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## PERFORMANCE OF STEEL FRAMES IN EARTHQUAKES

Studies have demonstrated that steel framed houses can perform extremely well during seismic events and are increasingly being used for construction in earthquake regions. The durability and reliability of steel frames as a strong, light and safe construction material is enhanced by the sophistication of the FRAMECAD™ end-to-end building solution. Delivering an accurate system maximises the benefits of steel in earthquakes.

"In an earthquake zone, homes can be designed with ductile structures to absorb the energy from an earthquake. Steel is manufactured under tight tolerances and the entire FRAMECAD™ steel framing system is engineered precisely," says FRAMECAD's Design Services Manager, Dr Darrin Bell.

### During an earthquake

During an earthquake, buildings experience horizontal ground motion and relatively small vertical acceleration. The horizontal ground movement is normally amplified along the height of the building with the magnitude of the amplification dependent on the dynamic characteristics of the building (e.g., natural frequencies and damping). When the relative movement between the top and bottom of the structure is large, damage may arise.

To maintain structural stability, control the lateral movement and prevent walls from lifting, the structure should be tied together all the way from the roof to the foundation. The design flexibility of steel enables structures to be built to meet specific levels of seismic activity. Low cost housing, double storey houses, modular and multi-storey buildings are being successfully constructed from steel frames worldwide.

Steel remains straight, unlike timber, which can move and warp during and after construction. There is no jamming of windows and doors as steel members do not creep, expand or shrink; steel frames remain more airtight than other building materials and is non-combustible, so it will not contribute to the spread of fire which may be caused by an earthquake. Steel does not need to be chemically treated, offering indoor air quality benefits and there is no risk of rot, termites or other pests that may degrade the quality and strength of the frames.

### Research & scientific study of steel frames in earthquakes

Associate Professor Emad Gad of the University of Melbourne used a steel frame with brick veneer house in a simulation of a major earthquake in 1996. This Test House was built according to Australian practices and performed exceptionally well but since this time the industry has moved towards thinner sections.

The following overview* is based on testing undertaken by the National Association of Steel Framed Housing (NASH) in Australia at the University of Melbourne in April 2009. Testing was performed using FRAMECAD framing under the direction of Professor Emad Gad with

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technical support from Associate Professor Charles Clifton of the University of Auckland and NASH.

The test house was designed to replicate the dynamics of a single-storey brick veneer home, typical of construction in New Zealand, and was subject to full-scale shaking table tests. The performance of the test house was representative of the performance of similarly built structures and scientists predict extremely good performance in response to an earthquake.

TEST HOUSE Designed by Graham Rundle, Redco (NZ)
Specifications:

- 2.6 x 2.8 m in plan and 2.4 m height (approximately)
- FRAMECAD Light steel frame – 0.75 mm thick G550 lipped C-sections
- Brick veneer exterior cladding – standard 70 Series with Type B brick ties screwed to the flanges of the studs through a 40 x 10 mm thermal break
- Plasterboard interior lining
- Roof slab weighing 1,500 kg supported by the frame to simulate equivalent mass from a house roof
- Front and side walls separated at corners to simulate long brick veneer walls
- Natural frequency prior to shaking approximately 6 Hz

Simulation:

- Seismic simulation compliant with the New Zealand Earthquake Standard NZS 1170.5, based on levels of the 1940 El Centro North South earthquake
- Selection and scaling process in accordance with NZS 1170.5 Clause 5.5
- Excitations in each direction up to Maximum Considered Earthquake (MCE) level and greater although the main interest of this test was in the North-South direction

*Specific levels of excitation targeted*

Table 1: Earthquake levels adopted for testing corresponding regions in New Zealand and target performance limits

| Earthquake design level | Scale relative to El-Centro | Approximate level on Richter Scale (Ms) | Regions covered in New Zealand | Performance limits |
|---|---|---|---|---|
| Serviceability Limit State (SLS) | 0.89 | 6.1 to 6.3 | Regions with ZR = 0.20 which corresponds to greater value than the Ultimate Limit State (ULS) conditions for Auckland and Hamilton and is approximately equal to ULS conditions for Dunedin. | Localised hairline cracking of veneer and lining at most vulnerable locations. No post earthquake remedial work required. |
| Ultimate Limit State (ULS) | 1.28 | 7.3 to 7.5 | Regions with ZR = 0.42 which corresponds to ULS for Masterton and greater value than ULS for Wellington. | Noticeable cracking of veneer and linings, brick loss limited to < 5% of bricks or the top two rows above the top row of ties. Visible damage to frame expected but not to be significant and not to reduce ability of frame to support house. |
| Maximum Considered Earthquake (MCE) | 1.72 | 8.3 to 8.5 | Regions with ZR = 0.76 which corresponds to the MCE level for Wellington and Masterton and greater than the ULS for highest seismic location in NZ. | Significant linings and framing damage but not collapse of framing. Significant brick loss. |

**Table 1 taken from NASH News June 2009*

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RESULTS:

When subjected to seven earthquakes at MCE levels of shaking, the test house performed extremely well. While loss of the brick veneer walls would be considered acceptable in this test, only minor cracking of the plasterboard and brick veneer walls occurred.

