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Earthquake – Christchurch

AN.3 PRELIMINARY ADVICE NOTE ON REPAIR OF EARTHQUAKE-DAMAGED CHIMNEYS

Contents

INTRODUCTION

Historic chimneys are significant features of the architectural character of any building. They have always been emphasised as important elements of the composition of a design. While chimneys were essential to the functioning of houses, they were exploited as design elements in buildings of the early 20th century.

No two chimneys are the same. As they are all unique, repairs need to be specific to the design of each. Many of the techniques for stabilising these structures are applicable to a wide range of cases.

In earthquakes, chimneys are one of the features of older buildings most likely to be damaged. This is because traditionally, the majority of these were constructed from brick masonry, and because they necessarily stand high above the roof level to perform their function of dispersing smoke to the air. The effect of ground shaking is to induce cyclic inertia forces from the mass of the chimney. These horizontal forces will cause horizontal displacement of the chimney unless it is restrained by structural elements of the building. This restraint can be provided by masonry walls, or roof or floor framing, or the ground on which the chimney is founded.

Chimneys located within the body of a building are likely to behave differently from those on the outer face because of the differing levels of support offered by the surrounding structure. Chimneys in brick buildings may also behave differently from those in timber framed buildings because they are more fully integrated into the primary structure of the building.

This note is intended as a guide to the repair or reconstruction of masonry chimneys on historic buildings to restore them as authentic architectural features of these buildings. For this reason, this document does not cover repairs using synthetic materials.

Other solutions are available for *replication* of chimneys on non-historic buildings, where authenticity is not an important concern. Such techniques, including moulding in fibreglass, plastering on sheet material and mounting sawn bricks onto sheet material allow the chimney to be reinstated as an architectural feature, but are not generally appropriate where it is important to fully restore the architectural *integrity* of the building.

PATTERNS OF FAILURE

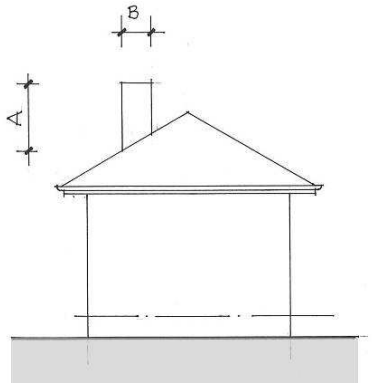
The failure of chimneys in an earthquake may have several causes, either alone or in combination, and this will influence the selection of techniques for stabilisation or repair.

1. Chimneys are comparatively tall and slender, which means that they are more likely to flex under the lateral forces generated in an earthquake. The risk of falling increases as chimneys get higher and is, of course, greater in areas more susceptible to earthquake or high winds. Note that chimneys on multi storey buildings are also more likely to be damaged in an earthquake.

2. Brickwork/masonry is made up of small units of masonry held together with an adhesive mortar and while they are generally very strong in compression, they have limited resistance to tension due to bending. This means that when a chimney is bent under earthquake forces, it is likely that the bricks on one side will separate under tension. Where the mortar is made with Portland cement, it is likely that the upper part of the chimney, or shaft, will simply break off and fall in one piece. Where the mortar is based on lime, it is more likely that the chimney will break into many smaller pieces as it falls.

3. Even where a chimney (or part thereof) does not fall over, there may be damage due to cracking within the stack, and this may not be apparent – especially where the stack is enclosed by other construction.

While the stability of a chimney is a factor of its height and thickness, the risk of failure will also depend on its location in New Zealand. The risk of earthquake varies between different parts of the country, so that the higher the "zone factor" the greater the risk of failure for a given chimney form. To provide a uniform risk of chimney failure across the country, the recommended height to width ratio of a chimney is reduced for higher "zone factor" areas of the country.



Zone Related Chimney Slenderness Ratio for Stability

A = height of chimney above roof level
B = least dimension of chimney

The **chimney is at a high risk of instability** if **A / B** exceeds prescribed slenderness ratios.

In Christchurch, for example, this is between 2.0 and 2.3.

