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CURRENT PRACTICES AND CODE REQUIREMENTS FOR BUILDING SYSTEMS SEISMIC RESTRAINTS

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ABSTRACT

Since the 1970's the restraint of non-structural components within buildings - especially the various building systems (e.g., heating, ventilating, air-conditioning, plumbing, fire suppression, and electrical systems) - has been given a greater and greater focus in North America. Many varying practices from various parts of the continent have been codified and with the adoption of a singular building code for the United States, places that had never restrained these systems were being required to do so. Ten years have passed since the adoption of the *International Building Code* in 2000 and now every state in the US has adopted some portion of this code. The current version defers to the American Society of Civil Engineers' document *ASCE 7* whose next version is due to be released this year (2010). In Canada, the recent *National Building Code* and subsequent provincial codes have also gone through some significant changes, though there is still much work to be done on both sides of the 49th parallel.

This paper and presentation will give a brief overview of the history and reasoning behind the practice of restraining non-structural building components before focusing on the present day practices being used across the continent. It is hoped that a greater awareness of the issues and concerns surrounding restraining building systems will benefit the design community at large and encourage further advancements in the field.

Codes Background

The first *International Building Code* (IBC) and its companion codes, including the *International Mechanical Code*, *International Plumbing Code*, *International Residential Code*, and nine others, were published in the United States in 2000. This family of codes has been revised and reissued every three years since – the current version being the *IBC 2009*. It was the result of many people spending many hours to integrate three separate building codes into one comprehensive product. The *Standard Building Code* (SBC), *Uniform Building Code* (UBC) and the Building Officials and Code Administrators' *National Building Code* (BOCA) were compiled into a single code. Every state in the Union has adopted some version of the IBC – most the 2006 version. Many states have additional state codes and amendments which build on

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the IBC codes and modify the requirements based on local needs. In the area of seismic design for non-structural components, most states have adopted the IBC verbatim without amendments.

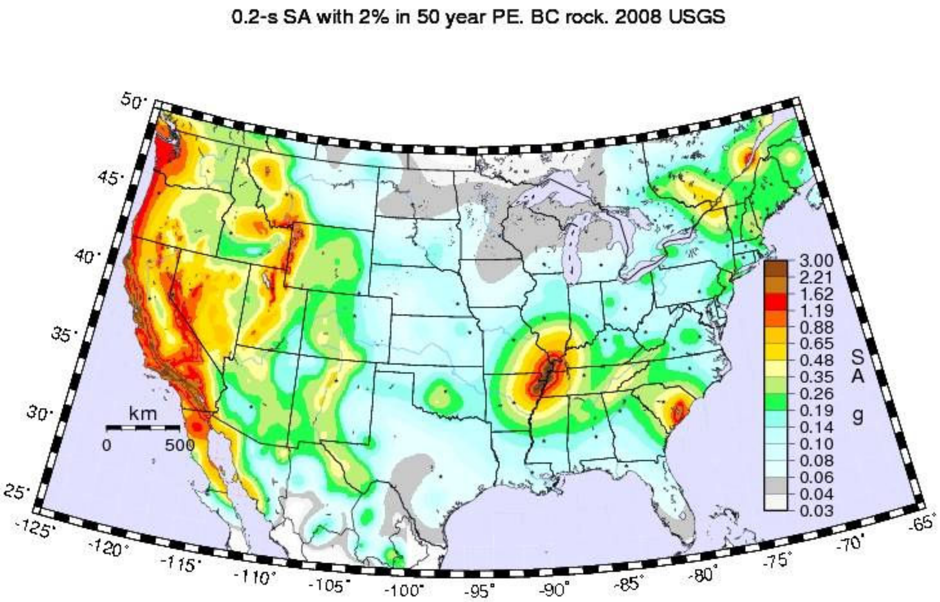

Figure 1. Seismic Hazard Map, continental United States

Seismic restraint requirements for HVAC, plumbing, and electrical systems and components and all other non-structural components are defined in Chapter 16 of the IBC. Since the 2003 version of the IBC, the details of those requirements are found in another document, the American Society of Civil Engineers' *ASCE 7 – Minimum Design Loads for Buildings and Other Structures*. This document is revised and published as needed, at least every five years. Its first version was published in 2002 and was referenced in IBC 2003. The second version was published in 2005 and it has been referenced in IBC 2006 and 2009. The next version will be published in 2010 and will become part of the IBC 2009 and the subsequent version, the IBC 2012. Each time these documents have been published, the specific requirements have been modified – sometimes with significant changes.

