploração de actividades geradoras de vibrações perto de edifícios, para evitar desconforto para as pessoas ou mesmo danos nos edifícios.

Relatam-se exemplos de medições e estudos realizados pelos autores, e retiram-se conclusões.

ABSTRACT:
Many times plaster cracks and other cosmetic damage are attributed by people to previous uncontrolled (not measured) or to still going on sensible vibrations, induced either by nearby motorized equipment (more commonly railway traffic) or by blastings (in rock excavations with explosives); many complaints state that cracks appeared after sensible vibrations occurred or began. Court Judges ask LNEC for expert assessment, stating if visible damage in buildings is or not due to past vibrations.

Most of the times, measured values are very much bellow the usual standards damage limits, either in international or Portuguese standards and criteria used by LNEC in the assessment of damage in buildings caused by vibrations. Unmeasured past vibrations are difficult to evaluate, and formulae available give results with large uncertainties.

Cosmetic damage is also due to mortars and plaster shrinkage, to temperature changes on time and temperature differences on both sides of building elements, and to uneven displacements of building elements and foundations; how vibrations add visibility to existing cracks?

Some basic rules are listed in order to avoid discomfortable or damaging vibrations in buildings, as an attempt to draw a code of good practice, whenever vibration generating activities are planned to or going on near people's houses.

Examples from the authors experience, studies, measurements and conclusions are related.

1 - FOREWORD

More and more complaints are forwarded to courts and to authorities (city councils, LNEC, etc.) blaming vibrations and also noise (sound waves from blastings) for cosmetic damage (plaster cracks and other, window glasses cracks) in people's homes. Vibrations and noise are also blamed for discomfort (at home, at work) and even psychological stress and health diseases.

Cosmetic damage is usually due to mortars and plaster shrinkage, to temperature and humidity changes (from night to day, from winter to summer) and temperature differences on both sides of building elements, and also due to uneven displacements of building elements and foundations.

How, in an assessment of damage, after the occurrence of sensible noise and vibration, is it possible to know whether the vibrations felt by people are also responsible for the visible damage on mortars, plasters and tiles, or even in deeper cracks through walls, ceilings and floors? How is it possible to judge the right of people claiming that adjacent works caused them psychological and physical diseases?

2 - VIBRATION THEORY AND PRACTICE BRIEFLY REVIEWED

As we all know, in all continuous bodies with mass and elasticity, vibration is easily established in the form of a travelling wave $u(x, y, z, t)$ with a characteristic speed c, characteristic of the medium (being E the effective Young modulus, ρ the mass per unit volume):

$$c = (E / \rho)^{1/2} \qquad (1)$$

For continuously travelling sinusoidal waves, wavelengths λ and frequencies f can be observed, related by

$$\lambda f = c = 2 \pi \omega \lambda \qquad (2)$$

Several types of waves may travel through the soils: compression **p** (longitudinal) waves, shear **s** (transverse) waves, Rayleigh surface waves (similar to the sea waves) and Love surface transverse waves. The **p** waves are the faster ones: c_p varies from about 340 m/s in the air, from 1000 to 2500 in compact soils, from 1500 to 4000 in soft rocks, 3000 to 3500 in concrete, and up to 8400 m/s in hard rocks. The **s** , Rayleigh and Love waves have lesser speeds.

In a **p** wave, strain ε is related with the speed c_p and with the particle speed $u' = v_p$ by:

$$\varepsilon = v_p / c_p = v_p / (E / \rho)^{1/2} \quad (3)$$

Soil waves frequencies vary, say between 2 and 100 Hz , depending on the process of the wave generation; near an explosion in hard rocks, the velocity (u') spectrum may contain significant frequencies up to 2000 Hz ; near a railway, up to 200 Hz .

Wave attenuation, from its source, depends upon two mechanisms: the geometric spread of the wave, and the damping. Higher frequencies components attenuate faster, which means, nearer to the source, and in harder soils, waves go farther than in softer soils, for the same frequencies.

One formula used for predictions is Medvedev's (u'_M in mm/s , r in m and W in kg) based on Buckingham theorem, establishes a relationship between the particle velocity u' and the scaled distance $r / W^{1/3}$ (where W is the weight of the explosive charge blasted in any given 8 ms period of time) [6].:

$$u'_M = 1900 (r / W^{1/3})^{-1.5} \qquad (4)$$

Fig. 4 shows some practical results including LNEC measurements [4].