PART 1: Checklist for action

A - Chimneys partly or totally collapsed

1 Is the place identified as an historic place or character building?

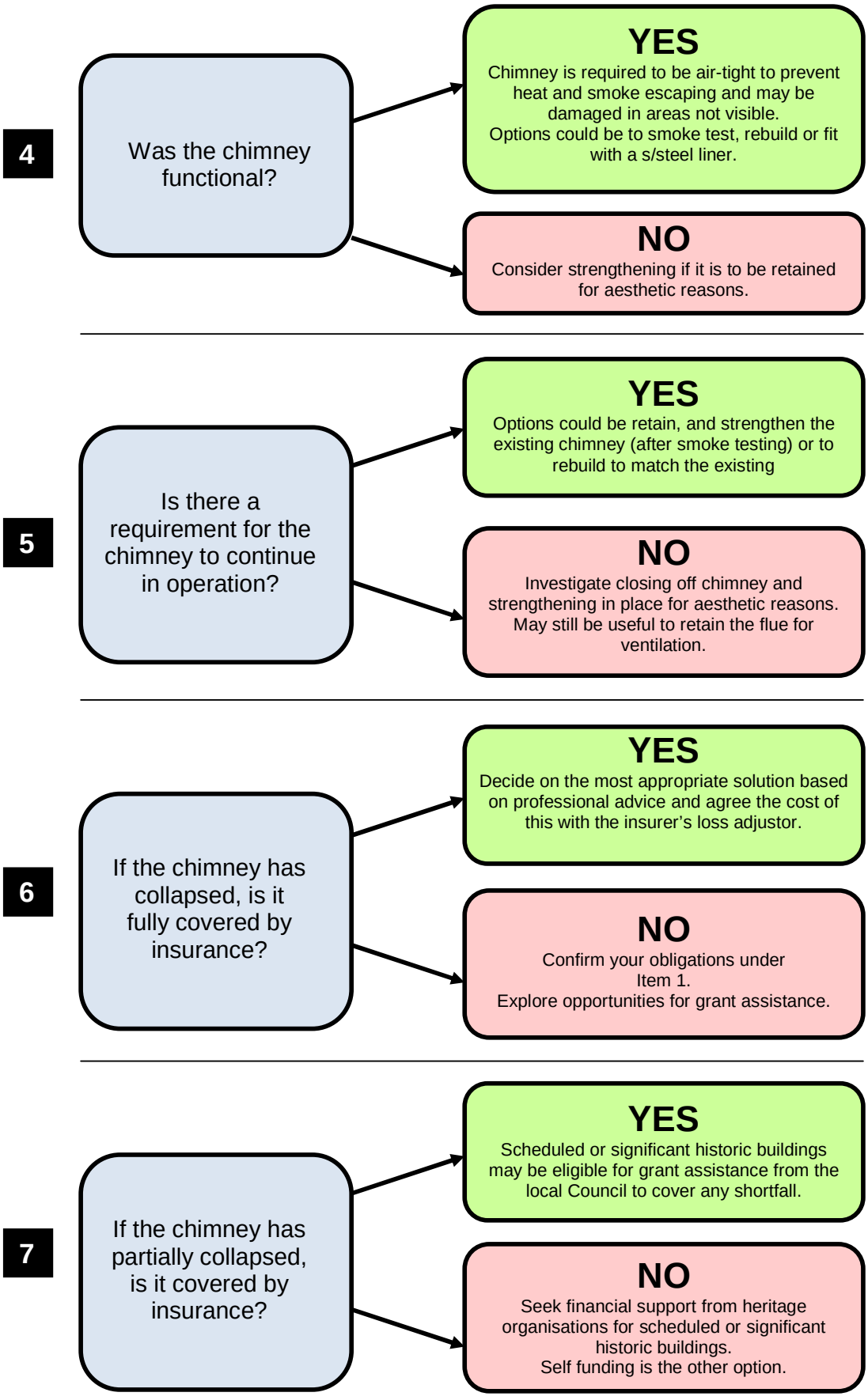
- **YES** – There will need to be a discussion with your local council and NZHPT about the most appropriate rebuilding solutions
- **NO** – There may be no requirement to rebuild your chimney but this decision should be made based on the functional and visual effect the chimney has on the house or building

2 Has an engineering assessment been prepared?

- **YES** – An engineering solution is a pre-requisite for repairs
- **NO** – Obtain an engineering assessment – NZHPT can provide a list of engineers who understand the particular importance of chimneys in historic buildings.

