Development of a standardised test for comparing pool isolation systems

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ABSTRACT

Pools in apartments and hotels are commonly isolated from the building structure to ensure noise and vibration from a pool is not transmitted to surrounding spaces. Currently no standardised test exists to compare the effectiveness of isolation systems. Previous testing has measured vibration levels in the building structure with a person using the pool. The inconsistent input forces applied to the pool creates limitations to how data from existing tests can be compared between pools. For this paper, vibration characteristics of pushing a barrel into a pool were compared with that of a person bombing into a pool, in order to test the validity of using a barrel to represent the impact of a person in future tests. The variation in vibration levels of each test was also examined, to determine whether a barrel drop produces a consistent vibration response. These tests were repeated in three pools, with a Svantek 958A analyser connected to a tri-axial accelerometer to record vibration levels from various locations. The vibration characteristics of a barrel impact were found to be similar to that of a person, albeit of a larger magnitude. The barrel was also found to produce vibration levels with less variation between tests.

1 INTRODUCTION

Vibration isolation is a common requirement in new apartment towers and hotels as pools and spas are increasingly being built near living spaces. The noise generated by people using a swimming pool can be transmitted through the building structure and re-radiated elsewhere, disturbing other occupants. Effective vibration isolation systems reduce the magnitude of the vibration transmitted to the surrounding structure from the pool, and hence the re-radiated noise and vibration in other parts of the building.

Swimming pool isolation systems range from relatively inexpensive pad systems to high deflection springs. Pad mounts are often used when a lower degree of isolation is required, such as when the pool is located over carparks or plant rooms, away from habitable spaces. For pools positioned near occupied areas, a higher degree of isolation is preferable and can be achieved with high deflection springs. These mounts result in a lower natural frequency of the isolation system, and hence more efficient isolation from impacts and high frequency excitation

Vibration generated from swimming pools is complex due to the varying ways that forces are applied to both the water and pool shell. In the case of a person entering the water without touching the bottom, vibration is transmitted to the pool structure via changes in water pressure alone. The initial impact on an incompressible fluid produces pressure waves that travel through the fluid. Subsequent fluid behaviour as water travels around the body and fills voids also results in complex forces applied to the pool shell. It is not currently well understood in the industry to what degree each of these effects is responsible for re-radiated noise.

The performance of a swimming pool's isolation system can currently be measured by taking vibration measurements of the supporting structure during pool use. This method provides valid data for each individual case, however the ability to compare data between pools and isolation systems is limited due to the unstandardised nature of a person jumping into a pool. This problem can be resolved with the development of a standardised force input that can be applied to any pool.

Previous work (Murray et al, 2017) has been conducted on comparing isolation systems using a barrel drop in a concrete tank. This provided data on the effectiveness of different isolation systems, however the ability to compare the barrel drop to a person jumping into the same tank was limited by the size of the tank.

Any proposed standardised test must be non-destructive, require no permanent changes to a pool and surrounds, and be able to be conducted efficiently.

In this paper, Embelton engaged in a series of tests to assess the validity of using a barrel drop as a substitute to a person jumping into a pool. This would assist in the development of a standardised test for the analysis of swimming pool isolation systems. Testing was conducted in three pools, each of different construction, and the vibration characteristics of a barrel and human impact compared.

2 TESTING METHODOLOGY

2.1 Barrel Impact

The ability to apply a repeatable impact force is an important factor of developing a standardised test for pool isolation efficiency. In order to apply a force without altering a pool and surrounds, or damage the pool, a plastic barrel was chosen as a human substitute. A plastic barrel is easily available, buoyant and will not damage a pool. The barrel was pushed from a height above water level representative of the height that a person typically jumps to when entering a pool. The choice to push the barrel was taken due to its simplicity, requiring no specialised equipment or permanent alterations to the surrounds of the pool. The platform the barrel is pushed from needs to be stable but temporary, and a 370mm high safety step was chosen for this. A 60 litre (nominal) barrel, 630mm high and 420mm in diameter filled with water to a total weight of 65kg was used in all tests.