Under certain boundary conditions, waves u(P, t) may become stationary, assuming then the form of vibrations ($\omega = 2 \pi f$), the bodies exhibiting characteristic (natural) frequencies ω_i:

$$u(P , t) = \sum U_i(P) \cos(\omega_i t) \qquad (5)$$

The well known one degree of freedom m - k - c model [1], shows one characteristic frequency, ω_o , called the undamped system natural frequency (compare with eq. 1):

$$\omega_o = (k / m)^{1/2} \qquad (6)$$

In practice, free vibration (being $\delta = c / 2 m$, $\omega = (\omega_o^2 - \delta^2)^{1/2}$)

$$u_h = u_M e^{-\delta t} \cos(\omega t - \varphi) \qquad (7)$$

can be used to identify the model parameters, k / m and c / m : $c / m = 2 \delta = 2 \ln(u_{M1} / u_{M2}) / T$; $k / m = \omega_o^2 = \omega^2 + \delta^2 = (2\pi / T)^2 + \delta^2$, u_{M1} and u_{M2} being two consecutive maxima and T the vibration period.

Damping is usually referred by the damping ratio:

$$\xi = c / c_{cr} = c / 2 (k m)^{1/2} = \delta / \omega_o \qquad (8)$$

For small oscillations, usual values of ξ are: about 0,3 to 0,5 % for steel structures, about 0,5 to 0,8 % for buildings of prestressed concrete structures and composite structures of concrete and steel, about 0,7 to 1 % for reinforced concrete structures, about 1 to 1,5 % for traditional stone and brick masonry and timber buildings.

For a sine wave excitation (through the system base, say the building foundations, or the slab edges) with frequency Ω :

$$\mathbf{A} = U / Y_o = (\Omega^2 / \omega_o^2) / [(1 - \Omega^2 / \omega_o^2)^2 + (2 \xi \Omega / \omega_o)^2]^{1/2} \qquad (9)$$

is called the amplification factor. The system resonates for $\Omega \approx \omega$. For small values of ξ the maximum amplification (resonance) is:

$$\mathbf{A}_M \approx 1 / (2 \xi) \qquad (10)$$

The more complex linear models may take the time dependent form of

$$\boldsymbol{D}\,\mathbf{u} = \mathbf{y} \qquad (11)$$

($\boldsymbol{D}$ being a differential operator that contains mass, stiffness and damping). In the frequency domain, using Fourier transforms, eq. 11 becomes ($\mathbf{D}(\omega)^{-1}$ being the transfer function):

$$\mathbf{U}(\omega) = \mathbf{D}(\omega)^{-1} \, . \, \mathbf{Y}(\omega) \qquad (12)$$

In practice, and in standards concerning discomfort and damage in buildings, two kinds of vibrations are generally considered: the impulsive (transient, or short-term) vibrations, and the continuously ongoing (continuous, or steady state) vibrations.

ISO 4866:1990 suggests a boundary between the two types: if the input duration exceeds $5 \times (\xi\, \omega_o)^{-1}$, ξ being the damping ratio $\omega_o = 2\, \pi\, f_o$ the main natural frequency of the system (ω_o in rad / s), the output vibration is considered "continuous"; otherwise transient.

3 - PORTUGUESE COSMETIC DAMAGE STANDARDS AND CRITERIA

3.1 - Transient Vibrations

For the so-called transient vibrations, due to short term inputs (blasting, pile driving, etc.), Table 1 shows the portuguese standard NP 2074:1983 acceptance criteria for cosmetic damage in buildings:

Table 1 - *NP 2074:1983 - Limit values for the maximum velocity (p.p.v., vector modulus) of the vibration measured on floor level on the building foundation ($|v|_M$, mm/s)*

$\vert v\vert_M$ \ ground → ↓ category of building\	Sands, incoherent or soft soils $c < 1000$ m/s	compact soils and soft rocks $1000 < c < 2000$ m/s	Coherent hard rocks 2000 m/s $< c$
sensitive buildings (e1)	1,75 - 2,5	3,5 - 5	7 - 10
current buildings (e2)	3,5 - 5	7 - 10	14 - 20
reinf.ced concr.te str. b. (e3)	10,5 - 15	21 - 30	42 - 60

Obs: 1 - The first values in each cell apply when more than three blasts occur per day, the second values for 3 or less blasts per day; 2 - The quantity to be measured is the modulus of the three orthogonal components of the velocity vector.

e1 - Sensitive buildings, as historical monuments, old protected houses, historical town centers, hospitals, water tanks, masonry or brick chimneys, etc.. e2 - Masonry & timber current buildings and houses in fair condition, old industrial buildings, etc.. e3 - Buildings with reinforced concrete structure, recent industrial buildings with steel or mixed steel-concrete structures, etc..

