A Practical Approach to Building Isolation

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ABSTRACT

As a result of worldwide acoustical consultant specifications, entire buildings have been isolated for over 60 years. Base Building Isolation has its merits, turning marginal properties (based on their proximity to rail systems) into multipurpose high-end developments free of vibration and re-radiated noise. This discussion will focus on Low Dynamic Stiffness (LDS) Structural Isolation Bearing Pads and the relationship between the acoustician, design team and manufacturer and focus on installation and construction. The acoustician, design team and manufacturer are more than capable of measuring, designing, detailing and complying with building codes to establish the proper natural frequency of support and the design criteria for construction. It is during construction when the acoustical integrity of the structure is most fragile, where the resulting vibration reduction is compromised by unforeseen short-circuiting of the isolation system, which is a function of location and the ability to inspect the isolation plane. This discussion will also focus on existing projects and understanding that the complications of any Base Isolation project are educating the contractors, being on site, and being vigilant about identifying and mitigating short circuiting before substantial completion. The intent is to identify common concerns and offer practical solutions to typical problems.

1 INTRODUCTION

The most critical aspect of any building isolation project is the relationship between the acoustical consultant, structural engineer, builder and supplier. Structural engineers are conservative by nature. So understanding that relationship is critical. No structural engineer wants to re-engineer a building isolation system after the job is bid when all parties have collectively breathed a sigh of relief that the system, as designed, will function properly.

After the acoustical consultant has taken measurements and performed an analysis to ensure no perceptible vibration or re-radiated noise will affect the structure, the design team has the task of coming up with a cost-effective method of supporting the structure to be code compliant for both wind and earthquake loads, all while addressing the requirement to reduce the vibratory energy that comes from proximity to some rail or highway. Recently the New York City Metropolitan Transit Authority released dozens of properties for development that were considered marginal, previously utilized as parking garages or warehousing, so they could be developed into residences or multi-purpose commercial buildings with no sacrifice to the type or method of construction. With the global urban construction boom, most major cities are developing commercial and/or residential properties near rail lines, so making the space tenable and providing a 100-year isolation system guarantee is required.

This paper starts with a discussion of the design team and the acoustical consultant's role, moves into design and manufacturing, then discusses the requirements of independent testing along with the development of data so that the product is not over-designed but fit for purpose in its ability to handle the service loads and resist creep. Then the discussion focuses on the contractor/builder's role and, finally, on the combined roles of the design and construction team during construction.

2 THE DESIGN TEAM

The design team consists of the architect, structural engineer, acoustical consultant, and for reasons to be discussed further, the isolation bearing supplier. Based on the developer's requirements, the architect designs the building in conjunction with the structural engineer with an isolation system based on an acoustical consultant's testing and analysis as a result of the construction's proximity to a rail line. During the process, code compliance, longevity and means and methods are all discussed and that is normally when the bearing manufacturer becomes part of the design team. Without developing concept drawings and establishing a functional design that incorporates isolation bearings, it's hard to progress the project without real details for the structural engineer and the architect. So, a finite design is required, and that is usually worked out with the acoustical consultant, structural engineer and isolation supplier. Many design team development meetings with all the players will likely occur.

The developer's concern is the most cost-effective way to achieve design intent. The structural engineer's concern is the integrity of the design and isolation materials, and the need to handle building code loads. The architect has to deal with interior and exterior finishes, which can potentially short-circuit the isolation system, i.e. internal stairways and curtain wall supported by the isolated structure but landing on non-isolated curbing on the ground floor subject to vibration.

The acoustical consultant has to "ride shotgun" over the entire group to achieve the desired result and this is where the most important aspect of construction comes up, multiple site inspections to prevent short-circuiting or flanking of the isolation system.

