General Rules for Seismic Strengthening of Buildings.

1. Introduction.

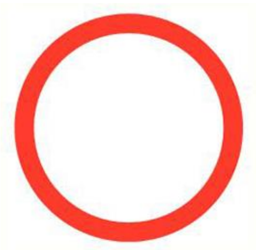
There exist many ways to transfer knowledge about earthquake resistant construction to a large population, but each person will remember the information in a different way depending on its education and knowledge of building constructions. While building engineers and architects should understand the national earthquake codes, these documents are often too complicated to understand for the general public. Graphic information such as pictograms, drawings, photographs, video and models can provide information that is easier to understand than text only.

This document is a presentation of series of sketches, using the format of traffic signs, with short explanations about what the main message is of these sketches.

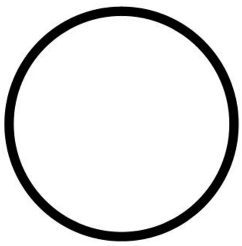
A simple way of instruction is to indicate: "**DO NOT DO THIS**", and "**DO THIS**".

This document gives these instructions using the principle of traffic signs. Traffic signs are developed to allow understanding of the message in a flash of a moment, and are based on repetitive showing. Although some seismic construction elements can be captured in very simple pictures, others need an explanatory text. The combination of simple drawings and text is easier to remember than lengthy texts or earthquake codes; by seeing again the drawing, the subject of the text is easier remembered.

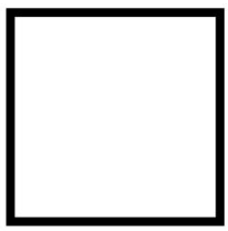
The principle of traffic signs is used for this document with as main groups the **red round** sign for **prohibited**, and the **blue square** sign for **obliged**, and the red triangular sign for attention (Δ).



Wrong or Not Good.



Not very good. Sometimes possible.



Several options possible.

Good, Recommended.

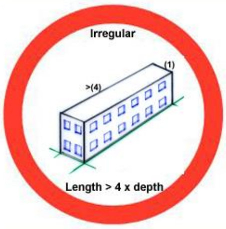
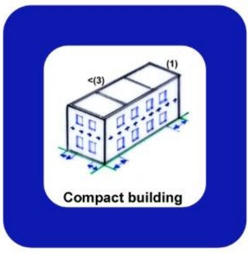
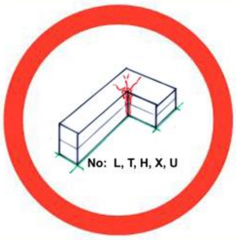
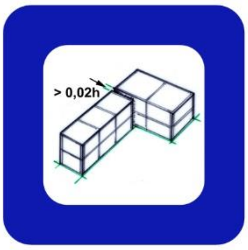
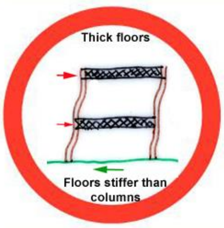
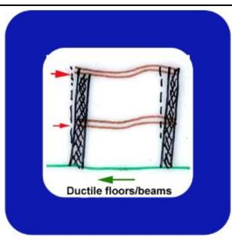
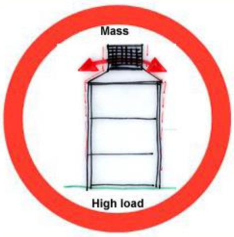
Because with low buildings or for several situations a certain solution is feasible, the black circle is introduced. Because for structural strengthening several techniques are possible the black square has been introduced. Most designs however, can be indicated as 'good' or 'not good' depending on the expected level of earthquake and location in the building.

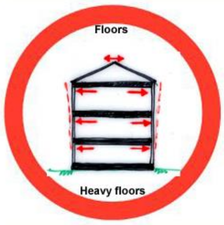
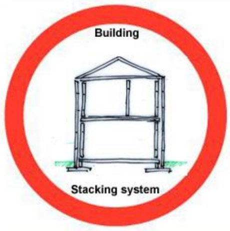
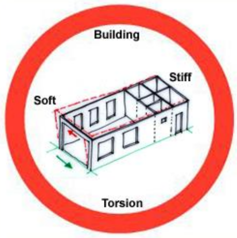
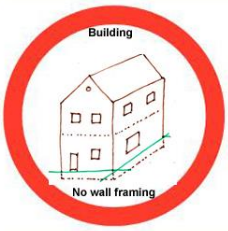
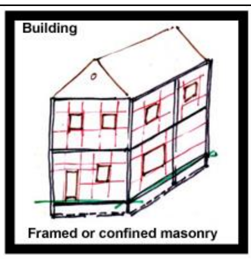
Abstract: Simple rules for earthquake resistant construction based on the principle of traffic signs with round red signs for prohibited and square blue signs for obliged. Intermediate round and square signs without colour. The differences between the **do** and **don't** signs are explained per category, covering general issues including: foundations, walls, diaphragms, roofs and reinforced concrete.

Key words: Good, wrong, do, don't, seismic strengthening, masonry, framing, foundations, walls, floors, diaphragms, roofs traffic signs, earthquake, reinforced concrete, stone, confined.

2. General Signs

The next series of signs cover general recommendations which are applicable to all buildings in seismic areas. The text on the signs can often be omitted or presented differently.

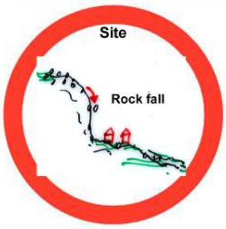
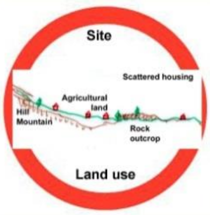
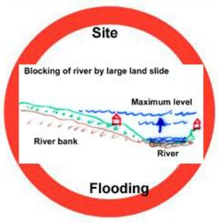
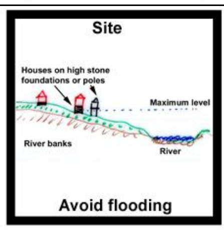
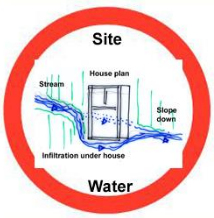
2. General Recommendations for Buildings	Explanations of the Issues
  2.1	The earthquake load on a building is directly related to the mass of the construction. When the mass is larger, also the earthquake load will be larger. For this reason it is important to keep the mass of the design, the construction or building elements as low as possible.
  2.2	Irregular or very long buildings receive larger earthquake loads than compact buildings. The length of the building should not be greater than four times the depth. Long buildings require dilatations to shorten the sections, or additional reinforcements.
  2.3	Irregular buildings in plan such as L, T, H, X, and U plans with long side will cause extra earthquake loads in the corners. These buildings need to be dilated when any length part is >3 x width. With reinforced masonry or concrete dilation = 0,02 x the height of the building.
  2.4	The basis of a building must be equal in width or wider than the upper building; except with special foundation engineering. When the upper building is wider than the foundation it will cause irregularity. Narrowing or setback $(L3 + L1) / L \geq 0,2$.
  2.5	The supporting walls and columns must be stronger than the floors. When a supporting column of wall collapses, the whole building will fatally collapse. When a floor gets damaged or ductile deforms, the building still remains standing.
  2.6	When a large mass is required in a building, it should be placed as low as possible. An example is a large water storage or masoned chimney. Low placed water storage with hydrofoor is a better option, as well as a lightweight chimney.

2. General Recommendations for Buildings	Explanations of the Issues
  2.7	Heavy reinforced concrete floors give a large horizontal earthquake load. Lightweight timber floors give a small earthquake load. 50% of the variable floor load needs to be added for the calculation of the building strength.
  2.8	The stacking method of building elements does not provide adequate connections between walls and floors; the stability is based on the own mass or vertical load. In a seismic zone the connections between walls or columns and floors or beams need preferably to be moment resistant.
  2.9	A difference in stiffness of more than 20% per building floor needs to be avoided. The ground floor storey of many buildings often has large windows such as shops, while the first floor has wide window piers. In these cases the ground floor storey must be specifically reinforced.
  2.10	A floor plan which has many cross-walls on one side of the building, but none on the other side, can develop torsion during an earthquake. By construction portals and develop strong floor diaphragm the danger of torsion can be reduced.
  2.11	Heavy elements such as chimneys, high gable tops, parapets, protruding from or above a building, will cause high risks during the horizontal vibrations of an earthquake. Balconies will develop high additional loads on walls or columns during vertical earthquake vibrations.
  2.12	In a medium earthquake zone (PGA*g* $\geq$ 0,20) the use of unreinforced masonry (URM) is not allowed for new constructions of load bearing walls. Brick, or stone, or block masoned walls require framing with stress reinforcement around all openings and along all wall endings.

This series of pictures depicts simple building construction, but these general rules are applicable to most of the constructions, in particular the rules about mass and irregularity.

3. Housing Sites and Planning

Although the building site may not be free to choose in relation to existing land properties. It is not wise to just built anywhere in an earthquake area. Steep slopes are dangerous for heavy buildings. Since agricultural land is very scarce, the best use needs to be planned by the community.

3. Housing Sites and Planning			Explanations of the Issues
		3.1	Rock flows or fans cause during heavy rains fast build-up of stone sediments along any location of the fan. Only large retaining walls can redirect the fan flow. Houses should be built well aside and above the fan area. Above the houses tree plantations are necessary to block rock fall.
		3.2	Rock flows or fans will push into the river and block the rivers flow, causing flooding on the banks. Houses should not be on low banks above the fan, but on high banks, behind the fan. Additional gabion walls can be built or deep excavations to control the fan flow.
		3.3	Small rocks can come loose and roll down the mountain, especially during rain and wind. Stay away from rock fall areas and plant large amounts of trees to block small rocks. Large gabion walls or very deep ditches also can block rocks rolling down from the hill.
		3.4	The best agricultural use should be made from the available agricultural and flat land. This implies that housing should only be built together on the nearby non-agricultural land. Having farm buildings and housing using space on own agricultural land should be avoided.
		3.5	Earthquakes can cause large landslides blocking rivers, or glacier lake bursts. Low built houses should have water and flood resistant foundations and basements. With seasonal flooding building on columns avoids building damage. Building far away from flooding area is recommended.
		3.6	Rivulets from the mountain should not be diverted by the foundations of the buildings. Rainwater should not drop on the high side of the house but drained to the low side. The mountain water should be blocked by deep retention walls having a water resistant lining.

