LIFT NOISE AND VIBRATION

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1 INTRODUCTION

A common acoustic issue is related to noise and vibration generated by lifts. Energy originates from the movement of the car and cables through rails and hardware connected to structure. Lift shafts provide an easy conduit to every level in a building. Energy can either cause undesirable noise through reradiation or vibration-related problems for sensitive equipment. High-end residential can have lifts exiting directly into private areas and rooms backing onto a lift shaft can suffer from reradiated noise whether a lift entrance exists or energy is structure-borne in nature.

Treatment measures are complicated by an extremely wide load range to cater for emergency conditions and a need to prevent excessive movement which can negatively affect ride quality. This limits what can be done to isolate, which is a problem when isolation performance needs to be quantified.

This paper presents baseline readings from an existing installation, a method of calculating driving frequency and measurements on technical resolution for isolating the rails and associated lift hardware. Measurements were used to demonstrate improvement in vibration levels. This work would be useful for any project with risk of lift noise or lift rails carrying vibration from external sources.

2 DEFINING THE SYSTEM

Most lift systems follow the same design principles irrespective of supplier. The mass of the lift car is suspended from multiple cables driven by a motor (winding gear) at the top of the shaft. The cables continue up and over the winding gear and support a counterweight to balance the weight of the lift car. Figure 1 shows this typical arrangement.

The lift car and wheels run along rails, hard mounted to the lift shaft walls. Efforts are significant to make sure that the guiding wheels/shoes run smoothly up and down constrained rails as a major contributor to ride quality. Deflection is a risk factor to this aim.

Vibrational energy is created through frictional contact between these running surfaces and through rotational/reciprocal motion of the winding gear motor which generates unbalanced forces. No system is perfectly balanced and due to the significant axial stiffness of the traction ropes, energy is easily carried to the car and counterweight, then via the rails into the shaft walls.

This energy can then cause undesirable reradiated noise, or unacceptable vibration for sensitive spaces and equipment. For the purposes of this paper, we have focussed on the generation of vibration through the guides when the car move up and down.

A paper review and site testing to quantify benefits of isolation was carried out.

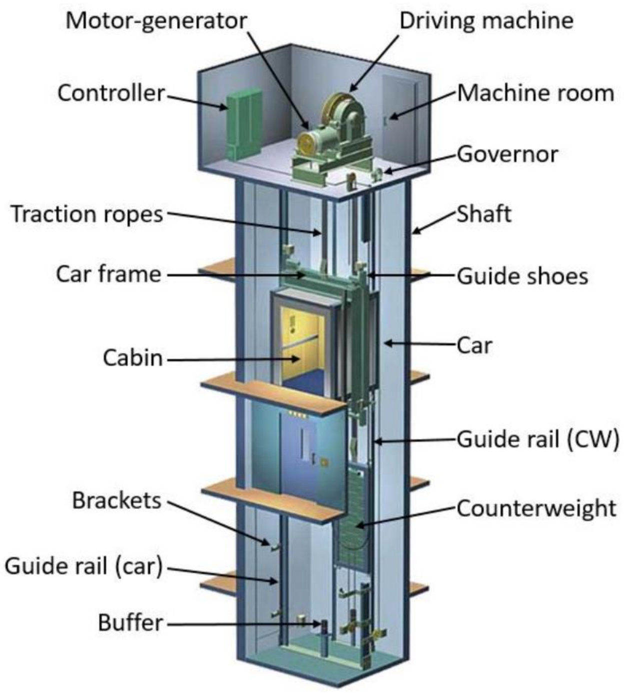

Figure 1 – Typical lift arrangement

The derivation of the principal natural frequency of the system is that driven by the mass of the lift car and the stiffness of the traction ropes [1]. The system is expressed diagrammatically in Figure 2.

