SUSTAINABLE STRUCTURAL SOLUTIONS

Retrofit Helical Wall Ties and Reinforcements for Seismic Upgrades

Seismic Upgrades

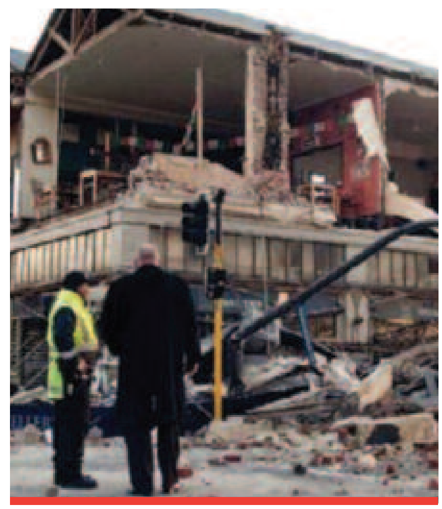
With earthquakes seeming to occur on an increasingly frequent basis around the world, the need for improved structural performance, to protect the public from harm and buildings from destruction, has been receiving far greater attention.

It has become more important to find a cost-effective means of maintaining and upgrading buildings in order for them to better withstand the stresses of seismic activity.

Helifix has an extensive range of remedial ties, fixings and reinforcements, developed through years of on-site application and experience combined with extensive independent testing, which have proved effective in maintaining and restoring structural integrity to aged, weathered and damaged masonry.

These retrofit systems are now being extensively used in seismic areas to add strength and ductility to masonry elements when upgrading vulnerable buildings.

Seismically upgrading buildings is important for both safety and practical reasons. Earthquakes cause major disruption and can lead to loss of life. Proactively using low cost Helifix retrofit systems may help manage seismic risk.



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Earthquakes and Masonry

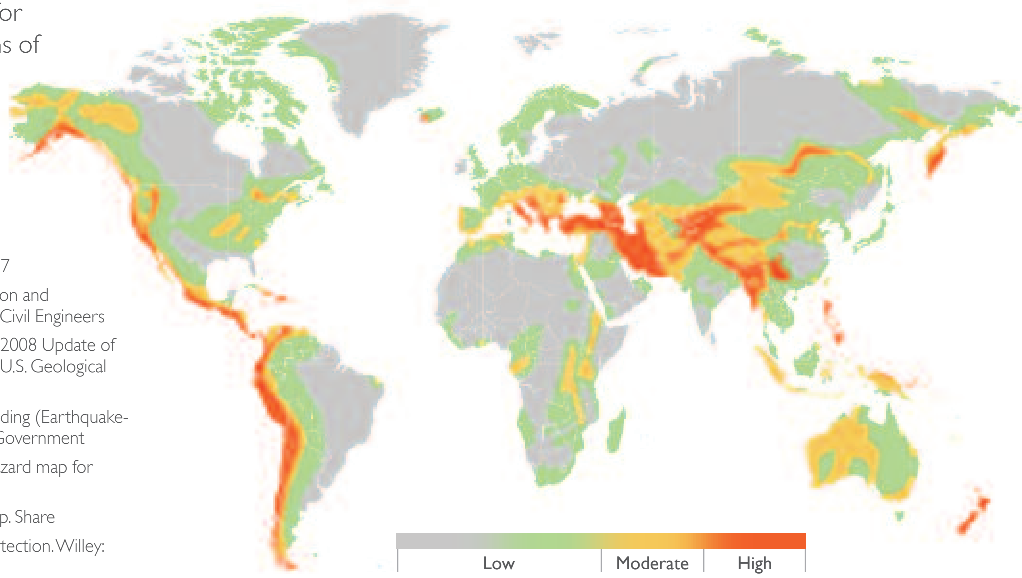
Earthquakes are a global phenomenon. Most occur at plate boundaries and are regularly felt in territories like California, Mexico, Japan, India and New Zealand that straddle or sit close to significant geological faults. Intraplate events may occur less frequently but can produce powerful and sometimes destructive forces in places less accustomed to earthquakes, like east coast and central Australia (Newcastle 1989, Kalgoorlie 2010), east coast Britain (Lincolnshire 2008) and east coast USA (Virginia 2011). The February 2011 Christchurch NZ earthquake highlighted that an earthquake, even of relatively moderate magnitude, may produce extreme ground accelerations and devastating consequences as a result of unpredictable factors including focal depth and proximity to urban centers[1].

