VIBRATION ISSUES IN TIMBER FRAMED APARTMENTS CAUSED BY DOMESTIC APPLIANCES

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1 INTRODUCTION

This paper discusses some of the findings from an ongoing project where a combination of factors have conspired together to cause disturbance to residents within a block of apartments. The disturbance is generally caused by operation of washer/dryers and footfall.

Our involvement in the project began with LinkedIn. An old client whom I had lost touch with over the past few years got in touch and asked me to give him a call. After an initial discussion and catch up, we agreed to meet on site to review the issues and set about trying to solve the problem.

Various tests of noise, vibration and sound insulation (airborne and impact) have been carried out, together with subjective assessments. These tests have been prior and subsequent to remedial measures being implemented, with some of these measures being more effective than others.

The issues and process are discussed in the sections below.

2 THE ISSUES

2.1 Resident complaints

In the 12 months since initial occupation, numerous complaints had been made by residents. These included:

- Unacceptable levels of vibration within apartments, corresponding with the operation of washer/dryers
- Unacceptable levels of impact noise due to footfall

The apartments had been subject to pre-completion testing prior to occupation, with good passes being recorded in every instance.

2.2 Building form and structure

The development consists of three residential apartment blocks. The construction is timber frame, with the following floor build-up (top to bottom):

- Fibre-reinforced screed
- High density fibre board
- Resilient layer
- 18 mm OSB board
- Metal web joists with nominal mineral wool insulation in-fill
- Resilient bars fixed to the bottom web
- 2 layers 15 mm fire-resistant plasterboard
- MF framework with 12.5 mm plasterboard

Floor finishes are a mixture of developer- and resident-installed timber flooring and carpets. Washer/dryers are mounted on top of the screed in the kitchen areas at the far end of lounge/kitchens.

Sound insulation tests carried out prior to occupation showed airborne results generally between 3 and 13 dB better than Document E requirements, with impact results having a 9 to 16 dB betterment.

2.3 Initial subjective impressions

Vibration was perceptible within the apartment containing the washer/dryers. Vibration was also perceptible within the apartment below. The nature and magnitude of vibration changed depending on the point within the spin cycle of the washer/dryer, and with the spin cycle speed.

Impact noise was audible within apartments due to footfalls in the apartment above. Noise was distinctly 'boomy'.

3 CONTRIBUTING FACTORS

3.1 Structural considerations

Prior to our involvement in the project, a structural investigation had been carried out by another firm of Consulting Engineers. The ensuing report highlighted the similarity in the natural frequency of the timber floor cassettes within the spin cycle frequency of the washer/dryers; both were between 15 and 18 Hz.

Our own structural engineers were commissioned to carry out computer modeling of typical floor cassettes. These analyses found that there were several modes present in the floor construction, in lateral, as well as vertical, directions. A number of these modes were between 11 and 18 Hz.

The modeling highlighted the structural issue due to the bottom webs of the joists being unrestrained. Although the resilient bars are designed to assist with airborne attenuation, they result in the floor construction being less stiff than if boarding were fixed directly to the underside of the joists. This feature is inherent in a number of Robust Details (e.g. E-FT-3, E-FT-4, E-FT-5 and E-FT-6).

A number of kitchen designs have washer/dryers located mid-span, resulting in input vibration being at the point of greatest possible deflection.

3.2 Use of floating screed on the timber floor

Use of screeds on timber floors is a tried-and-tested solution, being the basis of a number of Robust Details. However, a number of issues relating to this element of the overall construction are suspected to have contributed to the issues experienced, as follows:

- The board and foam insulation separating the screed from sub-floor is relatively stiff and, as such, will provide little vibration isolation against high-intensity sources such as washing machines
- The relative stiffness of the screed isolation system and continuous points of contact are unlikely to provide the same degree of low frequency impact resistance than less stiff, more discrete contact points

3.3 Installation issues

Many of the washer/dryers have been installed in the middle of the run of kitchen units. Due to the desire to fit as many usable cupboards in the kitchen as possible, this resulted in the space between adjacent kitchen unit carcasses and the washer/dryer being very small. In some cases, during the spin cycle, contact is made between washer/dryer and adjacent carcasses (due to lateral movement), thus bypassing any vibration isolation otherwise provided by the screed isolation.

