# Standardising structure-borne noise assessments with heavy impacts for potential gyms in lightweight mixed use structures

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**Summary**

Noise and vibration from gyms can be one of the most disturbing activities to sensitive occupants of the same building, and the trend in the UK to place gyms in vacant units close to sensitive receptors requires careful consideration of the suitability of a building for such a use. Determining the suitability of a building for fit out as a gym requires consideration of the building response as a whole to heavy impacts, as the resulting structure-borne noise that is generated is a combination of a complexed response to input forces. A standardised test methodology is proposed, based on a practical approach to enable the real building response to various input forces to be robustly assessed in a repeatable and consistent fashion. By exciting the base response of the building with a number of simulated impulsive vibration sources that represent real activities it is possible to identify firstly if the building is suitable, and secondly what levels of mitigation treatments may be required. This paper proposes a standardised method to stimulate debate within the industry, and with the view of assisting local authorities to standardise their approaches to changes of uses within buildings in response to society's demands for gyms.

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**Foreword**

This paper intends to stimulate debate within the acoustics industry about the future of in-situ structure-borne noise and vibration heavy drop testing for gyms. The authors welcome comments from all parties to assist in the development of a standardised, repeatable and reproducible methodology.

## 1. Background

Testing a structure's feasibility to house a gym is becoming more common in the UK, where gyms are regularly placed in refurbished retail units below offices, flats and hotels (or above, although less common). In the case of these refurbishment projects it is likely that the building was never originally designed to house a gym, and often includes lightweight structures. Without treatment it would not provide adequate resistance to impact vibration or the resulting structure-borne noise, and currently there is no common method of assessing whether the structure would be suitable. As some gyms operate 24/7, the intrusion of noise within sensitive premises sharing the same structure may have a significant impact on people's concentration or sleep.

In the UK, a number of acoustic consultants work on these type of projects, but as yet there is no unified test method for gyms [1], and consultants use different test methodologies to each other. This can cause problems where a local authority or another consultant may not be able to agree with the methodology used, or where they want the tests to be undertaken using a methodology that they are familiar with, or follows different guidance.

EN ISO 12354-5 [2] states about structure-borne sound "*even though there is no practical measurement method available at the moment. This allows estimation models to have a general form that could be developed and refined in the future*". This is discussed by McNulty in a recent article [2], but a standardised measurement procedure take into account all of the complex factors that affect a buildings response. The most common test method used by UK acoustic professionals is the heavy drop test, which is based partly on the guidance of EN ISO 10140 Part 5. The testing involves dropping a heavy object directly onto the ground floor slab so that the frequency response of the excited structure can be generated and measured in the sensitive receptor. EN ISO 10140 Part 5 refers to an ISO rubber ball that is 30mm thick, hollow and of approximate weight of 2.5kg rubber ball which is then dropped from 1m [3]. This impact generates an average force of 24.5N[1], however this was intended to replicate footfall on lightweight timber floors and is usually not enough impulsive force to excite the structure or be representative of the input forces created by many gym activities. There is no practical guidance on what type of object should be dropped, what weight it should be, and the height from which it should be dropped, the result of which being that every consultant conducts the test slightly differently.

This paper proposes a draft testing methodology which could be used by consultants to unify their approach and allow repeatable, reproducible testing associated with heavy drops which their peers and local authorities can then refer to as a benchmark for comparisons of results or to set out requirements for tests in conditions associated with planning permissions. In order to keep equipment costs low and the testing accessible for all consultants the methodology uses easily obtainable objects which are typically found in a gym or are sourced from sports retailers. The methodology also allows for a quick subjective check of the results on site to see if a building could be suitable for use as a gym, and if impacts remain audible then an opportunity to test what level of mitigation treatment would be effective.