It only makes sense that a single natural frequency of support for the entire structure be considered as it prevents the possibility of having a random frequency or resonance in the structure that needs to be mitigated once construction is complete. Retrofitting building isolation is practically impossible and the installed isolation system should result in functionality through a wide range of disturbing frequencies. The typical design of the structural bearings is less than 8 Hz and based on service loads as opposed to code loads, which facilitates achieving the desired vibration reduction. It is also prudent to perform a bearing natural frequency analysis at 80%, 100% and 120% of the service loads because factors of safety and conservative estimates often result in higher than specified natural frequencies of support. Working with the structural engineer and getting these points across is a critical step in achieving design intent.

The second most important step after selecting natural frequency of support is to determine the isolation plane. This discussion normally involves the developer and the design team. The debate about the location can take time and elevating it within the structure is one way to limit potential short-circuiting. Why isolate lower level car parks when they will impact the success of the isolation system? Put them below the isolation plane and solve two problems.

Once the architect completes their design and the structural engineer has worked with the acoustical consultant, then it is time for the isolation vendor to detail the isolation bearing design to facilitate the bidding process allowing the construction manager and builder to understand how the project is to be built and what areas to focus on.

Handling seismic and wind loads can easily be achieved with shear keys, shear pins or isolated columns in concrete pile cap pits as long as short-circuiting is prevented. The development of shear keys, shear pins and structural restraint systems normally evolve separately working with the structural engineer. The key is to understand that the structural engineer must comply with the building code and we must still achieve a cost-effective, non-vibration transmitting design that is easy to install. When the design team functions cohesively, the net result is a job that is easy to build.

3 BRIDGE BEARING PAD DESIGN

The design of a properly engineered structural bearing for building isolation requires a tested and certified low dynamic stiffness compound, shape factor curves, and a low stress low strain design for longevity. Shape factor curves, as shown at Page 5 (Figure 4), are required so that the bearings can be designed well below their maximum allowable stress/strain limit. Dynamic stiffness correction factors are a simple way to equate a structural isolation's bearing, actual natural frequency to that of a helical steel spring. As an example, if a steel spring is designed for 25mm's of deflection, the resulting natural frequency is 3.13 Hz. If a structural bridge bearing is designed for the same load and the same deflection, 25mm, then its corrected natural frequency, for a 60 durometer compound, is 4.07 Hz because the 60 duro compound has a dynamic stiffness correction factor of 1.3 and 1.3 x 3.13 gives us the actual natural frequency of the bearing at 25mm deflection. In order for that same bearing to be designed for 3.13 Hz, its thickness must be increased and the deflection required to achieve 3.13 Hz is almost 33mm. One of the problems is understanding the relationship between dynamic stiffness correction and bearing thickness to achieve the desired natural frequency of support. The most common misunderstanding in this design process is that a 25mm deflection helical steel spring and a 25mm deflection pad have the same natural frequency. Running independent tests for dynamic stiffness correction is the only way to design proper bearing with the correct natural frequency of support. For example, test results for a 40, 50 and 60 durometer bridge bearing quality natural rubber used for building isolation show that the dynamic stiffness correction factors are 1.17, 1.28 and 1.30 respectively, which means they are well below the standard acoustical threshold of 1.4. All dynamic stiffness tests should be independently performed and certified.

