Seismic risk management of NSW Education's buildings including heritage buildings

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Abstract

A building's high-level elements, such as masonry chimneys, parapets and gable walls, are considered to have a greater risk of damage and collapse during an earthquake event, with the potential to cause injury, or loss of life. To minimise risk to students and the public during an earthquake, NSW Department of Education (DoE) initiated a seismic risk management program for school buildings, including heritage listed buildings, located in higher seismic risk areas. A desktop study was done to screen school buildings for seismic risks, based on their location, age, construction types and high-risk elements. DoE supplied a list of their buildings in the higher seismic risk areas, including heritage listed buildings. Site visits were made to identify buildings with high risk elements followed by structural documentation to stabilise these elements. Gable and parapet walls were tied back to the roof structure. Masonry chimneys were stabilised by inserting a galvanised steel tube in the flue, grouting the annular space with cement grout, re-pointing weak mortar joints and/or using remedial ties to connect all brick skins together. As part of this work, chimneys were also fixed/braced to the internal roof structure and ceiling/roof diaphragms strengthened by adding ceiling/roof bracing.

Keywords: Unreinforced masonry, heritage school buildings, high seismic risk, chimneys, parapets, gable walls, flue stiffener, bracing.

Seismic risk management of NSW Education's buildings including heritage masonry buildings

Introduction

New South Wales Department of Education (DoE) is running a program to manage risk to education buildings, especially school accommodation for primary and secondary schools. The risk management approach involves seismic risk assessment, assessment of corrosion of wall ties in highly corrosive marine environments. The risk of peeling of the external skin and its probability of falling outwards is very high in an earthquake event, or even in high wind suction on the exposed wall with corroded wall ties. Risks due to non-engineered assets are also part of the compliance division of DoE.

Before the 1989 Newcastle earthquake, seismic risk in Australia was considered very low, and no specific design was required for low-rise buildings. The 1989 Newcastle earthquake, which was of moderate magnitude but caused a relatively large damage bill and broke this long-held myth [1]. However, the seismic risk is still relatively moderate compared with countries located on the ring of fire, e.g. New Zealand, Indonesia, Philippines, Japan, West Coast of America.

NSW Public Works undertook repair/remediation work of government buildings after the 1989 Newcastle earthquake [1,11]. The total damage bill exceeded $2billion. Public Works Advisory (PWA) was engaged by the compliance and maintenance division of DoE to undertake a desktop study to identify seismic risks to school buildings.

In the "Atlas of Seismic Hazards Maps of Australia", published by Geoscience Australia, several hot spots with higher hazard factors were delineated. The revised map showed two hot spots around Goulburn and Newcastle. Since damaged schools in Newcastle were repaired and strengthened after earthquake, school buildings falling under Goulburn hot spots were identified for further assessment. The seismicity, or historical records of earthquakes in this area, were also reviewed [5]. A pilot study by Public Works Advisory, called "Earthquake resistance review of existing school buildings", was also reviewed [7].

Seismic Vulnerabilities

Before the 1989 Newcastle earthquake, there was no requirement to design buildings for earthquake loading. Most buildings were designed for wind loads as the governing global design load and heavy masonry construction was suitable for wind loads. However, earthquake shaking is due to inertia, and the heavier the structure the more earthquake force will be imposed on it during an earthquake. The unreinforced masonry construction is non-ductile and may suffer major damage and/or collapse during an earthquake event of moderate magnitude [1].

Following the 1989 Newcastle earthquake, NSW Public Works (now PWA) inspected over 1000 state government buildings within 35 km of Newcastle and managed repairs to 651 buildings. Of these buildings inspected, 24 suffered major damage, 104 moderate damage and 523 minor damage. 400 buildings belonged to DoE, with 55 to the emergency services and 4 to the Department of Health. This list does not include damage to commercial, residential, educational and religious (churches) buildings.