Regulations are being updated to reflect changing perceptions of seismic risk. In the past few years consensus documents that inform USA building codes have been amended[2] and seismic hazard maps for both east and west coast territories re-evaluated[3]. The New Zealand government has similarly amended earthquake zonings and re-worked legislation to require building owners to strengthen earthquake-prone buildings within prescribed time limits[4]. New seismic maps have been produced for Australia[5], Europe[6] and other regions of the world, and seismic design guides are under review.

As a popular and well-established construction material worldwide, it is estimated that masonry collapse has been one of the main causes of earthquake-related fatality over the last century[7] but it is neither feasible nor desirable to attempt to replace all masonry buildings with modern 'resistant' structures. As a minimum it is important that masonry buildings are properly maintained and upgraded wherever possible so that they might better withstand seismic action.

Building maintenance is important because earthquakes exacerbate any pre-existing weaknesses caused by age, weathering or previous low level seismic activity. Cracked and unsecured masonry features, and masonry façades secured by corroded or inadequate wall tie systems, are hazards where inaction can add significantly to the seismic risk.

Earthquakes also magnify inherent inadequacies or faults in a building's original design and construction. Older, unreinforced masonry (URM) buildings, built to different standards are particularly vulnerable to seismic activity and in these cases adding strength and ductility may be essential to improve safety.



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4. New Zealand Government Bill 182-1 (2013). Building (Earthquake-prone Buildings) Amendment Bill. New Zealand Government
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Seismic Upgrade Techniques

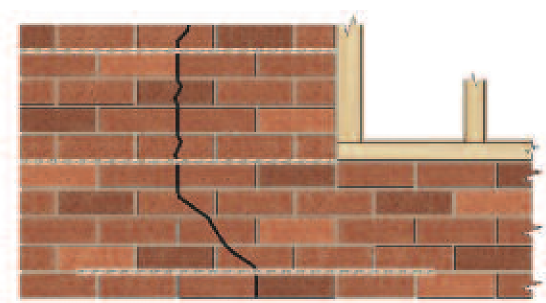
Seismic upgrade techniques for masonry buildings include:

- Connecting all the structural elements so the building acts as a cohesive unit
- Increasing the strength of masonry components and features through the installation of reinforcing elements
- Installing elements intended to prolong the onset of failure through improved ductility
- Introducing new structural members e.g. concrete, wood or steel frames to resist seismic activity and provide additional support to vulnerable elements

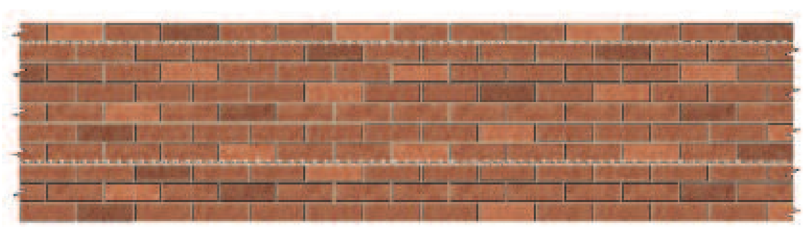
Helifix retrofit systems work effectively with all of these techniques. Our stainless steel ties and reinforcements can be retrofitted easily using concealed installation procedures. They are reliable, one-piece products that do not add to building seismic weight and are manufactured to exacting, ISO quality controlled standards.

HeliBar

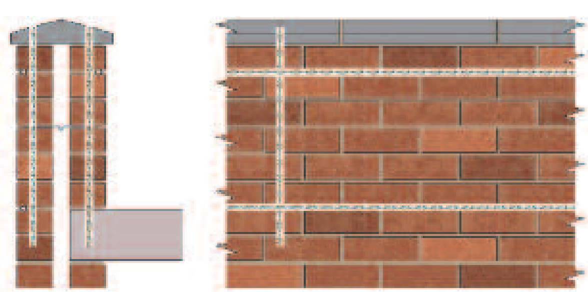
HeliBar reinforcement may be installed in long lengths to add strength by tying masonry together, stitch across existing cracks, distribute load and improve ductility.



