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# THE VIBRATION TOLERANCE OF COMPUTING SYSTEMS

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## 1. INTRODUCTION

Computer equipment is installed in many locations where it is subject to minor vibration but usually the intensity of vibrations in the normal room environment is well below the safe limits for these systems. However, these limits can be exceeded by certain external influences. The types of vibration inputs in question are those from neighbouring highway or railway traffic, construction activity (especially pile driving), blasting, demolition , heavy industrial equipment and computer operator activities.

## 2. MAIN SOURCES OF VIBRATION AFFECTING COMPUTER EQUIPMENT

In order to understand the effect of vibration on computing equipment it is useful to acknowledge the methods by which this vibration is produced. The excitation of a building structure is very complex and will greatly depend on the response characteristics of the different building elements. The main causes of excessive vibration in a building are outlined below.

### 2.1 Construction Activity and Blasting

Construction activity, in particular that involving blasting, demolition and piling, is frequently a cause for concern. Increased mechanisation has meant more use of powerful and potentially noisy machines in order to cut costs and improve general working efficiency.

Piling tends to be one of the first noisy activities carried out on site and the local population is likely to be more sensitive to this sudden invasion of their normally 'peaceful' environment. Although piling is only a temporary occurrence, the noise nuisance produced may result in a permanent loss of goodwill with nearby residents. Also, any damage to property or equipment may cause substantial problems later on.

Ground vibration is, by its very nature, very difficult to predict, due to the diversity of vibration transmission characteristics of soils, rocks and structures. This has led some authorities to set what would seem rather low vibration limits, in order to err on the side of safety. However, this over-caution could result in working restraints leading to unnecessary costs or even occasionally cutting short a particular activity. No British or International Standard defines vibration thresholds for damage to structures and the German Standard DIN 4150 (revised 1984)is usually used. However, levels with regard to computer systems subjected to short duration construction blastings are given by the Swiss Association of Standardisation as maximum peak values for amplitude and acceleration 0.1mm and 2.5m/s$^2$ respectively.

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2.2 Traffic

Traffic can cause vibration in buildings by two separate processes:

a) Low frequency sound waves generated at vehicle exhaust can couple into the structure via windows and doors causing different elements of the building to vibrate.

b) Forces generated by vehicles passing over the road surface profile can generate vibration in the ground which then propagates along the ground surface and through the underlying soil to reach the building foundations. Traffic vibration records are a mixture of impact-type and continuous vibrations.

In many cases resonance of the floor of a building will occur at frequencies in the range of 10Hz-30Hz, which is consistent with the suspension frequencies of heavy vehicles. Because of this the amplitude of vibrations of floors and ceilings can be four or five time that of the building foundations. Hence the need to monitor vibration levels on the raised flooring of the computer room.

Criteria recommended by the Swiss Association of Standardisation (1975) for sources of a continuous nature groups 'traffic' and 'machines' sources are grouped together. If computer centres are to be taken as 'sensitive structures' then a maximum peak particle velocity of 3mm/s over a bandwidth of 10Hz to 60Hz could be taken as the limiting value. However, caution must be exercised as these guidelines are aimed at the building structure itself and not the particular sensitivity of machinery within the building and its ability to withstand these levels of vibration.

2.3 Computer Operator Activities

The sources of vibration outlined above must be put into an 'ambient' environmental perspective. Clearly it would be difficult to justify a limiting level for construction induced vibration which is lower than that to which the computer systems are subjected in normal use.

The construction of computer centres is analogous to that of a modern steel framed office in terms of the resultant peak particle velocities likely to be the main source of vibration. Wimpey Environmental has experienced many situations where noticeable levels of peak particle velocity have been recorded from heavy footfalls or from, for instance, moving a chair close to the equipment measuring vibration levels. Any guidelines limiting permissible peak particle velocities to less than ambient values are unrealistic. Thus when recording vibration activity care must be taken to choose a suitable position where computer operator activities will not affect the recordings, preferably not under a table near where the operator is working as the equipment is likely not to be seen and could accidentally be knocked or affected by operator and chair induced vibration.

