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QUALITY ISSUES OF SEISMIC RESTRAINTS FOR NON-STRUCTURAL BUILDING COMPONENTS SUBJECT TO EXTREME CONDITIONS

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ABSTRACT

Mechanical and electrical equipment that generate noise and vibration are mounted on vibration isolators. For seismic applications these isolators are designed with restraint parts that limit the movement in specific direction. To enable easy manufacturing and assembly designers prefer standard bolts, studs that are readily available in the market. These bolts form the main restraint part of the seismic isolator. They are assembled in holes that include elastomeric elements to prevent metal to metal contact. Recent dynamic (shake table) tests exposed catastrophic bolt failures. Most of the failures were found to be related to material composition. Low grade bolts could not withstand the dynamic and repeated loading characteristic of the shake table testing. High grade steel has its advantages from mechanical performance prospective but they are vulnerable to environmental conditions as are most engineering metals. One of the most critical issues is their protection against corrosion. Hot deep galvanizing is widely used in the construction industry and many specifications call for it when isolators are to be used in outdoor conditions. This coating type presents a specific problem to high grade steel. It causes hydrogen embitterment which is undesirable and especially in dynamic loading can cause failure of the bolt and consequently failure of the isolator and the equipment itself.

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Mechanical and electrical equipment that generate noise and vibration are mounted on vibration isolators. For seismic applications these isolators are designed with restraining parts that limit the movement in specific directions. To enable easy manufacturing and assembly designers prefer standard bolts, studs that are readily available in the market. These bolts form the main restraint part of the seismic isolator. They are assembled in holes that include elastomeric elements to prevent metal to metal contact. Recent shake table and dynamic tests exposed catastrophic bolt failures. Most of the failures were found to be related to material composition. Low grade bolts could not withstand the dynamic and repeated loading characteristic of the shake table testing. High grade steel has its advantages from mechanical performance prospective but they are vulnerable to environmental conditions as are most engineering metals. One of the most critical issues is their protection against corrosion. Hot deep galvanizing is widely used in the construction industry and many specifications call for it when isolators are to be used in outdoor conditions. This coating type presents a specific problem to high grade steel. It causes hydrogen embitterment which is undesirable and especially in dynamic loading can cause failure of the bolt and consequently failure of the isolator and the equipment itself.

1. Introduction

Earthquake protection of non-structural building components and improving their performance is relatively new subject in the commercial industry. Considering the fact that major earthquakes are not everyday occurring events there is limited performance data available on the subject. Past earthquakes in the last decades have demonstrated the importance of these components. Hence recent building codes include requirements for non-structural building components but these codes are not able to cover all aspects. Recent changes in ASCE 7 meant that some critical equipment had to be qualified for seismic by shake table testing. These tests exposed isolator failures that were unexpected. Majority of the failures were related to the restraint bolts on the isolators and they were across the board and not limited to single manufacturer or type of isolator.

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2. Seismic Restraint Mounts for Mechanical and Electrical Equipment

Non-structural building components account for substantial amount in terms of material and cost in modern commercial buildings. Their seismic capabilities are directly correlated with building performance during earthquake. Especially mechanical, electrical and plumbing (MEP) installation and equipment play key part in achieving safe and high performance buildings. Some of the MEP equipment include pumps, fans, chillers, cooling towers, air handling units and diesel generators. Besides providing comfort and basic utilities their continued operation is critical for hospitals, police station and other types of emergency buildings, in natural disaster zones.