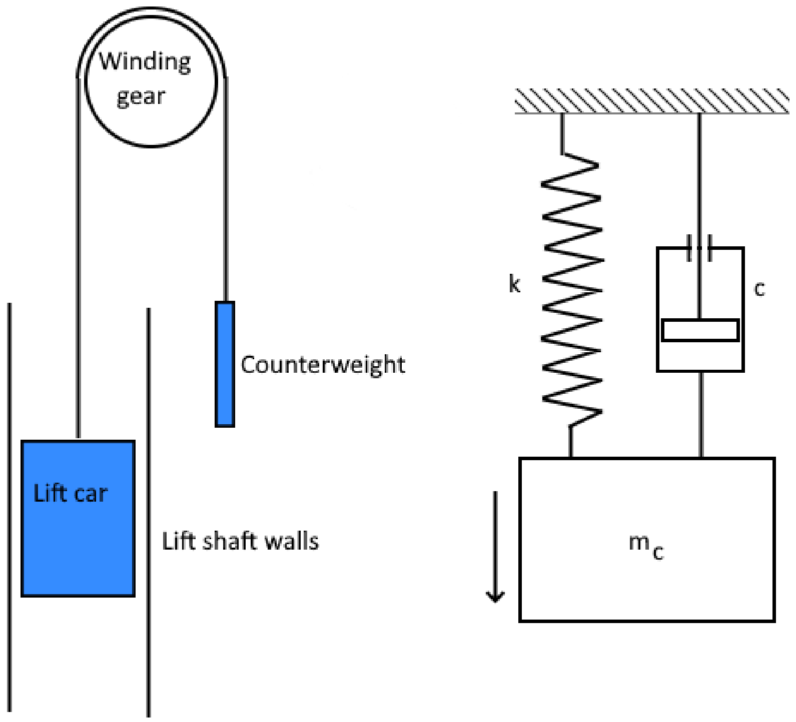

Figure 2 – Diagrammatic representation of lift car system

Where:

K = stiffness of the tension ropes = $N\frac{EA}{L}$

C = damping applied by inertial action of the counterweight

Mc = mass of lift car = $P + aQ + \frac{1}{3}nmL$

The stiffness of N quantity tension ropes is a function of the E (modulus of elasticity), A (cross-sectional area) and length (L). The length is a crucial element as the length of the rope determines response and hence drives the system natural frequency.

The mass of the lift car varies and constituent elements are the mass of the empty car (P), the rated load of the system (Q) multiplied by the loading factor a (which is 1 when the car is filled to capacity) in addition to the mass contribution of the ropes, quantity multiplied by mass per meter (m).

Natural frequency of the system can then be derived by the standard form:

$$\omega = \sqrt{\frac{k}{m_c}}$$

Given this is affected by the number of people in the car and position of the car (effective rope length), natural frequency will vary within bounds specific to each building and installation.

This is the theoretical approach, but we know that there are variations difficult to account for:

1. Rail straightness. Most lift shafts are formed from block or poured concrete which cannot be infinitely stiff. Surface variation is counted for by shimming rail shoes but as force is imparted walls will deflect.
2. Over time imperfections in the rails and guides will grow and is dependant on the environment, usage and maintenance carried out.
3. The natural frequency of the rope system described is believed to significantly contribute to audible noise from lift systems, but the wheels can produce rumbling due to physical contact with the rails.

Vibration isolation can only occur at contact points with the rail so defining the frequencies that require isolation can be modelled theoretically and best possible resolution generated with support of the lift provider. A minimum stiffness for any isolation system is critical to limit movement of the car.

Data was collected at multiple points from a conventionally installed lift (without isolation) to try and quantify these uncertainties. The data was collected because of risk to a scientific facility where a VC-A criteria had to be met; lift running was identified as a potential risk factor.

Figure 3 presents data collected at the base of the lift rail in the vertical axis and represents the principle natural frequency of the lift system as described, circa 7Hz. Figure 4 provides data in horizontal axes at the pit floor and represents flexure of the rails in that direction from car movement, circa 30-80Hz. The VC-A curve is overlaid and exceedance can be seen. This was sufficient evidence to add requirement for isolation.