3 Is the chimney an important architectural design element or valued?

- **YES** – Consider carefully the options for repair or re-building
- **NO** – If not required for heating, consider options for reinstatement after checking with the relevant local Council


4
Was the chimney functional?
YES
Chimney is required to be air-tight to prevent heat and smoke escaping and may be damaged in areas not visible.
Options could be to smoke test, rebuild or fit with a s/steel liner.
NO
Consider strengthening if it is to be retained for aesthetic reasons.
5
Is there a requirement for the chimney to continue in operation?
YES
Options could be retain, and strengthen the existing chimney (after smoke testing) or to rebuild to match the existing
NO
Investigate closing off chimney and strengthening in place for aesthetic reasons.
May still be useful to retain the flue for ventilation.
6
If the chimney has collapsed, is it fully covered by insurance?
YES
Decide on the most appropriate solution based on professional advice and agree the cost of this with the insurer's loss adjustor.
NO
Confirm your obligations under Item 1.
Explore opportunities for grant assistance.
7
If the chimney has partially collapsed, is it covered by insurance?
YES
Scheduled or significant historic buildings may be eligible for grant assistance from the local Council to cover any shortfall.
NO
Seek financial support from heritage organisations for scheduled or significant historic buildings.
Self funding is the other option.

8 Is the chimney integral to the structure of the building?

YES
Careful consideration will need to be given to the methodology of building repairs if the chimney is structurally integrated. Engineering advice is essential.

NO
Options in this case may be more flexible.

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9 Do you have documentation describing the design and form of the chimney? (i.e. record drawings or photographs)

YES
If rebuilding is undertaken, good documentation greatly assists this process. If the chimney is removed, then recorded, information can be left with the house or deposited with the local Council or NZHPT as a record for later generations.

NO
Family photographs and building plans may be a good source for this type of information. The Council Building/Resource Consent records may hold useful information as may the public library photographic collections.

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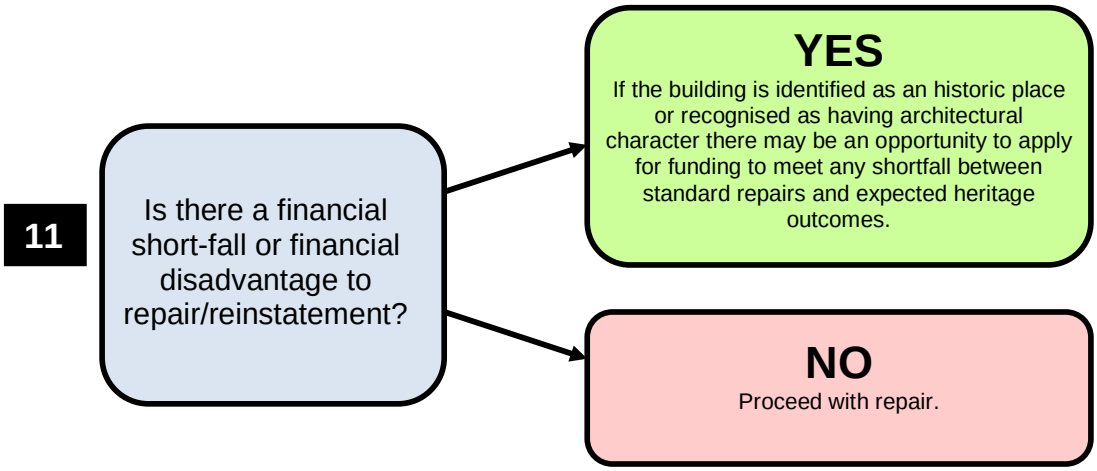
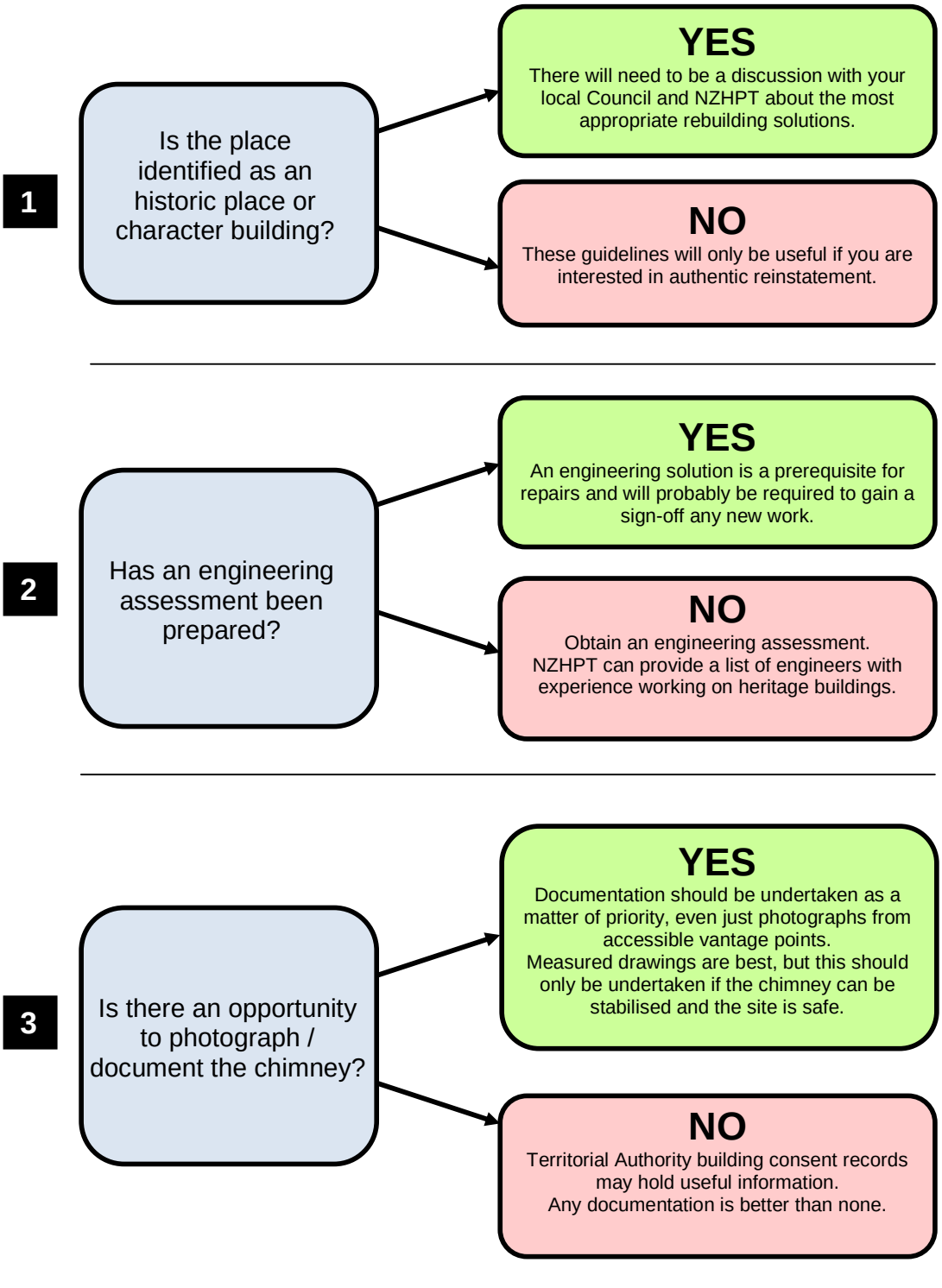
10 Have the collapsed materials been identified (e.g. bricks numbered) or kept aside in order for possible reassembly?

