The Newcastle Earthquake and the Masonry Structures Code AS3700

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Abstract

The 1989 Newcastle earthquake, although of relatively low intensity, resulted in major damage costing several billion dollars. A significant proportion of this damage was to structural and non-structural masonry in a wide range of buildings (from residential to commercial). In some cases this was directly the result of the lack of consideration of earthquake loading in design; however in many other instances the level of damage was the result of poor detailing, workmanship and construction practices, including lack of tying and support, corrosion of ties and fitments, low bond strength and generally poor workmanship.

As a result of the lessons learnt from this event together with the outcomes of subsequent research in a range of areas, the design provisions of the Masonry Structures Code AS3700 have been amended to ensure the future satisfactory performance of masonry structures in a seismic event. This paper provides an overview of the performance of masonry structures in the earthquake together with details of the resulting research and enhanced AS3700 provisions aimed at producing better quality masonry with adequate seismic performance.

Keywords: seismic, masonry, performance, design, codes, detailing

1. INTRODUCTION

The 1989 Newcastle earthquake, although of relatively low intensity, resulted in major damage costing several billion dollars. A significant proportion of this damage was to structural and non-structural masonry in a wide range of buildings (from residential to commercial). In some cases this was directly the result of the lack of consideration of earthquake loading in design; however in many other instances the level of damage was the result of poor detailing, workmanship and construction practices, including lack of tying and support, corrosion of ties and fitments, low masonry bond strength and generally poor workmanship.

A large proportion of the damage was to masonry in both new and old buildings. A proportion of this damage resulted from the lack of consideration of earthquake loadings or building deterioration due to poor building maintenance. However, there was also more general widespread evidence of inadequate standards of masonry design, detailing and construction, often in modern "engineered" structures. It was also an unfortunate coincidence that the areas subjected to the most severe seismic effects embraced the sections of Newcastle which contained a higher proportion of older buildings, some in a state of partial deterioration.

It is significant to note that in the applicable earthquake code at the time (AS2121-1979) Newcastle was deemed to lie in “Zone Zero” with no consideration of seismic forces being required. In many cases this would therefore have resulted in the lack of involvement of the structural engineer and/or the architect in the masonry aspects of building design and construction, particularly if the masonry was non-structural. It is also important to note that, although not specifically designed for seismic forces, there were numerous examples of masonry structures which survived the Newcastle earthquake intact, attesting to the fact that unreinforced masonry structures can successfully withstand this level of seismic activity provided they are correctly designed and detailed and constructed from good quality masonry.

As a result of the lessons learnt from this event together with the outcomes of subsequent research in a range of areas, the design provisions of the Masonry Structures Code AS3700 have been amended to provide a basis for ensuring the future satisfactory performance of masonry structures in a seismic event. This paper provides an overview of the performance of masonry structures in the earthquake together with details of the resulting research and enhanced AS3700 provisions aimed at producing better quality masonry with adequate seismic performance.

2. COMMON CAUSES OF DAMAGE TO MASONRY

Detailed discussions of building behaviour have been published elsewhere (I.E.Aust. 1990, Melchers & Page 1992, Page 1992). The following is a brief summary of some of the common causes of damage to masonry construction.

2.1 Face Loading

When earthquake ground motion is normal to the plane of a masonry wall, an inertia force is induced in that direction (a face loading). The resulting masonry damage is consistent with that produced by a lateral load acting on a brittle material with low tensile strength. As shown in Figure 1, damage from face loading includes failure of free standing elements such as parapets and chimneys, gable end failure, damage to walls from flexural cracking, excessive frame deflections, and sliding on damp-proof courses. This effect is exacerbated when the masonry lacks appropriate edge support (as in untied gable ends).

