BRANZ

STUDY REPORT

SR 209 (2009)

Base Isolation of Plant Items in Buildings

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Foundation for RESEARCH SCIENCE & TECHNOLOGY
Tuāpapa Rangahau Pūtaiao

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Abstract

This study evaluated the available off-the-shelf vibration isolators for their suitability as seismic isolators. The function of a seismic isolator is to reduce the acceleration levels that the equipment will be subjected to when installed in a building experiencing earthquake excitation.

While there were found to be many off-the-shelf vibration isolators available, they were all unsuitable as seismic isolators. This was because they were required to be snubbed for stability, meaning that they were effectively restrained against lateral movement and would be subjected to generally the same earthquake forces as an item rigidly mounted on the floor of the structure.

Three truly seismic isolators were found in the literature review. None of these isolators would be expected to provide a vibration isolation function as well. Two of these systems have an ability to return to the start position because they have either elastic locators or run on a curved surface.

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1. INTRODUCTION

1.1 Previous BRANZ investigations

Base isolation of structures has proven to be an economic way of providing protection from earthquake attack. The isolation principle lends itself to heavy-weight buildings of low to medium rise where the potential for overturning under earthquake attack is very low. Typical examples include the William Clayton building (New Zealand's first base isolated building), Wellington Central Police Station, Te Papa and the Parliament Building.

Previous investigations (Thurston 2006) have shown that the application of base isolation to light-weight timber buildings is not generally particularly feasible. Unless the value of the building contents was high, either because of their need to be available after an earthquake or their historic significance, it was not economically viable to isolate the building.

Furthermore wind effects on an isolated light-weight structure were shown to be significant, with the likelihood that the building would be too lively under the wind loading. This behaviour could be improved by the addition of mass such as the inclusion of a heavy concrete floor, but this comes with a cost penalty. Construction detailing and logistics were also considered because the construction was significantly different from 'conventional'.

Considered isolation systems included discrete isolators and slip-type isolators. Each of these has its problems. For the discrete isolator elements to work effectively together, there is a requirement for a rigid floor diaphragm to connect them. Slip isolation systems are relatively cheap to install and the construction process is not significantly different from a normal concrete foundation slab system. There is also not the issue with movement under wind loading.

Issues still to be considered with both systems include appropriate bridging between the isolated structure and the surrounding ground, and also the linkage of services such as power, telephone, water and waste water across the movement gap.

1.2 Current objectives

In line with the arrangement with GNS Science, the current objective is to contribute to the evaluation of the cost-benefits and practicality of low-cost isolation systems for equipment and machinery.

2. WHY WOULD EQUIPMENT AND MACHINERY BE ISOLATED?

This is the fundamental question. It is well known that reciprocating machinery, unless extremely well balanced, will introduce high frequency low amplitude vibration to the supporting structure. The simplest way to eliminate the possibility that the support structure will be affected by the machinery is to include an isolator system. Such systems include suspending the plant item on tension springs from the soffit of the floor or roof above, or supporting the machinery on coiled compression springs or rubber mounts.

Seismic isolation of the equipment is for a different purpose, this being to protect the equipment itself from damage in the event of an earthquake. Isolation invariably increases the natural period of the equipment with a corresponding lower damage because the shift in period results in a lesser seismic demand. The loadings standard, NZS 1170.5 (SNZ 2004), includes provisions for the seismic design of building parts. These parts include all of the plant items contained within a building. However, the commentary to this standard states that "it is important to restrain spring mounted equipment" or other "very flexible and lightly damped components" in buildings. No guidance is given on how this might be achieved.

Consideration is also required to be given to the connections between 'isolated' equipment and its supplies (such as power cables, water pipes, gas pipes, ducts etc) for failure of these due to over-displacement of the isolated equipment would be no less catastrophic than failure of the equipment itself.

Many proprietary isolation systems exist for protection from the machinery vibration, as noted above, but these are often incapable of providing the necessary seismic isolation. The small size of much of the equipment compared to a building structure means that there is not a significant cost in an individual isolator. It seemed appropriate therefore to consider whether off-the-shelf vibration isolation products could be used for seismic isolation, albeit with some modification.