4 SOLUTIONS AND RESULTS OF TESTING

Many tests have been carried out, both on the existing construction and various options for improvement of noise and vibration transfer.

The issues leading to issues reported by residents can be summarised as follows:

- Coincidence between washer/dryer spin cycle and natural frequency of the floor structure
- Unrestrained bottom web of the floor joists
- Lack of low frequency isolation to washing machine bases
- Lack of low frequency isolation to footfall
- Hard contact between washer/dryers and kitchen units

In order to address these issues therefore, the following needs to be considered in any solution:

- Stiffening of the floor structure to provide mis-match of coincident frequencies
- Restraint to the bottom web of floor joists
- Re-mounting of washer/dryers with greater isolation at key operational frequencies
- Provision of greater levels of low frequency impact resistance
- Separation of washer/dryer from adjacent kitchen units

A number of remedial measures have been tested, to varying degrees of effectiveness, and are discussed below.

4.1 Vibration transfer from washer/dryer

4.1.1 Floor stiffening

In order to provide increased stiffness within the floor joist zone, stepped blocking was introduced. This involved rigidly fixing timber members between joists in order to provide lateral stiffness. Accommodating this between metal web joists required careful placement to ensure a rigid fixing into the timber trimmers. The diagram below shows the principals adopted.

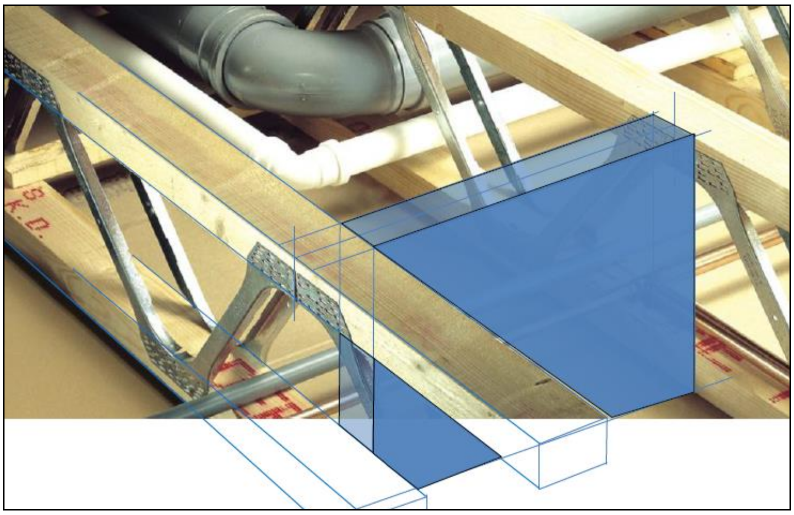

Figure 1 - Stepped blocking detail

In addition to the stepped blocking, the ceiling construction was reversed so that a stiff board (OSB) was fixed directly to the underside of floor joists with a resilient ceiling hung below.

4.1.2 Testing

The following chart shows the baseline condition, then options of step blocking only, diaphragm (OSB) boarding to the underside of joists only, together with the combined effect of both in place. In all cases of the remedial options, this includes an amended ceiling configuration, whereby fire protection is fixed directly to the underside of joists, then a resilient MF-type ceiling installed below.

