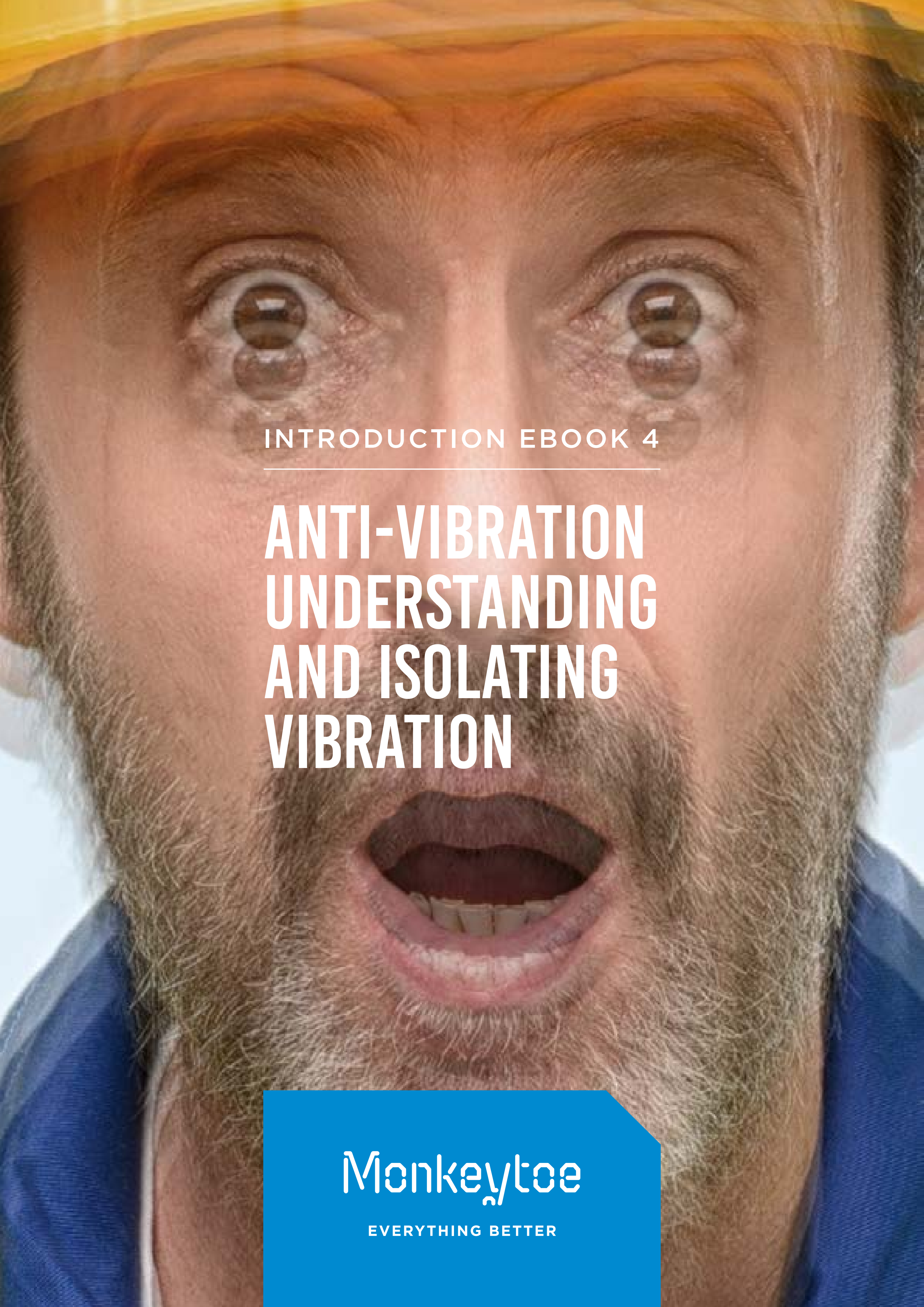

INTRODUCTION EBOOK 4

ANTI-VIBRATION UNDERSTANDING AND ISOLATING VIBRATION

Monkeytoe

EVERYTHING BETTER

A NOTE FROM THE DIRECTOR

Good design starts with understanding. That's why at Monkeytoe we're passionate about making sure that leaders in the construction industry are looking at the full picture and ensuring that all aspects of a project, no matter how small, are factored in.

We're often surprised by how – and what – some designers oversimplify or miss out altogether, including vibration. Vibration is a complex phenomenon, caused by periodic stresses – everything from the stomp of boots to motors, pumps and turning equipment, and even weather. When vibration travels, it can affect the smallest bolts or an entire structure, and to varying degrees. From noise to cracking, disruptions of sensitive equipment and workplaces to total catastrophic failure, vibration can go from nuisance to danger.
One of the key elements in vibration management is the use of 'isolators' to keep vibration from travelling to the connected structure and reduce the chance of those failures. But since there's no one-size-fits-all method of isolating vibration, getting this right first time is key.

Given that vibration is going to happen, and that it can affect every aspect of a design, it's no wonder that we're so invested in anticipating and managing vibration. As we're working towards better knowledge and understanding, we've looked at vibration and the ways it affects us in the industry. Read on to discover more about this surprising force.

Tim Prestidge
DIRECTOR OF MONKEYTOE

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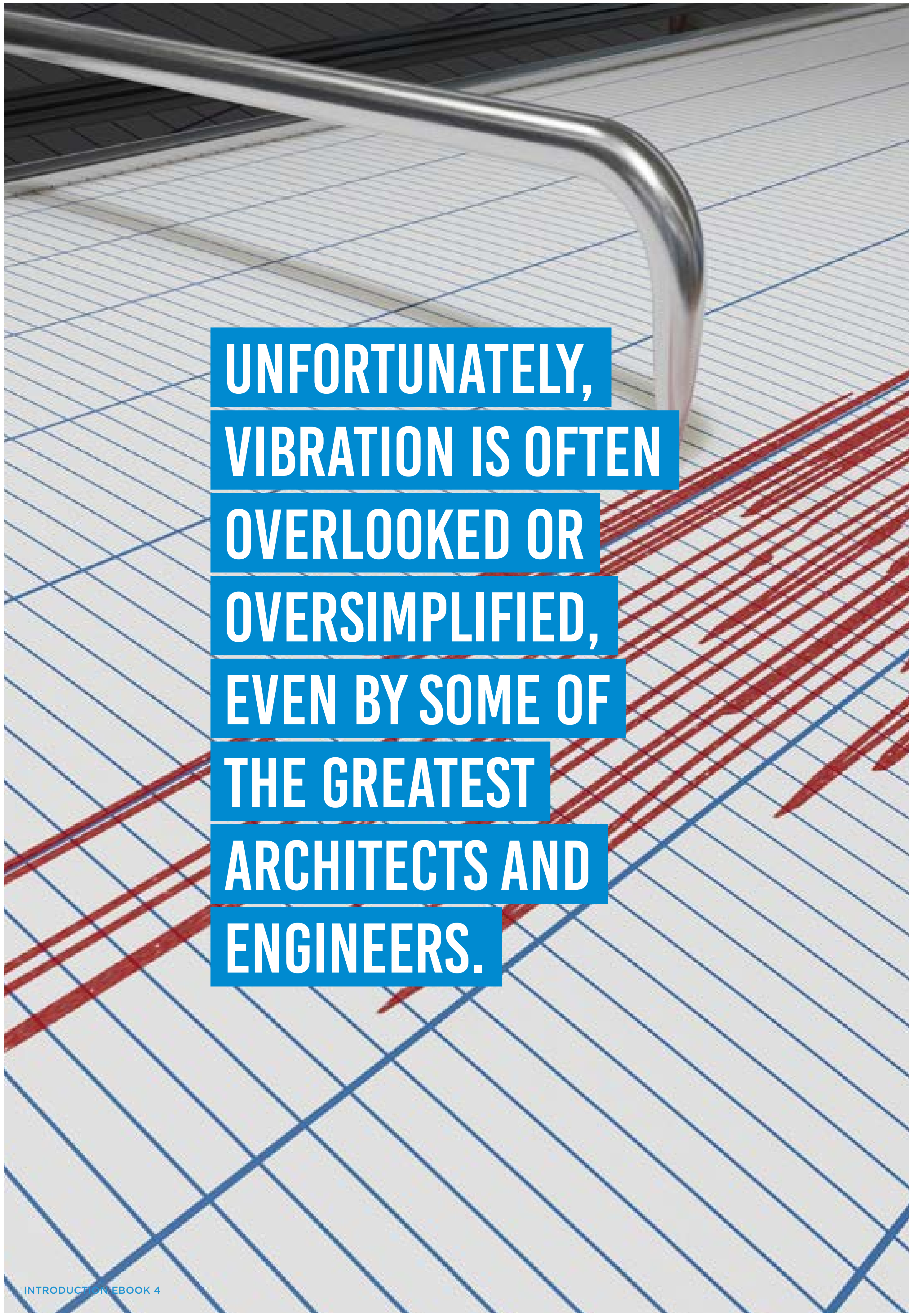


