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Structural Assessments for Commercial Property Agents

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Author: Ronald Gultom, Civil Engineering Leader/Analyst Auckland, CSI.

Introduction

As a seismically active country, New Zealand buildings are expected to sustain the impact of moderate to large ground shakings from time to time. While relatively new buildings, those built from 2004 onwards, are designed according to the most current standard for earthquake actions, New Zealand is also rich in buildings with heritage values. These heritage buildings, especially those constructed using the unreinforced masonry (URM) system prior to 1935 (NZSEE, Sesoc, NZGS, MBIE, & EQC, 2017), are known to perform poorly during earthquakes.

Since the inception of the Municipal Corporations Act in 1968 (NZSEE et al., 2017), actions have been taken by territorial authorities (TA) across New Zealand to enforce policies to identify and subsequently require action (assessments, remediations) on "earthquake-prone" buildings within certain timeframes.

The 2006 NZSEE Guidelines, which was due for their 5-year review in 2011, has been widely used by TAs and structural engineers to carry out assessments and improvement measures for existing buildings. However, recent seismic events that were initiated by the 4 September 2010 Darfield earthquake, followed by the 2011 Christchurch earthquake, the 2013 Cook Strait earthquake sequences, and the most recent 2016 Kaikoura earthquake, have highlighted the importance of assessments on existing buildings and the need of extensive revisions of the guidelines.

The Seismic Assessment of Existing Buildings, from hereon will be referred to as the guidelines, provides a technical basis for engineers to carry out assessments of existing buildings within New Zealand ("The Seismic Assessment of Existing Buildings – The Seismic Assessment of Existing Buildings," n.d.). The assessment will result in an earthquake rating for the building based on the minimum requirements and expected performance if a new building were to be built on the same site, considering a level of conservatism appropriate for the level of detail available (NZSEE et al., 2017). This rating is expressed as the ratio of the ultimate capacity of the building to the ultimate limit state (ULS) seismic demand corresponding to the building site, given in term of percentage of the new building standard or *%NBS*

The guidelines provide two levels of assessment, Initial Seismic Assessment (ISA) and Detailed Seismic Assessment (DSA). As the names suggest, the difference between the two types of assessments will lie in the objectives, the degree of information required, and the degree of information provided at the end of the assessments. Regardless of ISA or DSA, there has to be a certain degree of information about the existing building required to provide a reliable assessment.

CSI services

Concrete Structure Investigations (CSI) Ltd is a thought leader in the field of non-destructive testing (NDT) on the construction sector throughout New Zealand. CSI provide a wide range of services to investigate structures or structural components built using different types of materials. CSI mainly use non-destructive approaches in the jobs and where required, intrusive approaches are also an option. The different services CSI provide and they nature are summarised in the following list.

Service number / name			Non-destructive	Intrusive
1		Corrosion testing		
	A	surveying	✓	✓ (small)
	B	determination		✓ (small)
	C	control		✓
2		Material testing		✓
3		Pile Integrity Test	✓	
4		Force testing		
	A	Coating test		✓
	B	Anchor test		✓
5		Quality assurance	✓	✓ (small)
6		Structural health monitoring	✓	
7		URM testing	✓	✓
8		Scanning		
	A	GPR	✓	
	B	Pacometer	✓	
	C	Ultrasonic (UT)	✓	

Table 1 List of current CSI services

How CSI services can help with assessments, and when required, strengthening on existing buildings

As mentioned in the introduction, there must be a certain degree of reliable information of the exiting building being assessed to be able to provide a reliable assessment outcome. The engineers decide the information he or she needs, which will depend on the type of assessments being conducted.

The most obvious source of information would be structural drawings for which the building was built according to. However, considering the age of most buildings being assessed, often these drawings and other specifications are not available anymore, or might not include subsequent alterations. Moreover, then as now, buildings were not always built according to the plans.

Where there is information about the existing building crucial to the assessment missing, or when it is suspected that the actual built condition differs from the specifications, CSI can help in collecting the information through their range of investigations services. This and subsequent sections will briefly describe the key elements inside buildings that require assessment according to the guideline and their potential catastrophic effect if found to be deficient. This will then be related to which services CSI offers in relation to Table 1 are most relevant to make sure that the inadequacies are not overlooked. Based on the current services offered by CSI, the discussion will be limited to RC, moment-resisting frame with infill panel, and URM buildings. In most cases, the same information can also be used as the basis for strengthening.