Here in Canada, the current National Building Code was published in 2005 and addresses seismic design for buildings including non-structural components – also known as Operational and Functional Components (OFC's) – in Chapter 4 of Division B. As with the various states within the United States, each Canadian Province incorporates and modifies the NBC requirements for their specific areas. The current Ontario Building Code – OBC 2006, for example, is essentially the same as the NBC. The Canadian codes are very similar to the American codes in form and function with a few differences. Both provide a means to establish a static design force to be used in determining appropriate restraints and both refer to other guides and sources to be used in selecting the specific restraint types and locations.

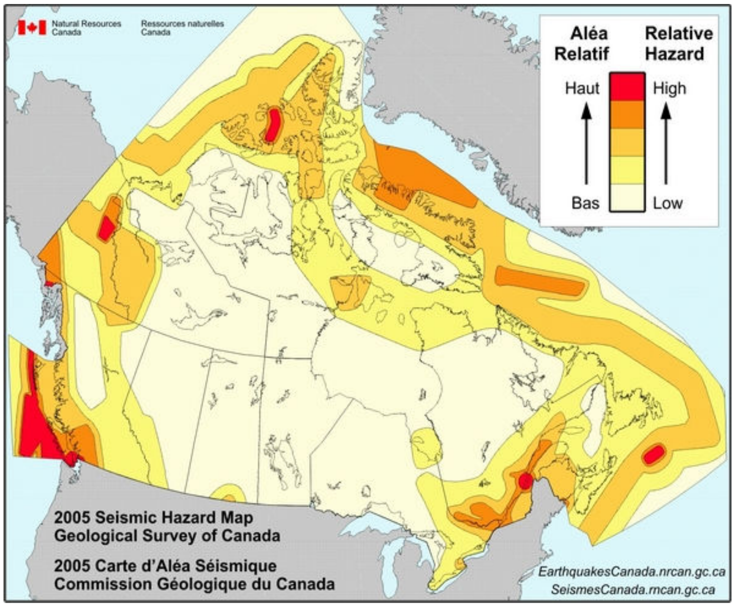

Figure 2. Seismic Hazard Map, Canada.

The primary purpose of restraining HVAC and electrical systems is to ensure life safety for building occupants. Any equipment or systems over certain sizes that may see significant seismic loads and serve life-safety related functions, such as smoke evacuation, stairwell pressurization, emergency power, and fire protection/suppression, need to be restrained. Also, any equipment or systems which carry hazardous materials such as medical gas, natural gas, fuel oil, or high pressure steam, typically need to be restrained. Equipment or systems over a certain size or weight must be restrained if there is a danger of falling or tipping over onto building occupants. In addition to these requirements, if the building has been deemed an "essential facility" in the US or a "post-disaster" structure in Canada due to its occupancy category, all equipment and systems over specific sizes that are required for the continued operation of the facility must be restrained; this includes hospitals, police stations, fire stations, water treatment facilities, and emergency shelters.

Another code-related purpose for restraining non-structural components and systems is to limit the economic impact of a seismic event. In recent history, there have been significant costs associated with the failure of these systems which have created significant hardships on the local economies. Secondary damage from compromised building systems, such as water damage from broken pipes, is a significant hazard which can render a structurally-safe building unusable. Some building owners expand on the code-minimum requirements to address their specific economic concerns for business continuity. This is often done by financial institutions to protect their data centers and other information assets.

