Chapter 1 Alphabetic listing of terminology and abbreviations related to the induced earthquakes

in Groningen from Accelerometer to Zechstein.

Abstract:
Explanation of terminology, concepts, and abbreviations, related to the Groningen Induced Earthquakes that occurred since 2000 and culminated in 2012, with comments and sketches.

Key words:
Accelerometer, aspect ratio, Base-isolation, behaviour factor, BENG, biogas, borehole, building code, building typology, capacity design method, compaction, cracks, cultural heritage, damage state, diaphragm, dilatation, ductile, earthquake, elasticity, epicenter, EVS, flexibility, foundations, fracture surface, fragility curve, groundwater, HAS, high risk, hypocenter, importance factor, IMG, importance factor, induced earthquake, inherent deficiency, KNMI, lateral force, LFRS, liquefaction, main structure, magnitude, maximum earthquake, measurement network, moment strength, NAM, natural gas, NLTHA, NPR, non-structural, peat, permeability, PGA, platform foundation, period, porosity, props, renovate, return time, reservoir, response spectrum, Richter, risk, RVS, safe, salt layer, seismic, seismogram, setting, shale gas, SodM, subsidence, sustainable, strong structural glass panel, sustainable, struts, test house, TCCB, tilt meter, trigger aspect, unsafe, value control, vibration meter, vulnerability, Zechstein.

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April 2023

Inhoud

Introduction.

This Chapter 1 is an Alphabetical explanation cover concepts and abbreviations of the book: “Repair and Strengthening of Brick Houses after the 2000-2015 Groningen Earthquakes”. It also gives an overview and insight about the several aspects of these induced earthquakes. It all started hundreds of millions of years ago with a (Zechstein) salt layer covering the Carboniferous layer, locking up the methane gas that were emitted form that layer. With the current gas exploitation came the small earthquakes affecting tens of thousands of houses in the province of Groningen.

This book or series of 12 documents with technical advice was developed for secondary vocational education in Groningen from the end of 2013-2015, to educate young professionals and building inspectors. The earthquake problem and seismic repair was unknown among the building sector in The Netherlands. A large demand for earthquake educated craftsmen was expected. The education of many staff for the retrofitting of houses was imminent. It had to be prevented that there would be casualties among the population because of the continued small earthquakes such as the 16 August 2012 Huizinge earthquake with a PGAg 0.085 (Richter 3.6) and many houses needed reinforcements. Theoretically larger and more frequent shocks would eventually occur if the natural gas would be continuously and centrally extracted in large quantities.

Structural repair costs have mounted rapidly since 2012. The estimated cost of seismic strengthening for the province's more than 250,000 buildings, according to exaggerated NPR9998:2015 (calculated in the end of 2013 with a PGAg 0.42), would be in the tens of billions of euros[1]. Efficient repair, strengthening, renovation and new construction methods were necessary, fitting within the Dutch building tradition. Training of many craftsmen from low to high had become an urgent matter.

In 2015, a major difference arose between the concept of 'safety' of the NPR9998:2015 guideline (Eurocode 8 = 'near-collapse') and the wishes of the population on the other side ('safe and fear-free living'). This document outlines in a dozen chapters that technical problems can be prevented, removed, or resolved in various ways. Economic, political, emotional, financial, and personal reasons played a significant role in deciding which methods would be used, where and when[2].

In early 2023 the Parliamentary Investigative Committee Earthquakes Groningen presented its 2000 pages report about the (mis)management of the gas exploitation in respect of the population of Groningen, from whom many felt as being unjust treated by the NAM and subsequent organizations that dealt with the repair and strengthening of the houses and the compensations they received.

That Parliamentary Committee and report did not deal with the technical aspects of the retrofitting, nor the misleading PGA or Richter estimates that were presented in 2014 to the population. Although they received timely the Dutch version of this information, it was not acted upon.

The first chapter of this book with the A-Z list of explanations, indicates a few of the aspects related to the PGA mismanagement and consequences, but the 11 other chapters deal with the practical and technical issues about cause of (earthquake) damage, strengthening and repair.

Ing. Sjoerd Nienhuys, April 2023

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[1] This PGA-value was already end 2013 not realistic and arbitrarily defined at 5X the Huizinge earthquake.
[2] The reinforcements were planned to take place from the epicentre outwards, public buildings first.

From Accelerometer to Zechstein

Some definitions were taken from www.Namplatform.nl or www.Wikipedia.nl , which in turn quote other sources and possibly explain them. However, that information is in Dutch. In some cases, background information is given when the context with the Groningen-induced earthquakes is required. With Internet search, the words are usually explained in a tectonic context; however, there are significant differences with induced earthquakes.

Most explanations, some drawings or photographs are taken from other sources. This avoids that the reader must search in these many other sources. Some terminology which is related to the Groningen situation has been expanded or simplified for clarity. Several specific definitions {with number code} have been taken from the National Practice Guideline[3], NPR9998:2015.

The first test buildings were reinforced according to the first greatly exaggerated seismic map of the NPR9998:2014 with PGAg 0.42. The second seismic NPR-map was published in 2015 with PGAg 0.36 for the epicenter. Later, in 2017, a more comprehensive NPR9998:2017 had again a new seismic map with a maximum PGAg 0.19. In a later version of the map of the NPR9998:2018 the PGAg became 0.13. In this 2018 version the increment of the realistic maximum earthquake was at least 50%. As from 2020 the NPR-annex map was replaced by a separate KNMI-Home Webtool[4] with the latest PGA-values per exact location, including the influence of the upper 30 m of soil layers. In 2021 the maximum PGAg of 0.11 was indicated with a return period of 475 years, still about 50% higher than the reality. In 2022, the 475 years were reduced to only 95 years because the gas exploitation would be finished within 10-20 years. The frequent changes of the maximum PGA were not properly explained[5] to the population and have led to a lot of mistrust and misunderstanding.[6]

Scientists worldwide have limited knowledge about induced earthquakes that originate at a depth of only 3 km, for example due to mining, gas extraction or fracking. Instead, they use the calculation methods, extrapolations and uncertainties of much deeper tectonic earthquakes (10-80 km deep) that are the result of the continental drift of the earth's crust. That is very different from compaction in a relatively thin layer of sandstone; hence the weird 2013 PGA-calculations of the KNMI.

The large difference between the reality and the 'theoretical future (scientific) projections' has led to great unease and uncertainty among the population of Groningen, who in the meantime had to deal with all sorts of building damage and strong value devaluation of their homes. The 2015-2018 approach of cosmetic repair of the walls or strengthening to prevent future earthquake damage has not sufficiently calmed people down.

The need to minimize energy consumption and CO_2-emissions is becoming increasingly important in connection with the climate, but also circular construction. Thermal insulation must be improved and the use of materials in the built environment must be minimized through reuse and recycling. Structural reinforcing a building also requires making it more durable and sustainable.

For a sustainable retrofitting a good understanding of the existing situation is essential.

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[3] Free version to be downloaded from: https://www.nen.nl/npr-9998-2020-nl-278147

[4] KNMI website with actual values: https://seismischekrachten.nen.nl/map.php

[5] In reality the extreme high PGA could not be explained at all, as this was the result of theoretical calculations based on tectonic models, extrapolated in time and force, and additionally increased because of the so-called uncertainties. The latter was an argument to continue extensive research (financed by the NAM).

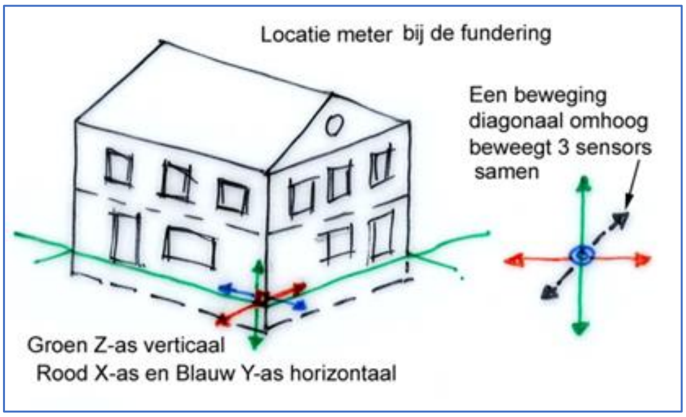
[6] The reducing of the PGA on the later NPR-maps was interpreted by some public action groups as a means of the NAM to minimise the repair or strengthening of the buildings, thus economizing expenditures. The issue here was that the NAM only wanted to 'avoid collapse' as per requirement of the NPR (tectonic earthquakes), while the population did not want foundation settlement or cracks in their houses.

Accelerometer, Seismometer

An accelerometer, seismometer, or vibration meter is an electronic measuring device that can register and measure acceleration. It is used, among other things, in seismology to measure the vibrations of the earth in the area close to the epicentre. The electronic vibration meters indicate the movement of the ground or building in three directions. Horizontal in the x direction; horizontally perpendicular to it in the Y direction, and vertically in the Z direction.

Locatie meter bij de fundering = Location of meter near the foundation.
Een beweging diagonaal omhoog beweegt 3 sensors samen = A diagonal movement upwards, moves 3 sensors together
Groen Z-as verticaal = Green Z-vector vertical
Rood X-as en Blauw Y-as horizontaal = Red X-vector and Blue Y-vector horizontal

Figure 1. An oblique movement in a horizontal plane gives a deflection in the x and y coordinates. An oblique movement upwards therefore gives a deflection in all three x, y and z coordinates. The degree of deflection is also determined by the direction of the earthquake, the mass and height of the building, the location of the vibration meter and the elastic structure of the building.

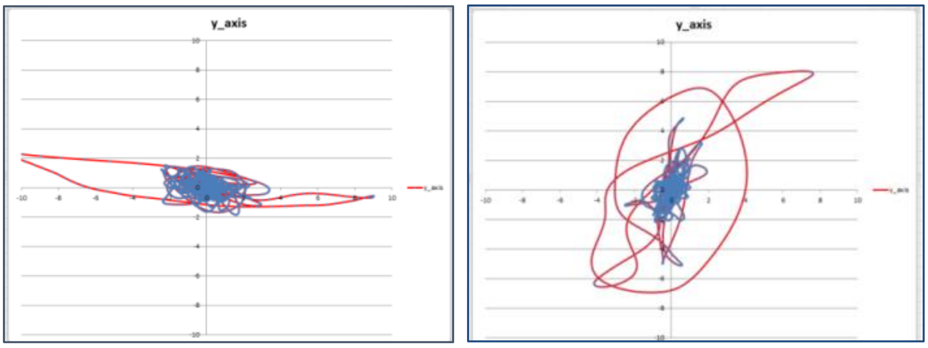


A vibration meter that is located at the top of the free soil will only display the pulses of the vibrations caused by the (elastic) subsoil. A vibration meter in a building will also display the building response and continue to vibrate for longer.

The coloured graph below represents a vibration from a meter bolted to a foundation. After the high peak (red), the continuing smaller vibrations (blue) are the movements of the building that return to the foundation (response) through the elasticity of the building.

When a vibration meter is placed at the top of a high and elastic building, it will register the long reverberation or swaying of that high building. Vibration meters in both the foundation and the top can then be compared with each other to evaluate the elastic behaviour of the building.

Figures 2. Left: a single back-and-forth pulse from a foundation vibration meter. Right: a more complex movement of a building that also gives a different elastic (response) back to the foundation.



A building on concrete piles, or with concrete foundation beams connected to each other, will vibrate much longer than a building which has been constructed on undisturbed soil and with a masonry foundation. A masonry with cracks will absorb the vibration to some extent.

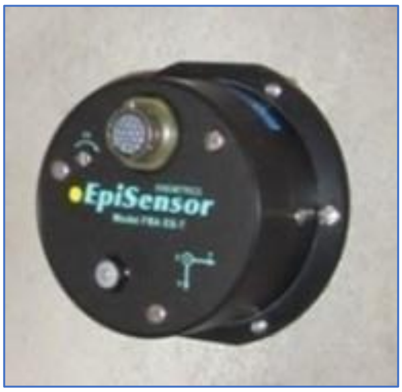
Buildings with stronger foundations such as reinforced concrete slab-beam structures can sustain more damage at the top of the building (chimneys).

Vibration frequency affects the level of damage to a brick building; a low frequency (< 10 mm/sec.) has virtually no influence. A high frequency with a vibration strength of > 30 mm/second however, has a major impact on the building and often results in damage, in combination with other factors. The vibration frequency of superficial (3 km) induced tremors is quite high, such as in Groningen.

The reverberation of the building influences the foundation. If the foundation is too weak or not wide enough, this can lead to settlement. The interaction here is complex, especially for foundations on firm or undisturbed soil and on elastic soil types. The SBR vibration guideline from 2017 does provide a good indication about what buildings built after 1980 should be able to withstand without any damage, but that does not apply to pre-1945 construction.

An accelerometer is also called a vibration sensor. See also 'Seismometer'. To accurately capture building vibrations, the accelerometer must have a high Hertz value (500 Hz). Simple meters often have a 100 Hz registration that only registers a position every 1/100th of a second. Accelerometers of 500 Hz are used to analyse the short duration induced earthquakes in different directions.

Figure 3. In the province of Groningen, hundreds of accelerometers have been attached to the foundations of buildings since 2014, which send signals of the three types of vibration (X and Y = 2 horizontally perpendicular to each other and 1 vertically = P) that are transmitted via a network with a central measurement room are connected.



Each quake is mapped precisely with direction and strength. The accelerometer measures the three PGAs (two horizontal X and Y and one vertical Z) as the most important values for determining earthquake strength[7]. They only register when several meters go off at the same time, so not when someone slams the door in a home. To prevent a vibration meter from also registering the slamming of a heavy door, a vibration is not transmitted until it is detected by three meters. NAM has also installed several pairs of depth geophones (borehole gauges) that measure ground acceleration at depths of up to 2 km.

There are other measuring instruments such as tilt meters that can measure the tilt of a structure very precisely. These can provide additional information such as the subsidence of a building. By measuring differences in angular displacement over a longer period, and the vibrations, one could establish whether the vibrations have caused subsidence or uneven settlements in foundations. These tilt meters are used in Amsterdam for the Metro construction, for example, but a number have also been installed in Groningen. As a test since 2017, the NCG has installed several tilt meters, for example in dike bodies.[8]

[7] See map: http://rdsa.knmi.nl/opencms/nl-rrsm/.
[8] https://www.rtvnoord.nl/nieuws/181057/Nationaal-Coordinator-Groningen-start-proef-met-tiltmeters

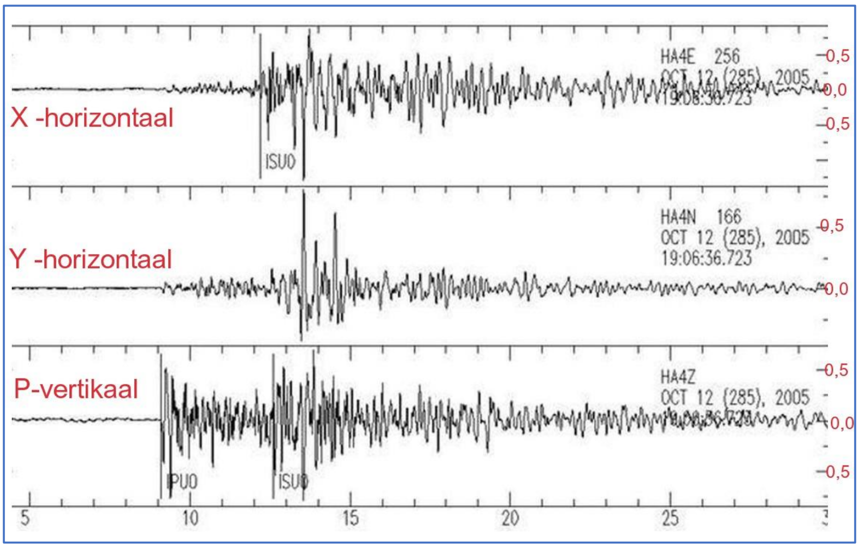


Figure 4. Registration of sensed (by people) of an earthquake shock[9]*.*
They sensed a big bang at which the building crunched. Date 12 October 2005 at Smilde near Assen. Mw 2,5 and PGAg ≈ 0,06.

The P shock comes up first, then the horizontal shocks. Depending on the distance between the epicentre and the meter, the registration is different.

Aspect ratio

Ratio (number) between the length and the height of, for example, a shear wall. Length-to-width ratio or the ratio between a span and the thickness of a structure. The ratio is used in a RVS inspection to quickly estimate the proportions of structures such as window piers, free wall lengths and heights of chimneys. If these parts fall outside the recommended ratio, their strength must be calculated, and the structure possibly reinforced.

Figure 5. The ratio of the wall piers in this building (red outlined wall pier on the right width/ height = 0.2 and therefore very weak. By mounting strong constructive glass panels in the window frames, the new ratio including the adjacent wall piers becomes w/h = 0.8 and about 4X as strong.
In the assessment of chimneys that stand on the roof base, a ratio of w/h = 0.5 is already risky because there is no connection to the underlying masonry due to the lead flashing.

For example: a window pier w:h < 0.25 is already a risk at PGAg > 0.1. A free-standing (loose standing) brick chimney measuring w:h < 0.1 can already pose a risk at PGAg > 0.1.

Base-isolation

The principle of Base-isolation is that the building is structurally disconnected from the lower foundation (base) in such a way that the horizontal earthquake movements of the ground are not directly transferred to the building above. Rollers or series of stacked metal/rubber plates are used.
The method is frequently used for large buildings and monuments in earthquake zones and is easy to apply to new buildings because an additional foundation does not have to be constructed under the existing building.

[9] https://www.knmi.nl/over-het-knmi/nieuws/aardbeving-bij-smilde-drenthe

Intertie van gebouw = Inertia of building. Belaste hoeken of vervorming = Loaded corners or deformation
Gebouw blijft op dezelfde plek staan = Building remans standing on the same location
Fundering = Foundation Grond beweging = Ground movement. Dubbele fundering = Double foundation
Vering uitgetrokke = Spring extended Vering ingedrukt = Spring compressed
Beweging fundering = Movement foundation Verplaatsing van lagers = Displacement of rolbearings
Verplaatsing onderste fundering = Displacement of lower foundation Gebouw = Building
Kogellagers of rubbers = Ball bearings or rubbers Statische toestand =Static position
Vast in de grond = Ffirm in the ground Principe van Base-isolation = Principle of Base-isolation

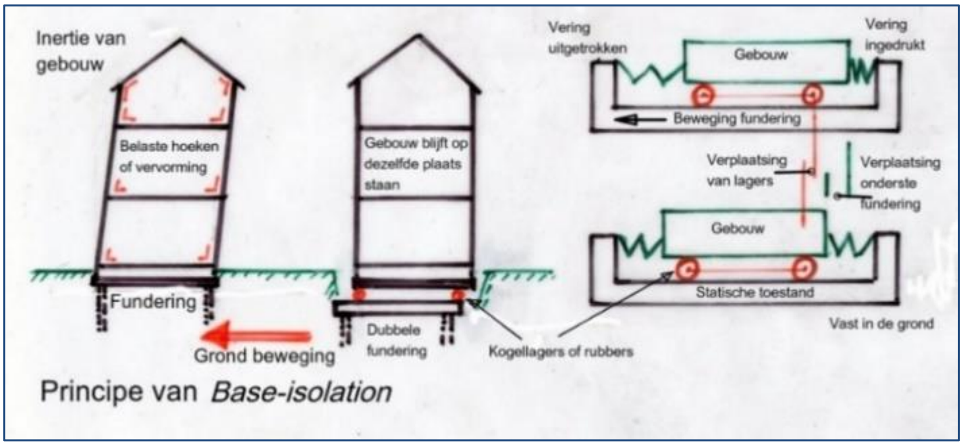
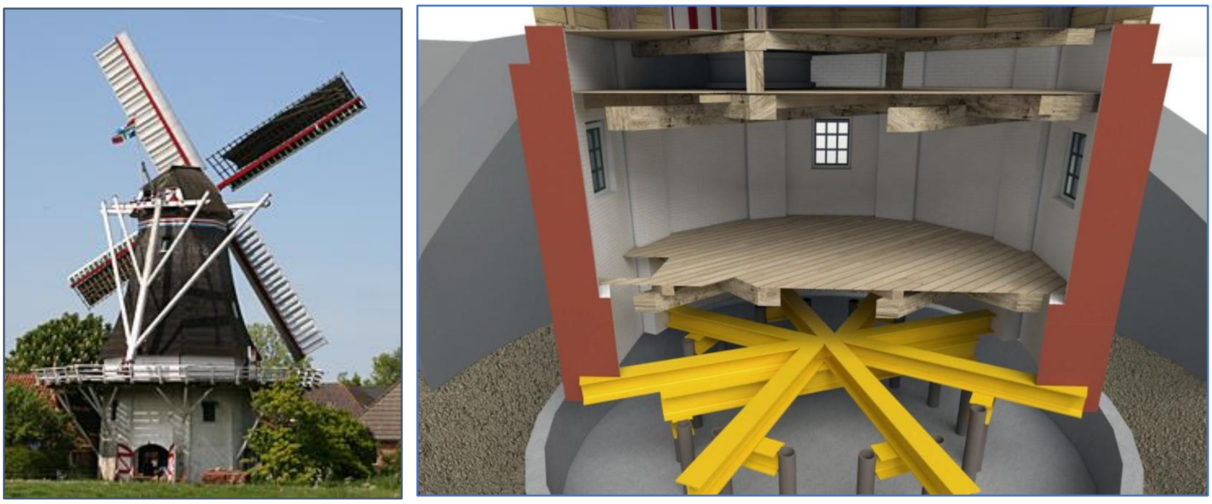


Figure 6. The rollers with springs, rollers in a bowl or rubbers ensure that the building returns to the center of the support.

