Seismic Performance of Non-Structural Components

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Abstract

The effect of Non-Structural Components (NSCs) in buildings during a seismic excitation can be devastating. In some cases, especially in importance level 4 structures, the consequences can be even more severe than the structural damage to the building structure itself. However, the support and attachment systems of NSC to the main structure can, and should be engineered to withstand the loads, especially in post disaster function buildings such as hospitals, aged care facilities, government buildings and alike. This paper will address the potential damage that can be caused from NSC and the potential aftermath repercussions. A short review of AS1170.4-2007 Section 8, and the earthquake action calculations mentioned including a comparison between the simple method and the acceleration method for earthquake actions calculations. Also, this paper will demonstrate real life design and installation difficulties from recent projects and the main obstacles in the construction industry in relation to seismic restraints of NSC, and the level of education about this topic in the industry.
Finally, we focus on our opinion of the most cost-efficient method to incorporate seismic engineering for NSC into new projects and the cooperation needed between the disciplines to design and construct efficiently.

Keywords: Non-Structural Component (NSC), earthquake action, seismic restraint, existing structures, cooperation between design and construction

1. INTRODUCTION

Non-Structural Components (NSC) within a building are defined as permanent elements that are not a part of structural system but are supported by the primary building structure. NSCs usually include:

- Architectural features such as interior partitions, exterior cladding and glazing and ceilings.
- Mechanical components such as pipes, ducts, equipment, pumps, generators and unit packages.
- Electrical elements including cable tray, lighting, switchgear and control centre cabinets.
- Plumbing systems such as pipes and equipment.

On average the structural elements and NSCs form 15-25% and 75-85% of construction costs, respectively (Fema-74-2011, 2.1.3). Figure 1.1 represents the contributing costs including structure, NSCs and contents for important buildings.

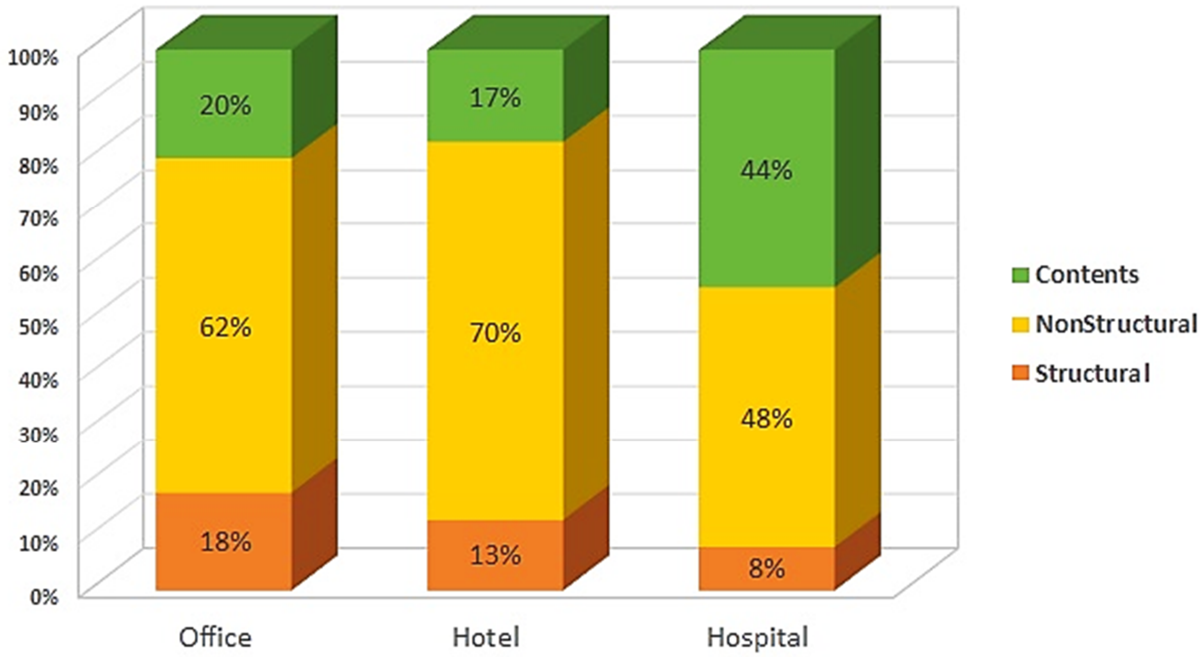

Figure 1: Typical investment in important building construction (Fema-74-2011)