Majority of MEP equipment generate vibration, hence the use of external or internal vibration isolators are inevitable. There are many types of isolators in commercial use but in broad terms they can be categorized in two main groups elastomeric and spring type mounts. Their adaptation for seismic use is achieved by incorporating steel housings and restraining parts. Typical seismic mounts are shown bellow in Figure 1:

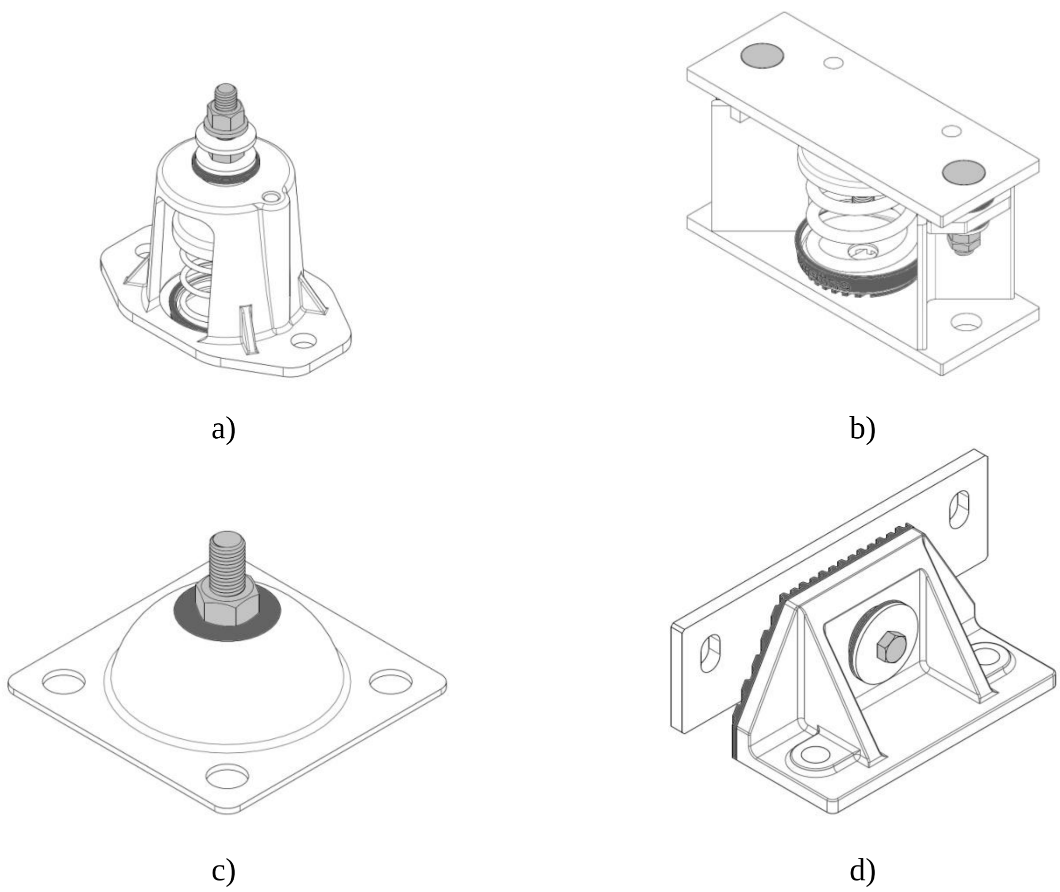


Figure 1 Typical examples of seismic mountings for mechanical and electrical equipment. *a) Restrained spring isolator; b) Restrained spring isolator with top plate; c) Rubber mount with steel housing; d) All directional snubber used together with open spring isolator or elastomeric pad;*

Restrained mounts are installed under MEP equipment and they form one of the most important attachment link between equipment and structure. They are fixed to the equipment base by means of bolts-nuts or welding. On the other hand mounts are secured to the structure with anchors, bolts-nuts or welding depending on the application type. They are the primary components that transfer the seismic force experienced by the equipment to the structure, and they do this through their restraining parts and steel housing. Restraining parts which are standard fixings (bolts, studs, nuts, washers) usually become the weakest link in the load path. Typical restraining bolt and stud detail of spring mounts are shown bellow in Figure 2:

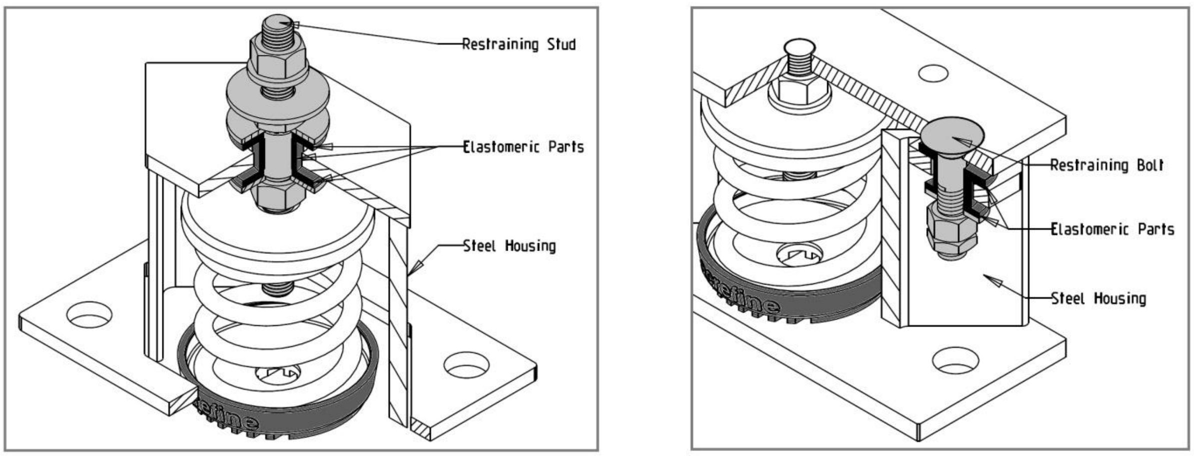


Figure 2 Restraining bolt and stud detail of spring mounts (highlighted with grey color)

The importance of the restraining system becomes more apparent when one considers the time scale for seismic events. It is very likely that tens of years could pass before isolators are subjected to seismic forces. Under normal circumstances restraining parts are not exposed to any type of loading. They are separated from the steel housing with 6mm (1/4 inch) gap to prevent vibration transmission. So their real performance can only be validated during an earthquake. In the meant time these parts are exposed to environmental conditions. Especially mounts installed in outdoors are most vulnerable.

3. Corrosive Environments

The impact of the outdoor corrosive environment varies with the geographical location and human activity. They are classified as mild, moderate, heavy and severe depending on how much damage they cause. Example for heavy and severe environment include costal and marine which are characterized by the abundance of sodium chloride (salt) and sulphur compounds. These chemicals are carried in land by ocean/sea breeze and deposited onto metallic surfaces. Human activity can cause extremely corrosive environments and industrial location is one such example. Beside of emitting corrosive chemicals industrial sites produce dust particles which can be laden with harmful metal oxides, chlorides, sulphates, sulphuric acid, carbon and carbon compounds. These articles, in the presence of oxygen, water, or high humidity can be very corrosive.

Intensely populated areas can also cause highly corrosive environment. Generally they have high levels of automobile emissions and high rates of the by products of the combustion of building heating fuels. Both conditions elevate sulphur oxide and nitrogen oxide concentrations. Corrosion severity in this environment depends on pollution levels, humidity, average temperature, and equipment usage. It is common for all these three environments to exist in the same location which contributes in creating extremely corrosive conditions.

4. Surface Protection for Seismic Restraint Mounts

4.1. Traditional Methods for Coating Steel Parts

Standard surface finish for fasteners and fixings is zinc plating, which is one of the most economical ways to achieve corrosion protection. To increase the performance zinc plated parts are chrome passivated. Yellow and clear passivations are most common types. Yellow chrome passivation has better corrosion resistance properties compared to clear passivation. When tested in accordance with ASTM B117 parts with 8 µm zinc thickness can withstand 150 hours before red rust is formed. Clear passivated parts with the same zinc thickness are only capable of achieving 72 hours in natural salt spray test. Yellow passivation includes hexavalent chromium (Ch6+) that is toxic chemical. To minimize the impact of hexavalent chromium on environment and humans some industries ban the use of this substance. Automotive industry is leading the way and bringing forward more innovative and high performance coating technologies.