Because the building mass has an inertia, the ground moves together with the lower foundation separately from the building above.

The building experiences only a small lateral load due to the spring action and will have no tilting effect. It therefore receives very little stress forces on the connections between walls and floors or roofs. The type of Base-isolation depends on the building mass and the maximum horizontal displacement of the maximum earthquake. In the induced earthquakes of Groningen, the horizontal displacement is very small (at PGAg 0.1 about 1 cm) compared to tectonic earthquakes, which sometimes are decimetres.



Figures 7. Left: Government monument Zeldenrust windmill (Internet photo by R. Bakker)[10] at Westerwijtwerd. A windmill is well constructed to withstand vibrations from all wind directions and has a flexible timber upper structure that is not affected by small earthquakes. Right: design of the Base-isolation under the windmill.

[10] See article with photograph: https://www.dvhn.nl/groningen/Een-primeur-rubber-beschermt-molen-Zedenrust-in-Westerwijtwerd-tegen-bevingen-21036894.html

Placing this windmill on a Base-isolation was mainly a technical exercise or test to try out the system, rather than a measure to protect the building against the earthquakes. In principle, the entire windmill vibrates when the large blades rotate, whereas the thick stone base of the building is very solid, while the wooden superstructure is flexible.

Base-isolation for the province of Groningen requires a very smooth running system that only has to bridge a small lateral movement (≈ 10 mm at PGAg 0.1). At the maximum earthquake according to the too high NPR9998:2015 (with PGAg 0.36) this would be a maximum of 3 cm horizontal displacement.

A Base-isolation usually does not absorb the vertical vibrations or load of the ground on the building. Because Dutch housing is designed for vertical loads, no extra reinforcement is required for the small vertical shocks. However, vertical vibrations do cause settlement in the ground and with that for the foundation and can/does therefore lead to cracks in the walls. An important condition of Base-isolation is therefore that there must be absolutely no settlement of the foundation.

In 2014, several buildings were considered for Base-isolation because this would be cheaper than reinforcing the entire building, or because monuments should not be seismically reinforced on the outside or the inside. For example, a new primary school building was built on rubber blocks Base-isolation. Schools or other buildings where many people congregate (building class, consequence class CC3) require higher security (safety) than residential buildings, which is why according to the seismic building codes higher earthquake loads are calculated for this type of CC3.

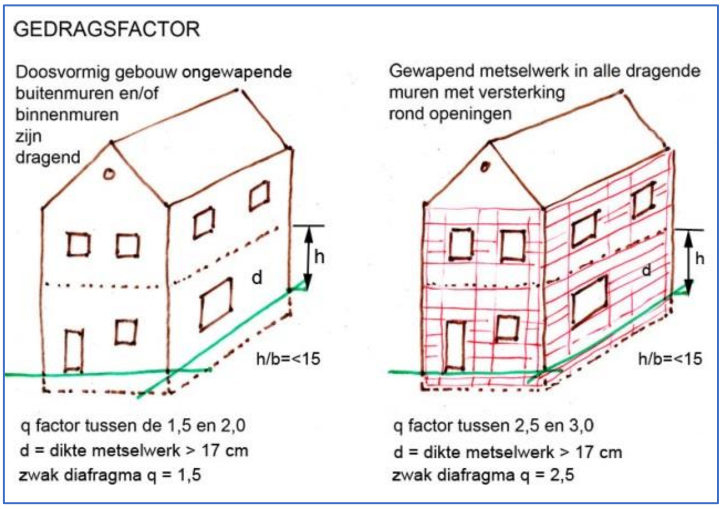
The costs of Base-isolation are relatively very high for small and low buildings compared to high buildings, because of the necessary double foundations and to prevent any subsidence of those foundations. It is much more expensive to construct Base-isolation for existing buildings than for new construction. For houses of few storeys sometimes several times more expensive than the entire building value. Chapter 5 takes a closer look at Base-isolation.

Behaviour factor {Eurocode 1.4.2.6}

The behaviour factor is expressed in q being the factor to reduce the forces according to a linear calculation based on the deformation capacity of the structure.

GEDRAGSFACTOR = BEHAVIOUR FACTOR
Doosvormig gebouw, ongewapende buitenmuren en/of binnenmuren zijn dragend = Box shaped building, unreinforced external walls and/or inside walls are load bearing.
d : dikte metselwerk = d : thickness masonry
Zwak diafragma = Weak or not to the walls connected floor diafragm.

Gewapend metselwerk in alle dragende muren met versterking rond openingen = Reinforced masony in all load bearling walls with reinforcements around openings.

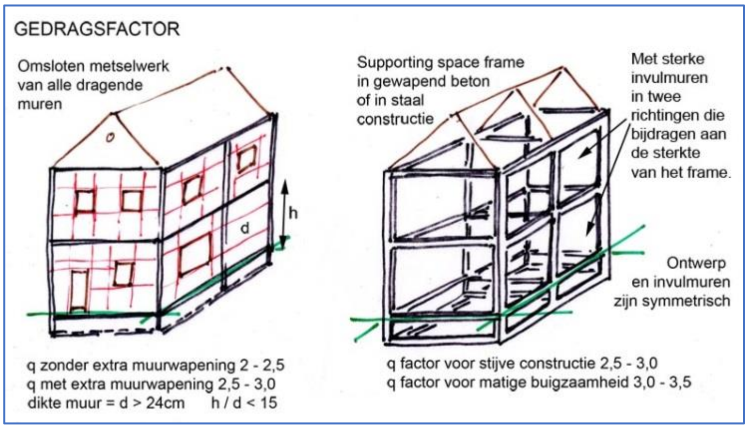


The early (2014) construction of this Base-isolation under the windmill was inspired by the panic of the extreme high PGAg as proposed by the KNMI. Placing the Base-isolation apparently was also a mere technical research exercise to determine the feasibility of the technology (interesting job for the engineers) and at the same time to placate the monuments organization.

Figures 8. <u>Left</u>. Box shape and non- reinforced masonry. ***This is the Dutch standard method with q 1.5 to 2.0.***
<u>Right</u>. Reinforced masonry with q factor between 2.5 and 3.0.
Reinforced masonry is mandatory with a PGAg <0.2.
In a brittle and rigid construction, the q-factor is low. With a flexible construction, the q-factor is high. This flexible construction method for housing does not occur or rarely occurs in the Netherlands.

Unreinforced masonry has a q = 1.5. This factor is applied below the fraction line in the calculation. The higher the q-factor, the greater the reduction and the stronger the building's resistance to earthquakes. **In the province of Groningen mainly the first type exists.** In areas with tectonic earthquakes with a PGAg > 0,2 reinforced masonry is mandatory (Eurocode)

GEDRAGSFACTOR = BEHAVIOUR FACTOR
Omsloten metselwerk van alle dragende muren = Encased masonry for all load bearing walls
q zonder extra muurwapening 2 - 2,5 = q without extra wall reinforcement 2.0 - 2.5
q met extra muurwapening 2.5 – 3.0 = q with extra wall reinforcement 2.5 - 3.0
dikte muur = d > 24 cm h/d < 15 = thickness wall = d > 24 cm h/d < 15
Supporting space frame in gewapend beton of in staal constructive = Reinforced concrete or steel construction space frame

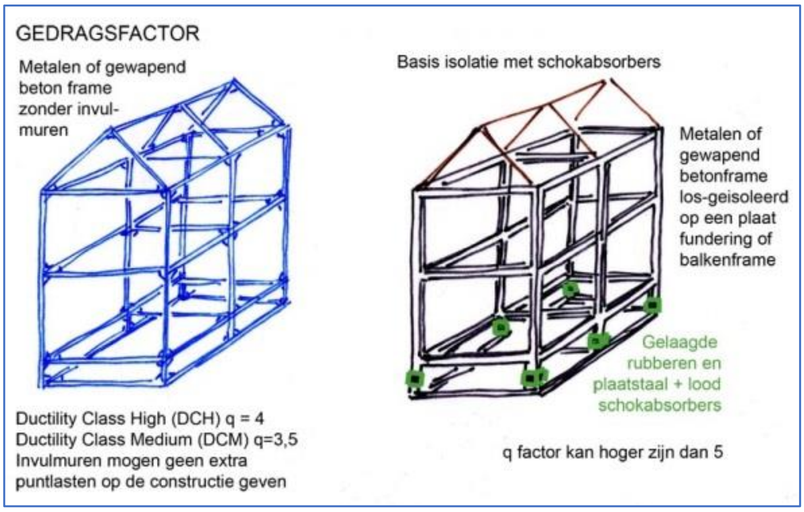


Met sterke invulmuren in twee richtingen de bijdragen aan de sterkte van het frame = With strong infill walls in two perpendicular directions contribute to the strength of the frame.
Ontwerp en invulmuren zijn symmetrisch = Design and fill-in walls are symmetrically positioned.
q factor voor stijve constructive 2,5 - 3,0 = q factor for stiff construction 2.5 - 3.0
Q factor voor matige buigzaamheid 3,0 - 3,5 = q factor for slight elastic deformation 3.0 to 3.5

Figures 9. <u>Left.</u> Buildings with enclosed masonry and/or a load-bearing frame construction such as a concrete frame. <u>Right</u>. Concrete and steel structures that can deform (ductile) without collapsing have an even higher q-factor. Load-bearing structures such as timber frame construction (HSB) also have a high q-factor.

In reinforced concrete construction (in The Netherlands), extra brackets are used in column ends, but not to the extent required in a tectonic earthquake zone.

GEDRAGSFACTOR = BEHAVIOUR FACTOR
Metalen of gewapend beton frame zonder invulmuren = Metal or reinforced concrete frame without infill walls
Invulmuren mogen geen extra puntlasten op de constructie geven = Infill walls may not cause additional loads on construction
Basis-isolatie met schokabsorbers = Base-isolation with shock absorbers
Metalen of gewapend betonframe los-geïsoleerd op een plaat fundering of balkenframe = Metal or reinforced concrete frame, separated by base-isolation and placed on a slab foundation of beam construction



Gelaagde rubberen en plaatstaal + lood schokabsorbers = Layered rubber and steel plates with lead shock absorbers.
q factor kan hoger zijn dan 5 = q factor can be higher than 5

Figures 10. Left. Metal frame or reinforced concrete buildings that do not have structural or rigid infill walls can be calculated with an even higher q-factor.
Right. A building on a base- insolation has the highest q-factor. With an easily moving roller construction it will score higher than with a stiffer rubber block or sliding construction.

The load factor of the building on Base-isolation depends on the stiffness or resistance of those Base-isolation elements. With a high sliding resistance, this load factor can still be PGAg 0.03.

BENG. Bijna Energie Neutrale Gebouw

Almost Energy Neutral Buildings. The relation between the former Energy Performance Category (EPC) and the new BENG standards are indicated in the table below. See also Chapter 12 Sustainability. The document NTA 8800:2019-06/INT-V1:2020[11] gives the interpretation of the new BENG-standard[12] 1, 2 and 3, which apply from 1 January 2021 and concern the amount of energy that a building may consume per unit area per year. With new construction and major renovations, buildings must comply with this standard, whereby the insulation of the outer shell is an important factor[13]. Also see 'Sustainability'.

For BENG 1: Outer shell divided by living area for ground-level dwellings = Als/Ag ≤ 2.2.
Structural modifications such as seismic reinforcement must follow this standard, whereby the reinforcement constructions must not cause any heat leaks. Adjusting the building to prevent cracks while insulating are also major adjustments.

Year construct	Rc-wall m².K/W	Rc-roof m².K/W	Rc-floor m².K/W	Thickness insulation	Rc-glass m².K/W	Energ y label	Points score	EPC Calculation factor	BENG 1 kWh/m² per year	BENG 2 kWh/m².yr fossiel	BENG 3 kWh/m².yr renewable
								0,0	0		
		10,		30 cm		A++++	51-61	0,1	≤ 15	0	> 50%
		8,0		28 cm		A+++	41-50	0,2 < EPC ≤ 0,4	≤ 30	0 < 50	> 50%
		6,5		17 cm		A++	31-40	**0,4 < EPC ≤ 0,6**	**≤ 70**	**30 < 50**	**> 40%**
2021	4,7	6,3	3,7	15 cm		A+	21-30	0,6 < EPC ≤ 0,8			
2015	4,5	6,0	3,5	13 cm	1,2	A	2-20	0,8 < EPC ≤ 1,1			
2005	2,5	2,5	1,3	8 cm	0,6	B	< 2	1,05 < EPC ≤ 2			
1992	2,5	2,5	1,3	8 cm	0,5	C		1,4-1,8			
1987	2,0	2,0	1,3	5 cm	0,5	D		1,8-2,1			
1982	1,3	1,3	1,3	3 cm	0,5	D		1,8-2,1			
1976	0,7	1,0	0,3	2 cm	0,5	E		2,1-2,4			
1965	0,43	0,86	0,17			F		2,4-2,7			
<1930	0,35	---	---			G		< 2,71			

Overview of the development of the Dutch thermal insulation standards, the energy label, the EPC values and the BENG requirements. Where the EPC is a dimensionless number (without kWh or joule), BENG does look at energy consumption, namely in kWh per square meter floor surface per year. It also sets a maximum on the amount of energy a building needs for heating and cooling.

The maximum energy use of buildings has been reduced over the years, starting with the oil crisis in the years 1971-1973 and it became increasingly strict as more importance was attached to the environment and CO_2 emissions from heating the buildings. In 2020, approximately 40% of national energy consumption will be related to construction (including transport, infrastructure, and demolition), with almost 1/3rd being necessary for heating and cooling buildings.

[11] See: https://www.gebouwenergieprestatie.nl/app/uploads/sites/8/2020/01/NTA_8800_interpretatiedocument_20200106.pdf
[12] BENG https://www.duurzaamgebouwd.nl/artikel/20181214-beng-is-veranderd-maar-wat-betekent-dat-nu-echt?
[13] See also: https://www.bouwwereld.nl/bouwkennis/beng-vereist-goede-uitvoering-van-isolatie/

Better thermal insulation of the outer shell of the building is therefore a key element in sustainable construction. **Insulate, insulate, insulate!**

Because the province of Groningen has been an area with a shrinking population and economic decline for decades, the residents invested little in the built environment. Relatively little new construction was realized compared to the rest of the country. As a result, a large proportion of the homes have poor maintenance, poor thermal insulation and the renovation costs will be on the high side in addition to the seismic retrofitting. Building financing models for sustainability must be adapted to this situation.

Biogas

This is mainly (>60%) methane gas (CH_4) obtained through the fermentation of manure from livestock, agricultural waste, and residues from the food industry. It is important that manure and urine remain separated otherwise Ammoniac (NH_3 nitrogen deposits being detrimental for the nature) is generated. The wet mix of urine and cow manure may not disappear into the large underfloor manure cellars (for the watery mix), which are commonly constructed in The Netherlands. The fresh manure must be directly fed into the biogas reactor or bio-digester. This way neither Ammoniac, nor Methane will be emitted into the atmosphere.

Other gases, water vapor and elements must be purged out before this biogas is upgraded and can be added to the national gas grid [14].

Figure 12. Internet photo. Biogas installation from www.Host.nl with two large gas storage containers. The biogas must be purified and can be burned for energy (at night when there is no sun) or can be made into LNG for trucks.

CH_4 ≈ 21 x as damaging or insulating as CO_2 in global warming. When you burn 1 x CH_4, only 1 x CO_2 remains and the heat or energy. In that case you remove 20 x CH_4 emissions.

When the Groningen natural reserve expires, and biogas production has been developed for all bio-industry farmers a substantial supply of biogas can be supplied to the grid.

[14] In 2013, the NAM did not want to re-examine the option of having biogas produced by the many livestock farmers in the provinces of Groningen and Friesland, because five years earlier a cost calculation had been made that did not provide NAM with any large commercial advantage. In the meantime, however, by 2013, the biogas production technology had improved and become cheaper with osmosis technology, but again the NAM considered it not profitable enough and it would require long time development with farmers. Although it was clear in 2013 that the Groningen natural gas reserve would expire in a limited number of years, there was no intention to supplement the natural gas with purified biogas. The livestock sector remains a very large factor in CH_4 and NH_3 and CO_2 emissions and therefore global warming. By 2020 the many years (>20 years of warnings by the European Commission) excessive NH_3 emissions from the large cattle farming industry (mixing urine with manure and fertilizing the grass fields), became a critical political issue (obliging farmers to close business). This could have been avoided if all livestock farmers would have timely converted to biogas. The fossil energy industry had no intention to minimise emissions or consider climate issues. It speculated until 2020 that large amounts of low-cost Russian natural gas would be available, which would be far mor profitable for them than bothering with a reorganisation of the strong cattle farmers section in The Netherlands.

Borehole seismometer

This kind of accelerometer is placed a few hundred meters deep inside a borehole and makes it possible to register weaker earthquakes than with instruments on the surface. These weak vibrations are also called micro-vibrations[15].

In the province of Groningen, several borehole seismometers have been installed at a depth of approximately 200 m to prevent the influence of vibrations on the upper soil layer. In addition, deep seismometers have been placed at a depth of 3 km, down into the gas-containing sandstone layer. These boreholes have 15 seismometers over a depth between 2800 m and 3200 m. The exact location of the origin of the vibrations in the sand layer or fault line can be determined with these instruments. It was confirmed by these borehole seismometers that the tremors come only from the gaseous sandstone layer and not from the Carboniferous below. With more measurements it was established that there are also light (non-perceptible) vibrations coming from the soil layers above the Zechstein salt rock/stone.

Figures 13. Due to the deep location, surface vibrations (bottom noise) are avoided. Soil compactor in the street. A piling installation can still be felt by people up to 500 m (photo Arcantus, Appingedam new construction).

Building Directive

On 1 August 1902, by the Pierson Parliament the housing law of 1901 was declared, being the basis of municipal housing estates in The Netherlands. The first Building Directive[16] became effective in 1992 by which all technical specifications became similar for the entire country. On 1 January 2003 an updated version of the Building Directive became active. The newest Building Directive 2012 refers to the standards of the NEN from the Standardisation Institute (Normalisatie-Instituut) and the Eurocodes. These replace the standards NEN 6700 to NEN 6790.

Since January 2015 the increased thermal insulation standards (EPC = 0,4) are applicable, which was not obligatory for reconstruction. Per 1-1-2021 the new BENG-norm is applicable for new construction which is linked to an EPC of $\leq$ 0,2 [17].

Brick masoned buildings that were constructed according to the Building Directive 2015 will hardly suffer any damage from the light earthquake shocks up to PGAg 0,1 except for terraced houses

[15] Generally, for every 10 micro vibrations there will be one small vibration of about two times the strength of the micro vibration. For about 10 small vibrations there will be one medium vibration and so on. This is called the Gutenberg-Richter constant. Measuring the number and size of these small vibrations (cannot be sensed by people) it can be estimated when a one grade larger vibration may occur.
[16] Source: Wikipedia https://nl.wikipedia.org/wiki/Bouwbesluit
[17] See: https://ondernemersplein.kvk.nl/nieuwe-gebouwen-moeten-voldoen-aan-de-beng/?gclid=EAIaIQobChMI2uGrhf337QIV0uN3Ch0vVgbeEAAYASAAEgKPpfD_BwE

haven extra-large front and rear windows and very narrow piers. This type of buildings only considers the latest standards for storm loads. For a block of 5 to 7 terraced houses, the storm load is very limited on the small head, while earthquake forces are fully applicable in both directions.

Windbelasting op de kop van een enkele woning is bijna gelijk aan de windbelasting van een rijtje = The wind load at the head of a single house is almost equal to the wind load of the whole line of terraced houses.
Aardbeving belasting is viermaal de enkele woning = Earthquake load is four times that of a single house.

Figure 14. The wind load at the head of a single house is approximately equal to the wind load at the head of a block of 5 to 7 terraced houses.
The earthquake load on the head of a block of four terraced houses is 4X that of a single house.

A maximum storm load on a 50 m^2 head facade is approximately 50 tons. A cube-shaped terraced house weighs about 1500 tons. A PGAg 0.1 means an earthquake load of 0.1 x mass (1500 t) = 150 t, so approximately three times the storm load. According to the building standard, a block of 4 terraced houses is also designed for a storm resistance of 50 tons on the short end, but it will receive approximately 600 t perpendicular to the row of facades of the 4 houses. Because of the partition walls between these houses, these constructions can easily handle that load perpendicular to the long façade, but not to the short head. Although the storm load on the head is only 50 t, the earthquake load in the length direction is 0.1 x 4 x 1500 t = 600 t.

