Design and Acoustic Performance of a Spring Isolated Outdoor Rooftop Basketball Court

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ABSTRACT

The proposal of a rooftop basketball court created an issue of significant impact/footfall noise and structural vibration ingress to the sensitive environment beneath. As part of a new building in a dense urban environment, a unique solution had to be designed due to the maximum weight capacity of the underlying rooftop structural slab and FFL design controls. Further challenges were faced in the form of fluctuations of up to 30 mm in the level of the underlying structural slab and subsequent excessive deflection caused by a relatively high live load. The final design incorporated the use of over 300 cast in 'jack-up' style mounts complete with 25 mm deflection springs within a 100 mm secondary concrete slab covering an area of approximately 630 m^2. Installation of the court encountered few problems and upon completion small deflections of the slab could be felt underfoot however there were no unfavourable 'trampolining' effects generated by live loads. Completion testing showed a significant reduction in impact noise levels between the isolated court and an exposed portion of the structural slab.

Keywords: Impact, Sports, Transmission   I-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

Basketball courts are subject to frequent impact forces from bouncing balls and people jumping. Typically basketball courts are constructed at grade to avoid issues of noise and vibration transmission through connected structures. In this case, a combined basketball/netball/tennis court was to be constructed in a dense urban environment, and limited spatial availability necessitated that it had be located on a rooftop directly above commercial space. Without sufficient vibration isolating measures, the impact forces from activity on the court would likely cause distracting noise to the people below in the connected structure.

A common solution for above ground sports floor isolation is to use plywood under the floor lining with multi-layered pads or rubber mounts regularly spaced underneath. This provides a degree of vibration isolation as well as impact absorption for the comfort of the people using the floor. However, a high level of isolation from the adjacencies in this proposal would likely require deflection which is beyond the capabilities of regular pads. Since the playing surface for this project was outdoor, the surface and isolation needed to be designed to withstand the effects of weather for a long life, and this typical solution was deemed inappropriate.

The structural floor was a 150mm composite slab with large transfer beam spans which yielded a relatively low natural frequency for the structural slab (see Section 3.1). The natural frequency of the courts system needed to be calculated carefully to avoid resonance with both the underlying structural slab and with activities such as footfall and ball bouncing.

The proposed court size was approximately 630m^2 and the finished court height was restricted to 150mm from the structural floor. The court system was also to contain several large penetrations for poles which were to be supported from the structural slab. Other design constraints included the support capacity for a live load of 5kPa and an allowance for appropriate drainage measures.

The final design of the system incorporated a 100 mm thick concrete floating floor which was supported by springs with housings which were cast into the concrete. This design aimed to achieve a consistent air gap of 50 mm between the floor and the structural slab. From the experience of the authors it is much more common to use rubber mount isolation for sports floor applications due to factors such as cost, discomfort from vibrations due to large amplitude deflection where springs are used and resonance at walking frequencies. However, it was believed that the overall effect of these issues could be mitigated, as it was the only solution which satisfactorily met the design constraints.

1.1 Noise level criteria

It was important to develop design criteria which would result in acceptable levels of noise in the tenancies below the basketball court. The tenancies below would be constructed as part of a separate fitout contract. As such, their use was not fully confirmed at the time of design. However, it was known that these tenancies would install a plasterboard ceiling in the space below to conceal structure and building services. Possible uses for the space included a medical clinic or small retail units, etc. From AS2107:2000(1) a medical clinic has the stricter requirements with a satisfactory design sound level for consultation rooms in health buildings at 40dB $L_{Aeq,T}$ with a maximum of 45dB $L_{Aeq,T}$.

The average noise level ($L_{Aeq,T}$) from impact noise on the slab above is unlikely to be the determining factor in disturbance or annoyance to the users of spaces below. The primary factor in this would be the impulsive / maximum noise levels (L_{Amax}). As such, it was considered that if the L_{Amax} levels from activity on the slab above did not exceed the above criteria then the noise was not likely to cause disturbance to occupants.