INTRODUCTION

From the largest superstructures in the world to the smallest fans in a computer, good designers have to anticipate vibration in its many forms.

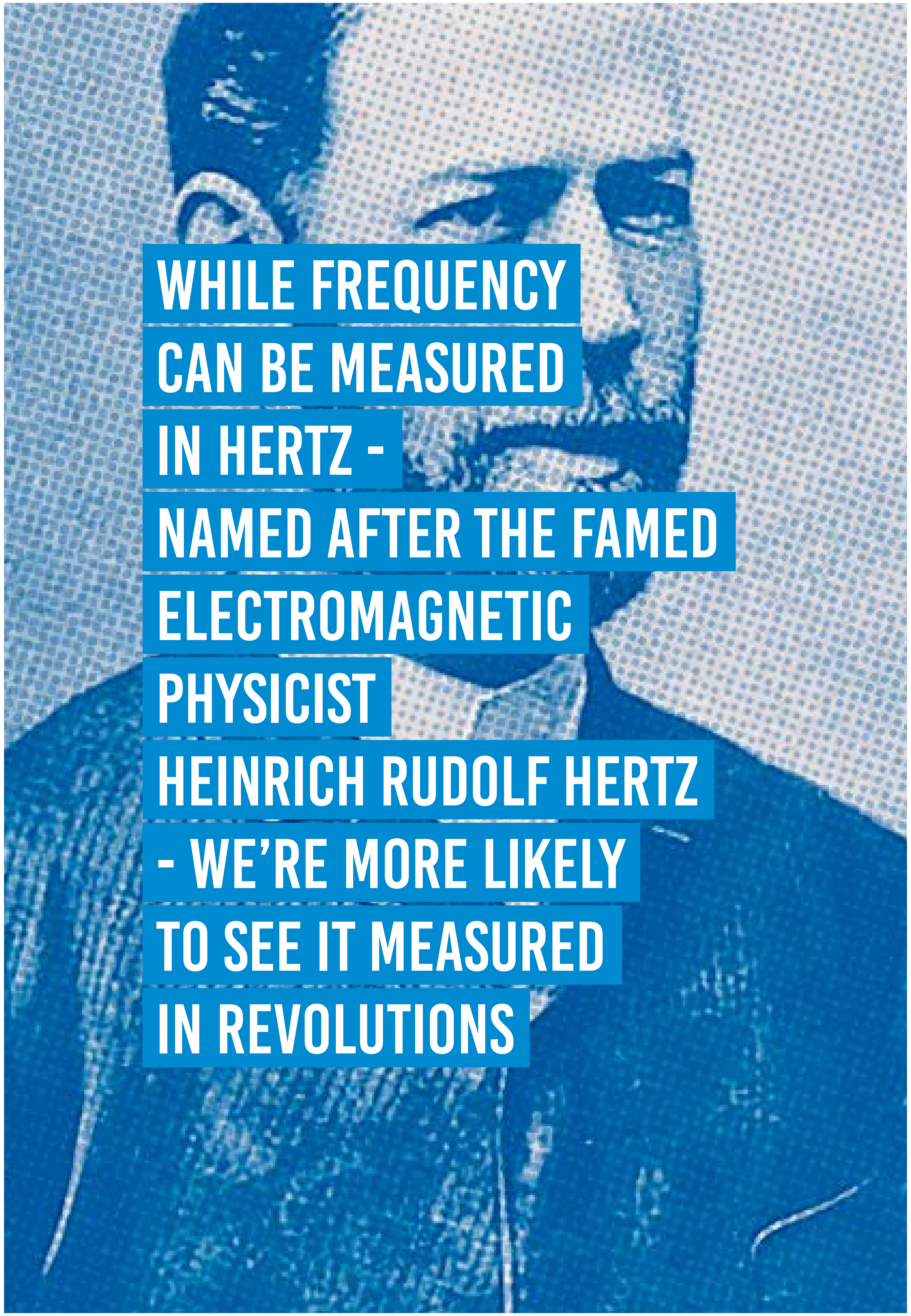
Unfortunately, vibration is often overlooked or oversimplified, even by some of the greatest architects and engineers. There are plenty of stories of vibration-related oversight and failure too – some of them serious, some of them just plain surprising.

Consider the example of ducting fans in train toilets - why did the fan bearings keep failing every six months, even though the fans were designed for purpose? The issue was simple, but not obvious. Since the fans weren't mounted with any rubber or springs to isolate them from the train, the fans moved rigidly. Hundreds of tonnes of dynamic torque from the rattle of the train were bearing down on the fans, and their lifespans were shortened significantly, resulting in unhappy clients who kept having to foot the bill for replacing theNot ideal.

At one extreme, no vibration control or isolation can result in cracking, fractures and total product failure. Imagine taking the suspension off your car and going for a drive. You'd pretty soon be feeling that in your back teeth, and you'd want to stop before the windows rattle themselves out of the doors.

At the other extreme, put too soft suspension in your car and you'll run the risk of kangarooing up the road when you're at speed.

Finding the best suspension spring is about understanding how and where the mass is in your car, how much and how often you're going over bumps, and what each kind of spring is going to offer. It's the same principles with vibration isolation, but we're dealing with pumps, fans, generators, air con and other units that we encounter a lot of in the accessway and Monkeytoe industry. Because we believe that we should always be striving towards better knowledge in our industry – and best and safest practices – we've put together some key points for understanding vibration in architecture, with a special focus on the kinds of situations we encounter a lot as leaders in accessway design.



THE BASICS OF VIBRATION

01

To understand vibration, we'll need to cover off some of the basics so we're all on the same page.

In engineering, as you'll know, there are two broad types of stresses: static and dynamic. Static stresses are generally weights and loads without movement – the weight of an accessway on a roof, for example, or the pressure of one level of a building on the structure. Static stresses are the focus of deflection, buckling, yielding and slippage analyses.