2.2 Human Impact

The same 75kg person jumping into each pool was used for the human tests. A typical "bomb" entry was conducted, with the person assuming a tucked position before water entry. Impact with the pool base was avoided. A number of activities were conducted in a pool to confirm that a bomb entry produced the highest levels of vibration. Maximum acceleration levels recorded in the pool shell at the closest point to impact are shown below in Table 1.

Table 1: Acceleration levels of various pool activities

Activity	Maximum Acceleration (mm/s^2)
Bombing	35.8
Kicking off walls	26.9
Splashing	10.3
Stamping	10.1

2.3 Test Pools

Three pools were chosen as the test sites for this paper.
Pool 1 dimensions and features:

- Approximately 66 square metres
- L shaped, 10,000mm long, 3,750mm wide
- Depth varying from 200mm to 1,500mm
- Concrete pool shell
- 250mm base thickness
- 300mm wall thickness
- Rigidly supported on underlying structure
- Water weight of approximately 61 tonnes
- Total weight of approximately 158 tonnes

Pool 2 dimensions and features:

- Approximately 31 square metres
- Rectangular, with rounded short sides
- Constant depth of 1,100mm
- Above ground aluminium pool shell
- Water weight of approximately 34 tonnes

Pool 3 dimensions and features:

- Approximately 24 square metres
- Rectangular
- Depth varying from 1,200mm to 1,800mm
- In ground pool
- Water weight of approximately 38 tonnes

2.4 Test Equipment and Procedure

The barrel was pushed from an elevated platform, providing both vertical and horizontal motion similar to a person jumping from a pool edge. Testing was conducted in the deepest section of each pool to avoid both the barrel and person impacting the bottom. The person jumped from the pool edge or a low elevated platform as required by the pool geometry, into the same section of the pool as the barrel. A minimum of six tests of both the barrel and person entering the water were conducted in each pool.

Vibration levels were measured in 1/3rd octave bands between 0.8 Hz and 3 kHz using a tri-axial SV207A accelerometer placed at various locations as close to the area of impact as practical. Background vibration levels were also recorded at the same position.

For pool 1, the layout of the pool required a platform to be placed in shallow water for both the barrel and human tests. The barrel was pushed from a height of 430mm above water level, and the person jumped from a lower platform in the same spot at a height of 110mm above water level. The accelerometer was placed on the slab under the point of impact.

For pool 2, the barrel was pushed from a height of 610mm above water level, and the person jumped from the same spot but at a height of 240mm above water level. The accelerometer was placed on an upright steel post supporting the pool shell.

For pool 3, the barrel was pushed from a height of 530mm above water level, and the person jumped from the same spot but at a height of 160mm above water level. The accelerometer was placed on the pool edge near the point of impact.

The plan view of pool 1 is shown below in Figure 1, along with a typical test setup in Figure 2.

