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CHALLENGES INVOLVED WITH PROVIDING SEISMIC RESTRAINT FOR MECHANICAL AND ELECTRICAL EQUIPMENT IN BUILDINGS

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ABSTRACT

Seismic restraint of non-structural components in buildings is a requirement of the National Building Code of Canada. Damages associated with non-structural components due to the earthquakes in Loma Prieta (1989), Northridge (1994), and Kobe (1995) highlight the importance of providing adequate seismic restraint. Implementation during the design and construction of buildings to provide seismic restraint for mechanical and electrical equipment typically occurs too late in the process, and is often missed or difficult to achieve. Current practice in the Ottawa region is to require the mechanical and electrical contractors to supply the design and installation of the seismic restraint system for their respective equipment. Given that the complexity of the seismic restraint system is not necessarily known at the time of tendering, it is difficult for the contractors to estimate the total scope of work involved. Also, without adequate coordination during the design phase, architectural and structural details may lead to issues with providing sufficient seismic restraint to the equipment. Contractors typically rely on the seismic restraint system suppliers to provide the engineered design for their systems and this results in varying designs depending on the Code interpretations of the individual suppliers. The current practice results in the seismic restraint system being considered at the final stages of construction when there is little left in the schedule and the budget for construction. In order to adequately provide seismic restraint for mechanical and electrical equipment, consideration during the design and at the initial phases of construction is required.

Introduction

Seismic restraint of non-structural components in buildings is a requirement of the National Building Code of Canada (NBC 2005). Damages associated with non-structural components due to the earthquakes in Loma Prieta (1989), Northridge (1994) and Kobe (1995) highlight the importance of providing adequate seismic restraint. The 1994 Northridge earthquake (M6.8) in California caused damages estimated at $20 billion U.S., and of that 77% was associated with non-structural components (McLeod, 2004). According to the International Risk Management Institute "Poor performance of non-structural components, equipment, and systems is the greatest contributor to damage, losses, and business interruption for most facilities after an earthquake" (Gould, 2003).

The intent of 2005 NBC Code provisions with respect to seismic restraint of non-structural components is to provide life safety for the building occupants during a design level earthquake and to minimize damage to mechanical systems and adjacent components after a moderate earthquake. For post-disaster buildings such as hospitals, the intent of providing seismic restraint is to maintain performance of vital

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equipment after an earthquake.

Halsall Associates Limited has been providing seismic restraint engineering services to mechanical and electrical contractors in the Ottawa region since 2004. Earthquakes ranging in magnitude from M5.9 to M7.2 have been recorded in Eastern Canada. A magnitude M6.0 earthquake is considered representative for the Ottawa region. The current practice to provide seismic restraint for mechanical and electrical equipment in buildings leads to many challenges. All parties involved in the design and construction of new buildings are impacted by seismic restraint of mechanical and electrical equipment.

Code Requirements for Seismic Restraint of Non-structural Components

The 2005 NBC requires that seismic restraint of non-structural components be provided when $I_E F_a S_a(0.2)$ is greater than 0.35, and for all post-disaster buildings. For buildings located in Ottawa, Ontario, with $S_a(0.2) = 0.66$, seismic restraint of non-structural components will be required in every building. Mechanical and electrical equipment is to be anchored to the structure to accommodate the deflections of the structure due to seismic loading, and be anchored for a lateral force as per Equation 1:

$$V_p = 0.3 F_a S_a(0.2)\, I_E S_p W_p \qquad (1)$$

where F_a is a function of the geotechnical site characteristics, $S_a(0.2)$ is the spectral acceleration at 0.2 seconds and is a function site seismic hazard, I_E is the building importance factor, W_p is the weight of the equipment, and S_p is a function of the type of mechanical or electrical equipment being restrained, and its location in the building relative to the buildings overall height.

The 2005 NBC requires that forces shall be applied in the horizontal direction that results in the most critical loading for design (2005 NBC 4.1.8.17(7)). The direction of earthquake forces that will be applied to the equipment cannot be predicted. When resolving the seismic forces to each support location, the seismic restraint engineer must not only consider the seismic forces being applied in the two orthogonal directions of the equipment, but must also consider the seismic forces being applied at some angle that may result in higher support reactions. As well, torsion, whether accidental or due to the equipment configuration, must be considered in the seismic restraint design. Minimum accidental eccentricities should be allowed for in the seismic restraint design.