These houses have large windows front and rear, without internal walls on the ground floor. These are not designed for this earthquake load and therefore run a high risk of damage and falling over (like a card house). Thousands of such houses exist in the Groningen province.

Building typology

Building typology is a classification of the buildings that have a similar structural and strength structure with a similar horizontal resistance and behaviour during an earthquake. In Groningen, twelve main categories have been identified, with subdivisions according to the construction period and according to the type of foundation (on firm ground or piles) or the type of floor diaphragms (flexible or rigid).

Terraced houses and canal houses being built side by side, belong to the weakest categories of building types, partly due to the lack of transverse walls. Terraced house with large windows and having relatively heavy concrete storey floors have few or no piers in the front and rear facades, but extra earthquake load due to these heavy floors. The 1960-1970 buildings are therefore an extra weak category. Old pre-1940 buildings with wooden floors without rigid connecting floor diaphragms are also among the very weak constructions because without the floor diaphragms the walls will be loaded perpendicular to their wall plane (and fail).

The classification is derived from the English-US version for Un-Reinforced Masonry (URM).

URM	Building description	Period	Floors	Image of frequent present Groningen housing. The oldest houses have the most damage.
1	Standing free. Flexible timber floors, half-brick (12 cm) inside walls. Exterior whole brick walls 22 cm. About 10% of the housing and with most of the earthquake damage	< 1920	1-2	   
2	As URM 1 . "Mansion". Attic in use Flexible timber floors, half-brick (12 cm) inside walls. Exterior whole brick walls 22 cm. About 5% of the housing and with most of the	< 1920	≥ 3	   
2a	As URM 1 . "Mansion". As 2, but often classified as monuments. Including the 'head' sections of the large truss farms. Some of these are masoned with clay making them extremely vulnerable.			   Left: Monumental 'head' of farm being placed on Base-isolation as option to avoid further damage.

URM	Building description	Period	Floors	Image of frequent present Groningen housing. The oldest houses have the most damage.
3-4	Free standing or two-under-one-roof. Flexible timber floors, half brick (12 cm) inside walls and whole brick (22 cm) exterior walls. High chimneys from period 1930 are an additional high risk objects.	1920-1960/70	1-2 and > 3	   
5-6	Free standing or two-under-one-roof. Reinforced concrete floor stiff diaphragm. Less damage, but large building mass.	>1960/70	1-2 and > 3	 
9-10	Terraced houses, Timber floors, half brick (12 cm) inside walls. Whole brick (22 cm) or cavity outside walls.	1920-1960/70	1-2 and >3	 
11	Terraced houses with large windows front and rear. Few or no inside cross walls. Reinforced	>1960/70	1-2	 

In the above list, only a few main typologies of homes are indicated, but in 2018 a total of 60 different typologies were identified (variations of the 12 basic types), of which very detailed NLTHA calculations and Reinforcement Advice (RA's) were made in 2020. These RAs were financed with government funds but still not available to the public at the beginning of 2021.

From older houses[18] the wooden floor beams are usually not well connected to the walls, or only every other beam. It is common for only some beams to be joined by their head ends to the walls

[18] Many homes are sometimes adamantly stated that no amplification is required at a PGAg < 0.05, which is the NPR seismic amplification limit. This is incorrect; typologies 1, 2 and 11 can also be damaged by the Groningen type of short earthquakes and repeated earthquakes of that PGA value, while these shocks can cause the chimneys of typology 3 to fall off. Variables such as foundation quality, soil type, damage or damage and renovation can be the causes.

and not at all to the parallel side walls. It is also possible that floors of adjacent rooms are not interconnected so that the building diaphragm is interrupted.

Floors made of concrete elements have been used in houses since 1953. These form very rigid floors, but if they are not connected to each other or to the side walls, they do not create diaphragms. They are also **heavy structures**, so heavier loads during earthquakes. This design is especially a risk for terraced houses if these buildings have none or few structural transverse walls. Schools or higher residential buildings are not included in the table above and have a higher behaviour factor q (more victims in case of collapse) and must therefore be calculated with a higher load.

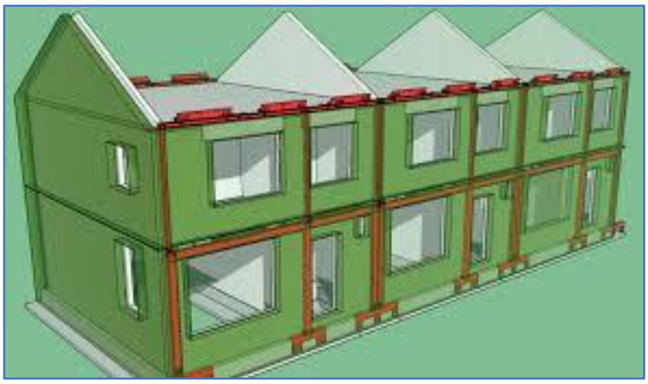
Houses built after 1980 are mainly stacked buildings with their own typical problem of a lack of strong connections between the floors and load-bearing walls. Many floors consist of separate elements that are not sufficiently connected to each other and do not form a diaphragm.

In houses built after 1985, wider cavities in the outside walls are used in connection with thermal insulation (10 cm instead of 5 cm), which improves the strength and stability of the walls. Due to the wider cavity, good wall ties increase the resistance moment of the wall slightly.

In houses built after 1990, glued sand-lime blocks are regularly used for the inner walls, so that the inner load-bearing walls can have a higher compressive strength than masoned sand-lime bricks. This is because with brick joints, only the compressive strength of the joints is decisive, and the joints are seldom filled with mortar across the entire width of the brick. The glue quality of sand-lime blocks is usually much better than the mortar masonry quality.

When a house needs to be seismically reinforced (retrofitted), this may mean that extensive measures must be taken, especially on the load-bearing walls and to make floors as diaphragms. The load-bearing walls of the outer shell must then be also adapted to the thermal standards in accordance with the current building regulations.

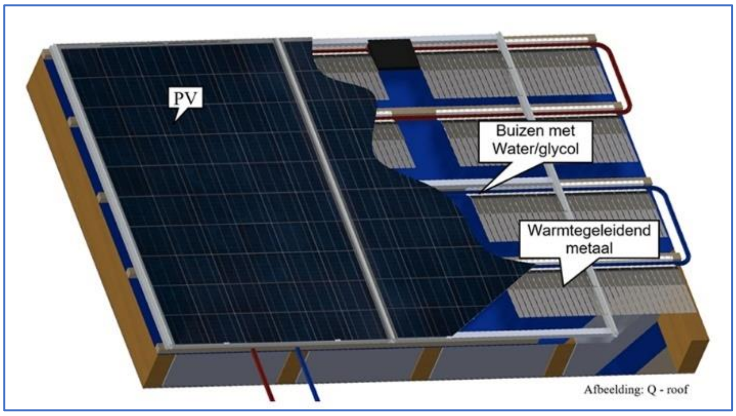
Figures 15. When internally reinforcing an exterior wall with a timber frame construction (with tensile joints on the inner cavity wall), thermal insulation in accordance with the latest building standard (BENG 4.7 m^2.K/W) is also required. The thermal insulation will hide the reinforcement construction, but the rooms become a little smaller.



With external reinforcement, for example when placing steel portals in the location of the outer cavity wall, thick thermal insulation and brick slips can then be applied, whereby the upper storey can have a more flexible plastic or wooden facade cladding. This way the houses do not become smaller inside, exterior finish is more expensive than interior finishings.

With a major renovation, the requirement will be (as of 30 June 2021) for generating a minimum amount of renewable energy - such as solar panels or heat pumps.

The obligation arises from the EU Renewable Energy Directive II (RED II) directive. This stipulates that European member states must prescribe a minimum amount of renewable energy for major renovations that include the heating or cooling installation(s).



Figures 16. In addition to PV panels, there are also solar water heaters. Photo left. These supply approximately 50% of the domestic hot water requirement but may not be very effective during the clouded winter.
Right. Thermal PV panels (PVT) are connected to the heat pump. Under the PVT panels are radiators that absorb the air temperature and use that to upgrade the inside temperature.

Centrally coordinating plan development for each housing typology can, in theory, save a lot of costs and speed up the process of strengthening and making it more sustainable[19].

Capacity design method {Eurocode 8: 1.4.2.7}

Design method that ensures that the non-deformable elements or the rigid parts of the structural section are stronger than the flexible or deformable or dissipative elements.

When a flexible structural element (the wooden roof of a building) gives way under a load, that load will be resisted by the inflexible, rigid part (e.g., brick masoned gable end). The non-flexible (rigid) part may not collapse, otherwise the structure will collapse. The flexible sections will give less resistance to the load than the rigid ones (and absorb part of the forces). When combining different stiffnesses, care must be taken that no damage occurs in the non-flexible or rigid elements. Thus, the rigid element, such as brick masonry, will always receive most of the load and will therefore crack first when the load exceeds the bearing capacity.

When using different constructive (structurally supporting) building materials with different stiffnesses, and with non-structural infill elements, damage must be avoided by means of dilatations or soft joints. For example, large steel trusses of a large barn that are filled in between the rafters with brick (cracks are guaranteed here), must have flexible joints between steel and brick.

[19] Although repairs of earthquake damages are paid for by the NAM, there are only subsidies for sustainability measures. This causes the NAM to be very reluctant about financing these other costs and it also resisted to mount a long-term sustainable home improvement housing fund (they said it was not their business). Most of the house owners however, are not able to finance the additional costs for making their buildings more energy efficient or sustainable. Homeowners should be able to call on other funds to realize both activities (improvement and sustainability) simultaneously and to a sufficient extent. A building fund could be created from which sustainability of homes can be financed, which is only repaid when the home is sold.

A stiff brittle brick wall will soon crack in an earthquake, but that does not necessarily mean that the wall loses its load-bearing capacity. When covering (plastering) that (inner) wall, the finish must be elastic (slightly movable panelling or fiberglass plates), so that the crack does not become visible again in the event of a new shock.

Gewapend beton = reinforced concrete
Stalen kolom – Steel column
Vervormbaar = able to deform
Grote vervorming = large deformation
Stijf en bros = Stiff and brittle
Verbonden = connected
Aardbeving = earthquake
Baksteen = brick masonry
Kracht = force
Kleine vervorming = small deformation

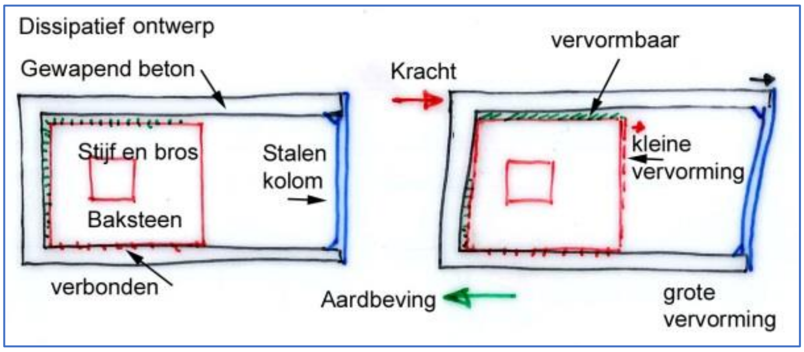


Figure 17. Sketch of a facade. The rigid brick wall has only half the ductility of the reinforced concrete column. The steel column can deform twice as much as the concrete column. When calculating the maximum permissible horizontal earthquake force, the loads must be distributed in accordance with the stiffnesses. The stiffest elements receive the largest loads. In the above case, the masonry should be connected in a flexible way to the reinforced concrete construction.

This is important when reinforcing brick facades with metal portals. A building may be strong enough against collapsing, but the brick walls can still crack at maximum load if the stiffnesses and dilatations have not been considered. In a facade with wide and narrow window piers, the widest piers will absorb the most forces. This phenomenon is further explained in Chapter 6.

Circular building construction

For a more sustainable society it will be necessary to waste or degrade as little material as possible. Buildings must be designed for an optimum reuse of materials when the (economic) lifetime of the building expires[20]. It distinguishes 5 main phases.

- **A 1-3**, the production phase.
- **A 4-5**, the construction phase.
- **B 1-7**, the use phase.
- **C 1-4,** the demolition, and processing phase; and
- **D**, the environmental benefits, and burdens beyond the boundaries of the building [21].

Chapter 12 Sustainable housing elaborates on the issue. Retrofitting damaged buildings must consider these concepts. Investing large amounts of materials and funds in a building that economically may not last very long is very wasteful.

The supporting core construction of a building should last for a long period (at least 200 years)[22]. The built-in elements such as partition walls or a non-structural outer shell for a medium term (> 100 years). The installations with mechanical parts that move and require maintenance > 50 years.

[20] See RIVM: clear determination of the circular building concept and the environmental building performance as point of departure. https://www.rivm.nl/bibliotheek/rapporten/2017-0128.pdf

[21] See: https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/circulaire-economie/circulair-bouwen

[22] Many buildings in the Netherlands have existed since the 17th century and are therefore >300 years old and are still in use because they were well built with large dimensions so that these buildings could also be used for other functions. This is not the case with 1960s or 1970s terraced houses (material destruction).

Technical installations should also be designed to simply replace components that wear out quickly, rather than replacing the entire unit (commonly in 15 years). The personal furnishings should last at least 20 years. So not a different/new/stylish kitchen every 10-15 years. Also see 'Sustainable'.

Cracks (in masonry)

When assessing building damage in Groningen, the location of the crack in the walls and the crack size are included. Slight cracks < 0.3 mm is rarely visible in photos, unless in a white plastered wall. Moderate cracks of 0.3 to 3 mm are most observed.[23]

Light cracks and moderate cracks have no structural consequences in brick masonry for the building strength. Heavy cracks of > 3 mm often run far and can be accompanied by shifts in the wall; this percentage detected is very low, but clearly visible, and can have structural consequences.[24]

For buildings built between 1920 and 1940 and buildings built after 1970, hardly any serious cracks occur at a PGAg < 0.1. Buildings from before 1970 have many moderate damages to the exterior facades. However, in houses built after 1970, such as semi-detached houses, there is more moderate damage to interior walls because of the rigid construction method and reinforced concrete beam foundations. Buildings built on firm ground (usually pre-1940) have relatively high levels of moderate cracking, especially in the foundations due to vertical settlement.

Figure 18. Crack at the support/connection of a lintel that is supported on the inside wall of the cavity wall construction. Most cracks around window and door openings are building related and the cause of poor construction details, often combined with light settlement in the foundation. Vibration from heavy traffic or an earthquake can make them wors.

The three main causes of the cracks are:
(1) Building-related causes (construction, thermal, construction defect) and foundation settlement.
(2) Earthquakes, which often result in foundation settlement.
(3) Earthquakes with lack of building strength in the two horizontal directions and lack of connections between floors and the walls (floor diaphragms).

Existing soil settlements can be aggravated by all earthquake vibrations, and with that exceeding existing stresses in the masonry and leading to moderate cracking. For less than 75% of the damage, it was usually possible to clearly determine the cause. In most damage cases, there is a combination of factors such as building on firm ground (no pile foundations), uneven foundation depth (cellars),

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[23] Extensive reports have been written about crack formation in Dutch housing. For example the PhD report by Ilse de Vent, https://repository.tudelft.nl/islandora/object/uuid:e9a3a2f9-16b5-4b22-a1f4-6511f3543f6e/datastream/OBJ/download "Structural Damage in Masonry". The subsequent chapters of this book mainly deal with the cracking caused by the earthquakes and increased by earthquakes.

[24] The SBR, Stichting Bouw Research (Organisation for Building Research) has two documents: "Crack formation in masoned walls, 1976" (Scheurvorming in gemetselde wanden, 1976) and crack formation in housing, 1969" (Scheuren in woningen, 1969). Also see the research report by Witteveen en Bos about the NAM cracks. https://www.nam.nl/nieuws/2017/nam-zoekt-oplossing-deel-schades-zuidlaren/_jcr_content/par/textimage.stream/1510311678487/efc5414fe61f9117ea8445febc94cba8fcbf0a76/rapd-bijlage-verzamelen-van-informatie-ii.pdf

construction period, age (over 100 years old has more cracks), settlement in peat or clay (soft elastic soils) and construction errors (by construction or later by owner).

Until 2015, NAM did not recognize the cracks in the foundations caused by earthquakes (wrong understanding or financially motivated). In practice, this meant that about 25% of the damage reports required further investigation by other parties and reporting and lengthy (costly) discussions arose about the NAM directive about compensation[25].

A related problem was that most homeowners could not finance the additional costs, or the costs resulting from damage cause by their own (poor quality) building construction. A further problem is that the costs for thermal insulation of the building could also not be financed by them.

After several small earthquakes, NAM recognized in 1993 that building damage could be caused by earthquakes and a damage settlement was set up in 1994. Before the largest earthquake of 16 August 2012 hit Huizinge, 1100 claims had already been compensated [26]. Because of the unfamiliarity with the quality and strength of Groningen housing in relation to the induced earthquakes, many different studies were started to clarify this. Finally, a building vibration guideline became available in 2017 which indicated that buildings should be able to withstand light tremors to a defined extent. [27] The results of this guideline were widely disputed because cracks by earthquakes were legally to be compensated by the NAM.

This glossary deliberately does not address the legal issue of the burden of proof or reversed burden of proof and other political or social measures.

Compaction

The natural gas reservoir consists of slightly porous sandstone and is located at a depth of about 3 km under a 1 km thick sealing layer of salt rock and another 2 km thick layers of soils (together 670 bar pressure from above). One bar is the atmospheric pressure or 100.000 Pa = $1 \cdot 10^5$ Pa = 100 kPa. Per m^2 surface of the earth, the atmospheric pressure is about 10.000 kg.

When a hole is drilled into that sandstone, the natural gas spurts out under very high pressure. By extracting the gas, the gas pressure in the sandstone reservoir decreases (from 350 bar in 1965 to <60 bar in 2020), the grains of the sandstone rock are compressed by the weight of the overlying layers. This compression is called compaction (squeezing).

The more gas is extracted, the further the internal gas pressure drops, the greater the compaction becomes. It depends on the porosity of the rock and the thickness of the sandstone layer how much the compaction will be.
The greatest layer thickness and greatest porosity was measured under the municipality of Loppersum (including the villages of Ten Boer, Zeerijp and Westeremden, being the area with the most and strongest earthquake shocks). When compressed beyond the resistance of the elastic compaction, the sandstone layer will suddenly crush (causing the earthquake), much like a rusk/biscuit suddenly collapses under too much pressure from a flat hand.

[25] Most of the damage experts that were hastily recruited in the years 2012 and 2013 had little construction background, and no seismic knowledge at all, which is why many damage claims were challenged by the house owners. In fact, earth vibrations have already been measured because of natural gas exploitation since 1975, which did affect buildings, especially built on soft soils.

[26] These repairs were rather cosmetic and were required again after every earthquake as no reinforcement was applied. Because of the sudden shortage of craftsmen, the costs of the repairs multiplied in 2012 and 2013.

[27] https://www.building.nl/uploads/fckconnector/bbb3c9ac-bf69-4a11-ad06-95a88aeca916/3016759984

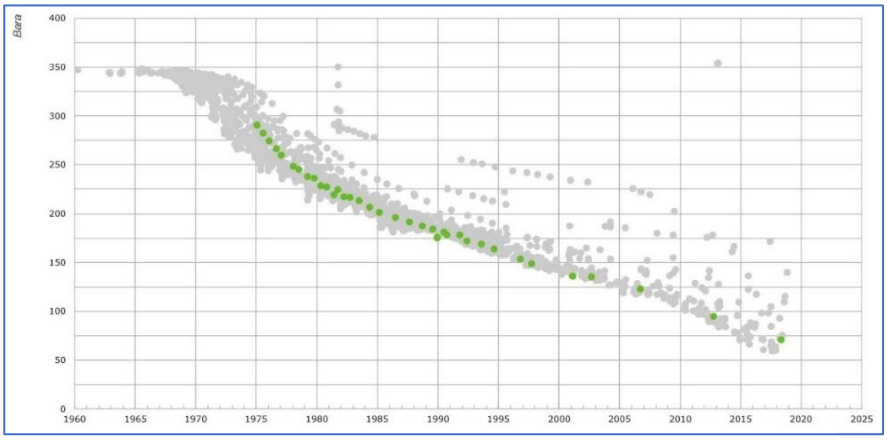
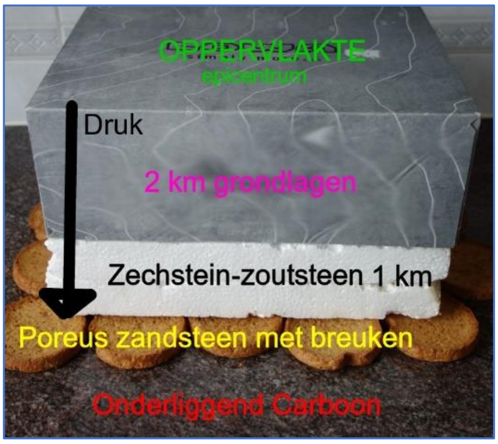


Figure 19. In this graph of the internal gas pressure from 2019 the pressure per measuring point (grey or green dot) is indicated. [28] *Measured since 1965*

In August 2015 rock samples were taken from the 3 km deep gaseous sandstone layer. These samples have a length of 30 m with a total length of 180 m. Drilling to these cores is done with a derrick and a hollow drill head, like the functioning of an “apple drill”. These nuclei were analysed for their possible compaction.