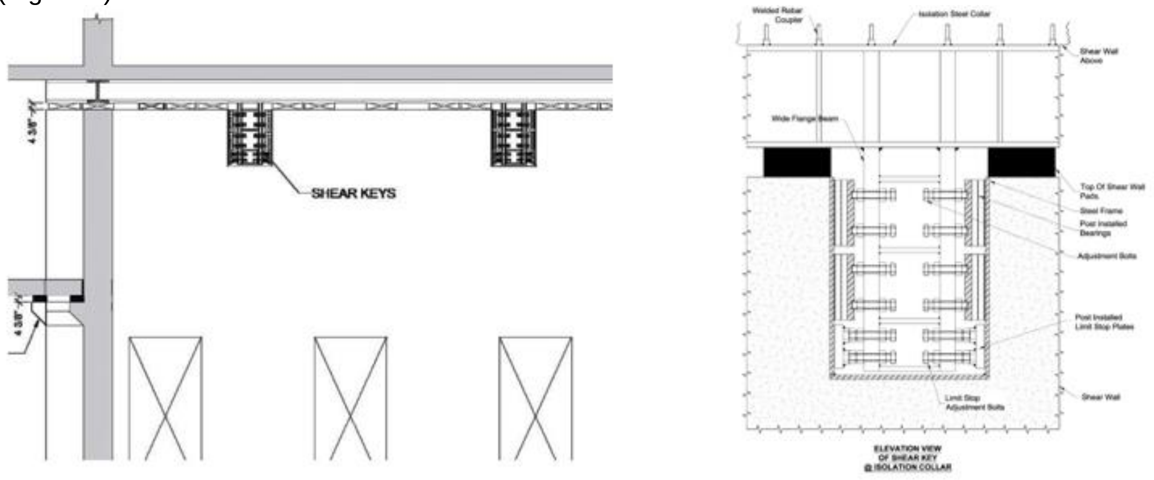
When we talk about 'low stress low strain', the impact this has on the design team is that the bearings become larger impacting column capitals' sizes, wall widths, etc. All too often, bearing suppliers utilize higher durometers with higher dynamic stiffness correction factors to create smaller bearings that are over-stressed but cost less to manufacture. Designing high stress bearings directly affects their longevity. After years of debating synthetic vs. natural rubbers, it was found that bridge bearing quality natural rubber ultimately is the best building isolation material. When designed, manufactured and installed properly, it can be said to have a life equal to the structure.

A design issue of equal importance and not always discussed, is the effect of long term creep and the requirement for creep testing. Every manufacturer should have independent long term creep testing done on all of their bearing formulations so additional deflection over time is a known value for all durometers.

4 ENGINEERING EXPERIENCE

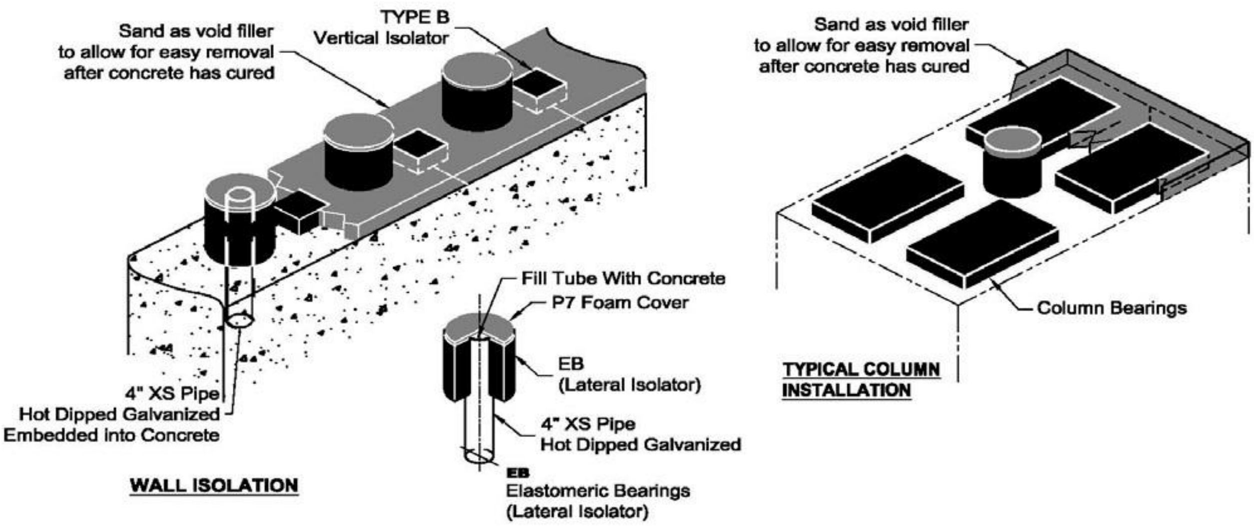
On most building isolation jobs, one should start with the design of the isolation bearings. The heavy lifting involves the coordination of the bearing dimensions to their structural supports and working with the architect and the builder to confirm the 100% design drawing set is buildable. Working closely with the design team and generating the necessary details proves the most reliable way for the construction process to run seamlessly.