Beside the environmental impact of zinc plating the process of depositing zinc layer via electroplating is a major cause of hydrogen embrittlement. Hydrogen embrittlement is associated with fasteners made of carbon and alloy steels that have higher tensile strength. The phenomenon is caused by the absorption of atomic hydrogen into the fastener's surface during acid pickling and alkaline cleaning prior to plating, and then during actual electroplating. The deposited metallic coating entraps the hydrogen against the base metal. When load or stress is applied the hydrogen gas migrates towards points of highest stress concentration. Pressure builds until the strength of the base metal is exceeded and minute ruptures occur. Hydrogen is exceptionally mobile and quickly penetrates into any recently formed cracks, lesions or material surface discontinuities, which become high stress areas. Cracks will promulgate through the component surface, weakening the component due to the loss of cross-section area. The failure is usually completed by a ductile fracture. The effects of hydrogen embitterment become more apparent under fatigue or oscillating loading such as seismic.

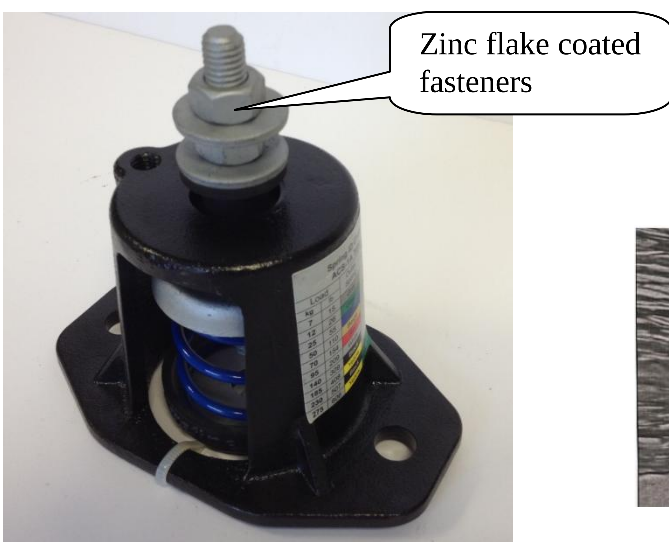
Cadmium plating is also used for protecting high strength steel fasteners, and exhibits similar issues described above for standard zinc plating. The environmental and health hazards associated with cadmium and hexavalent chromium are well established and legislations limiting their continued usage become more common.

Hot-dip galvanising is another common method used for protecting steel form corrosion. Galvanizing forms a metallurgical bond between the zinc and the underlying steel, creating a barrier that is part of the metal itself. During galvanizing, the molten zinc reacts with the steel to form a series of zinc/iron alloy layers, that gives the coating its excellent surface protection properties. Unfortunately the process causes hydrogen embrittlement and cannot be used for high strength fasteners Class 10.9 perr ISO R898 (SAE J429 Grade 8). According to ASTM A143 (Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement) hot-dip galvanising is not recommended for these bolts. This is further reinforced by specific references found in both the ASTM A490 specification and the ASTM A354 specification. Hot-dip galvanising can trap hydrogen gas within the grain structure of the steel alloy. This gas can cause structural weakening of the steel and catastrophic failure of a fastener.

4.2. Zinc Flake Coating

Zinc flake coatings are rapidly becoming one of the most important type of corrosion protection systems. They are preferred to zinc dust, which is made of spherical particles of zinc of around 3 µm. Zinc dust is more cost effective but spherical particles have very small area of contact, which downgrades the corrosion performance. On the other hand zinc flake particles are capable of overlapping to give high surface area contact between zinc particles and the substrate.