The earthquake damage showed weakness in structures which had not been designed for earthquake, were of heavy masonry construction and it highlighted maintenance issues and poor construction practices. The extent of damage depended on the following factors:

- Foundation conditions – significantly higher damage to buildings on soft soil/alluvium. The amplification of earthquake shaking on alluvial soil foundations is now well known.
- Type of construction - ductile versus non-ductile construction. Ductile construction can absorb large amount of energy by undergoing plastic deformation.
- Regular vs irregular construction, both in plan and elevation.
- Building features – high level freestanding elements, e.g. masonry chimneys, parapets, gable walls, bell towers and decorations/appendages, have a higher risk of collapsing during the shaking of a moderate earthquake.
- Age of buildings – older masonry buildings with weaker mortar joints and corroded wall ties. It is worth noting that the earliest residential buildings (pre-1910), which didn't have cavity walls, survived the 1989 Newcastle earthquake better than the cavity wall constructions built in a latter period [1,7, 11].
- Maintenance and quality of workmanship - lack of maintenance and poor workmanship lead to higher damage.

The failures of the heavy old masonry have been observed during moderate earthquakes in seismic regions all around the world. [1,2,3,4].Seismic vulnerabilities of the old heavy masonry constructions are:

- Out-of-plane actions on the walls,
- untied roof/floor to wall connections,
- lack of rigid floor and roof diaphragms,
- large voids in diaphragms,
- free standing appendages, parapets, chimneys and gable walls

Following the earthquake in Newcastle [1,11], some structural strengthening was carried out during repair work to earthquake-damaged buildings to give them greater resilience to future earthquakes. Structural strengthening was recommended for the damaged buildings. Approved strengthening methods included:

- Bracing/tying of parapets.
- Bracing/stiffening of walls.
- Stiffening of diaphragms.
- Tying side of wall to frame/walls
- Strengthening chimneys.
- Tying the top of walls to frames/ceilings.
- Tying gables and
- Other.

Desktop study

A desktop study of schools in the Goulburn area was done using information available from the DoE. This was supplemented by data capture plans, plan-room plans and site visits.

The objective was to:

- identify building blocks with vulnerable elements.
- use a staged approach – high risk to life safety studied first. Complete upgrade studied during second stage/during major upgrade/retrofit.
- recommend remediation works to reduce risk of collapse of these high-risk elements, to reduce life safety risk. These works will not necessarily prevent damage to the building.

The desktop study identified 15 schools located in the hot-spot area around Goulburn with heavy masonry construction, that may have vulnerable elements.

After further site inspections of these schools, only seven schools had vulnerable elements. Also, all these schools were heritage listed on the DoE register and on the local LEP. The seven schools were: Yass Public School, Goulburn PS, Goulburn North PS, Goulburn HS, Dalton PS, Crookwell PS and Breadalbane PS. The other eight school buildings did not have any vulnerable elements.

Seismic assessment and strengthening.

There are two Australian Standards that apply to earthquakes in Australia, namely:

AS1170.4-2007 “Structural design actions Part 4: Earthquake actions in Australia”, and

AS3826-1998 “Strengthening existing buildings for earthquake”.

AS1170.4-2007 is referenced by the Building Code of Australia (Part B1) and is mandatory for the design of new buildings.

AS3826-1998 “Strengthening existing buildings for earthquake” sets out minimum requirements for the assessment and analysis of earthquake resistance of existing buildings and their strengthening. This standard is not intended to prevent damage to the existing building but to minimise the risk of loss of life and injury from structural collapse and not to impose severe economic impact. (AS3826-1998 was withdrawn in June 2019)

In the case of existing buildings, including heritage buildings, it is recognised that it is not always economical, or practical, to comply with AS1170.4-2007 and AS 3826-1998 ‘Strengthening Existing Buildings for Earthquakes’ requirements. Strictly speaking the need to comply AS1170.4 is not mandatory for existing buildings until substantial alterations/additions works are planned for the building, that would require compliance with the NCC [13].

The owner of building has a legal obligation to ensure the protection and conservation of the heritage building and provide an acceptable safety level for people, both inside and outside the building. In the absence of clear legislative direction, it is effectively left to the discretion of the building’s owner to choose to what extent to strengthen the building will result in different levels of safety, impact on heritage fabric, disruption to building occupants, and cost.

