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TC 13 'Aardbevingsbestendig Ontwerpen' van Bouwen met Staal

Typologie versterkingsopties in Groningen

In deze notitie is uit beschikbare literatuur en documenten informatie verzameld over de versterkingsopties tegen aardbevingen ten gevolge van de gaswinning in Oost-Groningen om de kans op slachtoffers tot een aanvaardbaar minimum te beperken.

In Arup's 'Structural Upgrading Study' (onderdeel van document 1417) zijn de volgende 7 versterkingsniveau's onderscheiden:

Permanent upgrading measures – intervention levels:
· **Level 1**: Mitigation measures for higher risk building elements (potential falling hazards);
· **Level 2**: Tying of floors and walls;
· **Level 3**: Stiffening of flexible diaphragms;
· **Level 4**: Strengthening of existing walls;
· **Level 5**: Replacement and addition of walls;
· **Level 6**: Foundation strengthening; and
· **Level 7**: Demolition.

In § 4.4.2 (p. 68-77) worden deze nader beschreven en geïllustreerd. Deze pagina's zijn hier als bijlage 1 opgenomen.

In de Leidraad Ontwerpconsultatie (stuk 1425) wordt gefocust op de niveau's 2 en 3. Daarin wordt voor niveau 2 in figuur 1 en 2 een systematische indeling gegeven van wand-vloer- en wand-dakverbindingen, uitgewerkt in bijlage 2 met details van aansluitingen en in bijlage 3 met concept details van versterkingsmaatregelen.

Uit de FEMA 547 (document 1426) 'Techniques for the Seismic Rehabilitation of Existing Buildings' is hoofdstuk 21 geselcteerd dat gaat over het versterken van ongewapend metselwerk. In bijlage 2 is tabel 21.3-1 overgenomen met daarin gehighlight de voor staal relevante onderdelen, gevolgd door de hierop betrekking hebben paragrafen en figuren.

Bijlage 1 Globale uitwerking van de 7 versterkingsniveau's in Arup's Structural Upgrading Study § 4.4.2

4.4.2 Intervention levels

The nature of the structural upgrading measures needed has been characterised into a number of intervention levels. Commencing at level 1, the intervention levels have been set out in order of the most cost-effective solutions that can be deployed most rapidly to reduce risk most quickly. There is a step change in cost/time/complexity between one level of intervention and the next.

Levels 1 to 3 can be considered as 'lighter' interventions, whereas Levels 4 onwards can be considered as 'stronger' interventions.

Permanent upgrading measures – intervention levels:

- **Level 1:** Mitigation measures for reducing higher risk building elements (potential falling hazards);
- **Level 2:** Tying of floors and walls (and checking/installing/replacing wall ties);
- **Level 3:** Stiffening of flexible diaphragms;
- **Level 4:** Strengthening of existing walls;
- **Level 5:** Replacement and addition of walls;
- **Level 6:** Foundation strengthening; and
- **Level 7:** Demolition.

Temporary upgrading measures will be implemented for specific building types for quick risk reduction, for example terraced houses; semi-detached houses, shop front buildings etc.

4.4.2.1 Permanent level 1: structural upgrading of falling hazards

Level 1 intervention greatly reduces the immediate risk of falling elements starting at potentially low level of ground acceleration. The risks can be assessed rapidly and simple, cost-efficient measures can be implemented to stabilise vulnerable elements. The implementation of level 1 intervention is already under way as part of the Pilot 2 programme.

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Examples are given in Figure 31 and Figure 32. These are primarily external interventions resulting in limited disturbance to occupants.

Figure 31 Parapet restraint.

Figure 32 Chimney Restraint

4.4.2.2 Permanent level 2: tying of floors and walls

Ensuring that principal building components are adequately tied together is the most effective means to enhance seismic capacity by improving overall building robustness. Tying walls to floor and roof diaphragms prevents walls from collapsing and substantially increases the ability of the walls to resist out-of-plane seismic forces.

Positive connection to floor and roof diaphragms allows the diaphragms to transfer and distribute the seismic forces to the load-resisting structural elements

Tying requirements are relatively quick to establish detail and implement with minimal impact on occupants. It is still necessary to enter the house, remove ceilings etc. They are a very cost-effective means to improve seismic response.

Experience with past earthquakes in other countries highlights the vulnerability of the outer leaf of cavity wall masonry where cavity wall ties have corroded. The integrity and presence of cavity wall ties should be inspected with a boroscope and, if inadequate, replacement or additional wall ties installed (see Figures 33 and Figure 34).