2. INVESTIGATED ALTERNATIVES

Due to the likely cost implications of providing an isolated secondary slab for the extent of the Basketball Court area, a number of alternative options were investigated during the early design stages of the project.

2.1 Isolation of spaces below

The option was explored to structurally isolate the spaces below, such that they did not share a direct connection to the slab above nor the columns passing through the space. Due to a high floor to ceiling height, this was seen as a feasible design option.

After a detailed investigation, designing the building in this way would have had several consequences. Firstly, it would place restrictions on the layout of the spaces below, likely restricting the ability to have large open floor plans without significant supporting structure. Secondly, there was a risk of vibration generated by the court activities causing re-radiated noise elsewhere in the building. Further complications included the space below potentially needing an isolated facade line, and a limitation of future flexibility and changes to spaces below the court. As a result, mitigating the noise transfer in this way was not seen as a reasonable solution.

2.2 Resilient matting on non-isolated slabs

The use of a resilient layer of 5mm matting below the finished sports surface had been implemented successfully in a number of education facilities. Two schools with multi-use games areas located above classrooms constructed were visited.

From testing the facilities with a sample basketball bounce, it was clear in both instances that noise from the court was clearly audible above background noise and even audible above low levels of activity noise in both cases. This audible noise was acceptable for the uses where tested, as the games areas were mostly in use when teaching is not conducted in the spaces below.

Furthermore, both facilities had thicker primary structural slabs (circa 250mm – 300mm) than the proposed facility (see Section 3.1). As a result, it was concluded that this solution would not provide the levels of noise isolation required for the proposed development.

3. STRUCTURAL PERFORMANCE

3.1 Structural slab

The structure of the building in this location was complex as it needed to contain a large span composite steel framed slab, designed to be constructed over an operating driveway which served the adjacent Etihad stadium. Due to the use of the space as a joint retail and sports facility, despite these large spans the resulting structure needed to be relatively stiff to satisfy the structural and acoustic requirements.

The floor structure is typically a 150mm composite concrete slab (Bondek II Metal tray), supported at 2m centers by 900WB175 composite secondary steel beams spanning 15m.

The project structural engineers performed detailed finite element modeling on the full structure in order to assess the resonant frequency of the slabs. This work showed the resonant frequency to be 5.6Hz on the tenancy level, and 8.9Hz on the basketball court level above.

3.2 Spring selection

In order to avoid the 5.6Hz and 8.9Hz structural resonances, WSP required the natural frequency of the floating floor to be √2 or greater away from the resonances(2) under purely dead load (DL) conditions. The rationale for this was to ensure that with minimal damping the resonance of the floating slab would not induce a resonance of the two structural slabs. Therefore the system required a natural frequency of less than 4Hz or greater than 12.6Hz.

$$5.6/\sqrt{2} = 3.96Hz \tag{1}$$

$$8.9 \times \sqrt{2} = 12.58Hz \tag{2}$$

A single degree of freedom system's natural frequency can be represented in terms of its static deflection as per equation 3. This equation is derived from the ideal single degree of freedom mechanical spring-mass-damper system, and is accurate for helical steel springs (4).

Avoiding the resonance of the basketball court level slab was considered the most important factor in the design. Additionally, a resonance of greater than 12.6Hz would limit the overall isolation that would be achieved in audible (>20Hz) frequencies. As such, it was decided that the natural frequency of the floating floor should not be greater than 4Hz.

Frequencies generated by human motion range between 1.7Hz for a slow walk up to greater than 3.2Hz for sprinting(3). A natural frequency of lower than 2Hz was not achievable within the constraints, so the floating floor was designed to have a natural frequency marginally lower than 4Hz under dead load conditions, which required precision in spring selection and load calculations.

The calculations determined that the system required isolation mounts to be used with a minimum deflection of 15.5mm.

$$d = g/(2\pi f_0)^2 \tag{3}$$

Where g= 9.81 m/s2 and f_0 = 4.