## 3. COMPUTER CENTRE DESIGN WITH VIBRATION AND SHOCK CONSIDERATIONS

The design of a computer room should be considered at this stage. Selection of a site for data processing equipment is the first consideration in planning and preparing for the installation.

THE VIBRATION TOLERANCE OF COMPUTING SYSTEMS

Raised flooring is usually used for large computer systems in order to accommodate air conditioning, cables and flexibility in the arrangement of equipment. The flooring, 150mm-500mm high, consists of removable panels supported either on pedestals or a subframing network. When a raised floor panel is cut for cable entry or air supply, an additional panel support may be required to restore the structural integrity of the panel. Castor point loads on machinery can be quite high, in the order of 500kg, and the panels should be rated to handle these levels of concentrated load anywhere on the panel. IBM[5] typically designs its machines to impose a load of not more than $340kg/m^2$.

When the equipment is moved the dynamic load on the castors is significantly greater than when the equipment is stationary. Adequate service clearance must also be allowed, although this is obviously limited by the space available. Careful design of the layout can reduce the necessity for frequent operator movements close to the mainframe.

## 4. MEASURING VIBRATION LEVELS IN THE VICINITY OF COMPUTER SYSTEMS

In order to accurately monitor the effects of activity on the computing equipment it is necessary to define exactly just what constitutes a 'safe' limit of vibration and how it is measured, as large mainframe computers will have completely different tolerances to portable desk-top models.

### 4.1 Relevant British Standards

British Standard 2011 'Basic environmental testing procedures'is adhered to by the computer manufacturers. It is equivalent to the International Standard IEC 68. Part 2.1 is particularly important as it deals with the testing procedures to be undertaken with regard to vibration and shock tolerances of equipment. In part 2.1 are sections dealing with sinusoidal vibration (test Fc), random vibration (test Fd) and shock (test Ea). Each component tested must then be given a specification involving, for instance , in the case of test Fd - 'random vibration wide band general requirements' - the following minimum details concerning:
- mounting of test specimen
- frequency range of test
- ASD spectrum levels
- duration of conditioning test
- reproducibility of test
- initial measurements
- functioning of test specimen during conditioning
- final measurements

From the construction point of view British Standard 5228 'Noise control on construction and open sites', especially part four which is the 'Code of practice for noise control applicable to piling operations', gives guidance on the protection of persons living and working in the vicinity of such sites and those working on the sites from noise. It recommends procedures for noise control in respect to construction and open site operations and aims to assist architects, contractors and site operatives, designers, developers, engineers, local authority environmental health officers and planners, regarding the control of noise.**

4.2 Computer Manufacturers' Specifications for Vibration Tolerances
Manufacturers' vibration limits apply on the floor supporting the disk drive, the most sensitive part of the computer system regarding vibration, close to a foot that is on the raised computer floor and not the structural concrete floor below. These levels are generally applied to floor mounted machines weighing less than about 230kg[5]. This is because most of the floors will not mechanically drive machines with weights exceeding this value, due to the high mechanical impedance of larger machines. The manufacturers usually state that if their specified limits are only just exceeded then reliability during the vibration cannot be guaranteed.

When specifying vibration tolerances, two types of failure can occur-either functional failures where the component fails to operate normally during vibration (particularly important for computer disk drives where valuable information may be lost), or survival where the equipment is still in working order after the vibration has ceased (although it may have failed to operate normally actually during the vibration period). Thus manufacturers often give vibration tolerance limits for both functional and survival operation. The vibration can also be sustained (generally five seconds or longer duration) or intermittent (less than five seconds duration), sinusoidal or random.