YES
Documenting and labelling fallen material will assist greatly in establishing the original form of the chimney when decisions are made to reinstate.

NO
If this is still practicable, photograph and label fallen elements and set aside in a clean dry area for reuse at a later date.


11
Is there a financial short-fall or financial disadvantage to repair/reinstatement?
YES
If the building is identified as an historic place or recognised as having architectural character there may be an opportunity to apply for funding to meet any shortfall between standard repairs and expected heritage outcomes.
NO
Proceed with repair.

B - Chimneys standing or deformed



4 Can the chimney be safely stabilised by temporary supports?

YES
If the chimney can be supported in place there will be a greater opportunity to maintain its integrity, either by making repairs, or recording a careful dismantling process.

NO
Careful dismantling will be required.

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5 Are the repairs/works fully covered by insurance?

YES
Decide on the most appropriate solution on the basis of professional advice and in agreement with the insurer's loss adjustor.

NO
Confirm your obligations under Item 1.
Explore opportunities for grant assistance.

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6 Is there a financial short-fall or financial disadvantage to repair/reinstatement?

YES
If the building is identified as an historic place or recognised as having architectural character there may be an opportunity to apply for funding to meet any shortfall between standard repairs and expected heritage outcomes.

NO
Proceed with repair.

PART 2 – GENERAL METHODOLOGIES

REPAIR OPTIONS

Some techniques used to repair a chimney ***after*** an earthquake will be different from those which might ideally be used ***before*** an event.

But whether repair or strengthening is being undertaken, methods need to take account of the inherent weakness of chimneys – the combination of height, slenderness, lack of reinforcement and construction of many small elements held together with mortar.

This advice note considers four situations:

A. Where a chimney is intact, but at possible risk of earthquake damage
   - The challenge is to strengthen it without transforming its appearance.