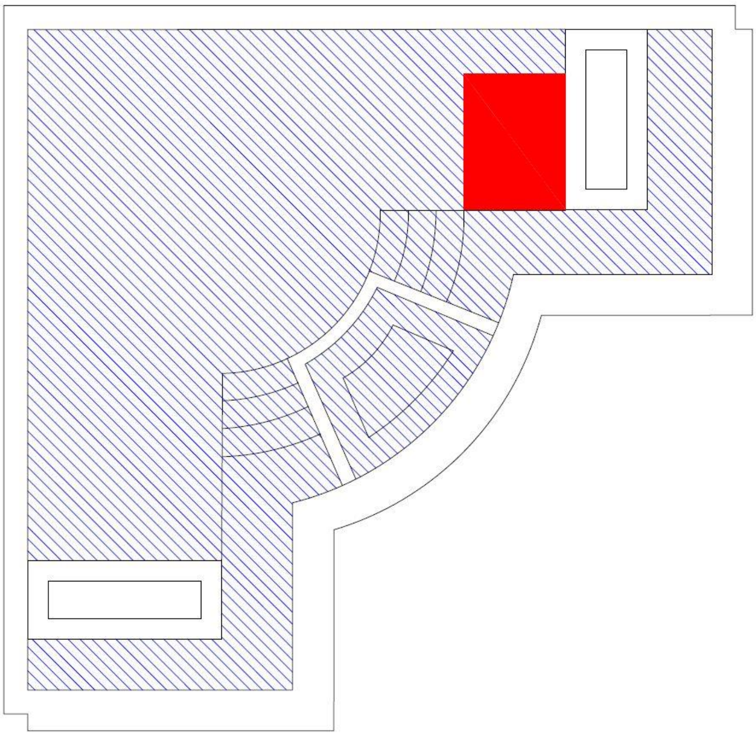

Figure 1: Diagram of pool 1 with test area in red

Figure 2: Typical barrel test setup

3 RESULTS AND ANALYSIS

3.1 Frequency Spectrum – Pool 1

The frequency spectrum of the magnitude of vibration levels in 1/3rd octaves for the horizontal and vertical axes for tests conducted in pool 1 are shown in Figures 3 and 4. The vibration levels have been separated into horizontal and vertical directions to provide clarity to the areas where the barrel and human tests differ.

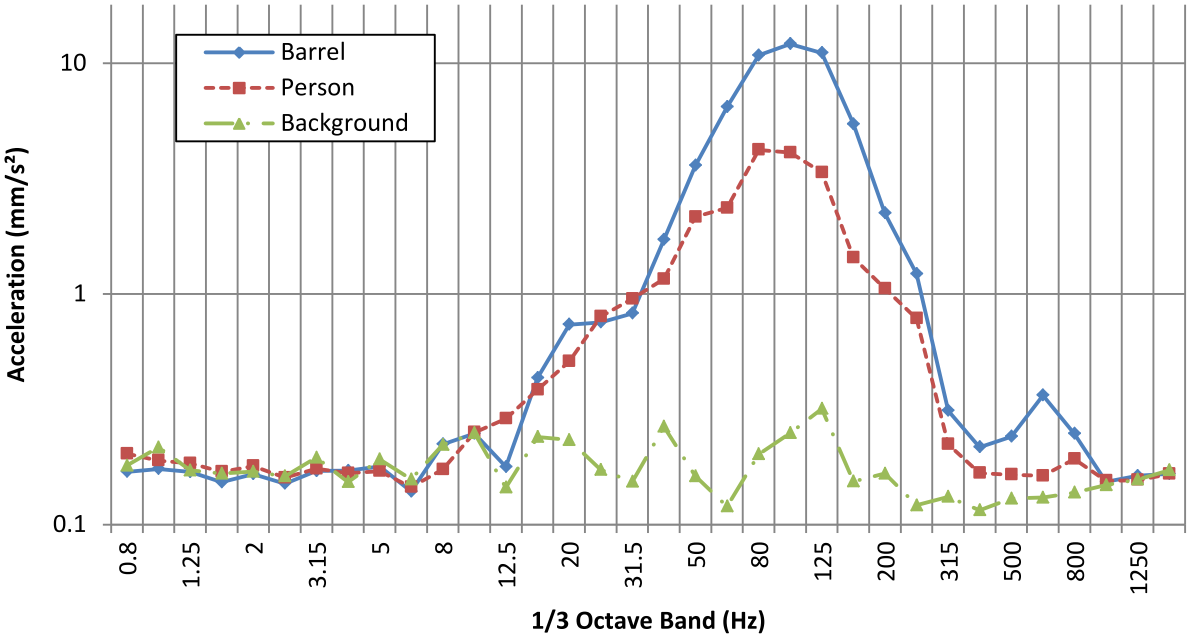

Figure 3: Frequency spectrum of horizontal averaged maximum acceleration for pool 1

The horizontal vibration levels show a broad peak at 80 Hz – 125 Hz for both the barrel and human test, with a very similar characteristic of vibration between the barrel and human impacts. The magnitude of vibration for the barrel is higher than that of the person at almost all frequencies.