This deflection within the constrained height could not be practically achieved with rubber mounts; typical rubber mounts have a deflection up to a maximum of 12mm and relatively high damping at high loads, which reduces their isolating capabilities. The above calculations only apply to the dead load of the slab and don't take into account the greater deflection required for the live load. For these reasons it was considered necessary to use spring mounts.

Whilst the structure was required to support a live load (LL) of 5 kPa from a safety aspect, under normal use as a sports court this load equates to approximately six 80 kg people standing in each square metre, which is an unlikely scenario. Achieving this LL condition provided practicality issues with the requirement for a spring to provide the minimum deflection under DL and support DL + LL within the constrained space. For this reason, the upper bound of design load was reduced to DL plus a third of LL as a more realistic loading for normal use. Under this condition, at the full LL the springs would bottom out, which would cause an increase in the transmission of vibration but would not damage the springs, or the structural integrity of the slab. This was considered an acceptable compromise in order to achieve the acoustic requirements under realistic operating conditions.

For selection, springs needed to deflect at least 15.5mm under dead load without bottoming out under an additional third of live load. The spring range selected had a rated maximum deflection at 25mm with an extra 50% safety factor designed into it to allow extra deflection from live loads. For a typical location within the playing areas of the court it was calculated that after a third of LL was applied to the spring there would still be 10mm deflection available before bottoming out. The calculated deflections can be viewed in Table 1.

Table 1- Calculation spring deflection (mm) of a typical spring located inside the court's playing area.

Spring Type	DL	DL + 1/3LL	DL + 5kPa
85mm Diameter Spring	16.7	27.6	Bottomed out

Using equation 3 gives a natural frequency of 3.86Hz under DL and 3.0Hz at one third LL. In other locations, such as near the corners or edges of the slabs, the springs were selected for similar deflection under the two conditions.

3.3 Concrete Slab Design

Standard AS3600 table 4.10.3.2(5) states that the reinforcement in the slab within 50km from the sea requires 40mm coverage. This resulted in a minimum concrete slab thickness of 100mm so that the reinforcement is adequately covered on top and underneath. The air cavity itself has an important role in vibration isolation, so it was logical to use a 50mm air cavity with a 100mm thick slab. This also allows for the full travel of the springs to be used so that the springs will compress to solid before the floating slab touches the structural slab.

A typical construction for a spring-mount supported slab system is for a deck to be placed over the mounts to support the formwork while concrete is poured over the top. However, the required springs would not fit within the 50mm cavity. The solution was achieved through a jack-up mount system, which would allow a large proportion of the 100mm height of the slab to be utilised for the springs as well. This had the negative effect of having a reduced airborne noise performance due to the holes required in the floating slab, but since the major concern was for vibration isolation this was felt to be a reasonable compromise.

It was decided that the spacing between mounts should be as large as practically possible to reduce the number of transmission points, decrease the number of penetrations through the slab and increase the dead load per spring. This had the additional benefit of making the project more economical. The maximum practical spacing was 1.5 x 1.5m based on available spring mountings. The corresponding loading required a spring diameter of 85mm, with 330 mounting locations in total.

The court slab was constrained around its perimeter by a 150mm high concrete hob, and was sealed with 20mm thick closed cell polyethylene foam to prevent rigid contact between the slab and the hob which would cause bridging. The edges were also sealed with flexible sealant to prevent water ingress under the floating slab.

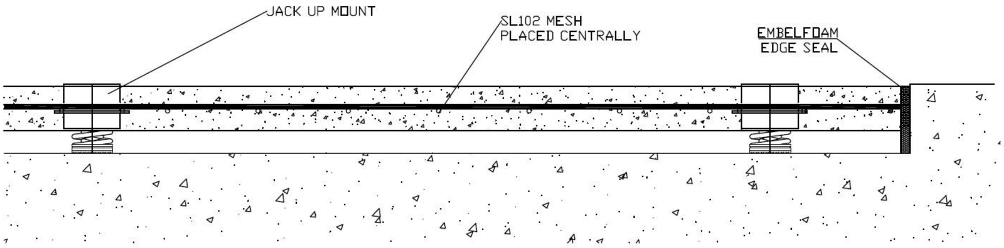

Figure 1 – Section drawing of the court slab design

3.4 Basketball, netball and tennis post isolation

The posts for the basketball hoop were to be supported on hobs that were not on the floating floor. It was important that these were isolated from the structural slab while not allowing too much movement in the post as any movement would be amplified at the hoop due to the distance from the base.