Oppervlakte = surface   Druk = pressure   2 km grondlagen = 2 km soil layers   Zechstein zoutsteen = Zechstein salt rock
Onderliggend Carboon = underlaying Carboniferous   Na alle gas extractie = after all gas extraction,
Elastische compactie = Elastic compaction   Grond druk 670 bar = soil pressure 670 bar

Figures 20. To make a comparison, you can load rusks/biscuits under two masses more heavily. A reduction in pressure in the sandstone corresponds to a greater load from above. With extra pressure, the rusks are slightly compressed until they crush.



Impression of the grain structure in the sand layer that is compressible. By compressing the cores in a laboratory, as was done in the sandstone layer, one gets an impression of the elasticity of the sandstone layer and at what pressure it will be crushed (causing an earthquake shock).

In 2015, NAM took a few soil samples from a depth of 3 km for testing [29].

Cultural heritage

The province of Groningen has a lot of cultural heritage in the form of old farms, mansions, churches, rentier houses, characteristic buildings, windmills, and industrial buildings. The preservation of those buildings is an important part of human identity, history, experience, and pride.

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[28] See: https://www.nam.nl/feiten-en-cijfers/gasdruk#iframe=L2VtYmVkL2NvbXBvbmVudC8_aWQ9Z2FzZHJ1aw
[29] *See: https://www.nam.nl/nieuws/2015/gesteentemonsters-van-3-kilometer-diepte-uit-groningen-gasveld.html*

The seismic retrofitting (to the extent of the very high PGAg) of these buildings is complicated when it is not allowed to make visibly changes on the outside of the building. In some buildings, changes to the interior are also not desirable. Many of these buildings were built before better building standards were adopted in 1901 and are seismically weak in construction. In that case, the retrofitting requires extensive internal structural reinforcements such as portals and floor diaphragms, after which the historic interior must be restored.

Figures 21. The determination of what is and what is not cultural heritage, and to what level these buildings should receive special conservation treatment, depends in part on the building owners, officials and institutions dealing with history and architecture involved. For several monuments Base-isolation was adopted.

Chapter 3 discusses the chimneys that can be replaced in a simple manner by lightweight imitations (and removed internally), so that the roof and building load is considerably reduced. This way the building is relatively stronger without the risk of a heavy brick chimney falling off.

The masonry foundations of these old buildings are often constructed on undisturbed soil and are subject to settlement over time, which can be exacerbated by the earthquakes. To preserve these buildings, an improvement of the entire foundation is then necessary, about which more details are given in Chapter 4.

Chapter 5 explains the Base-isolation method in detail, but this is an expensive method for low-rise buildings, unless a suitable low-cost model for Groningen is produced locally. The high costs of the double, stronger foundation and imported Base-isolation systems make it an expensive operation.

CVW, Centrum Veilig Wonen, Centre for Safe Living

After the earthquake of 16-08-2012 in Huizinge, the direct responsibility and involvement of NAM in the building damage settlement process resulted in many reassessments, arbitration and conflicts, which became increasingly time-consuming and expensive. The cost of the reporting and arbitration became three times as high as the cost of the actual repairs.

The dissatisfaction of the population with the NAM continued to increase. That is the reason why (in 2015) the CVW in Appingedam was established, to place the entire process of damage reporting, inspection, assessment, and supervision of the implementation of the wall repair at a distance from the NAM.[30] Technical staff from NAM consulting contractors were listed under the CVW.[31]

[30] This action, however had limited effect, because the NAM paying for all the repairs had given (not disclosed) guidelines to the CVW that did not comply with real earthquake damage assessment (no foundation damage was approved), to minimise the repair costs. The resulting arbitration, also to be paid by the NAM, caused that

The CVW handled more than 75,000 claim files, carried out 12,000 inspections and recordings, it supplied 5,000 reinforcement recommendations, about 950 houses were strengthened, over 3,000 houses were made safer (and a multiple of them removed from top-heavy chimneys), 200 temporary houses and countless schools were assessed, strengthened, and constructed, village halls were placed on Base-isolation including churches and other buildings. (Source: CVW website).

The CVW carried out the thousands of inspections and assessments on the same basis as the NAM used to do. However, with the same procedures, with financing from the NAM and therefore also with the large number of arbitrations. One of the problems was that the NAM, and subsequently the CVW, did not acknowledge the foundation damage as a result of the earthquakes.

The CVW stopped on 31 December 2019. The National Coordinator Groningen (NCG) is then the implementing organization for earthquake damage and treatment in the province. Some of the approximately 140 experienced CVW technical staff employees also transferred to the NCG.

In a later stage, the NCG realised only the retrofitting and strengthening projects and a new organisation, the IMG occupied itself with the lighter repairs.

Damage State.

Damage State is the level of damage to a building[32].
The following values are defined internationally (American FEMA code):
DS0. *Damage State* 0: *ND = No Damage*.
DS1. *Damage State 1*: Not structurally. Building may remain occupied, *IO = Immediate Occupation*.
DS2. *Damage State* 2. Light damage, *DL= Damage Limitation*. Support structure of the building is not in danger.
DS3. *Damage State 3*. *SD = Significant Damage*. Structurally the building is at risk with the repetition of a similar earthquake. Substantial structural improvements are required.
DS4. *Damage State* 4. Very heavy damage, *NC = Near Collapse or Ultimate Limit State.*
DS5. *Damage State* 5. *Collapsed*. This version has not been sketched below.

The PGA specified in the NPR9998 is the maximum tremor value after which DS4 is the result.
The interpretation of these damage situations and the NPR, which indicates the amplification level up to DS4 at the maximum earthquake value (in the epicentre), leads to a difference of understanding between the engineers who had to calculate with that NPR since 2015, and the population that does not want any DS1 damage at all [33].

The following five *damage states* are defined according the American HAZUS FEMA 2013 and the *European Seismological Commission* (EMS) 1998. The NPR9998:2015 only analyses the first 3 DS, because with the higher *Damage States* most buildings will be considered as economic loss.

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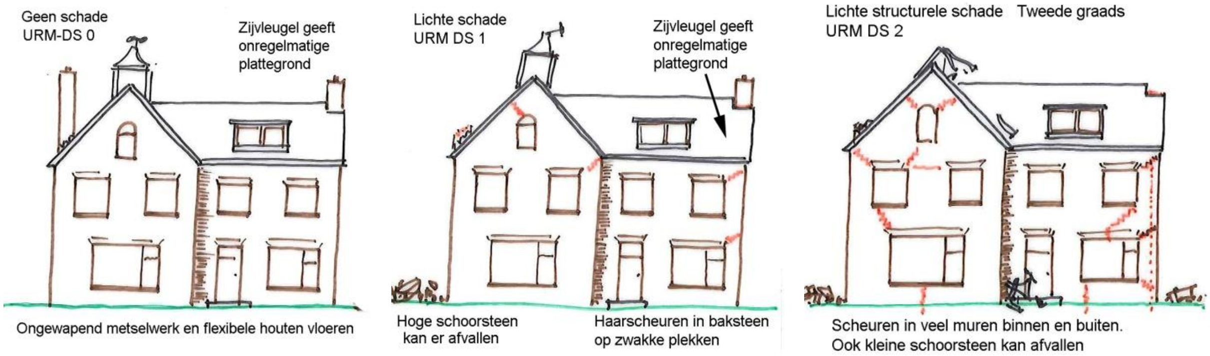
massive funds were spend on thick reports, rather than on repairs. This again resulted in widespread dissatisfaction under the population.
[31] The abbreviation, referring to “Safe Living”, was chosen because of the assumed unsafe houses that might collapse with future earthquakes. Based on the actually light earthquakes, it was unlikely that any houses would collapse, unless these buildings already had serious structural deficiencies. The safety of the population was never in risk, but the unsafety was strongly promoted by the media as a key issue.
[32] For detailed explanations with images and photographs see: https://www.iitk.ac.in/nicee/wcee/article/0705.pdf and https://ec.europa.eu/echo/files/civil_protection/civil/act_prog_rep/peadab.pdf
[33] The large conflict in the province of Groningen is that the population want damage-free housing. This is totally different from the NPR concept of Near Collapse, being adhered to by the NAM.

Geen schade = no damage.
Zijvleugel geeft onregelmatige plattegrond = Sideway building extension causes irregular building plan.
Ongewapend metselwerk en flexibel houten vloeren = Non-reinforced masonry and flexible timber floors.
Lichte schade = Light damage
Hoge schoorsteen kan er af vallen = High chimney can drop down.
Haarscheuren in baksteen op zwakke plekken = Thin cracks in brickwork at weak locations.
Lichte structurele schade = light structural damage. Tweede graads = second grade
Scheuren in veel muren binnen en buiten = Cracks in many walls inside and outside.
Ook kleine schoorsteen kan afvallen = Also a small chimney can drop down.

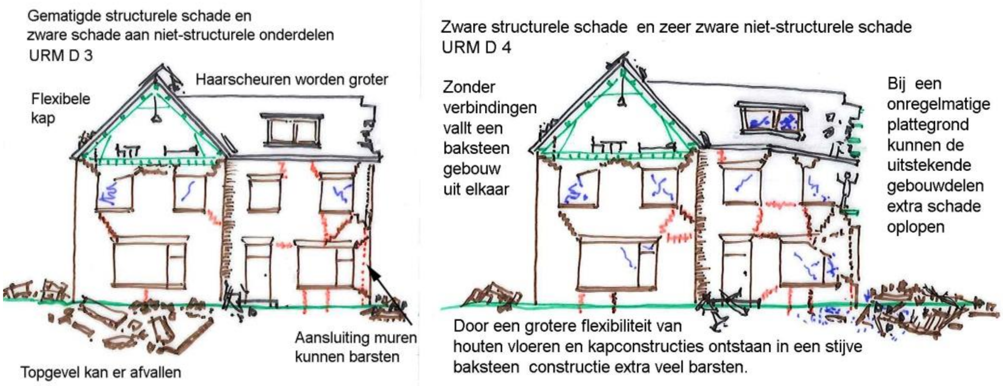


Figures 22. These three: DS1, DS2 and DS3 are in the NPR. Mainly DS1 has been shown in the province Groningen. The necessary seismic strengthening according to the NPR is to prevent D4 (partial collapse).

<u>Left below.</u> Gematigde structurele schade en zware schade aan niet-structurele onderdelen = Moderate structural damage and large damage to non-structural elements. Flexibele kap = Flexible roof construction.
Haarscheuren worden groter = Thin cracks are becoming larger.
Topgevel kan eraf vallen = Gable top may fall.
Aansluiting muren kunnen barsten = Connections between walls can break.

<u>Right below.</u> Zware structurele schade en zeer zware niet-structurele schade = Large structural damage and heavy non-structural damage.
Zonder verbindingen valt een baksteen gebouw uit elkaar = Without connections a brick house will fall apart.
Bij een onregelmatige plattegrond kunnen de uitstekende gebouwdelen extra schade oplopen = With a non-regular floorplan the protruding building components may receive additional damage.
Door een grotere flexibiliteit van houten vloeren en kapconstructies ontstaan in een stijve baksteen constructie extra veel barsten = Because of the lager flexibility of timber floors and roof construction, an additional number of cracks will appear in the ridged brick masonry.

DS2 only exists in Groningen when the building has been erected according to old standards or if serious construction errors were made.



The NPR reinforcement requirements define that the (partial) collapse of a building must be prevented, because with collapse, there could be more fatalities than the (arbitrarily) determined risk of 10^{-5}. This is the 'safety criterion' that has been established for the new building.

The NPR regulations specify that at the maximum PGA (for the specified area), the building 'Just Does Not Collapse' (Near Collapse state), or the DS4 status is reached. That is excluding chimneys or top facades that may fall off. If you want to strengthen weak houses (uneven foundations, large windows, narrow piers, unconnected timber floors) so that there is no longer any crack-damage or settlement damage at a PGAg 0.05 (NPR after 2020), many serious technical reinforcement measures will still be necessary. Those reinforcement measures to prevent cracks will be far more extensive and expensive than just seismic reinforcement for old brick houses (to avoid collapse). If cracks are to avoid all together, the best option is to place the building on Base-isolation.

If you were to reinforce a building based on a PGAg 0.36 (maximum earthquake version NPR9998: 2015), then you would probably not suffer any damage with an actual earthquake type Huizinge (PGAg 0.085), because that reinforcement value is 4X as high as the maximum force. In brittle brick buildings it will remain very difficult to prevent light cracking in the brick facades.

Thus, "slight reinforcement" to prevent damage at a low PGAg 0.05 or PGAg < 0.1 is not necessarily strengthening less to prevent collapse at a PGAg 0.36. It is smart reinforcement so that foundations and wall repairs take place in such a way that they do not crack again.

A new problem[34] for the citizen with house damage was developed early 2021 because of the thousands of Strengthening Advice (SA) that were calculated by the engineering companies.
These SA's were created with the NLTHA method and based on far too high 2017 NPR-PGA-values[35]. According to those old SA's, the reinforcement costs could be many tens of thousands of euros per house, up to over 100,000 euro and millions of euros for monuments. If the citizen accepts these SAs, then of course the house is reasonably strengthened with a largely reduced risk of any damage.

However, if the citizen has the house reassessed against the latest NPR9998:2020 PGA value, no reinforcement will be needed (as it will not collapse), and that citizen can spend euro 30,000 himself. In the case of light earthquakes, damage will still occur, existing damage can increase, or earlier cosmetically repaired wall sections can crack again. In that case, however, the damage assessment and repair procedures must start all over again.

Diaphragm

The diaphragm or floor diaphragm is the connecting floor element in a building that connects all load-bearing parts (inner walls and the inner side of the cavity wall or the brick outer wall) of a building. The functioning of the continuous and all sides connected floor diaphragm ensures that the walls cannot come loose from these floors. Installing a floor diaphragm (improving the connections of all floors to all walls) is especially important for the first floor; this is often the attic floor in low-rise houses.

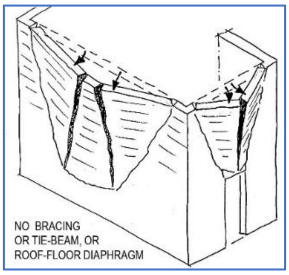
With a rigid floor slab (reinforced concrete floor) or horizontal disk (diaphragm), during an earthquake, several walls are loaded perpendicular to their plane. Perpendicular to the plane of the wall it has very little resistance. The horizontal forces, resulting from the building mass and the floor are transferred to the side walls, which are then loaded in the plane of those walls. The stiffest walls then take the largest loads. See Chapter 9.

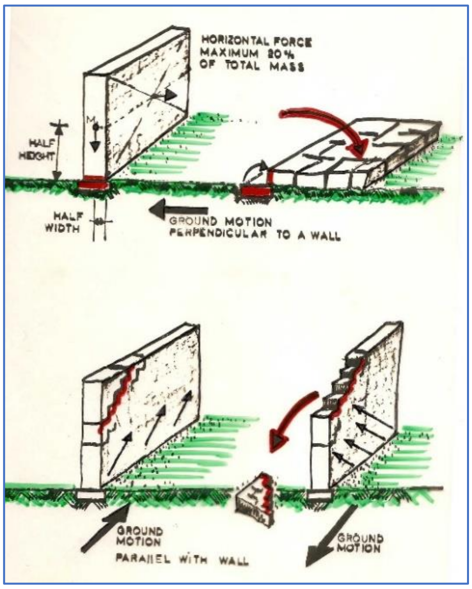
[34] This was because of the new regulations that were presented in the 'Bestuurlijke Afspraken Versterking Groningen' (Management agreements strengthening Groningen) of 6 November 2020 with agreements about expenses, indemnities and reimbursements.
[35] The making of a SA's for a simple house would cost euro 20.000 and were produced on the basis of older seismic data from the NPR-map. They had no relation with the latest seismic maps of the NPR, because based on the real seismic values nothing would collapse.

Figures 23. <u>Top sketch</u>. With an earthquake, the basis of a wall suddenly moves with the PGA. The mass of the wall has an inertia, represented by a force. When this force is perpendicular to that wall, it will try to push over that wall.
The pushing over of the wall is prevented by a floor that is connected to the top of that wall. That floor must be connected to side walls, to transfer the building load back to the foundation.

<u>Lower sketch right.</u> When the earthquake force is in the length direction of the wall, that wall can easily withstand the force.
However, when the wall is made from loosely piled blocks, the top blocks may fall off.

<u>Left sketch</u>. Lack of a diaphragm will cause the topside of unsupported wall to break outside their plane.

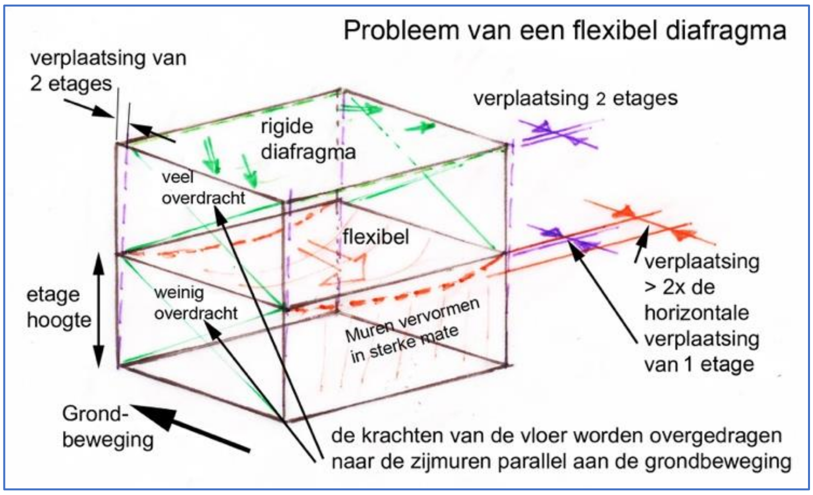




Verplaatsing van 2 etages = Displacement of two storeys. Etage hoogte = height of storey.
Veel overdracht = large transfer (of forces). Weinig overdracht = Little transfer. Grond beweging = ground movement.
Verplaatsing > 2x de horizontale verplaatsing van de 1 etage = Displacement > 2x horizontal displacement 1st floor.
De krachten van de vloer worden overgedragen naar de zijmuren parallel aan de grondbeweging = The forces from the floor are being transferred to the side walls, parallel to the ground movement.
Muren vervormen in sterke mate = walls deform in great extent.

Figure 24. A rigid diaphragm will transfer maximally the forces from the floor to the side walls that are parallel to the ground movement and strong in their plane.

A flexible diaphragm will deform strongly in its own plane and will greatly stress and deform (crack) the front and rear wall.



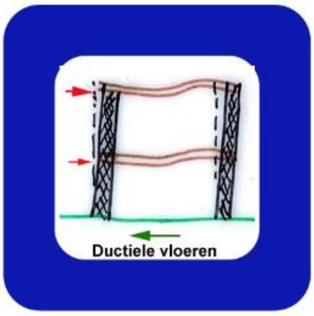
A **flexible** diaphragm is a (floor) plate or disc that has a horizontal deformation over its length that is twice the horizontal displacement per storey height (orange).

A **ridged** diaphragm is a very ridged (floor) plate or disc that has a horizontal deformation over its length that is at most half the horizontal displacement per storey height (for example, a reinforced concrete floor).

A **stiff** diaphragm is in between a rigid and flexible diaphragm (elements with rigid and through-screwed plating such as plywood).

In the vertical plane, the floors must NOT be stiffer than the connections to the load-bearing walls or columns. If the floors or diaphragms are stiffer/stronger than the columns, this will result in an increased load on the columns in the event of an earthquake, just below and above the ridged floor, where the maximum moment zone already exists. This can endanger the columns if the load is too great. When the walls or columns give way, a building will collapse, not when floors collapse.

Te stijve vloeren = Too ridged floors   Ductiele vloeren = Ductile floors



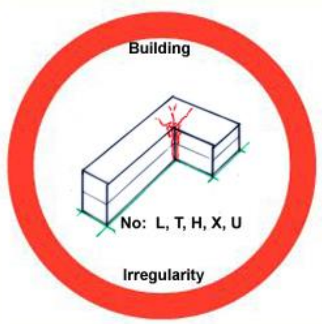
Figures 25. Left. The wrong design/situation with ridged floors and flexible columns (red.)
Middle. Good design/situation with strong columns and flexible floors (blue).
Right photo. With the failure of columns, the entire building will collapse, and the building will pancake.

Dilatation of a building

Buildings with an irregular long floor plan or other long wings on a building, or with different flexibilities of the building sections (large truss farms and churches), must be dilated to prevent undesirably large stresses in the event of earthquakes. Buildings with L, T, H, X and U shapes must be checked for these aspects.