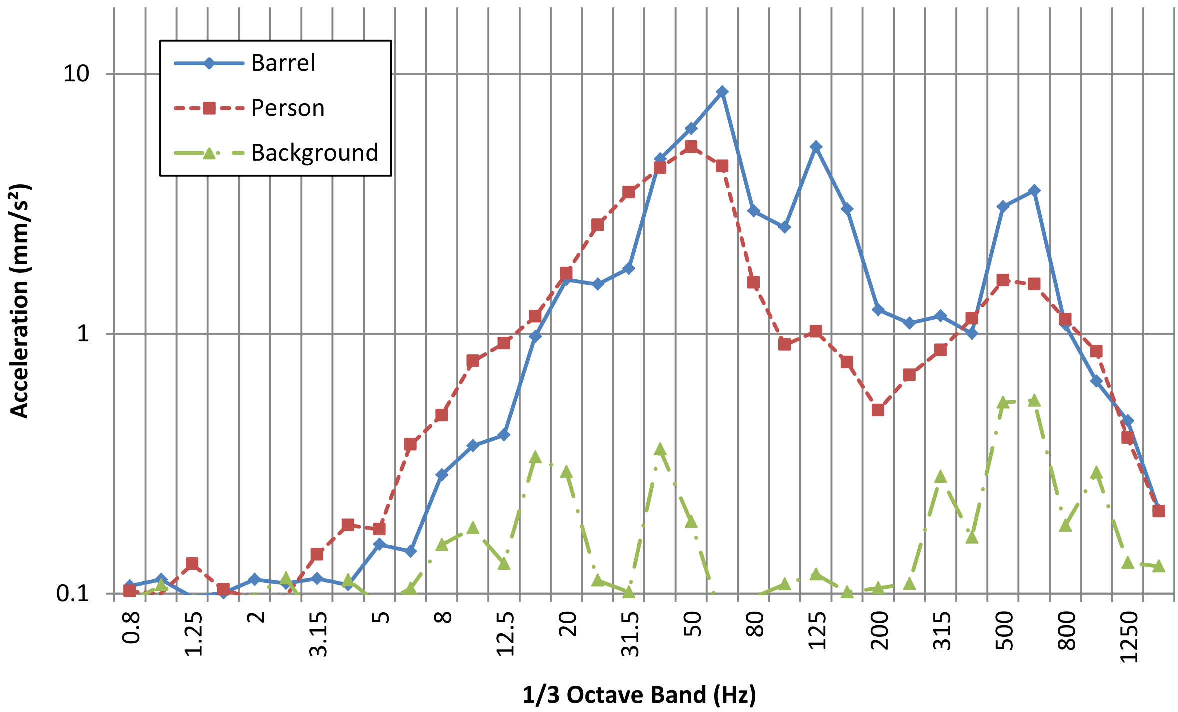

Figure 4: Frequency spectrum of horizontal averaged maximum acceleration for pool 1

The vertical vibration levels have a peak vibration frequency of 50 Hz for the person compared to 63 Hz for the barrel. There is also a significant peak at 500 Hz to 630 Hz for the person, barrel and background suggesting excitation of a structural mode. The human tests show a larger magnitude of vibration than the barrel for low frequencies, between 3.15 Hz and 31.5 Hz. This was unexpected when compared to the horizontal vibration results, but the general characteristic of vibration in this region was similar between the barrel and human tests. The most significant difference between the vibration characteristics of the two tests is the presence of an additional peak frequency of vibration at 125 Hz for the barrel test. It is possible that the smaller additional peak at 125 Hz in the barrel tests is a harmonic of a fundamental mode of vibration at 63 Hz.

3.2 Frequency Spectrum – Pool 2

The frequency spectrum of the vibration levels in 1/3rd octaves for tests conducted in pool 2 are shown below in Figure 5. Due to the construction of pool 2 and the location of the accelerometer, the vibration levels normal to the pool wall are considered.