B. Where chimneys have collapsed and it is proposed to rebuild
   - This provides an opportunity to incorporate measures to strengthen the structure against further earthquake damage. This could include reconstructing the chimney with a structural core, say of reinforced concrete or structural steel.

C. Where a chimney has been damaged, but is still standing
   – Repairs should be straightforward but strengthening may be difficult to achieve without some intervention. This could include de-constructing the chimney and reconstructing with a structural core, say of reinforced concrete or structural steel.

D. Where the chimney has been lost and the remains of the base remain below the roof line.

In every case it is probable that professional structural advice will be needed to satisfy the Council that the repaired or stabilised structure will adequately resist earthquake forces.

For heritage buildings, it may also require a heritage architect to ensure that repairs recover (or maintain) original features and appearance of the chimney.

In every case, it will be important to use tradespeople experienced with conservation work to undertake these repairs.

The objectives in all cases are:

- To increase resistance to earthquake damage.
- To compensate for the inherent weakness of the structure.
- To preserve the structure as an architectural element of the building in which it is located, *and (in some cases)*
- To allow the chimney to be used for its original purpose, or a sympathetic new alternative purpose.
- Preserve the integrity of the building.

ASSESSMENT – **understanding the structure**

It is important not to underestimate the importance of a chimney (or other tall structure) to the architectural integrity of a heritage building – even where it may no longer serve its original purpose.

i. Establish how much of the chimney stack and wider fire-place area needs to be upgraded.- Often it may only be the part of the stack (or shaft) above the roof that is damaged. However, the strengthening elements may require extending further down below the roof line and into the building to engage adequate support for the chimney.

ii. How many flues are in the chimney shaft, and are these straight or do they change direction?

iii. It may be important to examine the chimney within the roof space to determine if it is vertical throughout – Look also for cracks in either the mortar joints or the bricks themselves.

iv. Determine the type of mortar used (this may require expert assessment)
   a. is it sandy and "soft", with a slight ochre or pale colour? – this is likely to be a lime-based mortar.
   b. is it hard and grey? – This is likely to be cementitious mortar.

v. Is the chimney freestanding within the structure of the building? if so, it should be completely independent of any timber, except for the supports at roof and floor plane levels.

vi. Is the chimney part of the outer wall and is it independent of the wall structure, or is it an integral part of the wall? – This will have an effect on its behaviour in an earthquake and may be a factor in damage to the wall.

vii. What is the roof covering? – How will waterproofing be achieved where the chimney passes through the roof?

RECONSTRUCTION

Where an original chimney has been wholly or partially dismantled – whether as a result of seismic activity or subsequent to this. There is the opportunity (as well as a building code requirement) to incorporate a modern structural support system for the structure throughout its height. The techniques used may depend on whether a chimney will continue to be used for smoke extract or whether its purpose will be mainly architectural.

The aim of conserving historic places is to maintain the authenticity of those places and their key elements. This is fundamental when considering such issues as design, presentation, finish and materials. Only in very exceptional circumstances should alternative approaches be considered.

Replacement of original parapets, towers, chimneys and other elements lost as a result of earthquake activity, with replicas in synthetic materials is not ideal because this is not authentic. Such measures should be considered very carefully. This type of work is outside recognised practices for the conservation or restoration of heritage and is not recommended.

Methods and Techniques

The task is to rebuild a chimney in such a way that it retains its original (architectural) design integrity but with additional strength and support to resist further damage.

For any reconstructed chimney, it will be necessary to obtain professional engineering advice to design a structural method of support. It will also be necessary to obtain a building consent for that structure.

If the building is a scheduled or registered historic structure, then a resource consent is also required. It may be necessary for this purpose to obtain the services of a heritage architect to assist with both detailing and consent processes and to ensure that the reconstructed shaft is authentic in its design and detail and faithful to the original building.

For heritage buildings, it will be extremely important to salvage all masonry from the original chimney and to reuse as much of this material as possible. Where possible, photographs of the building prior to damage should be obtained and these should guide the reconstruction.

It is important to note that for many buildings erected prior to 1900, mortars for brickwork were predominantly based on lime. The importance of this cannot be overstated since, for many early bricks, the greater strength of modern cement mortars can be extremely destructive over time and this results in progressive cracking and erosion of the original masonry. Cement-based mortars also contribute to the accumulation and retention of water in the construction.

No mortar will prevent earthquake –damage; the role of the mortar is to hold the masonry units together and to allow water in the construction to evaporate. Where a chimney is reconstructed, its structural integrity will be based around a new complying structural system, and the masonry of the chimney will be supported by this, not by the mortars.