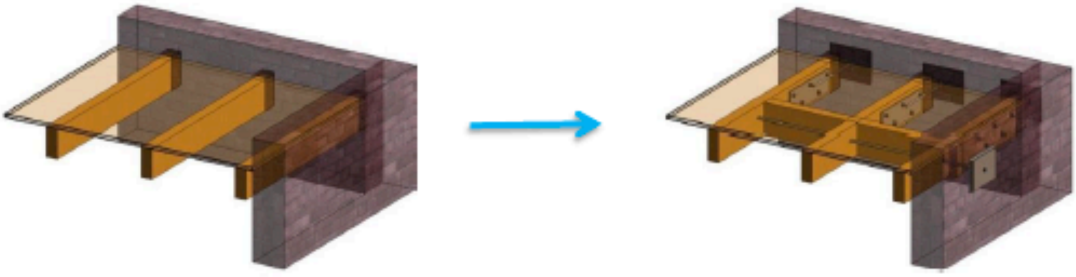


Figure 33 Positive mechanical tying of walls to floors and roofs

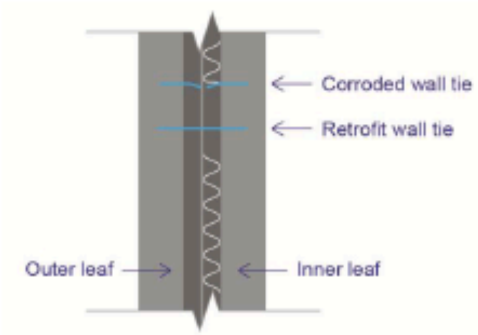


Figure 34 Replacement of corroded cavity wall ties

4.4.2.3 Permanent level 3: stiffening of flexible diaphragms

Once walls have been tied to diaphragms, the next most effective level of intervention is to ensure that the diaphraghms have sufficient stiffness to transfer load in-plane to walls, acting in their strong, in-plane, direction. This intervention improves the overall building capacity by ensuring box-like action.

Depending on the specific building, diaphragm stiffening could be as straightforward as adding another layer of planks and joist stiffeners, or could involve steel transfer frames and braces if diaphragms are discontinuous.

This level of intervention is a step change up from level 2 and will require temporary relocation of the building inhabitants.

Where feasible, undertaking level 3 interventions on a given building simultaneously with level 2 would clearly be more economical and reduce disruption to occupants as both are internal construction activities.

