Curtainwalls; Seismic Experience, Design and Assessment

P. Lalas

Corresponding Author. Peter Lalas, Principal Facade Engineer, Janus Facades Pty Ltd

Email: peter@janusfacdes.com

Abstract

This paper includes case histories, PWC Tower, Amagh St and the glass wall on the Christchurch Arts Gallery following the 2011 Canterbury earthquakes. Both curtainwalls, suffered obvious detail damage, but very little gross obvious damage and only minimal broken glass, meaning that they survived their ULS conditions. The most common type of curtainwalls in Australia and New Zealand are unitised. These do not appear in the typically available USA literature on seismic capability. The various types of curtainwall are explained. Serviceability is important for an aluminium/glass curtainwall as there must be no measurable reduction in performance due to application of seismic SLS conditions. The glass can break under ULS conditions but must not collapse if this can cause injury to occupants leaving the building. It is not possible to assess all curtainwalls with one formula as attempted by EQ-Assess in C10.6.8.2 due to many variations of curtainwall details. The document does not consider the beneficial effects of seismic blocks or structural silicone glazing, especially with laminated glass. The diagram which claims to show curtainwall sections is actually a shopfront which should not be used above 2 floors. A modern curtainwall has much greater clearances to accommodate seismic actions.

Keywords: curtainwall, seismic design, SLS, weather performance, serviceability, ultimate

1. INTRODUCTION

For a façade engineer, their major concerns with respect to curtainwalls are not only structural adequacy (including seismic resistance) but equally weatherpoofness. This includes exclusion of water and a limited air infiltration (leakage). The Limit States of concern are equally Serviceability (SLS) and Ultimate (ULS). Following the application of SLS conditions the curtainwall must remain fully serviceable with no breakages and no reduction of weatherproofness. With the application of ULS conditions, there must be no collapse which could cause danger to occupants, although the curtainwall may be broken and require replacement.

A curtainwall can be designed to accept seismic deflections when the seismic displacements are known. The facade engineer does not typically have the knowledge of the building structure to determine those displacements and so must rely on the building structure Engineer to provide such movement displacements and their details, such as directions. However, the building structure Engineer often does not compute the movement dimensions, considering them to be "small" and their calculation being outside of its scope. They often quote "Standard" values, such as 1.5% or 2.5% of floor height as the ULS value. For a 3.6m floor height, this is 90mm which is a large value for a curtainwall to absorb. Such values often appear to be excessively conservative, resulting in larger joints in the curtainwall than are really required and larger curtainwall members and less glass area.

2. TYPES OF CURTAINWALLS

The most common type of curtainwalls in Australia and New Zealand are unitised (panelised) curtainwall systems. These have largely superseded stick curtainwalls. Semi-unitised curtainwalls are now virtually non-existent in Australia and New Zealand, although they are used in the USA and Europe, especially with structural silicone glazing. There are also many different hybrid curtainwall systems, of different geometries and layouts.

Lalas[1] first presented curtainwalls to structural engineers in 1988 at an ACSE seminar in Sydney. In a seminar at UNSW Lalas[2] included a table indicating the differences between stick and unitised curtainwalls.

Stick curtainwalls were common in Australia up until the mid-1980's, although they are still common in the USA. They are delivered to site as sticks and assembled on site, in the order of brackets, mullions, transoms and then glazing. They are very labour intensive on site, but flexible with respect to installation which can start and stop anywhere on the building.

The earliest and most primitive type of stick curtainwall is the pressure-plate system. Alcan's system is shown in Figure 1 below. The date on the data sheet is 1988, but this diagram represents 50-year old technology. The problem with these pressure-plate systems is that they rely on a very thin sealant layer between the transom ends and mullion side faces for sealing. Seismic action tends to force the rectangular grid of the curtainwall system into parallelograms, breaking the seals resulting in water ingress. These systems have no effective capacity for building movements (including seismic) and they are a weatherproofness nightmare.

Much more sophisticated stick systems were developed by Comalco Fabricators and others in the late 1970s and early 1980s. An example is the Rialto Towers in Melbourne. These have a much greater capacity to absorb building movements (thermal, wind sway and seismic) without seals failing.