Care is required when putting different materials together; they are not always compatible. For example, where a structural concrete core is used to support the exterior wythe of brickwork, moisture separation is required between the concrete and brick. If there is no separation, moisture movement can cause unsightly efflorescence on the surface of the brickwork.

Methods for rebuilding chimneys will be similar to those outlined below for strengthening chimneys which are still standing.

There may be cases where replacing the chimney is not practical and there may be very little aesthetic reason for reinstatement. In these cases it would be appropriate to confirm the stability of the chimney base and, if secure, keep this in place and make good the roof cladding.

STRENGTHENING STANDING CHIMNEYS

The task is to strengthen and/or repair a standing chimney in such a way that it retains its original design integrity and to make sure that its junctions with the rest of the building remain waterproof.

The challenge is to enhance the underlying strength of the stack as a unit and also to hold its various components together. A number of possibilities are discussed below. These are intended to keep the chimney stack intact or to help it move as a single element under earthquake load, rather than disintegrating or breaking off. As with reconstruction, it will generally be necessary to obtain professional engineering advice to design the structural support and it will be necessary to obtain a building consent for that structure.

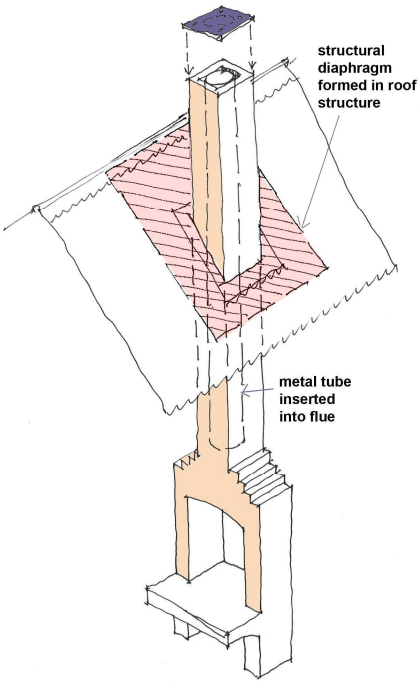
Structural diaphragms can be used to distribute the horizontal loads from the chimney to the various supporting elements of the building, then back down to ground. These diaphragms can be formed by plywood fixed to the existing or new timber framing that lies in the plane of the roof and ceiling, or diaphragm action provided by existing floors, if they have sufficient strength and stiffness. Generally, metal strapping and/or blocking is required to distribute the load from the chimney into each diaphragm. Note that where the chimney shaft extends well above the roof plane and the chimney stack is over one or more storeys, support for the chimney requires at least two diaphragms spaced well apart vertically. These spaced diaphragms form a couple to stabilise the upper section of the chimney shaft where it projects above the roof.

As a general principle, it is better not to think of filling a chimney with concrete as this will change its behaviour in an earthquake and will increase the weight in the upper part of the shaft.

The following methods describe a range of approaches to strengthen an existing chimney flue. All require specific professional design with varying degrees of complexity.

Metal sleeve inserted into the flue

Support for the chimney is provided by a metal tube (eg. galvanised steel tube) fitted into the chimney flue. This tube ties the stack together through its height and carries the horizontal inertia loads from the chimney to the supports such as a masonry wall, or diaphragms or hearth breasting or foundations.



The tube is to be sufficiently strong and stiff to carry the inertia loads from the chimney to the supports by shear and bending in the tube, and limit the flexing of the chimney to within the capacity of the brickwork. However, diurnal movement of the brickwork should not be restrained so that excessive tensions do not develop in the brickwork.

To inhibit the brickwork from breaking away from the inner tube, stainless steel wire hoops (or Helifix[2] threaded rods) can be fitted into say every third horizontal mortar joint, and held in place by new pointing into the perimeter of the joint.

a. A metal tube – say 200mm diameter – is supported in the flue while a small amount of cement mortar is placed to close the flue at the base of the tube (a pneumatic tube placed around the tube and inflated, will support the wet concrete).

b. The space between the steel tube and masonry is back-filled with either granular 'pea' gravel or weak grout (Centricrete MV)[1]. This helps stiffen the shaft, without reducing its flexibility to diurnal effects, and dampens the earthquake actions.

c. The top portion of the cavity is to be sealed with non-shrink grout to stop water entry between brickwork and the steel tube.

d. As required, horizontal hoops should be provided in the horizontal mortar joints of the brickwork.

