HELICOPTER PAD VIBRATION ISOLATION

Adam Fox CEng MIMechE
Mason UK Ltd, Farnham, Hampshire GU9 8HT, United Kingdom, adam@masonuk.co.uk

1. INTRODUCTION

Tyréns of Stockholm are the acoustic consultant for parts of the new Karolinska Institute in Stockholm. When the building structure was modelled, they determined that it was susceptible to structural vibration transmission and that the type of vibration originating from the rooftop helicopter pad could cause problems to sensitive equipment and research on lower levels. Rather than isolating the equipment, it was decided to isolate the helicopter pad.

The contractor (Skanska AB) was instructed to use suitable isolators to support the entire 24,000kN roof. The contract was won by Mason UK.. This paper discusses the design and installation of spring isolators, required to have a maximum natural frequency of 2.0Hz. The project was complex and required careful design, working with Tyréns and the structural engineers Ramböll. The project is unique. Isolating buildings against vibration is common, but the low frequencies required at Karolinska and the structural requirements demanded specialist components and design.

2. DEVELOPMENT

2.1 Defining the Problem

The Karolinska Institute in Solna district, Stockholm is a major hospital and globally renowned research centre. It is currently undergoing major development, including new buildings and facilities constructed by Skanska AB. One of the buildings features a rooftop helicopter pad – the hospital has high levels of traffic so the helicopter pad is large and can accommodate two aircraft at the same time.

The Karolinska Institute is a centre of excellence for medical research. This requires specialist and sensitive equipment so it was very important when designing the building to provide a suitable working environment. This includes minimising vibration, which can seriously disrupt equipment such as electron microscopes and magnetic resonance imaging machines. Vibration can be controlled by placing the sensitive equipment on high mass inertial blocks, typically concrete supported on resonance free air springs. It can also be controlled by isolating the source of the vibration, preventing the energy from entering the structure.

Tyréns of Stockholm modelled the building structure in an effort to determine how well vibration can pass through the structure. They also defined the major sources of vibration. It was found that the structure could transmit vibration and that helicopter operations on the roof would be the most significant source. Tyréns specified that isolators with a natural frequency of 2.0Hz should be used to support the entire helicopter pad roof structure. Mason U.K. won the contract to design, supply and commission these isolators. This paper describes the complete project, from the initial design to project completion

2.2 Vibration Transmissibility

When selecting an isolator, elastomeric spring or air, transmissibility is the first step. This is the relationship between the lowest dominant source frequency and the natural frequency of the isolator (f_n). The difference between these determines how effective the isolator will be - how much energy will be absorbed. Figure 1 shows a transmissibility curve from an undamped system. In reality, damping will flatten the curve but the basic properties remain the same. It can be seen that the greater the difference between the source frequency and the isolator natural frequency the greater the energy which will be absorbed. As the two frequencies approach each other, the energy absorbed reduces to zero then increases – i.e. the isolator begins to resonate in sympathy with the source.

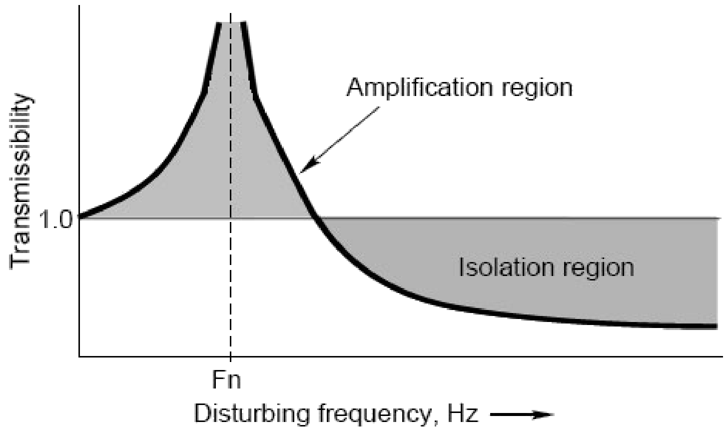

Figure 1: Transmissibility response curve

When designing a structural isolator, transmissibility must be considered twice. First, between the source (the dominant frequency produced by the helicopters) and the isolator, but also between the isolator and the structure. All objects have a natural frequency and it is critical to understand the response properties of the supporting structure. If the isolator has a natural frequency that is similar to the building natural frequency, resonance may occur if there is sufficient energy in that part of the spectrum.

