COMPARISON OF POOL ISOLATION SYSTEMS

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Swimming pools are a common amenity in high-rise apartments and hotels. Many activities associated with swimming pools such as diving, kicking off the ends and jumping on the pool floor are sources of low frequency noise and vibration. As pools are often placed above penthouse suites, selecting the correct isolator to achieve high levels of attenuation is critical. The most common products used for isolating a swimming pool are: rubber matting, rubber pads and spring mounts. Each swimming pool is a unique case due to factors such as building height, slab stiffness, shape, depth, features and isolators. As such, complications arise in providing an accurate comparison between isolation methods. For this paper, a concrete filled tank was placed upon each of the aforementioned isolators with a water-filled barrel dropped into the pool to simulate a person jumping in. A Svantek 958A analyser was used with accelerometers placed on the main structure to measure vibration transmission. The results of each isolator type were compared and the characteristics of vibration analysed. The spring mount products significantly outperformed the rubber products in attenuating transmission of low audio frequencies from impact.
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1. Introduction

Rooftop swimming pools have been a known source of significant low frequency noise and vibration annoyance for residents for over 40 years [1]. Impacts from pool related activities such as diving, kicking off the ends and jumping on the pool base transfer vibration through to the structure and re-radiate as noise. Typically, the space underneath a rooftop swimming pool is occupied by a high value apartment or penthouse, which carries a stringent threshold for external noise pollution. As such, it is common practice in Australia to structurally isolate the entire swimming pool from the rest of the building.

An above ground pool structure contains multiple degrees of freedom, which includes the pool shell, the isolation mounting system and the underlying support from the main structure that must all be considered when designing an isolation system. In-situ concrete slab fundamental frequencies for a typical high rise commercial construction can be below 10Hz when unloaded and as low as 5.5Hz for composite steel construction [2][3]. Support for a swimming pool necessitates a stiffer slab arrangement than for office or residential loads; however, if the large non-structural mass is supported mid-span it can still result in a slab frequency below 12Hz. Consequently, an effective isolation system for attenuating re-radiated noise in one building can amplify inputs in another, despite the pool shell being of similar construction.

The vibration characteristics of swimming pools from excitation are complex. The impacted medium is an incompressible fluid that produces a reaction force in addition to shockwaves and sloshing from impact, meaning that vibration is generated from both impact and frequency based inputs. There is a lack of adequate test data available to the industry and as a result, it is not fully understood to what degree each input is responsible for the low frequency characteristic of the re-radiated noise.

In this paper, Embelton engaged in a series of tests using popular pool isolation systems under a common shell structure to assess both the relative performance from a pool impact and the characteristics of the vibration generated. The structure used was a concrete tank filled with water to a common depth for residential swimming pools of 1200mm.

2. Testing methodology

2.1 Impact Simulation

Diving and "bombing" are known to be the activities that generate the largest magnitude of vibration. During a typical dive, the swimmer does not impact the pool base, so vibration is wholly transferred to the structure via fluctuations in water pressure. A repeatable test was required to simulate this. A human body is approximately the same density as water, and the body shape of the diver is held relatively constant during impact. As such, a plastic barrel filled with water, dropped from a fixed height was deemed an appropriate simulation.

The average adult person in Europe weighs approximately 70kg [4]. A 60 litre plastic barrel 630mm high and 420mm high was filled with water to a total weight of 65kg. The average height from which a person falls into a pool carries significant variation but a reasonable height was taken to be 400mm [5]. Pool walls typically have a height above the water line of 100mm, requiring a total drop height of 500mm above water level. With a water depth of 1200mm, it was calculated that the buoyancy and drag forces would prevent the barrel from impacting the tank base.

2.2 Tank and Support

The concrete tank had the following dimensions:

- 1900mm outside diameter
- 1500mm height
- 85mm wall thickness
- 100mm base thickness
- Empty weight of approximately 2.3 tonnes
- Water weight of approximately 2.7 tonnes
- Full weight of approximately 5 tonnes

The tank and isolation systems were supported by a slab on grade in order to reduce the influence of an underlying structure, as reducing the number of modes influencing the system response allowed greater clarity in assessing isolator performance results. In most cases the stiffness of the underlying structure is the variable over which the isolation designer has the least control. In this configuration, the isolation system's behaviour can be compared with the response of a single degree of freedom spring mass damper model subject to a single impact.

2.3 Isolation Products

The following isolation systems were tested.