This method enables the chimney to ventilate the room or the interior. Where it is intended that the chimney will continue to function in conjunction with a fireplace, a proprietary product with multiple concentric stainless steel tubes can be inserted. This allows cooler air to circulate around the central flue.

It may also be advisable to connect such a metal flue to a new enclosed metal firebox, either by welding on site, or with the use of a fabricated metal collar.

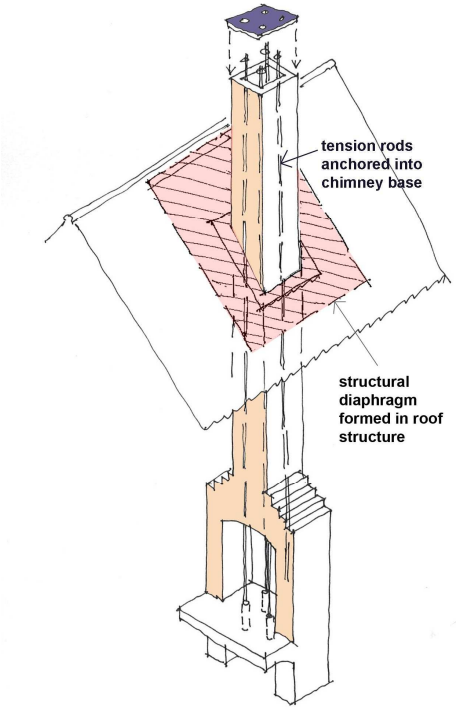
Tension rods within the flue

An alternative to the above method utilises the high compressive strength of the brickwork, but is dependent on the age and strength of the chimney bricks and the mortar used. The installation must be professionally designed by a structural engineer.

a. Fix at least two, preferably four, threaded metal anchors in the base of the firebox, down into the foundations of the chimney and well bedded in epoxy adhesive. Locate the anchors as far apart as possible but with a clear vertical flue cavity above, through to the top of the chimney. Alternatively, for a large chimney where the brickwork is sound on a vertical line for the full height of the chimney, core down through the height of the brickwork to insert each anchor in the foundation of the chimney. The coring of the holes for the full height of the chimney, placing, anchoring and stressing of the ties requires the services of a specilist contractor.

b. Make up and fit a stiff metal plate to cover the top of the flue, and drilled for the ends of the tension rods (if it ***is*** intended to continue to have fires, this plate will need to have an opening for smoke to pass through).

c. Locate threaded rods or tensioned wires into the anchor points and through the top plate, and tension these as directed by the engineer.



A method where the tie rods or wires pass up through the flue is more invasive as it requires a strong anchorage to be formed at the base of the flue within the hearth area and therefore depends on this part of the chimney retaining its structural integrity.

[1] Supplied by Building Chemical Supplies, Wellington
free phone 0800 22 55 62

Also, because the metal ties required will be exposed, it will inadvisable to use the chimney for its original purpose as the heat of a fire will weaken the tension rods.
If it ***is*** intended to continue to have fires, then the metal sleeve systems described above will be preferable, used in conjunction with a metal firebox.

Where the tie rods or wires pass up through holes cored in the brickwork, each rod or wire should be greased and encased in a plastic tube. The tie assembly is fitted into the cored hole, fixed at the base, stressed and grouted into the hole.

The grease filled plastic tube protection can also be used where the ties pass up the flue.

External strapping

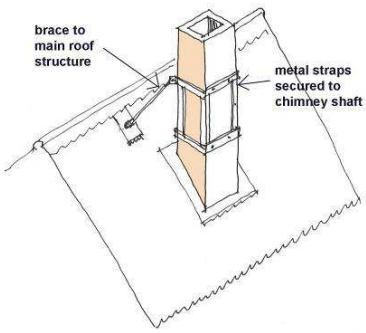
This is likely to be a fairly visible repair, in which case some thought should be given to its design and assembly and to finishing the metalwork with either a paint to match the chimney material or perhaps, where the design of the strapping has been carefully considered, with a contrasting paint colour (e.g. black). Where external strapping is used, it should be installed in conjunction with a structural system that inhibits the externally strapped section of the chimney shaft breaking away below the strapping, and tipping over as a whole.

The benefit of this method is its capacity to restrain the masonry over the strapped height from disintegrating under earthquake forces.

a. Galvanised pre-formed steel straps placed around the shaft both vertically and horizontally tie it together as if in a cage.

b. Metal work should be bolted together so that it can later be removed if necessary.

c. May also require some direct attachment into the masonry structure of the chimney.