The isolators used to isolator the helicopter pad at Karolinska required a natural frequency low enough to sufficiently prevent transmission of vibration from helicopter operations and also low enough to avoid a sympathetic relationship with the building structure.

2.3 Helicopter Vibration

Helicopters have multiple modes of vibration. There are many pieces of rotating equipment and linkages running at different speeds and different angles. However, the vast majority of these sources are contained within the helicopter itself. The source of concern to Karolinska is the blade passing frequency. As each blade rotates, air is deflected at an angle relative to pitch of the blade. During take-off, landing and hover, the air is typically deflected straight downwards. When hovering, the total air mass moved by all the blades is equal to the mass of the helicopter. From the ground, the air movement is felt as a series of pulsations as each blade passes. The speed of the pulsations depends on the number of rotor blades and their speed. This series of pulsations hitting the ground can cause vibration.

The type of helicopter to be used at Karolinska is the Eurocopter EC-135. This has four rotor blades and an effective blade passing frequency of 25Hz. This is the typical frequency generated when taking off and landing, when the most energy is passed into the helicopter pad. The rotor blades spin up to this speed during start-up and down after landing, but the energy is low as the blades are not angled to produce lift. The blades may spin faster, but this produces a higher frequency which would be isolated to a greater extent.

The isolators supporting the helicopter pad had to prevent as much of this energy as possible from passing into the structure. Therefore, the isolators were to have a natural frequency significantly less than 25Hz.

2.4 Structural Resonance

Tyréns produced a computer model of the building structure. This model confirmed that vibration could be transmitted throughout the structure. The model also determined the structural resonant frequencies, or jumping modes. The isolators were to have a natural frequency lower than these jumping modes to prevent any such sources entering the structure and to ensure that there was no coupling/sympathetic relationship between the isolators and the structure. The minimum ratio between frequencies is √2 which is equivalent to zero transmissibility. Figure 2 is an extract from the Tyréns model. This shows likely vibration propagation of the lowest likely structural resonant frequency of 3.3Hz. Based on this, the maximum acceptable isolator natural frequency is 2.3Hz.

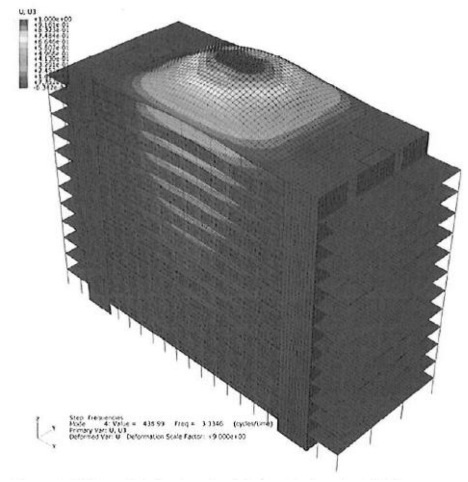

Figure 2: Karolinska structural response

Tyréns made a recommendation that the helicopter pad be supported by isolators, to be placed on the top of each column, see Figure 3. Each isolator would have a maximum natural frequency of 2.0Hz. This would provide over 99% isolation efficiency, or a loss of 22dB against the 25Hz source. 2.0Hz is also sufficiently low enough to prevent any resonant coupling with the structure.