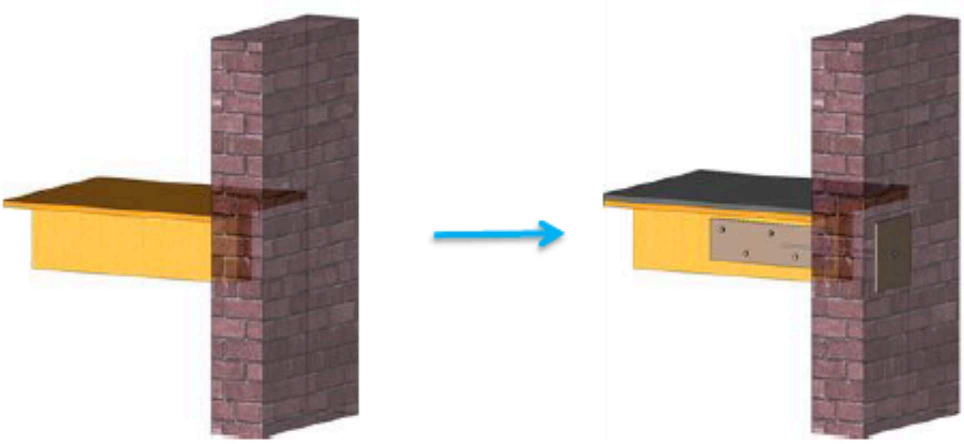


Figure 35 Stiffening of diaphragms and connection to walls

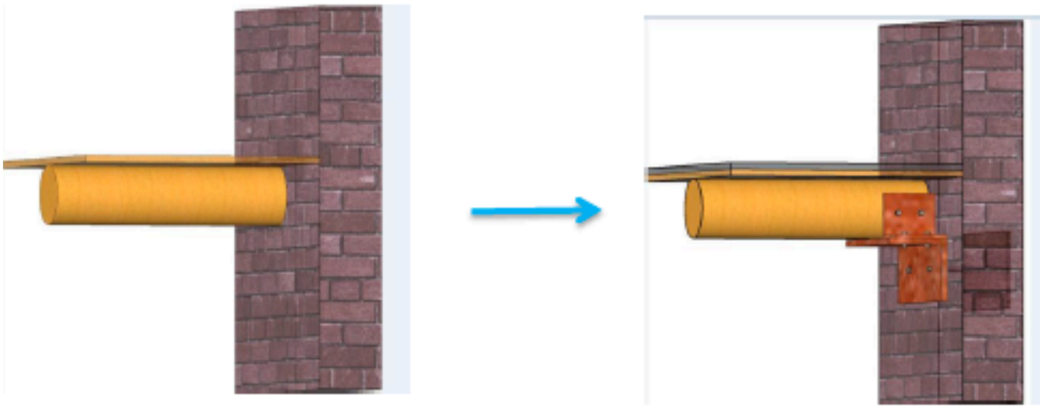


Figure 36 Stiffening of diaphragms and connections to walls

4.4.2.4 Permanent level 4: strengthening of existing walls

With an adequately tied building with stiff diaphragms, the seismic forces are distributed to the walls in a favourable manner. In the in-plane direction, if the capacity of the un-reinforced masonry is exceeded, the strength of the wall must be supplemented. There are many ways of achieving this and for the purposes of the concept design, the selected solution was carbon fibre-reinforced polymer (CFRP) bonded to the face of the masonry Figure 37. This applies to internal and external walls. This provides a tension-resisting mechanism, thereby increasing the bending and shear capacity of masonry piers and spandrels. CFRP has been used to test feasibility as it has both high strength and low mass. There are numerous other similar solutions using bonded fibres and bars that will be explored in due course as part of a cost-benefit process. There are also proprietary systems such as the CAM system, common in Italy that utilises tensioned metal, straps that will also be investigated.

Wall strengthening of this nature requires access both internally and externally and therefore temporary relocation of inhabitants and furniture, and removal and re-application of wall finishes after application, both inside and on the outside of the building, changing the appearance of the building.

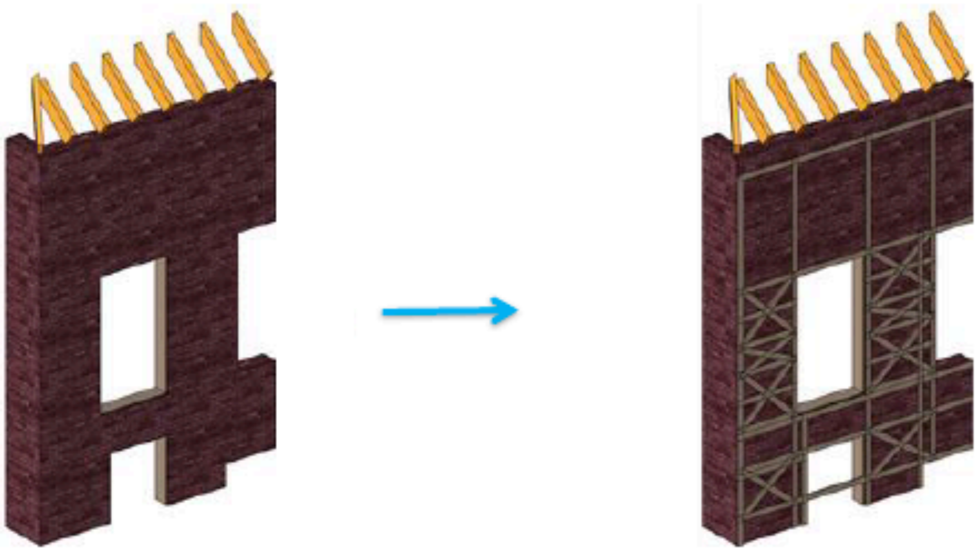


Figure 37 Addition of material to increase strength of masonry wall piers/spandrels.

Shotcrete or concrete overlays (see Figure 38) can be used to supplement both the in-plane and out-of-plane strength. This is the proposed solution for the utility buildings where the intervention can be carried out from outside the building, thereby avoiding disrupting business continuity.

Figure 39 below shows an alternative using a system of internal mullions to provide the capability to span out-of-plane. This solution has been proposed for the agricultural buildings where the loss in usable space and interior aesthetics has been deemed less important and a lower-cost solution may be more appropriate.

