Seismic restraints for non-structural components in Australian marketplace: prefabricated solutions

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Abstract

Non-structural components are the systems that are not supposed to take any structural loads; however, they are inevitably subjected to all dynamic loads applied to the structure. Earthquake loads are one of the most significant dynamic loads imposed to structures and consequently to their non-structural components. Mechanical services such as duct and piping systems and equipment; architectural elements such as ceilings, partitions and claddings and façade systems; electrical systems such as cable trays and equipment; are all examples of non-structural components that need to be considered for any seismic events.

In Australia, since this requirement is not significant for ordinary structures; the main subject of this research are the structures with higher importance levels where an accurate, constant design system is required.

This paper explores the importance of seismic restraint of non-structural components and how it is affected by various factors in design and practice. When proposing the type of seismic restraint, there is a broad range of varying factors to be taken into account such as: quality and safety, efficiency, cost and sustainability, and constructability and design. Prefabricated systems are then considered and evaluated as an option to reduce the varying factors in design and construction of such seismic restraint systems with a focus to Australia's marketplace.

Keywords: Non-Structural Components, HVAC, seismic restraint, Building Information Modelling, Prefabrication

1. Introduction

Investigating the response of non-structural components to seismic events is becoming one of the focuses of earthquake engineering literature. This focus mainly arises due to the considerable effects of seismic damage induced to these systems resulting in significant economic losses, life-safety concerns, and downtimes in structures with post disaster functions exactly when they are mostly needed.

The research history on significance of damages caused by non-structural components failure reveals the importance of seismic restraints to be designed for these non-load bearing components. Failures involve a wide range of components including plinth standing devices, linear components such as pipes and ducts, ceiling tiles, facades and shelves [1, 2].

Although the risk of earthquakes in Australia is seemingly low; the history of earthquakes in the country are not negligible considering the largest known earthquake with the magnitude of 7.2 (1906-WA-Central Coast) and earthquakes of 6.2 magnitudes (with return periods of 10 years) [3]. Section 8 of AS 1170.4 Structural design actions Part 4: Earthquake actions [4] defines the design process of non-structural components for seismic loads. Based on Chapter 8 of As1170.4, all non-structural components and their fasteners shall be designed both for horizontal and vertical earthquake loads. The design earthquake actions shall be calculated based on an established principle of structural dynamics, the general method introduced in AS1170.8 clause 8.2, or simplified method given in clause 8.3 [4].

Different non-structural components are typically supported by a particular range of supports for gravity purposes. Ceiling tiles are usually supported by cold-formed steel (CFS) frames hanging from soffit or partition walls. Linear mechanical and electrical services such as pipes, ducts and cable trays are typically suspended from steel rods fixed to the soffit. Other individual components such as fans, electrical cabinets and any other elements with considerable weight usually have particular arrangements to support the gravity loads. However, these gravity supports are not checked for any lateral load resistance capacity and the design process typically begins when the components are being installed if not installed already; which is a just in time design approach [5]. The non-structural component subcontractor usually installs the restraints based on an experience from other projects without having them designed or in the best practice they employ a project based engineer to conduct the design process. This means that usually seismic brace design is not reviewed and the installation is not checked in any later stages. This along with no particular design or construction review procedure requirement from building consent authorities leads to a poor overall design and installation of seismic braces for NSCs although Australian seismic codes have stated the requirement for seismic restraint of non-structural components.

2. Current practice

The common practice for seismic restraint of NSCs is via 3 methods: tension steel wires, cold-formed steel (CFS) struts and less likely CFS prefabricated frames. 2-way wires are used for transverse support only while 4-way wires are used for longitudinal and transverse support. CFS struts can be applied in various arrangements known as rigid assemblies to provide seismic restraint in any particular direction (ISAT REF). In some cases where the first two methods are not practical, the NSC subcontractors are obliged to choose the prefabricated frames which are initially more expensive compared with the other two but eventually they are proven to bring some advantages with them. Depending on the method of restraint, there are different issues in current practice that need to be addressed and coordinated by main contractor, NSC subcontractor, structural engineer (in charge of building design), mechanical engineer (in charge of Mechanical, Electrical, Plumbing design) and the structural engineer (in charge of MEP seismic restraint design). Followed is a review of considerations for design of seismic restraints for NSCs.