Deposition of zinc flakes to surface of steel parts enable four way corrosion protection, which are barrier, galvanic, passivation and self-repairing. Overlapping zinc and aluminum flakes provide an excellent barrier between the steel substrate and the corrosive environment. Galvanic protection is achieved by sacrificing zinc and making sure it corrodes before steel. The corrosion reaction of zinc and steel is slowed down with the use of metal oxides passivates. Self-repairing of the coating is done by zinc oxides and carbonates that mitigate to damaged areas of the coating and restore barrier protection. All these factors contribute to the corrosion performance of zinc flake coated parts and corrosion resistance of 600 to 1000 hours can be achieved. This is significant improvement over zinc plated and yellow passivated parts.



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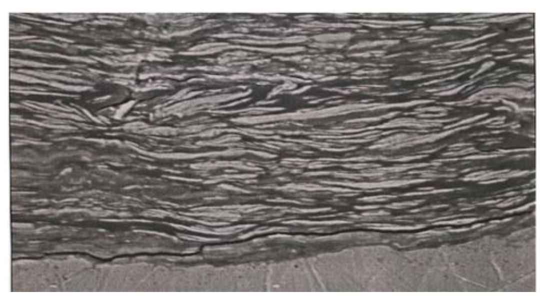


b)

Figure 3 Zinc flake coating application and microscopic view
a) Zinc flake coated fasteners on seismic restraint mount
b) Cross-section of a Zinc Flake Coating

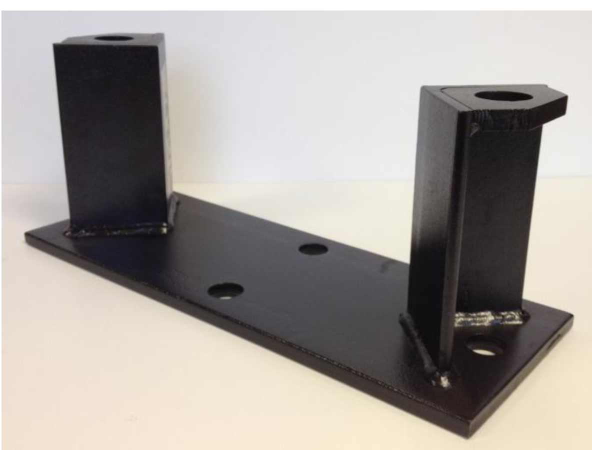
The water based zinc flake coatings are one of the most environmentally friendly coating technology available for zinc coating. They provide excellent resistance to atmospheric corrosion with limited “white” rust (zinc corrosion products) or other corrosion products in service. Neutral salt spray corrosion resistance exceeds that of many other common surface finishes, e.g. electro and mechanically plated zinc. Resistance to many “mild” chemicals and solvents including petrol and brake fluids is added benefit. And most importantly the process is non-electrolytic, eliminating hydrogen embrittlement. Because of this property zinc flake coatings are particularly suitable for coating high strength fasteners Class 10.9 and 12.9 per ISO R898 (SAE J429 Grade 8)

4.3. Cataphoretic E-Coating

Cataphoretic e-coating is another environmentally friendly water based surface protection for steel that is used extensively in the automotive industry. E-coating is an immersion coating process in which charged coating particles are attracted to an oppositely charged metallic surface. As the coating is deposited, it forms a finish which begins to insulate the metal from the surrounding charged solution. Deposition continues until the coating thickness becomes sufficient to form a barrier against further coating attraction.

Cataphoretic e-coating offers several advantages in the finishing of metal products. Corrosion resistance is superior to other coating application methods because immersion e-coating provides a complete, uniform coating. The coating is applied evenly in corners, on edges, and in hard to reach, partially enclosed spaces. This process is particularly suited for steel fabrications manufactured by welding, which have uneven surfaces and gaps. The coating layer is applied between 6 µm to 25 µm and corrosion resistance of up to 1000 hours can be achieved.