This study set out to identify what off-the-shelf isolation systems there were available and assess these on the basis of their ability to handle earthquake loads.

3. OFF-THE-SHELF PRODUCT SURVEY

A search was undertaken for available machinery isolation products and these have been categorised in terms of their application for seismic isolation.

Consideration was given to:

1. What is the primary function of the isolator (vibration/seismic isolation)?
2. Can the isolators be grouped into generic types (e.g. spring, rubber, slider)?
3. How does the isolator operate (its principle)?
4. Can the vibration isolator be modified to perform as a seismic isolator?
5. How would it perform in an earthquake?
6. What is the maximum weight of equipment that the isolator can support?
7. Can the equipment overturn or is this resisted?
8. If it displaces laterally, is there a maximum displacement allowance?
9. What does it cost?

An internet search was conducted to identify suppliers of isolation equipment. The following companies were discovered:

Robinson Seismic: www.rslnz.com/?pageRequired=showDoc&item=1

Dynamic Isolation Systems: www.dis-inc.com/floor_design.html ,

Floor isolation: www.dis-inc.com/floor_isolation.html

Cummins Power: www.cumminspower.com/newsletters/global-9-2008.jsp

California Dynamics Corporation: www.milliganspika.com/Seismic_Products.html

Ace Mountings Co Inc: www.acemount.com

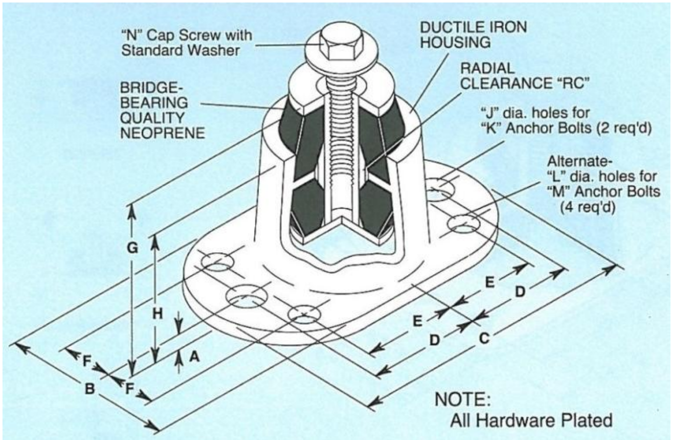
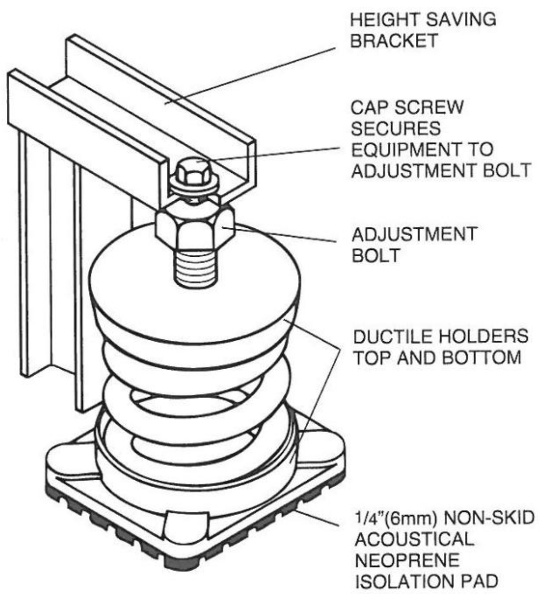
Vibro/Dynamics Corporation: www.vibrodynamics.com/english/sprng-vsc.html