In addition, the operational capability during and after a seismic event is even more vital for the serviceability in critical moments, which is a part of the definition of an important building. Therefore, the prevention of damages caused by NSCs plays a major role in most buildings. But in the important buildings with immediate occupancy after an earthquake the ability of operating without any hazard is a demand. Failure of NSCs impacts the performance of buildings. Also, the repair works interrupt the functionality and operation of the building during this period which carries significant downtime and costs.

According to Hazus (a FEMA program), the costs due to earthquake damage includes 15.6% for structural, 51% for NSCs and 33.3% for the contents. According to previous experiences in low intensity earthquakes the percentage of NSCs losses is higher than the structural losses. In most cities of Australia, low intensity quakes are most likely and the probability for NSCs' failure is high (J.E. Daniell, AEES 2014). Consequently, the performance of NSCs in Australia must be improved to withstand earthquakes.

2. Damage Examples

NSCs' damage from seismic events are well documented all around the world. This paper focuses on failure of mechanical/electrical/plumbing (MEP) services. Displayed below are common failures in buildings worldwide.

2.1 Mechanical Equipment

Mechanical equipment and plant are mostly just resting on the floor or roof. This type of failure also affects electrical wiring, gas and fluid pipework.

Figure 2: Compressor failure in 1994 Northridge and Rooftop condensing units toppled in 2010 Chile

2.2 Ducts, HVAC equipment with duct and suspended equipment

This category covers ducts, in-line equipment with duct and suspended equipment.

Figure 3: HVAC equipment failure in 2010 Chile and Air diffusers collapse 1994 Northridge

2.3 Suspended piping and pipe riser

This category includes pipework systems of fluid and gas in and around building.

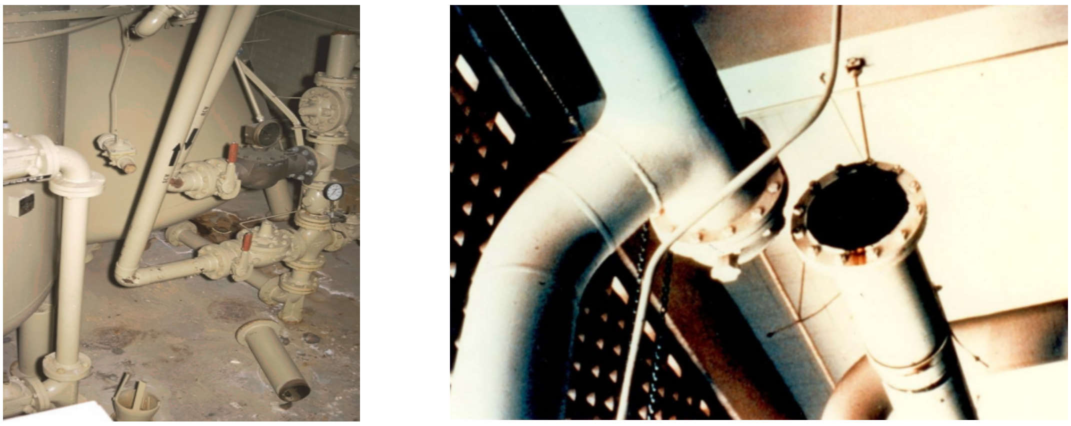

Figure 4: Pipework broken and pipe joint failure in 1971 San Fernando

2.4 Electrical and communication equipment and lighting fixtures
This category addresses floor, wall and soffit mounted electrical and communication equipment including battery racks, panels, cabinets and substations. Also, cable tray and lighting systems are in this category.