Based on these factors through consultation and involvement of the structural engineer, heritage architect and building owner the scope and degree of stabilization works were determined. Only vulnerable parts of the building were recommended for strengthening. Chimneys, gable walls and parapets should be strengthening to withstand two-thirds of the design earthquake load determined in accordance with AS1170.4

Case study – Yass Public school

Yass Public Schools was chosen for this case study, as it is listed on the DoE & local LEP heritage register and has all the vulnerable parts, for example, Block "G" (Library/classroom block) has 7 chimneys, eight gable walls, 11 gablet walls and one parapet. Chimneys extend 5.5m above the building's eaves level.

Refer to Figures 1 and 2, which show the front photo and elevation.

Figure 1 – Yass Public School – North-east elevation. Library and Classrooms Block "G". Inset photo shows year of construction 1877.

Figure 2 – Yass Public School – drawing of north-east elevation

Figure 3 – South-East Elevation – showing two tall chimneys, two gable walls and two gablets

Figure 4 – South-West elevation from 1940 drawings for amenities extension.

The building was built in 1877. The building is U-shaped in plan. The central part is the library, and the two sides are classrooms. The library's roof structure comprises scissor shaped timber roof trusses, under-purlins and timber rafters. The roof structure of the building's side wings comprises king post trusses, under-purlins and rafters. The rafters are lined with timber boards and a slate roofing. A suspended ceiling had been added to the side wings in the past.

The chimneys, gables walls and parapets were assessed to comply with requirement of AS 3826-1998 [10] which was current at that time. The unreinforced masonry parapets, gable walls and chimneys which have a ratio of unrestrained height above the uppermost connection to thickness (H/T) greater than 3:1 are considered unstable in an earthquake event. The scope of strengthening works comprise of those identified unstable parts and does not include earthquake assessment and strengthening of the of existing buildings structure as a whole for resistance to earthquake loads.

The force generated on the building parts was calculated using equation 8.2(1). as per Section 8 "Design of Parts and Components" of AS1170.4-2007

$$F_c = a_{floor}[I_c a_c/R_c]W_c \leq 0.5W_c$$

Two-thirds of force 'F_c' was used to design strengthening of chimneys, gable walls parapets and roof/ceiling diaphragm. The additional connections for these parts were designed for horizontal force of 10% of the seismic weight of the gable walls and chimneys ($0.1W_c$).

The chimneys were designed as a cantilever above ceiling/roof level and strengthening with steel stiffener installed in flue. The gable walls were strengthening with horizontal steel beams and designed for spanning vertically between roof, ceiling and steel beams.

The scope of seismic strengthening works for unstable parts comprised the following:

- Chimney were strengthening by inserting a galvanised steel tube stiffener in the flue and fill the annular space with cement grout. The stiffener was extended below ceiling about 2.0 meter and connected to ceiling/roof structure.
- Chimneys brick work was strengthening by inserting stainless steel 'Helibar' into bed joints around flue at specified vertical spacing. Weak mortar joints in chimneys were re-pointed as required.
- Gable walls were laterally restrained to existing ceiling and roof structure by masonry anchors. Also gable walls were strengthened to spanning vertically against face seismic load by steel beams at specified vertical spacing. The beams were fixed to gable walls by masonry anchors and connected to roof structure.
- The roof and ceiling structure acted as diaphragms were strengthen and stiffened by installing steel strap and rod bracing to provide lateral support to chimneys and gable walls to transfer loads to cross walls.
- Additional connections of the roof and ceiling diaphragm to masonry walls were provided by masonry anchors.

Refer to figures 5-10 for the design details for construction.