It was decided to use pads underneath the base of the post with rubber washers located above so that there were resilient elements restraining the post in all directions. To separate the anchor and the base plate a rubber sleeve was also incorporated. This prevented direct contact between the post and any rigid connection to the structure.

Figure 2- Basketball post isolation.

The netball and tennis posts were placed in sockets that were recessed into the structural slab. The posts were separated from the floating slab by creating a larger penetration through the floating slab so that the posts could never come in contact and bridge the isolation. The penetrations were capped to resist the ingress of water and sealed around the perimeter with foam.

3.5 Installation

The structural slab was greater than 30mm out of level. To ensure a degree of consistency in the level of the base of the springs, the mounts were packed underneath to allow for the floating slab to be poured flat. Packers were placed in the correct position and a chamfer was created around them to allow for the floating slab to easily separate from the packer when it was jacked up. The variety of height of the packers used over the floor affected the amount of concrete being supported by each mount substantially. The result of this was that each mounting point had to be carefully recalculated to provide an even deflection over the whole area of the court. Installation of the court system did not encounter any major setbacks or delays.

Figure 3 Typical packing under jack-up mounts.

4. PERFORMANCE ANALYSIS

4.1 ISO10140-1:2010 Impact Noise Testing Results

Field impact testing was performed on the 150mm bare structural slab prior to construction of the floating slab. Impact testing in accordance with ISO10140-1(6) offers a standardised $L_{nT,w}$ dB rating for the floor. This will provide a numerical value detailing the improvement over the bare slab floor. The test was conducted using a Bruel & Kjaer 3207 tapping machine with a Svantek 958A analyser. 4 tapping machine positions were used with 5 microphone positions for a total of 20 measurements as well as background noise testing and reverberation time.

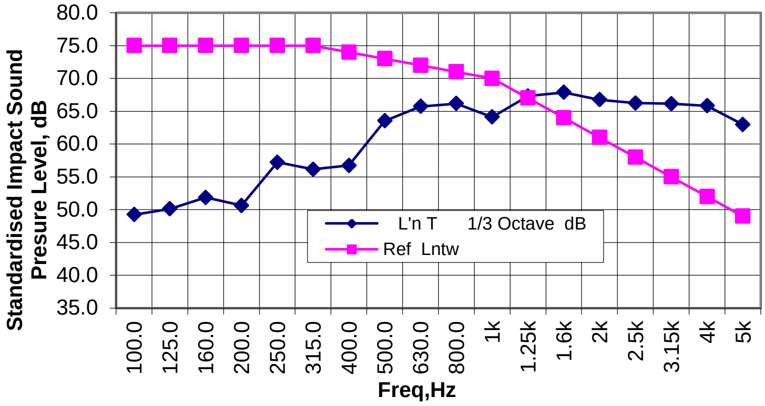

Figure 4 $L_{nT,w}$ measurement on the 150mm structural slab, in dB shown in 1/3 third octave intervals.

These measurements gave an $L_{nT,w}$ 73dB and an FIIC 15dB.

Testing was then repeated once the floating slab was poured and jacked up. ISO10140-1:2010 specifies that all measured values must be at least 6dB higher than background noise and preferably 10dB above. From the test results, the largest variation was 3.5dB above background noise, so providing an in depth analysis and graph of these values would not provide any benefit. Testing was performed at night after peak traffic times to minimise the background noise, however at the time of writing this paper the court was above an unfinished building site. While graphing the results will not give an accurate account of the performance, it will provide minimum values of performance. The measured values were $L_{nT,w}$ 37dB and FIIC 69dB.