Current Code Requirements

The building codes stipulate calculations to use in determining the seismic load design forces which are then used to design restraint requirements for non-structural components and systems. The primary equation in the United States is (ASCE 2006):

$$F_p = [0.4a_pS_{DS}I_p(1+2z/h)/R_p]W_p \quad (1)$$

where:
F_p = the design lateral force applied at the component center of gravity used to select and size seismic restraints and anchorage for a piece of equipment or section of duct or pipe.
a_p = the component amplification factor assigned based on the equipment or system inherent rigidity.
S_{DS} = Site-specific value based on geographic location and geologic soil conditions.
I_p = the component importance factor based on relative hazard and value to facility continued operation.
z/h = a ratio of the height of the component attachment to the height of the building.
R_p = the component response modification factor based largely on the equipment attachment to structure.
W_p = weight of the component.

The *ASCE 7* guide assigns values for a_p and R_p in its table 13.6-1 based on equipment type and support. S_{DS} is determined by the structural engineer for the project based on the site-specific Site Class (soil conditions, A through F) and the short-period spectral response, S_S, typically found using information from the National Earthquake Hazards Reduction Program (NEHRP) on the United States Geological Survey website (see http://earthquake.usgs.gov/research/hazmaps/design/index.php). The component importance factor is assigned by the HVAC design engineer; all components related to life safety and the continued operation of an essential facility are assigned a high importance factor (I_p=1.5). A building is deemed an "essential facility" if it has been assigned a building Occupancy Category "IV" designation by the project prime professional. The ratio z/h assigns a greater value the higher up in the building the component is located.

The code also defines which systems require restraint and which systems may be exempt from those requirements. This is accomplished by assigning the structure to a Seismic Design Category (SDC) based on its occupancy category and its site-specific seismic design parameters S_s, S_1, and the Site Class. For example, all mechanical systems in SDC A and B structures are exempt from seismic restraint requirements, while all systems in SDC D buildings must be restrained – subject to exemptions based on size and location. As an example, no ductwork under 6 square feet in cross sectional area needs to be restrained. Buildings in SDC C only require hazardous and life-safety systems and equipment to be restrained. Additional specifics can be found in Chapter 13 of the ASCE 7 document.

In Canada, the equation used in determining seismic design forces is (NRCC 2005):

$$V_p = 0.3F_aS_{a(0.2)}I_ES_pW_p \quad (2)$$

where:
V_p = the design lateral force applied at the component center of gravity used to select and size seismic restraints and anchorage for a piece of equipment or section of duct or pipe.
F_a = site-specific value based on soil type and geographic location; from a lookup table.
$S_{a(0.2)}$ = spectral response acceleration value at 0.2s; a site-specific value from a lookup table of

Canadian cities in an Appendix of the Code.
I_E = the building earthquake importance factor based on relative hazard and value of continued operation.
$S_p = C_pA_rA_x/R_p$

where:

C_p = a component factor assigned based on the equipment or system hazard level.

A_r = the component force amplification factor based largely on the equipment attachment to structure.

A_x = a factor $(1+2h_x/h_n)$ that accounts for the height of the component attachment in the building.

R_p = the component response modification factor assigned based on the equipment or system inherent rigidity.

W_p = weight of the component.

The NBC assigns values for C_p, A_r, and R_p in its tables based on equipment type and support. F_a must be determined by the structural engineer for the project based on the site-specific Site Class (soil conditions, A through F) and the short-period spectral response, $S_{a(0.2)}$, typically found using information located in a code appendix for specific Canadian cities. The earthquake importance factor, I_E, is assigned by the project prime professional or structural engineer.

A significant difference in the Canadian codes from the American codes is that there is little guidance given on exemptions for equipment and systems based on their weight or size or location. There is an exemption provided for non-post-disaster structures if the design values fall below a specific threshold – if $I_EF_aS_{a(0.2)}<0.35$. For specific applications, the Code refers to industry-standard and acceptable practice which is determined by the professional engineer of record.