Stick systems react to seismic and other building movements by angular changes at the mullion/transom joints and the glass will move in and out of gaskets. As with all curtainwalls, each glass light sits on two rubber blocks called setting blocks. The capacity of a stick curtainwall to absorb movements depends on the gap between the glass edges and aluminium members called the 'edge distance'. The likelihood of glass touching aluminium can be substantially reduced by installing rubber blocks between the glass and the mullions; these are called seismic blocks.

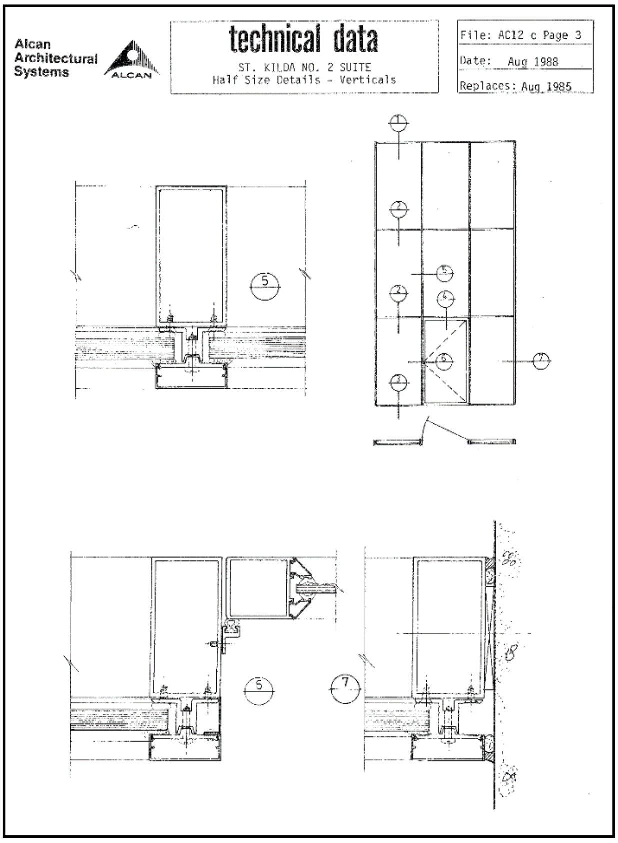

Figure 1; Alcan Pressure Plate Stick System

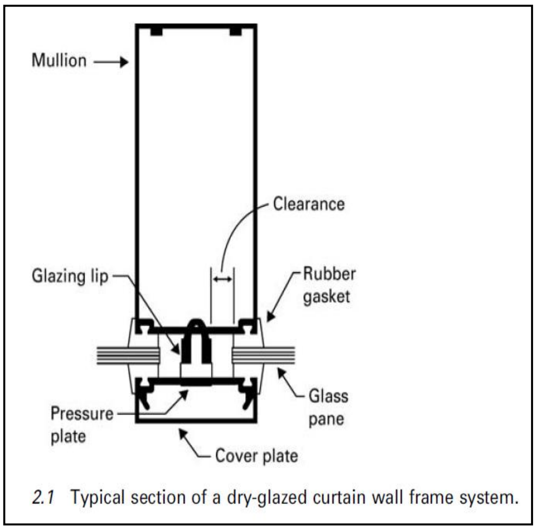

Figure 2; Stick Pressure Plate Mullion. This diagram is taken from Behr[3], page 31. The caption under the diagram claims that this is a "typical section", but it is in fact, 50-year old technology.

As seen in figures 3 & 4, the glass is gasket glazed. When movements such as seismic movements are applied to the building, the glass moves in and out of the gaskets. The edge distance must be designed to be adequate so that the glass does not touch the aluminium. Reasonable tolerances of glass size and installation variances must be considered when the edge distance is chosen. The façade engineer must know the expected seismic displacements so that the edge distance can be designed and these come from the building structure engineer.