3.2 - Continuously Ongoing Vibrations

In the Portuguese Committee of Standardization, CT 28, Acoustic Noise, Vibration and Shocks, the following acceptance limits were suggested for continuously ongoing vibrations:

Table 2 - *Damage: limit values for the rms velocity of the vibration measured in any local of the building (any component, v_{rms} , mm/s)*

v_{rms} mm/s	duration inferior to 1 hour/day	duration superior to 1 hour/day
sensitive buildings (e1)	1	0,7
current buildings (e2)	2	1,8
reinf.^{ced} concr.^{te} struct. b. (e3)	5	5

Obs: Value of the biggest component. When comparing with other standards, note that for these high building vibration, crest factors for velocity are expected to be less than 3. For lower levels vibrations velocity crest factors will be higher, up to 5 or 6.

The corresponding portuguese NP standard was never published: Happily, continuously ongoing vibrations of these levels are very uncommon...

4 - STANDARDS AND VIBRATION CRITERIA FOR DISCOMFORT

4.1 - Sensible Vibration

For sensible ongoing vibrations (railway trains produced included) two criteria are usually verified:

the ISO 2631 criterion for variable position of the persons in the building (see the whole standard), based on the 1/3 of octave bands rms velocity spectrum, and

the LNEC velocity criterion (sometimes broad band vibrations may pass in the ISO limit and be sensible or uncomfortable):

Table 3 - *ISO 2631-2 (1989) acceptance limits of rms vibration velocity spectrum in 1/3 octave frequency bands, 8 Hz < f_i < 80 Hz in buildings with human occupation, $v_{rms}(f_i)$, mm/s*

Use of building	Time	Ongoing vibration	Transient vibration
very sensitive	day or night	0.10	0.10
home	day	0.20 to 0.40	3.0 to 9.0
home	night	0.14	0.14 to 2.0
office	day or night	0.40	6.0 to 12.8
workshop	day or night	0.80	9.0 to 12.8

Table 4 - *LNEC Acceptance Limits of RMS Vibration Velocity, for Ongoing Vibrations* v_{rms} *, vertical component (or horizontal, if significant)*

Sensation (discomfort)	v_{rms} , mm/s
none	< 0.11
perceptible, bearable for small duration	0.11 to 0.28
very perceptible, annoying, lowering work conditions	0.28 to 1.10
very annoying, disturbing work	> 1.10

4.2 - Acoustic Vibration

If the vibrations have significant components in the audible range, they may not be sensed, but heard:

Table 5 - *Acceptance Limit of Vibration Velocity normal to a slab or wall, measured in a bit off center point, and filtered of all the components of frequencies contained in the octave bands up to the 31.5 Hz central frequency octave band*

Acoustic velocity acceptance limit $v_{rms}(f_i \geq 63$ Hz) mm/s
0.03

5 - EXAMPLES OF LNEC CASE STUDIES

5.1 - Continuously Ongoing Vibration

<u>5.1.1</u> - Vibration of a whole building: A spin drier, with a 1.6 m diameter basket, was placed in the 5.th floor of a 16 m high industrial building with reinforced concrete structure [1]. In operation, its speed started from zero to 750 r. p. m. (12.5 Hz) in 5 minutes, stayed there for drying, and reduced to zero in a symmetric way. When the drier speed was about 260 to 270 r. p. m., the whole building underwent a resonance, the centrifugal force frequency coinciding with the horizontal first natural frequency of the building. Values obtained through the measurements were: peak (horizontal) acceleration $a_M = 104$ mm / s^2 , peak velocity v_M = 3.76 mm / s (r.m.s. value $v_{rms} \approx 2.7$ mm / s), peak displacement (at the same 5.th floor) x_M = 0.135 mm (!).

This vibration, although very frightening, didn't produce any damage in the building. Acceptance limit would be $v_{rms} = 5.0$ mm / s (see table 2, section 3.2), probably that building could bear more intense vibration. Workers and factory owners were afraid that an earthquake could knock down the building.