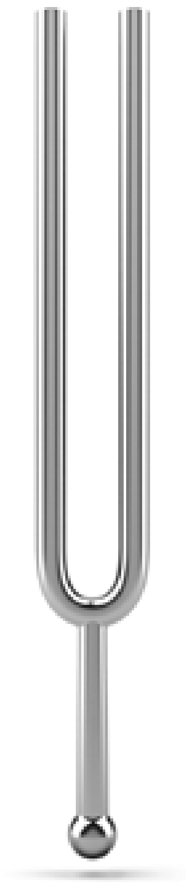
Dynamic stresses are forces that vary – that's a periodic or oscillating stress, including vibration. Here, vibration can cover everything from the music from speakers to the hum of an engine through the steering wheel and the seismic forces on a building. Vibration is the focus of time-dependent analyses, like fatigue.

Vibrations have a magnitude and a frequency. The magnitude is the size of the wave, or how intense the pattern of stress is. It's basically the volume. The frequency is the rate at which the pattern of stress or pressure goes back and forth; it's the pitch of the musical note, how high or low it is.

While frequency can be measured in hertz (Hz) – named after famed electromagnetic physicist Heinrich Rudolf Hertz – we're more likely to see it measured in revolutions (or cycles) per minute (RPM) since RPM tends to give a better representation of frequency for most engineering-based situations.

Depending on the circumstances, it may make more sense to describe a motor as running at 1000 RPM than at 16.67 Hz.

While there's a lot of complex physics we could cover, our focus is on how vibration is going to affect engineering design, and what good architects can do about minimising and isolating vibration in their designs.



GETTING TO KNOW ENGINEERING VIBRATION

02

Now that we've got a good understanding of the principles of vibration, let's look at the types we encounter in architecture and design.

The first is static vibration. This might seem like a contradiction of terms, but don't stress it. Static vibration is the one-off events with low frequencies. Thump your fist on the table, and you've created a static vibration event. Second is quasi-static vibration. This is the kind of sporadic vibration from environmental factors like wind or waves causing wires or louvres to flutter. At up to 3 Hz (equivalent to 180 RPM), quasi-static vibrations tend to be well below the range of human hearing but can travel far throughout a structure – if they're not isolated.

Lastly, there's full dynamic vibration, caused by rotation equipment like fans, air conditioning units, pumps and motors, everywhere from 3 Hz up to hundreds of Hz or thousands of RPM. These much faster – and so higher – oscillations and vibrations can span the range of human hearing and can affect equipment in a myriad of ways.

Each type of vibration has the same principles – magnitudes, frequencies, certain periods of duration – but, from an engineering perspective, they require vastly different approaches. And often it's this last type – the full dynamic vibration – that gets overlooked or shortcut in the design process, and that can be a big problem. Let's take a look at why.

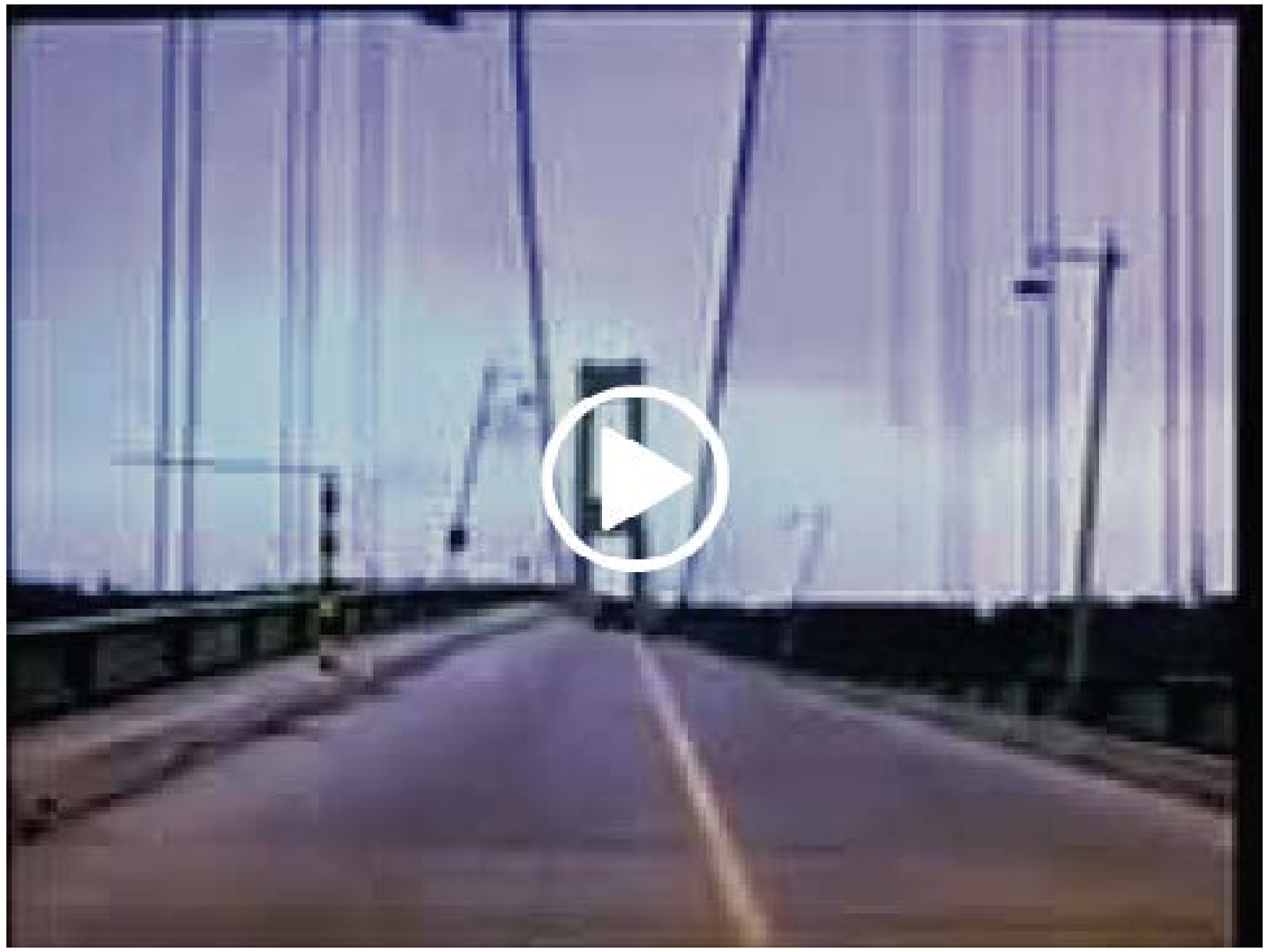
Monkeytoe Louvre Screen

WHAT'S THE ISSUE WITH VIBRATION? 03

The reason we're so concerned about vibration is that if it's not properly understood – or not correctly handled – you're setting up your structure for disaster. Oscillating stresses happen, from the environment down to pumps and fans, so it's necessary to design with these vibrations in mind. The most common vibrations are due to non-uniform masses in motion – a motor with a tiny imbalance, say, operating in a basement or attached to a hospital wing. Since the machine vibrates, it's going to transmit that to its environment. It causes stresses on structures and machine parts.

It shortens mechanical lifespans and increases the chance of early and potentially unpredictable failure. It can be a huge nuisance, especially if it's in the range of human hearing. Even deep bass vibrations can affect users' wellbeing in ways they may not be quick to identify, since they can feel it but not hear it.

The trick is then to minimise or isolate the vibration. Take the suspension off your car and drive across the country. With no dampening or isolation of the road vibration, you'd not only cause some serious damage to your car, but also be in for a pretty uncomfortable ride. That's one risk of unchecked vibration.