Handling earthquakes, wind loads and in some cases (due to proximity to rail lines) the impact force of a rail car would become the greatest priority for the structural engineer. Shear keys in saw tooth arrangement are shown below (Figure 1).



Source: Mason Industries, Inc. (2017)
Figure 1: Shear Keys 60 Bond Street, Brooklyn, NY

Shear pins (Figure 2) function well around a building's perimeter and at column capitals and are acoustically separated from the structure by a bearing with equal deflection to the bearings handling vertical loads, so there is no loss of isolation efficiency through the shear pin. Shear pins and shear keys have been utilized on dozens of projects worldwide.



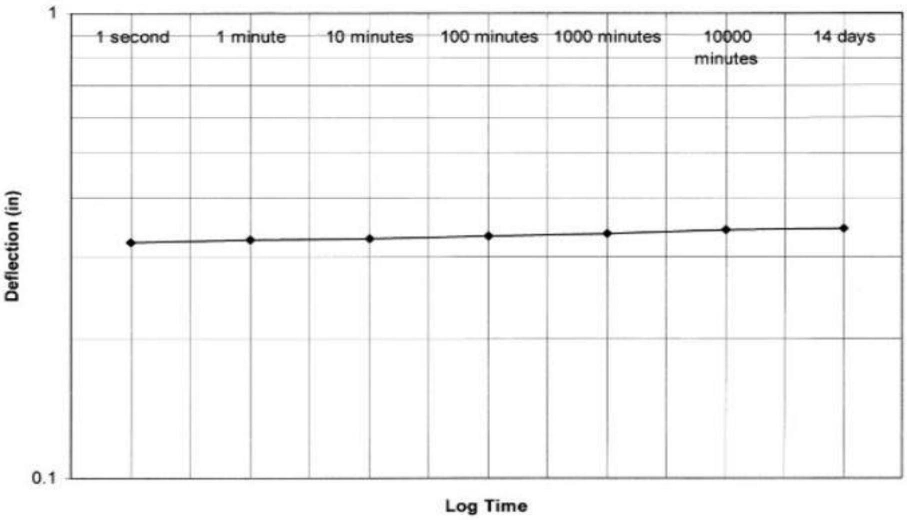
Source: Mason Industries, Inc. (2008)
Figure 2: Shear Pins

Handling shear loads to the structural engineer's satisfaction is critical to progressing the design to be construction-ready. In order to ensure proper installation and function of the bearings and lateral restraints, one should expect that 20 to 100 site visits are required for inspection depending upon a project's complexity. One should also allow for approximately 100 to 200 hours of engineering dedicated to the design and layout of the shear keys, tension rods and bearings, all coordinated to the sizes of column capitals, shear walls, plinths or curbing, and required so there is no question about means and methods once the drawings are issued for construction.

There are two additional items that need to be addressed, and they are fire protection and limit stops. Fire protection is normally fire resistant cladding or insulation and we've seen a number of different products utilized that comply but vary by building code from Country to Country. When elastomeric bearings are exposed to extreme heat, they tend to harden so there is no loss of elevation. However, exposing bearings to fire will eventually cause them to fail, so insulation or cladding is typical. Utilizing vertical limiting down stops is an alternative method and they can be formed from concrete, so long as the allowable stress isn't exceeded, or steel plate. The choice is based on whatever the design team agrees what method best supports building code compliance.