RC buildings

Part C5 – Detailed Seismic Assessment of Concrete Buildings of the guideline (NZSEE, Sesoc, NZGS, MBIE, & EQC, n.d.-a) provide a generally observed behaviour resulting from typical structural deficiencies in RC buildings, which include:

- Inadequate splice (overlap) development length, in beam, column or wall, resulting in concrete crushing/crumbling around the splicing region and potential weak-column/strong-beam mechanism (Figure 1)
- Inadequate shear reinforcement and confinement in column and wall elements especially those with high axial load. This is mostly due to too large of transverse reinforcement spacing in critical regions and results in axial-shear failure and buckling of longitudinal reinforcement (Figure 2)
- Different type of beam longitudinal reinforcement anchorage into the beam-column joint, which lead to different expected performance and failure mechanism (Figure 3)
- Inadequate longitudinal reinforcement ratio in walls, which results in large, single crack in the plastic hinge region and potential tensile rupture of longitudinal reinforcement, which can lead to sudden collapse.

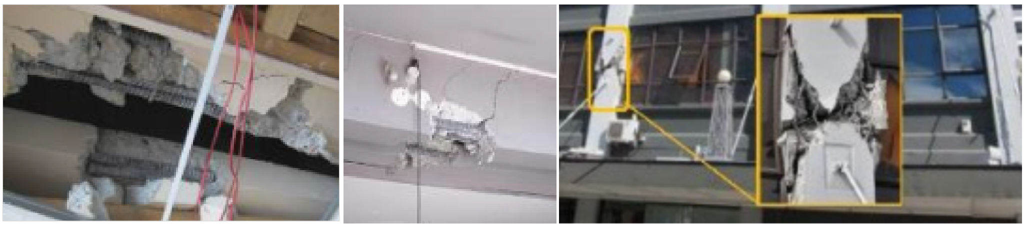

Figure 1 Failure due to inadequate lap-splice length (NZSEE et al., n.d.-a)

Figure 2 Failure due to inadequate transverse reinforcement and confinement (NZSEE et al., n.d.-a)

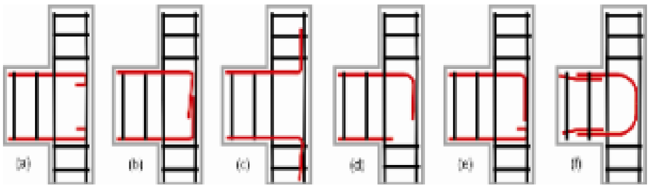

Figure 3 Different configuration of beam long. reinforcement anchorage into joint zone (NZSEE et al., n.d.-a)

Figure 4 Single crack opening of wall with low long. reinforcement ratio (NZSEE et al., n.d.-a)

The common ground of all the issues described above is the importance of available information regarding the reinforcement configuration. Scanning, through the GPR and Pacometer technology, can provide this information using an NDT approach, within their limitations. Specifically, the GPR can provide information on the number of longitudinal reinforcements in beam and column elements, the spacing between longitudinal reinforcements in wall elements, as well as the spacing between transverse and/or confinement reinforcement in beam, column, and wall elements. On the other hand, the Pacometer can provide diameter estimations. In summary, referring to Table 1, the above information can be obtained using services 8A and 8B.

Other issues in RC buildings which potentially need to be identified as structural weakness and therefor of crucial importance to obtain related information are:

- Connection detail and seating length of precast flooring system to lateral load resisting elements, to ensure the desired diaphragm action is mobilised. Figure 5 shows diaphragm failure duet to the lack of adequate connection detailing and seating length.
- Poor penetration locations into diaphragm or to lateral structural elements, such as cutting through steel reinforcement (especially prestressing strands) poses significant structural weakness

Again, services 8A and 8B can provide insight into this information without the need of intrusive measures. In particular, scanning provides the locations of reinforcement which will indicate ‘safe zone’ on the structural elements to penetrate without having to cut through the reinforcement. This will avoid interrupting crucial stress paths and therefore maintain the integrity of the elements.