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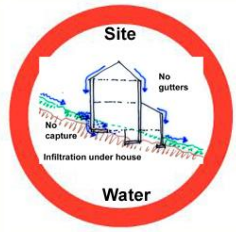
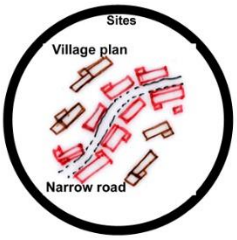
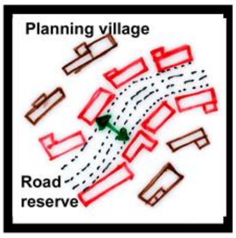
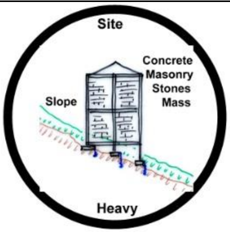
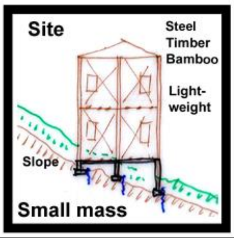
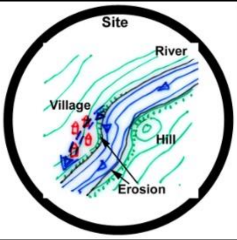
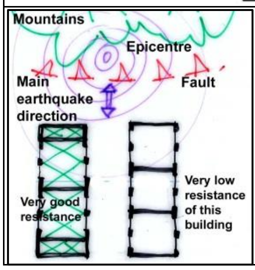
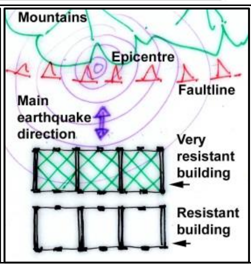
 	 	3.7	Rivulets from the mountain should not be diverted by the foundations of the buildings. Rainwater should not drop on the high side of the house but drained to the low side. The mountain water should be blocked by deep retention walls having a water resistant lining.
 	 	3.8	Toilets with septic tanks or soak away should not be placed on the high side above the house. The high side needs retaining wall and water drain. Soak away should be placed in absorbing soils and having tree and other plantations. Water may not accumulate behind retention walls.
 	 	3.9	Village planning needs to allow sufficient wide road reserves for parking and future development. As an alternative the new road can sometimes be constructed around the village. The old narrow roads than can become communal pedestrian areas.
 	 	3.10	Buildings with a large mass such as constructed with concrete floors, masonry and stone walls can slip with earthquakes. Buildings on slopes should have a small mass. This is possible with steel frame, timber and bamboo construction, using lightweight infill walls.
 	 	3.11	In mountain areas rivers can cause very strong and fast erosion of embankments. Villages should not be planned on soft banks facing the arriving river. Gabion wall constructions can contain excessive or seasonal river erosion.
 	 	3.12	In mountain areas rivers can cause very strong and fast erosion of high sediment embankments. Villages should not be planned on these high banks since these can collapse due to undermining by high water levels and fast currents. Gabion wall constructions can control erosion.
 	 	3. 13	When the distant location of a possible maximum earthquake is known, the support walls should be in-plane directed to that zone. In addition the floor and roof diaphragms should hold the walls out-of plane. With many windows, special strong zones can be constructed in the building to resist the shear forces.

4. Foundations on Slopes.

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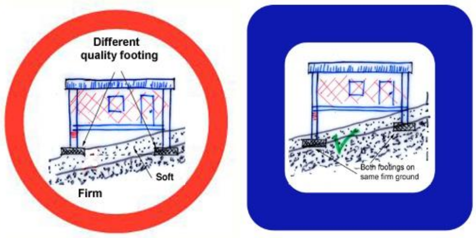
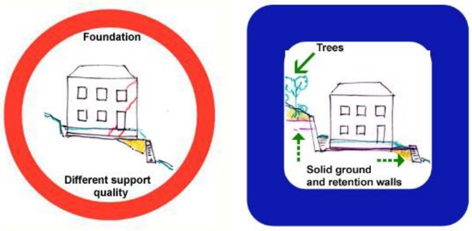
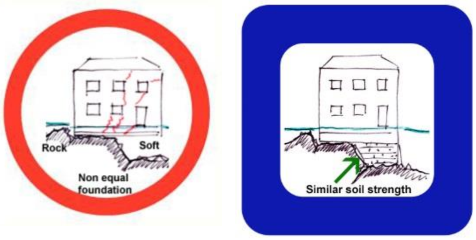
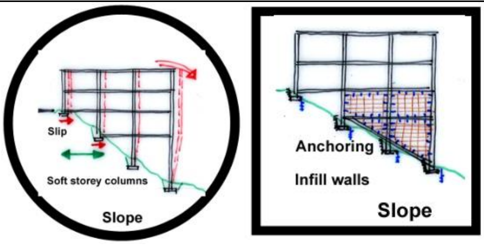
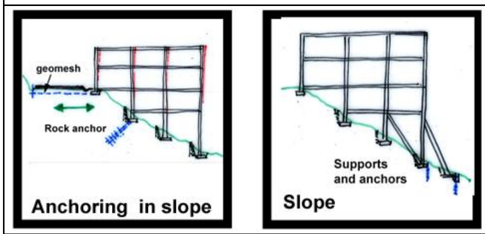
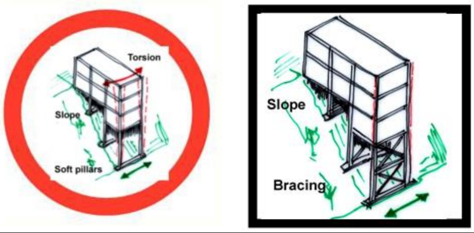
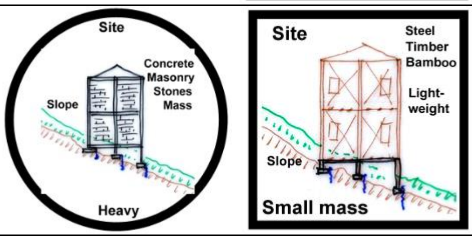
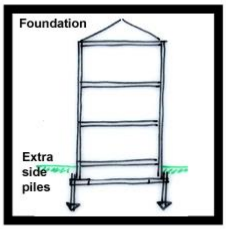
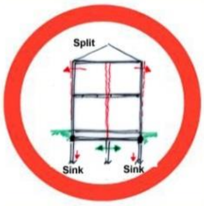
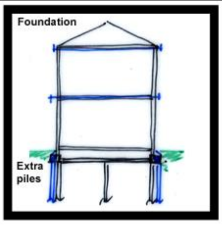
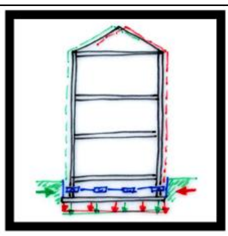
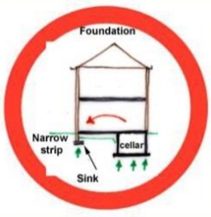
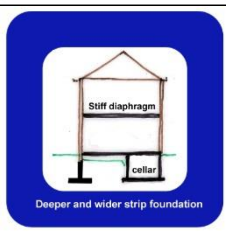
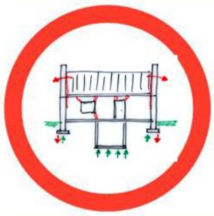
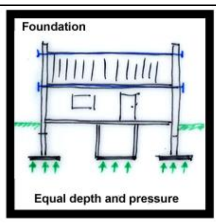
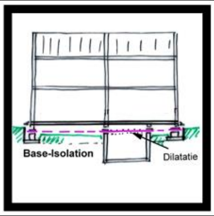
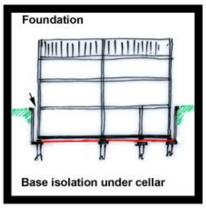
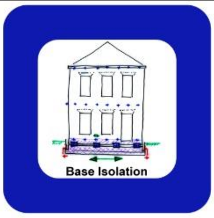
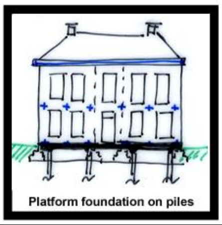
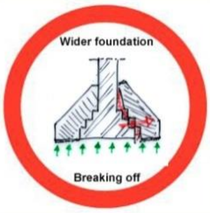
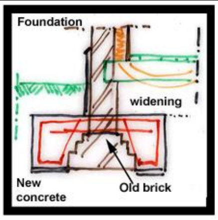
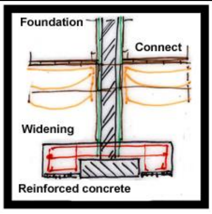
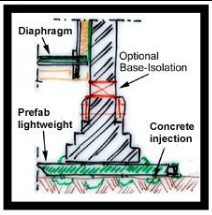
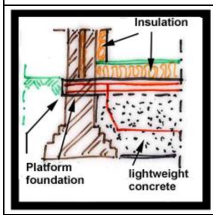
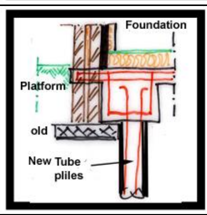
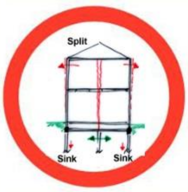
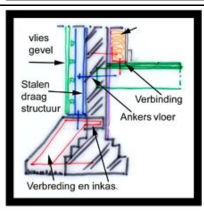
	4.1	All sides of the building should have the same quality of soil under the foundation. Different soil types will allow settlement. The foundation should be on firm soils or very firm ground. With additional vertical or horizontal earthquake loads there should be no settlement.
	4.2	Soil under the foundations should be kept stable with retaining walls. The lower retaining wall can be anchored below the building with geomesh. The upper slope needs to be stabilized with trees and water should be drained away; no water accumulation is allowed behind a retaining wall.
	4.2	With building sites having rock or very firm soils in one section and softer soils in another, the foundation needs to be made deeper to create a similar foundation quality under the entire building. The added foundation should be strengthened with gabion or stress reinforcements.
	4.3	On steep slopes with foundations on the soil and on columns, the flexibility of both sides should be the same; otherwise a partly soft storey will exist. This soft storey can lead to sliding off or down the hill of the non-flexural part. Filling in the area between the lower columns and pinning all the foundations is an option.
	4.4	Connecting the upper foundation with geomesh to the upper slope, for example under through a road, is another option. Constructing extra supporting diagonal beams and pinning or anchoring all the foundations is another option.
	4.5	With part of the foundation on high columns and another part directly on the soil, torsion will occur in the lower part during an earthquake which is parallel to the slope. The high columns need to be stiffly braced by infill walls or diagonals.
	4.6	Buildings with a large mass such as constructed with concrete floors, masonry and stone walls can easily slip with earthquakes. Buildings on slopes should have a small mass. This is possible with steel frame, timber and bamboo construction, using lightweight infill walls.