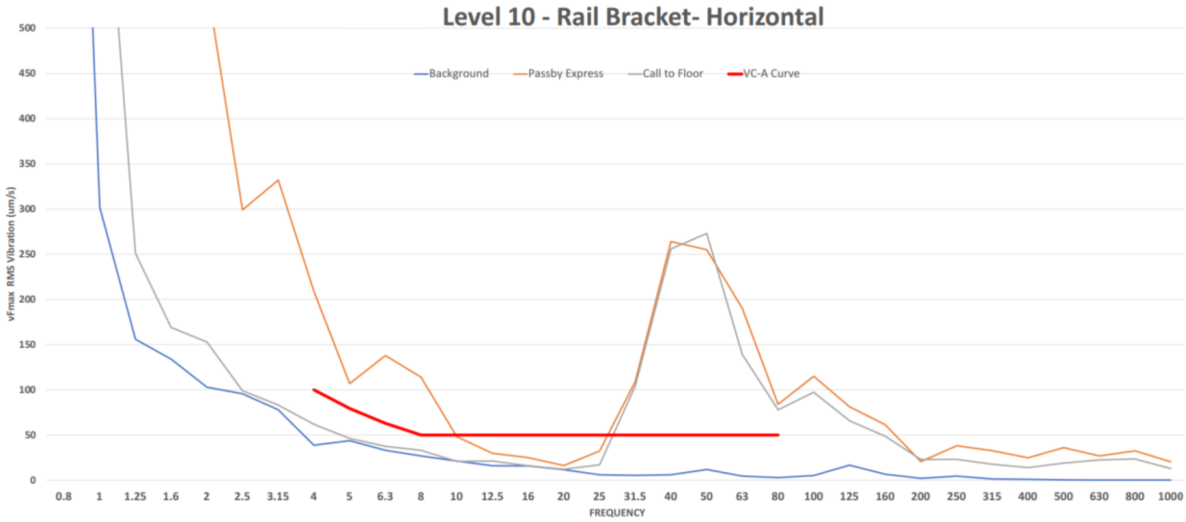

Figure 3 – Horizontal axis measurements directly on rail bracket

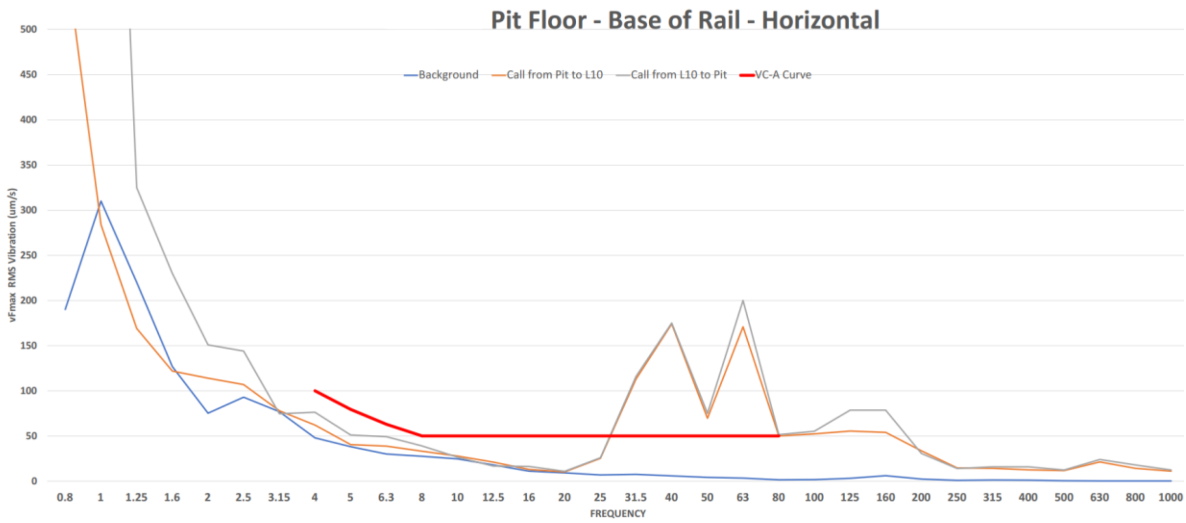

Figure 4 – Horizontal axis measurements at base of lift rail

3 DESIGN CONTRAINTS

Decoupling connection points between lift hardware and structure is typically be done at rail/wall brackets. This removes need to affect design of safety critical elements such as braking system and connection to cars and tension ropes.

