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ENGINEERING QUIETNESS

Pool Vibration Isolation: The Influence of Supporting Structure

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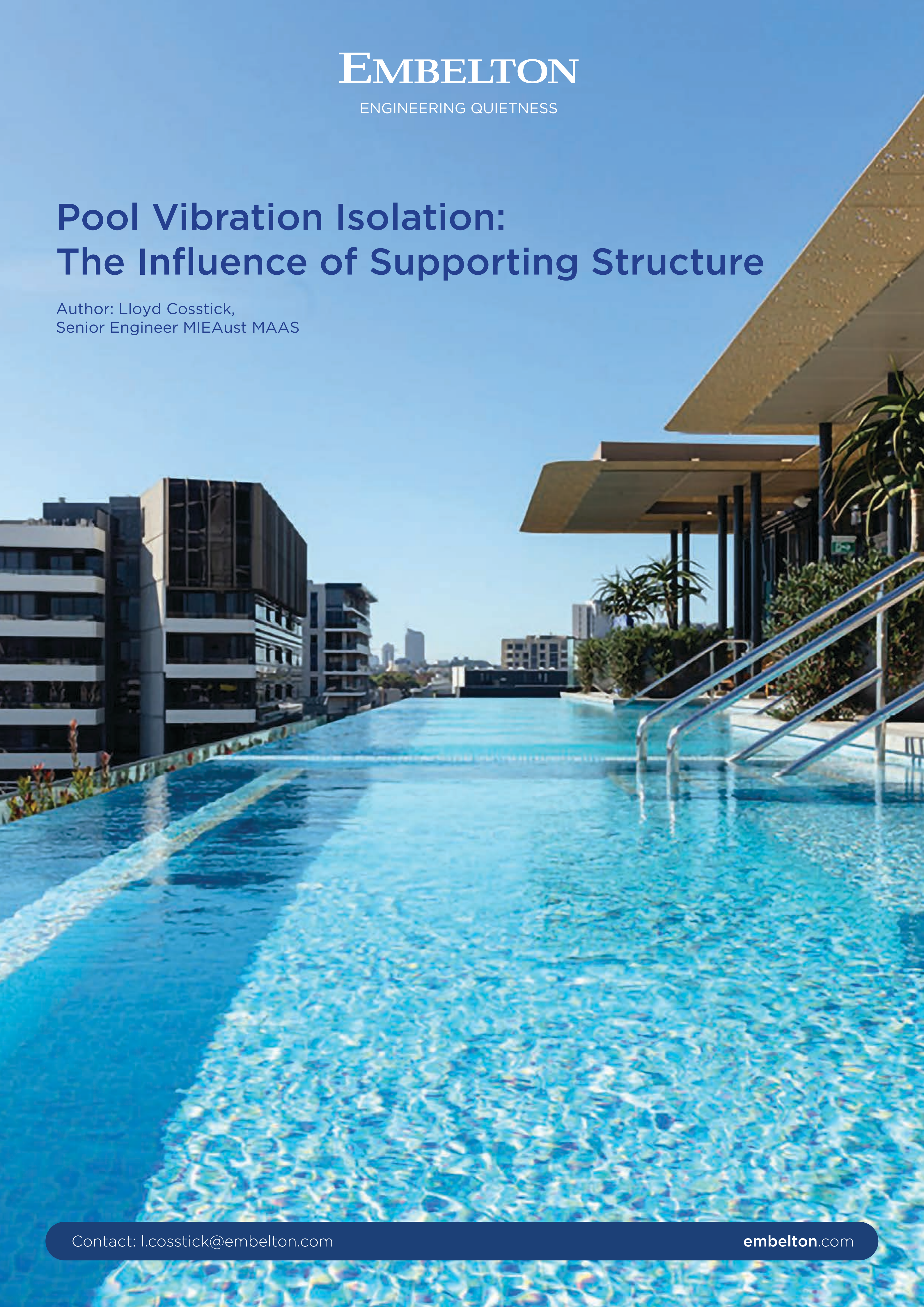

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Recently, the market for swimming pool noise and vibration isolation systems in Australia has become more competitive as product suppliers produced new documentation, promoting their preferred systems. Generally, the case is made for stiffer, lower profile elastomer to be used in many situations where high deflection spring isolators would previously have been specified. However, this is without proper consideration of structural dynamics and the vibration source. The purpose of this document is to clarify the technical approach utilised by Embelton in analysing swimming pool isolation applications and, in doing so, share a theoretical basis for system design with respect to both elastomeric and spring bearing systems.