The provisions of 2005 NBC require seismic restraint of all machinery, fixtures, equipment, ducts, tanks and pipes regardless of size or weight. In many cases, it is not practical to provide seismic restraint to every piece of mechanical or electrical equipment in a typical building. Engineering judgment is required to assess seismic restraint requirement for smaller pieces of mechanical and electrical equipment, as well as small diameter pipe and ducts.

CSA S832-06 - Seismic risk reduction of operational and functional components (OFCs) of buildings - is a standard to evaluate the seismic risk of mechanical and electrical equipment in buildings, and outlines requirements for seismic restraint (CSA S832-06, 2006). This standard outlines procedures for the seismic restraint engineer to evaluate the risk associated with all equipment in the building. The risk is assessed based on the performance criteria for the building. The risk of equipment failure in a post-disaster building required to operate after an earthquake is higher than equipment failure in other buildings. Also risk is assessed based on the location of the equipment in the building and the danger the equipment poses to life-safety. CSA S832-06 provides recommendations for the type of seismic restraint required for each type of mechanical and electrical equipment, and references other standards available for mitigation techniques.

Other Standards/Guidelines for Seismic Restraint of Non-structural Items

After the Loma Prieta and Northridge earthquakes in California, the National Earthquake Hazards Reduction Program (NEHRP, 2003) and the Federal Emergency Management Agency (FEMA) carried out extensive studies on the earthquake performance of buildings and the earthquake performance of nonstructural components. As a result of these studies several NEHRP/FEMA guidelines have been published related to the seismic restraint of mechanical and electrical equipment, as well as pipe and duct. These guidelines provide information to installers on how to attach equipment to the structure to minimize damage, but do not provide any design guidance for the seismic restraint engineer. FEMA design recommendations for seismic restraint of mechanical and electrical equipment are included in the 2003 NEHRP provisions.

Observations made after the Loma Prieta and Northridge earthquakes showed that smaller diameter pipe and duct that was not restrained generally was not damaged. It was also observed that the life-safety risks associated with equipment less than 1.8kN (400lbs) that was mounted less than 4ft above the floor were relatively low. Based on these observations, the NEHRP design guidelines for seismic restraint of mechanical and electrical equipment exempts some equipment as well as smaller diameter pipe and duct in non-post disaster buildings. The International Building Code (IBC, 2003) has adopted the NEHRP provisions for seismic restraint. The IBC provisions provide specific information on what mechanical and electrical equipment does require seismic restraint.

In addition to the guidelines published by FEMA, organizations including the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE, 1999) and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA, 1998) have developed guidelines to assist designers and contractors that provide seismic restraint for mechanical and electrical equipment. These guidelines also recommend specific equipment that requires seismic restraint. These guidelines are not completely consistent with the NEHRP or IBC provisions.

Recommendations for Mechanical and Electrical Equipment that requires Seismic Restraint

There are many different guidelines available and each has specific recommendations regarding seismic restraint. The challenge the seismic restraint engineer faces is providing a consistent level of safety in the building with respect to the support of the mechanical and electrical system given the various guidelines available. Providing a seismic restraint design that exempts equipment based on all of the available guidelines may result in a system that does not provide a level of life-safety consistent with the requirements of the 2005 NBC. For normal occupancy buildings in Ottawa, Table 1 outlines recommendations for mechanical and electrical equipment that requires seismic restraint.

Table 1. Recommendations for Equipment that Requires Seismic Restraint.*

Component	Seismic Restraint Requirements	Reference
Pipe	All 62.5mm (2.5”) diameter or greater pipe except for the following: - 25mm (1”) diameter or greater pipe containing hazardous materials; - 31.25mm (1.25”) diameter or greater pipe in mechanical rooms. Pipes supported by trapeze where the cumulative weight of pipe supported on the trapeze exceeds the above weights of pipes supported individually.	ASHRAE, 1999
Duct	Square duct that is $0.56m_2$ (6 sq. ft) or larger in face area; Round duct that is 800mm (32”) diameter or greater.	SMACNA, 1998
Floor Mounted Equipment	Equipment 1.8kN (400lbs) or greater that is mounted 1.2m (4ft) or higher above the floor.	IBC, 2003
Suspended Equipment	All isolated suspended equipment 0.09kN (20lbs) or greater. Equipment in-line with duct or pipe 0.3kN (75lbs) or greater.	IBC, 2003
Wall Mounted Equipment	Equipment 0.09 (20lbs) or greater.	IBC, 2003

*For post-disaster buildings there are no exemptions for any size equipment, pipe, or duct.