Lift rails are fixed back to shaft walls via brackets, placed on regular centres. Normally rigid in nature, it is possible to introduce isolation between the bracket and wall if dialogue is started early with the lift supplier. This is because of two crucial points:

1. Lift rail connections are by default assumed to be rigid in nature which cannot be the case when isolation materials are introduced as they must establish a non-rigid spring rate to absorb energy. Permissible movement must be established to maximise spring rate and isolation performance.

2. Forces handled by any isolated brackets must be clearly defined. Loads must be fully unfactored which includes working and emergency loads. The latter can be significant but rare. Designing to handle emergency loads can result in an overly stiff system so care should be taken how these forces are handled.

Lack of access and option to service should also be considered. Materials should have consistent properties without risk of degradation equal or longer than that of the lift hardware itself as should be considered safety critical.

4 TYPICAL ISOLATION SYSTEM DESIGN

Isolation is typically introduced between the wall and the rail. Lift supplier designs are typically very stiff as in their interests to use a stiff materials (avoiding deflection) and to fix with an easy to apply anchor also designed to reduce resilience.

A typical design can be seen in Figure 5. Design flaws include the clear vibration pathway from the rail to the wall and the fact that the bolted fixings are not isolated. The isolation material is a plastic type with only negligible resilience.

Figure 5 – Typical lift supplier isolation system.

5 CASE STUDY – APPLICATION OF THEORY

For the case study associated with this paper, we knew that isolation of the principle cable frequency was critical in the vertical direction and calculation via Section 2 formulae showed this likely to be lowest 17Hz. It should be noted that this lift differed to that shown in Figure 1 as winding gear was mounted to the top of the rail inside the shaft but this was not judged likely to affect the calculation.

We also had to avoid horizontal transmission in the 40-80Hz range as likely transmission of rumbling from wheel/rail interaction when the car is moving and braking.

Constraints were as per that identified in Section 2. Maximum permissible movement under working loads of +/-2mm was provided by the supplier. Pads were selected to have minimum possible stiffness within deflection constraints to respect principles of laterally applied pads raised in previous works [2].Precompression of 1mm on an 8mm Neoprene Mason Waffle pad and HG isolation washers for all rail supports and 2.5mm compression for Mason natural rubber bearing pads at the rail bases were required for durability and essential low-dynamic-stiffness properties.

5.1 Lift rail design

Figure 6 shows the agreed rail design and installed photo. This contains a waffle pad for higher spring rate using a solid material that will not suffer from long-term degradation. Bolts are isolated using a solid rubber washer. Material is sized to be the minimum possible area while supporting the loadings.