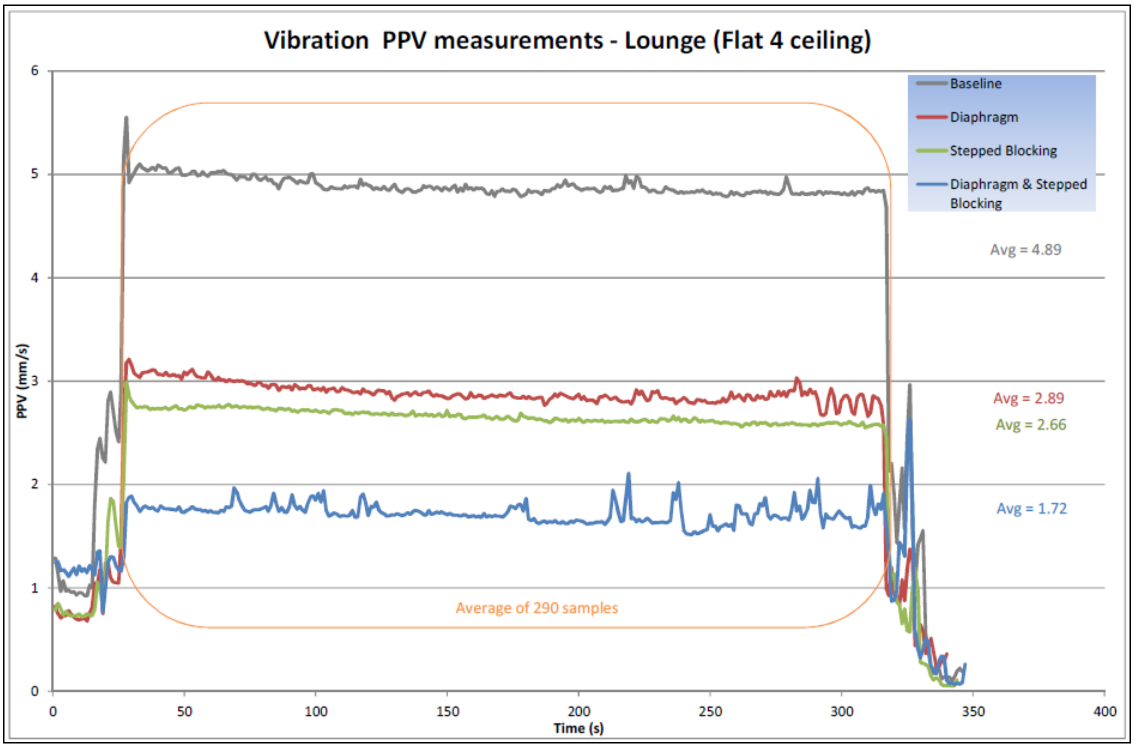

Figure 2 - Results of vibration testing (PPV)