The amount of detail in each specification provided by computer manufacturers varies considerably, there being no apparent set format. However, the author has gained the following general data, for mainframe disk drives, with the kind co-operation of IBM, ICI, Hewlett Packard and NCR. (It should be noted that these limits have also been converted to peak particle velocity (zero peak) values for ease of comparison at 20Hz. This frequency was selected as it is within the usual piling range of 5Hz-40Hz). Peak particle velocity is used as it has been found to relate to damage occurance.

a) Constant Apmlitude Vibration Limits

These are usually specified over a frequency range 5Hz-500Hz. Functional limits are typically between 0.2g and 0.25g where as survival limits can be as much as 0.5g. Using the conversion $\ddot{u}_{max} \simeq \dot{u}_{max}\,\omega \simeq \omega^2 u_{max}$ these limits correspond to PPVs (zero to peak, peak particle velocities)of approximately:

15mm/s-20mm/s @ 20Hz(functional).
40mm/s @ 20Hz(survival)

b) Random Vibration Limits

These are usually specified over a frequency range 5Hz-500Hz. Functional limits are typically about 0.3g whereas survival limits are about 2.7g. These limits correspond to PPVs of approximately:

23mm/s @ 20Hz (functional)
210mm/s @ 20Hz (survival)

c) Shock Vibration Limits

Functional limits for intermittent shock have been set at about 3g, provided that the vibration does not exceed 11ms duration. This corresponds to a PPV of approximately 230mm/s @ 20Hz. However, earthquake simulation tests have shown that this is a slightly conservative estimate and disk drives have still functioned at levels up to 4g at ground level(upto 25Hz)ie under severe earthquake conditions

## 5. DESKTOP COMPUTING SYSTEMS

As disk drives are increasingly used in desktop computer systems, they are exposed to shock and vibration. Hard disks are more vulnerable than floppies and designers have to take steps to make their units withstand shock and vibration.
The first Winchester disk drive memories were very susceptible to rough handling and had to be operated in relatively benign environments. This was not considered a problem as the first Winchesters were heavy bulky instruments that were rarely used outside the climate-controlled confines of mainframe computer rooms. These days Winchester drives are also incorporated in transportable personal computers and must withstand vibration levels during travel in cars, trains, planes etc. In these conditions the disk drives can encounter vibration at frequencies ranging from one to a few hertz. On airplanes, for example, vibration forces have been known to occasionally reach over 20g, and forces of a few g are common.
The most obvious way to reduce vibration during transportation is to pad the shipping containers with eg foam rubber. Often the disk has dedicated head landing/shipping zones to which the read/write heads can be retracted whenever the drive is powered down. This occurs when the carriage and spindle heads are locked. These zones, frequently the inner-most rings, do not contain data tracks and are assigned for parking the heads when the drive is not in use.

Although head mechanisms weigh only a few grams they can still hit the disk with enough force to break free sizable chunks of disk surface, thereby losing stored data and perhaps eventually ruining the heads. Shock mounts are used to isolate the head and disk assembly from forces on the outer frame or casing. A shock mounting system will reduce the natural frequency of the shock-mount, frame, and head/disk system to that well below the range where most severe vibration amplitudes occur. The shock mounts will then only transmit relatively weak forces to the heads and disks. If the drive is operation when the vibration occurs, transmitted vibrations hopefully only cause errors from which the drive can recover.

## 6. RELATING TYPICAL VIBRATION LEVELS PRODUCED BY PILING OPERATIONS TO VIBRATION TOLERANCES SPECIFIED FOR COMPUTER DISK DRIVES

Typically the main cause of excessive levels of vibration for mainframe computer disk drives is intermittent shock from impact piling and more frequent vibration from vibratory piling operations. Wimpey Environmental has a great deal of experience in monitoring such sites.
When piles are driven by impact, each blow tends to product damped free vibration of the ground, which tends to be excited at its natural frequency. The free vibration due to one blow has usually died away before the next blow arrives. The vibration record close to the pile driver is similar to that from forge hammers and drop-stamps. Amplitude diminishes with distance but the vibration may well still be noticeable at a distance of about 100m.