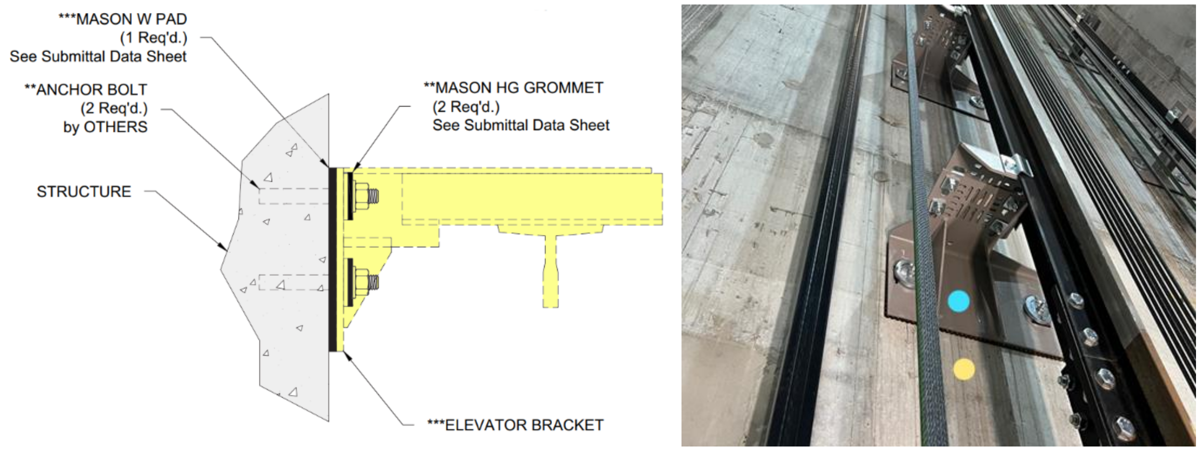

Figure 6 - Isolated rail design and installation

Figure 7 shows the rail base design and installation photo. The moulded pad had an embedded steel plate for positive connection to the rail system plate as the loaded pad had sufficient safety margin with frictional connection to the concrete below, but not with the steel rail baseplate.

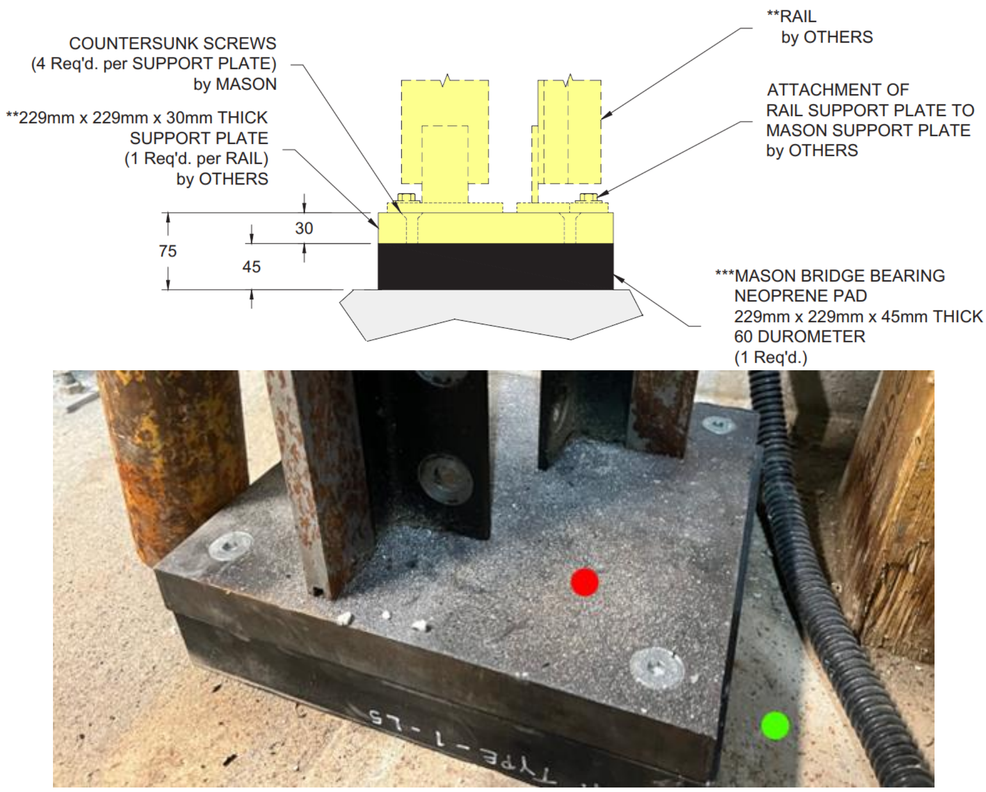

Figure 7 - Isolated rail base design and installation

6 RESULTS OF CASE STUDY

The project concerned required isolation of lift hardware to achieve VC-A criteria in surrounding spaces. Data collected [3] from other locations highlighted the risk this would not be met without isolation. Using the equation derived in Section 2, the natural frequency for the system was 17Hz. Measurements were taken above and below the isolation and compared to VC-A levels.

Specific measurement locations are highlighted on Figure 6 and 7.