Swimming pools cause noise and vibration?

It is little-known outside of the acoustics industry that swimming pools have high potential to cause structure-borne noise and vibration problems to other rooms in the building.

The loudest disturbance to adjacent spaces from a swimming pool usually occurs when a person enters the pool after jumping or diving from the deck. The major impact occurs from the person breaking the surface tension as they enter the water. A second, smaller impact occurs immediately after as water collapses into the void created behind the person's body. In an affected space, when combined this would be heard as a low, extended thump. A third impact may arise if the jumper contacts the bottom of the pool.

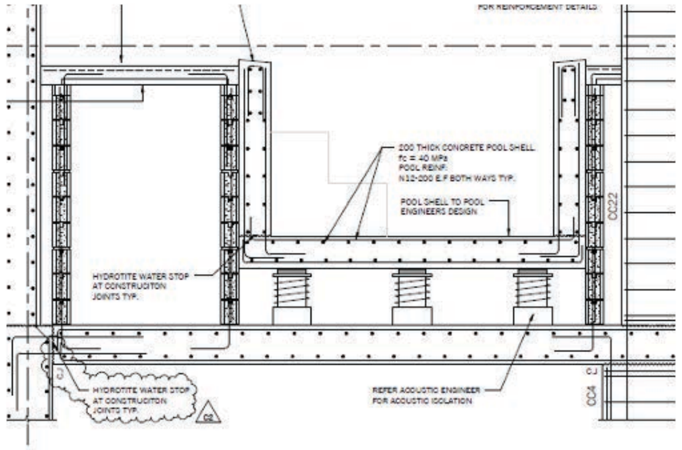

Figure 1. A typical above ground pool supported by suspended slab via a vibration isolation system.

So it's an impact problem? What does that mean?

While the breaking of the water surface tension generates a shock with low frequency signature into the pool, more simply put, there is a force that requires reaction as the swimmer's downward momentum is resisted. In an above ground pool setting, this reaction will result in small oscillations of the supporting structure at its modal natural frequencies. Components of this vibrational energy transfers through the supporting structure to other parts of the building which, if strong enough, will generate noise. If the pool is located nearby to occupied spaces, often a vibration isolation system is required to meet noise criteria. The isolation system aims to keep a large proportion of the impact energy and hence movement to within the pool shell.