5. Foundations under Housing

Depending on the soil conditions several foundation options are feasible. Soft and medium soft soil however, will cause most problems in an earthquake area. While a building can stand stable on a soft or medium soft soil, it may settle under the influence of vertical or horizontal earthquake vibrations. Non stress reinforced foundations may split under these circumstances when floor diaphragms are not strong enough to hold the building together.

<table>
<tr><th>5. Foundations under Housing</th><th></th><th></th><th>Explanations of the Issues</th></tr>
<tr><td></td><td></td><td>5.1</td><td>Earthquake forces tend to rock the building if the building moves as one block. The rocking causes increased soil pressure under the sides of the building.
A wider foundation causes lower soil pressure and reduces the rocking effect.</td></tr>
<tr><td></td><td>
</td><td>5.2</td><td>Making wider foundations as an integral part of the whole foundation may be difficult. In soft and medium soft soils settlement may occur.
Piles along the sides of the building will increase the bearing capacity of the sides of the building, and will reduce rocking. (slow-press system)</td></tr>
<tr><td>
</td><td>
</td><td>5.3</td><td>With buildings which are already constructed in soft soil and on piles can suffer settlement of the extreme piles. This in turn can cause the building to split when floor diaphragms are not strong.
Adding more press piles and strengthening the floor diaphragms will avoid these problems.</td></tr>
<tr><td></td><td></td><td>5.4</td><td>The rocking is caused by the horizontal earthquake forces on the mass of the building.
Base-Isolation reduces strongly the horizontal forces on the building and with that the rocking.
Therefor it also reduces the increase in soil pressure under the sides of the building.</td></tr>
<tr><td>
</td><td>
</td><td>5.5</td><td>With a partial cellar under a building, the soil pressure under the cellar can be lower than under the wall foundation. Vertical and horizontal earthquake vibrations can make the building turn. Increasing the foundation width under the walls will reduce this effect and equalize soil pressure.</td></tr>
<tr><td></td><td>
</td><td>5.6</td><td>With unequal foundation depth and heavy outside walls, these walls can settle as compared to the cellar section. This may result in separation of the walls to the sides. Making the foundation under the walls deeper and larger will avoid this.
Stress anchors in floor and roof are recommended.</td></tr>
</table>

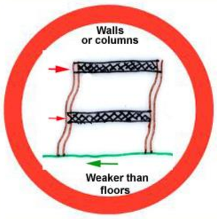
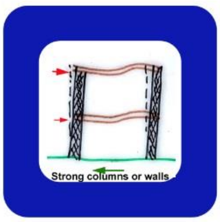
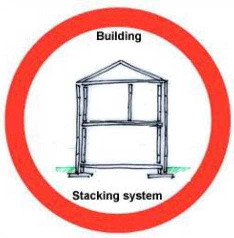
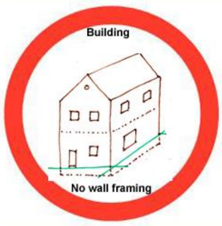
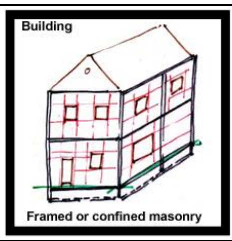
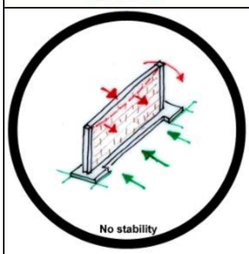
5. Foundations under Housing	Explanations of the Issues
  5.7	Under the entire building a Base-Isolation can be constructed through the cellar. Also the cellar can be extended, and under the entire building a platform foundation can be made or a Base-Isolation.
  5.8	With unreinforced masonry (URM) and old houses without lintels, cracking will occur over the openings, becoming larger in higher storeys. With Base-Isolation the horizontal loads on the construction will significantly reduce, reason why less reinforcement will be required.
  5.9	Vertical earthquake vibrations may cause side wall settlement and sideways movement at roof level. Under the entire building a through-going platform foundation can be made, increasing considerably the bearing surface. However, the entire building still needs full earthquake reinforcement.
  5.10	With older and heavier buildings on soft soil, piles can be slow-pressed through a new platform foundation. The platform is than closed over the piles and the building supported by the piles. On the piles a Base-Isolation can be constructed.
  5.11	Widening of a traditionally masoned foundation without reinforcement is not always possible. New reinforced concrete strips on each side need to connect at short intervals through the masonry foundation walls. This way the masonry will be carried by both sideway extensions.
  5.12	Thin load bearing inside walls need to be reinforced on both sides with glass fibre reinforced textile or another method. Pushing in-fill pallets under walls is an option. All the floors need to be made as strong and stiff diaphragms, and connected to all walls.
  5.13	Platform foundation is encased at short and regular intervals into the masonry bearing walls. It can be cast over lightweight concrete or over a new pile foundation. The piles are hydraulically pressed into the soft soil without any vibrations.
  5.14	By removing the outside façade of the building, mass is reduced. A lightweight steel frame can be placed on a new and wider outside foundation. This new reinforced concrete foundation is one-sided encased in the old masonry foundation.

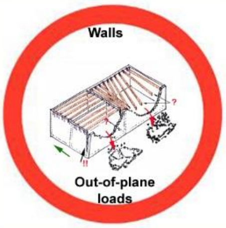
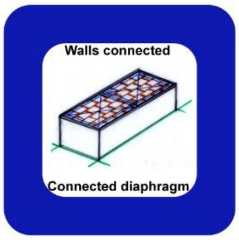
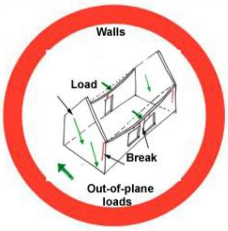
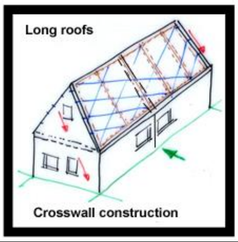
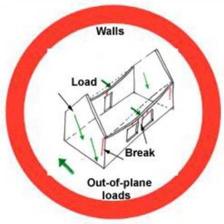
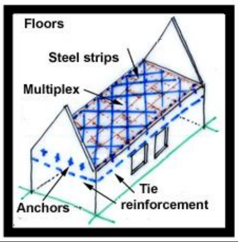
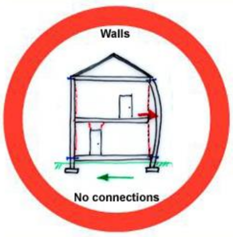
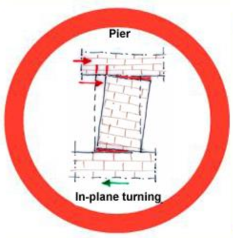
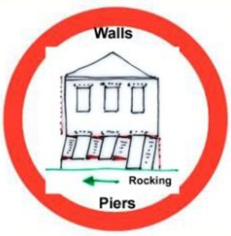
6. Supporting Walls or Columns

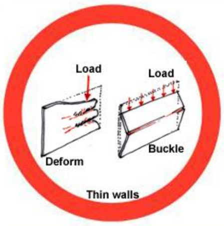
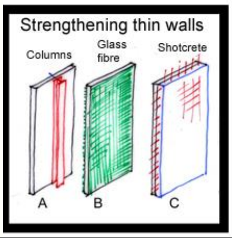
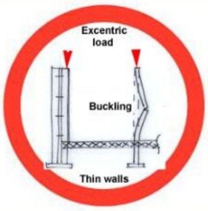
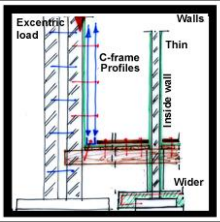
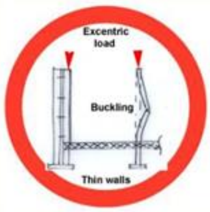
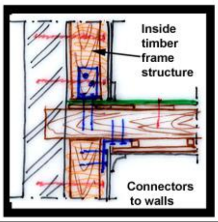
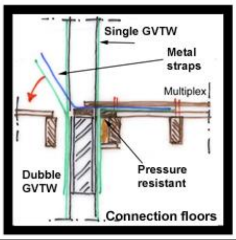
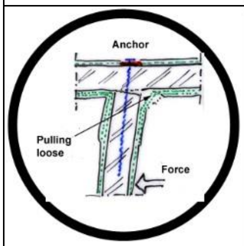
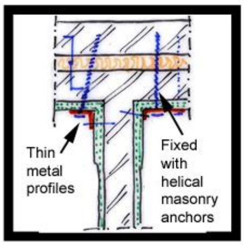
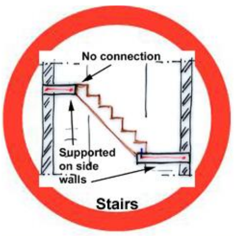
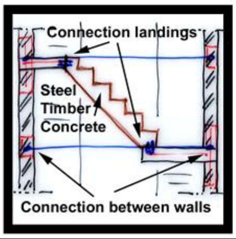
For seismic resistant buildings the structural walls or columns should be designed and analysed together with the floors. These elements work together in resisting the earthquake forces from below and the reaction forces from the building back to the foundation. Many houses are constructed by means of stacking small and large building elements, using masonry mortar. These constructions do not have moment resistant strength in their connections. Buildings like terraced houses and 'throughsun' houses therefore have little strength in the plane of their windows.