Figures 34. Large timber truss farms have stiff masoned front buildings and must be dilatated between the different masses and flexibilities of those masses.
Lack of dilatations between building parts caused a lot of building damage in the province of Groningen.

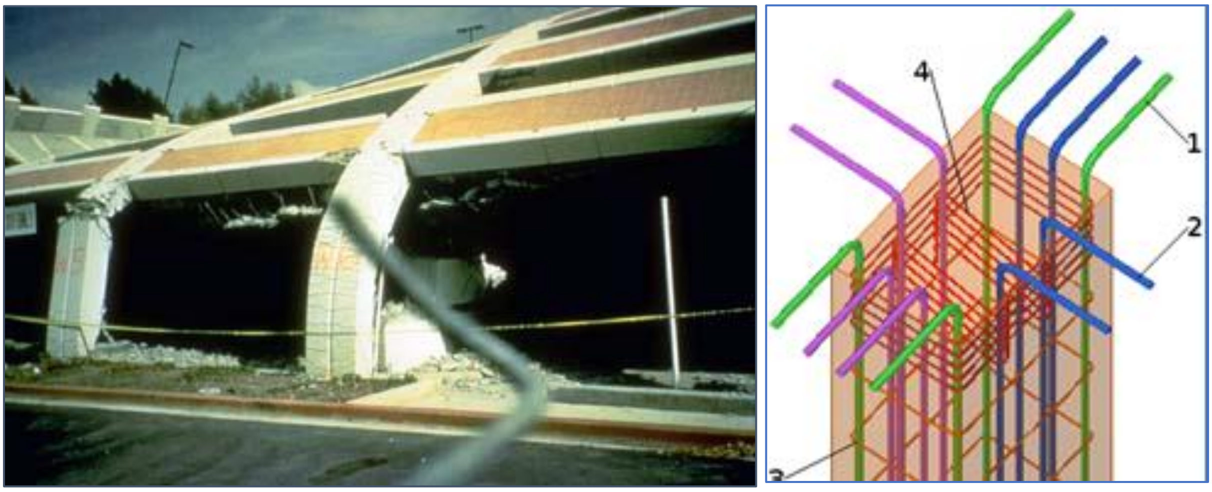
Left. Elongated buildings or buildings with side wings without dilatations can suffer major damage at their inside corners in the event of tremors. Dilating extensions or side wings prevents such damage.
Right. Example of cracks in the inside corner of an L shaped building.



Ductile

The capacity of a material or building to withstand repeated and irreversible non-elastic deformations, while maintaining a very large portion of its maximum load-carrying capacity or resistance. The best-known material is metal which can withstand even higher tensile force beyond the elastic limit. See the tensile diagram of steel.

Due to the non-elastic deformation, a large part of the earthquake load will be absorbed. In reinforced concrete structures it is important that the combination between the tensile strength of the steel and the compressive strength of the broken concrete is maintained as long as possible. To achieve this, many close positioned reinforcement bars are located around the maximum moment areas, that will contain the broken concrete is the maximum resistance of the concrete has exceeded.



Figures 35. (Internet photo) Ductile columns of a parking garage. The earthquake load on these columns was much higher than the calculated strength. Ductility is achieved by both the material used (bendable steel) and the way in which the reinforcement forms a basket in the maximum moment zones, so that the concrete remains within the basket and does not lose its compressive function.

Designing buildings in tectonic earthquake zones continues to pose unknown risks. By designing the structures ductile, total collapse will not occur in the event of too heavy load (than the design) or repeated shocks and failure. The basket construction in the maximum moment areas keeps the broken concrete in place so that it can still absorb pressure.

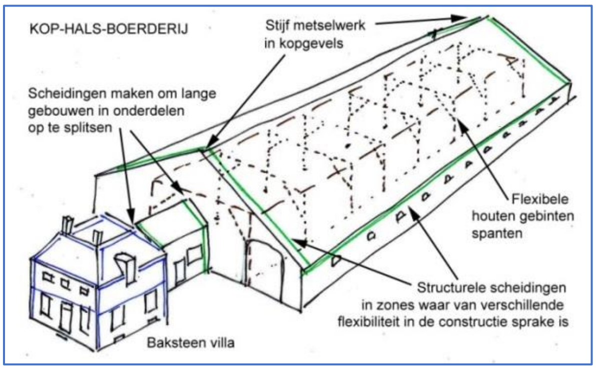
Brick is a brittle or non-ductile material and will crack if overloaded. This is especially the case with the sudden short shocks of the Groningen earthquakes, but this has no constructive consequences when for cracks < 2 mm. To prevent this kind of damage, only Base-isolation or excessive reinforcement is an option. Alternatively, the damaged brick wall can be insulated and re-clad with a slightly flexible material such as wood or glued brick slips.

Figure 36. Brick slips can be produced in many (including classic) designs and glued to thermal insulation boards. By adding them with a slightly flexible component adhesive, the load-bearing construction can move slightly without this being visible by cracks in the outer facade.
Retrofitted houses will be well insulated and show no more cracks in their facades.

Dynamic independent unit {Eurocode 8: 1.4.2.10}

Part of a building structure that is directly subjected to ground motion and whose response behaviour is not influenced by the (response) behaviour of adjacent units or building structures. Buildings with a highly irregular floor plan should be dilated and each part of that building should be calculated as a separate (independent) unit.

Dynamic independence is a fancy term for a dilated construction. Unequal building parts (high and low) or adjoining building parts with unequal stiffnesses must be able to move independently of each other during an earthquake. This is because the height of a building influences the vibration frequency of that part of the building.



Figures 37. <u>Left:</u> By dividing a traditional head-neck-trunk farm building into three parts: the house, the intermediate piece and the barn, each part has its own dynamic independence. In this way, damage between the differently shaking building components is prevented. The different parts with their different stiffness can be calculated as independent units and each reinforced in its own way.
<u>Right:</u> This traditional head-trunk farm built as fully connected must be disconnected behind the head of the more flexible large-truss barn to prevent damage to both buildings.

The (old) brick head-house (*Figure 37 right*) has a different height, mass, rigidity, and function from the large timber truss barn which is a very flexible and hollow construction. This shed will therefore move differently from the main head building during an earthquake. The old house can eventually be placed on Base-isolation when it is a monument, or it must be considerably reinforced throughout. Chapter 2. Shape of buildings.

Earthquakes

Earthquakes are ground tremors caused by sudden shifting or sudden deformation of rock masses in the deep underground. The sudden shock movements occur along fault lines in the earth's crust, tens of kilometers deep, where continental crusts press against each other and suddenly shift by which tensions are released (tectonic earthquakes). Fault lines also occur in the natural gas-containing sandstone layer 3 km deep under the province of Groningen and the North Sea. When pressure differences arise in that sandstone layer because a large amount of natural gas is extracted quickly on one side of the fault line and not in another zone, an elastic compression is first created in the sandstone layer. When this deformation exceeds the compressive strength in that zone, the structure of the sandstone pulverizes with a shock that vibrates to all the surrounding rocks[36]. At the earth surface, people often hear a bang and when strong enough can feel the vibration. Because the natural gas in the province of Groningen is extracted by humans, these quakes have no natural cause and are called ‘induced earthquakes.’

[36] See: https://en.wikipedia.org/wiki/Elastic-rebound_theory

Zoutsteen = saltstone
Zandsteen = sandstone
Grondlagen = soil layers
Breukvlak = fault
Elastische vervorming pletten = elastic deformation compaction
Vervorming = deformation
Drukt samen = compression
Vervormt niet = does not change in shape
Uitstraling beving = progression of shock

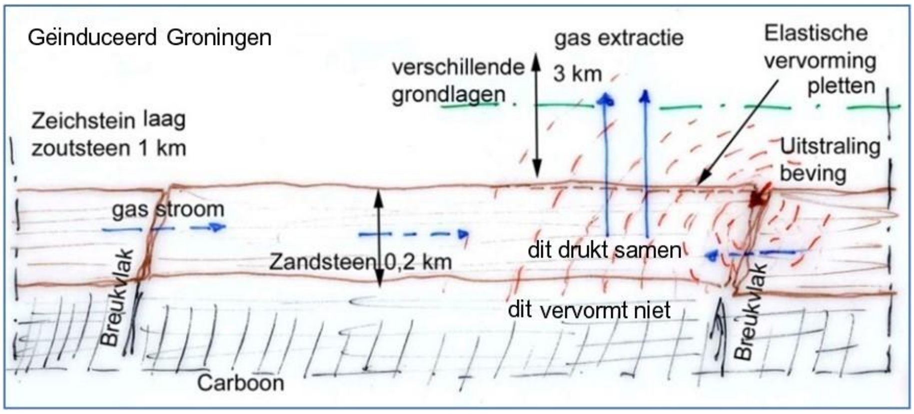
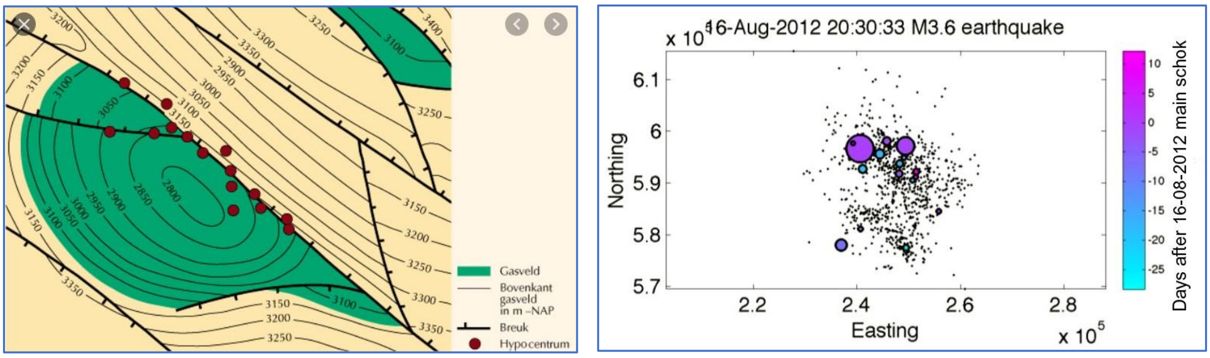


Figure 38. Induced earthquake. The rapid extraction of natural gas from the porous sandstone causes a local pressure reduction inside that sandstone layer on one side of a fracture or fault line. The upper pressure remains the same and causes elastic compaction of the sandstone. The carrying capacity of the sandstone layer is reduced because of the lesser internal gas pressure. Due to the constant weight of the 3 km soil layers, the sandstone is suddenly crushed when the combined carrying capacity is exceeded (stone + pressure), causing a short shock wave. The same will lead to small soil settlements above the tough salt rock layer of the Zechstein.

All rocks are a little elastic. A long and thin piece of marble or granite can bend slightly. When the deformation due to pressure or bending has reached the elastic limit of the material, it will break. This releases the built-up tension. The vibrations released during the fracture propagate as shock waves in the rock and soil in all directions. One shock often triggers immediately other shocks. In that case, the earthquake continues and feels longer. Because the shock causes the building to vibrate, most (elastic) structures will continue to vibrate for a while, making it seem to the people inside the building that the earthquake is lasting much longer.

Seismometers can record these tremors or earthquakes on the Earth's surface. The KNMI has set up many measuring stations across the country[37]. The vibration signal can be graphically displayed as a seismogram. Seismometers have been placed in boreholes deep under the earth's surface in Groningen to register the lighter (induced) earthquakes caused by the gas extraction from the 200 m thick sandstone layer.



Figures 39. Left: Depth lines/contours and measured locations of the shocks (Hypocenters) along a fault line[38]. Right. The main and aftershocks of the Huizinge 16-08-2012 earthquake. These show that in the next four days many small extra shocks/settlements occur all around the main shock. These small settlements (shocks that cannot be felt by people) also occur above the tough salt rock layer (about 1 km thick) and affect the ground level. These smaller shocks/vibrations, however, do have an impact on the soil surface and can negatively affect the build environment, causing cracks in brittle masonry.

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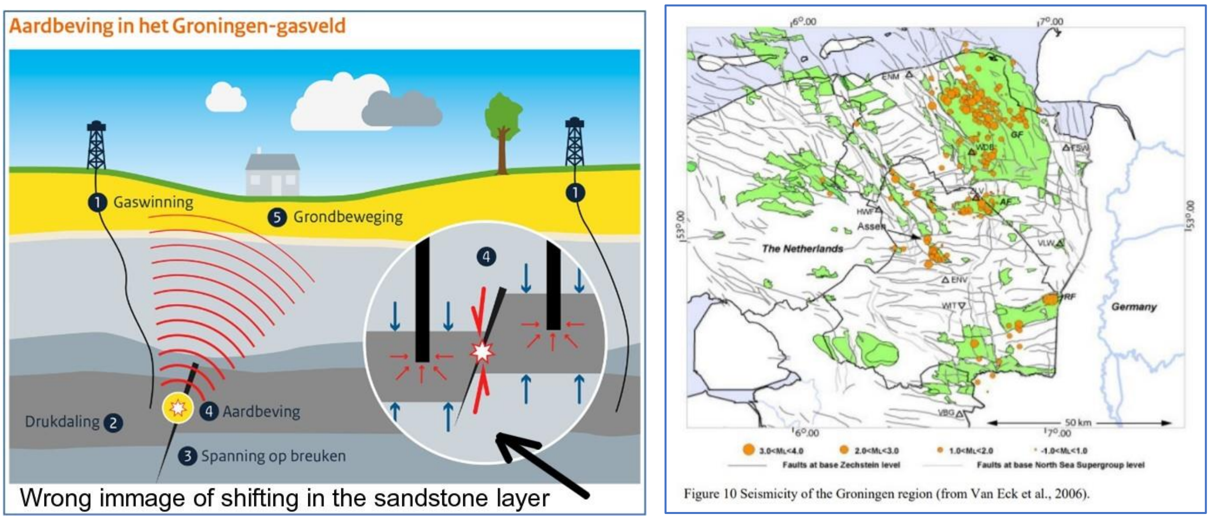
[37] To better measure the effects and characteristics of the earthquakes dozens new measuring points were installed by the NAM, KNMI and the TNO (Independent Netherlands Research Institute).
[38] Source: De Groene Rekenkamer. The Green Calculator. Detail of registrations over the entire gas field.

The deep placement of seismometers prevents interference from vibrations at the earth's surface (pile-driving for new buildings, heavy traffic). Since 2014, vibration meters have also been installed in the foundations of a few hundred homes in the province of Groningen[39]. A few 3 km deep vibration meters have also been installed. The KNMI network consists of borehole geophones (up to 300 m depth), accelerometers and broadband seismometers.

Aardbevingen in het Groningen gasveld = Earthquakes in the Groningen gasfield



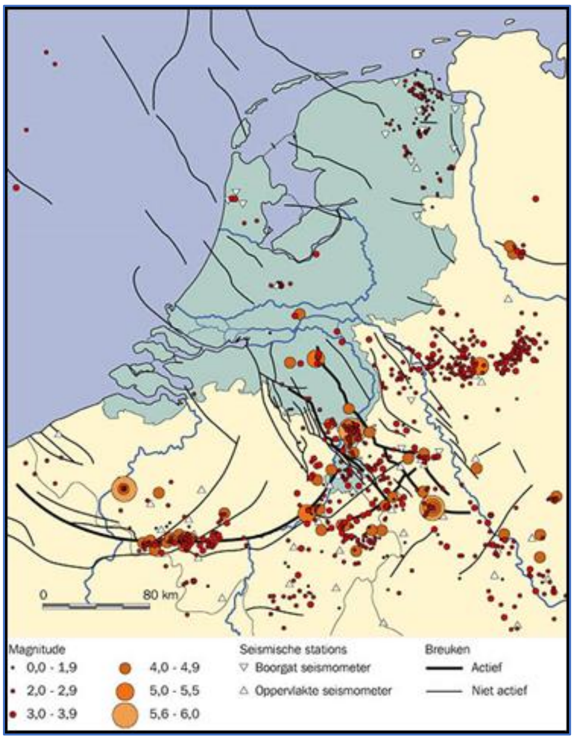
Figures 40. Left: Example of a misrepresentation of the fault shifting process as presented in various publications and by the KNMI about the origin of the induced earthquakes. This image is copied from tectonic earthquakes. This image suggests that the underlying Carboniferous layer is pushing up along the fault lines. This is not the case, only the gas containing sandstone layer is compacted/crushed.
The image also suggests that there is subduction over the area the sandstone is pressed upwards.
Right: Already in 2006, this detailed map was made of the then known fault lines in the sandstone layer, which extend below the North Sea and probably connect all small gas fields to some extent. Research shows that the fault lines come from the Carboniferous and continue higher into the sandstone layer. The Carboniferous, however, is not pushed down, only the sandstone layer is crushed.

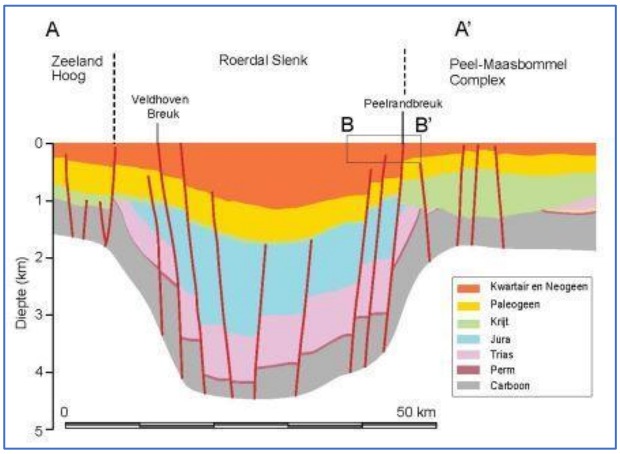
Earthquakes in the Netherlands

Soft peat soils and elastic clays react very differently to earthquakes compared to rocky soils. In elastic or soft soil such as peat, long-lasting earthquakes can have a so-called ‘acceleration effect’ or, in the case of quicksand, can cause ‘liquification’. This liquification does not occur in the Netherlands due to the short duration of the induced shocks (maximum a few seconds). For the same reason the acceleration effect does not exist.[40] Soft soils slow down and absorb the short sharp Groningen shocks a bit; the latest PGAg card takes that into account[41].

There is no established definition in The Netherlands of what constitutes an earthquake and what constitutes a tremor. In general, one can say that vibrations are those that are not directly felt by humans (Mw <2.4 or PGAg <0.04) and lasting shorter than 1 second. When the shocks are larger, the surface vibrations and building resonance will last longer and will be felt earlier by people. However, both tremors and vibrations do influence foundations and can cause damage.

[39] In a later stage also tilt-meters have been fitted to buildings with other measuring options and functions
[40] When in 2013/2014 the extreme high PGA was proposed, the option emerged that an acceleration effect could be possible, requiring also substantial strengthening of buildings remote from the epicentre.
[41] The estimated annual settlements are about 1 to 1,5 cm/year. In the centre a subsidence of 60 cm has occurred in 50 years since 1970, the beginning of the gas exploitation.





Figures 41. Above. Map KNMI earthquakes 1900-1996 with tectonic and induced quakes (top of the map). Right above: Jan Timmers LR with a cross-section of the Peel edge fracture below the main rivers in the map. Tectonic earthquake Roermond.
https://www.deurnewiki.nl/wiki/index.php?title=Peelrandbreak

Photo from after the earthquake 13-04-1992 in Roermond where the ground sank locally by 60 cm. Despite their relatively low magnitude, on the Richter scale of up to 3.6 (PGAg < 0.1), the gas-induced earthquakes are strongly felt. This is due to their shallow hypocentres. These induced earthquakes rarely last more than a fraction of a second, but buildings on the surface vibrate because of the clay and peat soil layers and their own elasticity. In fractures that are mainly in the sandstone layer, such as in the province of Groningen, the subsidence differences at the earth's surface will be small, only millimetres. When in a brick masoned building one part of the foundation settles 2 mm, then a 2 mm crack will occur in the brick wall, being very visible in plasterwork.

Between 2012 and 2015, foundation damage was barely/not acknowledged[42] by the NAM. To clarify the type of vibrations that can cause building damage, a Vibration Guideline SBR-A2017[43] was drawn up in 2017. This Vibration guideline states that buildings can withstand a certain amount of vibration without sustaining damage. However, such statement applies to new buildings, not 100-year-old.