Current Practice in Ottawa

The mechanical and electrical engineers on the project typically specify the requirement for seismic restraint of mechanical and electrical equipment. Seismic restraint performance specifications are included in the contract documents that make the seismic restraint system a deliverable of the respective contractors. A common problem with this method is the use of generic specification sections that do not adequately define the required scope of work for the seismic restraint engineer and supplier. In many cases, the mechanical and electrical engineers do not fully understand the Code requirements for seismic restraint and rely on the contractors to interpret the Code provisions to provide an adequate system. This results in several different seismic restraint engineers and seismic restraint systems being installed on one project. For each project the plumbing contractor, the heating, ventilation, and air-conditioning (HVAC) contractor, and the electrical contractor will each have their own seismic restraint supplier/engineer. Each of these separate suppliers/engineers may have a different interpretation of Code requirements.

On a typical project the performance specification for seismic restraint of mechanical and electrical equipment requires that the contractors provide engineered shop drawings that specify the type of seismic restraint systems to be installed and the locations to install the seismic restraints. Specifications require that the contractor provide seismic restraints that have been seismically rated by approved testing and have listed load capacities. Alternatively, the contractor is to provide equivalent engineered details. Seismic restraint shop drawings are to be sealed and signed a Professional Engineer registered in the jurisdiction of the project. The mechanical and electrical contractors will retain a seismic restraint engineer/supplier to provide the engineered shop drawings and the seismically rated restraint kits, and then use their own forces to install the restraints. The most common seismically rated restraint kits available are manufactured in the United States. In many cases, these manufacturers have engineers that are licensed in the jurisdiction of the project that can prepare the required shop drawings. In these cases the shop drawings submitted typically consist of generic details that may or may not be applicable depending on site conditions.

Seismic restraint shop drawings are submitted by the contractors to the base building design team for review. It is the responsibility of the mechanical and electrical engineers that specified the requirements for seismic restraint to ensure that the contract requirements have been met. The base building structural engineer should also review seismic restraint shop drawings to review the loads due to the seismic restraint systems transferred to the structure. Current practice also requires the seismic restraint engineer to review the installation of the restraint system to ensure that they have been installed in accordance with their design details. As contractors experience with installing seismic restraint systems varies widely, several site visits may be required for one project to ensure that the system is installed properly. This can be an issue on projects where the seismic restraint engineer works for the restraint system manufacturer located in the United States and is not able to carry out site reviews.

Common Issues with providing seismic restraint for mechanical and electrical equipment

The 2005 NBC provisions for seismic restraint are included in Part 4 that outlines the structural requirements for buildings. The loads resulting from the attachment of mechanical and electrical equipment to the building must be considered when designing the base building structure. The structural engineer typically does this design by making assumptions regarding the method of connection of the equipment to the structure, and by making allowances in the loads used in their design. However, the structural engineer does not have all the necessary information required to detail the connections between the equipment and the structure. The mechanical and electrical systems are designed and specified by the mechanical and electrical engineers. The mechanical and electrical engineers also do not have all of the required information to detail the seismic restraint connections. Until the suppliers specify the actual mechanical and electrical equipment that will be installed, specific restraint details cannot be designed.

Construction review to ensure that the seismic restraint systems have met the Code requirements and the requirements of the specifications is also required. This includes both the review of seismic restraint shop drawings submitted by the contractor and the site review to ensure that the restraint system has been installed in accordance with the submitted shop drawings. Seismic restraint systems are often installed at the end of the construction schedule. At this point the structural engineers construction review of the base building has already been completed. The mechanical and electrical engineers that specify that the contractor provide the seismic restraint for the equipment should ensure that those contract requirements are addressed as part of their review during construction. Mechanical and electrical engineers may not be able to adequately review seismic restraint shop drawings and construction installations. Installation of the seismic restraint system imposes loads on the structure that should be reviewed by the structural engineer. It is critical that the installed seismic restraints are connected to elements of the structural that can safely resist the seismic forces.