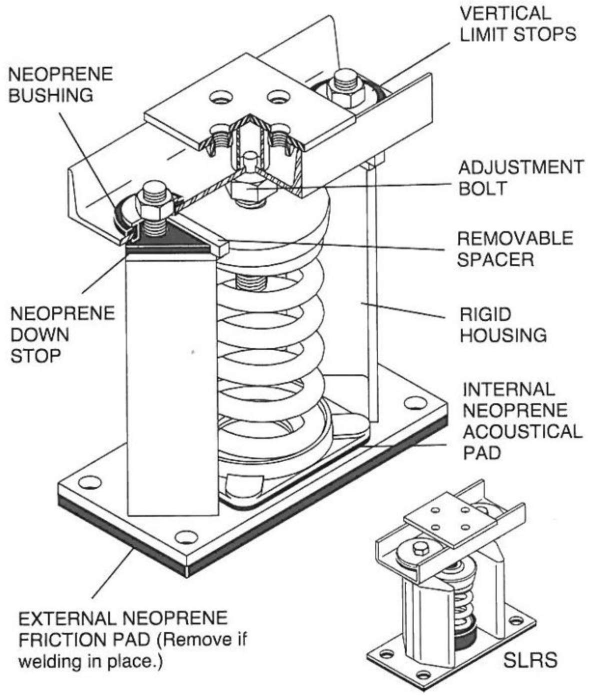
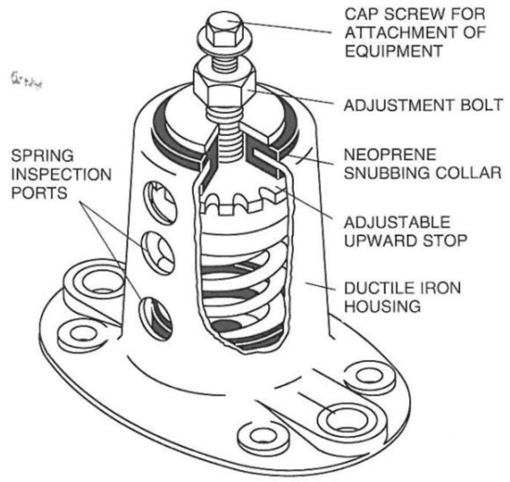
Kinetics Noise Control: www.kineticnoise.com/seismic/fms.html

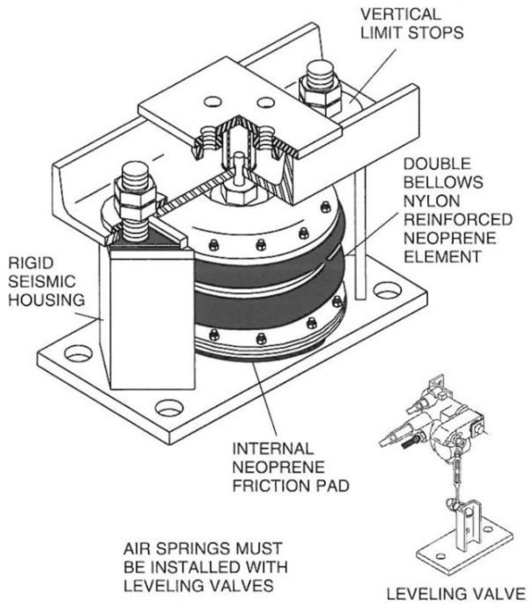
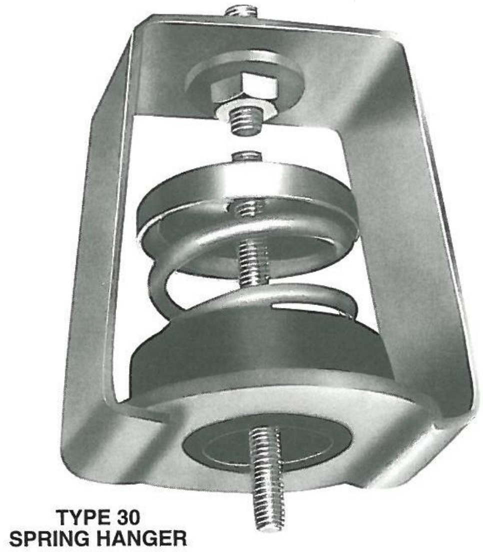
Mason Industries Inc: www.mason-ind.com/masonind/private/hvac_seismic/hvac_seismic_main.cfm

