Sampling and evaluation of the exposure to mechanical vibrations in the construction sector
INDUSTRIAL HYGIENE

Construction workers are exposed to vibration risks from the machinery they need to use in their tasks. These vibrations are passed on to the worker’s body through the hand-arm system and the whole body. Our aim here is to ascertain and evaluate the state of these workers, measuring their exposure to vibrations and comparing results against the exposure limits laid down in Royal Decree 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks. An analysis of the vibration passed on through the hand-arm system shows that the handling of vibration-inducing tools during short periods of time does not call for obligatory use of protectors. Demolition hammers, on the contrary, do call for compulsory use of such protection. In the case of whole-body vibration, although the exposure time is longer than in the case of manual machinery, there seems to be no need for protective elements, but the machinery should be well chosen in the first place and then properly maintained thereafter.

By MARCOS D. FERNÁNDEZ BERLANGA ¹, JOSÉ A. BALLESTEROS GARRIDO², SAMUEL QUINTANA GÓMEZ³, ISABEL GONZÁLEZ RODRÍGUEZ⁴.

(2) Telecommunications engineer. Assistant professor.
(3) Telecommunications Engineer, specialising in sound and image. Tenure holding professor of the Escuela Universitaria.
(4) Audiovisual Communications Graduate. Tenure holding professor of Escuela Universitaria.

Mechanical vibrations are oscillatory movements generated by a vibrating body. Energy is translated into oscillations of the particles making up the material and these oscillations are then transmitted or propagated from an originating source through any physical medium. In general, and barring the appearance of resonance phenomena, the vibrations undergo attenuation, the degree of which depends on the medium through which the vibration is propagated (1, 2).

As regards exposure to vibration and its effect on health, this can be broken down into two groups:

Hand-arm vibration. This is the vibration transmitted through the worker’s hand-arm system, arising from the use of mechanical tools of a manual, rotary or percussive nature, as well as the handling of steering wheels and levers of vibration-generating machines and vehicles (1, 2). The main sectors affected by vibration of this type are forestry,
construction and industry, due to the handling of manual machinery and percussion tools. Royal Decree (Real Decreto) 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks (3) lays down a 5 m/s² daily exposure limit value standardised to an eight hour reference period (A(8)), and a 2.5 m/s² daily exposure action value standardised to an eight-hour reference period A(8). Exposure to hand-arm vibration (1-5) is the cause of many occupational illnesses. Periodic exposure affects fingers, with vascular disorders that are worsened by cold, provoking the so-called dead or white finger or Raynaud’s phenomenon. Vibration of this type also affects the nervous system. Lengthy exposure might therefore cause numbness and tingling in the hands.

**Whole body vibration.** This is the vibration transmitted to the worker’s whole body, mainly from the driving seat of the vehicle or vibration-inducing machine. It occurs mainly in work involving mobile machinery (used, for example, for transporting people or goods), although stationary machines of a large size and power might sometimes transmit vibration to the ground or structures upon which the worker is standing (1, 2). Royal Decree 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks (3) lays down a 1.15m/s² daily exposure limit value standardised to an eight hour reference period (A(8)), and a 0.5 m/s² daily exposure action value. Exposure to whole body vibration (1, 2, 6-8) entails particular risks for the back and stomach zone but scientific evidence is still pretty thin on its actual effects. Some countries, for example, have accepted the combination of back pain, sciatica and degenerative changes in the spinal system as an occupational illnesses when exposed to whole body vibration. Vibration of this type may also affect visual perception, reading and motor skills. The vibration is analysed in terms of magnitude, frequency, direction and exposure. Magnitude is generally expressed by means of acceleration values (m/s²) for certain frequency bands. The frequencies to be evaluated fall in the range 1 to 80 Hz for whole body vibration and 5 to 1250 Hz for vibration transmitted through the hand-arm system. Direction is normally analysed in three orthogonal axes (x, y, z), sometimes also taking the rotation angles into account. The concept of exposure in vibration terms is similar to its use elsewhere in other health and safety areas, calculated on the basis of the duration of the vibration and acceleration (1-8).