The test house was subjected to further shaking after MCE level testing was completed but this did not cause serious damage up to and including magnitude 9 on the Richter scale. In this and further tests, damage to the internal lining at 1.24 MCE caused more load to shed to the bracing system. This resulted in partial failure of the bracing system 1.51 MCE.

No bricks were lost from the out-of-plane walls up to 2.6 El-Centro, a considerable performance when considering the test house had already been subject to high level earthquakes. In reality, a single house would not experience this number and severity of earthquakes.

Based in the final results from this test using extreme seismic activity, it can be concluded that this form of construction, built under the most demanding seismic conditions in New Zealand, would perform exceptionally well.

*Results from the series of tests performed*

Table 2: Summary of tests performed and observations made

| Test No | Earthquake level and direction | | Observations |
|---|---|---|---|
| | N-S1 | E-W2 | |
| 1 | SLS | | No damage whatsoever. |
| 2 | ULS | | Minimal hairline cracks in the plasterboard lining at window top corners. Very limited hairline cracks at locations in brick veneer adjacent to opening. No damage to any brick ties or the screws or the thermal break. |
| 3 | | SLS | No increase in damage from test 2. |
| 4 | MCE | | Minvor increase in cracking of internal plasterboard at window corners. No increase in cracking in brick veneer. No visible damage to any ties. |
| 5 | | MCE | No increase in damage from test 4. |
| 6 | 1.16MCE (2.0 El-Centro) | | Noticeable rocking of wall brick piers at base of window. Hairline cracks post test extending right across pier base. No bricks lost. No visible damage to any ties. No visible damage to steel framing. Plasterboard cracks in window top corners now remaining open approx 1mm after test. |
| 7 | 1.34MCE (2.3 El-Centro) | | Increased rocking and cracking during test. No new cracks. No bricks lost. No visible damage to brick ties but in plane twisting for the East and West walls. No evidence of pullout of any ties. No visible damage to steel frame. |
| 8 | 1.51MCE (2.6El-Centro)3 | | Partial failure of connection between the top of diagonal brace and top plate for East and West walls. No bricks lost. No tie pullout from frame or veneer. |
| 9 | 1.57MCE (2.7El-Centro)4 | | Failure of connection of diagonal brace to top plate in East and West walls. Top 2 rows of bricks lost in East and West walls. No bricks lost for the North and South walls. Minimal to no damage to ties in the North and South walls. No tie pullout from studs in any location. |

1. For shaking in the North-South direction, the North and South veneer walls were subjected to out-of plane loading.
2. For shaking in the East-West direction, the East and West veneer walls were subjected to out-of plane loading.
3. El-Centro corresponds to a Richter magnitude (Ms) greater than 9.0.
4. El-Centro is the upper limit of the shaking table capacity for this test setup.

**Table 2 taken from NASH News June 2009*

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Tests are done with specific measurements of building materials and the simulated force of an earthquake; it must be noted that results reflect these exact specifications and may not adequately translate for variable situations.

RELEVANCE TO AUSTRALIA:
In the latest Australian Standard for earthquakes AS 1170.4-2007 there are no design specifications for houses less than 8.5 m high where the hazard factor is less than 0.11 and horizontal racing forces need to be checked if Z>0.11. There are only a few places in Australia where there are higher values such as Meckering in Western Australia (Z=0.22). The low seismic activity in Australia requires AS 2699.1 Type A brick ties, different to the Type B brick ties specific to New Zealand.

The serviceability limit state (SLS) test at 0.89 El-Centro is less than for design at Meckering and approximately double for the majority of maximum design cases around the rest of Australia. Results showed good performance of steel framed houses in earthquakes.

SOURCES:


- **NASH News June 2009* *http://www.nash.asn.au/nash/search_results_full.php?search=earthquakes&go=GO*
- *Interview with Professor Emad Gad, November 2009*
- *Build (October/November 2009) "Light Steel-Framed House Gets the Earthquake Test" pp 54-55. BRANZ, Wellington.*


**Reconstruction after the tremor**

The benefits of steel frames are especially significant for reconstruction during disaster relief, such as the aftermath of an earthquake, where relief centres and hospitals can quickly be erected. Light steel frames are easy to transport and work with, the pre punched steel enabling houses to be completed more simply and quickly than conventional masonry homes. The intelligence and integration of modelling and fabrication of FRAMECAD™ steel frames eliminate the need for skilled labour for assembly, also resulting in faster and more efficient construction.

Steel framed structures can be dismantled and re-erected elsewhere, making them effective temporary solutions for rebuilding. The FRAMECAD™ Mobile Factory is also compact enough to be airlifted into remote locations for immediate production of steel frame structures.
As a light weight material, steel frames allow for smaller foundations which means less excavation of sites to raise the building from the ground. With less material waste, steel frames are cost effective and enable more accurate and easier budgeting. All by-products from steel construction are reused and the steel can be recycled without losing any of its properties.

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The environmentally friendly site practice of FRAMECAD™ and the production of steel frames with consistent accuracy enables fast and effective rebuilding of housing in earthquake zones. FRAMECAD™ provide a proven training system, consultants and access to technical expertise at all times, giving the cold-formed steel manufacturing operations the confidence to advance anywhere around the globe.