5.1.2 - Vibration of a whole building: Due to mechanical motorized equipments (air conditioning, refrigeration) in adjacent buildings, a two storey building entered in resonance. The vibration (horizontal) was hardly noticeable, maximum 1/3 octave band rms value in the velocity spectrum was 0.16 mm / s , at 10 Hz , at day time (acceptance limit would be 0.20 mm / s , see table 3, section 4.1), but the inhabitants of the flat in the 2.nd floor, were restless.

5.1.3 - Vibration of a building slab: Due to underground passage of trains, the slab of a ground floor level lounge of an hotel (there existed a basement level, and the tunnel underneath) resonated, maximum value of the 1/3 octave rms velocity spectrum was 0.18 mm / s at 25 Hz , day time. Acceptance limit was considered to be 0.2 mm /s during the day and 0.14 at night in the lounge, and 0.1 in the rooms, at all times (see table 3, section 4.1). Measurements in the rooms, at higher floors, led to much lower values, and at night trains with less carriages and less passengers produced lower vibration. The hotel has a masonry and timber structure, except for the ground floor slabs and basement and foundations structure, which were redone in reinforced concrete, to resist the tunnel construction underneath. Distance from tunnel to ground floor level less than 10 m . The railway had a damping material underneath which cut higher frequencies. Vibration of the lounge floor was hardly noticeable, the administration was worried with the comfort of the hotel guests.

5.1.4 - Vibration of a house 1.st floor slab: Due to the nearby passage of trains, the slab of the 1.st floor slab of the sleeping room of a house, resonated. Maximum value of the 1/3 octave rms velocity spectra were (vertical comp.) 0.19 mm / s at 40 Hz , on the back yard wall , ≈ 5 m from the nearest track, 0.087 mm / s at 31.5 Hz , on the sitting room ground floor, ≈ 15 m from track, and 0.57 mm / s at 25 Hz , on the bedroom floor slab above the sitting room, day time, see **fig. 1** at the end of the paper. Owner complained of visible cracks on walls in the first floor, cracks on kitchen tiles, doors stone frames and stone tiles on ground floor. He added that older train carriages, less heavier, didn't cause any (sensible) vibration.

5.1.5 - Vibration of apartment floor slabs [2]: In a apartment building, with reinforced concrete structure and slabs, low damping, founded in medium soil, vibration from underground trains was heard. Distance from reinforced concrete tunnel to building foundations was ≈ 5 m . Typical measurements in one of the apartments, on a room floor, were: i) v_{rms} (vertical) = 0.137 mm / s ; max $v_{rms}(f_i)$ = 0.099 mm / s at 1/3 octave band of 50 Hz ; $v_{rms}(f_i \geq 63$ Hz) = 0.130 mm / s (pretty much above the acoustic limit of 0.03), at day time; ii) v_{rms} (vertical) = 0.083 mm / s ; max $v_{rms}(f_i)$ = 0.048 mm / s at 1/3 octave band of 50 Hz ; $v_{rms}(f_i \geq 63$ Hz) = 0.068 mm / s (above the acoustic limit of 0.03), at night time. Inhabitants claimed discomfort.

5.1.6 - Vibration of a house floor slabs [2]: In a house, with masonry and timber structure, founded in hard rock soil, vibration from underground trains was heard. Distance from tunnel to building foundations was ≈ 10 m . Typical measurements on a room floor, were: i) v_{rms} (vertical) = 0.046 mm / s ; max $v_{rms}(f_i)$ = 0.028 mm / s at 1/3 octave band of 63 Hz ; $v_{rms}(f_i \geq 63$ Hz) = 0.040 mm / s (above the acoustic limit of 0.03), at day (evening) time; ii) v_{rms} (vertical) = 0.053 mm / s ; max $v_{rms}(f_i)$ = 0.029 mm / s at 1/3 octave band of 50 Hz ; $v_{rms}(f_i$

≥ 63 Hz) = 0.042 mm / s (above the acoustic limit of 0.03), at night time. Inhabitants claimed discomfort. A letter sent to the railway company, signed by 32 neighbors, stated "vibrations [due to trains] look like an earthquake, the houses tremble, porcelain [in the cupboards] sounds, and sometimes is broken, walls and ceilings show cracks". The owner of the house, where vibrations were measured, had there a resonant panel that amplified the train induced vibrations.