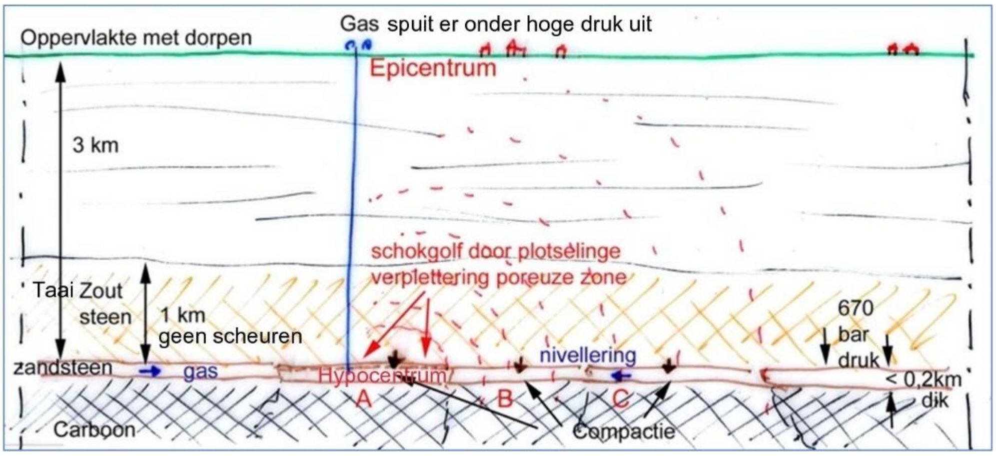
[42] This was initiated by the NAM who wanted to exclude foundation damage to limit expenses. Also when in 2014 the identification and inspection was carried over from the NAM to the CVW (Centrum Veilig Wonen, Centre Safe Housing) the apparent NAM instruction was to disregard foundation damage. This caused serious miscontent of the homeowners and resulted in many arbitration cases, all to be paid for by the NAM.

[43] SBR. Stichting Building Research. Report developed in 2017. The idea of the report was that tremors under a certain value were not subject to financial reimbursement or repair as common buildings would not be affected, unless these were already in a poor state of maintenance. The effect of that guideline was that damage claims outside the sandstone/gas field or the province of Groningen would practically be excluded from financial compensation, this being the objective of the NAM. However, many centuries old brick buildings with weak foundations can still suffer earthquake damage from light tremors and settlement. The disputes about repair and financial compensation continued despite the SBR-A2017 guideline.
https://www.building.nl/uploads/fckconnector/bbb3c9ac-bf69-4a11-ad06-95a88aeca916/3016759984

The soil consists of various layers of earth, such as the gaseous sandstone layer (≈200 m thick), on top of which a sealing salt layer (≈1000 m thick), and on top of that 2 km of other soil layers.
By extracting natural gas, the internal gas pressure decreases locally in that sandstone layer, causing it to be compressed; this is called compaction. This will lead to subsidence at the surface, which will take place very gradually over the entire province of Groningen and will not be felt. This subduction is precisely measured annually with the aid of satellites because it does have a major influence on the groundwater level, canals, sewerage systems and dikes[44].

Oppervlakte met dorpen = Surface with villages. Gas spuit er onder hoge druk uit = Gas is expulsed under high pressure. Geen scheuren = No cracks. Schokgolf door plotselinge verpletting poreuze zone = Shock wave by sudden crushing of the porous layer. 670 bar druk = 670 bar pressure.

Figure 42.
The sketch has been drawn in the correct height ratio for the sandstone layer.



Buildings at the epicentre experience most the vertical shoch impact.
Buildings that are more than 3 km horizontally from the epicentre experience more the horizontal impact from the shocks. The tough salt stone layer levels out the settlement over a wider area. A settlement of ≈ 60 cm takes place over the entire area over the 50 years, corresponding to the compaction in the sandstone.

Earthquake resistant {Euro code 1.4.2.22}

According to Eurocode 8, buildings are earthquake-resistant if the chance of casualties due to partial or complete collapse is sufficiently small[45]. This does not mean that no damage will occur. A building designed to withstand the theoretical maximum earthquake will JUST NOT collapse at this theoretical maximum earthquake, if built or reinforced according to the calculations.
However, the building will then be in a 'near collapse' situation. In such a case, the building will usually not be economically repairable.[46]

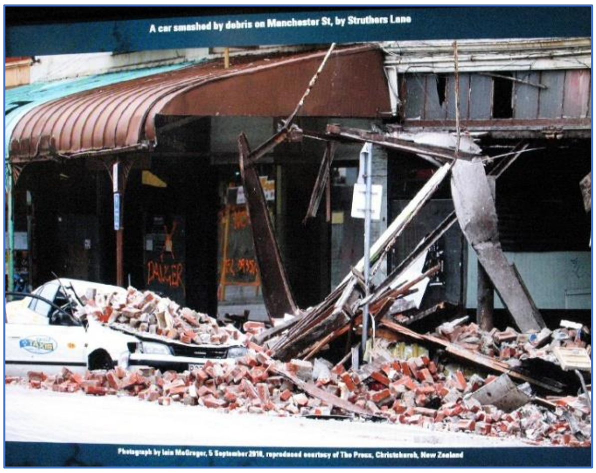
The assumed risk in the ‘Near Collapse’ situation (tectonic) is 1:100,000 or 10^{-5}. This means that in 100,000 buildings, one building (per year) may still collapse with fatal consequences. For Groningen province with > 200,000 buildings, that would mean > 2 collapses per year. However, with an average of 4 people to stay in a building, it means possibly 8 casualties (deaths) per year. The question is whether you can also apply the same (low standard) for induced earthquakes because these are

[44] Also see the map with ‘Subduction’ caused by the shrinking (drying out) of the peat soils.
[45] For new construction (>1992) this risk is 1:100,000. For buildings after 2012 the risk is 1:10,000 being larger.
[46] In some cases, the suggestion was made in Groningen that the building was ‘safe’ when during the earthquake the occupants of the house would be able to evacuate the building in time before it would collapse. This, however, is a totally wrong interpretation of the seismic code. Moreover, in the case of the induced earthquakes of Groningen the one-second shocks or earthquakes would not allow the house occupant to go anywhere during the earthquake. Running outside would cause a serious risk of falling gable elements.

deliberately caused by the commercial gas exploration company[47]. A smaller risk standard of 10^{-6}, as applies to the Dutch seawall and dikes, would be more logic and a lot safer.

Earthquake resistant does NOT mean that there will be NO damage at the maximum quake. On the contrary, it means 'almost collapsed', also except for falling gable tops or chimneys, because (according to the code) they are still allowed to fall and cause fatalities. People who try to run out of their homes when the earth shakes, can be hit by falling debris from facades[48]. Gable ends falling into the street caused the most fatalities during the Christchurch New Zealand earthquake.

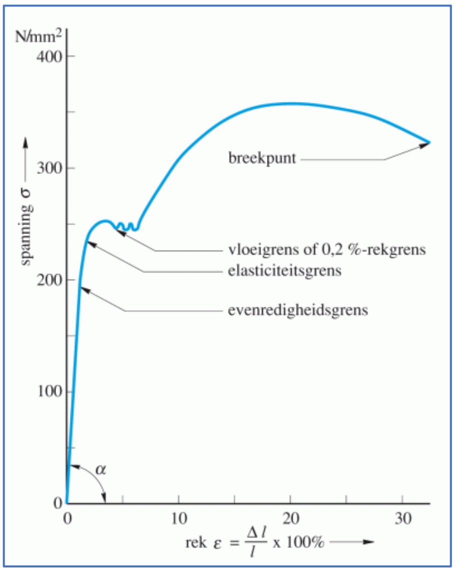
Figure 43. During the earthquake of February 22, 2011, in Christchurch, New Zealand, the tops of storefronts fell into the street in the middle of the day, killing dozens of people.
Running out of the house during an earthquake is rarely a good idea.
During the very short, induced tremors in Groningen of one or a few seconds, there is no time to leave the house.



A new-build home built in accordance with the 2012 Building Decree can withstand 30% to 50% higher loads than for which it was designed. This is because most construction standards for materials have a margin of safety built into them. The material standard often corresponds to the lowest value of a large series of tests, not the average. When calculating reinforced concrete structures, there is an extra safety margin on top of the material strength. Metal construction parts and the reinforcement in reinforced concrete are ductile (tough), so that they can still absorb high loads after deformation.

Evenredigheidsgrens = proportional limit
Elasticiteitsgrens = elasticity limit   Vloeigrens = liquefication limit
Breekpunt = point of separation

Figure 44. Tension diagram of steel. From architecture book.
The calculation standard is the proportional limit of the steel, where the elongation has the same % as the increase in tensile force.
This proportional limit of 200 N/mm² is used in the calculations, while the elastic limit is up to 230 N/mm². However, after deformation, the steel can still withstand a load of up to approximately 350 N/mm², almost twice the calculation standard.
To a lesser extent, this phenomenon also occurs with other building materials.



[47] The overarching issue here is that under current law in The Netherlands it is not allowed (with the realization of works, such as gas exploration) to cause damage to properties of others. Causing intentionally bodily harm to citizens because of collapsing houses is worse. Effectively meaning that the NAM may not continue to extract gas with the result of very heavy earthquakes that can cause collapse. In that respect, to suggest that the earthquakes can reach the extreme PGA strength as predicted by the KNMI is irrational.
[48] With a tremor of < 3 seconds it is impossible to realize there is a tremor and after that escape in time from the building. It is more safe to find a strong corner in the building or dive under a strong table.

Because earthquake-resistant renovation can be an extensive and expensive intervention, it can be decided to reinforce at least to the strength of the 2012 Building Decree or to 50% of the NPR 9998:2020, whichever yields the highest reinforcement. This is based on the above insight, that the new building standard is stronger than the net strength requirement.

To be able to make such a decision, it is necessary that the net material strength in the building is known, and a good analysis of the existing construction is made. The latter is difficult and costly in old buildings[49]. Each construction period in the Netherlands has its own construction method or typology; post-war housing is thus divided into blocks of ≈ 20 years.

During the many years that these older houses were inhabited, renovations were carried out and parts were added according to different building standards. Cracks invariably form between old construction and extensions when they are not properly dilated, while open kitchens can weaken the entire building structure against seismic loads.

By studying in detail a few similar buildings (same typology) from a certain construction period, it can be determined with reasonable certainty what the building strength is of all those buildings in that typology category, and what needs to be improved on such a building to make it earthquake resistant, create or strengthen.

Based on this concept, detailed calculations, and reinforcement recommendations (Strengthening Advice) of 60 housing typologies have been made by TNO since 2018, according to which the damaged homes could be repaired or strengthened. However, the 2018 PGA-values on which these calculations are based are still very high and the content of those recommendations (SA's) were not accessible to the public at the beginning of 2021[50].

Earthquake resistant new construction

This is the design and construction of the main supporting structure and the rest of the building according to existing earthquake code or guidelines; the Eurocode 8 indicates this. This Eurocode was translated into Dutch[51] in 2013-2014 into the NPR 9998:2015. However, the earthquake zoning with PGAg was based on the 2014 assumption about the theoretical and greatly over-estimated maximum earthquake strength.

After all, the forces of the shocks are related to the method of gas extraction. If the gas extraction method and speed changes further, as extraction was first spread in 2015 and then reduced several times (Wiebes 2018: "Tap closed in 2030 or earlier"), the vibrations will decrease in strength, duration and frequency. The NPR9998:2015 has therefore been amended several times[52].

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[49] To calculate this approximately with the Non-Linear-Time-History-Analysis (NLTHA) method, a home is extensively analysed and calculated, which can cost 2-3 weeks and more than EUR 15,000. On that basis, a reinforcement proposal can then be made (another EUR 5,000). At a maximum quake PGA, the building will still tear very heavily, but just not collapse.

[50] The reason why these calculations were not made accessible to the public was not given, adding to the public mistrust about these calculations. TNO operated here as a commercial entity, requiring payment. Using higher seismic loads than in reality will make a building stronger than required by the real seismic forces; it will make the risk for cracks smaller, although this is very limited with ridged brick constructions.

[51] It was unclear why that Eurocode 8 was translated and improved upon, because the code was fully adequate for the light earthquakes in The Netherlands, besides all technical personnel such as engineers who would be working with that Eurocode 8 could perfectly understand the English version.

[52] The latest version of the NPR is NPR 9998:2018+C1:2020 (nl), and can be downloaded free from: https://www.nen.nl/NEN-Shop/Norm/NPR-99982018C12020-nl.htm

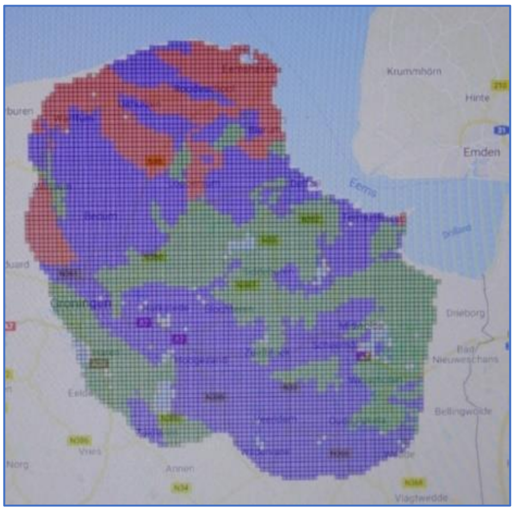

Figure 45. Example from Home Webtool NPR9998:2018.[53] *Instead of periodic changes, since 2020 the Home Webtool NPR9998 has been used to determine the PGA-forces, which shows the expected maximum PGA per location with horizontal and vertical factors for 95, 475, 975 and 2475 years.*[54]

For a return period of 95 years, the highest PGAg on this Web tool as of May 2020 is = 0.085 including the ground factor, and equal to the strongest earthquake on 16 August 2012 in Huizinge with Richter magnitude 3.6.
Since the sharp reduction in gas exploitation, the highest earthquakes are << Richter 3.6 (PGAg of << 0.1).
In the peripheral areas outside this map, the PGA can be < 0.05, at which point seismic calculation is no longer necessary.
Actual map on https://seismischekrachten.nen.nl/map.php

The NPR9998:2020, and the linked Design Guidelines for Earthquake Resistant Construction are no obligatory instructions. Also, there is no obligatory legislation tot that respect [55].

If one were to assume the existing standards or legislation, the supporting structure of the building must comply with the applicable Building Decree 2012 (with amendment of July 2013 for storm load). That is considerably less demanding than the NPR9998:2020.

The maximum PGA was end 2013 established [56] on PGAg 0,42 being **5 X** the Huizinge earthquake.
In 2015 this was lowered to **4 X** the Huizinge PGAg 0,085, becoming PGAg 0,36.
The Building Decree refers to the Eurocode 8 for earthquake-resistant construction, but the Eurocode 8 also refers to the national annex (being the map). This latest national annex with the earthquake zoning map can now be found on the website.

Earthquake resistant reconstruction

Earthquake reconstruction[57] or retrofitting of the main supporting structure in accordance with the Design Guideline for Earthquake-Resistant Buildings must be based on the NPR9998. The zoning map of the province of Groningen was replaced in the September draft version NPR9998:2017 by a map that also defines the upper 30 m. This upper layer of soil, including the groundwater, determines the acceleration of the earth's surface because of a shock in the hypocentre; the shear wave velocity (Vs;30). The calculation values will differ per location and therefore per soil type. The latest NPR9998:2020 with the Home Webtool C1:2020 is now implemented as a mandatory calculation method. The latter NPR also remains on the high (conservative) side and is dependent on the development of the remaining (gas exploitation) activities in the subsoil.

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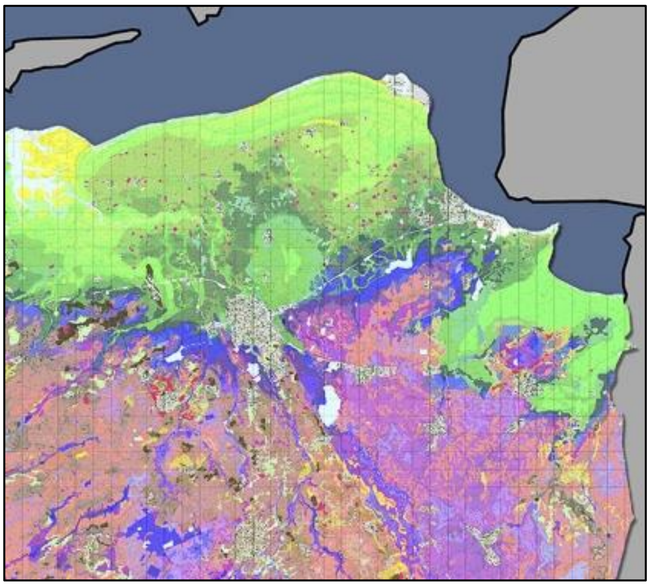
[53] See : https://www.nen.nl/media/PDFjes/Achtergronddocument_NPR_9998_webtool_module_7__2020-07_update_2021-01.pdf
[54] The notion that theoretical calculations have been made for 2475 years illustrates the tectonic origin, because gas exploitation is already reduced will be finished in about 20 years at the most.
[55] The NAM and the NCG, however, demanded that engineers calculated with these high seismic values.
[56] The word 'established' is used because likely no real calculations were used. It was suggested that first a 2,5 X safety factor was applied (2,5 X PGAg 0,085 = PGAg 0,2125) and after that multiplied with 2 for extra safety, because they were 'not very sure about anything'. The result was 2 X 0,21 = PGAg 0,42.
[57] The terminologies 'Earthquake Resistant Reconstruction', Safer buildings and Retrofitting were introduced by the Minister of Economic Affairs on 15-08-2015 by means of a letter to the Groningen 'Discussion Platform'.

Figure 46. The accompanying soil map of the province of Groningen and the surrounding area indicates the most important soil types.

This map from NPR-2017 with the shear wave velocity Vs;30 indicates the soil types down to a depth of 30 m.

The green and light green areas (clay soils) in the NPR map give the highest values for Vs;30 and therefore also for the PGAg.

The purple, firmer soils give a lower value for the Vs;30, which means that the quakes are also less strong and can last shorter.



If "only" the current 2012 Building Decree would apply to the renovation of existing buildings, then reinforcements will usually be required for old buildings from before the 1992 building legislation to meet the standard value of the NPR9998 [58].

With a large reconstruction or renovation are mandatory sustainability and durability measurements necessary[59]. In The Netherlands, per January 2021 the BENG is applicable. Bijna Energie Neutraal Gebouw = Nearly Energy Neutral Building. The BENG specifies a maximum energy use of 25 kWh/m^2 usable floor surface per year of the building. See also under BENG.

To seismically reinforce a 1970s terraced house in the province of Groningen of 120 m^2 (2014 value < € 100,000) to NPR9998, about € 100,000 may be needed, with only the newly reinforced walls being insulated. An additional € 50,000 may be needed to further insulate this house (roof, windows, ground floor, heat pump) and make it more sustainable according to the 2021 BENG standard. The homeowner will often NOT be able to afford these extra costs, to make the house more sustainable in the long term. The house only becomes stronger [60].

After these interventions, the resulting building (without land in 2015) will then have a market value of < € 150,000, which is why demolition and new construction of old terraced houses is preferred in the current economy. The resulting material destruction by demolition and rebuilding and extra CO_2-emissions are illogical in terms of the national sustainability ambitions.

Older buildings from before the turn of the 1900 century are sometimes monument listed buildings and often may not be modified on the outside. To strengthen monuments according to NPR9998, lengthy approval processes apply, and little modifications may be made to the wall construction. Usually this leads to the costly Base-isolation. See the Chapter 5.

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[58] Since 1965 the model-building-instruction 1992 of The Netherlands Municipalities (Vereniging Nederlandse Gemeenten) was reviewed. Among others the wind-load factor which is determining for building strength
[59] See for new built: http://atriensis.nl/nieuws//459/strengere_eisen_isolatie_nieuwbouw_gevolgen_bij_renovatie
[60] The NAM company did not feel responsible to provide the additional finance for making these houses sustainable, as they felt that their responsibility was limited to only strengthening the building. At the same time, they had extracted for over 400 billion euro's of value from Groningen soil, leaving a sinking land and cracked houses. This attitude is typical of large exploration and mining companies operating in a capitalistic world, where they do not feel responsible for the environmental damage or the deteriorated circumstance of the population, once the mining resource has been exhausted.

Buildings built before 1920 and built on firm or undisturbed soil often have high windows and, with wooden floors, are seismically very weak structures. This means that considerable reinforcements must be applied, starting with the foundation, the load-bearing walls, the making of floor diaphragms, up to and including the roof structure and the chimneys. Even if an aesthetic value is attributed to the building (for example, in the case of a protected town-view or municipal monument), this was considered economically unprofitable [61].

The most buildings do not need to be reinforced if they must meet the Near Collapse rating according to NPR. The NPR, with the Home Webtool values are still conservative in 2020 with between 50% and 100% above the true value. When gas exploitation is stopped, no greater shocks will occur than the 16 August 2012 in Huizinge (Richter 3.6 with PGAg 0.085).

Figures 46. Common terraced houses with and without wide windows and small piers in the lower facades and without moment-resistant floor-wall connections in the longitudinal direction of the building block, belong to the weakest building categories.
Good reinforcement methods are available for all types of buildings, but economic factors play a major role in the decision-making.

These two older buildings (period 1800) are seismically among the weakest construction types.
<u>Left.</u> The ground floor has very narrow window piers and high windows. This type of town building has no interior cross walls for stability that can absorb the transverse seismic load.
<u>Right.</u> This old farm building front-house was purchased by NAM and the occupants relocated based on the 2014 very high PGA-value. The non-cement masoned walls and other aspects considered; it was deemed that the building could not survive several PGAg > 0,2 earthquake shocks that could occur in the next five years.