Gym operators rarely consider the construction material of the building, even though it does have a significant effect on the suitability of a structure. Unlike high stiffness structures (e.g. those made of concrete), steel structures can easily transfer vibration from the floor, making lightweight steel framed buildings generally unsuitable for gyms in which heavy weights are used (Olympic style weightlifting[2]) without significant localised isolation treatments. At the Imperial Sports Complex in London, a 5 tonne steel 'ingot' was imbedded in each column to achieve the required stiffness [4].

Figure 1 overleaf presents a sample test results of structure borne testing with a 20kg weight, when dropped from 1m onto the ground floor slab of a steel framed building. This generates an average force of 196N[1].

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[1] *where gravity is 9.8ms$^{-2}$ and by applying equation 1*

[2] *athletic discipline in the modern Olympic programme in which the athlete attempts a maximum-weight single lift of a barbell loaded with weight plates*

The measurements were undertaken in one of the hotel rooms on the second floor of the building, and a peak at 125Hz (shown by red circle) can be clearly seen where the steel structure is resonating in response to the heavy impact.

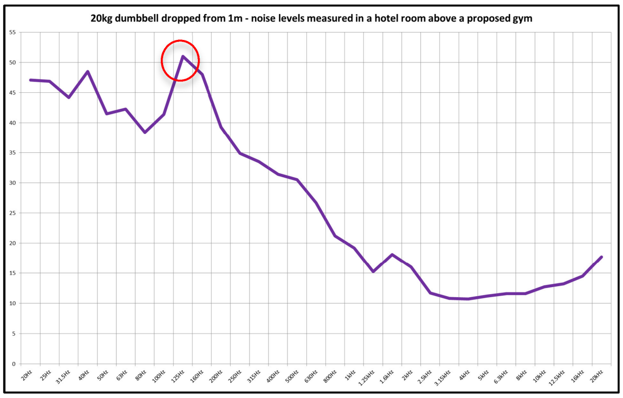


Figure 1. Test result showing 125Hz peak in the receive room of a steel framed building in dB over the frequency range 1 to 20kHz.

It can be seen from Figure 1 that the area of interest is the low frequency region between 31.5Hz and 250Hz, which sound insulation testing generally focuses on the region of 50Hz to 5kHz [5]. The justification for proposing the use of a 20kg weight is primarily that this is the limit for a safe single person lift close to their body at around chest height under UK manual handling regulations [6]. It can be seen from Figure 2 below that 16kg would be the upper limit for women at waist height, and so a greater height drop correction will be recommended to allow for gender inclusivity.

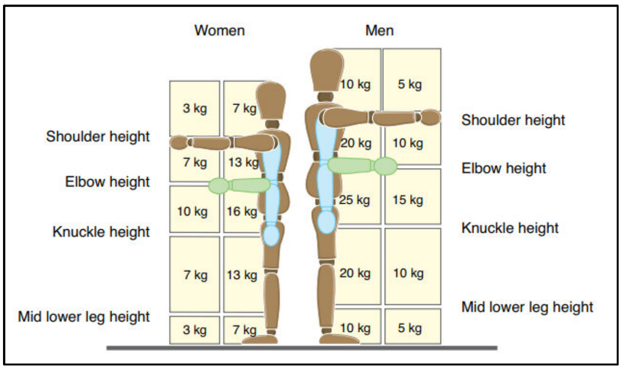


Figure 2. Lifting and lowering risk limits for manual handling in the UK, reproduced from guidance [6]

If the height from which this is dropped that varies the impulsive force into the structure. Newton's second law defines force as:

$$F_{average} = ma_{average} = m(\Delta v/\Delta t) \quad (1)$$

Where m is mass, $a_{average}$ is the average acceleration over the measurement time, $v$ is velocity and $t$ is time.

Impulsive force can be therefore be described as the change of the momentum of an object provided the mass is constant, and expressed as:

$$F_i = F_{average} .\Delta t = m.\Delta v \quad (2)$$

This shows that the impulse is proportion to the change of the velocity and the change of time over which the force is applied, which gives the mechanism for reducing the impulse force through mitigation.