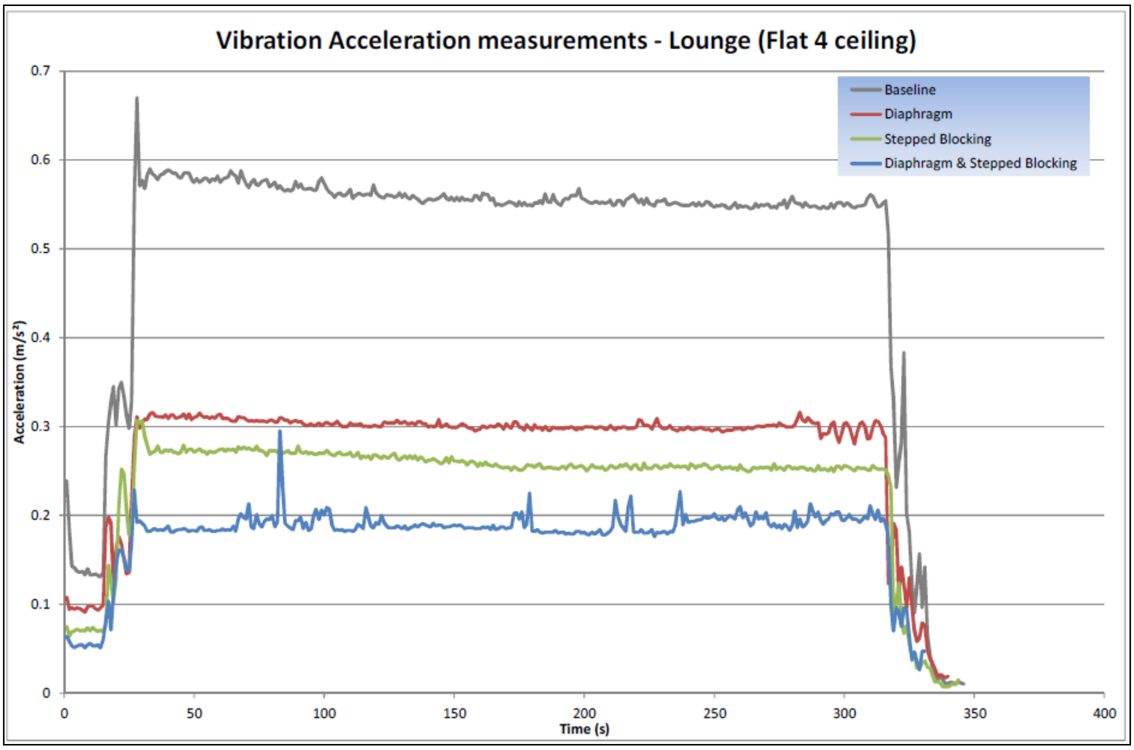

Figure 3 - Results of vibration testing (Acceleration)

As can be seen from Figures above, the magnitude of PPV and acceleration, when measured on the ceiling of the apartment under the washer/dryer, was significantly reduced by floor stiffening measures. It can also be seen that the greatest benefit was when both stepped blocking and diaphragm boarding were used simultaneously, with a 65% reduction in magnitude when compared with the existing construction.

4.2 Washer/dryer isolation

A number of options were investigated in order to better isolate the washer/dryer from the structure.

4.2.1 Re-mounting washer/dryers

Physical isolation of washer/dryers is a key factor in mitigating the resident issues. As with any vibration source, isolation is best carried out before energy can pass into the structure.

Testing was carried out with a number of different options for re-mounting the washer/dryers, offline on a concrete slab in a basement. Although this did not give the same type of structural response as in the timber floors, the key result was the amount of energy transmitted into the floor directly adjacent to the mount.

The difficulty with achieving this with a washing machine is the high magnitudes of lateral movement, changing centre of gravity and varying frequencies of excitation. To this end, the isolation solution adopted includes lateral restraint by means of steel channel upstands; this not only prevents excessive lateral movement, but also minimises impact energy transmitted into the flooring.

The graphs in Figure 4 show results of tests carried out on the plinth containing the washer/dryer.