Figure 1. Damage from face loading *(Page)*

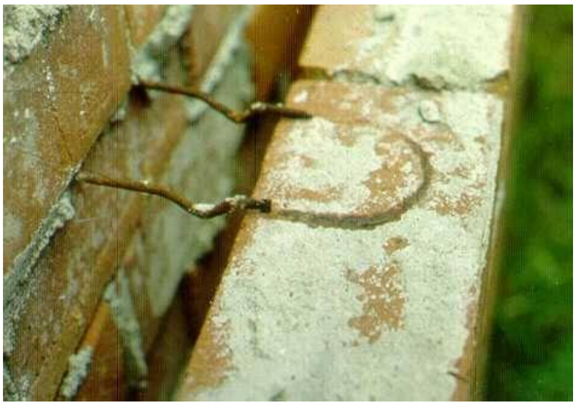
2.2 In-plane Loading

When the ground motion is parallel to the wall, racking damage results. This can be relatively minor (in the form of fine diagonal cracking), or quite substantial cracking and damage requiring major repair (Figure 2). If timber floors or roofs do not have the necessary level of stiffness to act as effective in-plane diaphragms, excessive lateral deflection of the buildings will occur at these levels, with consequent distress in walls attached to the floor or roof system.

Figure 2. Damage from in-plane loading *(Page)*

2.3 Masonry deterioration

Deterioration of buildings was a contributing factor to damage, and in general, older buildings fared worse than their modern counterparts for this reason. Most of these buildings were constructed from brick cavity masonry with weak lime mortar joints (often in a state of deterioration). The strength of the masonry was low, as was its capacity to anchor wall ties. There was already evidence of masonry deterioration in older buildings prior to the earthquake, and this phenomenon is almost certainly not confined to Newcastle. Wall tie corrosion was widespread and worst in exposed walls and in buildings located close to the coast, with the worst corrosion occurring in the bed joints of the outer leaf of cavity walls. The presence of corroded or inadequately anchored ties resulted in the loss of support for cavity walls against lateral loading, with subsequent distress or failure (Figure 3).



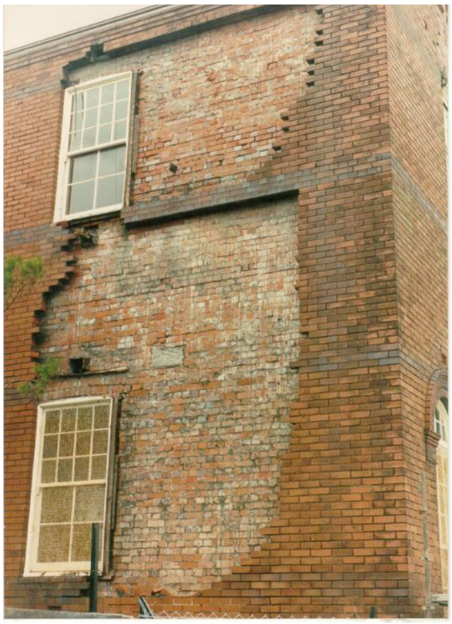
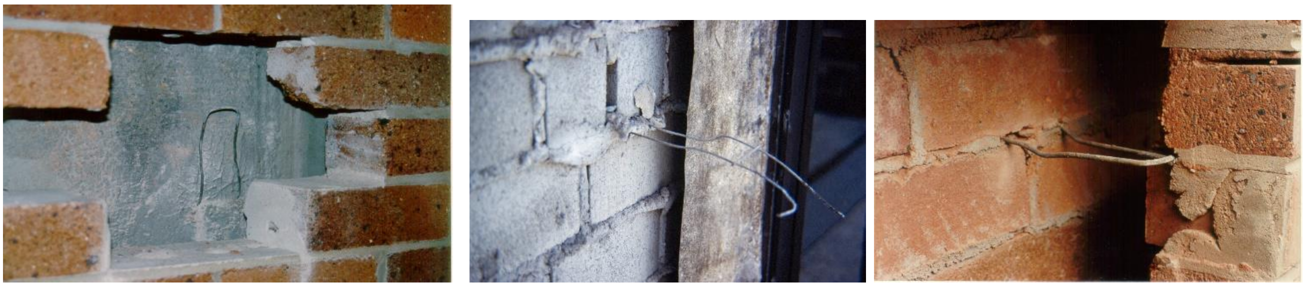


Figure 3. Wall tie corrosion *(Page)*

Older buildings which had been recycled and put to different use often suffered more severely. This was due to the inappropriate removal of internal walls, the insertion of beam supports into masonry with lack of attention to detail, excessive chasing of recesses and holes in masonry, and the lack of bonding of new to old. Any or all of these aspects would have potentially influenced their seismic performance.