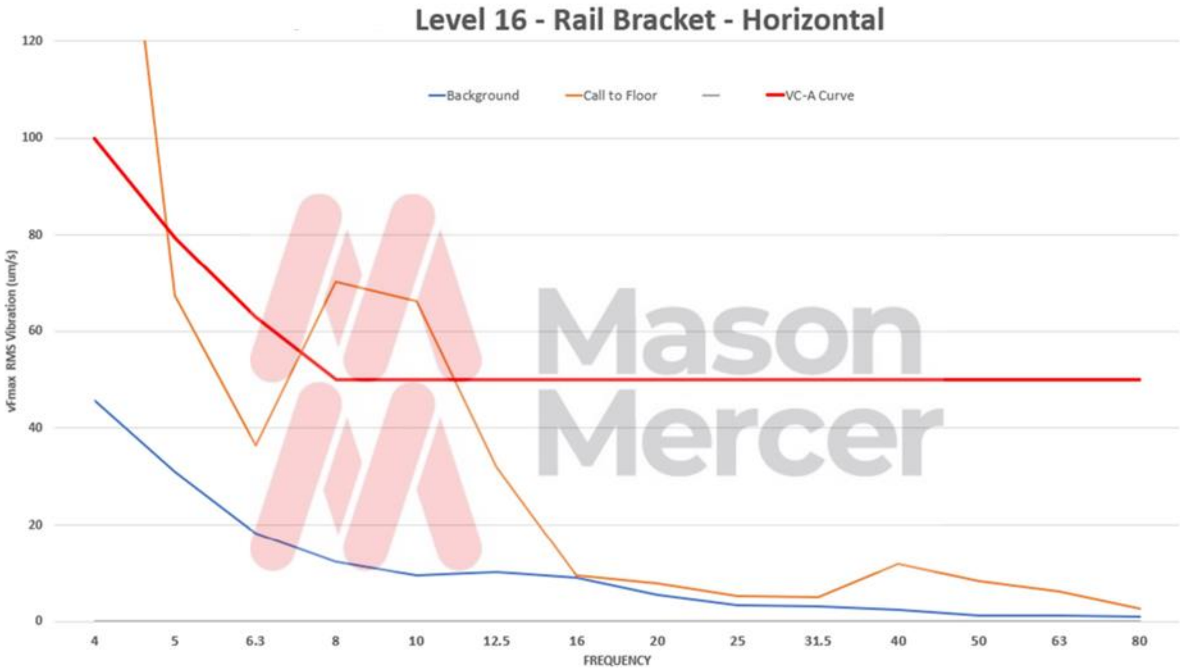

Figure 8 – Horizontal axis, before isolation on the rail bracket (blue dot on Figure 6). Non-compliance with VC-A.