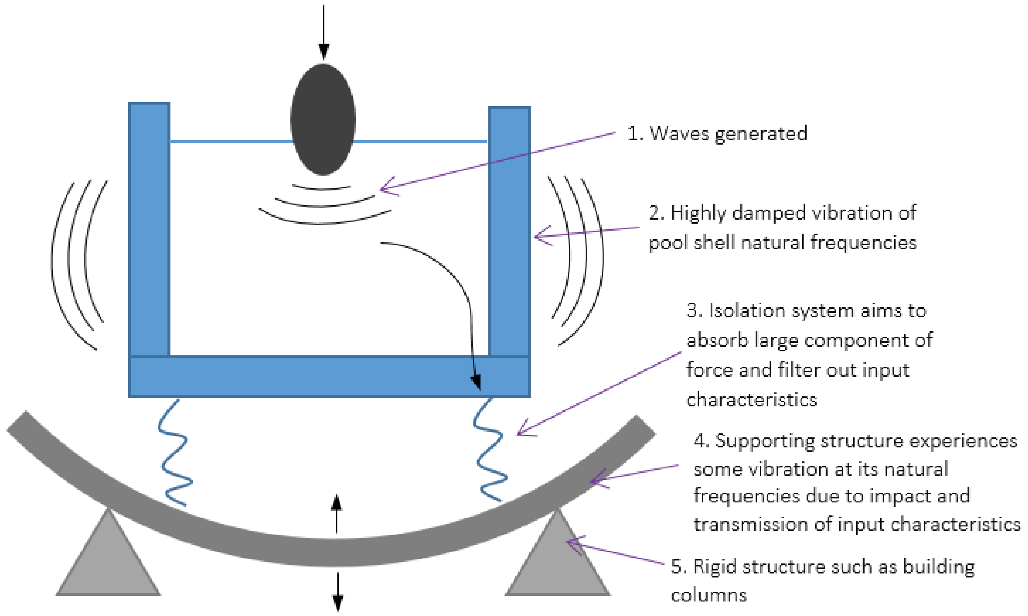

Figure 2. Noise and vibration transfer from isolated swimming pool.

As a market leader, Embelton has been supplying systems for pool vibration isolation for more than 30 years. Our product offerings currently fall into two categories.

Elastomeric bearings

Elastomeric compounds are commonly used as an isolation material due to their highly resilient nature and long service life. Embelton's most common supply employs multiple layers of the nitrile-based Supershearflex pad which can be easily cut to size to accommodate different localised loads from pool stairs, benches or shallow areas. Most selections are 3 or more layers of pad, as layering will lower the stiffness. However, there is a balancing act between increasing the thickness and deflection under load of an elastomeric bearing and increasing the footprint for stability. For very high point loads where small footprints are required, Embelton will supply bridge bearing grade rubber.

In ambient conditions, out of direct sunlight, and free of exposure to chemicals, high quality expertly designed elastomer can exceed 50 years in service. However, it is extremely difficult to find published cases in which chlorine exposure has been tested for such a length of time. As such, an expectation of bearing mechanical properties enduring a 50+ year lifespan in a pool environment should be treated with caution.

Figure 3. Multi-layer pad isolators

Figure 4. Pre-compressed spring mounts

Spring mounts

Helical compression springs offer a significantly larger deflection range with linear stiffness than elastomer, resulting in the capability of a much lower system stiffness. Decreasing bearing stiffness will slow the change of momentum occurring during an impact which is generally desirable, provided amplitudes do not become excessive and there is some damping to remove energy from the system. Pre-compressing high deflection springs removes the potential for large movements when the pool is under construction or emptied of water for maintenance.

Using steel components in a pool environment carries corrosion risks if the pool leaks or is located near the coast in environments with high humidity. Protective marine-grade coatings will extend spring steel life for many years in such environments. However, spring isolation systems should be designed with access for maintenance and inspection in case of pool leakages. Cavity drainage should be implemented to all isolation systems.

Modelling swimming pool isolation systems

Pools which require isolation are almost always above ground, so the supporting structure contains a degree of flexibility itself. Therefore, to represent the generic case we employ a two degree of freedom mechanical model (diagram in Figure 5). The supporting structure is treated as another lumped mass (M1) underneath the isolated pool mass (M2) with its own stiffness equivalent to the member's bending stiffness (K1) with modal damping (C1). The pool's support structure is usually a suspended slab or a combination of slab and concrete beams. The system in Figure 1 is represented in Figure 5.

As there are two masses with freedom of movement, there are two system natural frequencies. The first is given by the pool's mass and isolation system stiffness. For the second we use the bending stiffness and structural mass to model the fundamental bending mode of the supporting structure. Both stiffness elements K1 and K2 are required to be linear (or close to). Due to high axial stiffness the building columns/load bearing walls assume the role of the rigid structure in the vertical direction. X1 and X2 represent the movement of each mass with reference to the ground. Vibration is quantified in terms of velocity or acceleration which are derivatives of X1, X2 with respect to time.

This representation removes higher order structural modes from analysis. These modes vibrate with diminishing intensity compared to the fundamental mode so only have minor influence on the peak vibration levels but are important to be mindful of as they will contribute to noise characteristics.