[61] 'Economic profitable' is used in the context of a similar building volume and user function that can be realised fort the same amount of money. This does not apply for important historic buildings and central government monuments. With these economic calculations the durability or the CO_2-emissions are usually not calculated. If they were, repair retrofitting and recycling would rapidly be more economic.

For monuments and iconic buildings, a reinforcement budget of 150% of the repaired value was applied for the demolition and reconstruction costs. The low market value of the existing building was not considered as it was usually already very low, meaning the market value before damage. Seismic retrofitting according to the NPR PGA-value costs far more than the market value after renovation unless it is possible to apply a cheap type of Base-isolation method. The required and necessary durability improvement such as thermal insulation must still be added to the budget. There were different views/opinions about the costs of the reinforcement process, the procedures to be followed or the regulations of the NCG and IMG; these views differed widely.[62]

Earthquake resistant strengthening

This is the process of strengthening an existing building in such a way that it can withstand the theoretical maximum earthquake without partial collapse (Near Collapse state). The earthquakes must not cause many human casualties (norm 10^{-5}) because of the collapse of building parts or the entire building. Preventing cracks is not part of this strengthening, as is laid down in the ACI-317 and the Eurocode 8, both the basis of the NPR9998. The terminology "strengthening" is therefore an elastic concept. This concerns the entire building including the main supporting structure, the primary construction components, but also the secondary components. It also covers the secondary components such as heavy chimneys on extending gable tops above facades. These elements demand first attention because they can fall in the event of light earthquakes or shocks[63]. These high placed building features are called 'high-risk' elements. Only Base-isolation is an adequate solution to prevent damage to old weak and brittle brick houses. The principle of 'damage-free living', as desired by the population, usually requires more extensive and therefore more expensive reinforcement than seismic reinforcement alone, or the application of Base-isolation, which greatly reduces the earthquake forces on the second (upper) foundation of the building[64].

'Damage-free' for the brittle brick masonry buildings built on solid ground is almost unfeasible as an objective unless one has reinforced masonry throughout the building. This hardly exists in The Netherlands for two- and three-story buildings and is very difficult to implement afterwards.

Scheuren = cracks

Figure 47. Effect on a weak brick house without and with Base isolation.
The whole building is cracking around all openings (danger).
Due to the Base solation, only light forces are exerted on the structure above (safe).
Chapter 5 takes a closer look at the theme of Base isolation.

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[62] See: https://www.nationaalcoordinatorgroningen.nl/binaries/nationaal-coordinator-groningen/documenten/rapporten/2020/06/24/critical-review-over-de-benutting-van-kennis-in-de-versterking/Critical+review+Benutting+van+kennis+in+de+versterking.pdf

[63] When high-risk elements such as a chimney are removed, including reducing the building mass or making a dilatation, the risk of damage is immediately reduced. Relatively speaking, this strengthens the building. However, it did not count as building reinforcement according to the administration (mistakenly). A few thousand houses were improved in 2014/2015, but officially the administration counted only a few buildings that received inside large metal support structures. This created the impression that no progress was made.

[64] The population of Groningen does not want any damage at all, and certainly not reinforcement to just the Near Collapse principle. The difference between the legislation (Near Collapse) and 'no damage' is not clear to most residents. The additional problem is that the stiff and thin brick constructions in The Netherlands are not earthquake-resistant at all and immediately suffer crack damage, also with smaller shocks.

Before reinforcing the building, first an analysis must be made of the current construction and the quality of the foundation base (on firm soil or on piles). Many old buildings often do not have construction drawings available, also over time internal modifications are often made. On the basis of the structural analysis and the NPR requirements, a proposal must be made that should be discussed with the owner and approved by the Municipal Building Authority. In the case of large modifications, the building must be made durable as well with the appropriate thermal insulation. When it is a listed monument, it requires approval from the Monuments Authority.

The various sustainability aspects must therefore be included in a renovation plan, such as thermal insulation of the entire outer shell. When a building has a significant inherent defect, the costs of repairing that inherent defect will have to be discussed with the owner[65].

In the case of seismic strengthening to the very high NPR9998:2015 PGA, or for crack-resisting, many houses cannot accommodate for many months the houseowner and requires temporary alternative shelter (additional cost). All in all, strengthening a building against earthquakes or making it crack-resistant will often take more time and costs than demolishing it and erecting a sustainable (insulated) and stronger new building (lighter, ductile, such as timber frame construction).

Council housing built during the first 25 years after the World War II were not insulated and have small internal dimensions. Even if they have been fitted with double glazing and cavity wall insulation in the meantime, the combination of seismic reinforcement and preservation according to the high standards and economy of the current society is far more expensive than demolition and new construction.

When 15 cm of internal wall insulation is applied in a house with small bedrooms, the bed can no longer fit. Along stairs, kitchen, and bathroom walls, taking 15 cm off also causes problems. For houses that were built in later periods it may be possible to remove the entire outer shell of the cavity wall and replace those with a new well insulated wall, thus not affecting the inside dimensions.

Figure 48. The suburb Opwierde-Zuid in Appingedam. Demolishment of 233 houses for rebuilding. Photo: Gea v Loon, 9-1-2020. Dagblad v Het Noorden.

According to the building standards, new constructions are automatically calculated with a safety margin (part of the material strength value), which means that they are approximately 30% to 50% stronger than the breaking/failure point of the calculated value. For tectonic earthquakes (in the USA, New Zealand), the maximum PGA is also an estimate with a safety margin. For the retrofitting (seismic reinforcement) of existing buildings, tectonic zones often require that buildings that are too weak (high risk of collapse at the maximum PGA) be reinforced to 50% or 2/3 of the desired standard seismic strength. Taking the safety margins into consideration, the building will reach the Near Collapse strength. This will substantially reduce the retrofitting costs for thousands of buildings.

[65] A building from before 1900 was built according to none or different standards than today. This is not an inherent defect (legal term from the insurance world), but the building has in the meantime not been required to conform to the newer or current building standards. The NAM declined to pay for inherent defects.

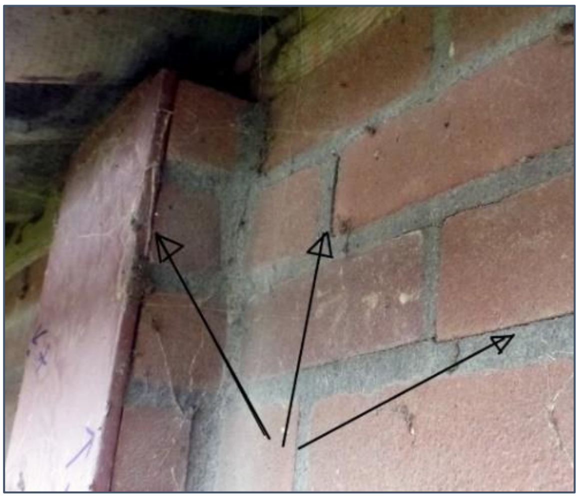
Elasticity

Each material has a certain elasticity that is expressed by the elasticity module or the Young module (within the elastic zone). When the maximum elasticity of a material is exceeded, permanent deformation will occur. In the tensile diagram of steel reinforcement bars, the elastic limit is 200 N/mm^2 and the very high modulus of elasticity is 220 kN/mm^2. *Figure 44.*

Baked bricks (hard grey) have a very low modulus of elasticity of about 4 - 8 kN/mm^2, and the softer red masonry brick of only 1-7 kN/mm^2. Brick can handle very little elastic deformation; if deformation is slightly too large, it will therefore crack or break. In a brick building that is already under tension due to regular settlement under the building, a short impact from an earthquake shock will cause a crack. This is the reason why so many new cracks appeared in the Groningen earthquake zone; many buildings were already under tension due to old settlements in the foundations.

A building that has a high degree of elasticity, such as timber frame construction (Timber Skeleton Building) or the steel frame construction of an agricultural shed, has a high q-value[66] and therefore absorbs well the forces of the earthquakes. Rigid infill material of brick masonry with blast furnace cement mortar does not have that. That is why cracks invariably appear between the flexible frame and the rigid infill walls. See also **'Capacity mode'**. Old buildings that are built with softer and deformable lime mortar will not show any cracks with small deformations (< 1 mm).

Figures 49. Along the steel columns of this steel truss chicken shed, the joints in the brick have cracked because of different elasticities between the steel frame and the rigid brick infill wall.
In such a construction, the different materials must be dilated from each other. This "damage" has no negative constructive effect whatsoever.
*See also under **Capacity mode.***
Such "damages" however incurred extensive claims and arguments and costly procedures.



By dividing up the very large end facades of old farm barns (separation at the stable doors) and making the tops of those facades in flexible sheet material, cracks due to settlement or movement of the flexible roof construction are prevented.

[66] For a detailed explanation of the q-value see, **Behaviour factor.**

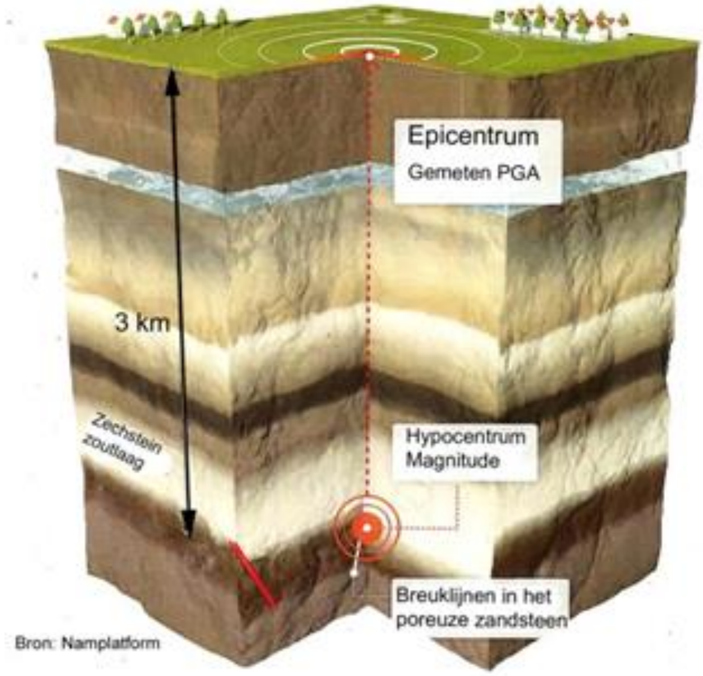
Epicentre

An epicentre is the place on the earth's surface directly above the earthquake source, the **hypocentre**. Since the epicentre is the point on the earth's surface closest to the focus, this is also the point where the vertical earthquake waves are felt most strongly. At a horizontal distance from the epicentre that is further than the distance from the hypocentre, the vertical movements become smaller, but the horizontal movements can increase and slow down. In Groningen this means that the strength of the quakes beyond 5 km from the epicentre gradually decreases.

Figure 50. The 0.5 km to 2 km (average 1 km) thick Zechstein salt layer is too tough to undergo fractures.

The Carboniferous layer below the sandstone reservoir does have fractures, but the rock layer does not move along those fractures during a displacement or an earthquake in the sandstone layer.

In the province of Groningen, the epicentre is about 3 km above the hypocentre. An earthquake takes about one second to travel this distance.



Every earthquake has its own epicentre that can be determined very accurately with many vibration or seismic meters. The largest earthquakes occur in the region of the municipality of Loppersum, with Ten Boer, Zeerijp and Westeremden. Further away from the epicentre, the vertical PGAg becomes smaller, but the horizontal PGAg can continue to be felt far away in the soft soils. In the outer areas of the earthquake area, it is therefore possible that new damage is identified, while this is no longer the case in the central area because everything has already cracked.

Emergency measurements

Measures that have been or will be taken to prevent the risk of collapse, or to prevent worse damage to a building. In some situations, the need is identified through a RVS or EVS (Rapid Visual Screening or Extensive Visual Screening). The most important measures are shoring up structures or buildings to prevent walls from falling over, and cordoning off the walking area around the building so that building components cannot fall on people.

In the province of Groningen, emergency measures were often taken at old farms because the wooden roof constructions are very flexible and push away the stiff brick side walls in the event of an earthquake. Emergency measures are also used in old homes, including the placement of scaffolding and props inside the building to support floors that lose their wall connection. Another emergency measure is evicting the residents. This may sometimes have to be done legally by the local municipality, at the behest of Building Supervision Authority.

Figures 51. Left. Barrier around a high-risk facade construction. The flexible roof provides no support (but does provide additional load) on the already large mass of the high-top facade. Right: Struts of an old bad side wall.

EVS (Extended Visual Screening)

Abbreviation for a non-destructive but comprehensive investigation of the safety of buildings in an earthquake zone. This FEMA[67] methodology of house inspection was introduced by Arup[68] and slightly modified for the inspection of the buildings in Groningen.

This EVS is the follow-up examination after a Rapid Visual Screening (RVS) detected likely faults. Based on this EVS, it can be determined whether measures need to be taken to improve the seismic safety of the building. In the province of Groningen, these studies were carried out by specialized agencies and the former Centrum Veilig Wonen, 2015-2020, the CVW [69].

This EVS investigation can include requesting construction drawings and a comparison between drawings and construction. A photo report is often a standard element in more complex situations. With an EVS, destructive testing is usually not yet done, such as the opening of constructions (ceiling, floor, digging up along foundations).

In Groningen, an EVS was used as standard for public buildings such as schools and, if possible, the connections of the structures were examined. This elaboration was decided because public buildings, where many people gather, must meet higher security requirements than private homes. See also **Importance class** and **Consequence class.**

Fault areas

A crack in the rock along which (due to pressure differences or movements in the earth's crust) two rock masses or layers have shifted relative to each other.

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[67] The National Earthquake Hazards Reduction Program (NEHRP) leads the federal government's efforts to reduce the fatalities, injuries and property losses caused by earthquakes. Congress established NEHRP in 1977, directing that four federal agencies coordinate their complementary activities to implement and maintain the program. These agencies are: Federal Emergency Management Agency (FEMA), National Institute of Standards and Technology (NIST), National Science Foundation (NSF) and U.S. Geological Survey (USGS).

[68] Arup is the major engineering firm appointed by NAM in 2012 (after the Huizinge earthquake) to prepare a plan for earthquake damage assessment and make proposals for seismic reinforcement. Many homes have been analysed and extensive calculations carried out under Arup's leadership. Some of the photos and graphs of the reports are incorporated into this book.

[69] The CVW was established in 2015 for the claims handling process, separate from the NAM. On January 4, 2020, the Temporary Groningen Act established the IMG instead of the CVW.

The tectonic earthquakes originate along these fault planes that can shift further. These fault areas exist in the million years old Carboniferous (coal) layer and continue into the 200 m shallow gas containing sandstone layer. The sandstone layer under Groningen is about 50 km wide across the province. Its relatively small thickness results in the many fractured areas.

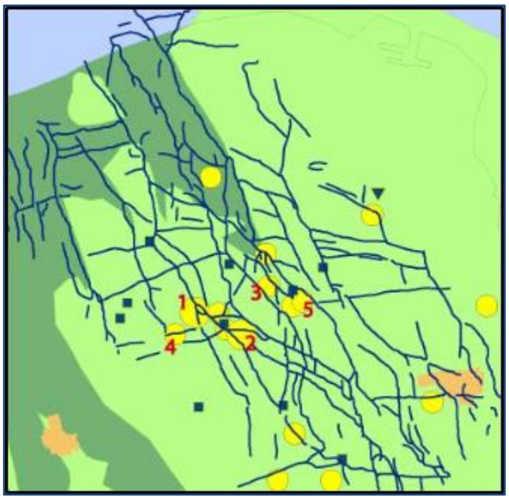


Figure 52. The 2014 KNMI-NAM map shows the largest fault areas in the gaseous sandstone layer. Outside the Groningen gas field there are many other small gas containing areas, about 1700 in total. The red numbers are the locations of the largest shocks up to 2012. In the above the sandstone reservoir positioned (sealing) Zechstein salt-rock there are no fracture planes or faults, and no shocks occur there.

Recent maps are much more accurate and show many more fracture planes in the sandstone layer.

Flat bowl shaping

The very slow and gradual subsidence of a large area because of compaction and soil subsidence over a large area. As a result, the earth's surface forms a very flat bowl relative to the original sea or groundwater level. The final depth of that flat bowl is equal to the subsidence map.

If the maximum subsidence over 10 km is equal to 200 mm, then the angular displacement or tilt of buildings over 10 m is only 0.2 mm (both 1/1000th). This is hardly perceptible for a building[70], and does not affect load patterns in a building. Subsidence does influence the groundwater level. Strong bowl formation also occurs in areas of salt exploitation. Although there can be a demonstrable tilt of buildings, it has no effect on the building strength.

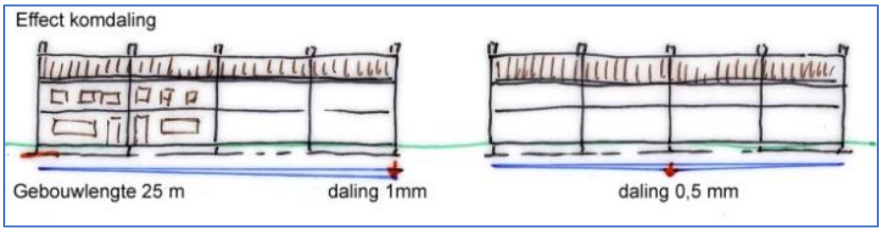


Figure 53. A building that is perpendicular to the contour lines of the subsidence will sink more on one side than on the other.

Also see ‘Subduction’ and ‘Compaction’ and ‘Settling’.

Flexibility of buildings

The ability to undergo deformations while keeping the material or material strength intact. Because a building deforms during an earthquake, the earthquake force is partially absorbed by:

(1) The materials of the structure itself are elastic (steel or wood).
(2) The connections between the construction parts are elastic (steel).
(3) The connections between the structural parts are moveable (slightly loose or ductile).

[70] This is measurable with a tilt measuring device. On several buildings such devices are placed to detect rotation away from the vertical position.

Flexible structures have an increased behaviour factor q, which increases the building's resistance to earthquakes. Stack construction often has some flexibility due to the weak connections between the rigid prefab elements (concrete slabs).

In earthquake areas these connections can be purposely designed to be slightly movable or ductile. Allowing the joints to deform ductile gives the building some flexibility, even if it consists of stiff concrete panels. If this flexibility is considered with the precise NLTHA calculation, it will appear that the building is more resistant to earthquakes than if it is only calculated statically. This mainly applies to tall buildings having many connections.

Figure 54. Dijkzicht flat in Delfzijl. Photo RTV Noord.
A detailed NLTHA survey was done on the seismic strength of this and other apartment buildings. Due to the assumption of somewhat flexible connections between the elements, the building turned out to have a reasonable strength.
This is a consequence class CC3 building.

An interesting example of a building with rigid reinforced concrete construction elements and somewhat ductile or loose connections is the Dijkzicht flat in Delfzijl (photo above). After detailed NLTHA measurements of the actual structure and very detailed calculations (assuming possible movement in the joints), the building's resistance to earthquakes was estimated to be greater than the simple static calculation indicated.

Foundation on firm soil

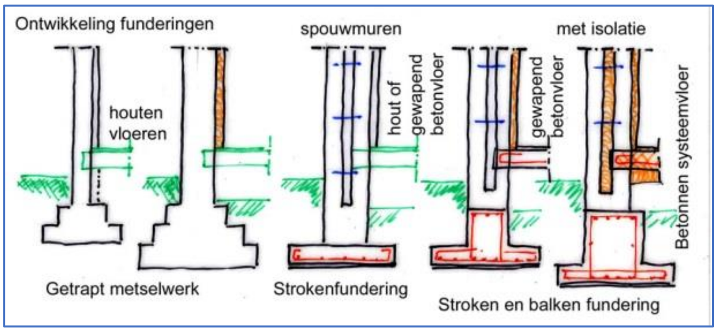
'Firm soil' is meant to be undisturbed compact soil that is fully supporting the foundation. The width of the foundation base is calculated, based on compression tests, but in the past mainly on experience with neighbouring buildings. Shocks of the earthquake create additional foundation load and can cause vertical settlement, especially in soft soils. Firm soil foundations are preferably built on undisturbed sand, but this is rarely the case in the province of Groningen. When houses are constructed on the softer clay and peat soils, settlement of foundations is more likely.

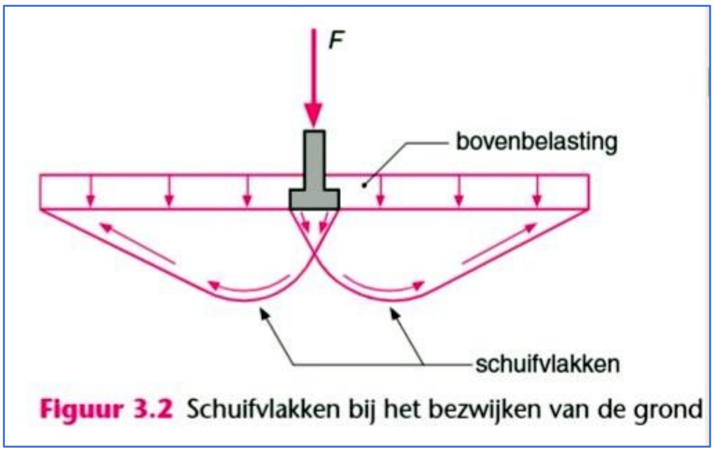
With a foundation is made on wet soil, the groundwater can be squeezed out from under the foundation, causing this foundation to sink and causing cracks in the brick walls [71].