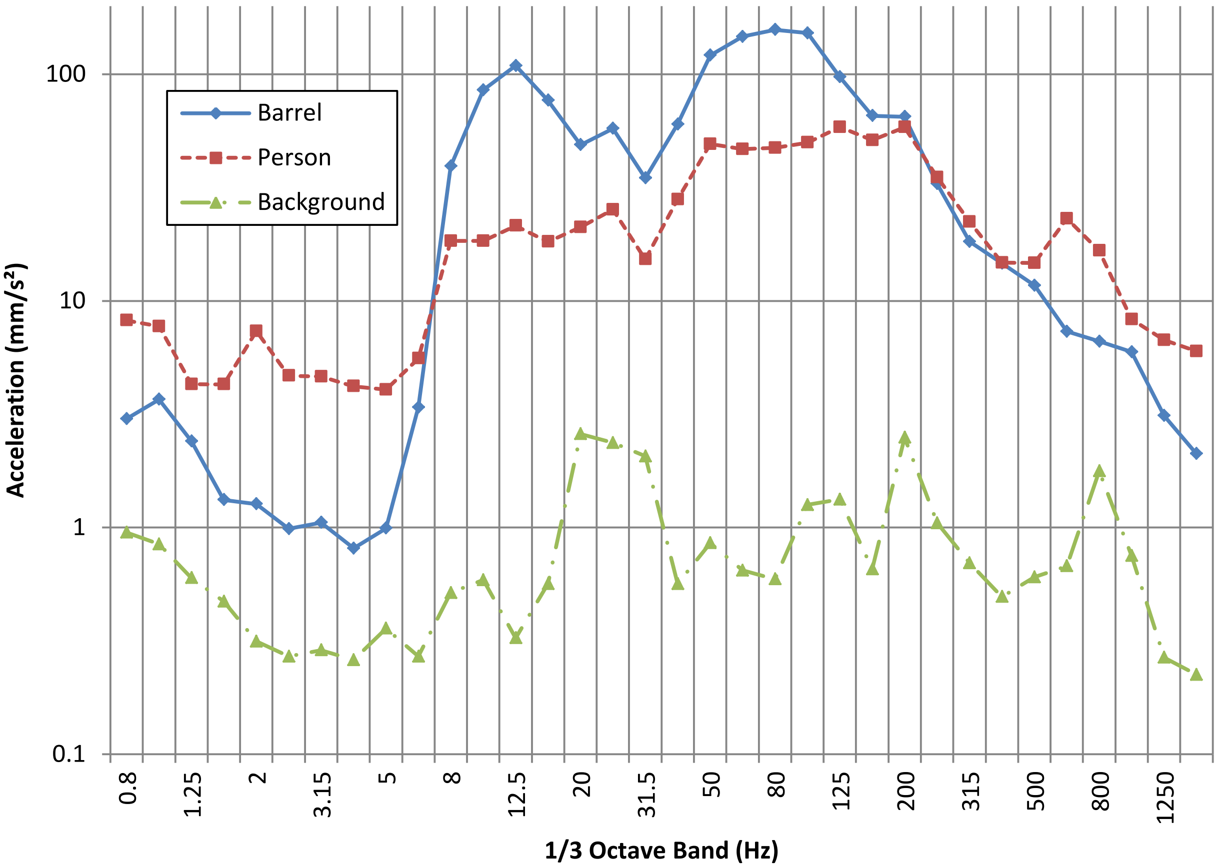

Figure 5: Frequency spectrum of averaged maximum acceleration normal to the pool wall for pool 2

The barrel impact shows two distinct peak frequencies of vibration, centred at 12.5 Hz and 80 Hz. The human impact is generally similar to the barrel impact, however the vibration frequency peaks are broader and less distinct. There is a broad peak of vibration between 8 Hz and 25Hz, and another broad peak at 50 Hz to 200 Hz. Although these peaks are less well defined, they are similar to the results seen in the barrel tests.

The higher levels of vibration at frequencies less than 8 Hz during the human tests is due to the variation in time between tests for the barrel and human impact. The time between each barrel test was significantly longer than for the human tests, resulting in the water in the pool having more time to settle to a steady state. With the main area of interest being the vibration caused by the initial impact on water and in the moments after, this does not have any significant bearing on the results. However, the time between tests should be sufficient to allow the movement of water to settle between tests in the proposed regime.

3.3 Frequency Spectrum – Pool 3

The frequency spectrum of the vibration levels in 1/3rd octaves for tests conducted in pool 3 are shown below in Figure 6.