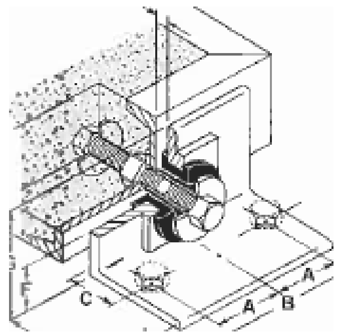
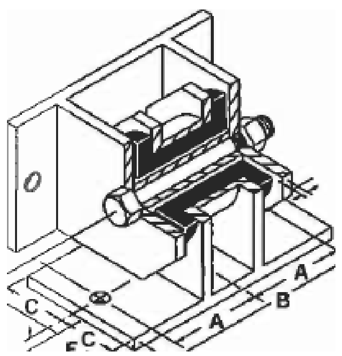
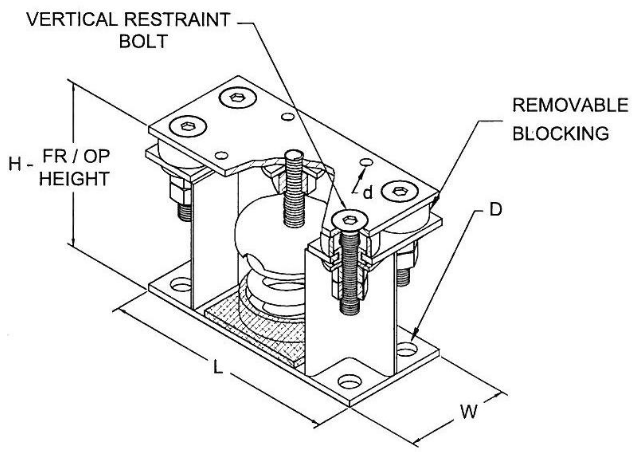
All available information on products marketed by the above organisations has been tabulated in Table 1.

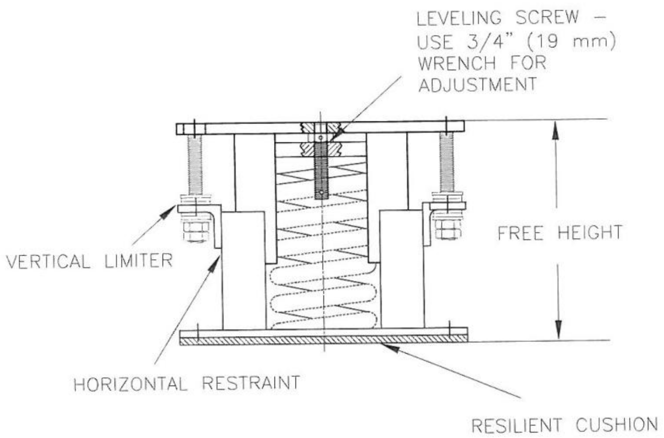
Table 1. Vibration isolators for equipment

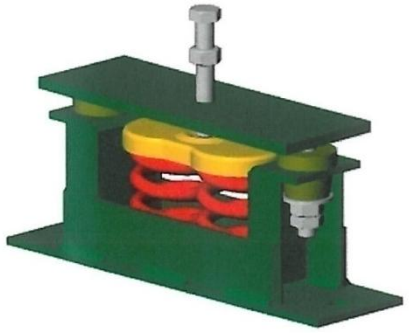
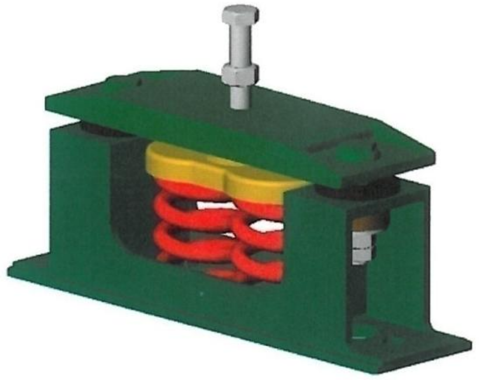
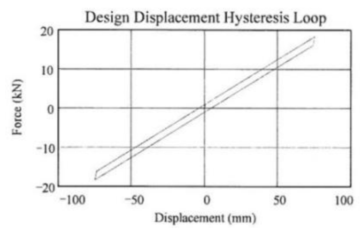
Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
Restrained BR Mount	Mason Industries Inc		NA	Unknown	9 – 476 kg	Various sizes: 156 – 5,716 kg (minimum four isolators) 39 – 1,556 kg uplift resistance (per isolator)	Neoprene bearing supports vertical load. Lateral load resisted by bearing housing	??	3 – 13 mm lateral deflection in shear. Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
SLF Spring Mount	Mason Industries Inc		NA	Various sizes: from 1 spring: 227 g up to 16 springs: 54 kg	NA	Various sizes: from 1 spring: 10 kg up to 16 springs: 17,300 kg	Spring force	Various sizes: from 1 spring: US$28 up to 16 springs: US$1,030	Needs to be combined with a snubber or other arrangement that dissipates horizontal energy and arrests plant displacement (e.g. Z-1011 or Z-1225; see full description below)