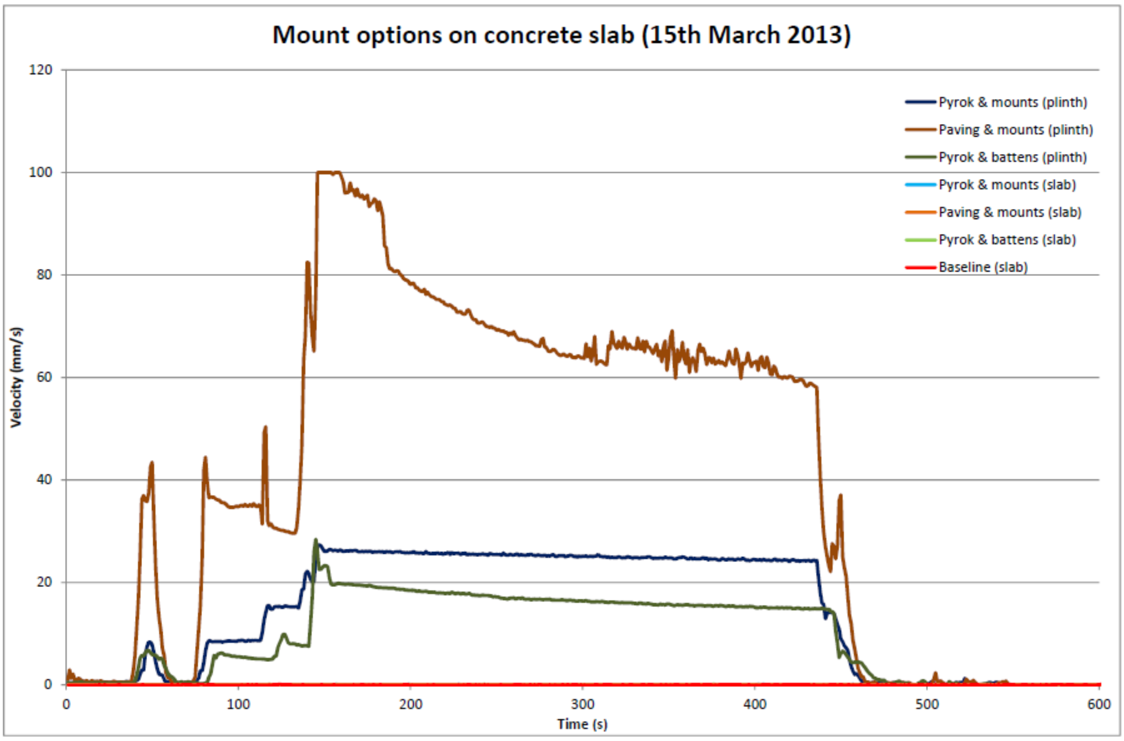

Figure 4 - Vibration tests on plinth (PPV)

The magnitudes of vibration on and off the plinth were so different that it is not possible to display both on the same chart. Figure 5 shows the transmitted levels of vibration.