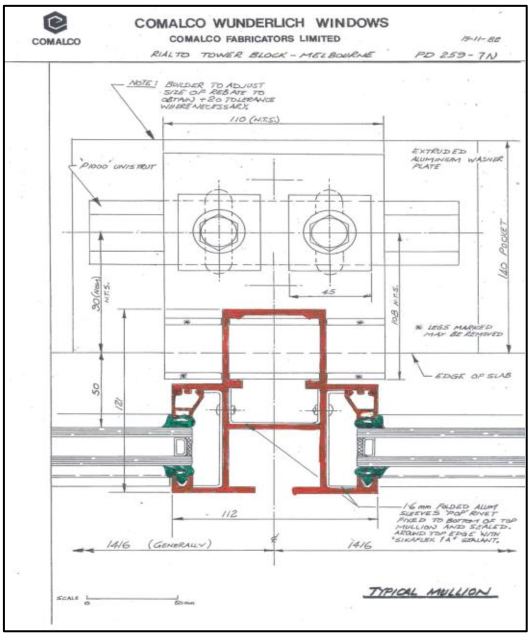

Figure 3 Comalco Fabricators Stick System Curtainwall; Rialto Towers; Mullion

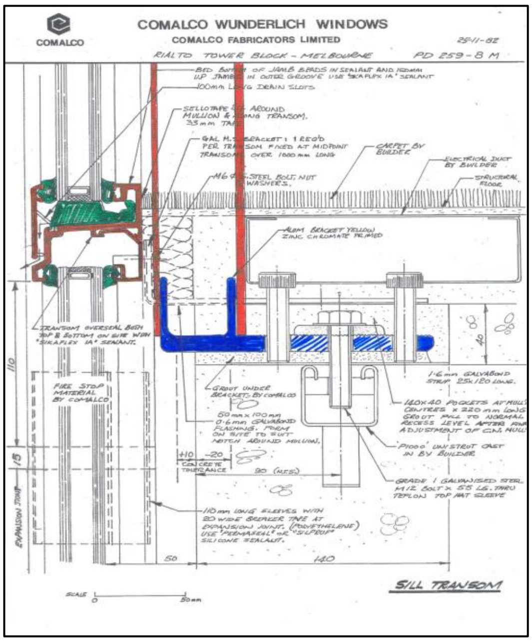

Figure 4 Comalco Fabricators Stick System Curtainwall; Rialto Towers Sill Transom

Unitised (panel) system curtainwalls are made of completed glazed aluminium frames which are shuffled together on site. Most of the labour involved with unitised curtainwalls is concentrated in the factory. However, the panels require sequential installation, generally starting at the bottom of a building, being installed around a complete floor and then up to the next floor.

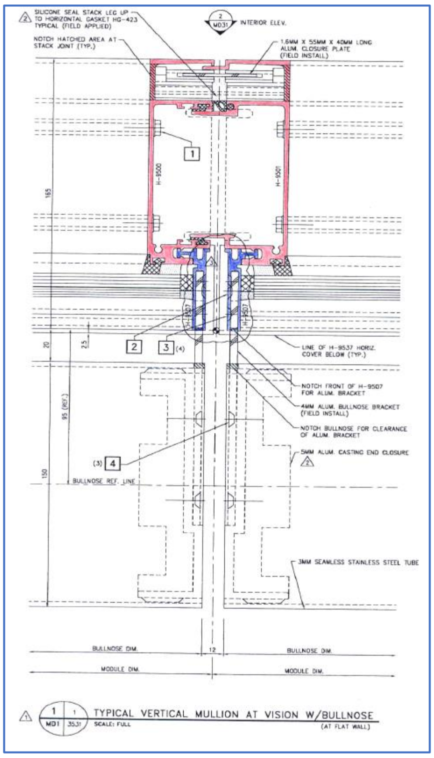

Figure 5; Harmon Contractors Unitised System Curtainwall Mullion; KLCC Twin Towers