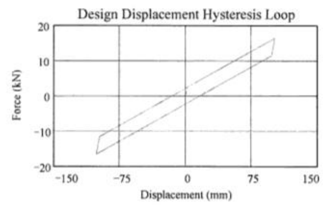
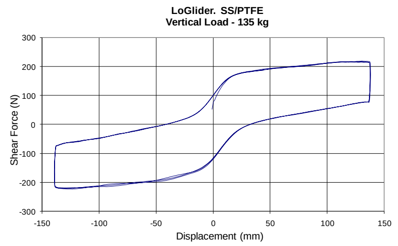
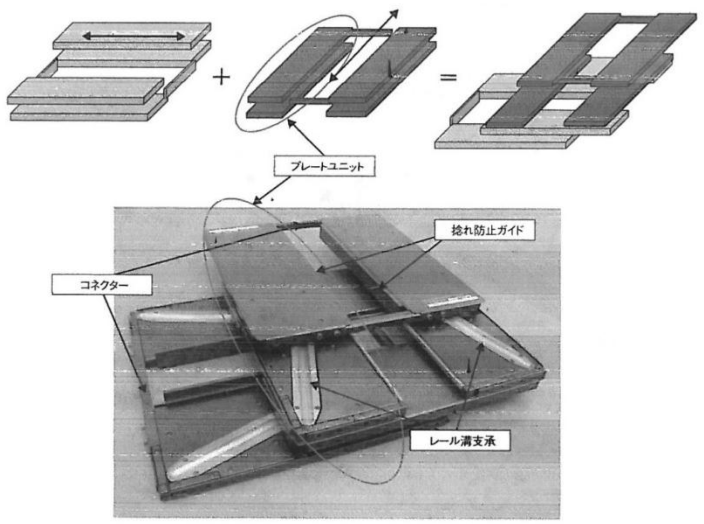
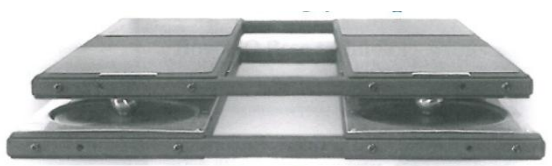
Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
SLR & SLRS Spring Mount	Mason Industries Inc		NA	Various sizes: from 1 spring: 7.7 kg up to 16 springs: ?? kg	Various sizes: from 1 spring: 3.5kN up to 16 springs: 116kN	Various sizes: from 1 spring: 10 kg up to 16 springs: 17,300 kg	Spring force with neoprene bushing snubbers	Various sizes: from 1 spring: US$75	Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
SSLFH Housed Spring Mount	Mason Industries Inc		NA	From 900 g to 43 kg	from 163N to 2kN	from 10 kg to 2,000 kg	Spring force with neoprene snubbing collar	From US$75 to US$1,130	Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
SLR Air Spring Mount	Mason Industries Inc		NA			From 1,360 kg to 5,455 kg	Air filled bladder is inflated to desired pressure		Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
30 Spring Hanger	Mason Industries Inc		NA	1 kg	NA	Up to 95 kg	Compression spring	Up to $US27	These are the most basic of the spring hangers offered by Masons. Others include a second spring in the form of a Neoprene pad and can support greater weights. These provide no resistance to lateral loading