5 TESTING OF CERTIFIED BEARINGS

Proper design and testing of bridge bearing building isolation allows owners and developers to understand through the design team that the bearings are engineered properly based on loads defined by the structural engineer and are manufactured with longevity in mind. The most important test on any building isolation material is long term creep. Long term creep is defined as the additional deflection over time after a bearing is fully loaded. If the building isolation bearing deflects 5mm after construction and 10 years later it has deflected 6mm, there is 1mm of deflection due to long term creep. Reducing creep is the goal of the supplier/manufacturer. Every bearing supplier must be able to certify long term creep testing by an independent laboratory. Long term creep is a cornerstone of the building isolation process. In addition to long term creep, there should be physical properties' testing, all of which are relatively simple. In order to correctly certify a bearing's physical properties, the test methods and material properties should comply with internationally recognized standards. These include ISO, ASTM and AASHTO, American Association of State Highway Transportation Officials, and conduct tensile strength, elongation at break, with additional testing after heat aging of tensile strength, elongation at break, ozone resistance, compression set and dynamic stiffness.

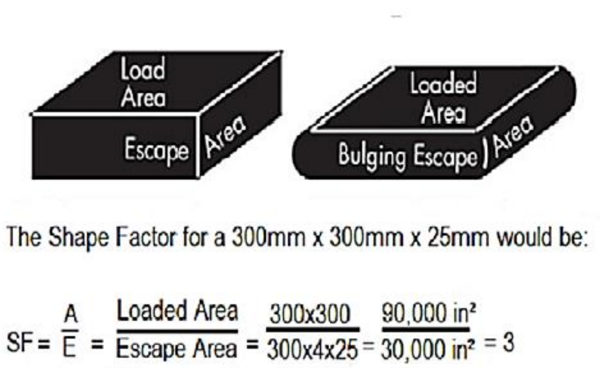


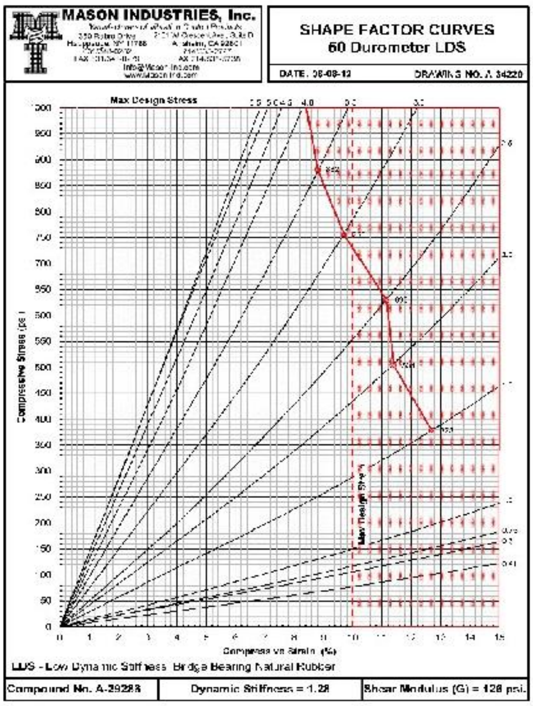
Creep Test Results:

Time	Deflection (in)
1 second	0.32063
1 minute	0.32512
10 minutes	0.32829
100 minutes	0.33152
1000 minutes	0.3356
10000 minutes	0.34149
14 days	0.34472

Source: Environmental Services Inc. (2013)
Figure 3: Example of Creep Test result for one column pad (60 Duro)

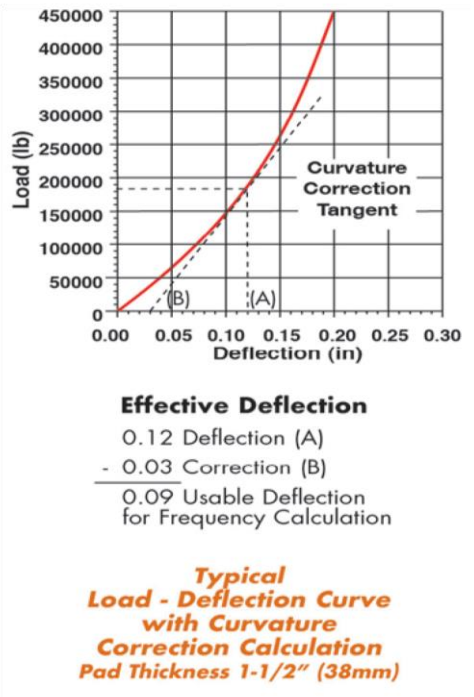
In addition to the tests above (Figure 3), the fundamental method of determining a bearing's stress strain relationship is the development of compound specific shape factor curves. Shape factor is the bearings loaded area divided by the escape area. The escape area is based on the distance between shims, so as an example, if a bearing is 100mm tall and has 3 shims, then you subtract 5mm for the bearings' cover thickness x2, plus the 3mm for the steel shim thicknesses x3 and divide by 2 – the result, a bearing pad with an active thickness between shims is 40.5mm. A typical example of the calculation and shape factor curve for a common compound used in building isolation is shown in Figure 4. The curve is compressive stress vs. compressive strain, compressive stress is in pounds per square inch, and strain is a percentage reduction of the overall thickness under load.