The variables illustrated in Figure 5 can be estimated with reasonable accuracy by coordinating with the project structural engineer. The swimming pool lumped mass considers the concrete shell plus full depth water. While some water moves independently of the pool due to excitation, largely the water's mass moves as one with the pool structure due to the static pressure. Isolated pools will always be laterally restrained which restricts potential for rocking movements.

Figure 4. Pre-compressed spring mounts 4

The structure and pool mass/stiffness will vary between each project. The specified isolation system needs to achieve a reduction in vibration from pool to the structure that will satisfy acoustic requirements.

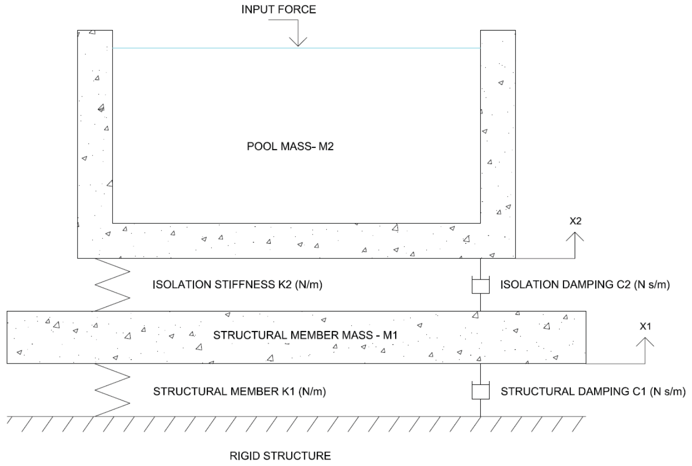

Figure 5. A two degree of freedom system to represent an above ground swimming pool.

Predicting performance

How do we know if a supporting structure is stiff enough to avoid noise and vibration problems? When will elastomeric pads be good enough? By running scenarios through the model, varying isolator and structural properties, we get a picture of how effective an isolation system is in reducing the vibration transfer to the structure.

In the data presented below, the relative peak velocity is calculated in the structure and the pool due to an impulse of the pool mass. If the structure does not experience a significantly lower level of vibration than the pool, it will not only itself vibrate (generating noise to adjacent spaces via the higher order modes) but also any element which connects to it such as ceiling grids, walls and/or fixed joinery can vibrate and generate audible noise too.

We expect that the isolation system will perform to a higher level if the combined stiffness of the isolators is many times lower than the stiffness of the supporting structure. This decreases the coupling between the two masses and the proportion of the impact absorbed by the isolation system will increase. **But to what degree?**

For 40mm static deflection springs and two common types of elastomeric bearings, we have given the model's results using two different structural masses, which represent a typical suspended concrete slab mass (Figure 6) and slab with regular concrete beams (Figure 7) supporting a 100 tonne 15x3.5m concrete shell pool (refer Table 1).

The stiffness of the isolation system (K2) is represented by the isolator natural frequency labelled on the graphs. Lower frequency means lower stiffness. 10Hz is towards the upper bracket for stiffness of elastomeric bearing supply appropriate for pool isolation. 6Hz is a low stiffness bearing- achieving 5Hz and below results in stability issues that present challenges to overcome. By comparison, 40mm static deflection springs exhibit a system frequency of 2.5Hz when loaded. We represent the comparative stiffness of the structure by the fundamental bending mode frequency. In doing so, we can model a relationship between the system performance and the relative stiffness of the isolation system and the structure.

Velocity, instead of acceleration, is used as the insertion loss unit due to it being more common in industry to convert vibrating panel velocity in dB to a noise level using an empirical equation such as the simplified Kurzweil equation. Noise, rather than uncomfortable structural vibration is the main cause of complaints.

Table 1. Inputs to the model for use in the analyses.

Input	Value	Comments
Force (F)	-	Unit force
Pool Mass (M2)	100 Tonnes	15 x 3.5m, 200mm thick walls/base
Structural Mass (M1)	50 Tonnes - Figure 6 90 Tonnes - Figure 7	18 x 5m, 300mm slab thickness 70% mass participation (Figure 6)
Spring Damping (C2)	0.5% of critical	Industry value
Elastomer Damping (C2)	8% of critical	Industry value
Concrete Damping (C1)	3% of critical	Murray et al, 1997, Floor Vibrations Due to Human Activity, AISC Design Guide No.11

For specific reduction to be considered acceptable to an adjacent space, the project acoustic engineer should be consulted. Indicatively, Embelton advises that 12dB insertion loss as a reference point which equates to approximately 75% less velocity experienced by the structure than the pool.