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
Z-1225 All-Directional Seismic Snubber	Mason Industries Inc		NA	From 4 kg to 23 kg	From 1.1kN to 22kN	N/A	Rubber compression	From US$60 to US$417	This snubber is intended to arrest a machine's horizontal movements during a seismic event. It could be used coupled with a vibration isolator
Z-1011 All Directional Seismic Snubber	Mason Industries Inc		NA	From 5 kg to 113 kg	From 2.2kN to 111kN in all directions	N/A	Rubber compression	From US$245 to US$1,800	This snubber is intended to arrest a machine's horizontal movements during a seismic event. It could be used coupled with a vibration isolator
Model FLSS Seismic Control Restrained Spring Isolator (1, 2 or 4 springs)	Kinetics Noise Control		NA		1g	From 113kg up to 30,000 kg for four isolators	Compression spring. Uplift restraint provided		Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
Model FMS Modular Restraint/Isolator (1, 2 or 3 springs)	Kinetics Noise Control		NA	Unknown	Up to 31,000 kg per isolator	Up to 40,000 kg for four isolators	Compression spring for vertical forces and elastomeric rubber for horizontal forces. Uplift restraint provided	Unknown	6 mm lateral deflection in all directions. Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
VSC Spring Mounts (1, 2 or 4 springs)	Vibro/Dynamics Corporation		NA	Unknown	Unknown	Up to 5,480 kg for four 1 spring isolators, 11,000 kg for four 2 spring isolators and 22,000 for four 4 spring isolators	Compression spring for vertical forces and steel guides for horizontal forces. Uplift restraint provided	Unknown	No lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly. Rectangular shape of 2 spring isolators suggests careful alignment of four isolators would be required
Series 630 Spring Isolators	Ace Mountings Co. Inc	 632  632-4 : California Seismic Zone 4 Applications	NA	Unknown	Rated for USA seismic zone 4 applications	Up to 4,500 kg for four 1 spring isolators and 9,000 kg for four 2 spring Isolators	Compression spring for vertical forces and elastomeric rubber for horizontal forces. Uplift restraint provided	Unknown	Small lateral deflection means easy to connect pipes etc, to equipment but does not alter the response frequency significantly

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
Series 820 Spring Isolators	Ace Mountings Co. Inc	 Seismic Zone 2 Capability	NA	Unknown	Rated for USA seismic zone 2 applications	Up to 18,000 kg for four isolators	Compression spring for vertical forces and elastomeric rubber for horizontal forces. Uplift restraint provided	Unknown	Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
Series 920 Spring Isolators	Ace Mountings Co. Inc	 **Seismic Zone 2 Capability**	NA	Unknown	Rated for USA seismic zone 2 applications	Unknown	Compression spring for vertical forces and elastomeric rubber for horizontal forces. Uplift restraint provided	Unknown	Small lateral deflection means easy to connect pipes etc to equipment, but does not alter the response frequency significantly
Rubber bearings	Dynamic Isolation Systems Inc	No diagram available		Unknown	18.3kN	Large	Shear displacement of rubber/steel shims	Unknown	This is a true isolator in that the period of oscillation is extended, but snubbers may be required at maximum bearing displacement. Tuning would be required and an appropriate bearing selected. Best use would be for heavy

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
									equipment such as boilers or chillers
Rubber bearings	Dynamic Isolation Systems Inc	Not available		Unknown	16.5kN	Large	Shear displacement of rubber/steel shims with internal lead plug for energy dissipation	Unknown	
LoGlider	Robinson Seisimic Ltd			Unknown	230N	1.35kN per glider	A sliding puck is suspended by 'bungy cord' ties to an outer ring	Unknown	The disc is 650 mm diameter. The system has no restraint provided against uplift
Magni Cradle G Series	Nachi		NA	Unknown	Unknown	Unknown	Ball bearing races in two orthogonal directions allowing movement in all directions horizontally	Unknown	No apparent damping. Ball bearings may rise up a slope in the track to dissipate energy
ISOBase Seismic Isolation Platform	Worksafe Technologies	 ISO-Base™ Seismic Isolation Platform with patented Ball-N-Cone™ Isolators	Not available	Platform 28 – 43 kg	Unknown	500 – 800 kg per platform	Four ball bearings in opposing concave dishes	Depends on installation. $6k but cheaper in	No apparent damping. Ball bearings rise up a slope of the dish to dissipate

Brand/Make	Manufacturer	Diagram/Photograph	Hysteresis Loop	Weight of Isolator	Max. Horizontal Force	Max. Plant Weight	Principle of Operation	Cost	Comments
								quantity	energy. Stops around top of dish

NA = Not applicable

4. OFF-THE-SHELF PRODUCT CHARACTERISTICS

As can be seen from Table 1, the majority of the discovered products are only vibration isolators, with no true seismic isolation that would alter the response of the equipment from a rigid support. These are therefore not true earthquake isolators because the snubbers constrain the equipment to move with the supporting structure.