Applying the Code Requirements

It is important to note that none of the codes, including the NBC, IBC, and ASCE documents, provide a complete picture of non-structural seismic restraints. They stipulate the design forces and, in general, define the equipment and systems that require restraints. Other guides must be used to give practical guidance on restraint types and installation methods.

Published Guides

The Sheet Metal and Air Conditioning National Association's (SMACNA) *Seismic Restraint Manual Guidelines for Mechanical Systems* is recognized as an authority in the HVAC community. As an example, it requires transverse restraints be applied on ductwork at least every 30′ and longitudinal restraints every 60′ maximum. Likewise, the Manufacturer's Standardization Society *SP-127 Bracing for Piping Systems Seismic – Wind – Dynamic Design, Selection, Application* is a recognized authority for piping systems; it requires transverse restraints be applied on piping every 40′ and longitudinal restraints every 80′. The National Fire Protection Association's *NFPA 13 Standard for the Installation of Sprinkler Systems* is the recognized authority for fire protection/suppression systems and has similar guidance.

There are a few other published practical guides that have helpful information to aid a specifying engineer, installing contractor, or reviewing code official in their work. Of note are a series of Federal Emergency Management Agency (FEMA) publications, *FEMA 74*, *FEMA 412*, *FEMA 413*, and *FEMA 414*. *FEMA E-74 Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide* is a web-based publication that gives an overview of the causes and effects of earthquake damage in nonstructural components and describes methods for mitigating such damage. It is available at http://www.atcouncil.org/FEMA74/FEMA74index.html. *FEMA 412 Installing Seismic Restraints for Mechanical Equipment*; *FEMA 413 Installing Seismic Restraints for Electrical Equipment*, and *FEMA 414 Installing Seismic Restraints for Duct and Pipe* all provide illustrations and practical guidance to installing contractors on means and methods of restraining building systems equipment and components. These guides do not provide information on sizing the restraints as that must be performed per the applicable code and by a professional engineer. They are all available for free download at www.viscma.com/publications.htm.

The American Society for Heating Refrigerating and Air-conditioning Engineers (ASHRAE) has a couple of helpful guides and publications as well. The *Practical Guide to Seismic Restraint* was published about 10 years ago and refers to codes that are no longer in effect, but the methodologies and explanations provided are useful. Most HVAC system designers have copies of the ASHRAE Handbook series which provide useful information on all aspects of building system design. The *2007 ASHRAE Handbook – HVAC Applications*, Chapter 54, "Seismic and Wind Restraint Design" is kept up to date by an ASHRAE technical committee and published every 4 years.

Common Practice – Rigidly Mounted Examples

Many components and systems in buildings are rigidly supported, or hard-mounted to the floor or suspended from the structure above. Depending on the seismic forces and equipment type, seismically-rated concrete anchor bolts can be installed through the equipment mounting holes into the structural floor.

Figure 3. Rigid restraint equipment snubbers.

Where the forces are greater or adequate mounting holes are not available, snubbers can be used to capture the equipment and restrict its motion to typically no more than ¼". Figure 3 shows two of many such snubbers mounted around a floor-mounted air handling unit – a large metal box housing fans, heat exchangers, filters and other devices. There are many other pieces of HVAC equipment that are typically rigidly mounted to the structure, such as boilers, tanks, heat exchangers, coils and filters and many different fans and pumps.

Fig.4 – Inline pump supported with stands

Figure 4 shows a vertical inline pump supported by its flanges which are supported by customized stands. Properly designed, stands can be used for resisting seismic forces. When a small amount of vibration isolation is required, neoprene pad isolators are placed under the stands. They are individually designed for the particular pumps and can be field-cut to match the flange heights and bolt patterns.

Figure 5a. Cable restraints on duct.