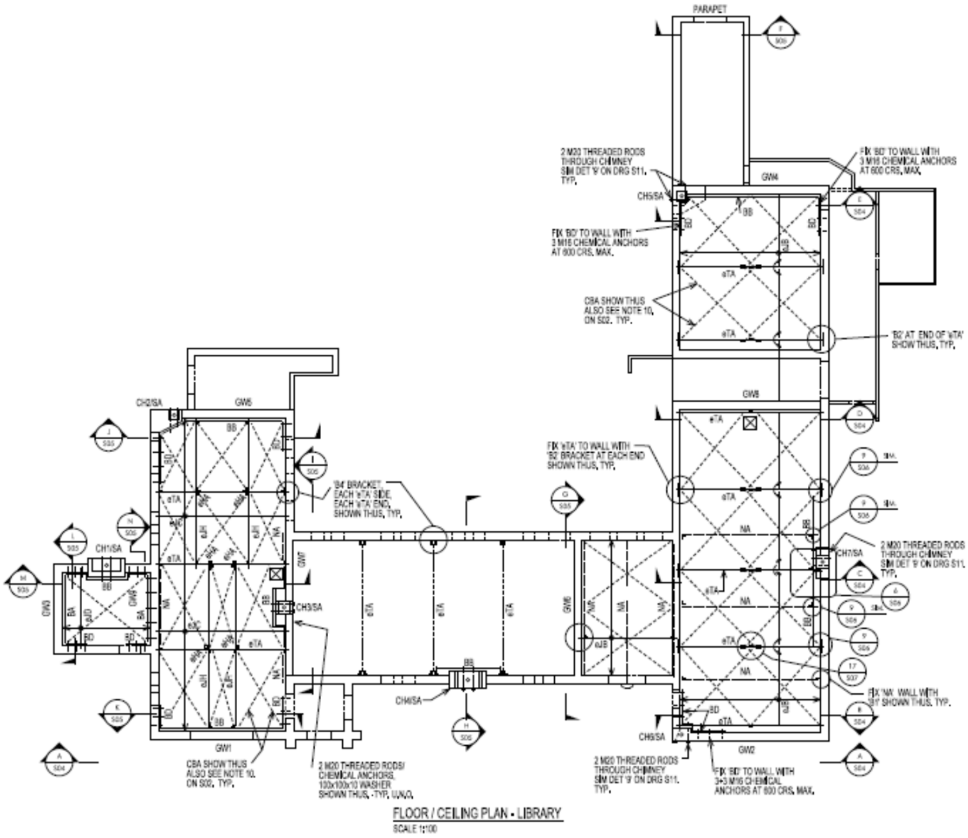

Figure 5 – Ceiling level bracing plan – Strengthening ceiling diaphragm.

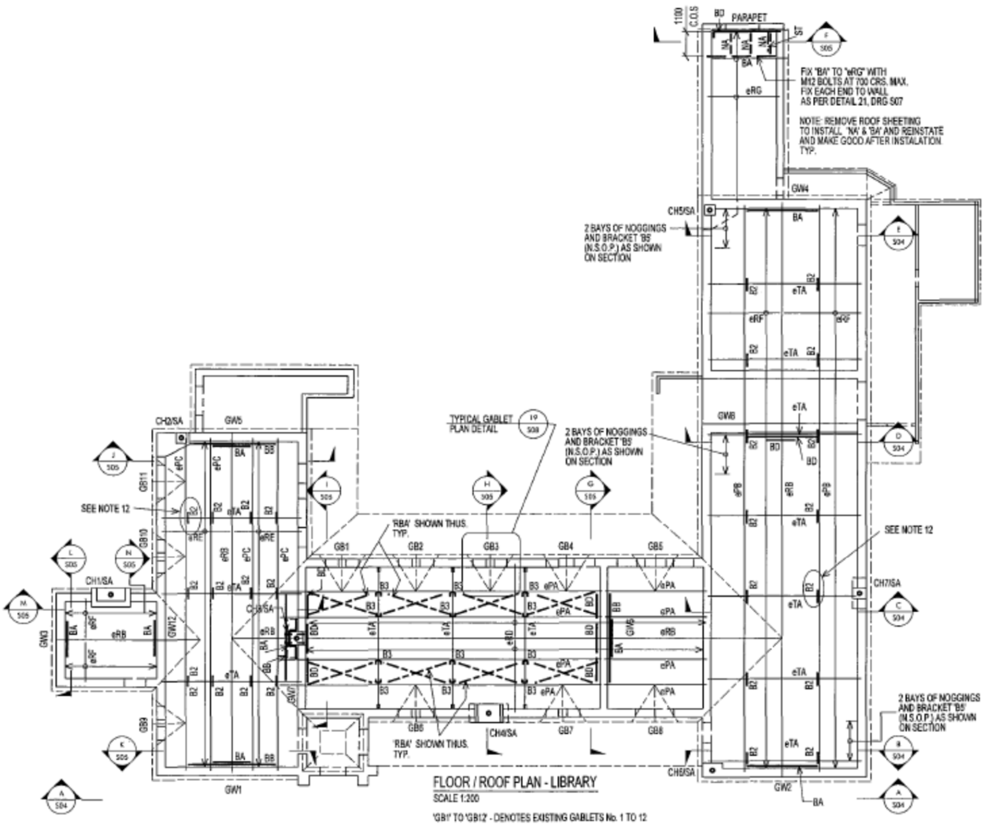

Figure 6 – Roof bracing for middle section with exposed timber scissor trusses

Figure 7 – Shows steel channel beam between roof trusses for chimney.