2.1. Cost

Project managers and estimators do not mainly consider the charges involved with seismic restraint of NSCs. The subcontractors usually have limited information about the design, material and installation costs associated with seismic restraints particularly in a low seismic risk region such as Australia. This becomes more significant at the times when there are some complications in the components to be restrained or the supporting structure and the costs will have a significant rise accordingly. In such cases, the cost for seismic restraint can become even more than the initial NSCs to be restrained.

2.2. Coordination

As previously stated, there is a wide range of NSCs need to be designed against seismic loads within a structure. Table 1 shows the range of components involved in seismic restraint of NSCs process which are the subject of this study. Typically, one individual subcontractor takes care of each (or a few of) components shown in Table 1; this introduces a number of five to ten subcontractors seeking seismic restraint solutions for NSCs in one major project.

Table 1: NSCs to be seismically restrained

Mechanical	Pipes	Water pipes
		Gas pipes
		Sewerage
		Fire sprinkler pipes
		Medical gas pipes
	Ducts	
	Equipment	Air handling units
		Cooling towers
		Chillers
Electricals	Cable trays	
	Lights	
	switch boards	
	Cabinets	
Architectural	Partition walls	
	Ceiling tiles	
	Façade	

On the other hand, the design phase of seismic restraint for NSCs is mainly postponed to the very last stages of the project; in some cases even after the components are already assembled and mounted with gravity supports to the main structure. Many advantages are offered by this approach e.g. ensuring the most up to date technology to be installed and minimising the redesign requirements [5]. However, this enforces lots of complications in seismic restraint design, installation and inspection process. Table 2 summarises the parameters need to be coordinated between different parties and usually complications happen through this process due to the delayed seismic restraint design approach. These parameters are further explained later in this section.

Table 2: Decision criteria and parameters need to be coordinated between different parties

		coordination parties				
		Seismic engineer	Structural engineer	Mechanical engineer	NSC Subcontractors	Main Contractor
Tasks with coordination requirements	type of restraint	✓			✓	
	Fabrication and installation time	✓			✓	✓
	Material and installation cost	✓			✓	
	Access to component	✓			✓	
	Access to the supporting structure	✓			✓	
	Extra constraint applied to the current component	✓		✓	✓	
	Anchorage and capacity of the supporting structure to take the loads	✓	✓			
	Fire, water and sound insulation deterioration due to retrofit anchorage	✓	✓		✓	
	Clashes and allowance for seismic gaps	✓	✓		✓	
	Other design actions involved	✓	✓	✓	✓	
	Internal performance and integrity of components to be restrained	✓		✓	✓	
	Inspections	✓			✓	
	Certification	✓	✓		✓	✓

2.2.1. Type of restraint

The first stage of the design is restraint type selection. This choice depends on various factors such as cost (material, design, installation), time limitations, access to the component to be installed (being already assembled or not), location of component within the floor level (floor mounted, hanging from soffit or any other arrangement), and weight of the component. Taking all these decision criteria into account, the seismic engineer can propose the proper seismic solution to the subcontractors.

2.2.2. Fabrication and installation time

Once the type of restraint is nominated, the seismic engineer proposes the restraint arrangements and how they are supposed to be attached to the supporting structure. This will give the NSC subcontractor an idea to evaluate the time required for installations. This will be coordinated with the main contractor to meet the project timeline. This coordination becomes crucial in case that the NSC seismic design is postponed to the very final stages of construction.

2.2.3. Material and installation cost

In projects with all different options being feasible for seismic restraints, this stage becomes the first decision criteria. The seismic engineer proposes all deign alternatives and if there is no time and access limitations; the subcontractor makes decision based on material and installation costs.