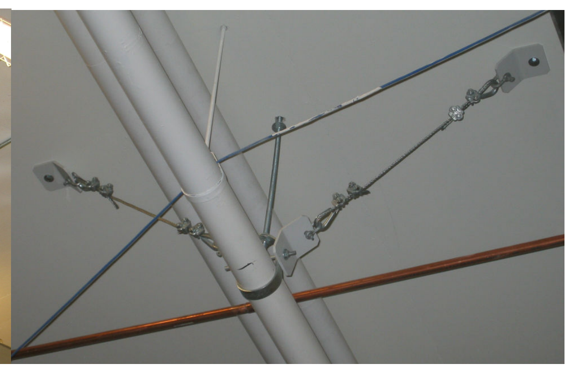

Figure 5b. Cable restraints on a pipe.

Figures 5a and 5b show some examples of cable restraint sway bracing on ductwork and pipe. The actual components used may vary by manufacturer, location and project, but generally consist of an attachment to the duct or pipe support – typically a bracket of some kind, a wire rope that is terminated on both ends using thimbles, wire rope clips, and/or compression sleeves, and a welded or bolted connection to the structure above. The restraint is angled away from the attachment point at approximately 45 degrees. Systems that are supported using vibration isolators must use cable sway bracing to minimize any transmission of vibration through the restraints. For non-vibration-isolated duct and pipe systems, sway bracing can be accomplished using rigid struts, structural angles and other shapes.

The duct or pipe system must be restrained in both the longitudinal and transverse directions at specific intervals to keep the duct or pipe from either breaking apart or damaging adjacent equipment or systems. The restraints must be sized correctly to handle the seismic design forces – and in the case of rigid restraints, they must be sized to handle both compression and tension. In addition, the anchorage of the sway bracing must be selected to withstand the design forces and this typically entails the use of welding, concrete anchor bolts or lag bolts. In rigid restraint systems, the support rod and its attachment to structure for the duct or pipe it carries must also be selected and sized to withstand the seismic design forces. For both restraint types, cables and rigid, the support rods near restraint points must be analyzed for resistance to buckling. Typically, additional angles or struts are clamped to the support rods to stiffen them where required, though other methods, such as installing pipes over the rods are also effective.

Common Practice – Vibration Isolated Examples

Many buildings are designed with some degree of noise control – especially where large vibrating equipment or associated ductwork or piping is located near occupied spaces. Vibration isolators are typically installed to mitigate structure-borne noise by allowing the equipment and connected systems to move freely. This, however, creates a problem where equipment needs to be restrained to minimize movement from seismic activity. If some type of rigid restraint were used, the equipment vibrations would be transmitted into the structure and create audible noise. There are many devices available on the market today that serve a dual purpose: noise control through vibration isolation and seismic restraint through limiting the motion in any direction.

Fig. 6 Isolated and restrained suspended fan

In the application shown in Figure 6, spring hanger vibration isolators have been installed on the supports for a vane-axial fan in combination with ¼" diameter wire rope cable sway bracing and vertical limit stops on the isolator boxes. The limit stop is typically a large washer-type element under the hanger box which will keep the equipment from "jumping" off the spring support. The support rods in this example are thick enough and short enough to prevent buckling failure, so no additional stiffeners were required.

For water-filled, floor/roof mounted equipment, a restrained spring housed isolator is needed to minimize stress on pipe connections by providing lateral resistance to wind loading and controlling vertical displacement caused by draining the equipment for maintenance. Nuts threaded onto bolts extending down from the support plate through plates at the top of the two stanchions restrain the spring from pushing up too far on the drained equipment. These restraining bolts also help to provide the necessary resistance during a seismic event to keep the equipment in place and to keep it operational.