- 10mm rubber matting, density 850kg/m^3, full contact with the base of the pool
- Discrete 3 layered - 55 Duro ribbed isolation pads - 10 mounting points, 54mm free height
- 20mm deflection spring mounts – 4 mounting points, 230mm free height
- 40mm deflection spring mounts – 4 mounting points, 280mm free height

A baseline test was also conducted using no isolating element between the slab and pool shell structure.

The 10mm rubber mat has a compressive strain of 10% or 1mm for a 200kPa load. The plan area of the pool was 2.84m^2, resulting in a distributed pressure onto the matting of 1.73kPa and negligible deflection. As a result, it was expected that the only improvement over the baseline test would be due to the added damping provided by the matting. The pads were sized to have a static deflection of 6mm with a dynamic stiffness ratio of approximately 2.5 and damping ratio of 0.13. The 20mm and 40mm spring mounts were selected to provide static deflections of 17mm and 35mm respectively.

2.4 Test equipment and procedure

The barrel was pushed from an elevated cage with the floor situated 500mm above the tank's water level, providing both vertical and horizontal motion consistent with a person jumping from a pool's edge. For each isolation system, 10 tests were conducted and the arithmetic average was taken.

Vibration levels were measured in 1/3rd octave bands between 0.8Hz and 1kHz using a tri-axial SV207A accelerometer, which was placed with a soft cover on the ground slab 200mm from the edge of the pool for each test. For the higher deflection tests, it was noted that the higher amplitude of displacement was affecting measurements due to a larger volume of water spilling over the edge and striking the cover that had been placed over the accelerometer. As a solution, the accelerometer was placed underneath the pool and 200mm from the edge to protect it from direct splashing. The barrel did not strike the pool base after impact and floated.

Figure 1: Typical set up

2.5 Impulse response for a single degree of freedom impact.

Equation 1 defines the amplitude of an impulse response, derived from the single degree of freedom model [6]. This allows the relative performance of the system to be estimated if excitation were affecting a rigid body. Acceleration results shown are from differentiating Eq. 1 twice with respect to time.

$$x(t) = \frac{1}{m\omega_d} e^{-\zeta\omega_n t} \sin(\omega_d t + \phi) \tag{1}$$

Where m is the rigid mass (kg), ζ is the damping ratio, $\omega_n$is the fundamental frequency (rad/s), ω_d is the damped fundamental frequency (rad/s), t is time (s) and ϕ is the phase shift (rad).

Table 1: Calculated theoretical performance

Test	Normalised maximum acceleration (mm/s^2)	Average dB reduction compared to baseline
Baseline (estimate)	100.00	-
Rubber mat	70.6	3.0
Multi-layered pads	11.8	17.6
20mm spring (17mm deflection)	8.3	21.6
40mm spring (35mm deflection)	5.8	24.7

The baseline was conservatively estimated using the same theoretical deflection as the rubber mat of 0.1mm with 2% damping. The rubber mat damping ratio was estimated to be 10%. The high damping of the pad mounts offset the high dynamic stiffness to achieve a calculated acceleration of 4dB higher than 20mm springs. If the pads carried the same damping as springs (1%), then the maximum acceleration calculated increased by a factor of 1.7.

A number of limitations are present in the above calculations with respect to the testing.

- Characteristic of impact differs to an impulse.
- Less than 50% of the mass of the filled pool was considered rigid.
- Excitation of rocking modes due to horizontal force component were not factored into model
- The pool shell contains structural modes

3. Results and Analysis

3.1 Single value impact results

Maximum acceleration results (Table 2) reduced as the static deflection of the isolation system increased. Spring mounts yielded the lowest measured levels above the background. Vibration levels were not weighted for human perception due to re-radiated noise being the primary source of annoyance.

Table 2: Recorded impact results on slab

Test	Average maximum acceleration (mm/s^2)	Average dB reduction compared to baseline
Baseline	364.6	-
Rubber mat	134.1	8.7
Multi-layered pads	51.3	17.0
40mm spring initial test	35.3	20.3
20mm spring	17.9	26.2
40mm spring retest*	13.5	28.6
Background	3.2	41.3

A preliminary test of the 40mm deflection pool springs resulted in a much larger splash and displacement of the pool structure from impact than observed in the other tests, which caused a large volume of water to strike the slab and register on the accelerometer readings. The large splash occured approximately two seconds after the initial impact suggested that the sloshing frequency of the water movement matched a harmonic of the spring fundamental frequency.