For critical scenarios such as penthouse apartments where inaudibility is required, higher values would likely be needed.

In Embelton's experience, suspended slabs which are stiff enough to support a pool will generally have a fundamental mode between 6-15Hz (shaded blue), when modelling the pool as a non-structural mass on top of the slab. We observe from Figures 6 and 7 that throughout this frequency range the spring isolation system provides above 15dB reduction in the structure's velocity while the two types of elastomeric mounts yield considerably lower attenuation.

The 6Hz bearing performance in the suspended slab zone may be considered acceptable for most applications if the structural fundamental mode is above 12Hz. The 10Hz bearing provides only minor attenuation on a 6Hz slab. Elastomeric mounts reach higher insertion loss levels when mounted to stiffer structures which would require stiff band beams or mounting nearby to columns or load bearing walls.

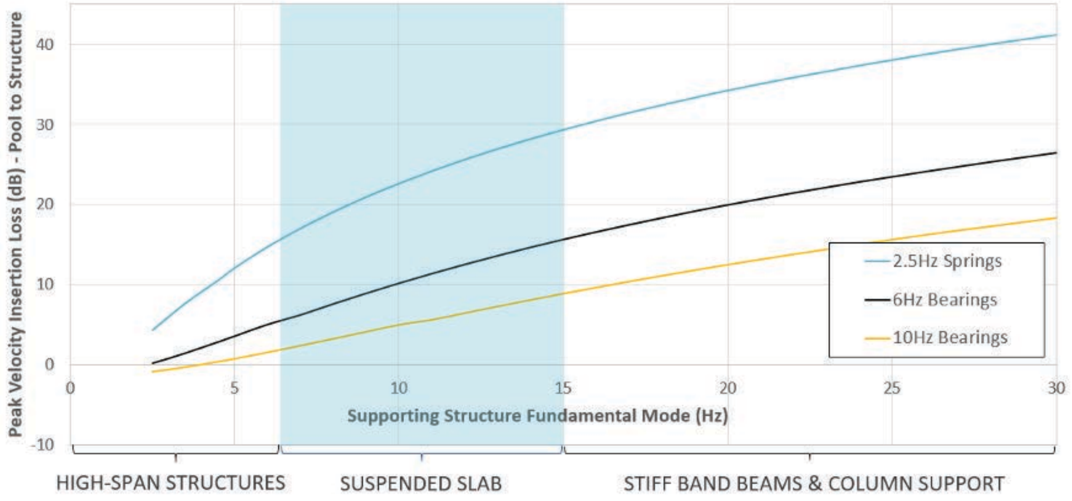

Figure 6. Scenario 1: Peak velocity insertion loss vs lower mass supporting structure fundamental mode from pool impulse. Inputs as per Table 1.