Certain frequency ranges are considered to be more harmful than others, so measurements of the vibration need to be weighted in terms of the amount of vibration produced in each one of the frequencies. The frequency weighting therefore represents the likelihood of the undesired effect being produced at each frequency. Suitable weightings need to be made for each one of the reference axes (1-8).

**Methodology**

The equipment chosen for measuring the vibration was Brüel & Kjaer’s human vibration analyser model 4447, with the necessary adaptors for fitting the accelerometer (vibration transducer) and the Vibration Explorer software from the same firm for assessing workers’ vibration exposure (9).

Measurements were pooled not in terms of the actual job being carried out by the worker but rather common use of the same machinery, on the grounds that use of the same machinery even within different crafts implies equal vibration exposure. A selection was made, however, of those jobs involving continual use of the machinery and therefore involving a higher risk to workers than jobs involving only occasional machinery use.
**Measurement Strategy**

Two independent measurement strategies have been established, taking their cue from R.D. 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks and the standards ISO 5349-1:2001 and ISO 2631-1:1997 and each referring to one of the groups into which the assessment of human body vibration exposure has been divided (1-8). Another factor taken into account here was the findings of other vibration exposure measurement studies (10-21).

**Hand-Arm Vibration**

Measurements of exposure to vibration in the hand-arm system are based on the standard ISO 5349-1:2001 (4), the recommended standard for assessments of this type in R.D. 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks (3), and the guide to good practices on hand-arm vibration (5).

The vibrations transmitted to the hand-arm system have to be measured in the three directions of an orthogonal coordinates system as shown in figure 1. The vibration has to be measured in the three axes simultaneously, for which reason the measurement equipment has to include a three-axis accelerometer.

![Figure 1. Coordinates system for the hand-arm system.](image)

The accelerometer has to be set up rigidly and properly coupled up between the hand and the vibration source. A series of adaptors has to be used for this purpose, ensuring that the positioning of the accelerometer does not interfere with the coupling between the hand and the tool being used.

The magnitude of the vibration has to be measured by using the root mean square (r.m.s.) value of the frequency-weighted acceleration ($a_{h,v}$) in m/s².

The measuring period for assessing hand-arm system vibration has to be chosen in such a way as to ensure that it is representative of the machine vibration. If the vibration is constant the measuring time can be shorter; if the vibration is cyclical, the measuring period must guarantee assessment of at least one full cycle of the machine. In all cases the measuring period used must be specified.

Machinery of any type will produce vibration in each of the three axes and the vibration measurement in each of the three axes should be indicated separately. Nonetheless the inputs in each axis can then be pooled in a single value on the grounds that they are all equally harmful. The value resulting from pooling the inputs in the three axes is calculated according to the following equation:

$$a_{hr} = \sqrt{a_{hrx}^2 + a_{hry}^2 + a_{hrz}^2} \quad ; [\text{m/s}^2] \quad (1)$$

When assessing the vibration transmitted to the hand-arm system we need to bear in mind that this depends not only on the magnitude of the vibration but also on the duration of the...
exposure, considering the exposure time to be the time the hands are exposed to vibration within the working day; the exposure time may be shorter than the whole working day.

To be able to make comparisons between different exposure sources or different durations, the daily vibration exposure is expressed in 8-hour energy equivalents, calculated by the following equation:

$$A(8) = a_{hv} \sqrt{\frac{T}{T_0}} \text{[m/s}^2\text{]} \quad (2)$$

where $T$ is the total vibration exposure time $a_{hv}$, and $T_0$ is the 8-hour reference value.

Where the work carried out involves different operations, the daily vibration exposure will be a combination of all the tasks performed, bearing in mind the exposure time of each one, using the following equation to do so:

$$A(8) = \sqrt{\frac{1}{T_0} \sum a_{hv}^2 T_i} \quad [\text{m/s}^2] \quad (3)$$

where $a_{hv}$ is the total vibration value for operation $i$, $n$ is the total number of individual operations and $T_i$ is the duration of operation $i$.