A number of picture sets are related to the thin (12 cm) inside bearing walls and thin cavity walls of The Netherlands, a typical feature of Dutch housing design. These thin unreinforced brick walls are not found in countries having tectonic earthquakes. Because of their weak earthquake performance different strengthening techniques are being developed for these walls.

With vertical vibrations the shear resistance between elements will reduce. With similar occurrence of the vertical and horizontal earthquake vibrations, and in combination with the stacking method of construction, the beams and floors can lose their support, causing the building to collapse. Walls of two storeys high which are not supported halfway have a great risk of buckling. The anchorage between the walls and the floors are therefore very important.

6. Supporting Walls or Columns	Explanations of the Issues
  6.1	The supporting walls and columns in a building must be stronger than the floors. When a supporting wall or column fails and collapses, the building will fatally collapse. When a floor deforms, rips or breaks, the building remains still standing.
  6.2	The stacking building system has its connections based on the building mass, and has little sliding resistance to large horizontal forces, especially not with vertical vibrations. In an earthquake area all connections must be resistant to sliding or shear, and preferably moment resistant.
  6.3	In a regional zone with moderate earthquakes (PGA*g* $\geq$ 0,2), unreinforced load bearing walls of masonry (URM) are not allowed. Masonry should be enclosed on all sides with stress reinforcement (confined with columns and beams) or, or reinforced throughout.
  6.4	Unreinforced masonry walls should not receive out-of-plane forces (perpendicular to the face of the wall); otherwise, during an earthquake they will topple over. A wall should be supported by cross walls and on the topside be connected to these cross walls.

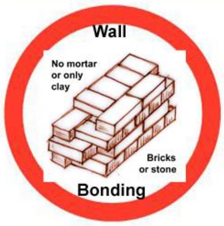
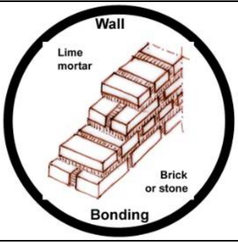
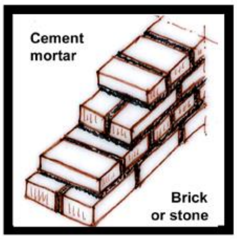
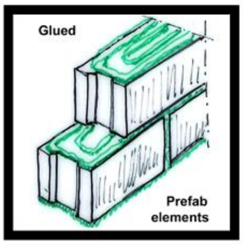
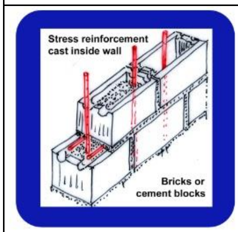
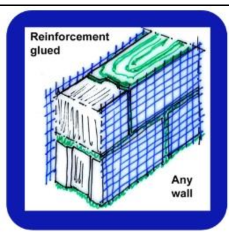
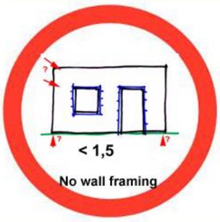
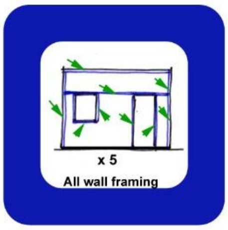
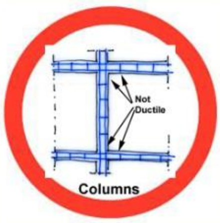
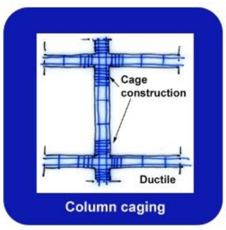
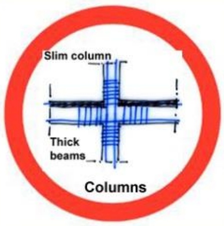
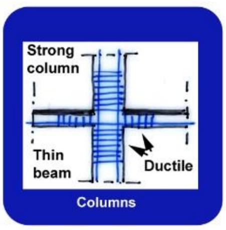
6. Supporting Walls or Columns		Explanations of the Issues
 	6.5	On every floor level the beams or concrete floors must be well connected on all sides to the walls This way the walls are retained on the upper side and all loads are diverted to other walls in-plane of the cross walls, and onwards to the foundations.
 	6.6	Wall that are out-of-plane and not supported will fail under perpendicular loads. Cracks will first be visible near lintels and openings. With the fully connected inside wall and strong wall plates, the out-of-plane forces are diverted to the end and middle cross walls.
 	6.7	Without the possibility of an additional inside wall, a strong and stiff floor diaphragm connecting all wall top sides is required. An existing attic floor can be strengthened with multiplex and screwed-on metal tension strips.
 	6.8	Supporting walls must be connected on every storey level with the timber or concrete floor diaphragms in both directions. The walls also need to be connected to the cross walls over their full height, but at least under and above window level, and at the wall plates.
 	6.9	With high widows and small piers, the first cracks will appear above the windows. In many houses no lintels exist, or these have short supports and are not continuous. By inserting stress reinforcement all around the building it is kept together.
 	6.10	Narrow piers alongside high windows will tend to rock with in-plane earthquake loads. By applying vertical stress reinforcement in the sides of these piers, and anchor this in the foundation and wall plate, the piers are seismically strengthened. Placing the bars in the centre of the pier is less effective.
 	6.11	The in-plane turning or rocking of high piers can cause failure of the thin load bearing walls. To strengthen these piers, vertical reinforcement should be applied along all sides, from the foundation to the wall plate. With large earthquake loads tis may not be adequate.

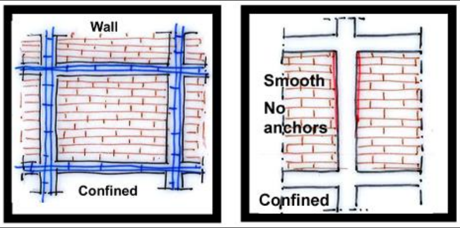
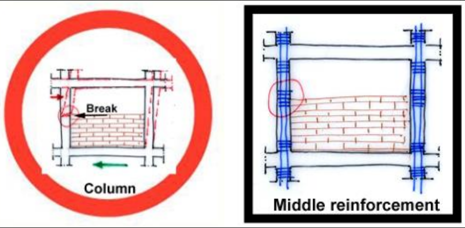
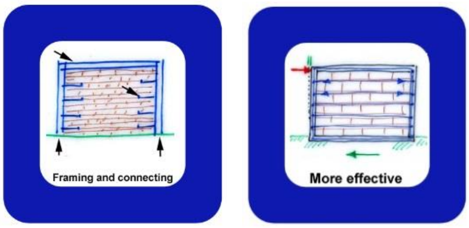
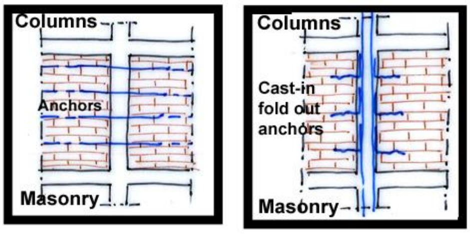
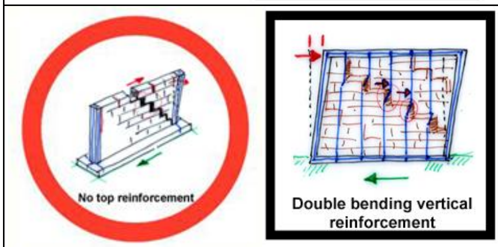
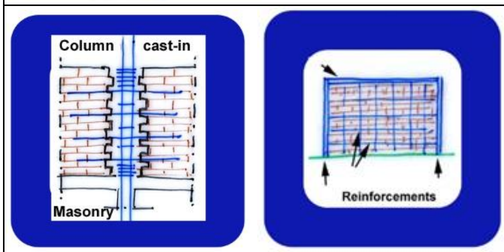
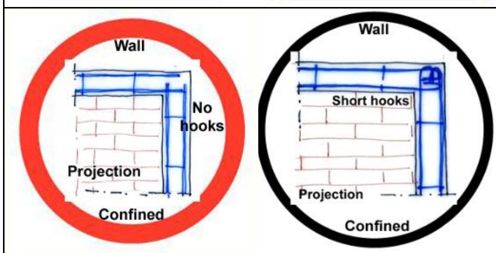
6. Supporting Walls or Columns			Explanations of the Issues
		6.12	Load bearing walls which are only 10-12 cm thick do not comply under earthquake regulations. These walls can easily buckle under eccentric loads or high loads. These walls can be reinforced with columns, glass or carbon fibre glued with epoxy on both sides, or shotcrete.
		6.13	Vertical or horizontal eccentric loads on thin walls must be avoided since this will easily cause buckling. Strengthening the inside of cavity walls can be with metal C-frames. Inside walls can be reinforced with glass fibre reinforcement on both sides, glued on with epoxy.
		6.14	Supporting walls can be internally strengthened with a full timber skeleton construction. The beams are connected at several points with (spiral, glued) anchors to the walls. The beams are also connected to strengthened floor diaphragms. This requires more space than metal C-frames.
		6.15	Thin load bearing inside walls must be reinforced on both sides against buckling. The glass fibre must be connected firmly to the timber or concrete floor diaphragms using glue. For concrete floor connections metal profiles are anchored in the inside corners.
		6.16	With vertical wall-to-wall connections using glass fibre textile, it must be avoided that the glass fibre can be pulled loose. Using light gauge corner plated, fixed with helical wall anchors, this will be avoided. These spiral anchors can additionally be glued.
		6.17	Staircases can be built as the stronger sections of buildings when they have fully masoned walls all around. The walls should not be able to separate, and the stairs elements themselves must have strong connections to their landings, and the landings firmly anchored into the walls.