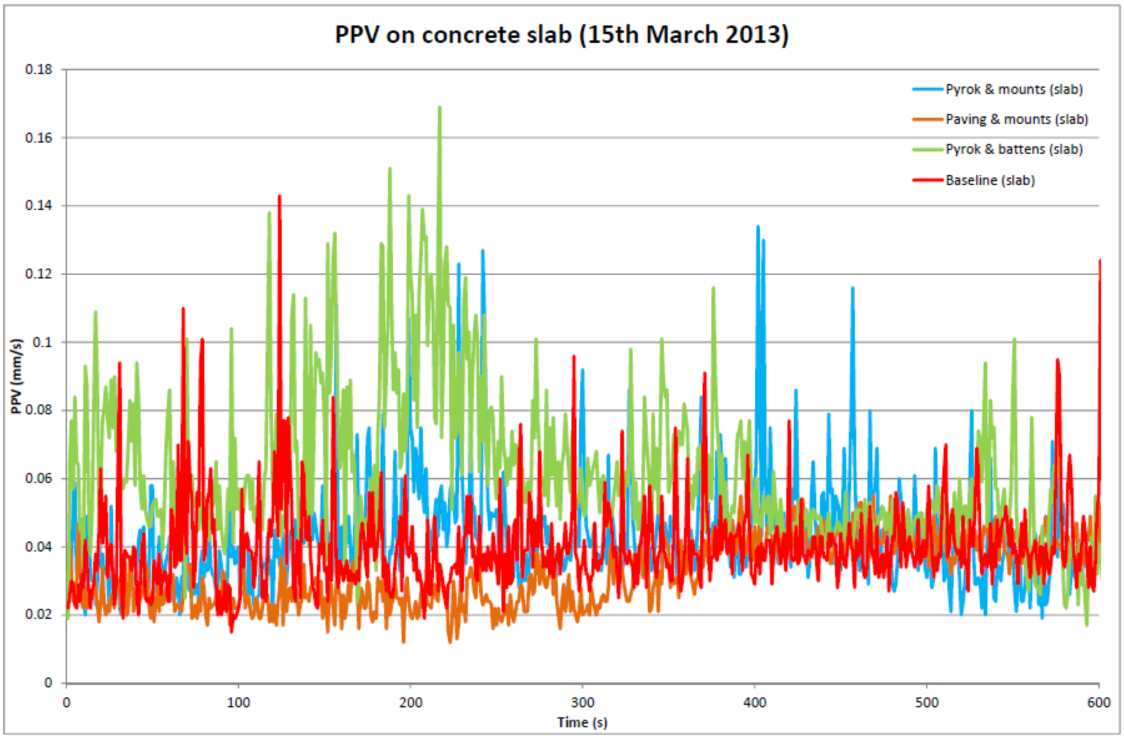

Figure 5 - Vibration tests off plinth (PPV)

As can be seen, the solution that allowed the greatest magnitude of vibration on the plinth (i.e. paving slab with rubber mounts) also transmitted the least amount of energy into the structure. The extract below shows the final mounting solution.

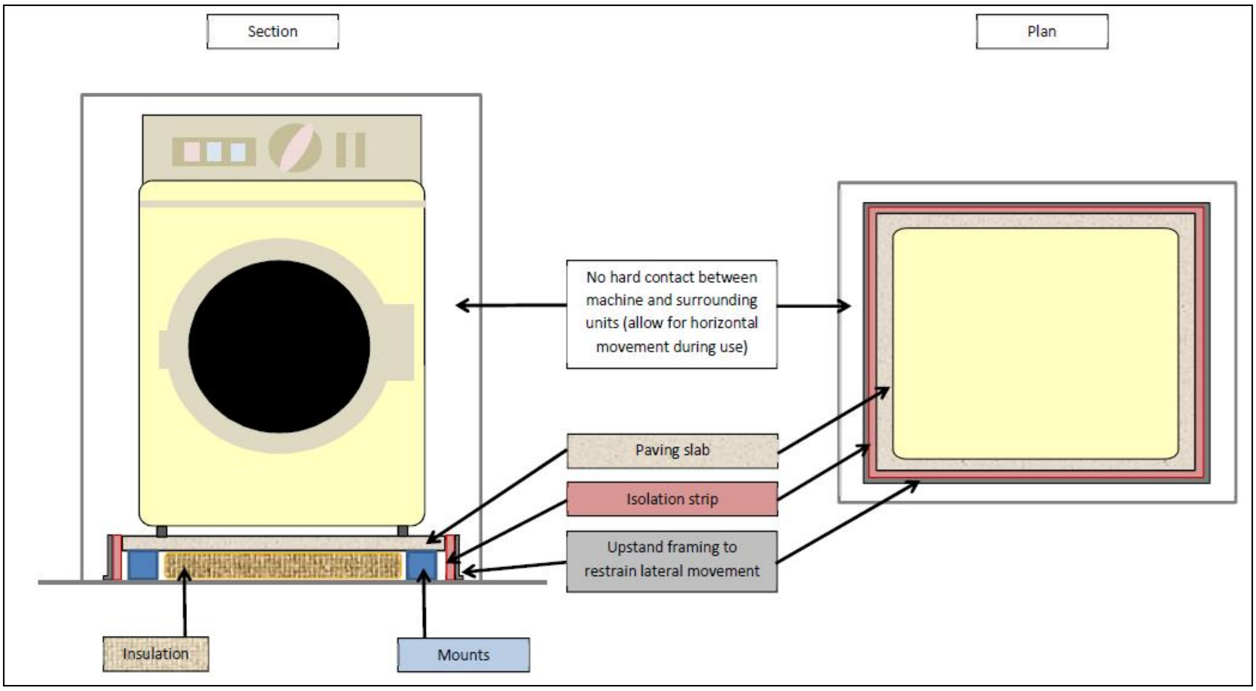

Figure 6 - Washer/dryer mounting detail

4.3 Low frequency impact noise

The problem here was that floors met and exceeded minimum criteria given in Approved Document E. This implied therefore that the subjective problems lay outside the normal scope of assessment and an alternative assessment was developed.