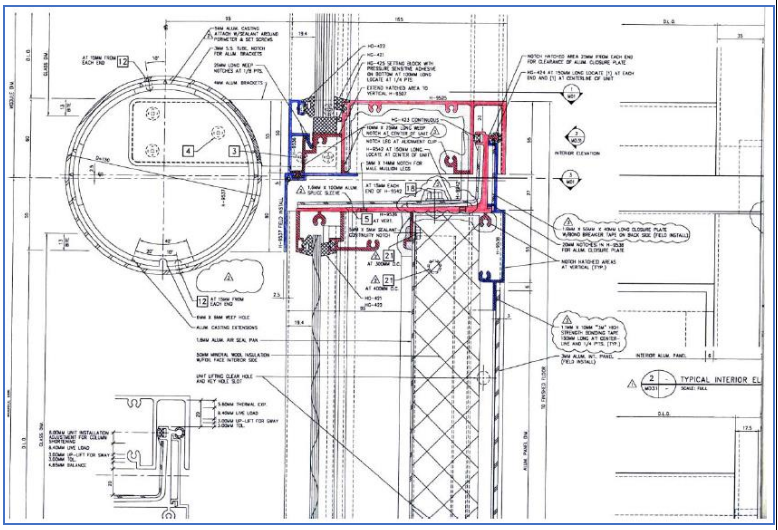

Figure 6; Harmon Contractors Unitised System Curtainwall 'Stack joint' Transom; KLCC Twin Towers Kuala Lumpur

The joints between the panels are designed to absorb seismic and other building movements, while isolating the frames and gazing from structural loads. The joints open and close due to applied structural displacements.

The unitised mullion is formed when the side of one curtainwall panel is fitted into the adjacent panel. The mullion in Figure 5 has a 6mm joint which can open and close ±6mm due to thermal movement, building sway and seismic effects. The stack joint is the transom formed when the top of one panel has the transom at the bottom of the panel above fitted onto it. The joint in Figure 6 is nominally 20mm and it can move ±20mm. These joints can be designed virtually any size required to meet the expected movements provided by the building engineer. The curtainwall designer will design the joints so that when the ULS seismic movement is applied, the joints will just be closed. There is a further safety factor because there is still the edge distance of the glass to be closed and the glass to touch aluminium before the glass is in danger of breaking.

Unitised curtainwall systems do not appear in the typically available USA literature on seismic capability. This includes Behr[3], which appears to be the main reference of EQ-Assess[4], Secondary Structures part C10.4.5 "Deformation-based assessment. "

Figure 7; Unitised curtainwall panel; KLCC Twin Towers, Kuala Lumpur

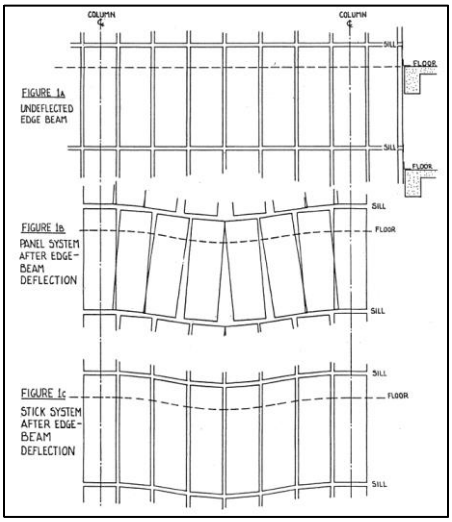

Figure 8; 1989; Comparison of Unitised & Stick Curtainwall, when building movements imposed.

3. CURTAINWALL TESTING AND CASE STUDIES

P. Lalas has been involved with seismic testing of curtainwall prototypes for more than 25 years. This involves racking of an intermediate floor of a curtainwall prototype. The prototype is installed as one wall of a test chamber. Performance testing in Australia and New Zealand is usually carried out in accordance with the procedures of AS/NZS 4284[5]. The test sequence involves SLS structural testing to design wind pressures, followed by air infiltration (leakage) testing, water (simulated rain) testing and ULS wind load testing. In New Zealand, it should be specified, that after the first water test, SLS seismic racking is applied to simulate inter-storey drift, followed by repeat air infiltration and water penetration testing to determine if the SLS seismic racking has damaged the prototype. The last tests are ULS loading followed by ULS seismic racking. The two limit states must be tested.

The method of testing AS/NZS 4284[5] is to install the test prototype to the test chamber with its outside face into the chamber. Looking at Figure 9, the internal face of the specimen is seen.

Figure 10 is a close-up of the hydraulic ram which is used to move the top support beam to simulate inter-storey drift.

Figure 9; AS/NZS 4284[5] Testing a cladding sample.

Figure 10; This is a close up of the top right corner of the test prototype of Figure 9.