The guidelines place less stringent requirements on material properties information required for assessment. In the absence of specific information, default values for the mechanical properties of the reinforcing steel and concrete may be assumed to be based on the relevant standards and practices at the time of construction, providing there is no general indication of poor material quality (NZSEE et al., n.d.-a). When qualitative assessment cannot ascertain acceptable material quality, Appendix C5D of the guidelines provide a list of material testing methods, both non-destructive and intrusive. CSI can provide services 1A, 1B, 1C, and 2, which are also covered in the Appendix.

Figure 5 Damage to diaphragm system with potential loss of seating (NZSEE et al., n.d.-a)

URM buildings

Vulnerability of URM buildings to earthquake can be attributed to its high mass, lack of integrity between elements and lack of deformation capability. The most hazardous elements in URM buildings are unrestrained element at heights (e.g. chimneys, parapets), and inadequate connections between walls and diaphragms as well as between orthogonal walls at the perimeter of the buildings (NZSEE, Sesoc, NZGS, MBIE, & EQC, n.d.-c). Part B of the guidelines explicitly state that the presence of URM walls or cantilevering parapets should be sufficient ground to rate a building as earthquake prone until the stability of the wall or the effectiveness of the restraint can be confirmed. Thus, where there are unrestrained elements at height which are generally visible from visual inspection, this should be tied to the main load-bearing structures before considering further assessment.

Once these unrestrained elements have been secured, the next crucial element is the connections. The different type of connections to be checked are:

- Cavity wall connections - cavity ties are used to tie outer whytes to inner whytes or main structural walls at regular spacing horizontally and vertically.
- Wall-diaphragm connections -there are different types of connections used for this purpose. The use of anchor plates, sometimes called rosettes, can be visually inspected from the exterior of the buildings, while connections using steel straps or concrete pockets with fish-tail are more concealed.
- Wall-to-wall connections - in most cases, there are no mechanical connections provided to tie orthogonal walls together (NZSEE et al., n.d.-c). Concrete bands or bond beams are sometimes used to tie orthogonal walls, but their effectiveness will depend on the reinforcement detailing in the junctions. Separation between orthogonal walls are

nevertheless likely to occur in large earthquakes and do not necessarily constitute significant structural damage, provided that the cantilevering walls are secured to the diaphragm.

These connections, except for rosettes, are concealed within the masonry elements. Consequently, CSI’s range of scanning services (8A, 8B) can confirm the existence of these connections and their spacings. However, the existence of these ties is not sufficient to obtain an earthquake rating above the minimum for earthquake-prone status. For buildings of three or more stories, the condition and effectiveness of these ties must be verified through intrusive measures. This is also a service that CSI provides.

Due to the standards and construction practices around at the time of their constructions, strengthening of URM buildings has become an urgent attention to TA across New Zealand. A lot of the strengthening methods involve attaching structural steel to the masonry structural elements to increase capacity or improve connections between structural elements. For example, wall-to-diaphragm connection using anchor plate (steel angle, Figure 6) or improving out-of-plane and in-plane stiffness with steel posts or steel frames

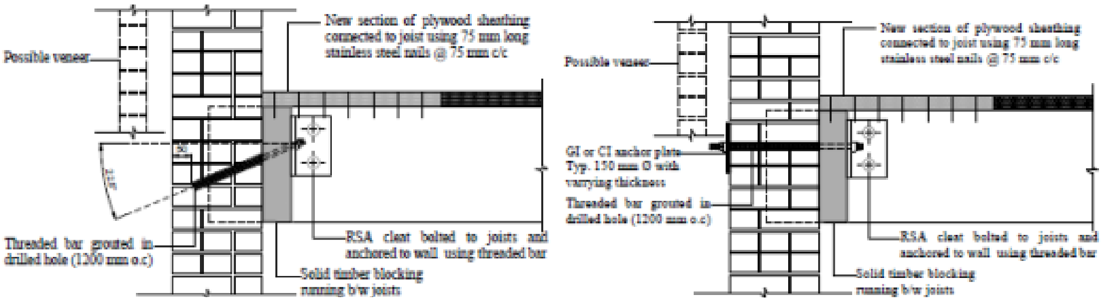

Figure 6 Anchored connection between masonry wall and floor joist using steel angle (NZSEE et al., n.d.-c)