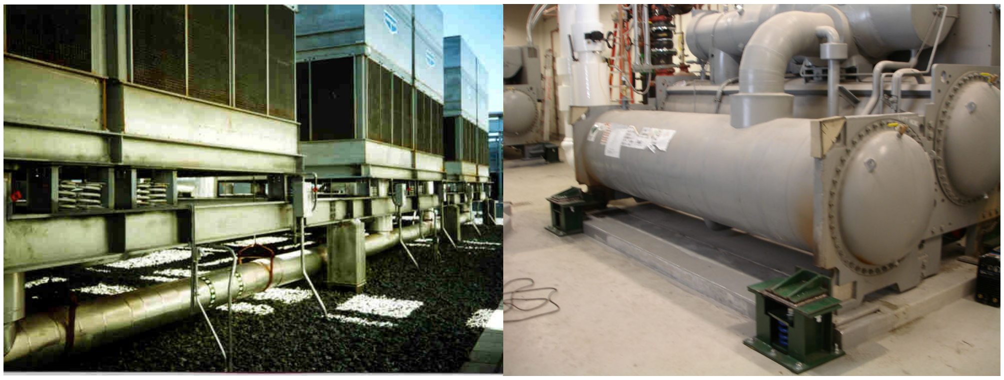

Figure 7a. Cooling towers on rigid steel frames with seismically-rated vibration isolators.
Figure 7b. Water-cooled chiller retrofit with seismically-rated vibration isolators.

Rooftop air handling units present a multitude of noise transmission paths which can create excessive noise levels in the spaces below. Packaged rooftop vibration isolation curbs are common solutions to address these significant problems. These curbs not only provide structure-borne noise control of the entire unit but also adequate support, height and waterproofing for the rooftop equipment. Since design forces for roof-mounted equipment are three times what they are for equipment mounted on the ground floor, the supports and structural attachments must be stronger.

Fig. 8a – A rooftop air handling unit with integral condenser section on isolation curb.
Fig. 8b – Internal frames of seismically rated isolation curb.

Common Practice – Analysis and Testing

Typically, analysis is done through calculation of static forces as prescribed by the applicable code. Design and analysis of restraints and of restraint systems is typically done by standard calculation methods and with some testing. For testing, there is a new standard published by ASHRAE called *ASHRAE 171-2008 Method of Testing Seismic Restraint Devices for HVAC&R Equipment* which helps define specific ways to test restraints. A companion rating standard, *VISCMA 102-07 Seismic Restraint Device Rating Standard* has been published as well to help define acceptability and allowable range of use.

For restraint structures that are outside of these testing and rating methods, other analysis methods need to be applied such as 3-dimensional (3D) modeling and Finite Element Analyses (FEA) to ensure that the designs are structurally sufficient. The components and sub-assemblies can be modeled to ensure they will be able to safely transfer the design loads. It is acceptable practice to allow local yielding as long as the overall functions of the restraint structure are not compromised. Plastic deformations that either compromise the vibration isolation function of the system or weaken the support function of the structure beyond reasonable limits cannot be allowed.

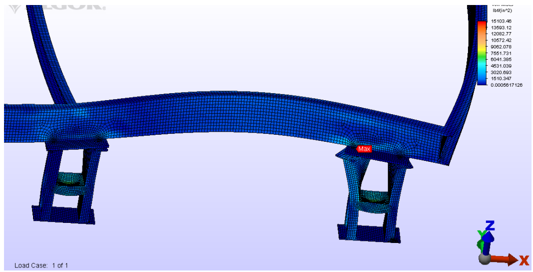

Fig 9 – Stress analysis for isolation curb frame.

Through the combined process of design, modeling, analysis, manufacturing and inspection, seismic restraint manufacturers can provide seismically-rated restraints and vibration isolators that not only can withstand wind and seismic forces as required on both a project- and a code-specific basis, but also can provide guaranteed noise and vibration control to meet background noise level criteria in the spaces below.

Conclusion

The current requirements and practices of restraining non-structural components have been developed over the last few decades to help protect life and property. Proper application of these requirements can ensure the continued operation and functionality of essential facilities even after moderate earthquakes which otherwise could cause significant non-structural damage. Equations and tables have been developed and relative hazards and importance quantified for the various building systems which comprise non-structural building components. There is still much room for continued development of means and methods, guides, code requirements, and, above all, for education. It is hoped that this short dissertation will help in some small way to advance the art and recognition of non-structural systems and components seismic restraints.

References

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