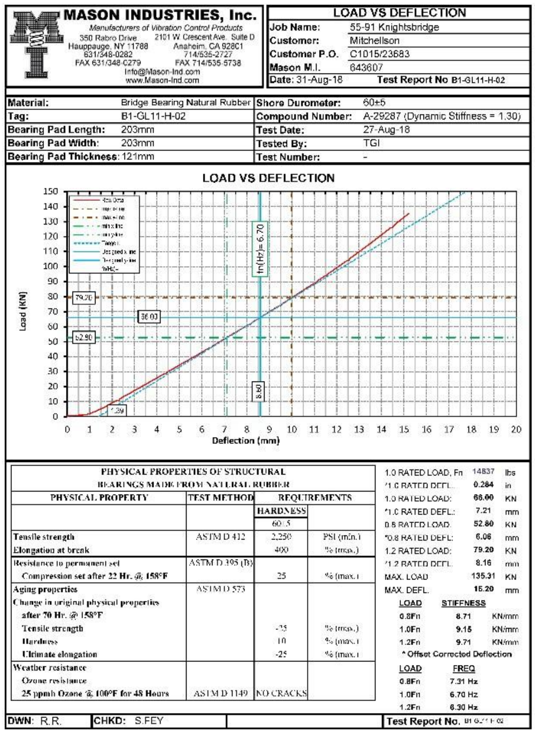




Source: Mason Industries, Inc. (2012)
Figure 4: Shape Factor Calculation + Shape Factor Curves

During the manufacturing process, it is equally important to test every bearing after it has been molded for load vs. deflection and bond strength. A load deflection curve is shown below (Figure 5) for a project recently completed in Knightsbridge, London, England. Load deflection testing verifies that the bearings not only handle the actual load and deflect as designed, but also handle 1.5 times the design load without bond failure. It is the combination of independent testing, shape factor curves and load deflection tests that allow the certification of longevity by providing guarantees and warranties.





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LOAD VS DEFLECTION

Job Name:	55-91 Knightsbridge
Customer:	Mitchellson
Customer P.O.	C1015/23683
Mason M.I.	643607
Date: 31-Aug-18	Test Report No B1-GL11-H-02

Material:	Bridge Bearing Natural Rubber	Shore Durometer:	60±5
Tag:	B1-GL11-H-02	Compound Number:	A-29287 (Dynamic Stiffness = 1.30)
Bearing Pad Length:	203mm	Test Date:	27-Aug-18
Bearing Pad Width:	203mm	Tested By:	TGI
Bearing Pad Thickness:	121mm	Test Number:	-

PHYSICAL PROPERTIES OF STRUCTURAL BEARINGS MADE FROM NATURAL RUBBER

PHYSICAL PROPERTY	TEST METHOD	REQUIREMENTS	
		HARDNESS	
		60±5	
Tensile strength	ASTM D 412	2,250	PSI (min.)
Elongation at break		400	% (max.)
Resistance to permanent set	ASTM D 395 (B)		
Compression set after 22 Hr. @ 158°F		25	% (max.)
Aging properties	ASTM D 573		
Change in original physical properties after 70 Hr. @ 158°F			
Tensile strength		-25	% (max.)
Hardness		10	% (max.)
Ultimate elongation		-25	% (max.)
Weather resistance			
Ozone resistance			
25 pphm Ozone @ 100°F for 48 Hours	ASTM D 1149	NO CRACKS	