**Whole Body Vibration**

Measurement of whole body vibration takes its cue from the standard ISO 2631-1:1997(6), the standard recommended for assessments of this type by R.D. 1311/2005 of 4 November on the protection of workers from actual and potential vibration risks, (3), and the guide of good practice on whole body vibration (8).

When assessing exposure to whole body vibration we need to measure the vibration produced in each of the three axes in due accordance with a reference system that situates the origin at the point where the vibration enters the human body. This depends on the position in which the work is carried out, as shown in figure 2.

![Figure 2. Coordinate system for the whole body](image)

The transducer should be placed between the human body and vibration source. The main contact areas are established as the surface of the seat, the back of the seat and the workers’ feet. The duration of the measurements should be sufficient to ensure statistically accurate assessment of a typical exposure event. The measuring time used must always be indicated.

The assessment of whole body vibration pursuant to the standard ISO 2631 has to include the root mean square (r.m.s.) value of the frequency-weighted acceleration, expressed in m/s².
Vibration’s affects on health, comfort, perception and dizziness is frequency dependent. Different frequency weightings are hence needed for each one of the axes (\(W_k\) for the z direction and \(W_d\) for the x and y axes), and a special weighting for assessing the low frequency causing dizziness (\(W_f\)).

Given that vibration does not occur in a single axis, the total weighted acceleration r.m.s. value is calculated from the vibration in each one of the three orthogonal axes according to the following equation:

\[
\mathbf{a} = \sqrt{\kappa_x^2 \mathbf{a}_{x}^2 + \kappa_y^2 \mathbf{a}_{y}^2 + \kappa_z^2 \mathbf{a}_{z}^2} \quad \text{[m/s}^2]\ 
\]

where \(a_{x}, a_{y}, a_{z}\) are the weighted acceleration r.m.s. values for each one of the three orthogonal axes and \(\kappa_x, \kappa_y, \kappa_z\) are the multiplication factors, which vary according to the purpose in view. When assessing vibration in terms of workers’ health the following values are established:

axis x: \(W_d, k = 1.4\)
axis y: \(W_d, k = 1.4\)
axis z: \(W_k, k = 1\)

To calculate the workers’ daily exposure \(A(8)\) and to be able to compare the results with the limits laid down in R.D. 1311, a calculation is made of the daily exposure value \(A(8)\) for each axis according to equations (5), (6) and (7), taking the maximum from the three axes as the \(A(8)\) value:

\[
\mathbf{a}_{x} = 1.4a_{x}\sqrt{\frac{T_{exp}}{T_0}} \quad \text{[m/s}^2]\ 
\]

\[
\mathbf{a}_{y} = 1.4a_{y}\sqrt{\frac{T_{exp}}{T_0}} \quad \text{[m/s}^2]\ 
\]

\[
\mathbf{a}_{z} = a_{z}\sqrt{\frac{T_{exp}}{T_0}} \quad \text{[m/s}^2]\ 
\]

where \(T_0\) is the 8-hour reference value.

When the work involves several separate tasks, the total exposure value is obtained for each one of the axes, according to equation (8), taking the maximum value of the former as the overall \(A(8)\).

\[
A(8) = \sqrt{A_{x}(8)^2 + A_{y}(8)^2 + A_{z}(8)^2 + \cdots} \quad \text{[m/s}^2]\ 
\]

**Results**

The following graphs compare the \(A(8)\) value (calculated for the duration of eight hours that the working day normally lasts) for each one of the machines making up the group, also indicating the action values (yellow line) and limit values (red line) laid down by R.D. 1311 for vibration exposure of this type.

**Large Grinders**

Large grinders are used mainly for cutting material (bricks, slabs, paving blocks, girders, pipework ...) to trim it to fitting size, removing concrete burrs in certain places and cutting slots and grooves for installation work.