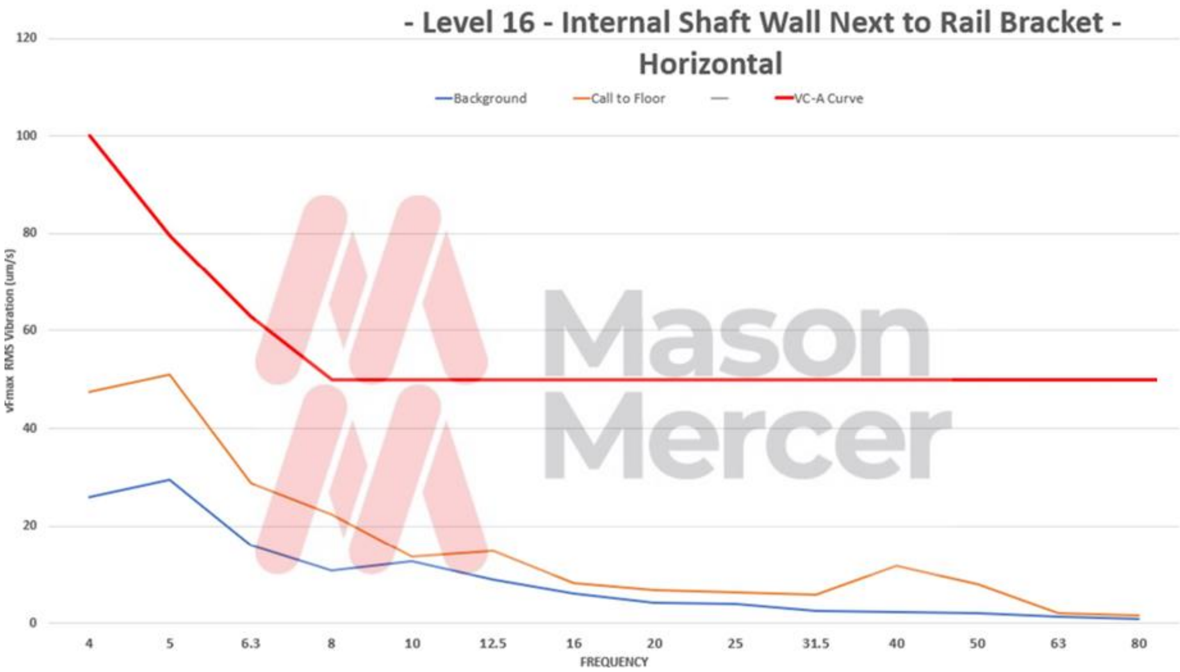

Figure 9 – Horizontal axis, after isolation on the wall next to the rail bracket (yellow dot on Figure 6). Compliance with VC-A.

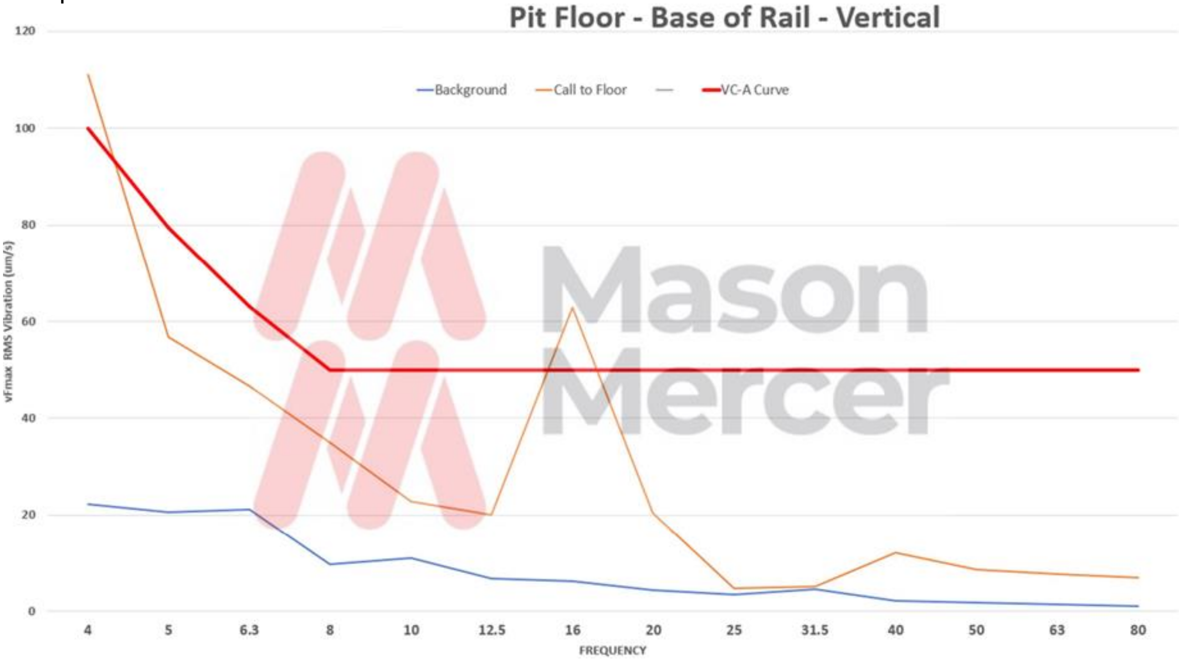

Figure 10 – Vertical axis, before isolation on base of metal lift rail (red dot on Figure 7). Non-compliance with VC-A.