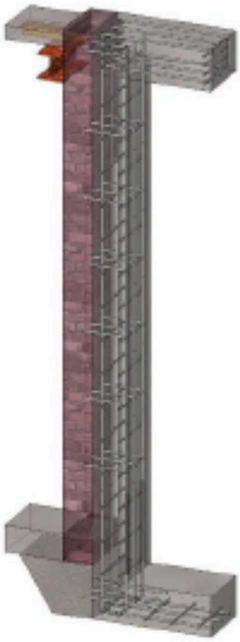


Figure 38 Reinforced concrete overlay

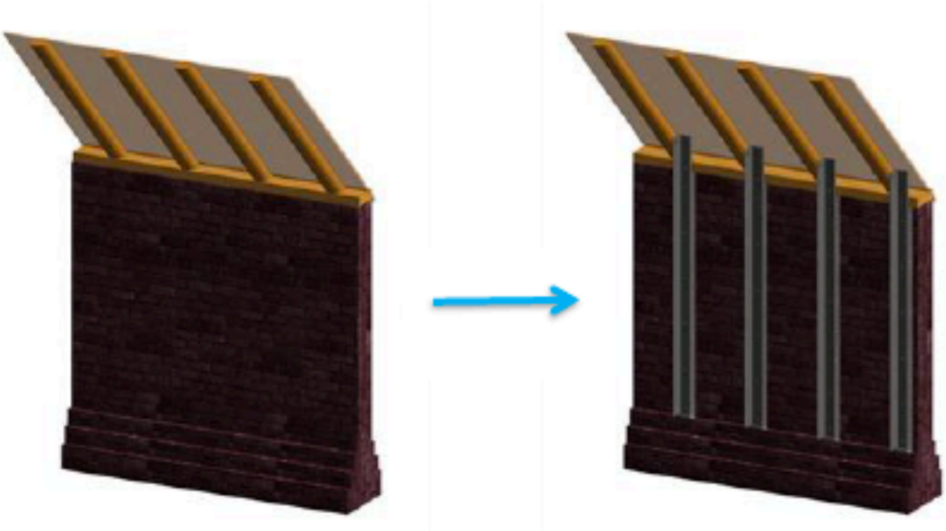


Figure 39 Addition of structural elements to increase in-plane and/or out-of-plane strength of wall piers.

4.4.2.5 Permanent level 5: replacement and addition of walls

If strengthening of walls is no longer cost-effective, URM walls can be replaced by structural systems with greater strength and/or ductility.

Figure 40 Replacing existing masonry walls with reinforced concrete walls.

Where an inadequate arrangement of shear walls exist, supplementary shear walls could be added to improve the overall distribution of seismic loads, as shown in Figure 41 below. Sufficient foundations must exist to support new shear walls, which may require the installation of additional foundation systems.

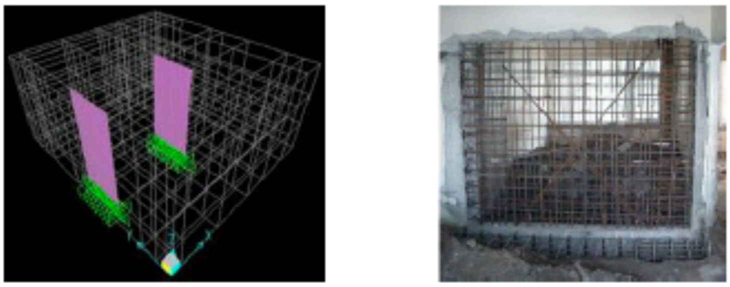


Figure 41 Additional reinforced concrete shear walls

For some terraced and semi-detached buildings where the strength in one direction is particularly low, façade panels could be replaced by systems that have adequate structural capacity.

Clearly, this level of intervention may require extensive disruption and cost, and probably temporary relocation of inhabitants or discontinuity of building function.

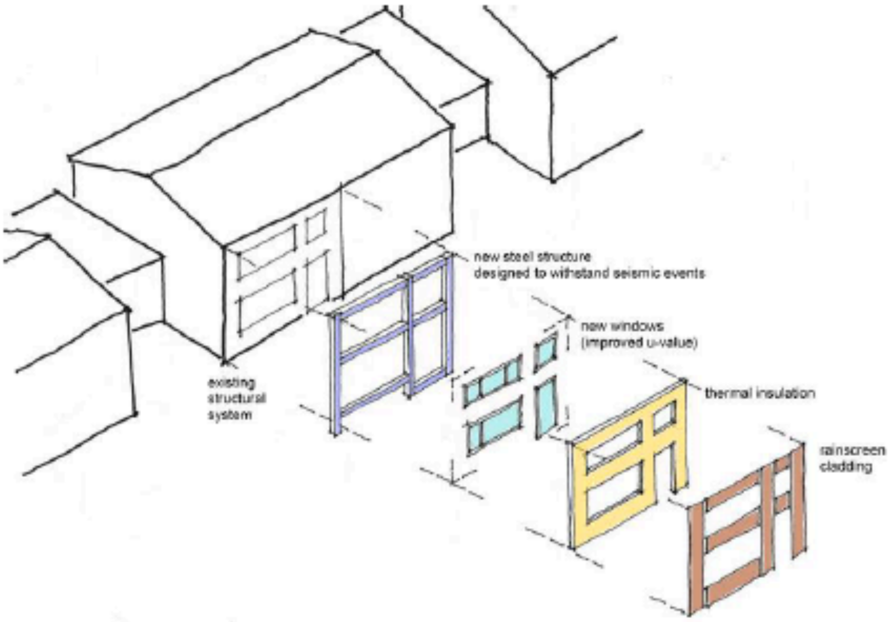


Figure 42 Replacement (façade) walls.

4.4.2.6 Permanent level 6: foundation strengthening

Where the seismic loads on the building exceed the capacity of either the existing foundation system and/or ultimate capcity of the soil, foundation enlargement or strengthening may be required. At high PGA levels, there is potential for elements of some building typologies to slide off the foundations. Therefore they will need to be adequately connected.

Where overturning bending moments on piers need to transmit a net tension to the foundation system, the piers, or tension-resisting component of the piers, will need to be anhored and tied down to the foundation.

Clearly, this level of intervention may require extensive disruption and cost, and probably temporary relocation of inhabitants or loss of business continuity.