Figure 11; Test prototype; KLCC Twin Towers unitised curtainwall

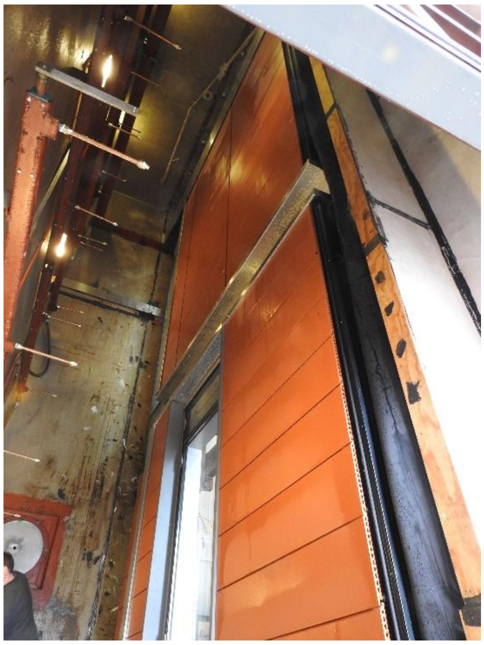

Figure 12; Von Haast Test Prototype

Figure 11 shows the first test prototype built for the KLCC Twin Towers. It was 3 floors tall and included 44 panels. Seismic inter-storey drift was applied by moving the middle floor sideways. Figure 12 shows a recent test of a prototype for the Von Haast building, UC, Christchurch.

Following the February 2011 Canterbury earthquakes Peter Lalas was asked by the owners to inspect and assess the PWC Tower, Amagh St and the glass wall on the Christchurch Arts Gallery.

Lalas[1] investigation of the curtainwall on the PWC Tower, Amagh St is documented in Journal of Civil Engineering and Architecture 10 (2016). This was a very poor quality unitised curtainwall. The joints in the mullions and transoms were only 6mm. For this curtainwall the horizontal joints should have been 24 to 26 mm to account for manufacturing and installation tolerances and for beam creep, as indicated in Figure 8, above. The vertical joints in the mullions should have been 10mm to allow for tolerances and building movements. Despite this, the performance of this unitsed curtainwall was better than satisfactory. The forces and displacements applied to the curtainwall during the September 2010 and February 2011 earthquakes exceeded ULS design criteria.

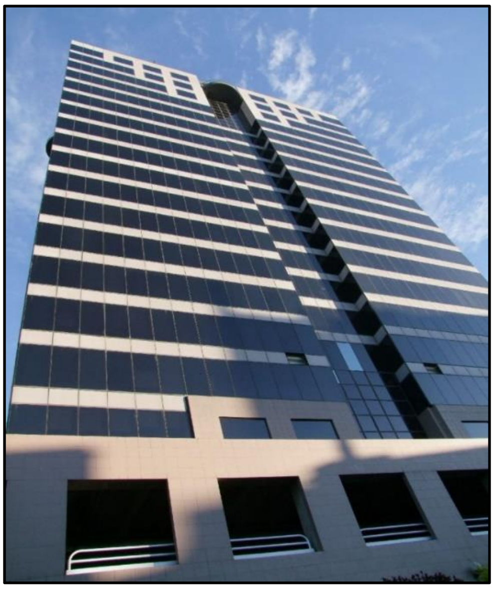

Figure 13; PWC Tower; the south face on 9 May 2011.

Figure 14; This is a concrete beam near the corner column.

Looking at the PWC Tower from the street, no obvious damage was visible. However, inspection from inside and when glass spandrels were removed, as in Figure 14, there was obvious structural damage. The curtainwall and its brackets at the corners of the building were damaged such that replacement was necessary.

Figure 15; PWC Tower; this glass panel was positioned between a curtainwall mullion and an internal wall.

Figure 16; PWC Tower; This is a broken internal partition; there were more broken glass panels inside than outside.

The other curtainwall I was asked to inspect was a hybrid design on the Christchurch Art Gallery. Again, there was very little damage despite the earthquake having exceeded all design parameters. The main damage was that all the transoms were attached to the structure with self-tapping screws. The aluminium around the screws was damaged such that most of the screws could be removed by hand.