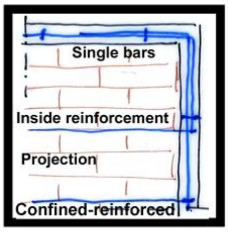
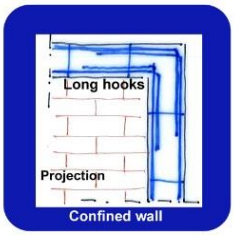
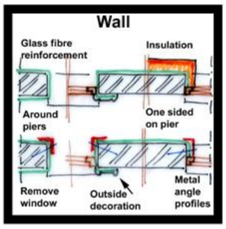
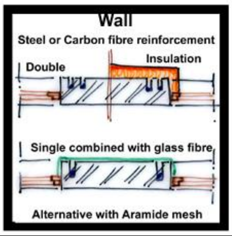
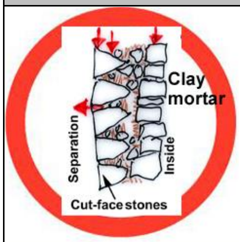
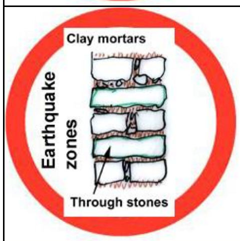
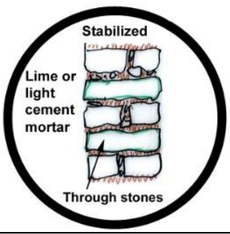
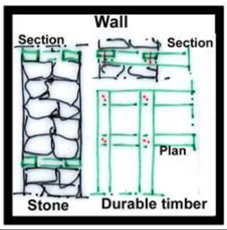
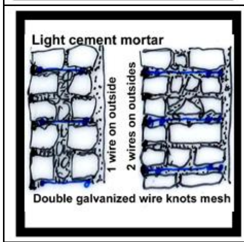
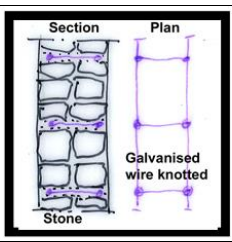
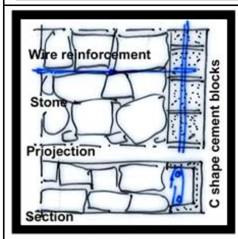
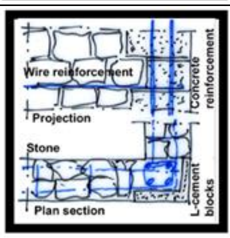
Columns are part of the supporting construction. Reinforced concrete columns are often used in housing and require special attention in respect of their reinforcement. In many non-engineered constructions and vernacular designs the reinforced columns are integrated with the masonry walls. In earthquake zones (PGA*g* > 0,2) the use of wall framing (confined) masonry is obligatory. The location of the reinforcement inside the concrete, however, is crucial for its ultimate strength.

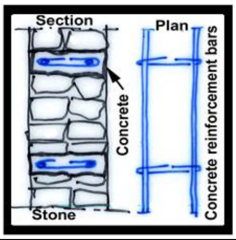
7. Confined and Reinforced Walls

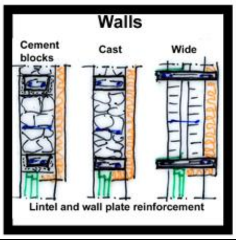
Confined walls commonly consist of a reinforced concrete framework of self-supporting columns and beams in which the masonry is filled in. These walls do usually not have anchorage to the columns. Reinforced masonry is connected to its framing and has horizontal and vertical reinforcement in the wall or applied from the outside on the wall. Steel construction is not included here.

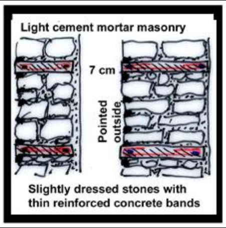
7. Confined and Reinforced Walls			Explanations of the Issues
		7.1	The quality of the bonding between the bricks, blocks or stones, contributes greatly to the strength of the building. Many small wall construction elements, without any bonding or only with clay, results in seismically the weakest buildings. No shear resistance.
		7.2	Cement mortar between bricks or stones greatly enhances the wall strength against small vibrations, but these when cannot be calculated as stress resistant. The application of glue will allow some stress resistance until the wall start cracking. Framed or confined walls can be constructed with these materials.
		7.3	Reinforcement bars, wires or mesh masoned into the brick, block or stone wall greatly enhances seismic resistance . Two sided glued on glass fibre mesh, Aramide or Carbon fiber improves the strength of walls in-plane and out-of-plane.
		7.4	A wall with only window and door frames is at the most 1.5 times as strong as a wall with only the openings. With along all the sides stress reinforcement is made and a through-going lintel and wall plate reinforcement, that wall becomes five times as strong as a non-reinforced wall.
		7.5	Column constructions need to be ductile in their maximum moment areas, where they are connected to the beams or floors. This is achieved by placing many stirrups. This will function as a cage to contain broken concrete and allows the construction to endure.
		7.6	Slim columns and thick floors (with beams) are not allowed. When the column fails the whole building will fatally collapse. The columns must be stronger than the floors. The maximum moment areas in both the columns and floors should be ductile.

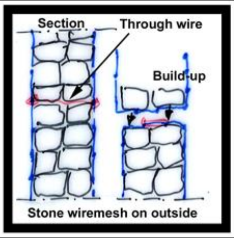
7. Confined and Reinforced Walls	Explanations of the Issues
 7.7	Reinforced concrete space frame of columns and beams without infill masonry is has soft storeys as compared to infill masonry walls. Concrete has some elastic deformation, but brick masonry almost none. With an earthquake this causes separation between columns and infill.
 7.8	When infill walls are only partly raised to allow for the placing of windows, earthquakes will cause large moment forces at the top of the infill wall. At this location extra stirrups or caging reinforcement must exist to create a ductile construction. Important in the design phase.
 7.9	When from the confining columns reinforcement is connected into the masonry, the strength of the construction will increase. With the horizontal reinforcement connecting from one confining column to the other it becomes a reinforced wall, with greater strength.
 7.10	Reinforced and framed walls can be made by wall anchors from the columns horizontally through the masonry. By casting anchors in the column they can be folded horizontal for the construction of the infill wall. The columns can be constructed with a groove to provide grip for the masonry.
 7.11	Framing of wall sections should be all around to be effective. Missing the top side can cause diagonal cracks with the displacement of the column. With a horizontal earthquake load in-plane on a wide wall, vertical wall reinforcement will bend and is therefore less effective than horizontally placed reinforcement.
 7.12	By first masoning the walls and casting the framing in between the masonry good bonding between framing and infill wall is achieved. Wall reinforcement which is bothe horizontal and vertical and connected on all sides to the framing columns and beans is the strongest option.
 7.13	The reinforcement of the wall framing should comply with common regulations about reinforced concrete construction. Concrete reinforcement bars should be bend around the corners. At building corners three beams come together causing crowding of steel which requires a fine concrete mixture.

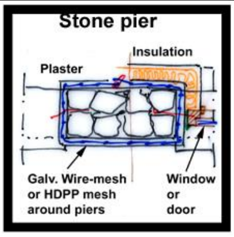
7. Confined and Reinforced Walls	Explanations of the Issues
  7.14	Depending on the building design, single sets of bars can be used for framing. In combination with horizontal wall reinforcement this can be an adequate solution. Concrete reinforcement bars should be bend around the corners for 2 times beam thickness.
  7.15	Wall reinforcement with epoxy glued on glass fibre textile around window piers, on one side of the piers, or in combination with angle irons. Wall reinforcement by steel barsl or aramide fibre cables, glued into grooves in the masonry walls. Many variations and combinations exist.
7. Stone construction	
 7.16 Clay soil mortar for laying stones do not provide shear force resistance and must be avoided in earthquake areas.	Cut-face stones are cut away behind their face and do not provide support inside the wall. By vertical vibrations the piramedical shapes of the cut-face stones will cause the outer wall face to bulge and come loose from the inside rubble wall. The outside cut-face wall will first collapse.
  7.17	The use square dressed stones and through-stones will improve the wall behaviour as compared to the cut-face stones. The wall must have many through-stones and joints must be thin. With lime or light cement mortar the wall strength will be improved.
 7.18 Durable hardwood has become very scarce in mountain areas. These walls are usually dry or clay masoned.	Timber reinforcement is possible for ground floor buildings only, but has poor bondage with stone and weak connections in the corners due to half timber overlaps. The timber construction does not allow vertical reinforcement and requires many cross walls.
  7.19	The use of galvanised wire in many layers gives a good force distribution. In light cement mortar it provides good bonding with the stones or brick. With light cement mortar the walls can be made less thick and therefore less heavy, which is an advantage in an earthquake area.
  7.20	The use of C- and L-shaped cement blocks as pre fabricated formwork for the reinforced concrete beams and columns is a suitable and fast construction method. Horizontal wire mesh reinforcement can be anchored into the columns and in the sides along window openings.