5.2 - Impulsive Vibrations

5.2.1 - Vibrations in a fort and nearby village on the Atlantic coast: a small old fort in the north coast of Portugal, was subjected to the blastings of the sea rocks nearby, done in order to improve the fishing and leisure ports. Peak velocities were kept under the NP 2074 admissible values, 10 mm / s in the fort case (sensitive building founded in rocks). Vibrations were measured "all the time" at one point at ground level inside the wall facing the sea, but other measurements were done at points outside the structure, at ground floor level, **fig. 2**, and at "top floor" level (in one of the sentry-boxes), and also in a village building facing the fort. Top values were: 11.0 (second 9.5) mm / s in the fort inside point [1]. No damage that can be attributed to the blastings was registered in the fort or in the buildings near the works. Sound waves pressure was also measured. A previous inspection to the houses near the blastings site, inside a predefined perimeter (with about 500 m radius, centered in the works site), was done before the start of the works. After the blastings operations a list of 14 complaints was sent to the contractor, 5 from people inside the inspection perimeter, 9 from people living outside the inspection perimeter, complaining of "cracks", "cement (sic) fallen bits", a "cracked door glass", "fallen and broken [porcelain?] objects".

5.2.2 - Vibrations in Madeira buildings: vibrations, dues to blastings in excavation works, were measured "all the time" at two fixed points chosen in different adjacent buildings, at ground floor level. **Fig. 3** shows the rock (basalt) excavation site. Peak velocities were also kept under the NP 2074 admissible value, 30 mm / s for reinforced concrete structured buildings in medium soil. Top value was 18.1 mm / s [1]. No damage was registered in the buildings near the works. In the law suit filed in the Madeira Court, the nearby flat owners claim that "the work of 16 excavating and drilling machines, 10 trucks and the use of explosives and other materials, producing noise, vibrations and dust, give them big annoyance, and make unbearable the life of the people who live by the works", "the electricity supply is affected every day, and TV sets and washing machines and other appliances were burned due to the oscillation of the mains voltage", the buildings lifts don't work, often people being stuck inside them", "the video systems to control main door entrance are permanently out of order due to the every day vibrations", and the father of Mrs. R., 81, had to put a pace maker due also to the daily stress caused by the facts above said [noise and vibration?]", Mrs. R., herself, is, "since the beginning of the works, ill and on leave from her job, suffering respiratory and hearing troubles, needing medicines and therapy, suffering [also] from sleeping and behavior troubles due to the stress [caused] by the dust and noise from works", Mr. V. R. "suffers from depression due to the stress and the loss of audition caused by the works", Mr. M. M. "had to have a heart chirurgy, being fitted 4 bypasses", most of these claims supported by medical and public health statements; Mrs. M. and her son, also "suffer from nervous depression due to stress caused by noise and vibration".

Fig. 4 shows the location of the velocity peak modulus values measured in the $|v|_M(r/W^{1/3})$ graph, compared with Medvedev's predictions.

6 - GUIDELINES FOR CONTRACTORS AND WORKS OWNERS GOOD PRACTICE

As related in the previous examples, people will always attribute cosmetic damage (cracks, fall of bits of plaster) in their homes to sensible vibrations ($v_{rms} \geq 0.11$ mm / s) [3].

After the finishing or refurbishing of a house, the mortars and plasters, in their drying process try to shrink, acquiring an initial tensile strain state, all over the year and during the days, temperature and humidity changes and outside-inside differences take place in walls and slabs, and at any time and during major works in the soils, uneven displacements of the buildings foundations may arise, slowly, the first being found natural, the latter being unsensed by the inhabitants.

Before starting and during vibration generating works or operating vibration generating equipments, some steps (precautions) must be taken in order to ensure that no harm will be done to the buildings nearby, and that, in a court of law, if it will be the case, the "innocence" of the vibration in damage complaints can be established.

The following guidelines apply also to uncomfortable vibration, but are written down in order to prevent cosmetic damage in buildings. They are meant for all vibration production activities near or in sensitive buildings as residential buildings, hospitals and schools, historical buildings or monuments. They are also important to reassure people that care is being taken to avoid them discomfort, and damage to their houses.

i) *Design*

Calculations should be made in the design stage in order to evaluate as accurately as possible future vibration levels in the buildings, at ground level and at upper floors.

ii) *Previous inspection*

When sensible vibrations are expected at people's houses, a previous inspection of the buildings condition, outside and inside, should be performed, and a report written down, with pictures, existing damage, cracks width measurements, etc. Care must be taken to not alarm people... Some reassurance that, within the standards acceptance limits (say, $v_{rms} = 0.11$ mm/s for human perception, and $v_{rms} = 3.5$ mm/s or $v_M = 30$ mm/s for cosmetic damage, in a recent and well kept building), no harm will came to them or to their house.