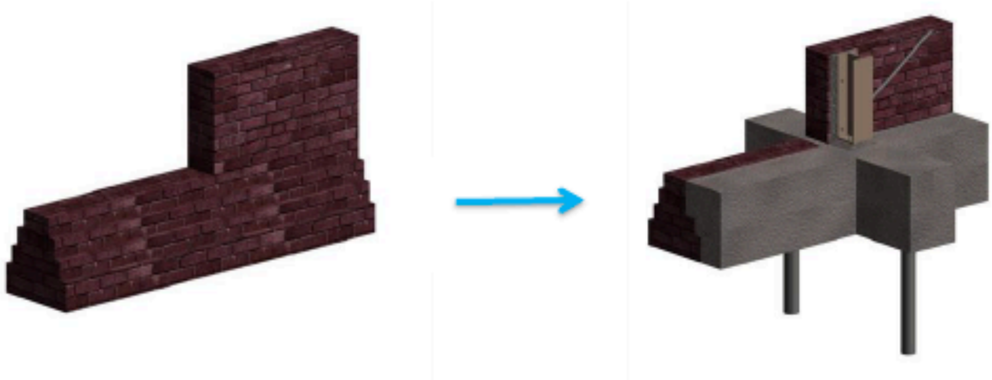


Figure 43 Increasing strength and/or stiffness of existing foundation system.

4.4.2.7 Temporary strengthening measures

Some building typologies are particularly vulnerable to ground motion in a specific direction. For example, some terraced and semi-detached buildings have limited lateral load-resisting structural systems in the direction parallel to the front and rear façades.

In order to reduce the vulnerability of these buildings, temporary measures can be deployed quickly and effectively to reduce the risk of collapse until permanent solutions can be implemented. For example, 'book-end' frames can provide a seismic load path in the longitudinal direction, which will increase the PGA threshold at which seismic effects cause the buildings to be at risk. These can be further supplemented by waling beams, braces and transverse frames to provide additional diaphragm capacity and transverse stability respectively.

Installation of strongbacks will prevent premature failure of masonry out-of-plane, thereby increasing the PGA threshold further.