The exceptions are the Dynamic Isolation Systems Inc. isolators, the Nachi Magni Cradle and the LoGlider isolator.

4.1 Dynamic Isolation Systems Inc isolator

This isolator is a true lead-rubber bearing manufactured by an organisation that specialises in the fabrication of isolation bearings for buildings. The available bearings are still quite large and would probably only be suitable for use with heavy chillers and boilers.

4.2 Nachi Magni Cradle

This system utilises two orthogonal tracks with ball bearings to isolate the equipment from the supporting structure. This is also referred to as a tuned configuration rail. Separate snubbers would be required to arrest the motion should the bearings reach the end of the tracks.

Other unidentified systems have been used to isolate suspended equipment such as operating theatre lights from seismic forces. The systems include similar sliding rails to the Nachi principle with apparently no available damping.

4.3 ISO Base Seismic Isolation Platform

The principle of operation of this platform is similar to the Nachi Magni Cradle. The simplest unit consists of four ball bearings sandwiched between two conical plates. As the surface beneath the unit accelerates horizontally, the ball bearings roll up the slope of the conical plates. The rising effect dissipates seismic energy and the upper part of the unit returns to its original position after the earthquake.

4.4 LoGlider isolator

The Gannon isolator employs a puck system between two smooth plates. The puck is held in position by ‘bungy cord’ ties to an outer ring. The height of the isolator is small, assisting stability but the plan area is large at 650 mm in diameter. The plan area of the supported equipment would need also to be large to accommodate at least three of these isolators. No resistance is provided to uplift forces, and so the supported equipment would need to be squat in shape so that overturning under earthquake motion would not be a possibility.

5. OTHER RESEARCHED SYSTEMS

The idea of supporting a rigid flat smooth base of the equipment on an equally rigid smooth flat surface with a pressurised fluid interface has been considered (Taskov et al, date unknown). The pressure in the fluid influences the slip resistance of the interface. In addition to the sliding surface, a series of horizontal springs was installed around the perimeter of the equipment base to ensure that the equipment returned to a centred position after the earthquake. The researchers found that it was important to make sure that the spring stiffnesses were correctly selected to ensure that the resonant frequency of the isolated system was lower than the predominant frequency of the design earthquake. Under harmonic motion and a series of earthquake records the acceleration of the equipment was recorded to be between one-half and one-sixth the excitation acceleration. Because there is no resistance to uplift, the expectation is that the supported equipment would need to be squat in shape. Also, a pump would be required to continuously maintain the fluid pressure.

6. CONNECTION OF SERVICES TO ISOLATED EQUIPMENT

Equipment that is vibration isolated with snubbers to prevent horizontal displacement in an earthquake will provide no obstacles to the connections of services such as power, water, gas etc. Rubber expansion joints are commonly used for the connection of pipes to vibration isolated equipment. This has a two-fold use: vibrations from the plant are not translated into the pipe system; and any small seismic displacements (before snubbers come into play) can be accommodated.

Seismically isolated equipment will require better fittings than expansion joints to accommodate the larger expected displacements of the equipment. Electrical cables may be connected by allowing sufficient 'slack' in the connection, so that as the equipment moves the difference is taken up by the extra cable length. For piped services, the connection is more difficult. Pressurised pipes must be connected with flexible links that can also withstand the pressure. Heavy walled rubber hoses can be used for low pressure systems.

7. CONCLUSIONS

This study has determined that the number of off-the-shelf true seismic base isolation systems available appears to be relatively small. Vibration isolation components are, on the other hand, in plentiful supply. While many of these have the potential to provide seismic isolation, lateral displacement beyond a certain point would result in instability. For this reason, snubbers are supplied to prevent the over-displacement of the supported equipment. Generally the snubbers are fitted very close to the edge of the equipment, meaning that the displacement of the structure is immediately transferred to the equipment, and this effectively nullifies the isolation of the equipment.

APPENDIX A REFERENCES

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