Tacoma Narrows Bridge 'Galloping Gertie'

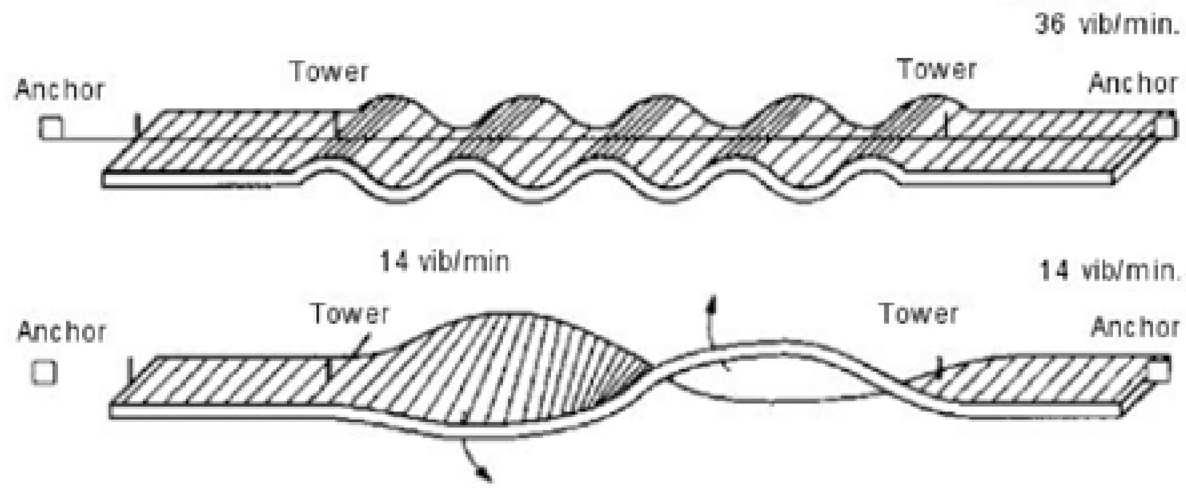


Diagram of Tacoma Narrows Bridge 'aerodynamic flutter' behaviour

There's also a big risk of a phenomenon in your structure called resonance.
If you've ever made a wine glass sing by running a wet fingertip around the rim of the bowl, you'll understand resonance in action. Resonance is when external, applied frequencies align with the natural frequencies of an object and amplify each other. In this case, as your wet fingertip slips along the rim, it causes the bowl to vibrate back and forth at its natural frequency. If you were to see that glass in slow-motion, you'd see the whole bowl of the glass vibrating back and forth. And with enough amplitude or volume, the glass vibrates itself apart and you'll end up with a mess on your dinner table.

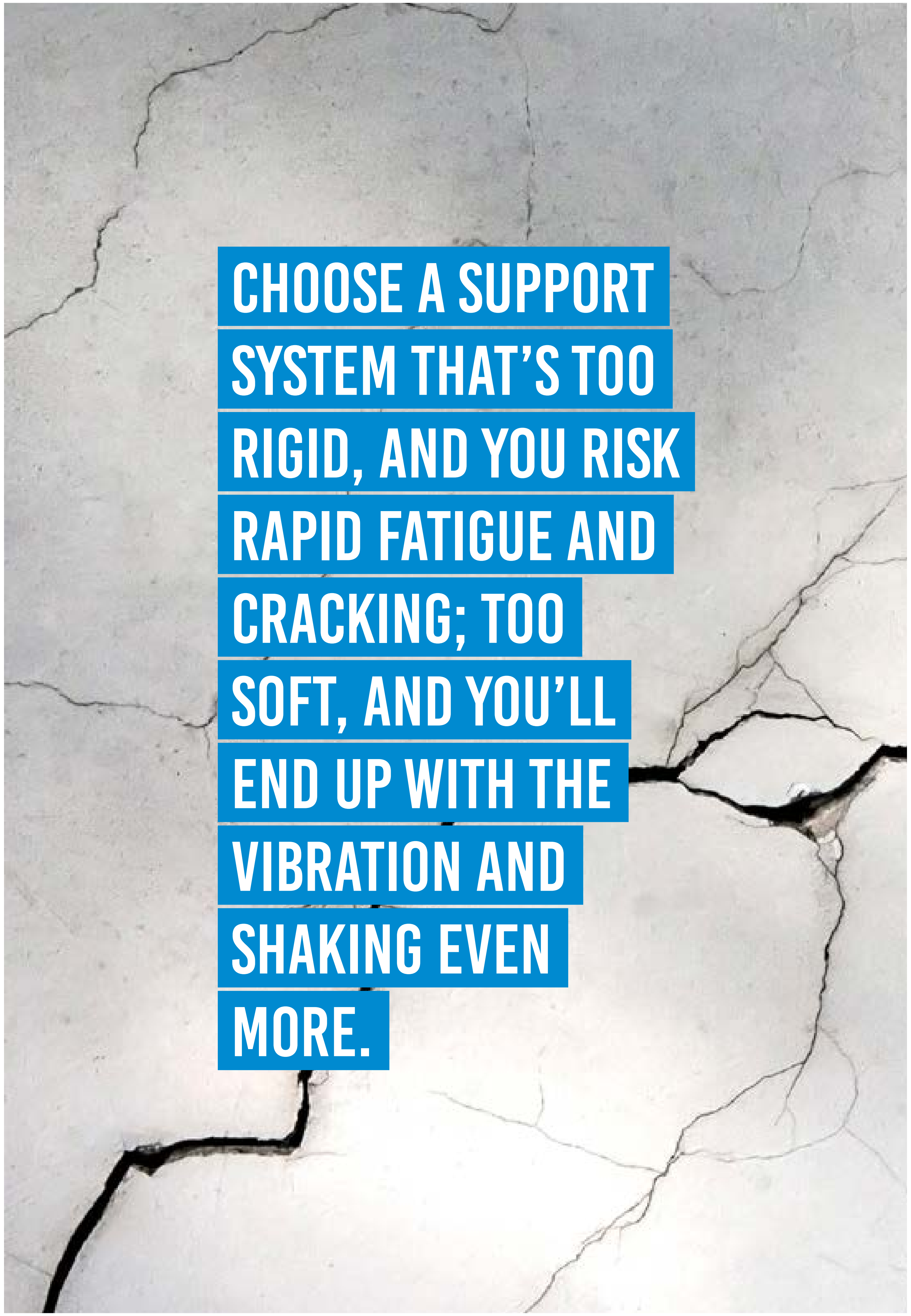
There's a classic example of the Tacoma Narrows Bridge that collapsed in 1940.

You've probably seen the black-and-white footage of cars trying to drive over 'Galloping Gertie' as the deck of the bridge swings and lifts wildly. The suspension bridge failed, in short, because the normal wind speeds in Washington State caused an 'aerodynamic flutter' – the bridge began to vibrate in the wind, which happened to also be at the bridge's resonant frequency. Thankfully there were no fatalities. There were plenty of confused and embarrassed engineers though.

The trick, then, is not just understanding the resonant frequencies of your structures – which can sometimes be determined with computer-aided design software – but more importantly, understanding how to prevent the frequencies of separate mechanical vibrating components from affecting the structure and each other so that resonance, wear and noise can be prevented.

That's why it's necessary to isolate each vibration in turn. Good design is a matter of taking a massively complex problem and breaking it down into a series of smaller equations, and that's the best practice here too. By identifying and isolating each vibration in turn, it's possible to limit the risks of stress travelling from each individual component and into the structure or building.

That's the subject of our next point: vibration isolation.