When working with this machine the worker grasps it manually for carrying out the abovementioned tasks, as shown in figure 3.
To measure the vibration, therefore, the three-axis accelerometer was fitted with the UA-3016 adaptor between the worker’s hand and the machine being used. The results obtained for the whole family of large grinders are shown in figure 4.

Los resultados obtenidos para la familia de amoladoras grandes se observan en la figura 4.

**Small Grinders**
Small grinders are used mainly for cutting less hard material such as tiles and slabs, to trim them down to installation size in finishing work. These machines are also used for finishing work in kitchens, for removing screws from walls and cutting slots and grooves in walls.

As in the previous case this machine is held by hand for carrying out the abovementioned tasks, as shown in figure 5. To measure the vibration, therefore, the three-axis accelerometer was fitted with the UA-3016 adaptor between the worker’s hand and the machine being used.

The results obtained for the whole family of small grinders are shown in figure 6.

**Drills**
This tool is used mainly for making holes in parts made from various materials (marble, stone, wood...) for fixing them in place.

As in the cases of grinders, this machine is held by hand for carrying out the abovementioned tasks, as shown in figure 7. To measure the vibration, therefore, the three-axis accelerometer was fitted with the UA-3016 adaptor between the worker’s hand and the machine being used.

The results obtained for the whole family of drills are shown in figure 8.
Demolition and Chipping Hammers

Demolition hammers are used mainly for making holes in walls and floors for fitting work and also for chipping away and trimming off excess concrete from floors or stairs.

These hammers are held in both hands for carrying out the abovementioned tasks, as shown in figure 9. To measure the vibration, therefore, the three-axis accelerometer was fitted with the UA-3016 adaptor between the worker’s hand and the machine being used.

The results obtained for the whole family of demolition hammers are shown in figure 10.

Heavy Machinery

Despite the sheer variety of machines assessed in this group we can say in summary form that they are used for loading, unloading, transporting and placing material, cleaning up rubble and digging trenches.

Workers using heavy machinery sit inside on a seat provided for that purpose. To measure vibration from these machines, therefore, the three-axle accelerometer 4315-B-002 was fitted between the seat and the worker’s body.

The results obtained for the whole family of heavy machinery are shown in figure 12.
Discussion

An analysis is now given of the results put forward in the previous section for each group of machines.

Large Grinders

The results for machines of this type, as displayed in figure 4, show that, in most of the situations assessed, the vibration limit value laid down in R.D. 1311 would be exceeded in an 8-hour working day. Only six of the 17 measurements taken fell below this threshold, two of them even falling below the daily exposure action value.

That said, we also need to bear the following factors in mind; firstly machines of this type are not normally used for the whole working day, in most cases the exposure being limited to two or three hours; secondly, even if they are used throughout the working day this is normally restricted to intermittent short spells when digging and cutting work is underway. This means that in most cases worker exposure to vibration of this type would not exceed the threshold values laid down in current law, though it would be recommendable to wear protective devices while using tools of this type, such as anti-vibration gloves.

Small Grinders

The results of figure 6 show that only three of the thirteen measurements made exceed the limit value laid down in Real Decreto 1311 for an exposure of eight hours. These threshold-exceeding measurements correspond to the tasks of cutting the hardest material (slabs and blocks) and cutting grooves in load-bearing walls.

If we now assess the daily exposure action value we find that all the machines exceed this threshold.

As in the previous case, however, we have to bear in mind that this machine is not normally used for the whole working day, in most cases the exposure being limited to two or three hours and that even if it is used throughout the working day this is normally restricted to intermittent short spells when cutting work is underway. This means that worker exposure to vibrations of this type falls well below the limit values laid down by law and in most cases it is not necessary to use protective elements when wielding machines of this type.

Drills

The results of figure 8 show that three of the five measurements made exceed the limit value of 5 m/s² laid down by law for hand-arm vibration exposure, while the two remaining measurements exceed the established daily exposure action value of 2,5 m/s².