Further tests were performed on the hobs around the perimeter to provide an indication of the improvement of the floating slab as opposed to a solid concrete slab 300mm thick. The single value results were $L_{nT,w}$ 59dB and FIIC 46dB so the floating slab offered a substantial improvement.

Additionally, the unfinished retail space from which measurements were taken was a concrete room larger in area than the court itself with an unfinished ceiling, and glazed door sets which were not sealed. Combined with a lower background noise, it would be expected that the finished space would measure significantly improved values than those shown above.

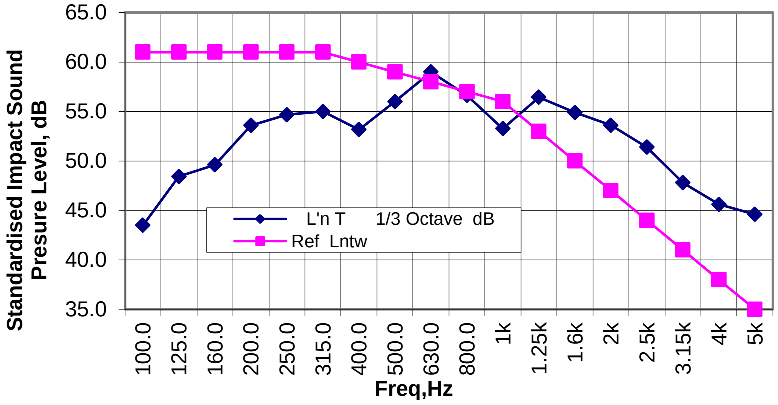

Figure 5 $L_{nT,w}$ measurement on the 150mm hob, sitting on the structural slab, in dB shown in 1/3 octave intervals.

4.2 Typical Activity Noise Levels

To test the expected noise levels from court activities, an informal basketball game was played on the floating slab with L_{Aeq} and L_{Amax} measurements taken in the space below. Measurements were taken over a 15 minute period during a weekday morning, with background noise registering an L_{Aeq} of 37.2dB. The results from the testing can be viewed in Figure 7. The L_{Amax} shows intermittent peaks between 48 and 56dB, which were generated by the basketball posts. As discussed previously, these were not located on the court slab but were separately isolated on the perimeter hobs to decrease vibration transmission. However, during the casual basketball game the ring was tied back to a post which was not isolated but rigidly connected to the hob. It was found that when either a ball impacted or a strong gust of wind rattled the backboard against this post it was clearly audible in the space below. It was expected that when fixed in the proper game position the isolation on the posts would be effective. Shooting for goal was restricted during testing; the peaks in Figure 7 are mostly the result of the wind gusts. Regardless, the L_{Aeq} averaged over the whole 15 minute period of continuous activity was 39.2 dB, which includes the peaks from the backboard. Discounting these spikes, the L_{Amax} peaked just past 46dB.