The depth of the water was subsequently reduced by 300mm to ensure that the impact of water on the ground was not influencing further results. The height of the barrel relative to the water remained at 500mm. While the reduction in static deflection on the springs of approximately 5mm would reduce the performance of the altered system, the reduction of water would both reduce inertial resistance and the non-structural mass participating in excitation of the structure. As such, the 40mm spring retest was not a direct comparison to the other tests.

Figure 2: Splash during the 40mm spring initial testing

Results in Table 2 were in reasonable agreement with Table 1 concerning relative dB levels between rubber matting and spring mounts. The largest deviation from the theoretical results was that the multi-layered pads provided less attenuation in testing. The difference between the pads and rubber mat was measured at 8.3dB compared with 14.6dB calculated.

3.2 Frequency spectrum of impact

The frequency spectrum yielded several observations about the system and isolation products. Peaks of various magnitudes were present for nearly all tests at 50Hz and 400Hz. Figure 4 provides greater clarity between the different isolation systems, and the lack of a clear peak at 50Hz for the background measurement suggests that 400Hz was the fundamental frequency for the slab on grade.

Fundamental frequencies of the isolation systems can also be identified as the following:

- Approximately 3.15Hz for 40mm deflection springs
- Approximately 4Hz for 20mm deflection springs
- Between 10 and 12.5Hz for pads

The absence of any other significant peaks strongly indicates that 50Hz is a mode of the pool shell structure.

The pad frequency suggests that the dynamic stiffness is greater than 2.5, which is derived from the product's datasheet. However, an observation from testing was that the slab was not level, and while each pad had packers it is likely that some pads were under greater compression that others of up to 2mm variation.

At 400Hz, a comparable level of attenuation from the baseline was present for the pads and spring tests (Figure 4). With the assumption that this is the fundamental frequency of the slab, it is likely that this was due to a small water splash over the edge of the pool striking the slab, which was consistent across all tests except for the 40mm retest, which as discussed in section 3.1 contained a reduced water level. However, the rubber mat test likely recorded a considerably higher acceleration magnitude at 400Hz as it directly transmitted a larger force to the slab from the impact.