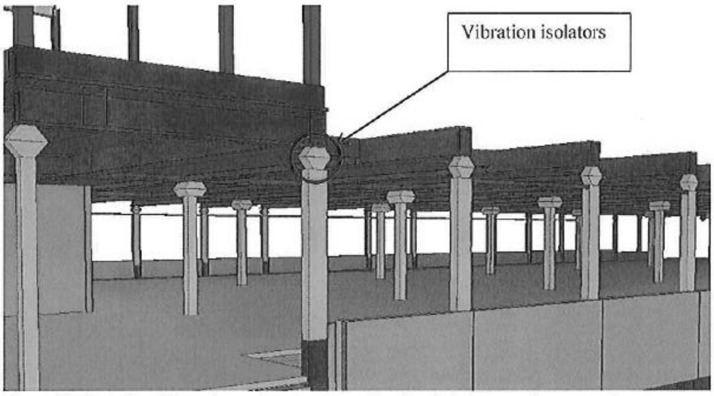

Figure 3: Isolator locations at column head

2.5 Isolator Design

The natural frequency of an isolator depends on the material, shape and how much it is compressed. The most common are blocks of elastomer, metal or air springs. Each has advantages and disadvantages, but the choice is usually based upon the required natural frequency.

The requirement of 2.0Hz, long service life and zero maintenance meant that helical compression springs were the logical choice. Compression isolation springs are designed to compress by a specific amount when loaded. The amount of compression determines the natural frequency. As a helical spring is compressed, the strain in the metal increases. As the strain increases, the spring responds to lower frequencies, removing energy as vibrations pass through the coils.

To provide a natural frequency of 2.0Hz, the springs had to compress by a minimum of 63mm. There are 58 columns supporting the helicopter pad. Each column supports a different area of roof, so some columns supported a higher load than others. The total mass of the helicopter pad was designed to be approximately 24000kN.
Mason U.K. designed springs to compress a minimum of 63mm at each location. There are two main designs for structural isolation springs – pre-compressed and post-compressed. Mason U.K. submitted a post-compression design.

Pre-compressed springs are supplied with a metal housing, which is used to compress the springs prior to installation using bolts which link the two halves. Pre-compression is typically around 80-90% of the design loading. Because the majority of the compression is introduced beforehand, the spring will not compress further during construction until the load surpasses the pre-compression level. This is useful for construction as, up to this point, the spring is a solid platform. When the building weight surpasses the pre-compression load, the spring will compress further. This releases the compression bolts so that the springs isolate. This method ensures that the structural engineer does not have to allow for movement until the last stages of construction. The disadvantage is that it is impossible to calculate the design load exactly so it is possible that the bearing will either not release or may be overloaded, creating internal stresses within the building structure. It may not be possible to adjust or replace them after construction is completed. These bearings also limit flexibility in the future should extra capacity be required.

Post compressed springs are simpler in design and are designed to be compressed following building construction. The weight of the building is taken on temporary stanchions/pillars during construction and when the building is complete the load is transferred from the stanchions to the springs. The major advantage of this method is that all construction takes place on the solid stanchions and that weight is transferred to the springs with no movement in the structure. The building structure is in perfect equilibrium. The weight is transferred using the load-transfer method shown in Figure 4.

The springs are gradually compressed in small increments against the weight of the building. As the springs are compressed, they support more and more weight. This continues until the springs support the exact weight at each location and the stanchions become loose. They are removed and the springs are then isolating correctly. The springs can be adjusted or changed if the design loading is incorrect and future structural changes can also be accommodated by further adjustment. The load transfer method is flexible as the springs are only compressed by the amount necessary to support the actual building weight – this removes risk from the installation.

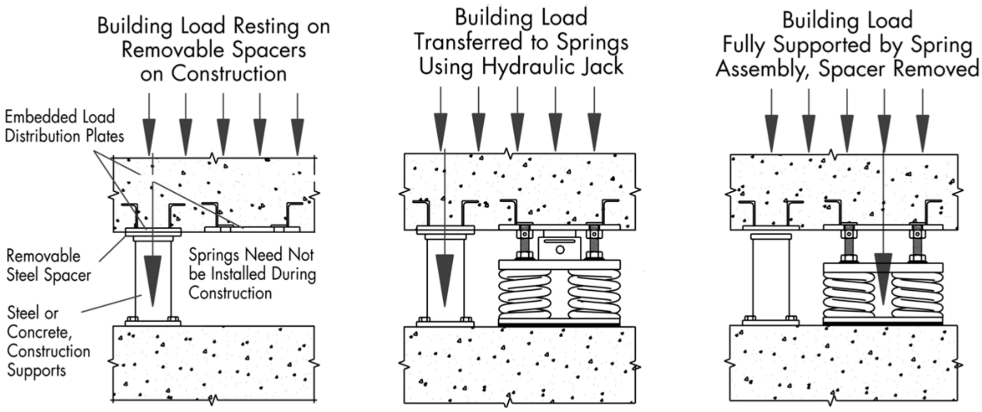

Figure 4: Load transfer method

The structural engineers (Ramböll) favoured the Mason post-compression system as constructing on solid stanchions was conventional and because the springs are adjusted to suit the actual load following construction, it is possible to compensate for variation in the calculated loads.