Crack stitching



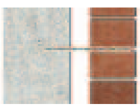
Tying masonry together to distribute loads and improve ductility



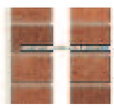
Parapet support

Helifix Remedial Ties

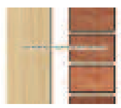
Helifix remedial wall ties can be installed to connect outer wythe masonry façades to inner wythe masonry walls or structural frames, roof and floor joists. Depending on application details, remedial wall ties may be installed into clearance holes with HeliBond cementitious grout, with epoxy resin or driven into position to provide a dry, mechanical connection.



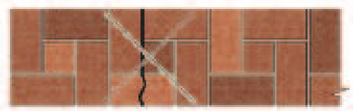
Tying masonry to concrete



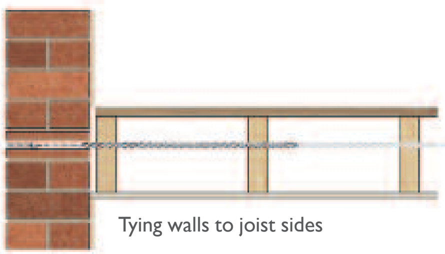
Wall tie replacement



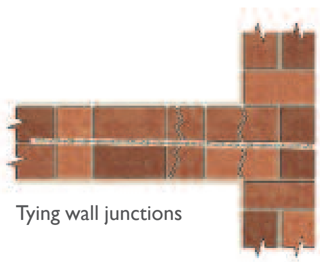
Tying masonry to wood



Cross stitching cracked masonry



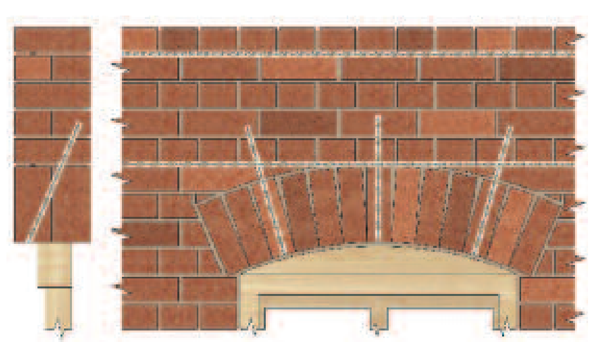
Tying walls to joist sides



Tying wall junctions

Combination Techniques

When used in combination with HeliBar reinforcement, Helifix ties can be installed to achieve positive results across a wide variety of applications from replacing wall ties and restoring structural integrity to individual masonry panels, to adding strength and ductility to complex masonry structures like arch bridges and tunnels.



Securing brick arches and lintels

Testing

Helifix products have undergone extensive independent testing at universities and well-recognized industry research centers around the world. Results and observations from recent seismic studies and references to related investigations are listed below.

Recent seismic studies

1. **EQ Struc (2013), Seismic performance of twisted steel bars used as wall ties and as remedial wall stitching: 2010/2011 Canterbury Earthquakes. Commissioned report**

This report reviews the performance of the DryFix and Crack Stitching systems as seismic strengthening techniques for unreinforced masonry (URM) buildings. Four case study examples were selected within the central precinct of Christchurch city following the events of the earthquake swarm of 2010/2011. Two of the buildings examined had been retrofitted with DryFix ties prior to the M7.1 earthquake on 4 September 2010, while crack stitching repairs were completed on two further buildings following this quake and the later 22 February 2011 event. The report concludes that the DryFix system is "effective in improving the out-of-plane performance" of the external masonry veneer in cavity brick construction, and HeliBar and HeliBond used together are "effective in repairing in-plane cracks and corner cracks in earthquake damaged URM buildings." These findings, although on a small sample, provide real-world confirmation of the effectiveness of Helifix's DryFix and Crack Stitching systems.

2. **Newcastle Innovation (2011 and 2012), Helifix wall ties testing. The University of Newcastle, NSW Australia. Project numbers: A/520 and A/559**

Australasian standards for wall tie composition and performance are presented in the joint Australian-New Zealand standard AS/NZS2699.1.
This standard informs AS3700, NZS4210 and NZS4230, the principal Australasian references for masonry construction. AS/NZS2699.1 outlines methods for testing wall ties for use in new build construction and lists threshold values for the classification of wall ties as either light (L), medium (M) or heavy (H) duty. The standard also provides for the classification of remedial wall ties.