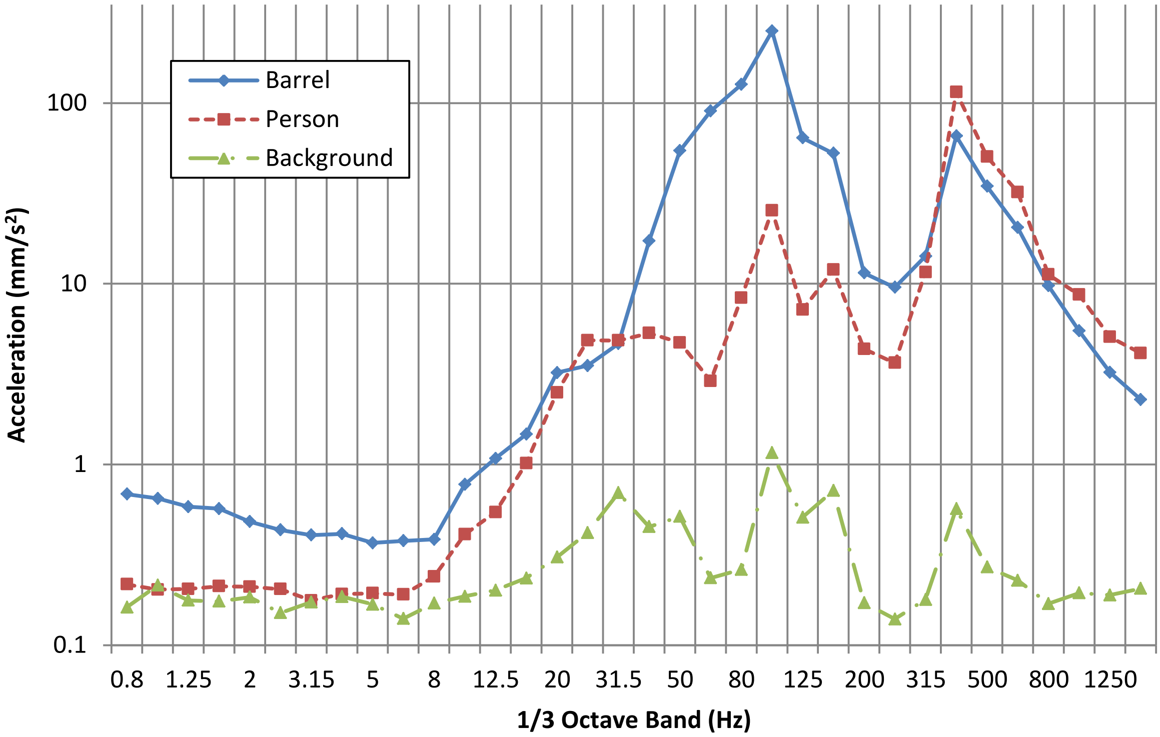

Figure 6: Frequency spectrum of averaged maximum acceleration for pool 3

The barrel impact shows two distinct peak frequencies of vibration, centred at 100 Hz and 400 Hz. The human impact shows two distinct peak frequencies of vibration centred at 100 Hz and 400 Hz as well; however there is a broad third peak between 25 Hz and 50 Hz that is not present in the barrel tests. This peak is not as clearly defined as the peaks at other frequencies, and it can be considered that the dip in vibration levels at 63 Hz in the human tests is the main difference between the two tests. The lack of a dip in vibration levels at 63 Hz would not make the barrel unsuitable for measuring the isolation performance of a pool.

The human tests show a very similar vibration characteristic to that of the background levels, only at a higher magnitude. This effect is also seen in the barrel tests, with the two distinct peaks occurring at the same frequencies as in the background vibration. This suggests that the impacts are exciting modes of the pool rather than imparting a forced frequency.

The barrel tests in pool 3 were noticed to be hitting the water square on the side of the barrel in all tests. This contrasted with the testing in pools 1 and 2, where the barrel was observed to be consistently hitting the water at an angle.

3.4 Vibration Levels in the Time Domain

Vibration levels for both the person and the barrel were taken in the time domain. Typical impacts for the human and barrel tests are shown in Figures 7 and 8.