2.6. Installation

The structural steel was fabricated by Contiga in Norrtälje. Mason U.K worked closely with Contiga to integrate the springs into the columns. Contiga manufactured the structural steel, the column heads and stanchions. The Karolinska stanchion design had two parts, an inner stanchion and outer stanchion. The inner stanchion fitted inside the outer and a bolt linked them together. The weight of the helicopter pad was to be supported by these stanchions until the springs were adjusted. The inner stanchion does not touch the outer stanchion but provide lateral support to meet building regulations. Each column had either two or four stanchions.

There was space for the spring mounts to fit between the stanchions. The spring mounts comprised of the springs, upper and lower compression plates, adjustment bolts and a natural rubber isolation pad. The rubber pad prevents transmission of any high frequencies which may exist - high frequencies are not absorbed by metal springs.

The springs mounts were fitted between the stanchions by Mason UK at the Contiga factory, see Figure 5. The springs were compressed by a small amount to make them secure during transportation to the Karolinska site. When they arrived, the columns with the spring mounts were lifted into place and the helicopter pad was constructed. See Figure 5.

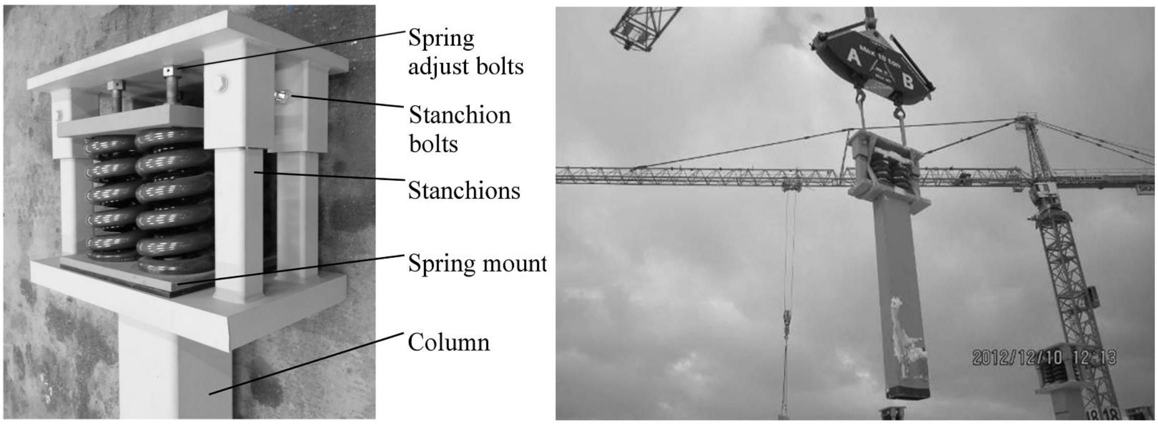

Figure 5: Columns and spring mounts being installed

2.7 Commissioning

The load-transfer method required the helicopter pad to be completed before the weight was transferred to the springs. Springs compress proportionally with load, so if the springs were set before helicopter pad was complete, as material was added the springs would compress further, lowering the helicopter pad. When the helicopter pad was complete (December 2013) Mason U.K. set the springs by transferring the load from the stanchions to the springs. This was done by compressing the springs against the weight of the building. As the springs compressed, they exerted an increasing force against the roof. When this force equalled the load, the springs were fully supporting the roof. The bolts running through the stanchions become loose and were removed.
Smaller spring mounts (normally used to isolate mechanical equipment) can be set by using a spanner to turn the adjustment bolts. The loads were too high at Karolinska to do this, so hydraulic jacks were used to compress the springs. As the springs were compressed downwards, the adjustment bolts were wound upwards. This continued until the springs are compressed to the correct amount, see Figure 6.