2.3 Workmanship, quality control and detailing

The ability of masonry to resist lateral loads depends upon its inherent strength, (particularly its bond strength), and its effective support and attachment to the other elements of the building. Shortcomings in these areas were common, with glaring examples even in modern "supervised" engineering structures. These included wall ties being bent down and not engaged, complete omission of tying systems, low bond strengths due to abuse of mortars (particularly overdosing with plasticisers), no provision for movements between wall and frame, and generally poor standards of workmanship (see Figure 4). It was apparent that, particularly in framed structures, the structural engineer (and to some extent the architect) had not been involved sufficiently in the supervision and/or inspection of the non-structural masonry.



Wall tie "abuse"

Loss of bond due to overdosing Mortar plasticisers

Poor workmanship

Figure 4. Workmanship, quality control and detailing *(Page)*

3. AFTERMATH OF THE EARTHQUAKE

In the aftermath of the 1989 earthquake, major reviews were carried out of the relevant design codes, including the Masonry Structures Code AS3700. The first edition of this standard had been published in 1988, and was a new document which unified the design provisions of the different types of masonry (clay, concrete and calcium silicate) which previously had differing and inconsistent provisions reflecting the historical development of each of the separate documents. One of the shortcomings of AS3700-1988 was that apart from a general reference to the *SAA Earthquake Code AS2121* and the *New Zealand Standard 4230P*, *Code of Practice for Masonry Structures*, no other specific seismic design requirements were provided.

The shortcomings of some masonry construction revealed by the earthquake prompted an overall review of AS3700 and its associated standards as well as increased levels of research in a range of areas. As a result, specific earthquake design provisions compatible with the revised earthquake loading standard were included in the later versions of AS3700, initially as a normative appendix and subsequently as a separate section in the main document. The provisions include general design requirements for in-plane and out-of-plane earthquake forces and inter-storey drift; structural ductility factors, performance factors and acceptable support and connection details for close spaced, wide spaced and unreinforced masonry; and height limits for loadbearing unreinforced masonry buildings. In parallel with this work, a design standard on the strengthening of existing buildings for earthquake (AS3826-1998) was also developed. This standard sets out minimum requirements for the assessment and analysis of existing buildings and the design and detailing of any required strengthening. A brief overview of some of the related research is given in Section 4.

4. RELATED RESEARCH

4.1 Frictional capacity of damp-proof courses

Most unreinforced masonry structures have joints which incorporate some form of membrane, to act as a flashing, damp-proof course (dpc) or a slip joint (to allow relative movements between the masonry and other structural elements such as concrete slabs). In the Newcastle earthquake, sliding was observed in some of these joints, confirming their limited frictional capacity. From an earthquake design perspective, these joints will often form part of the load path necessary to transmit the induced earthquake forces, so that knowledge of this limited frictional capacity is important. As a consequence, as shown in Figure 5, a comprehensive series of static and dynamic shear tests on masonry joints containing a range of different membrane materials was performed at the Universities of Adelaide and Newcastle (Page 1995, Page & Griffith 1998). Subsequently a table of design shear factors for a range of joint types (with or without a dpc membrane) were incorporated in AS3700 (Table 1).

4.2 Masonry Bond Strength

As previously described, there was widespread evidence of poor masonry bond strength in both new and old construction. Subsequent research indicated that the prime cause of the bond strength reductions was the lack of adherence to the AS3700 mortar requirements, and in particular, the use (and overdosing) of plasticising agents such as air entrainers or fire clay (Sugo et al. 1996). Figure 6 shows the results of a Newcastle bond study on the influence of air entraining agents on bond strength (note that field observations revealed overdosing rates up to 40 times the recommended level). In-depth studies of the influence of other supplementary cementitious materials on bond strength were also carried out (Lawrence et al. 2008), with the outcomes being reflected in the revised masonry standard.