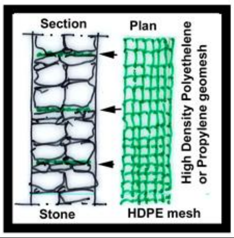
<table>
<tr><th>7. Confined and Reinforced Walls</th><th>Explanations of the Issues</th></tr>
<tr><td>


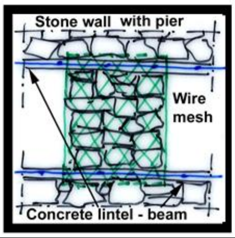


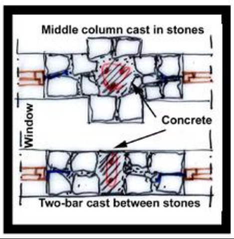
7.21
</td><td>Heavy stone walls require at regular intervals horizontal reinforcements. Beams, lintels and wall plates are minimal 7 cm thick. Casting the concrete in prefab cement blocks is fast and gives good architecture and protection. Wider beams can resist larger horizontal forces.</td></tr>
<tr><td>


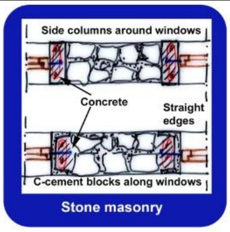
7.21
Clay soil mortar for laying stones do not provide shear force resistance and must be avoided in earthquake areas.
</td><td>Light lime or cement mortar needs to be used for the masonry of the dressed stones.
The minimum concrete thickness for covering the reinforcement all sides is 7 cm. It is better to apply more bands with thin bars than a few thick bands with double reinforcements.</td></tr>
<tr><td>


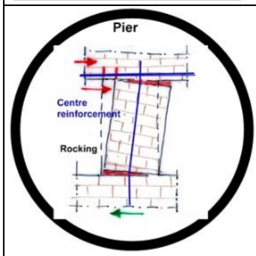


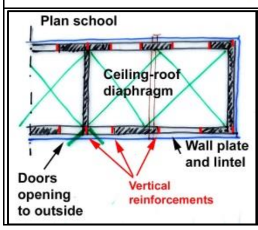
7.22
</td><td>Existing walls can be reinforced by stitching on both sides galvanised wiremesh or High Density Polypropelene mesh (HDPP), using galvanised wires through the wall for connections.
Window and door piers can be wrapped around after the temporary removing the frames.</td></tr>
<tr><td>


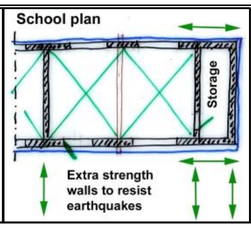


7.23
</td><td>With low quality (cement) mortar, the use of HDPP mesh in alternating layers provided stress reinforcement in two horizontal directions, also avoiding widening between wall faces.
With piers the mesh can be tied under window sill and around lintel or wall plate beams.</td></tr>
<tr><td>




7.24
</td><td>Vertical reinforcements cast inside stone walls and in the middle of piers provide reinforcement, but is less effective than reinforcements along the window sides. By using C-shaped cement blocks the building up of the window sides is fast and it provides instant formwork for the concrete.</td></tr>
<tr><td>


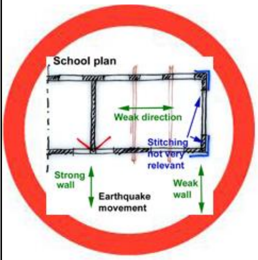
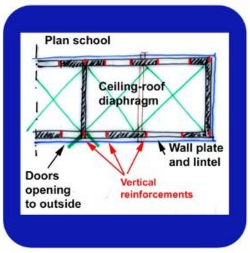
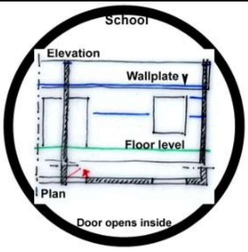
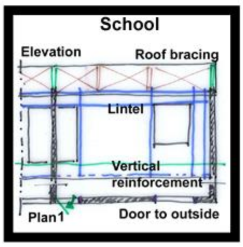
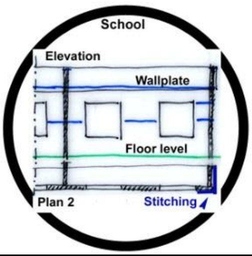
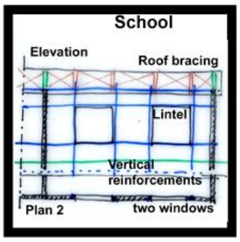
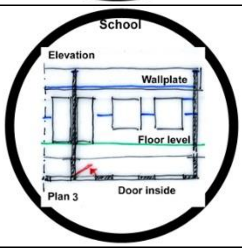
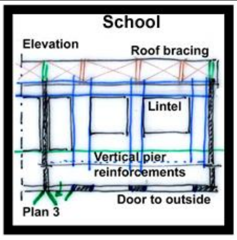
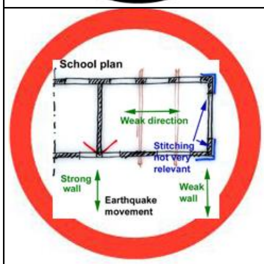
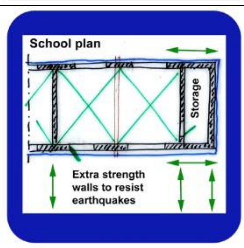
7.25
</td><td>Narrow piers alongside high windows will tend to rock with in-plane earthquake loads. Also with a single reinforcement in the centre.
By applying vertical stress reinforcement in the sides of these piers, and anchor this in the foundation and wall plate, the piers are seismically strengthened.</td></tr>
<tr><td>




7.26
</td><td>Stone building plans with only on two sides windows are weak in line with these windows. Vertical pier reinforcement is required here and attachement of the roof diaphram to the wall plate. Adding an extra end room with shear walls improves the overall design strength.</td></tr>
</table>

8. Small School Buildings

In mountain earthquake areas, primary school buildings are often built by village masons and on basis of on-the-job experience. A good design of these schools will be educative for other villagers to use the same technology for their private houses. In schools and meeting halls many children or people are gathered together, therefore these community buildings require a higher safety level than common one-family housing. Many elements explained above are applicable to small school buildings, but some general issues are summarized below.

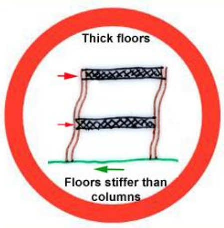
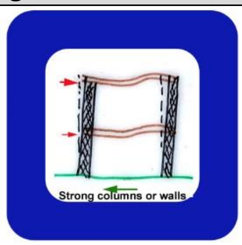
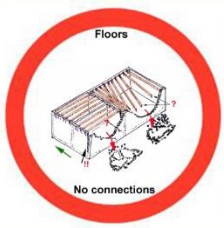
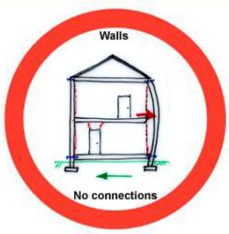
8. Small School Buildings	Explanations of the Issues
  8.1	Buildings with window openings on three sides can cause torsion. Solid walls are stronger in-plane than walls with large openings. Only a wall plate beam is not sufficient, also the lintel beam should be continued over all openings, and around the corners. The roof diaphragms need to be connected to all walls.
  8.2	The earthquake forces are best resisted by walls that receive the in-plane loads. At the lintel and ceiling level the room walls need to be all connected. Along all the openings, vertical reinforcement needs to connect the foundation with the wall plate level. Brick masoned gable tops need to be avoided.
  8.3	With several windows a window sill beam can be made under through these windows and around the corner. Stitching around the corners will tie perpendicular walls together. This is important. The stitching of piers that are less wide than high is less effective than vertical pier reinforcement.
  8.4	With many windows in a façade, the strength in-plane of that wall and the strength out-of-plane will be reduced. Narrow piers between the windows need to have vertical stress reinforcement. This reinforcement need to be anchored into the foundation and the wall plate.
  8.5	Buildings with many windows need in each direction stronger elements. In one direction these are the room separation walls. By constructing a storage room at both ends of a block of several class rooms, a strong end construction will be achieved in the other direction.