iii) *Monitoring*

When sensible vibrations are produced, they should be measured at all times (by independent and certified experts) in construction, demolition or excavation works, and in the start up of permanent installations or traffic ways (railways) and afterwards from time to time. Relevant distances are a few meters for permanent installations, up to 10 to 15 m in railways, up to 300 m in blastings. Vibrations values are to be kept under standards limits at all times. Monitoring has the further advantage of acting as a feed-back in the adjustment of the works procedures. In blastings, air pressure measurements should also be made. Other measurements like displacements and rotations at the buildings ground levels may be advisable and act as alarms if something goes wrong.

iv) *Works supervision*

A supervision board, independent from the contractor, must report also the agreement of measured values with standards limits considered, as well as comparison with design predictions. Complaints from neighbors should be immediately assessed and reported.

v) *Post inspection*

Immediately after the works, and according to neighbors complaints, a new inspection should be made, and damage assessed and reported, as in ii). The new damage that occurred during works should be carefully studied, considering documents from actions i) to v).

7 - GUIDELINES FOR LICENSING AUTHORITIES AND COURTS GOOD PRACTICE

In Portugal (as in other countries), many activities, namely building (including previous excavation and demolition) and noisy activities are subjected to a licensing procedure. The licensing authorities (government departments and local councils) must verify that the building designs or the activities descriptions take into account the relevant laws and by-laws before they issue the license (building permit). All the designs must be signed by an certified expert in the area, called the responsible engineer (*técnico responsável*, in portuguese), and the inclusion of these designs in the licensing file, assures the authorities and the public, that the relevant calculations and predictions were made, and the appropriate technologies and materials, together with the building good practice rules, are going to be used in the works, and also environmental laws and the more general "duty of care" (pater familias, in portuguese) are going to be complied with.

It is an unfortunate practice in Portugal, pushed by economic interests, that building works start without the proper licensing, causing the neighbors discomfort and damage, authorities making no real move to stop the works.

It is desirable then that:

i) No works without proper license be allowed to start, or, if unduly started, be immediately stopped by the action of the licensing authorities;

ii) In case of a court action, the judge verifying that there is no valid license for the disturbing activities or damaging works, decrees its immediate stop;

iii) Local or central authorities avoid the issuing of permission (license) for the construction of new buildings or refurbishing of old ones where noisy (cinemas, discos …) or vibration generating activities (workshops, big motorized equipments) coexist with housing flats in the same structure; be it the case, the noise and vibration generating activities licenses must be conditioned to the post verification at all time of the ambient and comfort regulations and standards.

8 - CONCLUSIONS

Following the increase of the dimension of the construction and excavation works, the machinery of increasing power and the increased use of explosives, in areas with high density of human occupation, the number of complaints and lawsuits is increasing, as people attribute damage in their houses to sensible vibrations.

It is necessary to take steps to avoid discomfort to people, and to ensure them that every care is being taken to avoid damage in buildings, caused or aggravated by vibrations.

Licensing authorities and courts must not allow that works without proper license start or proceed. Permits for permanent disturbing activities adjacent to homes should be avoided.

The cautionary steps include predicting and avoiding undesired vibrations and noise in the design stage, inspecting peoples houses and sensitive buildings before works, monitoring and keeping vibration values under the standards limits during works, supervising these by an independent board of experts, and doing a post-Inspection and an assessment of the damages arisen, to determine its causes.

REFERENCES

1 - Schiappa de Azevedo, F., Patrício, J. - Damage by Vibrations in Buildings. Evaluation Criteria. Experienced Difficulties and Future Good Practice - in Eleventh International Congress on Sound and Vibration (paper n.º 908), S. Petersbourg, Russia, 5-8 July 2004.

2 - Schiappa de Azevedo, F., Patrício, J. - Vibration Evaluation Criterion for the Emission of Noise at Home by Vibrating Slabs and Walls - in Tenth International Congress on Sound and Vibration (proceedings, vol. 9, p. 4787), Stockholm, Sweden, 7-10 July 2003.

3 - Schiappa de Azevedo, F., Patrício, J. - Critérios de Danos e de Incomodidade no Domínio das Vibrações Ambientes (Ambient Vibration Damage and Discomfort Criteria) - in Tecniacústica 2001. Logroño, 17-19 October 2001.