The standard details two test methods. One method allows for testing using tensile and compressive loading to assess characteristic strength only, with strength measured as the force required to induce either failure of the tie or excessive deflection. The standard allows for the classification of ties tested to these conditions as Type A cavity ties or Type A veneer ties. It also allows for ties manufactured for installation after a masonry wythe has been erected and assessed for strength using actual retrofit installation techniques to be classified as Type A remedial ties. The second method includes cyclic dynamic loading and procedures for measuring tie strength and stiffness. This method measures strength as the tension load resisted following cyclic displacement along the axis of the tie, and stiffness as the average of the tensile and compressive forces resisted at defined deflection limits. The standard refers to ties tested to these conditions as Type B seismic–resistant veneer ties, and allows for their classification as either earthquake light (EL), earthquake medium (EM) or earthquake heavy (EH) duty. The method also provides for the classification of Type B remedial ties.

Helifix 8mm ties, austenitic stainless steel grade 316 (1.4401), were tested to AS/NZS2699.1 at the University of Newcastle between 2010 and 2012. Ties were tested in accordance with the procedures for Type A cavity and Type B veneer ties. Additionally, a range of specimens were tested to provide indicative values for a number of Helifix remedial tie installation techniques. Specimens were produced to test connections formed between brick and wood frame, brick and steel frame and cavity brick. Specimens were organized to show performance formed through new build mortar-based connection, DryFix mechanical connection, RetroTie half resin/half mechanical connection and ResiTie full resin based connection. In keeping with a conservative testing regime, all samples were tested with a 75mm cavity, the maximum allowable under NZS4210. The results are summarized in Table 1 opposite.

3. **Ismail N., Peterson R., Masia M. And J Ingham (2011), Diagonal shear behavior of unreinforced masonry walls strengthened using twisted steel bars. Construction and Building Materials 25(12): 4386-96**

4. **Peterson R., Ismail N., Masia M. And J Ingham (2012), Finite element modelling of unreinforced masonry shear walls strengthened using twisted steel bars. Construction and Building Materials 33(1): 14-24**

These associated articles examine and model the in-plane shear behavior of URM walls strengthened with HeliBar reinforcing bars. A total of 17 walls were tested in induced diagonal compression in two series. Series 1 tested walls constructed from new bricks and hydraulic cement mortar with a cement:lime:sand ratio (by volume) of 1:1:6. Series 2 tested walls constructed from reclaimed bricks and a 1:2:9 hydraulic cement mortar mix to simulate historical masonry construction. Different HeliBar reinforcement schemes were tested and the results compared. Reinforcement schemes included HeliBar bonded with HeliBond grout into slots cut into the horizontal mortar bed joints, into slots cut vertically into the walls and into slots cut both horizontally and vertically to produce a reinforcing grid. Parameters investigated included failure modes, shear strength, ductility and shear modulus. Key observations and conclusions included:

- Observed improvements in shear strength from 114% to 189%
- Vertical and grid reinforcement schemes perform the best in terms of increases in strength and displacement capacity, while displaying ductile failure modes and continued load resistance at the completion of testing.
- The primary reinforcement mechanism for vertically aligned HeliBars is restraint to shear induced dilation resulting in increased frictional shear resistance along the shear cracks.
- The horizontal reinforcement scheme produced smaller increases in shear strength, on average, when compared to other vertical and grid installation schemes.
- The horizontal reinforcement scheme was "effective in bridging diagonal cracks which formed close to peak load" and resulted in large increases in observed pseudo-ductility.
- The helical profile of HeliBar reinforcement results in excellent mechanical anchorage over short bond lengths and the system does not increase the seismic weight of the structure.

5. Ismail N., Oyarzo V., and J. Ingham (2010). Field testing of URM walls seismically strengthened using twisted steel inserts. 10th Chilean Conference on Seismology and Earthquake Engineering. Santiago, Chile

This paper presents findings from out-of-plane field testing of URM walls strengthened using HeliBar reinforcement bonded into vertical slots with HeliBond grout. The URM walls were tested on site at a heritage building in Wellington that was constructed in the 1880s. Vertical slots were cut into the walls and HeliBar and HeliBond installed. Air bags fitted to a reaction frame were then used to apply a uniformly distributed pseudo-static load to emulate the lateral seismic load generated in the out-of-plane direction. The performance of walls retrofitted with the HeliBar-HeliBond system was investigated and compared with the performance of non-retrofitted walls. The retrofitted walls exhibited improvements in out-of-plane flexural strength ranging from 140% to 570% over the performance of the non-retrofitted walls.