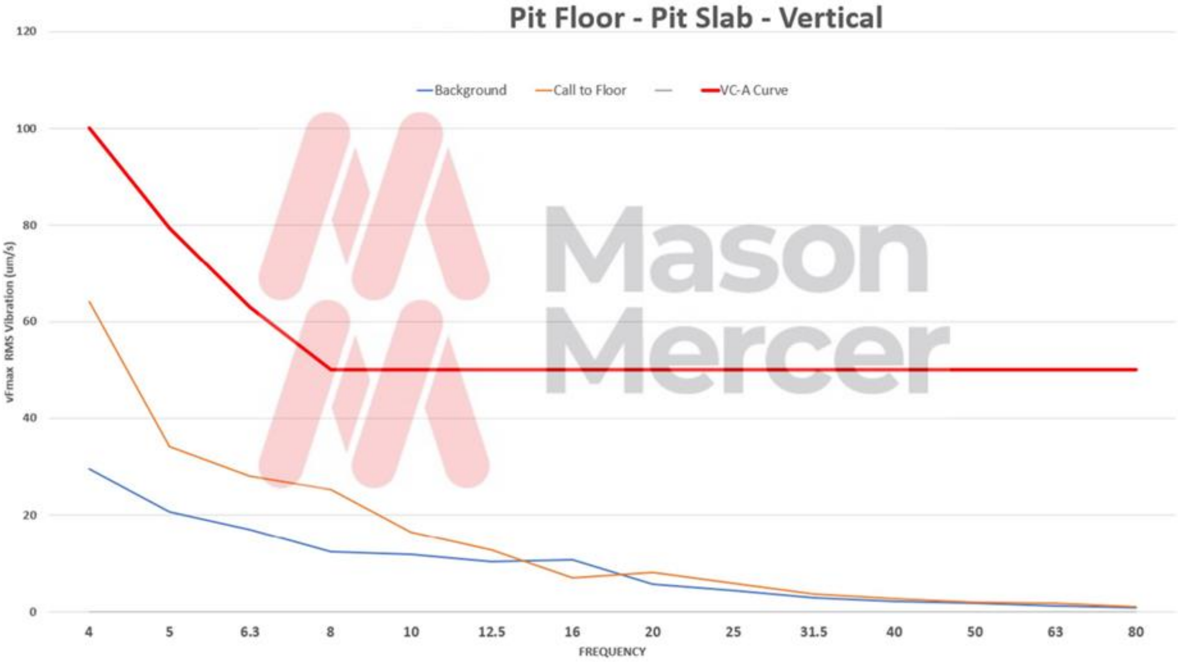

Figure 11 – Vertical axis, after isolation on the floor next to the isolation pad (green dot on Figure 7). Compliance with VC-A.

7 CONCLUSIONS

To the author's knowledge, no previous predication and measured qualification of remedial works have been carried out to demonstrate effectiveness of a well-designed lift isolation system. An equation was found following document review which was used for a case study of vibration sensitive facility to predict likely driving frequency.

This was measured on site and found to be accurate. This was used to inform design of an isolation system within a vibration sensitive facility. Vibration was found to have been reduced to acceptable levels.

Use of tailored isolator pads for rail brackets at pit floor and wall has been shown to be effective and will be more successful than industry standard non-tailored brackets which are likely to be overly stiff and effective only against frequencies far higher than that of concern in the case study project.

It is recommended that the formula can be used to estimate principal driving frequency of a lift system but this negates variables associated with different design of systems, construction tolerances and system aging which are outside the scope of this paper. The author recommends conservative approach to isolator design as a result.

8 REFERENCES

[1] S. Kaczmarczyk. Vibration Problems in Lift and Escalator Systems: Analysis Techniques and Mitigation Strategies. 3rd Symposium on Lift and Escalator Technologies.

[2] J. P. Talbor and H E M Hunt. The Effect of Side-Restraint Bearings on the Performance of Base-Isolated Buildings. Proceedings of the Institute of Mechanical Engineers Vol. 217, Part C, 2003.

[3] J. Watson. Mason Mercer Australia Lift testing 13th July 2022