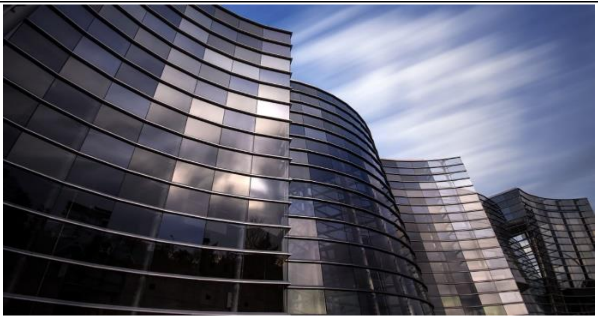

Figure 17; Christchurch Art gallery Glass wall.

Figure 18; Christchurch Art gallery Glass wall, viewed from inside the lobby.

4. EQ-ASSESS IN C10.6.8.2[4]

EQ-Assess has been written by New Zealand structural engineers. It provides advice and formulas for the seismic capability assessment of existing buildings. Section C10 concerns secondary structures including curtainwalls.

P. Lalas has recently had to refer to EQ-Assess C10-6-8 to analyse a 57-year-old unitised curtainwall in Wellington. The section on curtainwalls was found to be very inadequate and in some points, alarmingly unsafe. Behr[3] from USA appears to be the main reference and it does not recognise unitsed curtainwalls. NZ experience of testing curtainwalls confirms that they perform better than theoretical analysis indicates, as advised in EQ-Assess. Criticisms of C10-6-8 include the following;

1. Serviceability Limit State which must not cause damage, is not considered in EQ-Assess.
2. The two major types of curtainwall in the market, stick and unitised are not recognised in C10-6-8; they perform very differently in seismic events and each should be considered separately.
3. The statement regarding toughened glass is quite incorrect for glass lights above the ground floor. The glass can fall in large shattered chunks; 2 or 3 kg of anything falling 10 or 15 floors is lethal. AS1288[7] “Glass in Buildings” does not allow toughened glass in overhead glazing above 5 metres for this reason. The statement in C10-6-8 that toughened glass falls in small particles and is therefore somehow safe, is quite wrong.
4. EQ-Assess does not consider that a seismic test may have been carried out on a prototype of the curtainwall in question.
5. EQ-Assess does not consider the beneficial effects seismic blocks or structural silicone glazing, especially with laminated glass.
6. The diagram of a bent mullion (figure C10.8) is not correct; mullions do not bend as shown.
7. The diagram which claims to show curtainwall sections (figure C10.8) is actually a shopfront which should not be used above 2 floors. A modern curtainwall has much greater movement joints and typically much larger sections.
8. EQ-Assess does not include windows. The window Standard NZS 4211[8] does not consider seismic actions and does not require seismic testing of windows. Façade engineers should lobby to have that changed.

5. FINAL COMMENTS

- There is a great deal of knowledge in the curtainwall industry on how to design curtainwalls to absorb seismic effects without damage. This should be reflected in EQ-Assess.
- Curtainwall designs rely on the displacement information provided by the building Structural Engineer. This needs to become more accurate and reliable.
- Although the knowledge (first point above) is available, it is in the major projects, medium to high rise; it is not used in the smaller projects by second and third tier curtainwallers. The input to this end of the market needs to be improved.

6. REFERENCES:

1 Lalas, P. Design Engineering Criteria of Curtain Walls on High Rise Buildings (3 August 1988) Sydney ACSE Seminar; Facade Engineering Cladding Materials & Systems;

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3 Behr, R.A. (2009). Architectural glass to resist seismic and extreme climatic events, Woodhead Publishing Limited, UK.

4 EQ-Assess; The Seismic Assessment of Existing Buildings; Section C10 – Secondary and Non-structural elements; C10.4.5 Deformation-based assessment; The Ministry of Business, Innovation & Employment NZ.

5 AS/NZS 4284:2008 Australian/New Zealand Standard "Testing of building facades"

6 Lalas, P; Performance of a Curtainwall in the Magnitude 6.3 Christchurch Earthquake of February 22, 2011; Journal of Civil Engineering and Architecture 10 (2016) 1344-1354; doi: 10.17265/1934-7359/2016.12.005

7 AS 1288 – 2011; Australian Standard "Glass in buildings – Selection and installation".

8 NZS 4211:2008 New Zealand Standard; "Specification for performance of windows"