The change in velocity ($\Delta v$) from release to impact, assuming air resistance has a negligible effect, therefore is the velocity at point of impact with the structure ($v_i$). So for constant acceleration (i.e. gravity) the Torricelli equation independent of time:

$$v_i{}^2 = u^2 + 2(a.x) \quad (3)$$

Where $u$ is the velocity at t = 0, which is 0 so by combining Equations 3 and 2

$$F_i = m.\sqrt{2a.x} \quad (4)$$

So where $a$ is gravity ($9.8ms^{-2}$) this becomes:

$$F_i = 4.43m\sqrt{x} \quad (5)$$

Figure 3 shows the results when applying equation 5 for heights of weight drops for the weight limits imposed by manual handling guidelines.

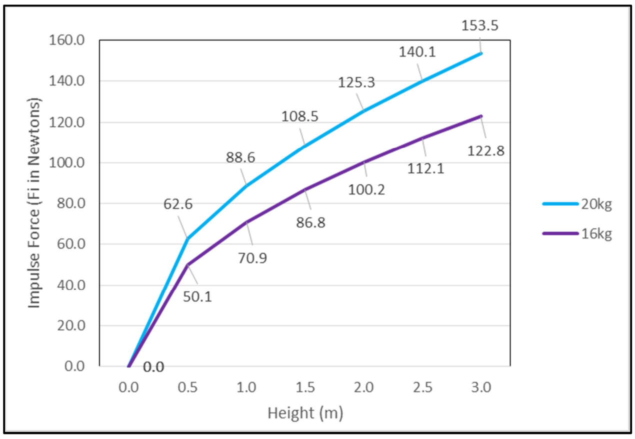


Figure 3. Impulsive force generated by different height drops for 16kg and 20kg weights

The commonly found weights in kettle bell sets are 16, 20, 24, 28, 32, 36, 40kg and the drop heights required to achieve a given impulse force, using equation 5, is presented in Figure 4.

For a 1m drop height it can be seen that 88.6N is produced for a 20kg weight. Using a 16kg weight a drop height of 1.56m is needed to achieve the same impulse force, which would require the operative to be approximately 0.5m off the floor.

This could be achieved using a low platform and 1.06m marker. Reducing this to a 1m high marker would reduce the impulse force to 86.8N. These are practical dimensions around which to base a gender diverse test.

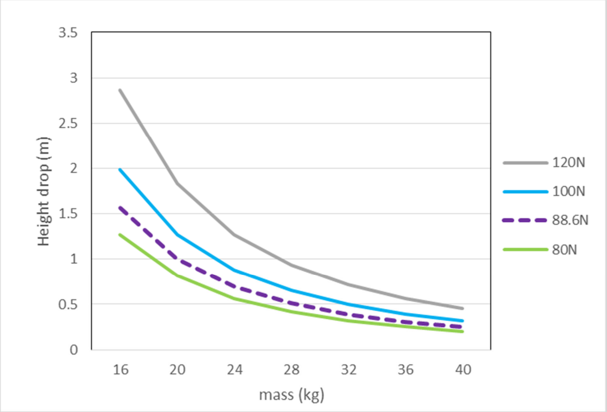


Figure 4. Drop heights for generating specific impulsive force for commonly occuring weights in kettle bell sets

Whilst Figure 4 shows impact forces using weights far above the manual handling limits it helps to identify the sorts of forces that would be created by weight drops in real situations in a gym. A test needs to input sufficient impulsive force to excite the building under test, and find the point at which it causes structure-borne noise in the noise sensitive areas. Our testing on numerous steel frame buildings has found impulsive forces between 80-90N to be a suitable point at which a structural response can be achieved. This threshold can be achieved with either a 20kg weight dropped from 1m height, or a 16kg weight dropped from 1.56m height. It can be assumed that other higher impulse forces would also be problematic. Whether it is necessary to reproduce a broader range of impulsive forces for each and every activity proposed, is discussed further in Section 3.