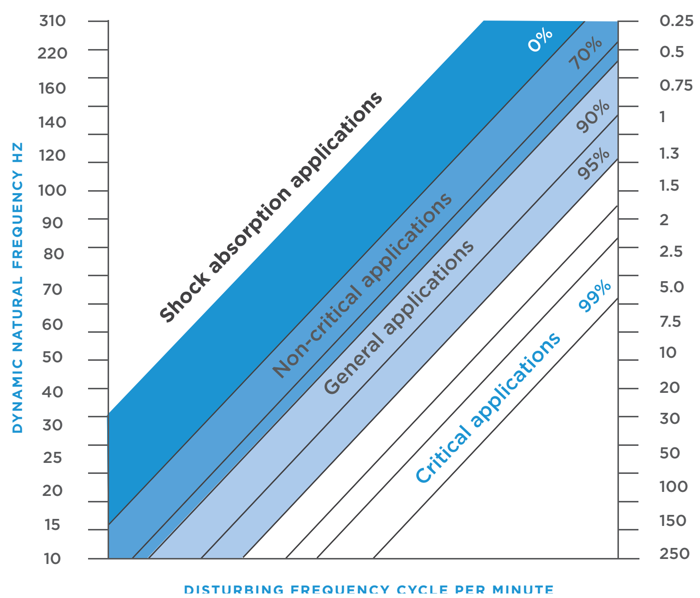


CHOOSE A SUPPORT SYSTEM THAT'S TOO RIGID, AND YOU RISK RAPID FATIGUE AND CRACKING; TOO SOFT, AND YOU'LL END UP WITH THE VIBRATION AND SHAKING EVEN MORE.

VIBRATION ISOLATION 04

As we've suggested, one of the most important things a good architect can do is to prevent vibration from travelling throughout a structure. It may be simple to think of isolation as a matter of throwing some spring mounts under a weight and letting it be. But not all scenarios are equal, and not all isolation techniques are equal. Vibration isolation is a complex field, but the principles are generally the same across the architectural and design worlds. It comes down to understanding the nature of the vibration you're dealing with, and how that's going to affect the environment.

The demands created by vibration on a roof are going to be different to those in a basement, or in a hospital wing. A fan will have different demands to a motor. Choose a support system that's too rigid, and you risk rapid fatigue and cracking; too soft, and you'll end up with the vibration amplifying and shaking even more. That's more stress, more risk, and more clients coming back asking why it wasn't done properly the first time.



The goal is to achieve the most appropriate isolation efficiency for the application. The isolation efficiency is the measure of what percentage of total vibratory force is absorbed by isolators at a certain compression or deflection, and at a certain disturbing frequency. That means that the efficiency of any one isolator can vary wildly depending on the application, so it's important to understand the situation before selecting an isolator from a catalogue.

Determining the isolator depends on a few major and related points, which we'll need a visual aid for.

Ideally, if you're designing a walkway that's perpendicular to the roof pitch, you'll be aiming for a walkway as close to level as possible.

For the same reason that slopes need to become steps if they have a gradient of greater than 7°, when a walkway is running perpendicular to the roof pitch and that roof pitch exceeds 7°, the walkway must be levelled.

This is another situation where minimising the difficulty for people also increases the safety.

Given that most new roofs are 5° or less, it's become very easy to design walkways that are not only under that 7° limit but, with some extra consideration, can be made level.