2.2.4. Access to components to be restrained and the supporting structure

Based on the phase of construction, access to the components subject to design and/or the main structure might be limited by other components or parts of the main structure such as beams, columns or walls blocking the access. Some other limitations are caused due to height of the component attachment location. This again becomes of great importance for projects with 'just in time' design approach and the decision for type of restraint might be affected based on this criteria regardless of cost and time criteria.

2.2.5. Extra restraint applied to the current component

By adding a seismic restraint, the seismic engineer needs to confirm that the extra confinement added to the component, particularly for mechanical components, is not interfering its operational properties. Components that require some translational degrees of freedom in particular directions such as pipes with hot content that might expand or shrink, and components with vibrational flexibility (particularly for noise control purposes) such as pumps and fans are examples requiring a close coordination between seismic engineer and mechanical engineer.

2.2.6. Anchorage and capacity of the supporting structure to take the loads

The type of anchors proposed by seismic engineer to attach the restraint to the main structure needs to be approved by structural engineer. Also, the capacity of structure to take the additional earthquake load of NSCs should be confirmed by structural engineer. Since the earthquake imposed loads are not considered in the structural design phase; it becomes challenging to accommodate it when the weight of components is considerable. Furthermore, some structures such as post tensioned concrete slabs, drilling holes to apply the retrofit anchors can be a quite critical and in some cases impossible process.

2.2.7. Fire, water and sound insulation deterioration due to retrofit anchorage

As previously mentioned, seismic restraints are attached to the main structure using seismically rated anchors or bolts. In cases when supporting structure or the actual component to be restrained are covered by fire rated material or any other type of insulation for water proofing or sound proofing, addition of retrofit anchors requires the approval by the structural engineer. And in most situations the insulation must be removed and reapplied after the restraint is attached.

2.2.8. Clashes and allowance for seismic clearance

One major complication with design of seismic restraints for a building with various HVAC systems and NSCs is positioning the seismic restraints. As previously discussed, one individual subcontractor looks after each set of NSCs shown in Table 1. This indicates the necessity of close coordination between different subcontractors and the seismic engineer. And the situation can become even more complicated when each subcontractor approaches a different seismic engineer or consulting company. Considering parallel seismic design procedure for each component, one can imagine the level of complication involved with clashes of seismic restraints for different components. Not only clashes, but also a minimum seismic gap needs to be allowed for, between components and their corresponding restraints [6].

2.2.9. Internal performance and integrity of components to be restrained

Operability and overall integrity of equipment and services is another concern that should be addressed by seismic engineer. The internal performance of equipment after a seismic event is usually out of the scope of seismic restraint design; however, seismic engineer coordinates this concern with mechanical engineer particularly with regards to the additional restraint induced to components via seismic restraints.

2.2.10. Other design actions involved

The NSCs gravity supports are usually designed for gravity load only. However, these components are often affected by other design actions as the structure itself. Actions such as wind load (if the component is not located in a closed area), impact loads (if the component is exposed to any type of impact loads), and any other possible actions. In such cases, the seismic engineer discusses the matter with MEP subcontractor to consider all possible combinations. This leads to further involvement of structural engineer for the same reasons as the seismic load.

2.2.11. Inspections and certification

For a seismic engineer to be able to issue the seismic restraint installation certificate, access should be provided for visual inspection of every individual restraint and its anchorage to main structure. The other practice is assigning a code number to each restraint and take a picture of each restraint to be sent to seismic engineer with the code attached to picture. This method facilitates the inspection both for seismic engineer and subcontractor.

2.3. Building information modelling

Recently most major construction projects are defined within a thorough Building Information Model. In order to reduce uncertainties, it is important to clarify all details of the building within the very initial design phase of project [7]. The use of Building Information Modelling (BIM) could lead to a significantly enhanced accuracy of seismic assessment particularly regarding to NSCs. However, it’s a common practice to neglect these non-load bearing components in initial stages of BIM. In Australia, in most cases the Building Information Models only represent the physical existence of the NSCs; and the seismic analysis and any possible restraint and their locations are ignored. This along with the ‘just in time’ design approach leads to crucial design process for seismic restraints of NSCs particularly in major projects such as hospitals.