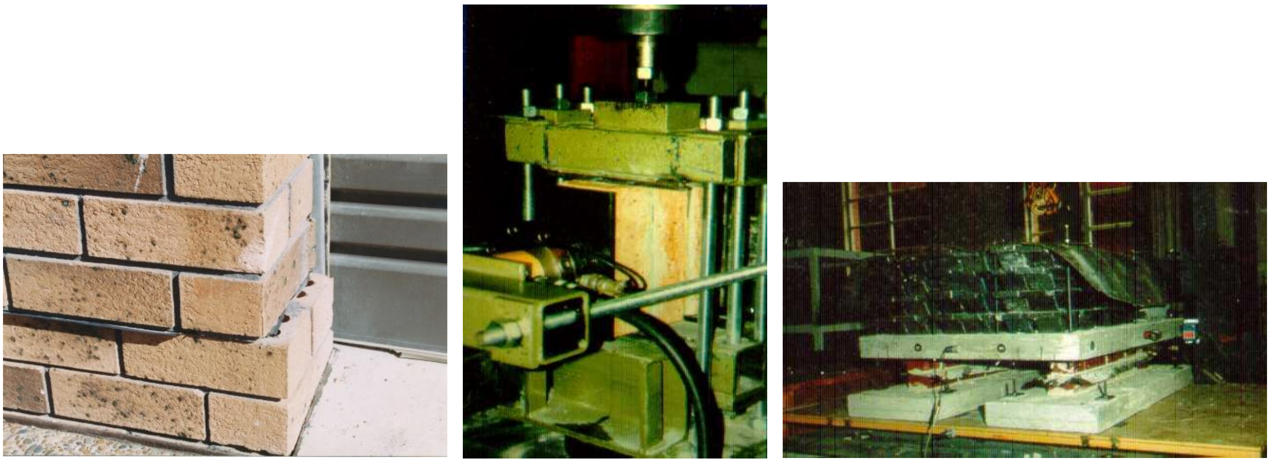


Figure 5. Static & shaking table tests on masonry joints *(Page)*

Table 1. Shear Factors at Masonry Interfaces

Bed Joint	Material	Shear Factor
Bed joints	Clay, concrete, calcium silicate AAC (thin bed mortar)	0.30 0.12
DPC & Flashings	Embossed polythene or bitumen coated Aluminium Aluminium with polythene & bitumen coating	0.30 0.15
Interfaces	Masonry & concrete Masonry & steel Other	0.30 0.20 0.0

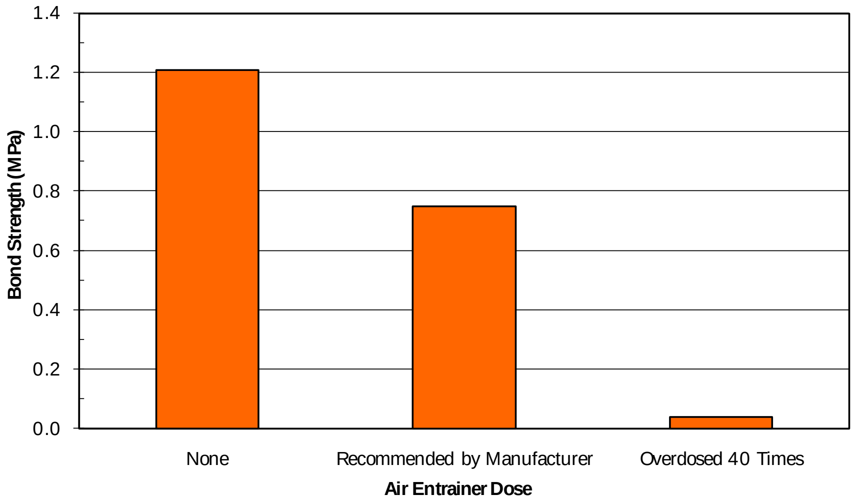


Figure 6. The influence of air entraining agents on masonry bond strength *(Sugo et al.)*

4.3 Durability

The aftermath of the Newcastle Earthquake revealed significant problems related to the various aspects of masonry durability, particularly with regards to ties and fitments in older structures. In particular, the corrosion of wall ties in the bed joints of the outer leaf of exposed, south facing cavity and veneer walls was fairly common. It is likely that these ties could have been corroded for some time, but this only became apparent when the walls were subjected to significant face loading from the earthquake event. It is also important to note that since the bulk of the corrosion occurred in the bed joints of the outer leaf, this would not necessarily be revealed by any form of optical inspection of the wall cavity.