Roof-top Equipment

Roof-top equipment is essential to building operations and includes air-handling units, condensers, cooling towers, exhaust fans, as well as many other types of equipment. While the roof is an ideal location for equipment due to space limitations within the building and the requirements for fresh-air intakes, it presents many challenges when providing seismic restraint. The 2005 NBC states that friction due to gravity loads can not be considered to provide resistance to seismic forces (2005 NBC 4.1.8.17(8a)). As friction due to gravity can not be used to resist seismic forces or displacements of equipment, positive attachment to the roof structure is required. Roof-top equipment, pipe and duct is typically installed on top of the roof membrane in a way that does not penetrate through the roofing membrane. Minimizing the number of penetrations through the roof membrane is critical to the performance of the roofing system. The requirement for seismic restraint of roof-top equipment, pipe and duct results in additional roof membrane penetrations. In order to reduce the number of seismic restraint anchors that penetrate the roof membrane it is recommended to minimize the amount of roof-top piping and duct.

Roof structures are typically sloped to allow drainage. Roof-top equipment is required to be level resulting in the requirement for roof curbs. Placement of the equipment on roof curbs increases the potential amplification of seismic forces due to the relative high of the equipment with respect to the roof elevation. In these situations, the roof curb must also be designed for the seismic forces generated by the equipment. Timber and sheet metal roof curbs that are not adequately cross braced may not be able to transfer the seismic forces. The corners of the roof curbs must be tied together adequately to distribute the seismic forces to the curbs in-line with the direction of the force. Roof curbs must be of a sufficient gauge thickness to facilitate seismic restraint connections. The roof curbs are typically supplied by the mechanical contractor, and unless the contract specifications specifically require seismically rated roof curbs, it is unlikely the curbs will be adequate to resist the seismic forces.

Another common issue encountered is roof-top equipment that is mounted on concrete piers, or on top of steel beams that span between concrete piers. Concrete piers need to be adequately sized to anchor the equipment. Inadequate edge distances can significantly reduce the capacity of concrete expansion anchors. As well, concrete piers need to be connected to the supporting roof structure to ensure that the uplift forces are transferred to the structure. Concrete curbs or house-keepings pads that support equipment must be reinforced for the potential seismic forces and also must be sized adequately to provide enough edge distance for the concrete expansion anchors. Concrete curbs and house-keeping pads have to be positively connected to the roof structure. Concrete curbs or house-keeping pads poured on top of non-composite steel deck do not have adequate resistance to lateral forces. Observed equipment damage resulting from earthquakes includes shattered concrete house-keeping pads due inadequate reinforcing to resist the vertical seismic forces, and equipment that skated across the roof structure because it was not positively connected to the roof structure (ASHRAE, 1999). Excessive displacements of equipment can result in broken services such as gas lines that can be hazardous and result in additional damage.

Equipment that is mounted to steel beams can result in horizontal forces being transferred to the beam causing weak axis bending. Damage to mechanical equipment after earthquakes is often related to the failure of the supporting steel beams (ASHRAE, 1999). Care must be taken to ensure that the supporting steel beams are properly sized not only to resist the gravity load of the equipment but also the potential seismic forces. Common issues include beam roll-over and local web buckling. Steel beams should be reinforced with web stiffeners at all points where the equipment is connected and transfers horizontal forces. Consideration should also be given to providing horizontal bracing between steel beams to resist the lateral forces. The use of independent steel beams should to be avoided if possible. The connections of the steel beams to the roof structure have to be designed for the potential seismic forces.

Vibration Isolated Equipment

Many common pieces of mechanical equipment such as cooling towers and chillers are mounted on spring isolators to ensure that equipment vibrations are not transferred to the building. Depending on the type of spring isolator used, the seismic forces can be amplified. The IBC recommends that seismic forces be increase by a factor of two when equipment is mounted on spring isolators. It is critical when selecting the size of the spring isolators, that the seismic forces be considered as the over-turning reactions and vertical seismic forces will have a significant impact on the forces required to be supported by the springs. Depending on the spring isolator housings, seismic snubbers may be required to control lateral displacements of the equipment when subjected to seismic forcers. The capacities of spring isolators are also dependant on how the isolator is connected to the supporting structure. The connection of the equipment to the spring isolator and the connection of the spring isolator to the structure must be designed for the appropriate seismic forces.