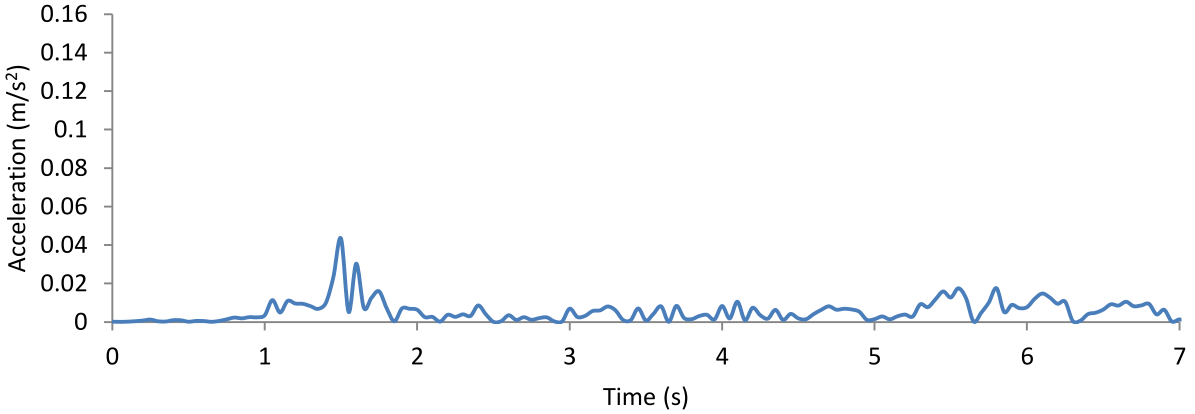

Figure 7: Acceleration for a typical human impact in pool 2

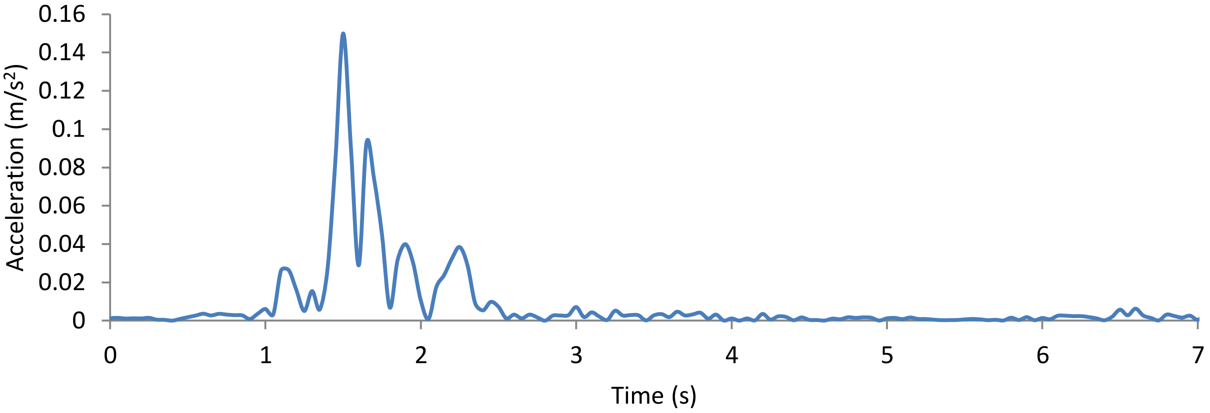

Figure 8: Acceleration for a typical barrel impact in pool 2

When each test is viewed in the time domain, it can be seen that there are two strong peaks for both the barrel and human impacts. This was also noted in the testing performed by Murray et al (2017). Both tests show a small initial increase in vibration, followed by two larger peaks. Aside from the magnitude, the biggest difference between the two is in the vibration levels after impact. The barrel test shows less variation in vibration levels after impact, with a smaller magnitude of vibration, than the human test, and this can likely be attributed to the motion of the person in the pool post impact. The magnitude of the vibration levels caused by the initial impact are much larger than those observed in the seconds after the initial peak, so these differences are not material in whether a barrel is a valid substitute for a person in the development of a standardised test method for measuring pool isolation.

3.5 Variability of Input Forces

The repeatability of the input force applied to the pool is an important factor in developing a standardised test. The coefficient of variations for total maximum vibration levels for the barrel and human tests for each pool are shown below in Table 2:

Table 2: Coefficient of variation of maximum vibration levels

Pool	Barrel	Person
Pool 1	19.7%	26.7%
Pool 2	21.3%	67.5%
Pool 3	22.1%	72.5%

The human tests show that the variation in input forces is higher than that of a barrel for all pools. This supports the need for a standardised input force for any future test procedure where it is desirable to compare different pools isolation systems. The human tests were all conducted with the aim of keeping the variation between impacts as small as possible, and this aim was only achieved in pool 1, with no discernible change to test methods that would cause the variance in pools 2 and 3 to be significantly higher.