If used indoors away from UV light the e-coating will provide sufficient and long lasting corrosion resistance for steel parts. Their corrosion performance should be further enhanced if parts are to be used outdoors and subject to direct sunlight then top coat is required. Polyester based powder coating can be applied after parts are e-coated to achieve excellent corrosion resistance for severely corrosive environments.



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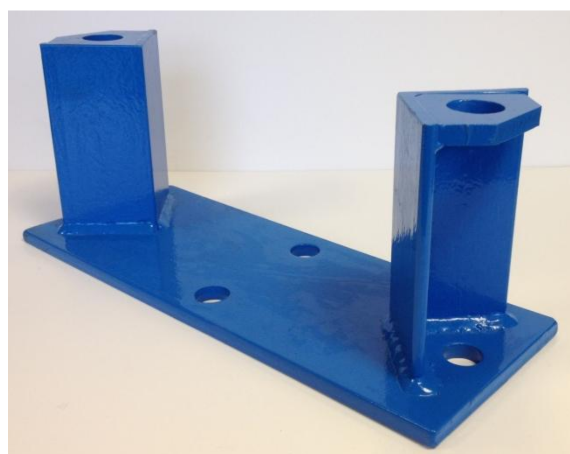

b)

Figure 4 Cataphoretic e-co coating application
a) Seismic isolator housing with cataphoretic e-coating
b) Seismic isolator housing with cataphoretic e-coating and polyester powder topcoat

E-coating is also suitable for high strength fasteners since the process does not cause hydrogen embrittlement. As mentioned above this should be adequate for indoor use, but for parts intended for outdoor use pre treatment with zinc or phosphate is recommended. Topcoat can also be applied to achieve exceptional corrosion resistance.

The integrity of above described coatings, like in all coatings, depends very much on the initial preparation i.e. the cleanliness of the base material and its freedom from oils, greases, scale, rust and oxide films.

5. Conclusions

Seismic isolators and snubbers provide crucial interface in mounting and securing non-structural building components. Lack of performance data and adequate standards for these parts allows designing and manufacturing of systems that may not perform at desired level. Shake table tests demonstrated the importance of using quality materials. High grade ductile steel is likely to become the common choice among manufactures of seismic isolators. It is important to preserve the qualities of this type of steel from extreme conditions and especially corrosion. Corroded steel is unlike to reach the design loads causing failure. Many years can pass before isolators are put to the real test, that is to perform in seismic event. Hence their corrosion protection becomes crucial and choosing the right coating very important.

6. References

1. Scott M. *Environmentally Friendly Anticorrosion Coating for High Strength Fasteners*. Pittsburgh, PA, 2011.
2. Zhmurkin D. *Corrosion Resistance of Bolt Coatings.* Harrisburg, PA, 2009.
3. Brahimi S. *Qualification of Dacromet for use with ASTM A490 High-Strength Structural Bolts.* Montreal QC, 2006.
4. The Fastener Engineering and Research Association, FERA. *Hydrogen Embrittlement, An Overview from a Mechanical Fastening Aspect.* Solihull, UK, 2001.
5. Miles M., Peffer R. *Electrocoat Primers for the Aerospace Industry.* Pittsburgh, PA, 2007.
6. *Hot-Dip Galvanizing for Corrosion Protection of Steel Products*. American Galvanizers Association, 2000.
7. *European End of Life Vehicles (ELV) Directive, volume 43, issue L269, pages 34-42.*, 2000.
8. Deveci M. M. *Teleflex PS227000: Corrosion Protection of Iron or Steel with Electrodeposited Zinc and Trivalent Chromium Coatings*. Basildon, UK, 2006.
9. ASTM B117. *Standard practice for operating salt spray (fog) apparatus*.