There are no specific adopted criteria in the UK regarding structure-borne noise from gyms, and so it is assumed in this paper that the criteria for acceptability will be determined with the regard to context and local conditions and by agreement with the relevant Local Authority. Commercial operators in the same building may also have their own criteria, including hotels.

The BSI standard EN ISO 10140 Acoustics – *Laboratory measurement of sound insulation of building elements, Part 5: Requirements for test facilities and equipment* sets out in Annex F.2 the standardised requirements for a heavy/soft impact source (based on a rubber ball). It focuses on the region between 31.5Hz and 500Hz as the area of interest, and defines a drop height of 1m (± 0.01m). The standard refers only to laboratory tests, rather than tests undertaken in-situ, so the methodology has been used as the basis for testing in potential gyms and is the basis for the proposed test methodology set out in this paper.

Gym activity noise and vibration generation falls into two main categories, which are the airborne noise from music and people and secondly structure-borne noise and vibration caused by exercises and weights. It is this second source that is the focus of the proposed test methodology set out in this paper. The activity noise and vibration can vary significantly, from high impact intermittent events such as free weights to lower impact sources like rope rolls, then continuous sources like treadmills, spin and rowing machines, and resistive training and circuits. Some gyms specialise in a specific areas and it is important therefore that a diverse test method is created that can be used and adapted for any proposed gym use.

## 2. Development of a Test Methodology

The proposed weight to be used is a rubberised dumbbell or kettlebell of a minimum weight of 16kg or 20kg (to cater for manual handling limits). For low to moderate risk of proposed activities it is considered that the following weights and set drop heights would be adequate, when carried out over different positions of the floor area being considered for use as the gym. Table 1 below shows the activity risk ranges that the authors have found require difference tests, which is not exhaustive but intended as a guide.

| Gym activity risk rating | Activity description |
|---|---|
| High | Olympic style weights, heavy free weights, CrossFit training (including tyre flips) |
| Moderate | Kettle bell free weights, rope rolls, static weight machines |
| Low | Circuit training, resistive training with free weights, Running, resistive machines such as rowing and spin |

Table 1. Risk rating for causing structure-borne noise issues in lightweight buildings

Table 2 shows the various heights for these one person tests.

| Drop heights | 16kg | 20kg |
|---|---|---|
| 1m | - | 88.6N |
| 1.5m | 86.8N | - |

Table 2. Proposed test impulsive force range, with the weights and drop heights suitable for low to moderate risk gym operations testing, for weights within UK manual handling limits

Where high risk gym activities are proposed it also may be necessary to use a heavier weight with a two person lift. For example, in CrossFit training facilities weights between 40kg and 100kg are lifted and dropped regularly [7] therefore it would be suggested (to work within manual handling limits for a double lift) to also use a 32kg dropped from 0.5m, which can be seen to generate an impulse force of 100N for a two man lift, and 24kg weight dropped from 0.5m height by two women to generate approximately a 80N impulse.

The measurements over a sample of at least 3 drops at each position should be recorded in the receiver room with a calibrated Class 1 sound level meter capable of third octave measurements and operated by a suitably qualified acoustician. The meter should be field calibrated before and after the test and any variation reported. It should be set up to log the results every 1 second and notes made of the times drops occurred to allowed post analysis of the data as overall figures and third octave bands between 31.5 and 500Hz. Where personnel allows, subjective listening tests should also be conducted in the rooms during test drops to describe the character of the sound and any localisation that can be determined (such as a column). To avoid disturbing measurements these observations should be done in spaces other than where the measurement takes place where practicable. The ambient with no impacts can be extracted from the data between impacts with spurious noise events excluded. It is also important to undertake the drops across the entirety of the floor slab, as high variation can be expected depending on the drop location. Figure 5 presents an example of a test where a grid of 9 measurements was chosen in an empty retail unit, proposed to become a low impact gym. The drop locations varied in distance to columns and walls to capture the best and worst-case scenarios but generally were 3m apart.