The review of the durability provisions of AS3700 after the earthquake resulted in significant revision and enhancement of the provisions to ensure adequate durability performance of the mortar, masonry units, reinforcement and built-in components (including wall ties) under the full range of exposure environments ranging from "*interior protected*" through to "*exterior severe marine*". For each exposure environment, requirements for masonry unit salt attack resistance grade, mortar class, durability class of built-in components and reinforcement cover are provided.

AS3700-2018 also has an informative Appendix I, relating the ISO 9223 Corrosivity Categories to the AS3700 Durability Class with specific protection solutions for wall ties; connectors and accessories; and lintels and shelf angles (in *Marine* and *Severe Marine* environments, these solutions will usually require the use of stainless steel).

5. THE PRESENT

The 1989 Newcastle Earthquake resulted in damage to many masonry structures. Some of the damage resulted from the lack of consideration of earthquake forces in design. However, a significant proportion was the result of poor detailing, workmanship and construction practices, including the lack of tying and support, corrosion of ties and fitments, low bond strength and generally poor workmanship.

In the ensuing 30 years, as a result of subsequent research into many aspects of masonry design and construction, the masonry structures code now incorporates provisions which address many of the shortcomings present in the masonry standard in 1989. In addition, the current version of AS1170.4 deems Newcastle to have a significant level of risk, and seismic effects must now be considered as part of the design process. Table 2 summarises the types of masonry damage in the 1989 event together with an indication of how the various aspects of the damage have now been addressed in the current masonry and earthquake loading standards. However, it should also be stressed that the involvement of the building designer and engineer in the design, detailing and construction processes is still critical in ensuring the adherence of the construction to the required standards of construction.

Table 2. Summary of masonry damage in the Newcastle Earthquake

Nature of Damage	Cause of Damage	Comments
General	Lack of consideration of E/Q loading: - Soft soil effects[2] - Building layout in plan and elevation[2] - No clearly defined load paths[2] Masonry deterioration[1]	*Seismic implications not considered* *Lack of inspection & maintenance*
Failure of masonry under face loading	Inadequate bond strength[1] Wall tie corrosion[1] Inadequate tying to back-up[1]	*Mortar "abuse"* *Inadequate corrosion resistance and lack of inspection/maintenance* *Inadequate strength and/or stiffness; incorrect installation*
Vertical cracks at corners under face loading	Stiff returns at vertical edges[1,2]	*Detailing problem*
Collapse of free standing elements	Unstable under E/Q forces[2]	*Not considered in design*
Failure of gable ends	Inadequate tying to roof structure	*Detailing problem*
Damage to masonry cladding and infill in framed construction	Lack of isolation of the frame & inadequate tying of the masonry[1,2]	*Detailing & design problem*
Sliding on membrane type dpc's	Inadequate frictional capacity[1]	*Not considered in design* *(friction values now in AS3700)*
In-plane diagonal cracking	Masonry shear failure – E/Q forces not considered[1,2]	*Not considered in design*
Displacement of internal non-loadbearing walls	Lack of support or tying – E/Q forces not considered[1,2]	*Not considered in design or detailing*
Collapse of suspended awnings	Failure of tie anchorage to masonry & masonry face loading failure[1]	*Design & detailing errors*
Cracking in older masonry structures	Excessive deflection of floor & roof diaphragms[1,2]	*Seismic implications not considered*

1: Now covered by AS3700 requirements

2: Now covered by AS1170.4 requirement

6. SUMMARY

The performance of masonry structures in the 1989 Newcastle Earthquake has been described. Since there was no perceived earthquake risk at the time, some of the damage was directly due to the lack of consideration of seismic effects at the design stage. However there were many other instances when the damage was directly due to poor design, detailing and construction practices. The revised and updated masonry standard which has been described has addressed many of these issues which should assist in better future seismic performance.

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