Pipe/Duct and Suspended Equipment

A large percentage of the mechanical and electrical systems in buildings, including pipes, ducts, cable trays, fans, and unit heaters, are suspended from the structure. The seismic restraint of suspended equipment depends on how the contractors install the systems. Drawings prepared by the mechanical and electrical engineers are schematic single-line diagrams that show general information regarding pipe and duct size requirements, and the general location where the pipe and duct has to go. The mechanical and electrical drawings do not specifically outline how the pipe and duct is to be supported, and in many cases, it is not until the contractors have completed their interference drawings that the actual routing of the services is known. Without knowing how the pipe and duct is supported, the seismic restraint system cannot be designed. Pipe and duct individually supported will require a different level of seismic restraint compared to pipe and duct that is supported on a trapeze with several other pipes or ducts that increases that lateral force at each restraint location. The diameter, length, and spacing of the hanger rods used by the contractors to support the pipe and duct will also impact the seismic restraint requirements.

The 2005 NBC states that seismic restraint for suspended equipment, pipes, and ducts, be designed to resist the seismic forces and displacement in a manner that will not subject hanger rods to bending (2005 NBC 4.1.8.17(12)). A common trend in the industry has been to exempt any pipe or duct suspended from the supporting structure with hanger rods less than 300mm (12”) in length from the Code requirements for seismic restraint. Items that are hanging on supports react to earthquakes as though supported on a pendulum (VISCMA, 2006). When equipment is suspended with hanger rods less than 300mm (12") in length, amplification of seismic forces and displacements is reduced since the natural frequency of the suspended equipment and hanger rod assembly does not coincide with the frequency content of the earthquake. Pipes and ducts will sway during an earthquake, but the displacement is limited, and as long as there is nothing that would prevent the sway of the hanger rod (adjacent equipment) and the hanger rod is connected to the structure with a pin-type connection that allows rotation, pipe and duct systems should perform adequately during seismic events.

Guidelines published by ASHRAE and SMACNA both include sections on seismic restraint of pipe, duct, and suspended equipment. These guidelines suggest maximum spacing of 12m (40’) for transverse seismic restraints and 24m (80’) for longitudinal seismic restraints for standard pipe and duct. The maximum recommended spacing is reduced by a factor of two when the systems contain hazardous materials. In many cases depending on the size, contents, and importance category of the building, the spacing of restraints will be less than the maximums suggested by the ASHRAE and SMACNA guidelines.

The seismic restraint engineer must calculate the actual seismic forces based on the spacing between restraints and ensure that the specified restraint system and its connection to the structure is adequate. The seismic restraint engineer must also consider the contents of the piping when determining the seismic restraint details. Piping that contains hazardous materials creates higher life-safety risks due to failure when subjected to seismic forces than standard plumbing piping. For some piping systems, such as the storm water system, judgment must be used when calculating the seismic force since the pipes may or may not be full during the earthquake. A similar approach to snow loads is recommended for storm water piping in that 25% of the weight of the contents of the pipes should be included in the weight of the pipe when calculating the seismic force.

The seismic forces resisted by the restraint system for suspended equipment, pipe, and duct results in vertical forces in the hanger rods. The vertical forces in the hanger rods are due to both the vertical accelerations resulting from the earthquake as well as the vertical component of the bracing force. The seismic restraint engineer needs to ensure that the hanger rod is sized adequately for the vertical forces, and is stiffened with rod stiffeners as required. This issue is complicated for the seismic restraint engineer given that the spacing, length, and the diameter of the hanger rods used by the contractor to suspend the equipment is not always known until after installation.

Wall-Mounted Equipment

There are several typical pieces of mechanical and electrical equipment that are wall-mounted including transformers, circuit panels, fans, and air-conditioners. A common issue often encounter is wall-mounted equipment that is supported on a back-up wall that is not engineered to resist lateral forces. These back up walls include non-engineered steel stud walls, timber stud walls, and unreinforced masonry walls. The seismic restraint engineer is not involved with the design of the supporting walls but must provide the base-building team the seismic loads due to the wall-mounted equipment that the wall is required to resist. The base building team should locate wall-mounted equipment only on engineered walls. For pipe and duct passing through engineered walls, the wall may act as a transverse restraint provided that the pipe/duct crosses the wall at 908 and is tight to the wall and may act as a longitudinal restraint provided the pipe/duct is positively connected to the wall. Equipment anchored to drywall or plaster cannot be adequately restrained.