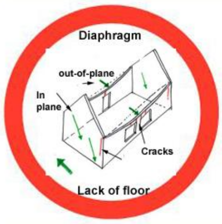
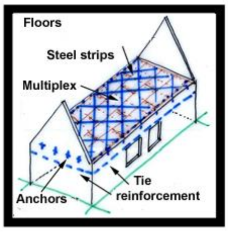
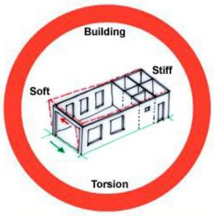
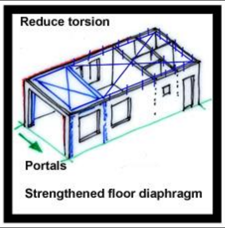
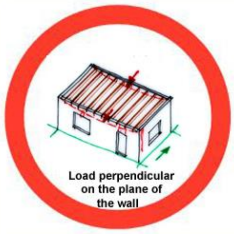
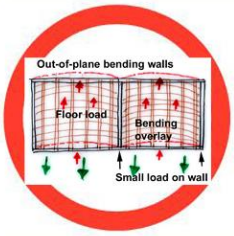
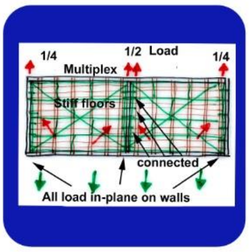
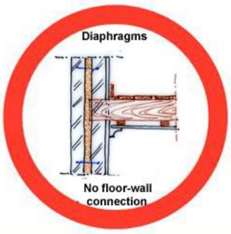
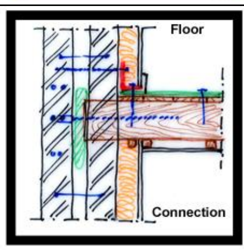
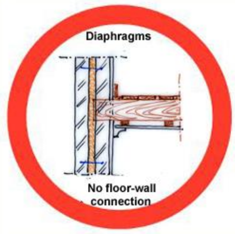
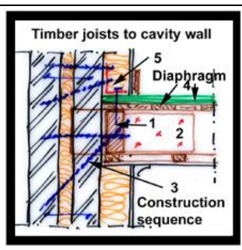
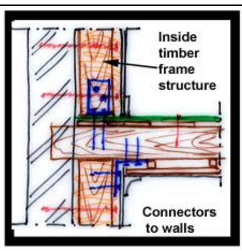
9. Floors and Diaphragms

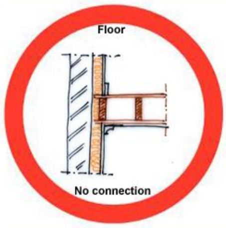
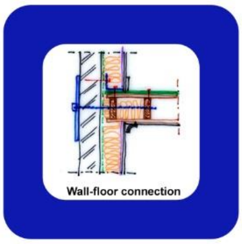
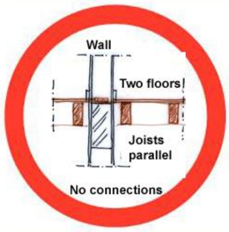
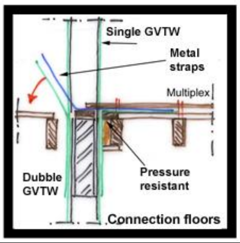
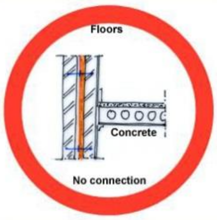
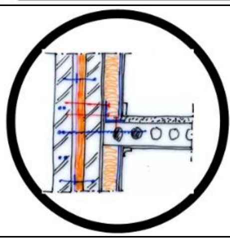
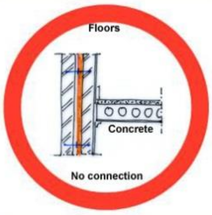
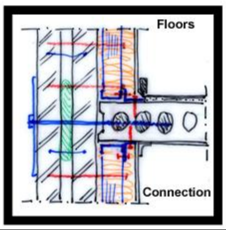
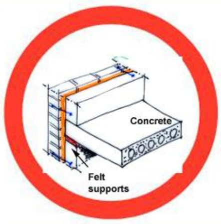
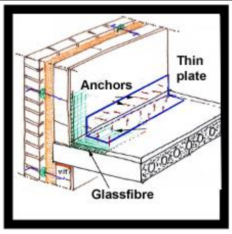
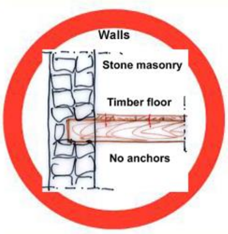
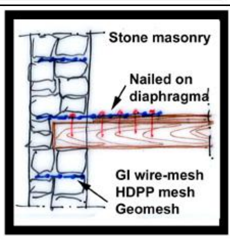
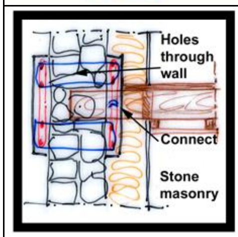
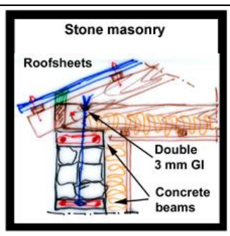
In housing several types of floors are common, whereas each type of floor has particular structural problems related to earthquake loads and strengthening solutions.

1. Timber joist floors with nailed planking. Joists have a typical section of 16.5 x 6.5 cm and are covered with 2.2 cm thick x 10-12 cm wide planking. In many cases only half of the joists are anchored on their extremes, while parallel anchoring to the walls is rare in old buildings.
2. Cast-in-situ concrete floors, minimal 12 cm thick exclusive the cement mortar finishing. These floors are horizontally very stiff, but cast on their supporting walls without anchoring. These floors have a large mass compared to other building components.
3. Prefabricated reinforced concrete hollow floor elements, or hollow brick masoned and prefabricated floor elements. These are supported on their extremes, but not on the side walls. These floors are stiff, but are perpendicular to the support direction not supported.
4. Prefabricated reinforced concrete floor elements with a top reinforcement in two orthogonal directions (T beams with infill elements). These floors are stiff but are often not supported parallel to the bearing direction.

To realize seismic strengthening the floors need to be stiffened in the horizontal direction and these diaphragms connected on all sides to the walls. This is only feasible when the supporting walls are strong enough to carry the earthquake loads and carry these back to the foundations. When floor diaphragms are not stiff enough, building loads will cause out-of-plane loads on the walls; in this case walls must have moment resistant connections with the floors. Therefore, it is not useful to separately addressing the stiffness of the floors, or the connections between floors and walls.

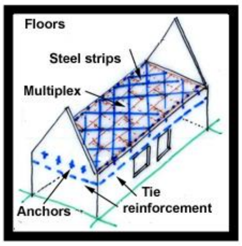
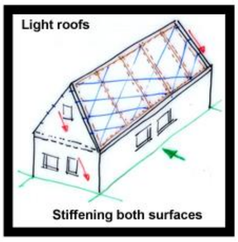
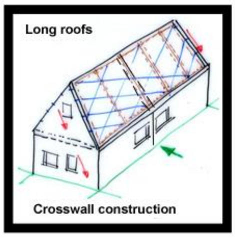
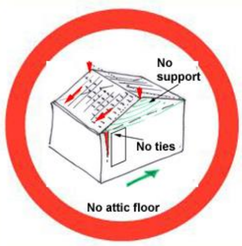
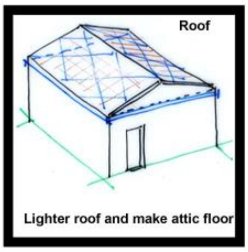
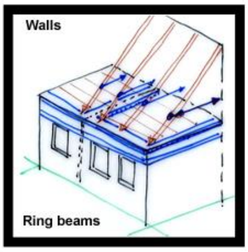
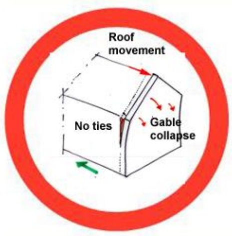
9. Floors and Diaphragms		Explanations of the Issues
 	9.1	Thick and vertically more stiff floors than the supporting columns and walls, can cause the column or wall to fail. When the wall or column fails the entire building will collapse. When a floor cracks, or deforms (ductile) the building will still remain standing.
 	9.2	On every floor level the horizontally stiff floor diaphragms must be connected to all the walls around the floor, also sideways to the walls being parallel to the beam direction. This way the top of the walls are held, and loads are transferred in-plane to the cross walls.
 	9.3	Floor diaphragms need to be fully connected at every floor level to the walls. The walls also must be connected to the floors, over their entire length. From the stiff floor diaphragm, the earthquake load is transferred in-plane to the two supporting side walls and to the foundation.

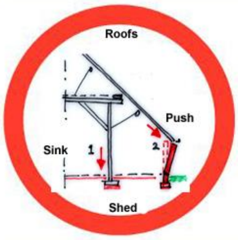
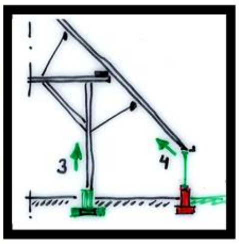
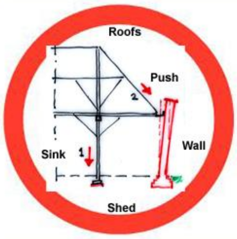
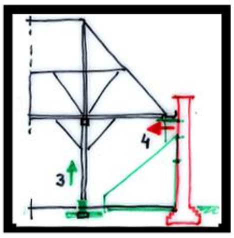
9. Floors and Diaphragms	Explanations of the Issues
  9.4	Without a stiff and strong floor which holds the upper sides, the free walls will break. Multiplex diaphragms will transfer the earthquake load to the gable walls and foundation. Diagonal metal strips screwed into the multiplex and floor joists will improve the tension strength.
  9.5	A building plan which has on one side many walls and cross walls and on the other side openings will cause torsion during an earthquake. By making the floor a stiff and strong diaphragm connected to the walls, the danger of torsion in the building will be reduced.
  9.6	Floor beams are over the shortest span. Overlay flooring with narrow timber board does not provide stiff diaphragm. Thick multiplex will transfer the out-of-plane forces from the one wall to in-plane forces in the two sidewalls. These side walls need to be strengthened with stress reinforcement against rocking.
  9.7	With making the two diaphragms stiff and connecting them both to all walls, the loads out-of-plane will be transported as in-plane to the side walls. The in-between wall will now receive half of the total building load instead of only its own mass. Wall strength and the foundations of the in-between wall must be adequate.
  9.8	Cavity wall. Timber floor joists are often only supported on the inside leaf without anchors. Some have only small anchors. The floor diaphragm is being strengthened with screwed on multiplex, and all joists need to be connected on both ends to both leafs of the cavity wall.
  9.9	By opening the timber floor and fixing blocks in between the joists (1+2), these blocks can be attached by drilling spiral anchors in from above (3). After making the stiff diaphragms (4), the floor can further be attached to the cavity wall with sheet metal angle irons (5). Then insulation.
  9.10	A supporting wall with many opening scan be strengthened with an inside timber skeleton frame construction. This is connected over the full height to the masonry with helical anchors (glued). The vertical timbers are connected with sections of corner profiles to the diaphragm.