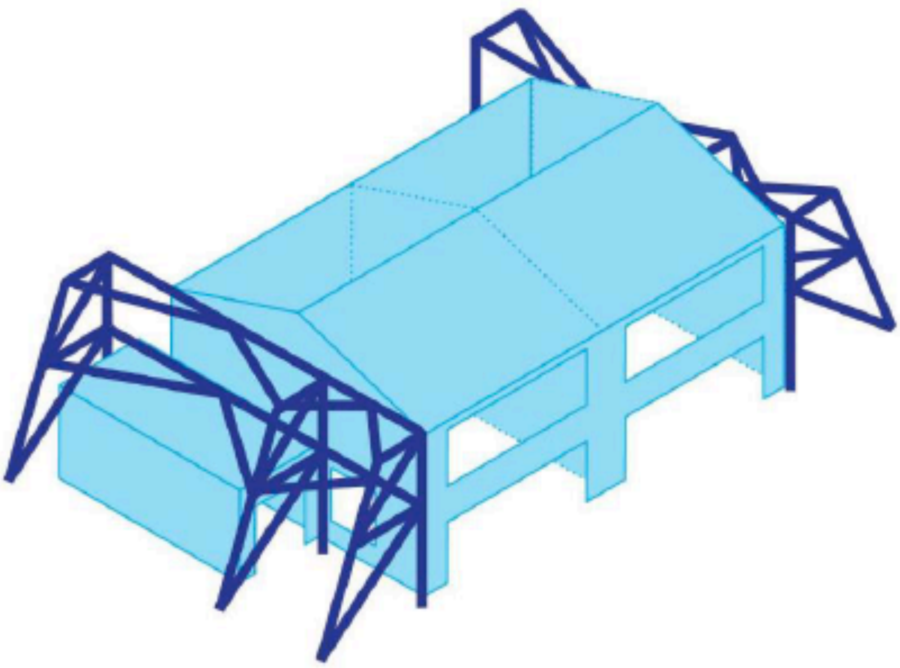


Figure 44 Temporary steel "bookend" frames

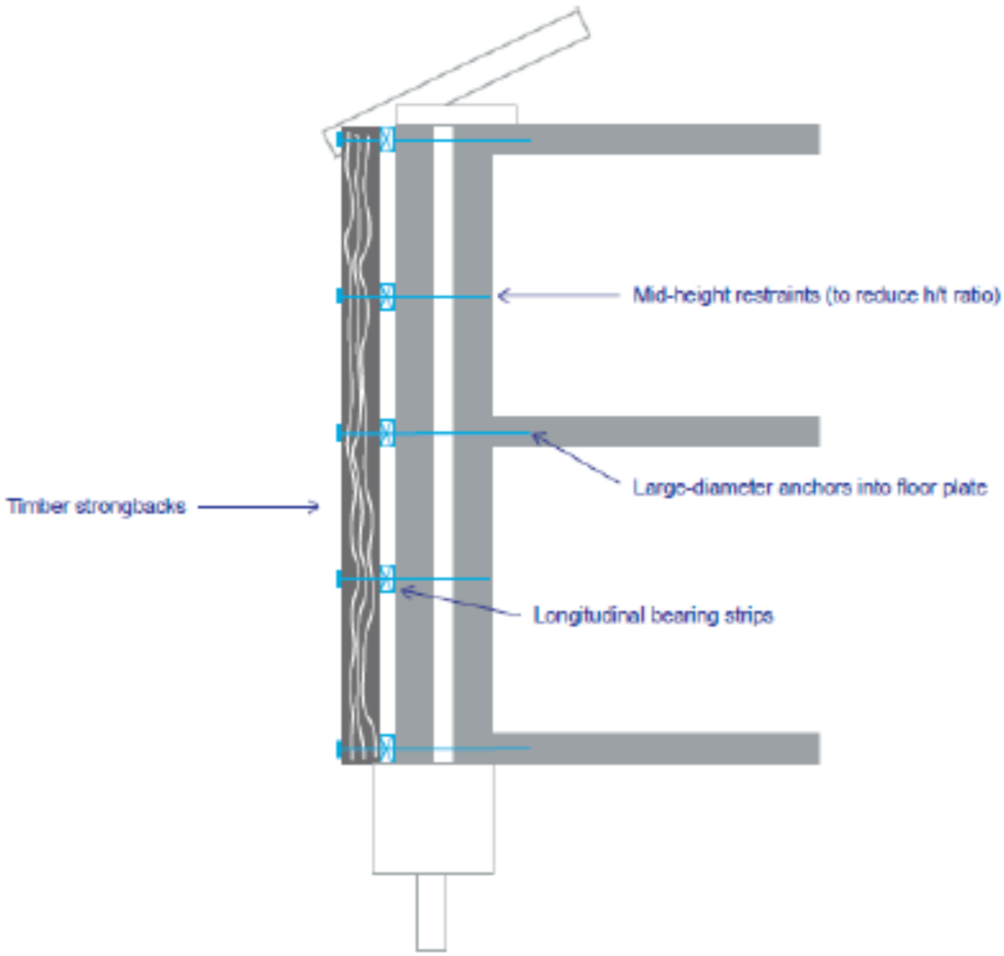


Figure 45 Temporary strongback system.

Bijlage 2: FEMA 547 gedeelte uit hoofdstuk 21

Table 21.3-1: Seismic Deficiencies and Potential Rehabilitation Techniques for URM Bearing Wall Buildings

Deficiency		Rehabilitation Technique				
Category	Deficiency	Add New Elements	Enhance Existing Elements	Improve Connections Between Elements	Reduce Demand	Remove Selected Components
Global Strength	Insufficient in-plane wall strength	Wood structural panel shear wall [6.4.2], [5.4.1] Concrete/masonry shear wall [21.4.8] Steel braced frame [7.4.1] Steel moment frame [21.4.9]	Concrete wall overlay [21.4.5] Fiber composite wall overlay [21.4.6] Grouting Infill openings [21.4.7]		Seismic isolation [24.3]	
Global Stiffness						
Configuration	Soft story, weak story, excessive torsion	Wood structural panel shear wall [6.4.2] Concrete/masonry shear wall [21.4.8] Steel braced frame [7.4.1] Steel moment frame [21.4.9]				
Load Path	Inadequate or missing wall-to-diaphragm tie			Tension anchors [21.4.2] Shear anchors [21.4.2] Cross-ties and subdiaphragms [22.2.3] Supplemental vertical supports [21.4.11]		
	Missing collector	Add collector [7.4.2]				
Component Detailing	Wall inadequate for out-of-plane bending		Exposed interfloor wall supports [21.4.3] Reinforced cores [21.4.4] Concrete wall overlay [21.4.5] Fiber composite wall overlay [21.4.6]			
	Undesirable wall in-plane behavior mode		Sawcutting to change shear mode to rocking mode			
	Unbraced parapet		Brace parapet [21.4.1]			Remove parapet and improve roof-to-wall tie [21.4.1]
	Unbraced chimney		Brace chimney [5.4.6] Infill chimney [5.4.6]		Reduce chimney height [5.4.6]	Remove chimney [5.4.6]
	Poorly anchored veneer or appendages		Add ties [21.4.12]			Remove veneer or appendages
Diaphragms	Inadequate in-plane strength and/or stiffness	Add horizontal braced frame [22.2.9] Wood structural panel shear wall [6.4.2] Concrete/masonry shear wall [21.4.8] Steel braced frame [7.4.1] Steel moment frame [21.4.9] Wood structural panel or steel moment frame crosswall [21.4.10]	Enhance existing diaphragm [22.2.1] Enhance woodframe crosswall [21.4.10]			
	Inadequate chord capacity	Add steel strap or angle				
Diaphragms (continued)	Excessive stresses at openings and irregularities	Add wood or steel strap reinforcement				
	Re-entrant corner	Wood structural panel shear wall [6.4.2] Concrete/masonry shear wall [21.4.8] Steel braced frame [7.4.1] Steel moment frame [21.4.9]		Collector [7.4.2]		
Foundation	See Chapter 23					

[ ] Numbers noted in brackets refer to sections containing detailed descriptions of rehabilitation techniques.