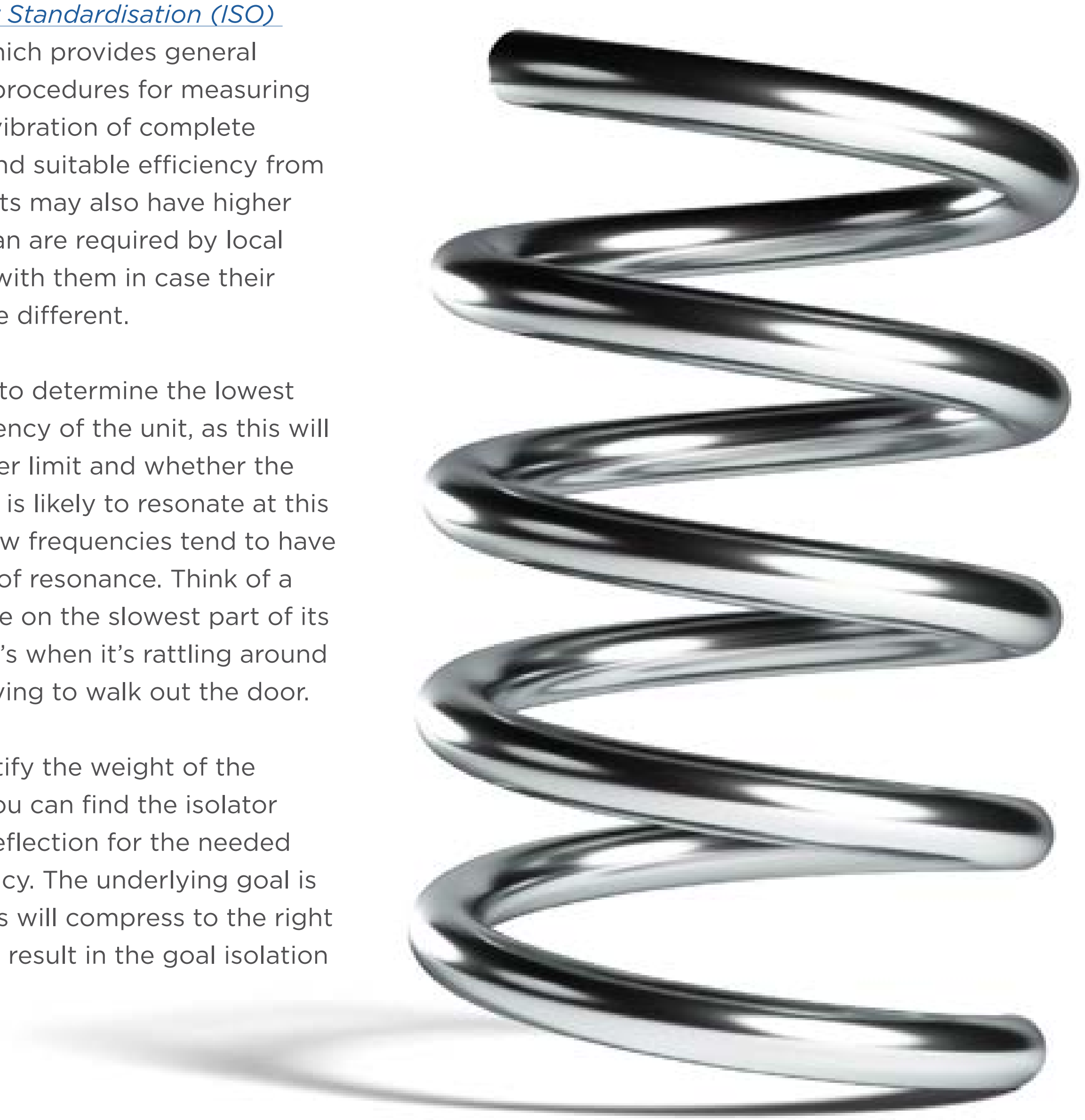
SUCCESSFUL VIBRATION CONTROL 05

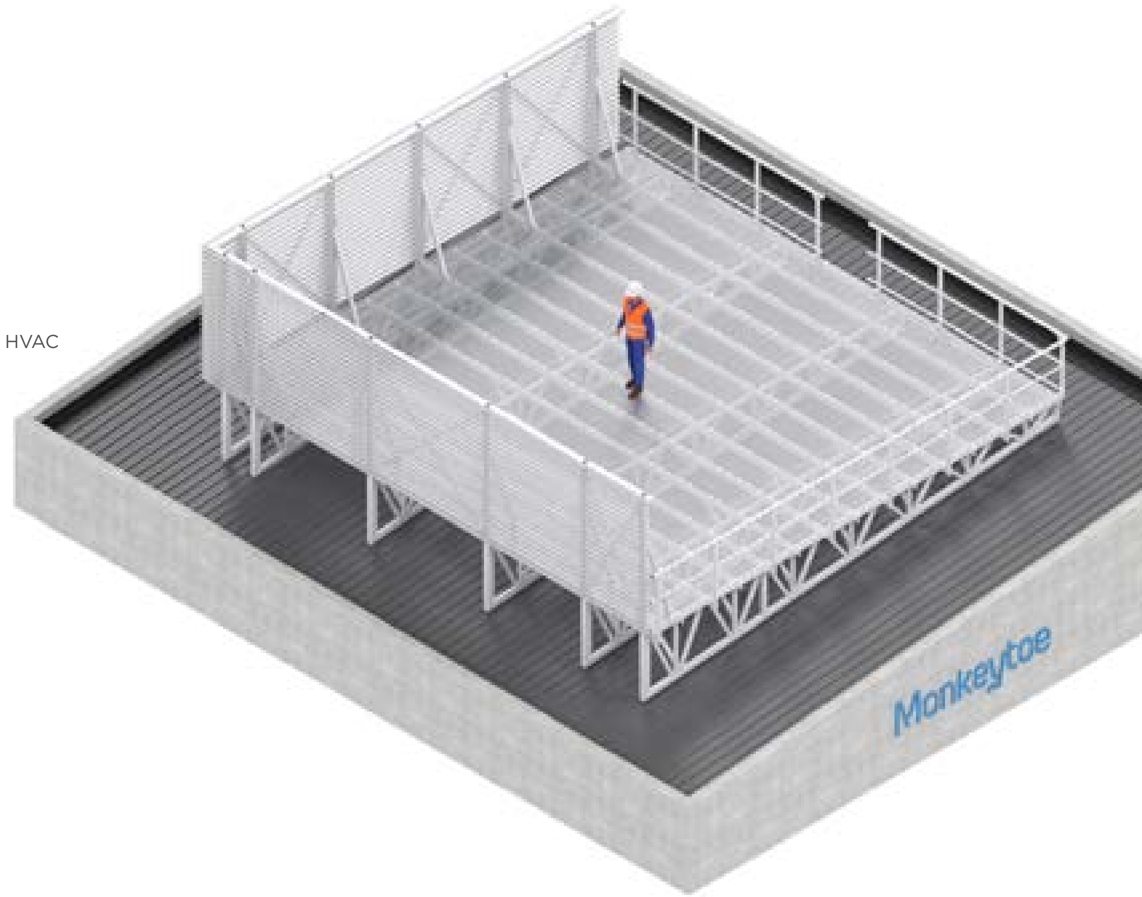
Successful vibration control depends on common sense and best practices.
The best place to begin for successful vibration control is by finding the goal isolation efficiency at operating speed or frequency. In a theatre or hospital, you'll be aiming for 98-99%; in a basement, 80% may be acceptable. Generally, the closer proximity to people, and the height above ground, will each increase the required efficiency of an isolation system. You can consult documents like the *International Organisation for Standardisation (ISO)* 20816-1:2016, which provides general conditions and procedures for measuring and evaluating vibration of complete machines and find suitable efficiency from there. Your clients may also have higher expectations than are required by local codes, so liaise with them in case their requirements are different.

You'll also want to determine the lowest operating frequency of the unit, as this will indicate the lower limit and whether the spring or mount is likely to resonate at this lower bound. Low frequencies tend to have the highest risk of resonance. Think of a washing machine on the slowest part of its spin cycle – that's when it's rattling around the most and trying to walk out the door.

From here, identify the weight of the equipment so you can find the isolator with the ideal deflection for the needed isolation efficiency. The underlying goal is that the isolators will compress to the right amount that will result in the goal isolation efficiency.

As you could see in the graph in the last section, the greater the deflection of a spring unit, the better the isolation efficiency. So you'll want to find an isolator that can compress as much as possible without compressing entirely, at which point it acts like a solid and fails to isolate at all.





Monkeytoe
Purlin Mounted HVAC
Plant Platform

As an example, you
a goal isolation of 9
springs that are des
each and together i
you could allow 10 springs at 150kg each.
And so on. Here you'll need to ask questions about what's going to be cost-effective, what's commercially available and what the equipment is going to be best suited to.

A related point is the necessity of balancing the load points, especially on a platform or isolation block. Most designers will pick one grade of isolator across four or six load points, assuming that it's a balanced weight – but that's an amateur mistake, and when the structure or unit rattles apart, someone's going to get the blame for a 'faulty product'. Understand the weight balances first, as this may necessitate different types supporting different ends of a unit – you may need two at one end at 200kg each, two at the other end at 150kg, and so on.

The above and the magnitude and nature of the vibration forces will point us to the right type of isolator (something we'll cover more of soon). Whether you choose seismic springs or rubber blocks depends on the above, as each isolator has an ideal band of amplitudes, displacements and frequencies that it's best suited to.

Next it's necessary to balance the centre of mass, which builds from balancing the load points but also takes into consideration the location of the equipment within the structure and the goal isolation efficiency. You may find it necessary to use inertia blocks or brackets to lower the centre of mass to limit the torque created by a vibration. This is especially true in pump-type applications, where you'll need a robust and solid base to fix the equipment to and keep its centre of mass low.

All of this will suggest a spring or mount that you can pick from a catalogue. Typically each isolator will have a range of suitable weights, so some quick calculations of weight distribution will tell you whether it's a good potential fit.

Let's look at some common types and what sort of applications they might be suited to.