Figure 6: Spring compressed with hydraulic jack

All 58 springs were set using this method. It was found that the column loads were different from the design loads in most locations, but because each spring was adjusted to suit the actual load the helicopter pad could still be floated on the springs. In some locations, the load was lower than expected. The springs were therefore not compressed by the required amount. In these locations, the 2.0Hz natural frequency was not achieved, but these locations were still acceptable because the relationship between compression and natural frequency is not linear; the rate of reduction in natural frequency reduces as a spring is compressed. Because of this, the lower spring compression did not have a significant effect on the natural frequency. Figure 7 is a graph showing the relationship between load, compression and natural frequency for one of the locations.

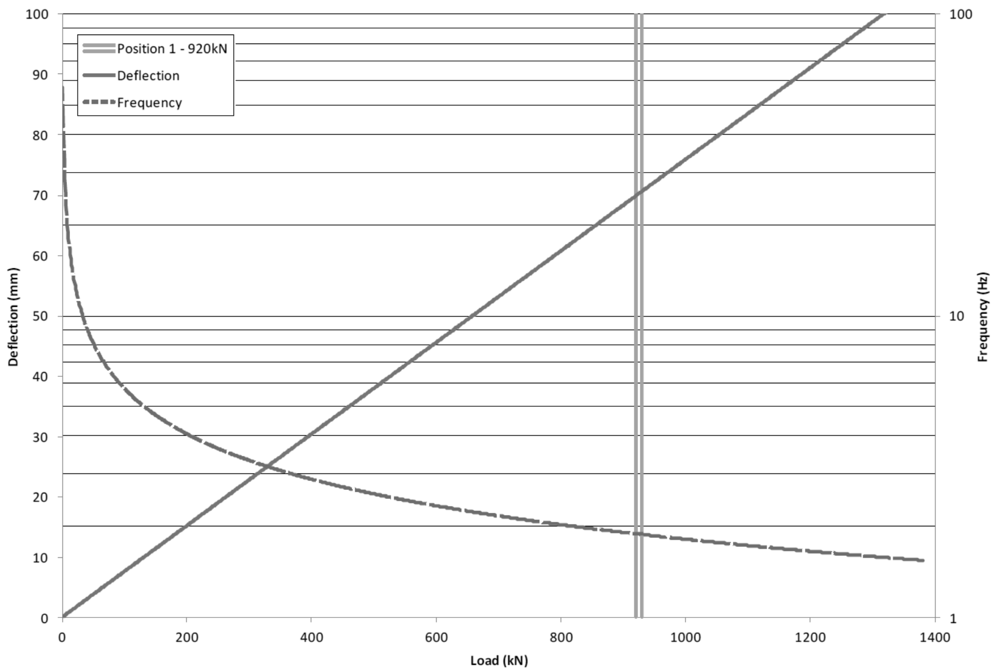

Figure 7: Relationship between natural frequency, load and deflection

The majority of columns were supporting a higher load than designed. Springs supplied by Mason U.K. have an additional 50% travel before they compress to solid. This can be used to absorb variation in design loads and also allows for a significant factor of safety, which assures that the spring will not experience damaging levels of stress. This extra capacity allowed the springs to be compressed to a greater amount and therefore support a higher load. Despite the load variations, the entire roof was successfully floated.

The springs themselves were manufactured in the USA using a hot winding process. This method of manufacture reduces residual stresses in the metal. The springs were also exercised to flat, shot peened and powder coated. All these techniques are essential if the spring is to resist fatigue, creep and corrosion during its life. The springs were designed to last the life of the building with zero maintenance.

3. CONCLUSIONS

The isolation of the helicopter pad at the Karolinska Institute was successful. Each spring mount performed as designed and is isolating the helicopter pad from the structure beneath as intended. The vibrations from helicopter operations will not pass through the spring mounts and disturb work in the hospital below.

The load transfer method ensured that the roof was correctly supported, despite differences between the design and final loads. The design of the column heads and spring mounts allow for the spring packs to be upgraded should extra weight be added in the future.