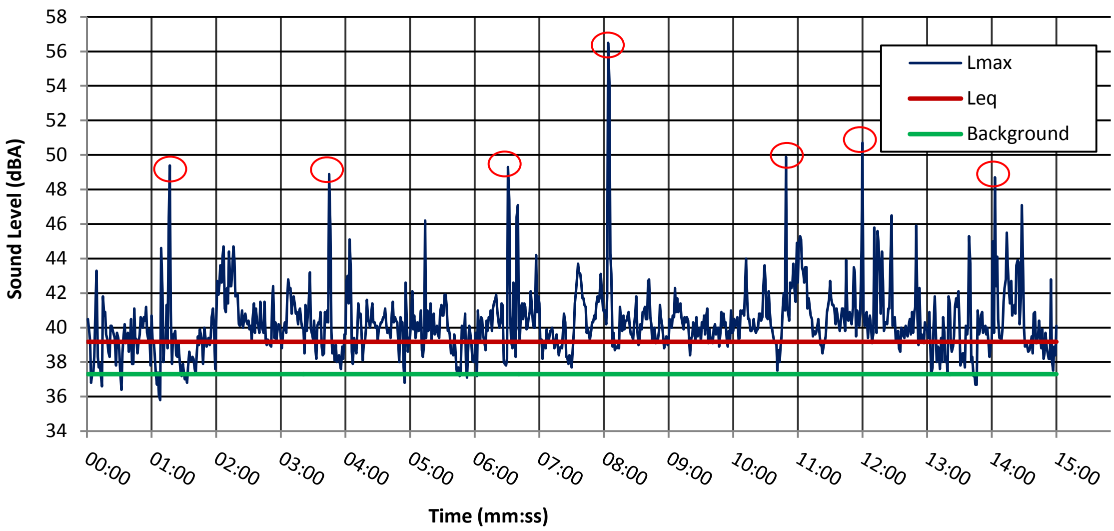

Figure 6 Measurements of sound levels (dBA) during typical court activity, including bouncing ball, running, passing and occasional shooting.

In order to further examine the sound insulation performance and noise mitigation of the floor system a number of scenarios were investigated. The focus of the testing was to obtain L_{Amax} for a number of simulation controlled basketball events that are likely to occur on the court. The three regular activities deemed likely to generate the greatest noise from on court activities were ball bouncing, jumping and shooting.

The environment surrounding the court includes Etihad Stadium and the associated plaza with numerous retail spaces. The plaza contains a number of flag poles which, even in light wind, generate noticeable noise from the chains hitting the metal flag pole.

The condition of the space during this phase of testing was part way through construction. Notably, full height walls had been installed within the retail space, which provided some improvement in reducing the level of background noise.

The results (as shown in Figures 7-9 and summarised in Table 2) indicated the following:

- For bouncing the ball on the court surface, the noise levels although perceptible were similar in value to external noise sources such as the flag poles. The characteristic and change in tone was noticeable above the typical external noise sources.
- Jumping and shooting created peaks in reading of the L_{AMax} that exceeded the typical background readings.
- There was a noticeable difference between the shooting with the hoop fixed back on the holding pole compared to when unhooked and in game position. The noise levels were higher in value and the event would last longer.
- The noise levels measured due to shooting would also be dependent on the outcome of the shot such as whether it hit the backboard or rim, force of the thrower, etc. To simulate this, the shooting style was varied with each attempt.

The main outcome from the testing was that all measured results were within 7 dB of the maximum target for the L_{Amax}. It is expected that the installation of the plasterboard ceiling in the commercial space will reduce peak noise levels in the space from basketball court activity by approximately 10-15 dB. The inclusion of mechanical services to the space will also create a steady masking noise level at circa 35-40 dB.

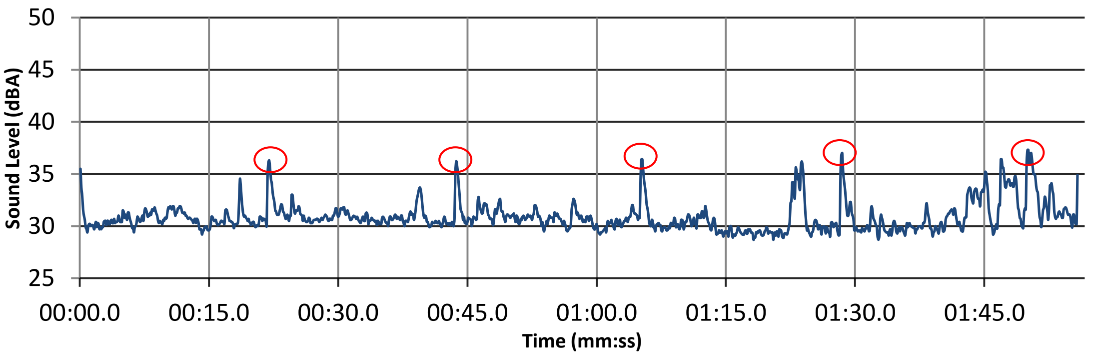

Figure 7- Measurements of sound levels (dBA) in the retail space during ball bouncing