CHOOSING AN ISOLATOR

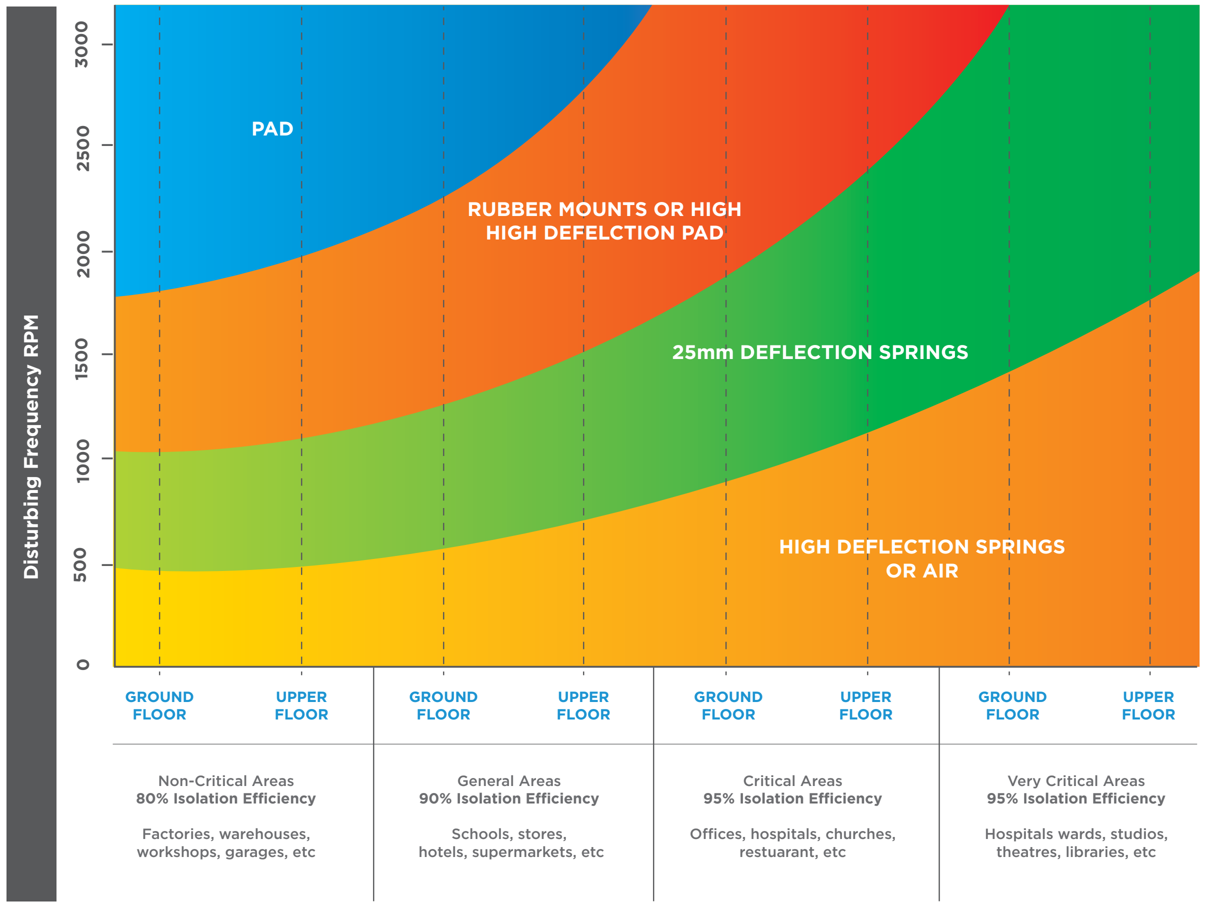
06

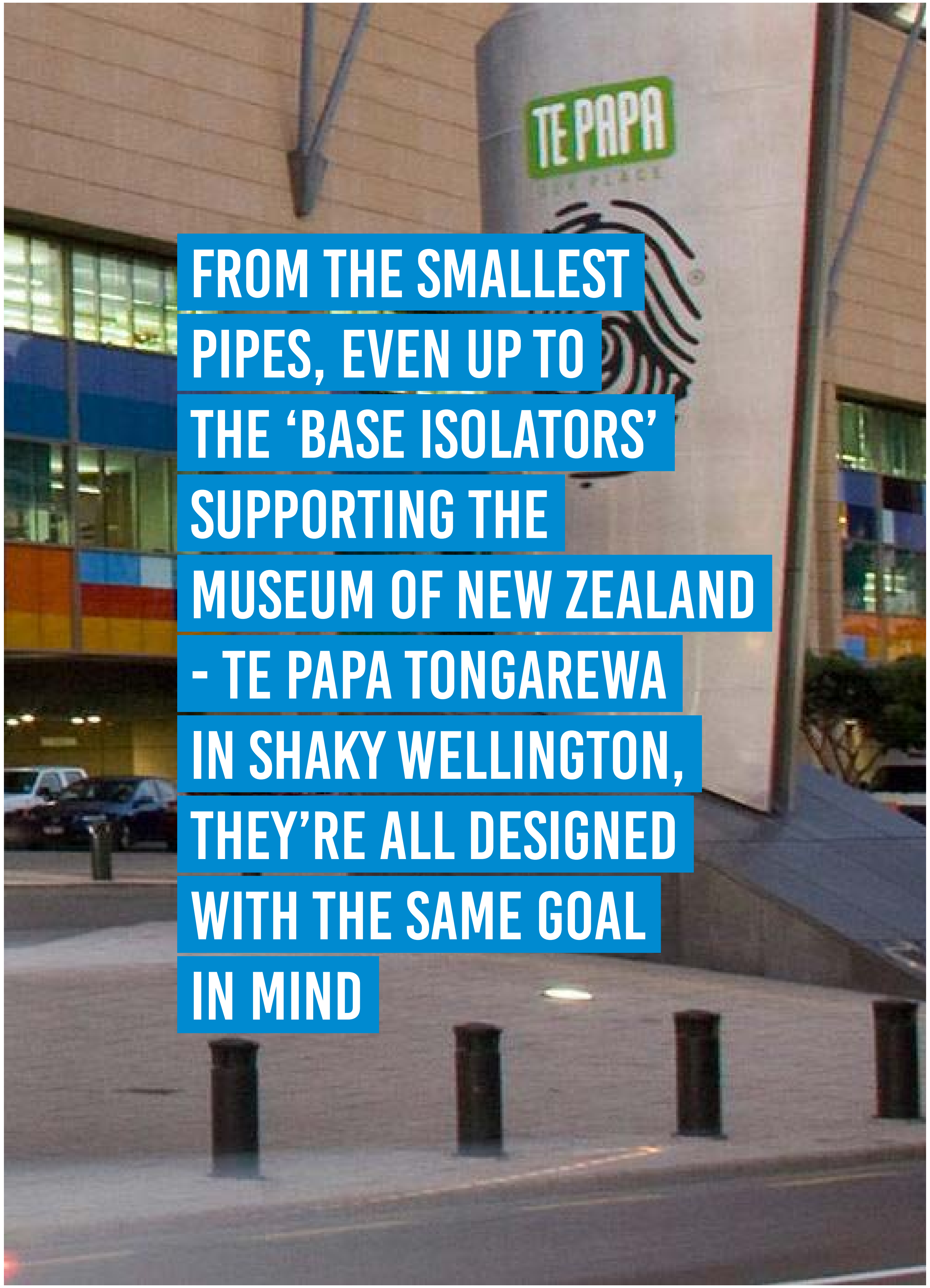
There are a myriad of ways to isolate unwanted vibration. In the past, vibration could be minimised by using cork or felt pads under equipment. Increasingly powerful auxiliary equipment like air conditioning units and power generators are now needed, however, and are often installed on upper levels of plant rooms or rooves. Equipment vibration can be a major issue on flexible structures in a way that cork and felt are unable to handle.

Nowadays there is a wide range of vibration isolators to choose from, including pads of cork or rubber, spring mounts, air mounts, isolation hangers and even seismic mounts. From the smallest pipes, even up to the 'base isolators' supporting the Museum of New Zealand - Te Papa Tongarewa in shaky Wellington, they're all designed with the same goal in mind: reduce vibration transmission. As we've seen, determining the viability of an isolator depends on the nature of the vibration and the environment where it is to be used. It also hinges on the type of isolator that can be used, and what sort of properties each type has which may make it more or less suited to each environment.

The below graph provides a good guide to acceptable isolator solutions depending on disturbing frequencies and the environments.

Let's look at these common types in turn and see what solutions they offer.





CHOOSING AN ISOLATOR

PAD MOUNTS

Pad mounts are low-cost – often under half the price of spring isolators – and can be made of rubber, cork or felt, or a combination of these sandwiched together. Pad mounts are ideal for situations including:

- Common disturbing frequencies in the order of 1,000-2,200 RPM.
- Loads in the order of 75-750 kilopascals (kPa, equivalent to 1000 kg per square metre).
- Static deflections arereasonably narrow (a few millimetres).

Pad mounts are an effective low-cost option with a reasonable degree of isolation efficiency that tends to improve with greater disturbing frequencies. They are generally used for standard, non-critical applications including pumps and fans, generator sets, general industrial equipment, mobile equipment, electrical transformers and packaged air.

CHOOSING AN ISOLATOR

SPRING MOUNTS

Spring mounts have great static deflection, making them great for a wide range of isolation applications. Since springs can be scaled in size, they suit a wide range of critical applications including fans, pumps, air conditioning units, engines, cooling towers and even heavy machinery. Springs represent a wide band of applications, including for:

- Disturbing frequencies from 50-5000 RPM, according to load and location.
- Loads in the order of 6-11,000 kg, depending on type.
- Static deflections from 15-100mm.