4.3.1 Investigations into void filling

Due to the 'boomy' nature of the transmitted noise, it was hoped that this could be remediated by additional insulation within the floor construction. A nominal amount of insulation was present within the existing floor void, so in order to improve the situation, this insulation was removed in a sample area and replaced by a pumped cellulose type that has strong internal damping properties; we have used this solution successfully on other projects, to increase low frequency performance of roof constructions and timber stud party walls. Low frequency performance improved slightly (2 to 3 dB), but this was not considered sufficient benefit to warrant the significant amount of effort required.

In order to better control impact noise at source, rather than its resonance within the structure, the next step is to trial rooms with the screed removed and replaced with a cradle and batten timber flooring. This will provide significantly more isolation from footfall energy, with the intention of reducing the inherent 'boominess'.

4.3.2 Testing

Inspired by the Japanese impact ball tests, a procedure was developed whereby a Medicine Ball was dropped on set points of the floor, from a height of 1 m, with the transmitted impulsive noise measured below.

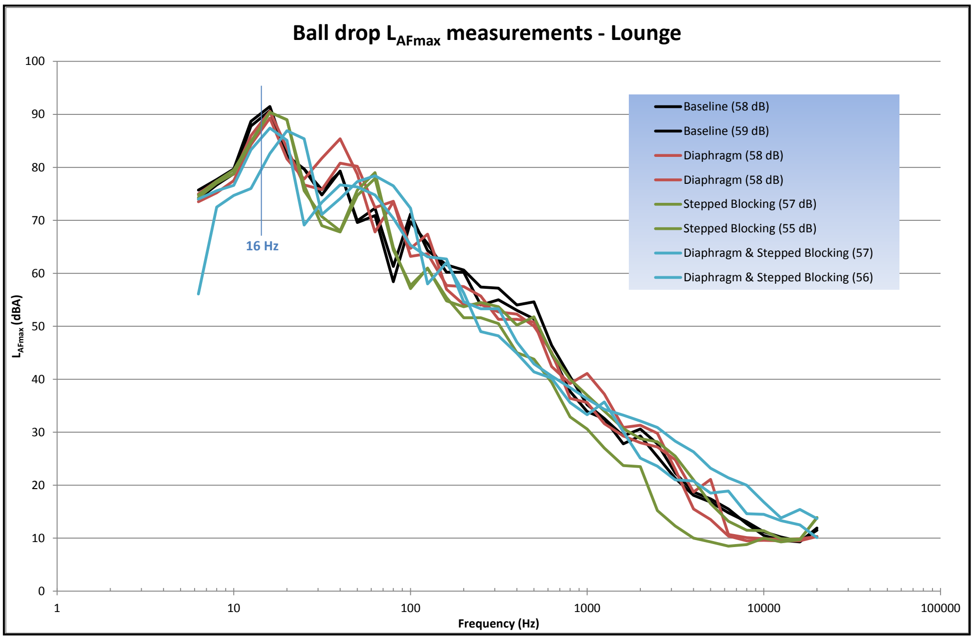

Figure 7 - Ball drop test results

As can be seen, stiffening the floor did make some improvement in the low frequency performance, and depending on the location on the floor under test, the main excitation frequency was shifted slightly upwards.

The conclusions drawn from this were that stiffening of the structure alone would not be sufficient to improve residents' reaction to low frequency impact noise transfer.

5 LESSONS LEARNT

The main lesson to be learnt from this exercise is that designers need to be aware of the big picture when looking at a building.

- Structural engineers need to consider the activities that will take place in a building and take this into account
- Acousticians need to be prepared to think beyond Building Regulations and consider enhanced frequency ranges, especially in lighter-weight structures. The lack of C_{tr} correction or regulation below 100 Hz for impact resistance can lead to 'good' standards being subjectively poor
- Detailing is all-important. Installation of domestic appliances such as washing machines needs to consider the dynamic potential of the structure it is set within