6. Ismail N. 2012. Selected strengthening techniques for the seismic retrofit of unreinforced masonry buildings. University of Auckland, New Zealand. Doctoral Thesis

Design provisions applying to the use of HeliBar-HeliBond in strengthening URM walls subject to in-plane and out-of-plane seismic ground excitations are presented in Appendix E of this doctoral thesis.

Table 1. Helifix Wall Tie Summary. University of Newcastle, Australia

Test Type	Outer Wythe and Connection Type	Cavity Width	Inner Wythe and Connection Type	Classification
Type A Cavity Tie[1]	Brick – Ties set in mortar joint	75mm	Brick – Ties set in mortar joint	Heavy Duty
Type B non-flexible veneer tie[2] (StarTie installation)	Brick – Ties set in mortar joint	75mm	90mm Wood stud – Drive-in connection	Earthquake Medium Duty (EM), for cavity 75mm
Type B remedial tie[3] (ResiTie installation)	Brick – Resin connection in brick	75mm	90mm Metal Stud – DryLink connector side fix (resin connection)	Earthquake Medium Duty (EM), for cavity 75mm
Type B remedial tie[3] (RetroTie installation)	Brick – Resin connection in mortar joint	75mm	90mm Wood stud – Drive-in connection	Earthquake Medium Duty (EM), for cavity 75mm
Type B remedial tie[3,4] (DryFix installation)	Brick – Drive-in connection	75mm	Brick – Drive-in connection	[4]Earthquake Medium Duty (EM), for cavity 75mm

Table Notes:
1. Type A cavity tie – "a tie, together with its anchorages, used to transfer face loads between skins (wythes) of a cavity wall while being capable of accommodating differential in-plane horizontal and vertical deflections between the attached elements". AS/NZS2699.1:2000. P.6
2. Type B non-flexible veneer tie – "a tie, including its anchorages, used to transfer face loads between a masonry veneer and a structural backing, while being capable of accommodating differential in-plane horizontal and vertical movements between the attached elements, during which time the cavity width may vary". AS/NZS2699.1:2000. P.7
3. Type B remedial tie – "a tie with specific seismic design characteristics manufactured for installation after a masonry wythe has been erected. Remedial ties are usually used to replace defective ties or where ties have been omitted". AS/NZS2699.1:2000. P.7
4. Classification does not strictly apply as test specimen is cavity brick. Structural upgrading of the load-bearing (typically internal) wythe may be required to reach even a proportion of the new build standard for a strong backing wall or load-bearing structural frame.
5. Specimens were prepared variously using radiata pine No.1 framing grade wood, 450mm lengths of steel studs, solid clay bricks supplied by Austral bricks.
6. Actual performance will be determined by the material to which the tie is fixed, the cavity width and the depth of embedment. Indicative pull-out values for each tie may be check by in-situ testing.

Related and other strengthening tests

7. Sumon, S. K. (2005). Innovative retrofitted reinforcement techniques for masonry arch bridges. Bridge Engineering 158(BE3): 91-99

A coordinated series of strengthening tests were conducted at the Transport Research Laboratory (TRL) in the UK to test the ability of a Helifix system to increase the load bearing capacity of masonry arch bridges without adversely affecting their stiffness. Full-scale masonry arch models were constructed using low strength bricks and damp sand, rather than mortar, to simulate a weakened arch suffering from ring separation. Monotonic loadings were applied and the performance of unreinforced arch structures compared to those of strengthened structures. The Helifix strengthening regime centered on the installation of HeliBar reinforcement to create circumferential beams and CemTies to pin the masonry arch rings. In the final test of the series, the Helifix system achieved the highest level of structural load capacity for any tested system repair, reaching more than double the 20 tons of the unreinforced arch. Key observations and conclusions included:

- Minimal strengthening can lead to a considerable increase in the ultimate strength of the structure
- Strengthening delayed the formation of cracks
- Progressive deformation but no catastrophic collapse
- Radial pins effectively restored the loss in integrity caused by ring separation

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