Figure 7 Anchoring steel posts or frames to increase in-plane and out-of-plane flexural capacity (NZSEE et al., n.d.-c)

CSI provides a force testing service for anchored connection in masonry structures; service 4B. There are two types of services; proof testing and ultimate testing. Proof testing is conducted to check the quality of installation, whether the correct procedure or manufacturer recommendation has been followed. Ultimate testing is conducted to provide the ultimate capacity of masonry units as the base material of the anchor connection, both in tension and shear.

Similar to RC buildings, the guidelines place less stringent requirement by allowing the use of default material properties. Simple on-site tests such as scratch testing is recommended, however the result of this test is highly subjective. The knowledge of representative material parameter values specific to the buildings will increase confidence in the reliability of the assessment outcome. CSI provides a more comprehensive testing regime to obtain the properties of masonry structures constituent materials, such as:

- Compressive test on single masonry unit and prism
- Compressive test on mortar sample
- Shear test on mortar bed joint

The above tests fall under services 7. Due to its intrusive nature, CSI also helps in removal of the test specimens as well as reinstatement using materials/elements with similar characteristics and properties.

Moment resisting frames with infill panels

This type of buildings was most common in New Zealand between the early 1920s and the mid-1960s (NZSEE, Sesoc, NZGS, MBIE, & EQC, n.d.-b). Most of these buildings are comprised of clay brick or concrete block as the infill panel and RC as the perimeter frame, while steel perimeter frames are more common in modern large storage or industrial buildings. CSI services that are of used for RC and URM buildings are also relevant for diagnostic testing for this type of buildings due to the similarity in the constituent materials.

Foundation

Foundations are an integral part of any structures and should be regarded as potential structural weakness to be included in the assessment. Regardless on the sound integrity of the superstructure, inadequate detailing or failure in foundations may result life-safety hazard, such as:

- Large differential settlement that will impose additional stresses to the superstructure elements that they may not be designed for.
- Detachment of the superstructure from its foundation, leading to the complete collapse of the superstructure when further shaking (aftershocks) occur.

The type of materials used to build the foundations determine the services CSI can provide for investigations, regardless of the type of the foundations. When the foundations are of RC or masonry types, the services CSI provide for the associated material as described previously are also relevant, as long as relatively easy and spacious access to the foundations can be provided. In addition, for pile foundations, CSI can investigate the integrity through Pile Integrity Test, or PIT (service 3 in Table 1). Within its limitations, PIT can provide the following information:

- The length of the pile - this is more relevant for cast-in piles as a quality assurance measure.
- Any defects, such as cracks, necking, and/or belling further down the piles.

Conclusions

This paper presents the services CSI can provide to collect information required for seismic assessment of existing buildings. This information is sometimes missing, i.e. non-existent drawings, or not representative to the actual built condition, i.e. built not reflecting the specifications or undocumented subsequent alterations. Table 2 provides a summary of they type of buildings that are most commonly assessed for earthquake rating and the services CSI offer to provide relevant information, to be read in conjunction with Table 1.

Building materials/types	Relevant services
Concrete or RC	1A, 1B, 1C, 2, 8A, 8B
Masonry (especially URM)	4B, 7, 8A, 8B
Frame with infills	1A, 1B, 1C, 2, 4B, 7, 8A, 8B
Foundation	1A, 1B, 1C, 2, 3, 7, 8A, 8B

Table 2 Summary of CSI services relevant to seismic assessment

With data reflecting the actual condition of the buildings at hand, engineers can provide more reliable assessments, which in turn can relay this information to the Commercial Property Agents. Commercial Property Agents and prospective occupiers/purchasers of the commercial properties are now equally informed regarding the earthquake ratings of the buildings, rather than simply ‘taking the landlord word for it’, which can help them to make more informed decisions regarding the property they are trying to sell or buy.

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For more information or any questions regarding this paper please contact the team at CSI on:

Phone: 0800 33 77 67 or email: info@csiscan.co.nz