Typical 'safe' distances outside of which piling would offer low risk of disk drive disturbance are, for instance, 15m for vibratory piling and 30m for impact piling as vibrodriver vibrations attenuate more rapidly than impact hammer vibrations. Alternatively limits could be related to hammer energies and drop heights.
New methods of pile driving have recently been introduced from the continent[4]. These methods have resulted in a range of pile drivers that can be 29dB(A) to 40dB(A) quieter than conventional pile drivers[6]. In one method the pile is driven by vibrating it at its own natural frequency, or the characteristic frequency of the ground, and should primarily be used in granular soils to produce local liquefaction. These vibrodrivers have been widely used for several years now and are nearly all hydraulic. Hydraulic systems use a high frequency vibration which transfers large vibratory forces to the pile, the frequency being so high that no soil resonance is possible and vibration decays rapidly. Vibrodriver types include the standard high frequency and the ABI mobil-ram. The advantages claimed are that piles can be driven or extracted more quickly than by conventional methods, that there is less damage to the pile, and that the method is much quieter and does not give rise to complaints.

## 7.VIBRATION MONITORING AND METHODS OF REDUCING RISK TO COMPUTER SYSTEMS

Alternative piling methods and noise and vibration reduction techniques could be used, such as vibration isolation of the computer system on installation, reducing the hammer drop in driven piling, or a working agreement to suspend operations of disk drives during pile driving in very close proximity could be implemented. One particular case where vibration monitoring was necessary involved a site in Wapping, East London, where piling occurred in the vicinity of an IBM mainframe computer belonging to a banking corporation[7]. In view of the need to limit the vibration of the computer building a suitable pile driving scheme needed to be designed to support the proposed structure. Data was obtained from the computer manufacturers concerning the intensity of vibrations which they felt would be acceptable for this particular installation. It was considered at the time that these limits for the computer could be complied with and a contract was awarded for the installation of a trial pile and a number of trial drives, during which monitoring of vibrations would be carried out for the computer room. When the results of the vibration monitoring were available the contract poles would be driven. At this stage an option was still made available to revert to continuous flight auger piles if the driven piles caused too much vibration.

Prior to driving the first contract pile, a continuously recording vibration monitor was set up adjacent to the vibration-sensitive computer module nearest to the site. The trace was inspected on a regular basis by the resident engineer, and more frequently when the very closer piles were driven. In this particular case close monitoring of driven piling enabled the contract to be awarded at approximately half the cost of the alternative bored pile solution, with no damage to the computer room.

THE VIBRATION TOLERANCE OF COMPUTING SYSTEMS

To summarise, this information emphasises the need for vibration tolerances to be specified at low frequencies(especially where impact piling is concerned)and the necessity for careful and accurate measurement of vibration levels wherever pre-estimates indicate that vibrations may possibly put the disk drive at risk of malfuctioning.

## REFERENCES

1. New, BM(1986). Ground vibration caused by civil engineering works. Transport & Road Research Laboratory Research Report 53.

2.Person, PA et al. (1980) Underground blsting in a city. In subsurface space: Proceedings of the International Symposium (Rockstore'80) Stockholm Berman M.ed. (Oxford Pergamon, 1980), Vol1, 199-206.

3.Nelson PM and Watts, GR (1987). Traffic vibration, and building damage. Transport & Road Research Laboratory Research Report. 146.

4.Steffens, RJ (1974). Structural vibration and damage. Building Research Establishment Report, HMSO.

5. IBM (1987). Installation manual-physical planning. Publication number GcC22-702-1.

6.Gill, HS (1983). Control of impact pile driving noise and study of alternative techniques. Noise control engineering journal, March-April 1983.

7.Grose. WJ(1986). Driving piles adjacent to vibration sensitive structures - a case history. Ground Engineering, May 1986, Vol 19, No 4. 23-31

** This standard is currently under revision and will include a section on computers and vibration.