Figure 5: Electrical Cabinets overturned 1999 Izmit and Lighting dangling 2010 Haiti

2.5 NSCs damage history in a Hospital, Olive View Hospital California
The hospital was designed to the current seismic standard and opened in December 1970, shortly after that it was severely damaged during the San Fernando earthquake (February 1971) and the building was demolished in 1973. The rebuilt hospital was opened in 1987. This redesigned building performed satisfactorily in the 1994 Northridge earthquake, but it was unusable because the chilled water system and the sprinkler system failed, including several air handling units on the roof came off their supports. (NIST-ICSSC-TR14-Northridge Earthquake-1994). This is a real example of a building classified as importance level 4 structure that shows that serviceability of MEP and the capability of operation after the event has the same or even more important of the performance of the structure.

3. Non-structural components in the Australian code

Earthquake actions for parts and components is addressed in AS 1170.4-2007 in a flow chart of the design procedure and is referred in section 8 for design. Based on AS 1170.4-2007, NSCs has 2 categories Architectural and Mechanical-Electrical categories. For MEP systems, all components are addressed with a few exemptions. Earthquake forces for NSCs are generated by two methods; the simple and the acceleration method.

The method using design accelerations in section 8 is identified as below equation;

$$F_c = \alpha_{floor}[I_c a_c/R_c]W_c \leq 0.5W_c \qquad \text{(EQ 3.1)}$$

In the simple method earthquake action force has been provided with this equation;

$$F_c = \left[k_p Z C_h(0)\right] a_x [I_c a_c/R_c] W_c \quad but \geq 0.05W_c \qquad \text{(EQ 3.2)}$$

3.1 Maximum amount for F_c from both methods
For the acceleration method we have a maximum load limitation but for the simple method there is no limitation. Below is a sample substituting figures in those equation to compare the results:

- For a hospital sited on shallow soil with 20m height, seismic loads on ducts calculated as follows:
  k_p=1.8, Z =0.11(Newcastle), $C_h(0)$=1.3, a_x=3(roof), I_c=1.0(chiller), a_c=2.5(spring mounted), R_c=2.5(non-brittle material)

F_c = $0.77W_c$ which is ≥ $0.05W_c$ but also it is bigger than $0.5W_c$(max action force from the acceleration method). Regardless the identical term $I_c a_c/R_c$ in both methods, in the more accurate method (the acceleration method) F_c is limited to $0.5W_c$ therefore worst case of F_c from both methods is $0.5W_c$.

3.2 Comparison of F_c in a real project

In the acceleration method, the main parameter is α_{floor} which is the effective floor acceleration at the level where the component is situated. Below we compare the results of these equations in one real example;

- This building is an embedded building under-ground, operating as a huge vent for tunnels.
  Related parameters are k_p=1.8, Z=0.08(Sydney), $C_h(0)$=1.3, a_c=1(not spring-type mounting system), I_c=1.5, R_c=2.5(non-brittle material) after calculating action load by the two methods we ended up with the following results:

				Simple Method			Acceleration Method	
				Rigid	Other		Rigid	Other
Floor	Elevation	h_x	a_x	C_r	C_o	afloor(mm/sec^2)	C_r	C_o
B04	-28.5							
B03	-11.3	17.2	1.49	0.42	0.17	591.05	0.09	0.04
B02	1	29.5	1.84	0.52	0.21	2794.7	0.43	0.17
B01	11.5	40	2.13	0.60	0.24	1727	0.26	0.11
L00	15.5	44	2.25	0.63	0.25	1757	0.27	0.11
L02	23.5	52	2.48	0.70	0.28	1021	0.16	0.06
R01	42	70.5	3.00	0.84	0.34	1958	0.30	0.12

Table 1: Comparison of C_r and C_o in simple and acceleration methods

As shown, the simple method developed more conservative results. Consequently, the simple method is a conservative method supporting NSCs but perhaps it is not representing the most cost-effective solution.

4. NSCs seismic restraints in projects

To understand the difficulties and barriers the construction industry faces in relation to the design and installation of seismic restraints, first we need to understand how construction projects are being managed and executed. For the purposes of this paper we are focusing on large scale projects and the information being presented here is based on our experience and personal opinion.