4 - Dowding, C. H. - Blast Vibration Monitoring and Control: A Thirty Year Perspective, in Amadei, Kranz, Scott & Smeallie, ed.s - Rock Mechanics for Industry, Balkema, Rotterdam, 1999.

5 - Moura Esteves, J. - Controlo de Vibrações Provocadas por Explosões na Indústria da Construção (Vibration Control in Construction Industry Blastings) - Lisboa, 1993

6 - Bachmann, H., Ammann, W. - Vibrations in Structures - IABSE, AIPC, IVBH, 1987.

7 - Dowding, C. H. - Blast Vibration Monitoring and Control. Prentice Hall, 1985.

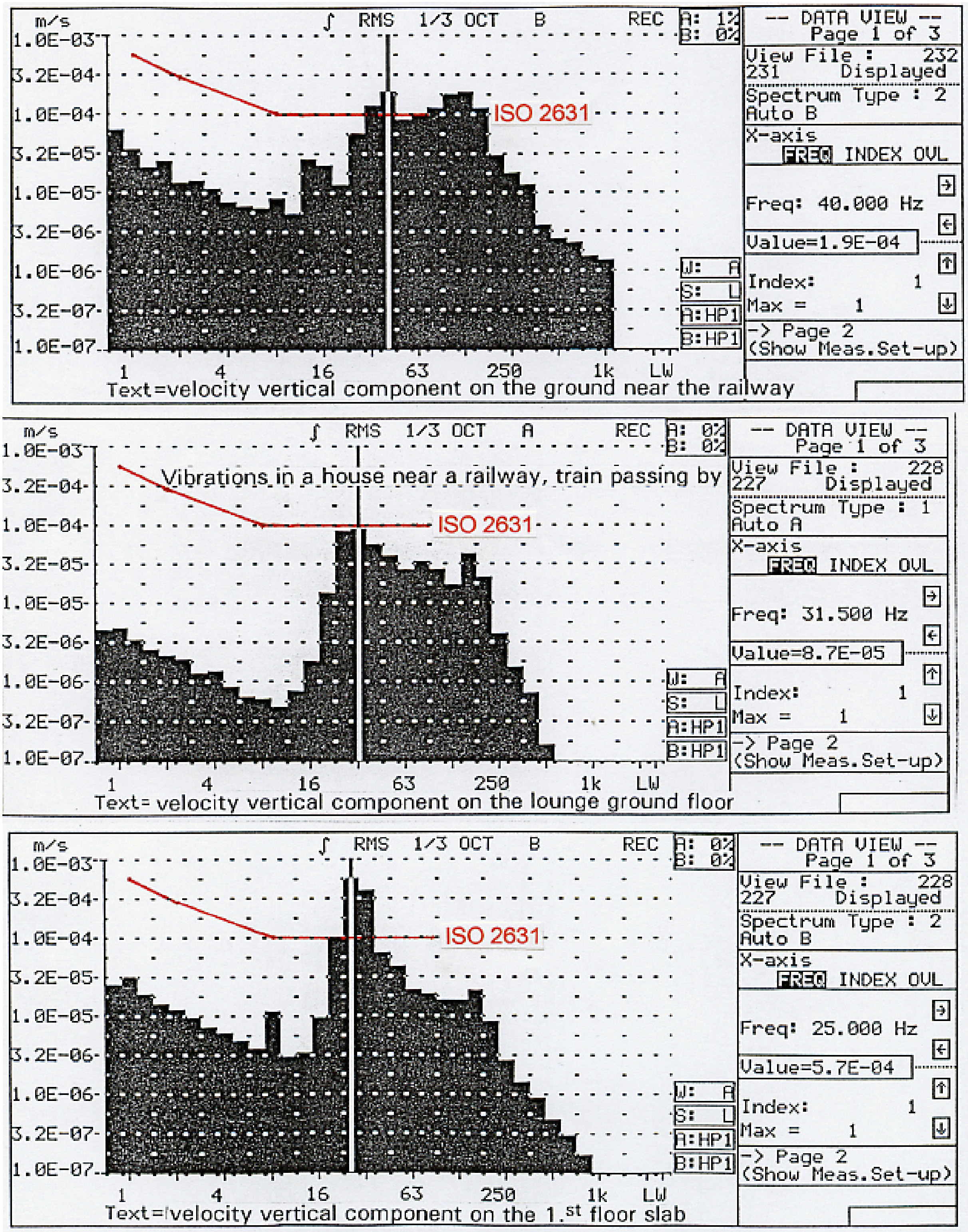

Fig. 1 - *Vibrations in a house near a railway*

Fig. 2 – *Blasting site, Fort and houses behind on the portuguese coast.*

Figure 3 - *View of the Madeira works site*

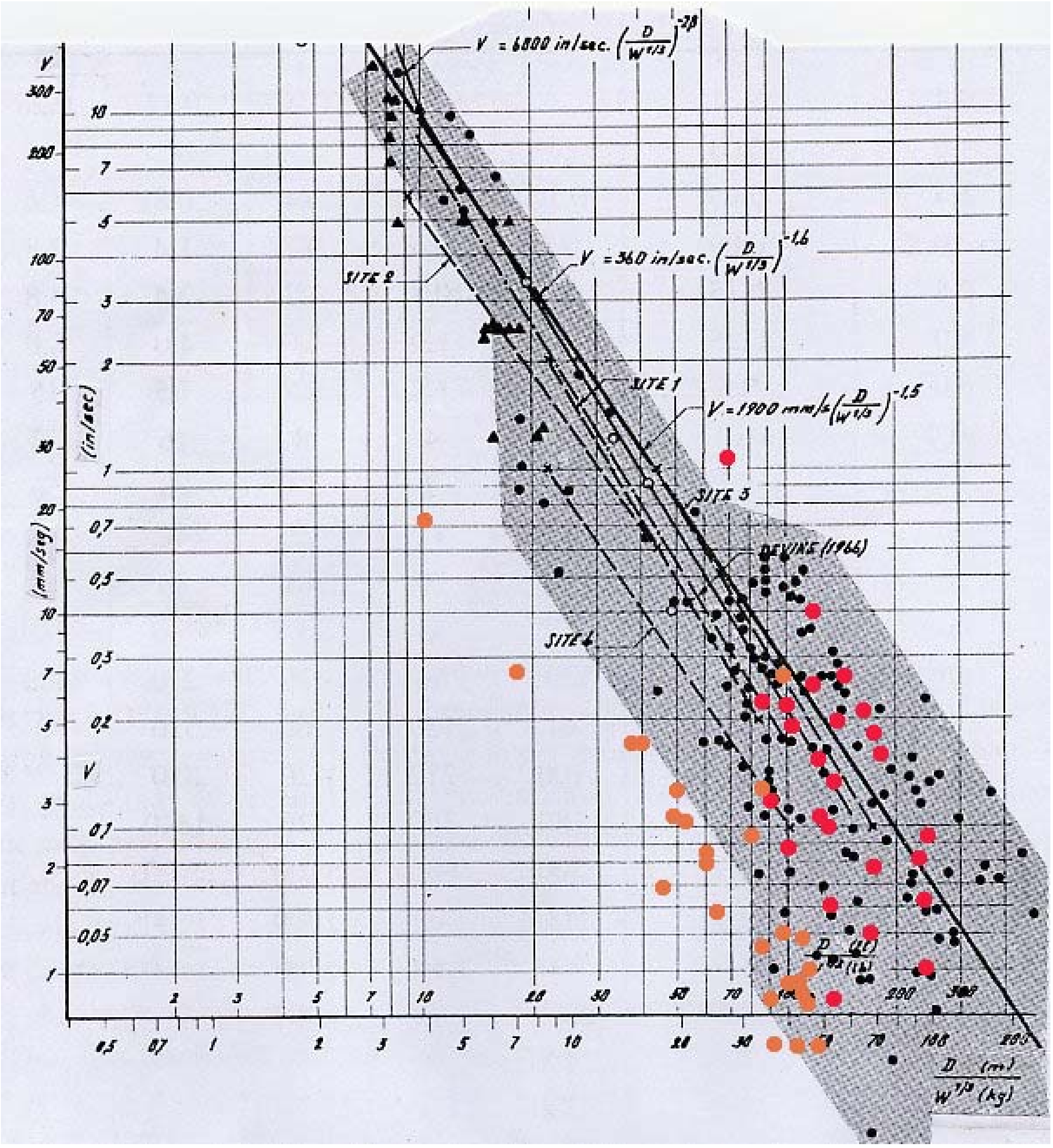

Fig. 4 - *Peak particle velocity, against the scaled distance* [4],
at Madeira (pale rose) and north of Portugal (pink rose) measurements.