Spring mounts may be open, or have a housing that restricts lateral (side-to-side) deflection, and often have rubber pads built into the mount to further reduce vibration transmission. They can help achieve a theoretical isolation efficiency up to 99% depending on the spring type and application.

Steel spring mounts provide effective isolation from mechanical vibration, however the spring itself has its own inherent surge frequency depending on its physical geometry and material properties.

CHOOSING AN ISOLATOR

AIR MOUNTS

Quality air mounts are made from a balloon of low permeability rubber sandwiched between plates (usually steel). They offer the highest efficiencies as they isolate the vibrating unit on a cushion of air, so they're often found in extremely critical applications in hospitals, research laboratories, and music auditoriums, or with:

- Disturbing frequencies typically around 1-5 RPM with high frequency peaks.
- Loads in the order of 10-4,500 kg, depending on type, and
- Static deflections from 15-100mm

Air mounts are great for shock absorption – you'll often find them in the transport industry where high loads are handled in small spaces like in trucks or trailers. They're also quite cheap in relative terms, however the constant dynamic load and nature of rubber and air leaks means they'll require a mechanical plant or maintenance cycle to ensure the pressure is maintained. This will need to be factored in when compared to the low-maintenance nature of springs or pads.

CHOOSING AN ISOLATOR

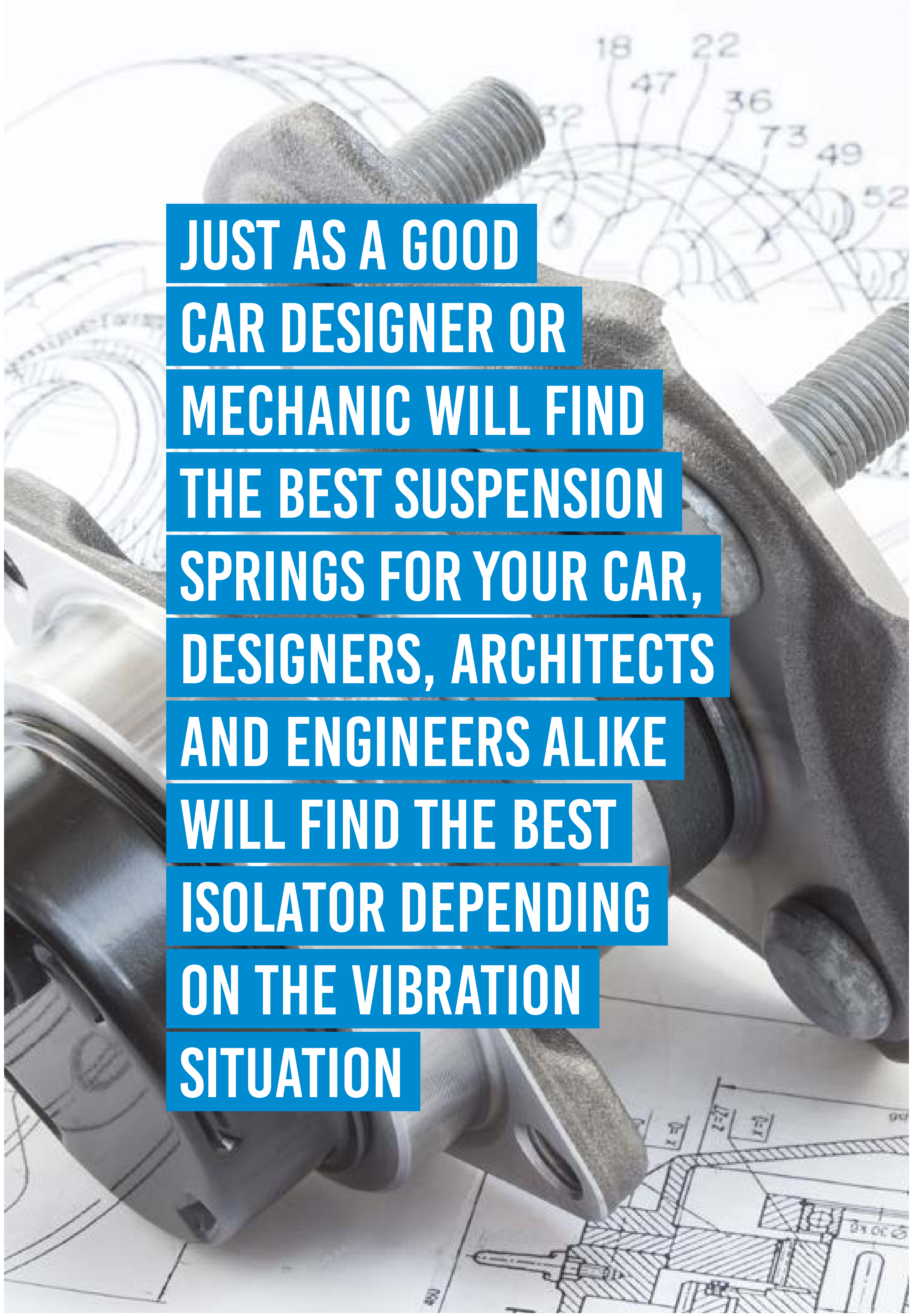
ISOLATION HANGERS

Isolation hangers are often the same spring mounts as before, but inverted and with a longer stud to fix it to the structures from above. Isolation hangers are used for piping, ductwork, fans, suspended ceilings, attenuators and other applications where it's necessary to isolate by hanging – as their name suggests. They're a critical part of the overall design, as piping and ductwork often connect directly to the source of vibration. Given they are of a similar nature as other spring mounts, they have similar features but lower weight tolerances, so are suitable for:

- Disturbing frequencies over 500 RPM.
- Loads in the order of 5-1,300 kg, depending on type.
- And static deflections from 5-55mm.

Isolation hangers may also be used as part of a thermal expansion control system, supporting piping where thermal variations can impose considerable vertical movement such as in the risers of multi-storey buildings.

Once you've determined your loads and the quality of your vibration, you'll be able to see what kind of isolator will be best suited and choose one from a catalogue according to your range.



CONCLUSIONS 07

Vibration will continue to grow as an important issue to overcome in industry designs as we push towards lighter structures supporting increasingly powerful equipment. It's a complex field, but fortunately some basic understanding of the nature of vibration goes a long way. And since it's easier to isolate vibration than to do the impossible and completely remove it, the question then becomes the way in which you go about preventing vibration from travelling.

The most important idea to recognise is that it's easier to isolate individual sources of vibration than to try and isolate combined vibrations. Some architects want to isolate the platforms that pumps, generators and other vibration sources sit on – and that seems like an obvious choice, since it groups together the sources. But as we've seen, that can create an interaction of competing and complex dynamics that simply can't be solved, even with the best the market has to offer.

In isolating each individual component in turn, from fire pump to fan, you solve a potentially complex issue by reducing it to a series of smaller solutions that can be checked off far sooner. Just as a good car designer or mechanic will find the best suspension springs for your car, good designers, architects and engineers alike will find the best isolator depending on the vibration situation.

It's worth noting that every component – be it a heat pump, generator, fan and so on – will have its own mounts designed by the manufacturer to best suit the application.

The original equipment manufacturer is the best person to determine what goes with what.

So making sure the installers fit it is key! But if they're not supplied, or you're working around existing equipment, then you'll have a good idea now of the best practices and procedures for successful vibration isolation. Happy designing.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