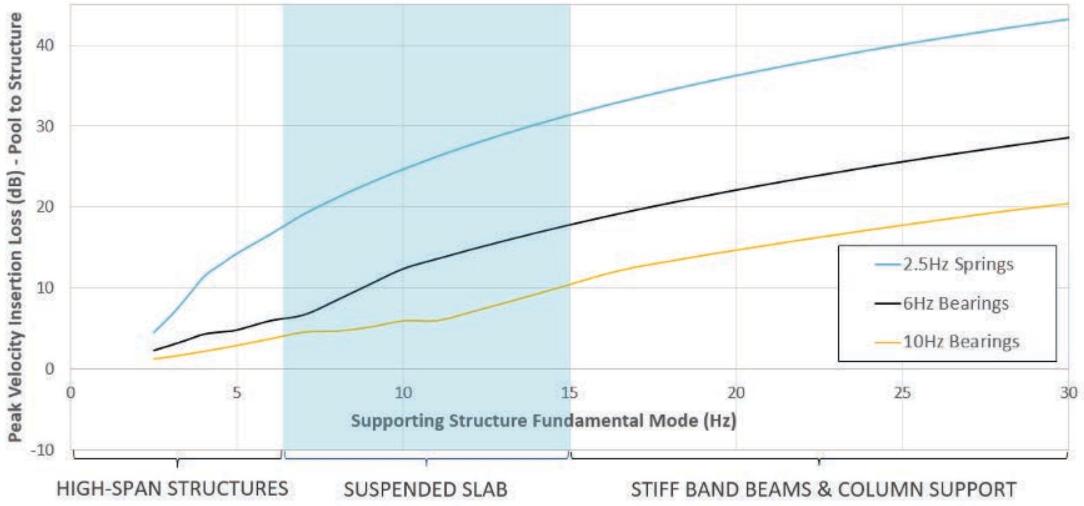

Figure 7. Scenario 2: Peak velocity insertion loss vs higher mass supporting structure fundamental mode from pool impulse. Inputs as per Table 1.

In Figure 7, increasing relative structural mass by 80% shifted curves slightly - but not significantly - towards higher performance. Larger variations occur at the resonant frequency of each bearing type in this scenario, likely due to coupling effects as both masses are now very similar. If we had reduced pool mass to ~55 tonnes instead the same curves would result.

The frequency characteristic of the input does not influence this analysis- however it is usually measured strongest between 20 and 80Hz, which is a range attenuated effectively by both elastomeric and spring bearings in most situations. Isolating the input frequency range will provide benefits compared to an un-isolated pool, but it is somewhat redundant if the structure experiences minimal reduction of the pool's impact energy at the fundamental mode frequency.

NOTE: Given variation of force input due to jumper weight and height above water, and assumptions involved in the model, the intended use of this data is not to be used to predict absolute noise and vibration levels.

In summary, what deductions can be made?

We can observe that due to much lower stiffness than the typical suspended slab structure, springs will provide a high level of decoupling for all but very high span applications without the need for further analysis. The suitability of elastomeric bearings should be assessed on a case-by-case basis. Confirming the stiffness of the supporting structure and evaluating the risk will take time, particularly if the structure is complicated, and the result may still suggest that an elastomeric bearing system will not meet criteria.

Most often elastomeric bearings are used conservatively in lower risk applications where sensitive areas are not directly beneath or adjacent, and Embelton is supportive of this approach. In some situations the design constraints may make it very difficult to accommodate springs, in which case analysis such as that set out in this document should form part of the consideration. Additionally, risk of elastomer not meeting requirements is lessened for small pools such as plunge pools due to expectations that the structure will have more relative mass and bombing activities would not be permitted.

Are there pools where elastomer may have been effective but springs were used? Undoubtedly; however the specifier may not have the opportunity to conduct an in-depth analysis.

Clearing the confusion

This modelling and analysis offers explanation for puzzling anecdotes given in the industry where a developer has used elastomeric bearings in the past and experienced no issues, but residents in another building where the same isolation system was used complain of noise from the pool and no fault with the installation is found. It is proposed that the difference in performance can be due to the differences in mass and stiffness of the supporting structure. Because of these project specific conditions, we would recommend that all stakeholders be cautious when anecdotal evidence from previous projects or an unrelated site test is used to make generalised conclusions on why an elastomeric solution will meet the criteria.

Other considerations

Where a complicated support structure exists with not just one or two dominant fundamental modes, Embelton would assist the consultant in studying the most flexible regions of the structure, the pool mass they are required to support and their proximity to sensitive spaces.

The two degree-of-freedom model does not consider the added stiffness of any trapped air beneath the pool. However, provided there is no sealed air cavity under the pool and the cavity is greater than 50mm, the stiffness of air should not be influential due to very low amplitudes of a concrete pool structure from typical impact.

Embelton has undertaken testing on several installed pools to verify that the fundamental mode of the supporting structure is a peak in the frequency domain response following impact. Please contact us if you are interested in further information or results.

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