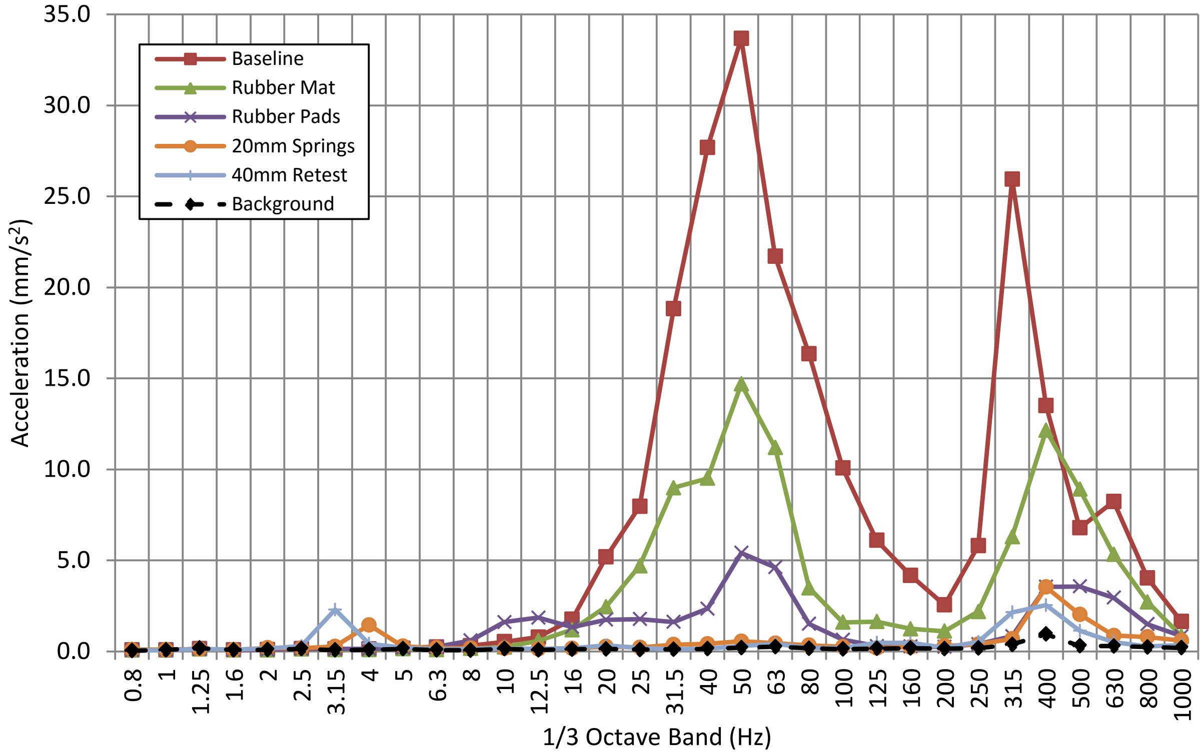

Figure 3: Frequency spectrum of averaged maximum acceleration

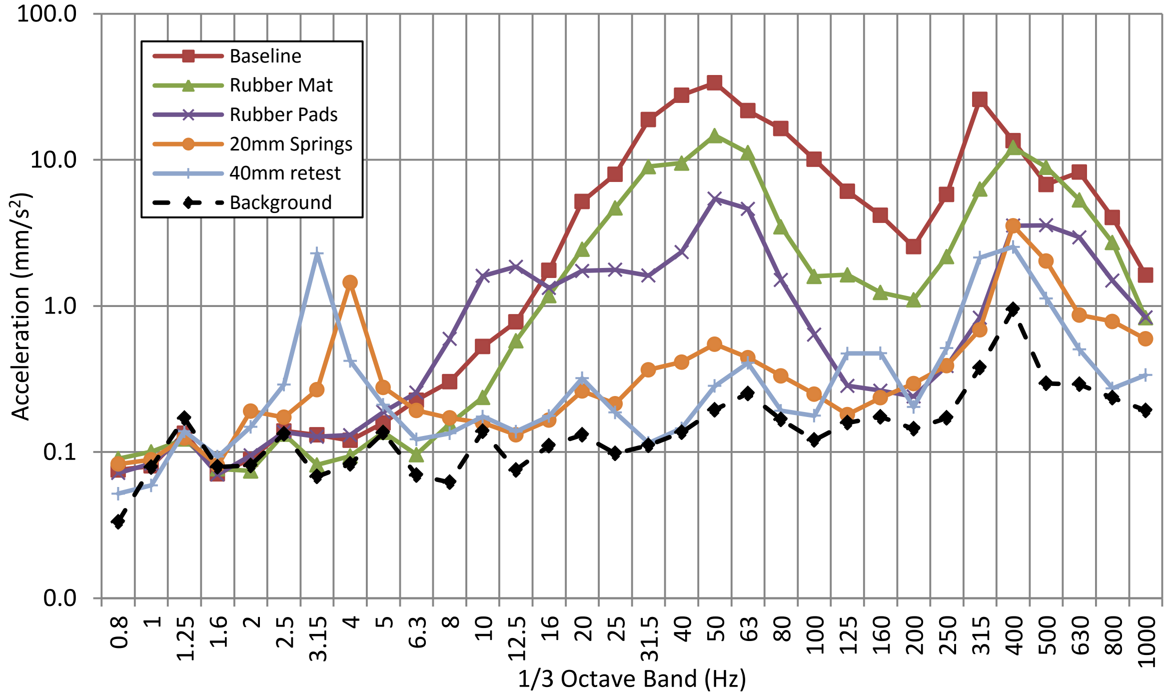

Figure 4: Frequency spectrum of averaged maximum acceleration- logarithmic scale

3.3 Response in time domain

When each test was viewed in time domain, it was noted that there were two strong peaks. The first was at the impact of the barrel on the water and the second was when the water rushed back to fill the space created by the barrel during impact. This second peak was consistently larger than the initial impact.

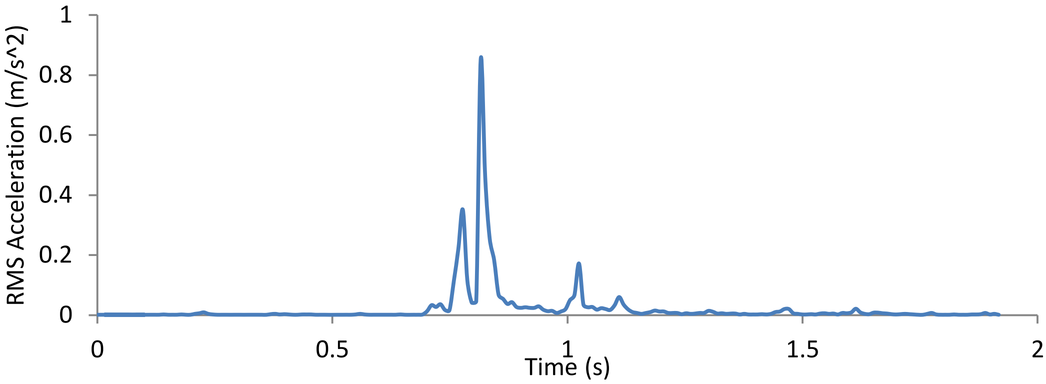

Figure 5: Typical impact under baseline condition

For the spring isolation systems, it was common for the largest peak to be delayed from the initial impact, when compared with the baseline, rubber mat and multi-layered rubber pads. This was due to the larger amplitude of the waves.