4.1 Real life of design and installation

Most builders commission contractors for a Design and Construct (D&C) scope of works, or for a construct only scope of works. The majority of subcontracts issued by builders to the subcontractors contain a clause that states that the installation is to comply with AS1170.4 -2007. While this appears to be the satisfactory, there is minimal enforcement and many contractors are managing to get away from this part of the contract. Speaking to contractors on the job site we often hear responses like “I haven’t allowed for it in the budget”, “There aren’t any earthquakes in Australia” or my personal favourite one “I have been doing this for 40 years and no one defected my work in the past”.

4.2 Main issues of NSCs seismic restraints

Unfortunately, the implementation of NSC seismic restraints in new buildings in the Australian market is not as straight forward as it should be. The first and biggest barrier we constantly face is the lack of education and basic understanding in relation to the BCA/NCC and Australian Standards minimum requirement and consciousness of the possible consequences that may occur.

Another barrier is communication and coordination of seismic restraints design and installation on site, or the lack of it. Because the way construction contracts usually work, a construction project will be divided into disciplines and contracts issued by builders will engage multiple contractors to accomplish the job under the management of the builder's project team. The result in relation to seismic design is not efficient or productive. In a building many of the NSCs interact with one another and a seismic solution must incorporate the system as a whole. For example, a light fixture installed by the electrical contractor and supported by a ceiling grid which is installed by another. This is a typical situation we see often when the ceiling hasn't been designed to withstand seismic loads and this restricts the electrical contractor from fixing the light fixture to the grid. The end result is an individual support for each light fixture, switchboards, communication racks etc. which evidently increases the total cost of the project and still won't provide full compliance for the project as a whole. We also very often see that under one project, a few contractors will go through the process of design and installation of seismic restraints, while others won't do it at all. Just think of designing a structure that will consider slabs under seismic loads and exclude load bearing walls from the seismic analysis, just because it's cheaper to do so.

Figure 6: Duct Supports without any positive connection to roof (without base plate) and gravity pipes without any seismic restraints 2018 Governmental building Sydney

4.3 Coordination between disciplines

This reality created a divided service providers market. On one side there are contractors that pride themselves in a high-quality workmanship and compliance with all relevant standards, and on the other side there are contractors that believe that compliance with the standards is optional. Unfortunately, there are more of the second type that believe that compliance with the standards is optional. Too frequently, contractors are trying to avoid the design and installation of seismic restraints, while most of them do get away with it, others are getting defected very close to the completion date of the project. This leads them into a very expensive journey of a rushed design combined with retrofitting solutions that are usually two or three times the cost if they had done it properly in the first place.

4.4 Cost-efficient method for NSCs seismic restraints

Looking back at those reasons, the cost and design time and coordination needed can't be overlooked. However, we do believe that this process can be refined to become more efficient and cost effective. Entering into the projects at very early stages of design is beneficial in many ways. We have been experimenting this approach in several high-profile projects across Sydney and the results to date are promising. The approach of an early seismic restraint design in detail may carry higher design costs at the early stages, but, provides massive benefits at the construction stage. Incorporating the restraints system into 3D models solves many clash issues and helps design the correct restraint system to the specific area. This also streamlines the site installation, reduces labour time and eliminates retrofitting altogether. Additional major benefits in the predesign allow us to investigate the structure and design the fixings to clear PT cables and similar obstructions and to make sure that the fixing point is rigid enough and isn't impacting another discipline.

Figure 7: Miscoordination between MEP discipline in design and installation in a governmental building in Sydney 2018

5. The future of NSCs in Australia

We still have a long way to go to achieve the same level of seismic engineers are doing it in New Zealand, but the topic is attracting increasingly growing attention from clients, consultants and builders.

In the future we would hope to see AS1170.4 – 2007 Section 8 being further developed and have more guidelines and requirements and exclusions that will suit the Australian construction industry, and maybe, if we are lucky, another standard for existing buildings too, or even a NSC extension for AS3826-1998 (Strengthening existing buildings for earthquakes).

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