9. Floors and Diaphragms		Explanations of the Issues
 	9.11	Example with solid one-brick wall. The floor joists parallel to the wall and the floor diaphragm must be fully connected to the walls. With any type of wall anchor it is important that sufficient layers of brickwork are anchored and not just a few bricks; few can be pulled out.
 	9.12	Timber floor diaphragms on the same floor must be connected through the inside supporting wall to make a continued diaphragm. This can be done by the application of steel tension bands through the wall and fixing these over the glass fibre mesh and on the plywood diaphragms.
 	9.13	Concrete floors are much heavier than timber floors. Therefore the connections should be stronger. Cavity walls must be able to receive these large loads and carry them to the foundation. Similar connections as for timber floors are not suitable here.
 	9.14	Weak cavity walls or walls with many openings can be reinforced on the inside with timber frames or C-steel frames placed over the entire height and connected to the wall with helical anchors. The horizontal frames are connected to the floor and ceiling. Inside is to be insulated.
 	9.15	The supported end sides of prefab concrete floors do not have a shear resistant structure because of the felt interface. This connection can be improved by pasting glass fiber on floor and wall and securing this in the corner with a 2 mm metal plate and spiral wall anchors.
 	9.16	All floors and roofs need to be connected to horizontally stiff floor diaphragms. New walls can be masoned with Galvanised wire-mesh, geomesh or other type of HD Polypropylene mesh. Using a wider mesh and nailing this on the floor creates a good connection.
 	9.17	Making under and above the floor holes in the wall and casting a reinforced concrete beam in and outside the wall allows the beams to connect to the inside reinforcement bars. Cast in GI wires can connect timber beams.

10. Roofs and Roof Diaphragms

In The Netherlands architecture, the housing commonly has roofs with a timber support structure. The roofing tiles are structurally small loose pieces. Timber is far more elastic than masonry and the roof constructions far more flexible; during wind load these roofs will slightly deform, while old and dried out roof constructions will deform more than newly built. Masoned gable tops will crack first when pressured out-of-plane by the flexible roof construction, and because they are located high in the building. By making the inclined roofs stiff diaphragms, out-of-plane loads on structural walls can be reduced or avoided. Some of the picture signs are equally relevant for walls and diaphragms, indicating the mutual relationship between the building, and that these elements influence one and another. The building should be assessed as an integral unit.

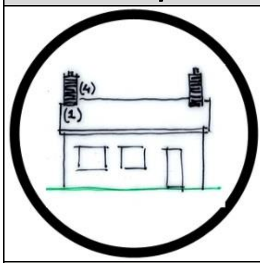
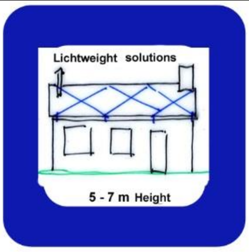
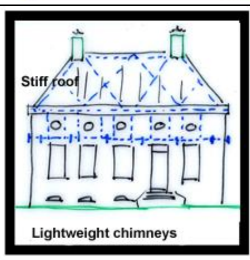
<table>
<tr><th colspan="3">10. Roofs and Roof Diaphragms</th><th>Explanations of the Issues</th></tr>
<tr><td>
</td><td>
</td><td>10.1</td><td>The load from the roof can push the outside walls of the building more outside.
By making the floor diaphragm of the attic horizontally stiff and strongly connected to the wall plates and cross walls, horizontal forces will be diverted to these cross walls and in-plane by these cross walls to the foundation.</td></tr>
<tr><td>
</td><td>
</td><td>10.2</td><td>By making both roof surfaces stiff and strong, forces from the roof load will also be directed to the end walls. Light roofs are preferred.
With short roofs this works better than with long roofs. Diagonal metal ties screwed to all trusses improve the stiffness and the transfer of forces.</td></tr>
<tr><td>
</td><td>
</td><td>10.3</td><td>With buildings without a ceiling or attic floor, tension bars need to be constructed from wall plate to wall plate, or a stiff attic floor needs to be constructed. The roof can be made lighter by replacing the roofing tiles with profiled metal sheets or integrated PV foils on stiff thermal insulation panels.</td></tr>
<tr><td>
</td><td>
</td><td>10.4</td><td>When a floor diaphragm cannot be made the horizontal force out-of-plane need to be resisted by ring beams and by tension bars in the roof truss itself.
The continued lintel and wall plate can be made wider and firmly connected to the lintel and wall plates in the cross walls.</td></tr>
<tr><td>
</td><td>
</td><td>10.5</td><td>In baked brick masoned gables will receive extra earthquake force because of their high position and can break off. Connecting it strongly to a stiff roof surface is possible. Best is to replace the gable with lightweight and flexible timber or panel materials.</td></tr>
</table>

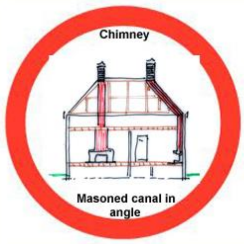
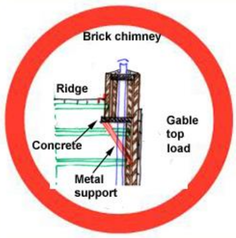
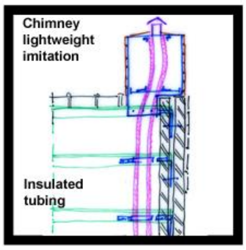
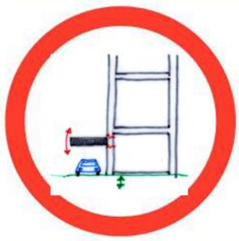
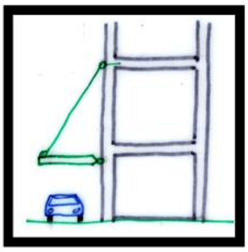
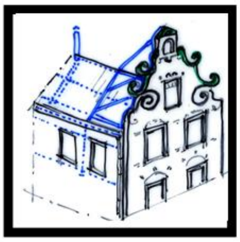
10. Roofs and Roof Diaphragms		Explanations of the Issues
 	10.6	The large timber frame constructions of old farm buildings will settle about 1 mm per year, due to small foundations. This will push the walls to the outside. By widening and lifting the foundations the roof can be repositioned in their original position. Side walls can be disconnected and shortened with timber paneling.
 	10.7	In the length direction of the large timber frame sheds, the flexible roof will push the heavy head wall outside. After placing the foundations of the timber trusses higher, the roof must remain seismically disconnected from the heavy wall and the walls separately supported with cross walls on their own foundation.

The last two examples show that the movement of the large shed roof is caused by the settlement of the foundation. Settlement of shallow foundations can be accelerated by heavy farm equipment and earthquake vibrations. In such a case it is not useful to only strengthen the wall, or its foundation, but the entire construction needs to be reviewed.

11. Chimneys and Protruding Elements.

Masonry chimneys have a large mass, are located in the top of the building and are in most cases just balancing on their basis. The chimney base is interrupted by lead slabs to prevent leakage, causing lack of structural continuity. Chimneys fixed on a flexible timber roof are subject to strong movements and can drop off their basis, while the masoned channels below can easily crack. Protruding building extensions such as gable tops, balconies and decorations are also a risk, while some can cause problems to the support structure of the building.

11. Chimneys and Protruding Elements		Explanations of the Issues
 	11.1	A masoned chimney has a large mass. A timber roof is flexible, also with terraced buildings. With a height up to 7 m the height : width relation should not be more than 4:1. With > 4/1 the masonry must be changed to a lightweight insulated pipe or a special featherweight chimney model.
 	11.2	With masoned chimneys on an old timber roof above the 10m the height : width relation should not be more than 3:1. With > 3/1 the masonry must be changed to a lightweight insulated pipe or a special featherweight chimney model. Also the high timber roof should be strengthened and stiffened.

11. Chimneys and Protruding Elements			Explanations of the Issues
		11.3	All chimney masoned channels need to be fully removed and exchanged for lightweight insulated stainless steel piping. Vertical free standing channels are usually leaking and also need to be replaced. When vertical chimneys are part of the support wall they need special assessment.
		11.4	A masoned chimney, on an extended shelve, will during an earthquake cause moment forces in the already vulnerable gable top. This design must be replaced with a lightweight design and insulated stainless steel pipe. The same applies for chimneys constructed on the timber truss construction of the roof.
		11.5	Heavy protruding elements on a building cause falling off risks during earthquakes and need to be avoided. These include chimneys, gable tops, parapets, cantilevered balconies and ornaments. Vertical earthquake vibrations increase the bracing moments of elements protruding from walls and columns such as balconies.
		11.6	A heavy awning attached to a column will cause large additional forces on that column. Combined with the additional building load from the earthquake those columns can collapse, causing the building to collapse. Suspending a lightweight design from the higher floor level is much safer.
		11.7	Building elements that do not have an aesthetic function can be removed or redesigned. High parapets and gable tops need to be fixed to the strengthened roof. Heavy plaster and protruding ornaments can be replaced with durable identical lightweight glass fibre copies.
		11.8	Small or large towers in the gable, overhanging the public area should be avoided. The same applies to large and heavy advertisements boards and signs. When these are not designed to be earthquake resistant they should be removed or replaced with lightweight copies.

The actual structural measurement needed in a building depends on the expected strength of the earthquake. The detailing of the construction determines its performance during an earthquake.

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