Diverse ankeroplossingen zijn opgenomen in § 21.4.2 'Add Wall-to-Diaphragm ties'.

§ 21.4.11 'Add Supplemental Vertical Support for Truss or Girder':

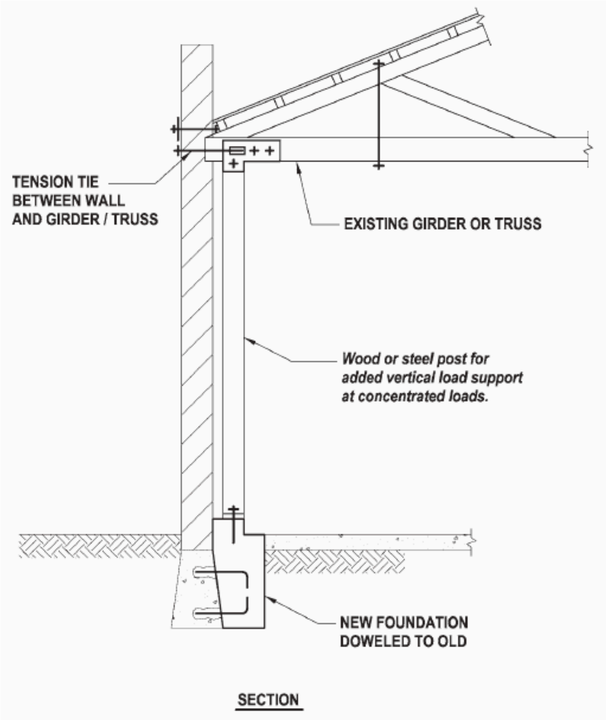


Figure 21.4.11-1: Supplemental Vertical Support

§ 21.4.3 'Add Out-of-Plane Bracing for URM Walls':

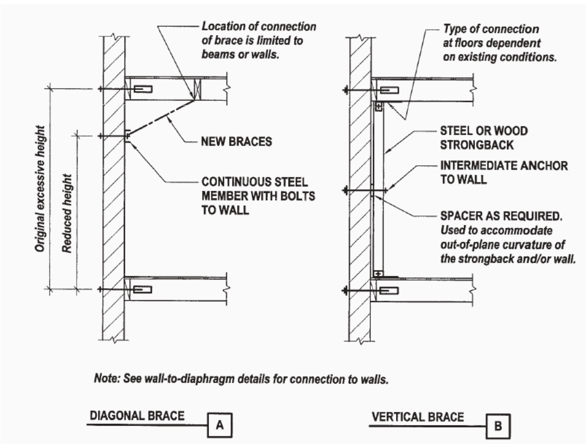


Figure 21.4.3-1: Exposed Out-of-Plane Wall Bracing

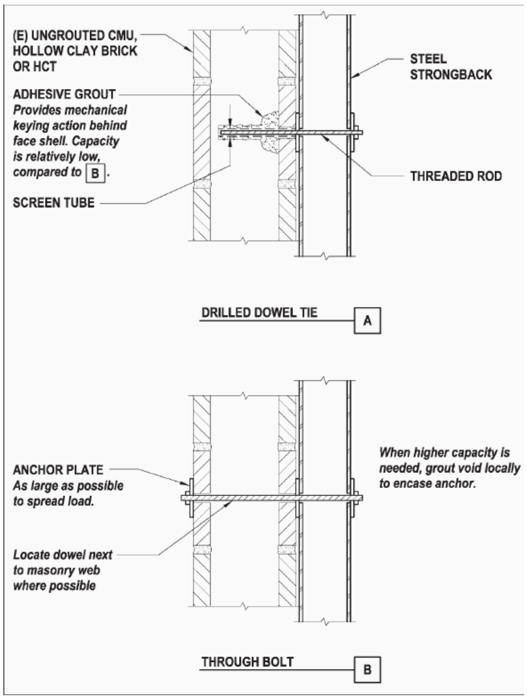
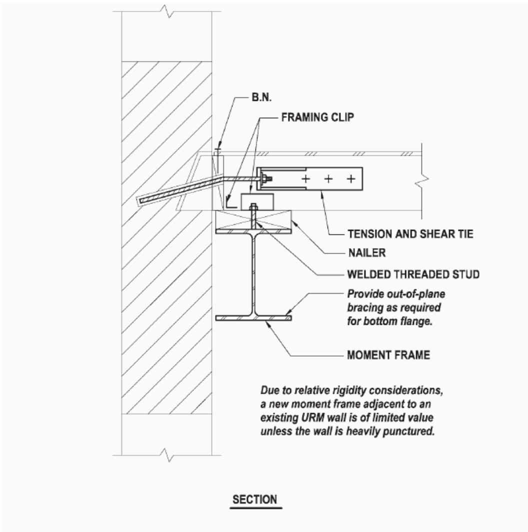