3.6 Development of a Standardised Test

The results above show that the vibration response from a barrel pushed into a pool from a height displays peaks at similar frequencies to that of a person jumping in, however with a larger magnitude, and the variance of vibration levels is reduced. The larger magnitude of vibration levels in the barrel tests is desirable in order to have a test that is conservative in nature. In many cases the peaks corresponded to peaks present in the background vibration levels, suggesting both impacts are exciting modes of the pool structure rather than imparting forced frequencies. In developing a standard test method for measuring the isolation efficiency of a swimming pool, it is suggested that a barrel drop be used as the method of imparting a force to the pool.

During testing of pool 3, it was noted that the barrel was consistently impacting the water flat on its side, in contrast to the testing in pools 1 and 2, where the barrel entered on an angle. The angle that the barrel enters the water at is partially dependent on the height above water from which it is pushed. As the height above water level increases, the barrel has more time to rotate, altering the profile of the barrel as it enters the water. While the results from pool 3 did not appear to be affected by this entry angle, in ensuring the input force is kept consistent, the standardised test should have a set height above water level from which the barrel is pushed. Further control over the barrel push could also be achieved by introducing a small lip onto the elevated platform, to ensure that the barrel is tipped off the edge consistently.

The average height that a person can jump to is be taken to be 400mm (Briggs, M., 2013), and a typical pool freeboard is 100mm. It is therefore suggested that the height of the platform above water level be 500mm.

3.7 Proposed Standardised Test

The results from testing indicate that the isolation efficiency of a pool can be compared with other pools by pushing a 60 litre (nominal) plastic barrel filled with water to a total weight of 65kg from a platform 500mm above the water's surface into the deepest sections of the pool. The elevated platform should have a 30mm lip on it to ensure the barrel rotates consistently. Measurements taken in 1/3rd octaves between 0.8 Hz and 3 kHz with a minimum measurement time of 5 seconds post impact with a tri-axial accelerometer placed on the surrounding structure near the point of impact. Background measurements should be taken before any testing occurs. Testing should be conducted at three barrel entry locations in the pool, with a minimum of five barrel drops performed at each location. The time interval between each test should be a minimum of 60 seconds, in order to allow the water in the pool to settle.

3.8 Future Work

Future work is planned using the proposed test in section 3.7 in order to evaluate the practicality of conducting the test, the quality of data obtained, and other factors that may need to be considered.

The role the flexibility of the supporting structure and its modes contribute to the vibration levels measured should be examined. This may influence the best location to place the accelerometer in order to provide a meaningful reading in the proposed test. The analysis of data is also something that needs to be further refined. In this paper, the maximum acceleration levels in 1/3rd octave levels have been used to look at the general vibration characteristics of the impacts. Measured results can be compared to required levels in AS2670.2 in setting acceptable levels of vibration. Noise levels in adjacent spaces should also be measured to further assess the isolation systems performance.

4 CONCLUSION

A series of tests were conducted to validate that a barrel pushed into a pool from height could accurately represent a person jumping into the same pool in regards to the vibration response. A water-filled barrel weighing 65 kg was pushed from a height into three swimming pools of different construction and the vibration of the pool shell or supporting structure measured with an accelerometer. Vibration was also measured with a person jumping into the same area of the pool. It was found that a barrel produced a vibration response with the same general characteristics, however with a larger magnitude than that of a person. Some inconsistencies in the vibration response were observed, however these were not considered to have an impact on measuring the isolation performance of a pool. The variability of the vibration measured from the barrel impact was also less than that of the human impact for two of the three pools. A standardised test is proposed to measure the isolation performance of pools, and enable the results to be compared to those measured in other pools.

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Murray, T., Cosstick, L., Hong, E. 2017, *Comparison of Pool Isolation Systems*, ICSV24 London