3. Prefabricated supports designed for gravity and seismic loads

Reviewing the process of design, construction and certification of seismic restraints for NSCs exposes the lack of a thorough engineered solution from concept through to design. Prefabricated mounts, designed for seismic actions are an innovative solution to address most of issues previously discussed in section 2 of this study.

Typically, all NSCs are separately assembled and installed on site by installers from different subcontractors. This practice introduces a major discoordination associated with the lack of a thorough BIM system. This leads to higher costs, construction time and level of complication. Having NSCs introduced to the BIM system from the stages of defining the details, and considering their seismic loads in the analysis and design process of building, brings in a clear status for design and construction of support systems for these components. Some industries have already considered prefabricated support systems with NSCs (HVAC) attached to it and delivered to site by trucks [8, 9]. This is a project based design and construction of NSCs supports taking the seismic loads (or any other actions based on client's request) into accounts. This approach eliminates majority of coordination complications and consequently, reduces the increased cost and time of design and installation.

One step further in advancing the process, is having as many NSCs as possible installed to the same prefabricated support. By early coordination of mechanical and structural engineers, all NSCs are located within a prefabricated frame system. This allows the seismic engineer to consider all involved component weights and locations to analyse and design the prefabricated support. Each of the supports carrying various components are called one module. After being analysed and designed, the modules can be assembled off site and delivered to the job site. This approach is even more efficient than the previous one since the seismic analysis and design process is conducted once for a number of components. This eliminates the access issues or any risk of clashes and reduces the onsite work resulting to enhanced quality control.

4. Harnessing forces of the Macro Environment

Construction trends can be aligned with Macro Environmental factors. Prefabrication provides clear opportunities for the many stakeholders, with minimal threats created to the status quo construction approaches.

4.1. Demographics concerns

Demographic forces relate to people: prefabrication removes people from construction sites and brings them into the controlled space of a manufacturing environment. This regulated workplace works with existing access to factory environment, generally away from populated areas, with permanent amenities, enabled work activities with increased safety and enhanced supervision and quality control. This results in highly improved quality of work, worker safety and opportunity for skill acquisition and integrated learning.

4.2. Political concerns

Prefabrication supports the Political desired outcomes with improved environmental, financial, societal and time concerns. Prefabrication has previously been adopted in order to speed up construction, and now is being harnessed to reduce risk, improve sustainability and provide assured outcomes.

4.3. Ecological concerns

Construction places great pressures upon the environment including resource usage, waste production, and transportation noise pollution. Prefabrication creates modules of complex systems but limits waste and eliminates the need for additional restraints. Modules are pre-assembled offsite in required order and transported to be attached to structure. This results in major reductions to site works in lay down areas, number of construction personnel, tools required, required storage of parts and components and waste.

4.4. Economic concerns

In Australia, local prefabrication combats overseas prefabrication where labour costs are lower and keeps the local economy active and growing in capacity. Local prefabrication enables multiple project costs to be lowered such as labour, material wastage, and effective work hours.

For example, offsite manufacturing provides effective worker output of 7.5hours per 8hr shift as opposed to 4.5 hours per 8 hour on site shift, without the need for site penalties, allowances, etc.

4.5. Socio-cultural

Prefabrication follows society’s basic values of wellness, work safety, and efficiency.

5. Conclusion

The traditional approach for NSC support systems considers the gravity only supports for initial design. Then based on the predicted magnitude of seismic loads, seismic supports are designed and added to the existing gravity support. By introducing prefabricated modular construction approach to NSC seismic support systems, the analysis and design process for gravity and seismic loads are unified. This significantly affects the time and cost involved with analysis, design, installation and inspection of supports. In addition, having all or as many NSCs as possible assembled to the same framing, leads to a clear analysis and design process of the support system and adds up even more to the efficiency of seismic restraint engineering of NSCs.

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