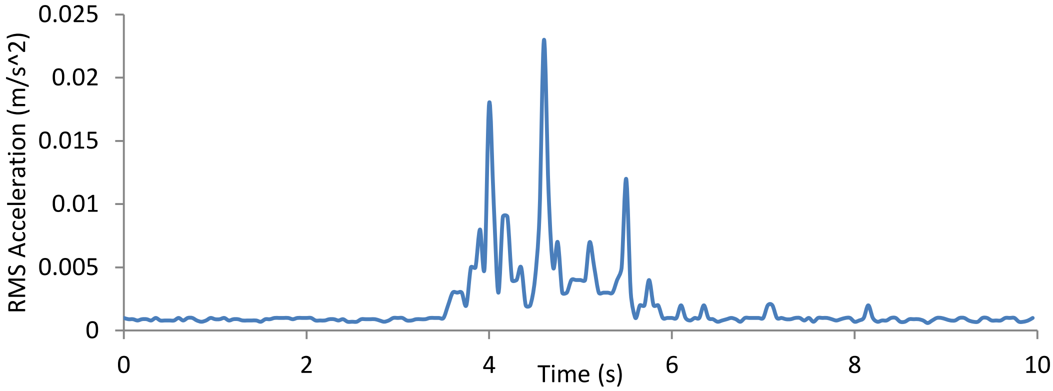

Figure 6: Typical impact with 20mm spring mounts

The low damping of the spring mounts is evident in the oscillation of the system after impact. It is clear that though the initial force from the impact has been substantially reduced when compared with the baseline, the lack of damping results in only small energy losses for each period of oscillation. It was common for sloshing waves to be visible for extended duration after impact. For a residential concrete pool the rigid mass is typically greater than 40,000kg and with the impact force remaining constant, the amplitude of the shell when on springs is not normally visible to the eye.

3.4 Applications for above ground pools

The analysis in sections 3.2, 3.3 in coordination with Figure 5 and Figure 6 indicate that the force of impact is the dominant characteristic of the excitation. The absence of peaks in the 0-1kHz range other than 50 Hz, the slab frequency 400 Hz and the isolator fundamental frequencies lead to the conclusion that driving harmonic inputs from the water itself following impact are negligible in comparison to the initial impact and subsequent water displacement providing a second impact. The general consistency in trends between calculated and measured single-value acceleration supports this.

Notably, the vibration levels for the spring mounts at all frequencies above 5Hz were not significantly above background levels, ignoring the 400Hz peak believed to be caused by splashing. These frequencies are unlikely to be in resonance with furnishings, structural members or surfaces within rooms thereby effectively removing vibration transmission as a noise source to adjacent tenancies.

In contrast, the damping of the multi-layered rubber pad decreases the magnitude of resonance peaks at the cost of providing poorer attenuation away from resonance. Combined with the high dynamic stiffness and corresponding fundamental frequency this resulted in acceleration levels of approximately an order of magnitude higher, or 20dB, above the 20mm spring results for low audio frequencies between 10 and 80Hz. Given that typical high-rise buildings will have the underlying slab and other structural modes in this frequency range, the results indicate that the effectiveness of pads in attenuating re-radiated low frequency noise from pool activities down to background levels for occupants in adjacent tenancies is limited.

4. Conclusion

A series of tests to simulate a person jumping into a pool were conducted to assess vibration characteristics and transmission performance of commonly used structural isolation systems. A 65kg water filled barrel was pushed from 500mm height into a 1.9m diameter concrete tank filled with 1200mm of water to simulate a person jumping into a pool and an accelerometer was placed on the supporting slab on grade. The isolation systems were compared against a baseline test of the tank unisolated on the bare slab. The systems responded to excitation in the manner of impact cushioning. All systems demonstrated varied improvement over the baseline test, with spring isolation providing the most effective transmission reduction, notably at low audio frequencies. It was also shown that rubber matting and discrete pads have fundamental frequencies that are likely to prevent significant reduction at low audible frequencies in high-rise structures.

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