Construction/Installation Issues

The mechanical and electrical trades have limited experience installing seismic restraints, and often do not understand the requirements. Many contractors regard seismic restraint as unnecessary due to their lack of understanding of the issue. This leads to several challenges to provide adequate seismic restraint. As current practice requires the contractors to provide the engineering, supply, and installation of the seismic restraint systems, the contractors have to estimate the costs for this work to include in their tender bids. Given the short time frames normally allotted for tendering, contractors are faced with a difficult problem of accurately estimating the costs for seismic restraint work. In many cases contractors under estimate the work and cost required. In these situations contractors will try to cut costs by limiting the scope of seismic restraint work carried out. Generic contract specifications that do not adequately define the seismic restraint scope of work allow contractors to make their own interpretations of seismic restraint requirements that may not satisfy the intentions of the Code provisions.

When the seismic restraint engineer prepares the restraint details, the exact location and orientation of the equipment is not always known. This means that the engineer needs to specify several different restraint details that the installing contractor can choose from depending on the actual site conditions. The installing contactor needs to be able to select the appropriate restraint detail depending on the type and configuration of the supporting structure. Making the appropriate selection relies on the contractor understanding the differences between the restraint details and the differences between supporting structural systems. Mechanical and electrical contractors that are not familiar with structural systems are being required to install seismic restraints between the mechanical or electrical equipment and the base structure. It is critical that the seismic restraint be properly anchored to the structure and that the restraints are located at points where the structure has the capacity to resist lateral forces. Inexperienced contractors can easily install seismic restraints that result in lateral forces being transferred to elements of the structure not designed for lateral loads. A typical example encounter on site of this is seismic restraint being anchored to the bottom chord of steel joists. The bottom chords of steel joists have very weak out-of-plane bending strength, unless braced, and cannot resist lateral loads. Seismic restraint should be connected to the top chords of steel joists where the steel deck provides the required lateral support.

In steel structures, the orientation of the supporting steel beams or joists must be considered when choosing the method of connecting the seismic restraint to the beam or joist. All connections must be positive and cannot rely on friction to resist the forces. In order to use beam clamps to connect the seismic restraint to the steel beam or joist, the restraint used to resist the seismic forces must be orientated at a right angle to the span of the steel beam or joist. If the seismic restraint is orientated in line with the axis of the beam or joist, then beam clamps cannot be used. In these conditions a welded connection or through bolted connection is required. When beam clamps are used to connect the restraint to the supporting steel structure, seismic beam clamps must be used. Most commercially available beam clamps are designed to only transfers vertical loads and do not have any capacity to transfer lateral forces. Seismically rated beam clamps must engage both sides of the steel beam flange so that they cannot be pulled off of the beam.

Seismic restraint systems installed in reinforced concrete buildings are typically anchored to the structure with post-installed drilled concrete anchors. Drilled concrete anchors used for seismic restraint systems must be seismically rated. Not all available drilled concrete anchors have been properly tested and rated for seismic loading, and these anchors are usually less expensive for contractors to purchase. Care must be taken on site to ensure that the anchors specified by the seismic restraint engineer are installed rather than non-equivalent drilled concrete anchors. The capacity of drilled concrete anchors is sensitive to the anchors being installed properly. Issues that can affect the capacity of the anchor include improper cleaning of the drilled hole, using a drill bit too large for the anchor size specified, or applying too much torque when tightening the bolt. Improper installation of post-installed drilled concrete anchors can significantly reduce the capacity of the seismic restraint system.

The construction schedule also presents several challenges. Typically seismic restraint of mechanical and electrical equipment is carried out in the final stages of construction. In many cases, the coordination between trade activities on the construction site does not consider the seismic restraint work. This can complicate installation of the restraint system as ceiling finishes and other architectural components interfere with the required restraints. As well, as more and more pipe and duct is installed, the installation of seismic restraints is complicated due to the congestion of equipment in limited spaces. For roof-top equipment, installation of the roofing membrane needs to be coordinated with the seismic restraint requirements of the equipment. Seismic restraint of roof curbs and house-keeping pads that require positive attachment to the structure needs to be installed prior to installation of the roof membrane. The tight construction schedule also leads to difficulties for the seismic restraint engineer to adequately carry out construction review services. Adequate time in the construction schedule needs to be allotted for site inspections of the seismic restraint installations. This includes inspecting the connections between the roof curbs and house-keeping pads with the structure prior to the roof membrane being installed, and review of seismic restraints of suspended equipment prior to ceiling finished being installed.