Bracing back to roof framing

This may be undertaken in association with strapping the chimney shaft, and is likely to be quite visible. Consequently this may be used only as an interim measure or, if it is to be permanent, then the design and location of the bracing element should be carefully considered.

a. Locate a robust fixing point in the adjacent roof structure and attach a structural anchor designed by a structural engineer.

b. Locate a support position on the shaft and fit a galvanised steel collar around the shaft with connection to the brace.

c. Connection to the roof structure will require penetration of the roof covering, leading to a risk of water entry. Therefore special care shouldbe taken with the design of flashings to exclude moisture.

d. Diaphragms fitted to the underside of the roof framing may be required to support the chimney stack where it passes through the roof plane and at the brace fixing points to the roof. Earthquake loads from the chimney are to be carried back into the supporting structure without causing excessive stress or deflection of the supporting members.

Note that the braces are to carry inertia loads from the chimney in two directions at right angles to each other. Therefore the braces should be splayed to take components of load in each load direction.

Near-face tension reinforcing

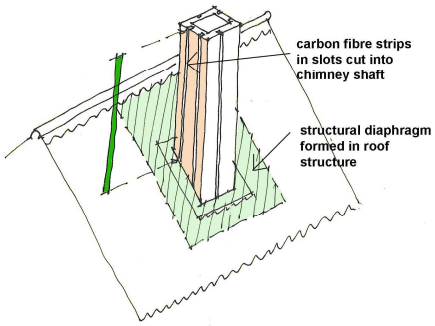
This method makes use of modern materials to increase the horizontal bending strength of the brick masonry. It relies on reinforcing strips set into slots cut in the masonry to achieve an effect similar to that of the external strapping. This technique will work well in rendered (plastered) chimneys, as the cuts made can be replastered to disguise their existence.

a. Open up the roofing around the perimeter of the chimney so that the saw cuts can be taken to below the roof plan.

b. Saw cut vertical slots in the face of the flue at intervals from the top of the chimney to below where bending tension will be generated in the brickwork due to horizontal earthquake loads.

c. Insert carbon-fibre strips into the saw cuts and bond these into the slots with epoxy resin.

d. Re-point the joints with mortar to match the existing construction.

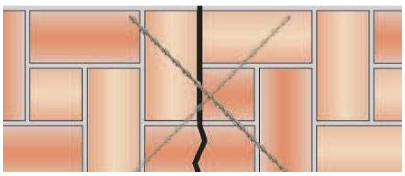


e. Form structural diaphragm within roof structure as noted above, and make good the roofing.

This method is less suitable for exposed brick masonry as it will require saw cuts to be made across the face of the bricks, and will be difficult to conceal, even using coloured mortars.

proprietary anchor systems

A number of modern anchor systems are available to locally augment the strength of a flue in conjunction with any of the above techniques. These systems rely on the use of slender threaded reinforcing rods which can be drilled though masonry to pin pieces together. These can be used in horizontal strips or on an angle and must be used with reference to their specifications.



They can be used to repair cracks, to join separate masonry skins (such as veneers) together and as reinforcement set into mortar joints. Examples include the Helifix system[2]. Other manufacturers may also offer equivalent systems.

2 see: http://www.helifix.com.au/crack_stitching.html
http://www.helifix.com.au/masonry_repair_details.html#BRF

OTHER METHODS

The above methods are intended for use where the repair to the chimney is intended as a full restoration as a part of the whole building. Other techniques which replicate the shape or form of the chimney using light-weight or synthetic materials, alone, or in combination with parts of original materials, are also possible.
Such techniques are beyond the scope of this Advice Note.

SUMMARY

Repair or reconstruction of chimneys is not a simple matter.
It will be important first to consider **structural stability and safety**.

Always consult with the local authority before embarking on repair.

It is strongly recommended, in all cases, that **professional engineering advice** is taken.

For heritage buildings, it is strongly recommended that **professional heritage advice** is taken. In the first instance this may come from the NZHPT or the local Council and a list of heritage specialist can be provided.

If it is intended that the chimney will continue to be **used for fires**, then particular care is required to design and construct a repair option which will be fit for the purpose and function efficiently for many years with minimum maintenance.

This Advice Note has been produced as general introductory guidance for those involved in the repair and reinstatement of heritage buildings. It is not intended to provide specific solutions for individual projects but, rather, to set out available options that are in accordance with accepted conservation principles.

It is strongly recommended that appropriate skilled professionals with proven conservation experience and qualifications should be appointed to specify repairs on a case by case basis.

Printed: 7 February 2011