Figure 21.4.3-4: Connection of Strongback to Hollow Masonry

§ 21.4.9 ‘Add Steel Moment Frame (Connected to a Diaphragm’’:



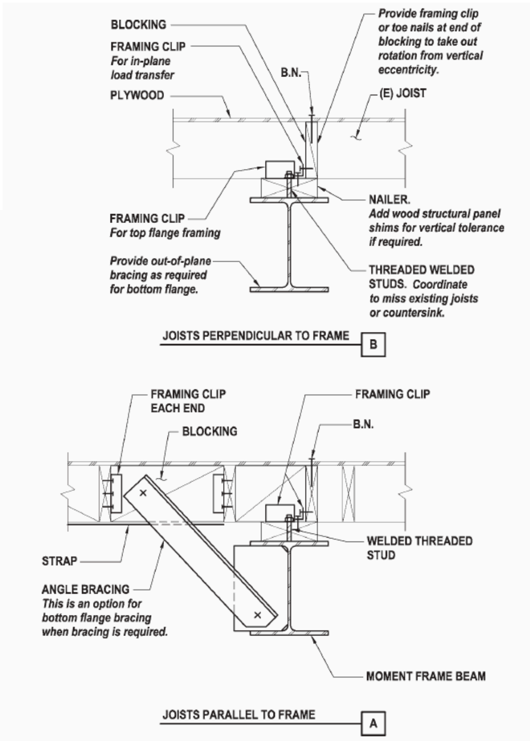


Figure 21.4.9-1: New Perimeter Steel Moment Frame to an Existing Wood Floor **Figure 21.4.9-2: New Interior Steel Moment Frame to an Existing Wood Floor**

§ 21.4.10 ‘Add or enhance Crosswalls’:

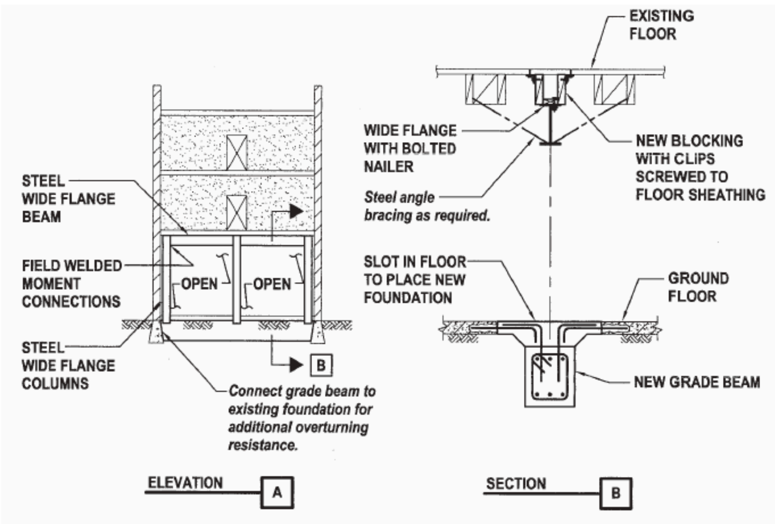


Figure 21.4.10-3: Add New Moment Frame as Crosswall

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§ 22.2.9 ‘Add horizontal braced Frame’:

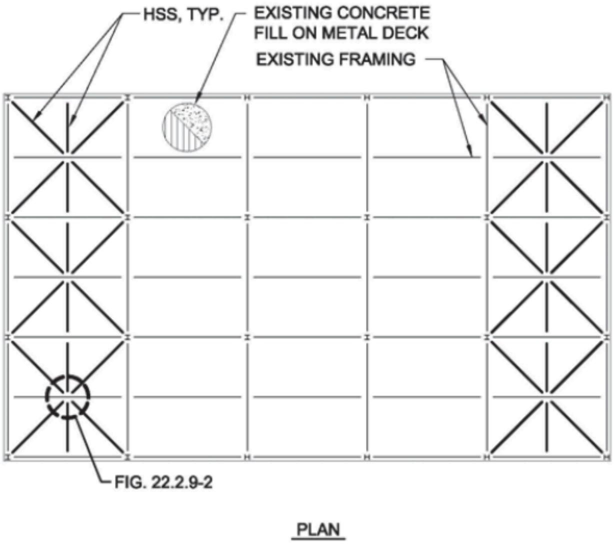

Figure 22.2.9-1: Diaphragm Strengthening using Horizontal Braced Frame