Recommendations

Industry Involvement

To overcome many of the issues discussed, a professional organization in the United States called the

Vibration Isolation and Seismic Control Manufacturers Association (VISCMA) that consists of companies and corporations that engage in the seismic restraint, vibration isolation or noise isolation, was established. The focus of this group is to standardize the industry to ensure that a consistent level of service and protection is provided by all parties involved in providing seismic restraint to mechanical and electrical equipment in buildings. In Canada, there is no equivalent body to VISCMA. There is no organization that ensures seismic restraint engineers and suppliers all provide an equivalent system. Engineers and suppliers are left to interpret the Codes and Standards on their own, and given complexity of this issue, individuals in the industry often take widely different interpretation. To ensure a consistent level of protection is installed for all mechanical and electrical equipment that requires seismic restraint, a similar organization to VISCMA should be established in Canada.

Pre-tender Seismic Restraint Design

Building developers and owners should consider engaging the seismic restraint engineer prior to tendering and awarding the job to a contractor. The seismic restraint engineer would work with the design team, including the architects, structural engineers, and the mechanical and electrical engineers to produce seismic restraint specifications and details that would be included in the contract documents. In accordance with the NBC 2005 provisions as well as CSA S832-06, the specifications would list all of the specific equipment, pipe, and duct that require seismic restraint, and identify the type of seismic restraint system to be used for each piece of equipment. This approach ensures a consistent seismic restraint system is installed on all mechanical and electrical components in the building. This approach also assist the contractors more accurately price the seismic restraint work. The main advantage of this approach is that the mechanical and electrical contractors are no longer responsible for providing seismic restraint engineering, but would only be required to supply and install the systems.

The seismic restraint engineer could ensure that coordination issues previously discussed are addressed prior to tendering the project. By working with the base building design team, the seismic restraint engineer can ensure that all equipment is located where positive connection to the structure can be installed, and that the base building structural engineer has the information required to design the structure for the equipment seismic loads. The seismic restraint engineer would also be responsible to review the installation of the restraint system during construction.

The difficulty with providing actual restraint details during the design of the base building is that the specific equipment size, configuration, and weight is not known until the project is tendered and the contractors specify the actual equipment that will be supplied. This issue could be addressed by having the mechanical and electrical engineers specify the actual equipment required, as opposed to specifying performance criteria for equipment. Alternatively, restraint details could be designed prior to tendering based on generic equipment that would meet the performance criteria required, and these restraint details could be modified as required when the contractor specifies the actual equipment to be installed. For pipe and duct, the seismic restraint engineer during the design phase can specifying seismic restraint details and spacing information. Once the contractor specifies the layout of the pipe and duct, the seismic restraint engineer could finalize the seismic restraint details.

Seismic Restraint Records

Requirements for seismic restraint shop drawings should be standardized. As-built drawings showing the location of installed restraints, as well as the type of restraint, and the force being resisted by the restraint should be submitted at the end of construction. As well, an inventory of all mechanical and electrical equipment in the building should be listed and the seismic restraint requirements of each piece of equipment specified. This document could then be included with the operations and maintenance manuals for the building systems to ensure that seismic restraint systems are not mistakenly modified or removed without adequate review during future building work.

Contractor Installation Training

A system of contractor training needs to be established to educate contractors on the requirements of seismic restraint and installation methods. Educating contractors not only on the installation techniques, but also on the background to the necessity of seismic restraint systems will result in a higher level of seismic protection for mechanical and electrical equipment.

Conclusion

Seismic restraint of mechanical and electrical equipment is a complicated issue that impacts all members of the design team. The current delivery mechanism for seismic restraint on projects results in inconsistent levels of safety due to the varying interpretations of Code provisions, and inexperienced trades installing the restraint systems. Addressing seismic restraint during the design phase of the project instead of during construction will reduce the number of coordination and construction issues typically encounter on construction sites. An independent seismic restraint engineer working with the entire base building team during design will improve service delivery for building developers and owners, and will result in a more consistent level of seismic protection.

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