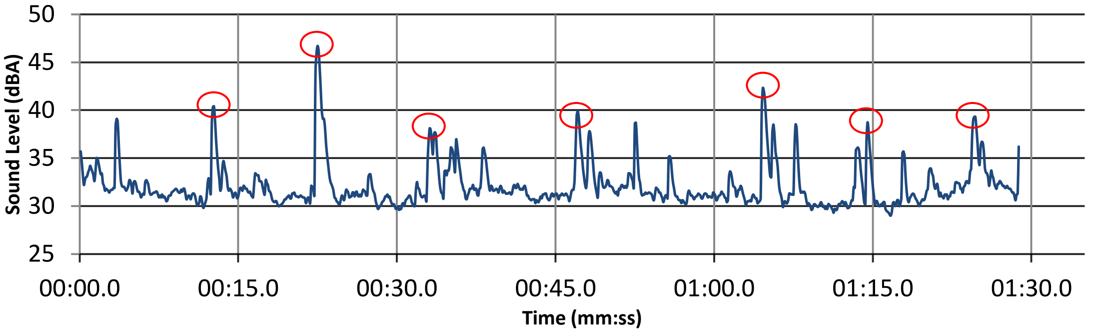

Figure 8 - Measurements of sound levels (dBA) in the retail space during jumping

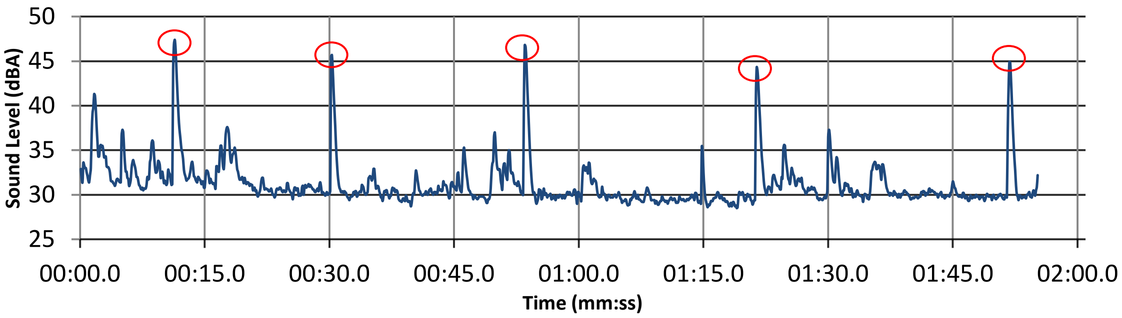

Figure 9- Measurements of sound levels (dBA) in the retail space during shooting with the hoop in game position.

Table 2: L_{Amax} in dB for controlled events and typical noise levels

Sound Level (dB)	Ball Bounce	Jump	Shooting-Hoop fixed off court	Shooting- Hoop in position	No activity
Average	37	46	49	41	32
Max	37	47	52	47	39

On court, it was found that when a player jumped near the corners of the slab a small shudder could be felt throughout, even at some distance away. However when this action was repeated within the playing area of the court the response was much less noticeable. Throughout the casual game this was not noticeable and there was no negative feedback regarding vibrations or flexibility of the court. A future design of a court with similar constraints could benefit from the inclusion of internal damping to the springs, which would dissipate the energy in the system caused by impacts more effectively, levelling out the slab faster. However, this damping may reduce the isolation effectiveness in the audible frequency range.

5. CONCLUSIONS

This paper has presented a spring mounted floating court system which provides effective noise and vibration isolation whilst meeting strict design constraints. The finished floating court system provided a substantial improvement over the performance of the structural slab with an $L_{nT,w}$ improvement of at least 36dB. Specific noise testing of typical on court activities resulted in a maximum L_{Amax} of 47dB. With a future ceiling to be installed, it is fully expected that this value will be reduced to below the established target criteria of < 40 dBA L_{Amax}. With the inclusion of mechanical services in the tenancies, the noise levels in the commercial space generated by a basketball game above may be inaudible and in any case are highly unlikely to be distracting or disturbing.

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