Figure 5. Example drop test layout.

Due to the quantity of drops across different locations, and to reduce uncertainty between measurements, it can be useful to use multiple sound level meters to measure the same drop test simultaneously in multiple receiving rooms. Care must be taken to ensure they are all calibrated with the same field calibrator so that the results are accurate and consistent, and that the clocks are synchronized.

The determination of the suitability of a site for a gym is the final step after the baseline testing of the structure has been undertaken. Most gyms have preferred floor finishes, and will install isolation floors for heavy weights areas, therefore it is not practicable to test how effective these would be. However the baseline results will enable the selection of appropriate isolation treatments. It is usually practicable to test the proposed floor coverings of each area, such as studios, by placing at least a 1m$^2$ sample on the floor of the test area and repeating the tests. The acceptability criteria is expected to vary from authority to authority but once determined this should be used as a threshold, and if exceed then further mitigation should be implemented until the criteria are achieved.

Isolation treatments can vary significantly in their performance depending on the type, the installation method, and the construction of the building. They can provide little dynamic isolation. Reliable published data is hard to find. It is even possible for some treatments to worsen the issue, as for some elastomeric products the isolation is provided only at high frequencies, allowing the low frequencies generated by the impacts to pass through and excite the structure. It is therefore essential to seek expert advice prior to specifying an isolation product to ensure that it will perform at the isolation frequencies required, to effectively treat the problem at source.

Assuming the criterion can be achieved with the correct activity level tests, then it is reasonable to conclude that with appropriate mitigation and management controls that the proposed unit would be suitable to allow a change of use to a gym, provided that the recommendations within the acoustic report are implemented and maintained. In addition, a noise management plan should be agreed and implemented to the Local Authority’s satisfaction.

The heavy drop test may equally be useful to determine the extent of the noise transmission laterally across the slab.

Rubberised weights have been recommended to avoid the high frequency peak that a metal weight produces as it hits a hard surface, and to be a good representation of a real impact that could occur.

Other measurement techniques which can be useful to determine the suitability of a low impact gym are exercises such as star jumps, squat thrusts, and running on the spot. These exercises can be undertaken on the slab directly, and if problematic and audible in the sensitive rooms will provide a good indication that the location would be unlikely to be suitable for higher impact activities. It is important to note however that while useful as a quick check of the structures performance on site these are not repeatable measures, so they are not included within the proposed test methodology of this paper.

## 3. Discussion

The test methodology outlined in this paper is designed to be repeatable and practical for acoustic professionals, taking account of manual handling limits and an inclusive test procedure. The authors would prefer to discuss the gender different requirements imposed by UK regulations to be seen as more of an ability based guide to promote inclusion. No specialist equipment outside of a Class 1 sound level meter is required. It follows and expands upon the little industry guidance there is at this time, developing the heavy drop test methodology for use in potential gym locations.

The methodology is specifically intended for use in lightweight structures that also contain noise sensitive receptors such as residential or commercial uses. This recognizes the need to also treat the proposed activity types planned to determine whether a low impact gym operation might be appropriate. This is intended to enable buildings to be assessed in a standardised way, to determine whether mixed use may be appropriate in locations that a high risk gym activity would be not suited to assist sustainable development and reuse of buildings. For high risk gym operations the proposed methodology allows for use of heavier impact forces as a way to test the resistance of the structure, but this does not replace the need for floating floors for free weight areas to be properly designed. It is intended to enable recommendations for the treatment of the rest of the gym floor where there might be occasional higher impacts.

The test methodology within this paper is a first attempt, which is intended to stimulate debate to begin further development and refinement of a methodology that we hope will end in a standardised test procedure. The authors welcome comments and suggestions from all in order to help further develop the unified guidance which this topic requires.

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