If we calculate the maximum permitted exposure time for the three threshold-exceeding measurements, this comes out at about three hours on average. In view of this, and also the fact that machines of this type are not used continually throughout
the whole working day but rather during more or less frequent periods thereof, the conclusion can be drawn that, even though the exposure value might not exceed the established threshold, it would be advisable to wear protective clothing while using machines of this type, such as anti-vibration gloves.

**Demolition and Chipping Hammers**

Figure 10 shows that all the measurements made for machines of this type far exceed the limit value laid down by R.D. 1311 for exposure to hand-arm vibration. The same holds true even when we calculate the maximum usage times of machines of this type, little more than one hour in most cases.

In light of the above, the use of demolition hammers should always involve not only risk mitigation measures such as anti-vibration gloves but also work-shift rotation or even the purchase of demolition hammers whose properties imply a lower transmission of vibration to the worker, with the aim of cutting down this exposure as far as possible.

**Comparison of the hand-arm vibration measurements**

A comparison of the mean hand-arm vibration exposures for each group of machines in figure 13 shows that, barring small grinders, all the machines exceed the limit value of 5 m/s² laid down by law to prevent occupational risk arising from exposures of this type.

![Comparison of hand-arm vibration measurements](image)

**Figure 13.** Comparison of the hand-arm vibration measurements.

Nonetheless, as explained above, prevention measures would be compulsory only in the case of demolition hammers, whose recorded values far exceed those obtained from other machines.

For the rest of the machines analysed, which are used only in short spells during the working day, it would not be compulsory to adopt preventive measures, albeit recommendable to do so.

**Heavy Machinery**

Turning now to measurements of whole body vibration, we find that only three of the 16 measurements exceed the limit value of 1.15 m/s² laid down by R.D. 1311, some even falling below the daily exposure action value of 0.5 m/s².

If we look at the three threshold-exceeding measurements we find they all involve vehicles being driven over rubble; this means that site clearance beforehand would help to reduce vibration exposure. The worker’s skill and expertise also plays a key role in work of this type.

The fact that few machines exceed the 1.15 m/s² threshold, and then only when using the machine the whole working day, shows that no additional measures are needed to cut down vibration transmission to the workers. The only necessary mitigation measures would be a good choice of machine and skilful handling
thereof to ensure that exposure values are not excessive.

**Conclusions**

In light of the above results and analysis we can conclude this study by saying that construction workers, due to the machines necessary for their tasks, are exposed to hand-arm vibration and also whole body vibration.

Although exposure to hand-arm vibration usually falls below the threshold values laid down in R.D. 1311/2005, it is nonetheless advisable to wear protective elements when using certain machinery such as drills or grinders, and compulsory when using machines of higher vibration levels such as demolition hammers.

In the case of whole body vibration, barring certain specific cases, the vibration involved does not exceed the thresholds laid down by R.D. 1311/2005, so a good choice of machinery is sufficient to safeguard workers from vibration and ensure it never reaches the limit values.

Another important conclusion to be drawn from the above analysis is that the inclusion of anti-vibration measures on a preventive basis in construction-sector work is a good practice, since, as we have already seen, the exposure values obtained depend on such factors as the machine and task involved and also the person carrying it out. In the construction sector vibration exposure would also vary in terms of the construction material involved in the particular task. Hence the fact that the results show different values for different workers carrying out similar tasks with the same machine.

Finally, attention should be drawn to the low worker awareness of these exposure risks. Although most of the workers surveyed claim to have been informed about the vibration-induced health risks, very few take any protective measures in their daily working life.

**PARA SABER MAS**


11. Mayton, Alan G. et al. Comparison of whole-body vibration exposures on older and newer haulage trucks at an aggregate stone quarry operation.


Figure 3. Work being carried out with a large grinder.

Figure 5. Work carried out with a small grinder.

Figure 7. Work being carried out with a drill.

Figure 9. Work being carried out with a demolition hammer.

Figure 11. Work being carried out with heavy machinery.