1.0 RATED LOAD, Fn	14837	lbs
*1.0 RATED DEFL.	0.284	in
1.0 RATED LOAD:	66.00	KN
*1.0 RATED DEFL.:	7.21	mm
0.8 RATED LOAD:	52.80	KN
*0.8 RATED DEFL:	6.06	mm
1.2 RATED LOAD:	79.20	KN
*1.2 RATED DEFL.	8.16	mm
MAX. LOAD	135.31	KN
MAX. DEFL.	15.20	mm

LOAD	STIFFNESS	
0.8Fn	8.71	KN/mm
1.0Fn	9.15	KN/mm
1.2Fn	9.71	KN/mm

* Offset Corrected Deflection

LOAD	FREQ
0.8Fn	7.31 Hz
1.0Fn	6.70 Hz
1.2Fn	6.30 Hz

DWN: R.R. CHKD: S.FEY Test Report No. B1-GL11-H-02

Source: Mason Industries, Inc. (2018)
Figure 5: Load vs. Deflection Test Reports

It's too easy to just 'say' that the bearing is capable; it's much more difficult, time-consuming and costly to 'prove' that the bearing is capable, and certified independent testing is the only way the developer and design team can sleep at night. Too often builders who are interested in price only will say: "What is the cost reduction for 30, 50 or 75 year guarantees?" The response should always be: "To design a bridge bearing properly, it has to be low stress low strain, so there is no cost reduction for reducing the length of the warranty or guarantee". It's a trap the industry shouldn't fall into.

6 SITE INSPECTIONS AND CONSTRUCTION

After the contractor has been chosen and the construction has started, the most important phase of any building isolation project consists in site inspections by the acoustical consultant and bearing supplier looking for short-circuits.

If the isolation plane has been chosen between the ground floor and first floor, then any system, whether elevators, mechanical, plumbing or electrical services, that pass the isolation plane, must not only be able to handle the deflection of the bearing pads during construction but must also ensure that they do not transmit vibration from the foundation to the structure. On every bearing project, multiple site visits are required to inspect construction and ensure the sanctity of the isolation plane. The number of visits can be anywhere from 20 to 100, depending on the type of isolation system or intricacy of construction. Anything that crosses the isolation plane, whether drywall in a stairwell, plumbing piping in a chase, supply and return risers for heating and cooling systems, or something as simple as fuel oil for the roof top generators, all require proper installation and flexible connectors to accommodate the deflection of the building isolation at the isolation plane. One of the most significant transmission sources is the elevator rail in shafts. The design team must address all of these issues in advance and site visits ensure that the construction achieves the intent. Multiple site visits are a fundamental part of every building isolation job. If a riser gets installed that is neither isolated nor flexed as it passes the isolation plane, retrofitting may not be possible or, if it is, quite costly. The build-it-right, build-it-once thought process requires attention to detail coupled with site inspections.

7 CONCLUSIONS

There are obviously many details involved in designing and constructing a building isolation project. The acoustical community should try to get involved as early as possible and progress the design and engineering so that 100% construction drawings are completed long before site preparation. Resolving design issues after a job has gone out for bid, leaves the owner, developer and builder open to unforeseen costs. Once the job is under construction, the most important thing is site visits. It is important to talk to all the building trades and explain the sanctity of the isolation plane and the need for proper vibration isolators by various sub-contracted works, including but not limited to mechanical, plumbing, electrical, fuel oil, ducting and fire sprinkler pipe. The construction/building teams must all be aware of the requirements before they start construction.

The most significant requirement during construction is pursuing anything that can short-circuit the isolation system. Once the design team understands and the builder's crew is educated, the results are achieved through vigilance. Building isolation is straight-forward, and working with educated consultants and knowledgeable suppliers gets a job done and done well.