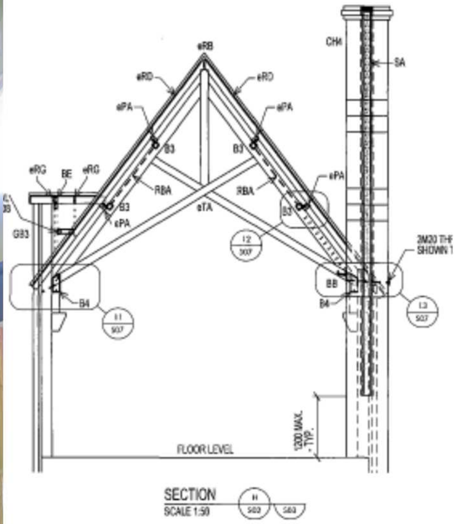

Figure 8 – CAD drawing of cross-section.

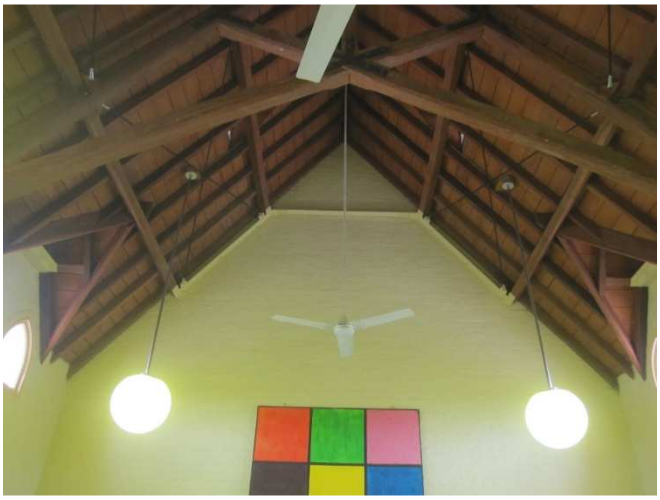

Figure 9 – Shows the steel angle and roof bracing connection to the gable wall.

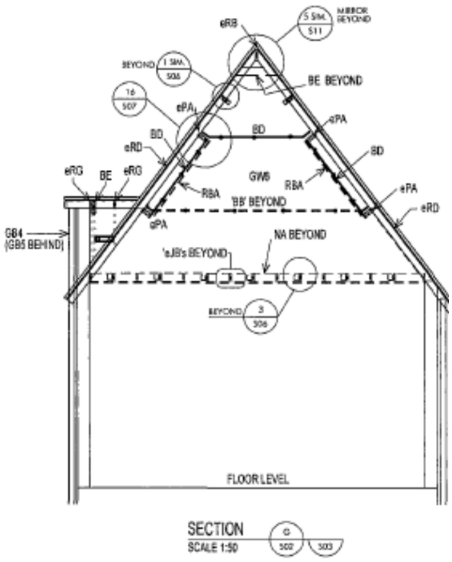

Figure 10 – CAD drawing of gable wall elevation and steel beam BB is behind this wall at lower under-purlins level (shown dotted)

CONCLUSIONS

The different extents of strengthening against earthquake actions will result in different levels of safety, impact on heritage fabric, disruption to building occupants, and cost. The acceptable level of safety and strengthening for such buildings should be based on risk assessment and determined through consultation and involvement of the structural engineer, heritage architect and building owner.

The case study has demonstrated that the client agencies acting proactively can significantly reduce the risk of collapse of most vulnerable parts in their building stock of a low cost and minimum disruption to the school. The seismic strengthening of masonry chimneys, gable walls and parapets can be carried out without any adversary impact on the heritage fabric and is acceptable from heritage point of view.

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