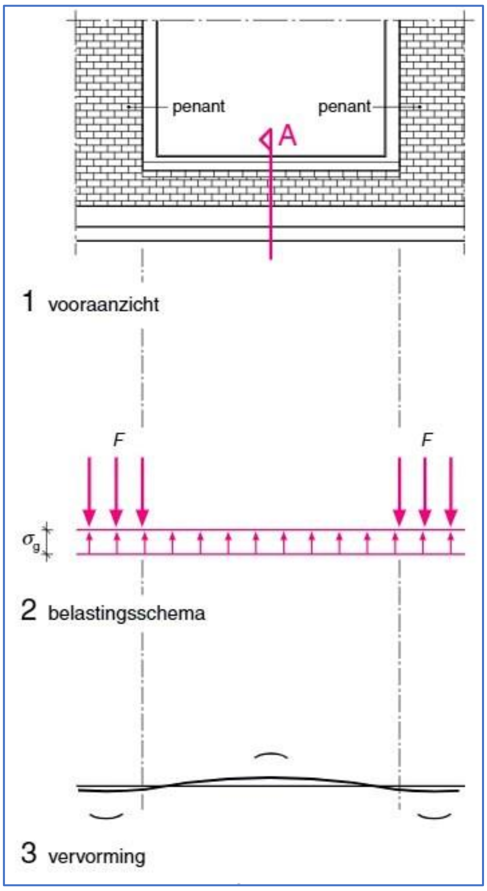
The foundation technology on firm grounds has been periodically improved by reinforced concrete slabs and integrated beam constructions and in later periods replaced by pole foundations.

Ontwikkeling funderingen = Development of foundations
Houten vloeren = Timber floors Getrapt metselwerk = Stepped masonry Spouwmuren = Cavity walls
Strokenfundering = Continuous slab foundation hout of gewapend betonvloer = Timber or reinforced concrete floor
Gewapend betonvloer = reinforced concrete floor met isolatie = with thermal insulation
Betonnen systeemvloer = concrete prefabricated floor Stroken en balken foudation = slab/strip and beam foundation

[71] A 2mm subsidence of one side of a brick foundation on firm soil will create a 2mm crack in the brick wall above. With foundations that are not level, such as with partial basements, these cracks almost always occur from foundation to the roof. With strong foundation slabs and beams, the building may tilt.



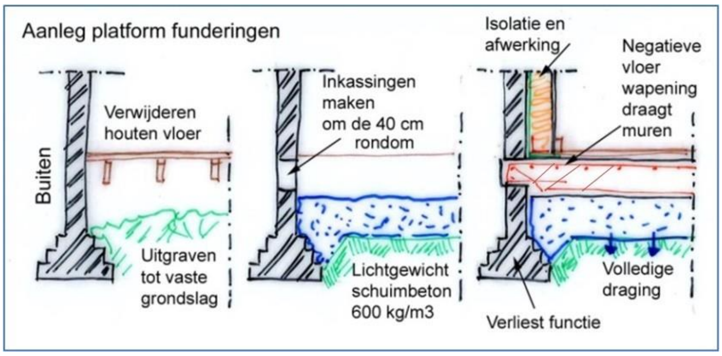




Figures 55. Top. By applying foundations on strips and beams, fewer cracks occur in the foundations, but possibly higher in the building (construction periods 1970s and 1980s).
Above. Calculations involve the mass of the soil besides the foundation. Foundations on undisturbed soils must be laid wider with higher building loads.
Right. With a smaller load under windows, foundations are subject to negative moment forces.
https://docplayer.nl/64563105-Jellema-2-onderbouw-_voorwerk-indd-20-25.html .

Foundation on a platform, platform foundation

Full slab foundation under the entire building, sometimes known as 'balanced foundation'.

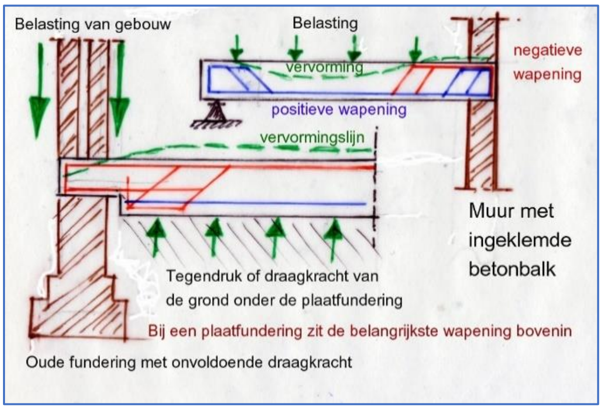


Figures 56. Photo and sketch of the construction of a platform foundation in an existing building. By making a fully load-bearing plate under the entire building, the ground pressure is reduced even more. See also Chapter 4.

Due to this design, the building mass causes a low, fully distributed pressure on the ground and the risk of settlement is greatly reduced or avoided, and thus also crack formation because of any settlement. This slab foundation (sometimes on foam concrete) can be added to existing buildings by constructing it with encasement into the walls at regular intervals and installing a load-bearing concrete floor with negative reinforcement in the concrete floor along all walls.

In case of weak foundations and/or soft soils and the need for seismic reinforcement, the method mentioned above is sometimes used. This is an excellent reinforcement method for reinforcing old brick buildings with foundations on firm grounds that show local subsidence. The technology does not protect the structure above against the horizontal loads of an earthquake. Additional wall and diaphragm reinforcements then remain necessary.

Belasting van gebouw = Load of the building Belasting = load Negatieve wapening = negative reinforcement
Vervorming = deformation Positieve wapening = positive reinforcement vervormingslijn = deformation line
Tegendruk of draagkracht van de grond onder de plaatfundering = reactive pressure by the soil under the platform
Bij een plaatfunderin zit de belangrijkste wapening bovenin = with a platform foundation the most important reinforcement is in the upper part of the plate.
Oude fundering heeft onvpldoende draagkracht = Old foundation has insufficient bearing capacity
Muur met ingeklemde betonbalk = Wall with sandwiched reinforced concrete beam.



Figures 57. Left. With a concrete beam, a negative moment is created when loaded and clamped in a wall. Here, 'negative' reinforcement is applied (red). With a slab foundation, the load on the building is all around along the edges of the floor, meaning the reverse load of an elevated self-supporting concrete floor. Negative reinforcement must then be placed in the entire top of the slab foundation. Right. Application of foam concrete after foundation repair. https://vandijkmaasland.nl/expertises/schuimbeton/woningbouw/

Fragility curve {Eurocode 8: 1.4.2.15}

Diagram or graph showing the probability of a certain degree of physical damage (cracks, collapse, subsidence) as a function of the strength of the earthquake.

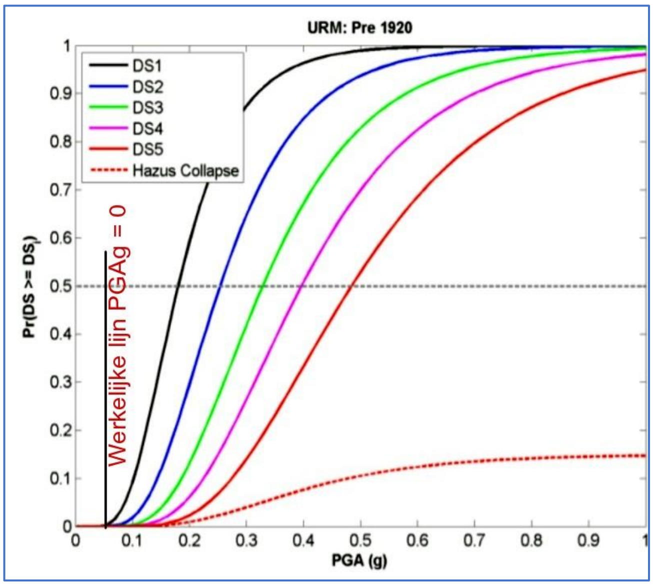
Each type (typology) of building has a different vulnerability diagram. Based on measurement and observation, the level of damage after an earthquake can be determined for several buildings of the same type, after which a vulnerability diagram can be established. This can then apply to all buildings of the same type. In 2013, the NAM consultant Arup estimated the various vulnerability diagrams of different types of buildings based on the data available at the time.

According to the diagram below, at a PGAg of 0.42 from 2014, only 50% of the pre-1920 houses would have almost collapsed, including the low-rise workers' houses (there is no difference with two-storey houses). The estimate in 2014 was that housing from before 1920 >80% would have completely collapsed. These graphs were made in 2013-2014 of different types of housing typologies and compared with the earthquake of 1992 in Roermond. However, the available information on this Roermond earthquake was limited. Since the induced earthquakes are smaller than PGAg 0.1 these types of graphs therefore give a very unprecise picture of the situation. However, they suggest correctly that with PGAg 0,4 most houses will partly collapse.

Figure 58. Arup 2013 vulnerability diagram of pre-1920 on firm soil -built dwellings with whole brick walls and large windows or narrow piers and wooden floors without diaphragm function. The left grading scale is the portion that is damaged at the PGAg value below.

The black line of DS1 (light damage) in this diagram already rises at PGAg 0.05 and is about 10% at PGAg 0.1. However, this does not correspond to reality, with >50% of the pre-1920 homes in Huizinge having damage at PGAg 0.085.

The vertical PGAg 0 line should therefore already start at the beginning of the black line AND the black line should be slightly steeper.



For the seismic (preventive) reinforcement of those typical buildings with standard structural solutions, a vulnerability diagram is a theoretical contribution to the decision-making process.

Figures 59. <u>Left.</u> (Photo Internet, by Funda) Old farmhouses are among the most vulnerable buildings in the province of Groningen, because they are often built with loam and lime mortar, have high windows, lack of floor-wall connections, high heavy chimneys on a flexible wooden roof construction. They are connected to the large and flexible timber truss shed. In addition, some of the buildings have a partial basement, which results in differences in foundation settlement. Because no dilations have been made between the head building and the so called 'neck' or between the 'neck' and the 'trunk' (large shed), they will tear apart at those connections. The large barn shed has its own seismic characteristics and problems.
<u>Right</u>. Terraced houses with all-window façade. Without internal structural walls, these types of buildings will collapse during an left-right direction earthquake.

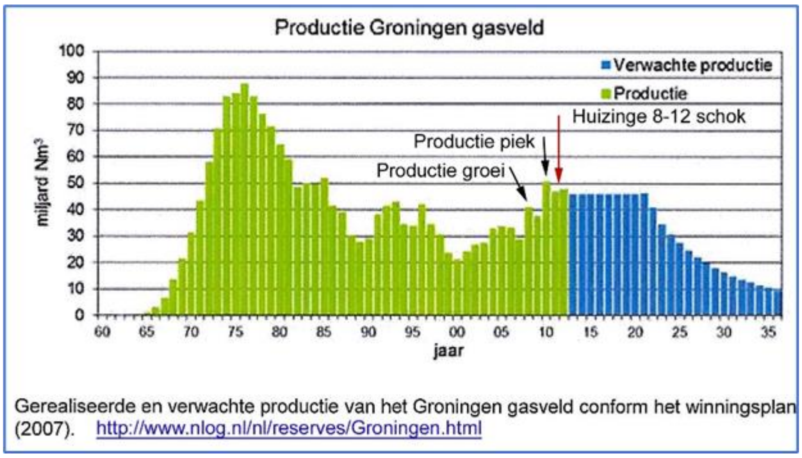
Gas field exhaustion

The depletion of the gas field was the objective of the 2007 extraction plan by the NAM and the first version of the 2013 extraction plan (after the 2012 earthquake at Huizinge).

Based on the data from the 8-08-2006 and 30-10-2006 earthquakes in Westeremden, natural gas production was reduced, after which there were no more major earthquakes for about a year, and in 2007 it was believed that an exploitation level of approximately the 45 billion m^3/year would not yield significantly higher earthquakes than PGAg 0.1 (Richter < 4). In that period the building damage or repair costs were manageable.

After the new earthquakes in 8-05-2008 (Zeerijp) the natural gas production was again reduced and the effect of that last earthquake and the earthquakes after that were assessed.

Figure 60. The 2007 extraction plan in which the planning of natural gas production is indicated up to 2040, with a possible extension to 2050. From 2022 it would no longer be possible to run at maximum capacity due to the pressure reduction.[72]



Due to the lack of occurrence of larger earthquakes after 2006 and 2008 within one year, the gas tap was opened further after the Huizinge earthquake in 2012 to study that effect as well.

Based on these three gas tap control actions, it could already be concluded in 2013 that it was unlikely that the PGAg values could exceed 0.15 (= 50% stronger than Huizinge 2012) if production were not increased above the level of 2012 (45 billion m^3/year) according to the original winning plan 2007. However, to maximise profit, the 2013 gas output **was increased** to 59.3 bcm. [73]

In the planning 2007, until 2022, the pressure inside the gas reservoir would have dropped considerably, which would reduce the internal gas flow[74]. With the existing number of gas extraction points it would not be possible to produce at full capacity. A plan must be made to close all production latest in 2050. A gradual reduction from 2022 until exhaustion is the result.

Due to the increasing building damage and growing resistance from the population, it was decided in 2015 to phase out gas exploitation earlier and to stop it completely sooner, although the SodM did consider the option of continue to produce at a very low level after 2022 (e.g., < 10 billion m^3/year). With such a low production, the quakes will not exceed the perceptible level (Richter 2) and the rest of the natural gas with a value of > 100 billion euros can still be extracted.

With the 2021 knowledge of the reservoir and the effect on the buildings, the exploitation can be distributed and controlled in such a way that the earthquakes are not felt by people (below the PGAg 0.03), with storage in the summer in Norg and in the winter into the gas network.

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[72] Based on this plan, and with the knowledge that the earthquake gradually become larger with the lower internal gas pressure, and with the 2012 knowledge that earthquakes larger than PGAg 0.1 (or Richter 3.6) were not acceptable to the population, it was very strange that the KNMI projected in 2013 earthquakes up to PGAg 0.42 (5X the acceleration force) or Richter 5.6 (100 x earthquake force).

[73] An annual fluctuation was allowed for the gas extraction. During the interviews by the Parliamentary Commission Earthquakes Groningen in 2022 it transpired that the NAM decided to increase the gas extraction to get as much gas as possible within their agreed period of more years. This in anticipation of the notion that there were plans to reduce the gas extraction. Also, because former gas reductions (after the earthquakes) showed that a new similar earthquake would only occur after a full year.

[74] In addition, the strength and frequency of the earthquakes would have increased with about 3% to 5% per year reaching approximately PGAg 0,12 by 2022, a strength being totally unacceptable by the Groningen population and most likely causing the first collapses for houses that were not timely strengthened. The very high likelihood of massive juridical claims would make gas exploitation beyond 2020 non-profitable.

In that case, by 2070 there will then be full exhaustion with minimum building damage and zero risk for the population (meaning no collapse)[75] .

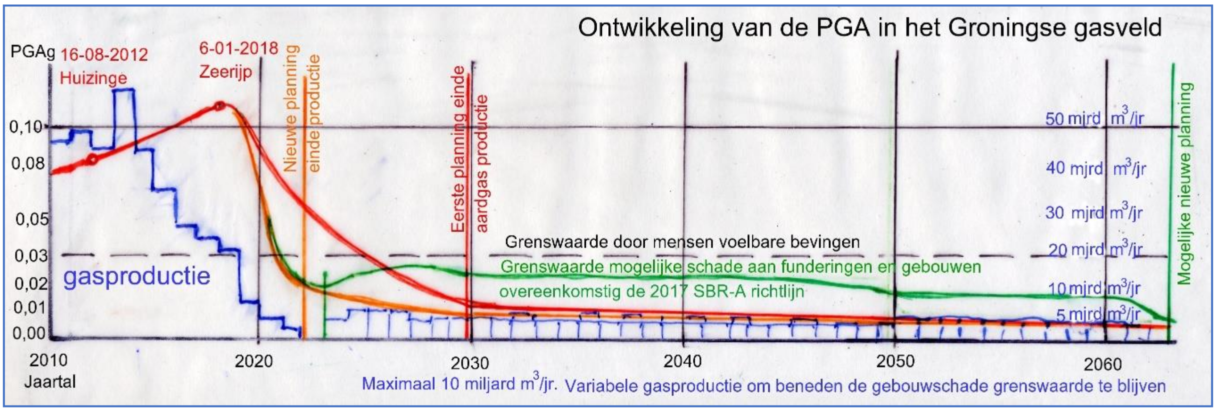


Figure 61. With the year 2021 knowledge of the subsurface and the relationship between gas extraction and earthquakes, it is possible to extract the remaining natural gas from the Groningen field with sufficient length of time without causing earthquake damage.

Whether or not NAM (including the government) may proceed to the gas field exhaustion in the future therefore depends on the manageability of the exploitation and vibrations and whether the houses have been sufficiently and correctly repaired or reinforced in the meantime[76]. If that cannot be guaranteed, old damage can still recur at lower earthquake values. It also depends on the knowledge of the population of Groningen about future tremors and the low risk they run. Newly built homes do not suffer from the vibrations anyway, but it is therefore all about the older buildings whether they have been reinforced in time and made sustainable [77].

GBB. Groninger Bodem Beweging

The GBB was created on 6 November 2009[78] with as aim: Standing up for the interests of people who are directly or indirectly harmed by gas extraction from the Groningen gas field.

Before that, there were already concerned citizens who had joined forces. More than 4,000 families support GBB initiatives as members (5% of the affected population). https://www.groninger-grond-beweging.nl/gbb/ Via their ‘Gasbevingen Portal’ of the GBB you will find extensive information about gas extraction and its consequences. https://bevingfeeling.nl/gasbevingen/

The GBB has been an important player in the creation of awareness of the population and focus on the negative social and financial impacts of the gas exploitation.

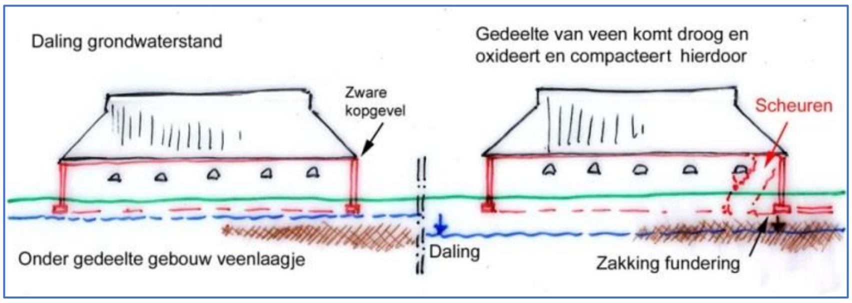
[75] With such a massive income, the sill occurring building damage can be repaired and much more (regional economic development). Sustainable housing, all cattle farmers on biogas production, new railway lines, and the clearing away of the old extraction pipes.
[76] The three-year delay caused by excessive testing and the frequent lowering of the maximum PGA value by the KNMI complicated the repair and strengthening programme, because the NAM was of the (economically convenient) opinion that strengthening only was required according to the **NRP9998 regulation which specifies the non-collapse strength requirement**. The population, however, did not want cracks and uncertainty about future shocks. They also did not want the devaluation of their property.
[77] Decision making, however is since 2021 not only a matter of calculations, but mostly political and about the acceptability of the population and their trust in the NAM decisions.
[78] After the earthquake of Zeerijp 8 May 2009. The force of the earthquake was 3.0 on the Richter scale.

Groundwater

Groundwater is the sub-surface water inside the soil and is therefore not visible until one starts digging. The height of the groundwater level can vary and depends on where we are and the amount of precipitation. Factors of influence include the height of the area, the presence of adjacent open water, the distance to a ditch or drainage and the permeability of the soil (soil type). With a high groundwater level in sandy soils, severe earthquakes lasting many seconds can soften the soil and cause it to lose carrying capacity (does not occur in Groningen because quakes are too short). With a lowered groundwater level, compaction can occur in peat (due to oxidation). Ground vibrations and different types of soil under a poor foundation can eventually cause differences in foundation settlement. These differences in settlement usually result in cracks of brick masonry.

Daling grondwaterstand = Lowering of ground water level Zware kopgevel = Heavy head façade
Onder gedeelte gebouw veenlaag = Under part of the building a peat layer Zakken fundering = subsidence foundation
Gedeelte van veen komt droog en oxideert en compact hierdoor = Part of the peat falls dry, oxidises and compacts
Daling = lowering Scheuuren = cracks

Figure 62. Example of partial subsidence of a long building because one side of the building rests on a dried-out peat layer.
The massive end wall of this type of shed causes great pressure on the ground and will then sag in relation to the (poorly) founded low side wall.



When the groundwater level drops for a long period of time, peat layers that have dried up can oxidize and shrink causing subduction at the surface. As a result, buildings that stand on that dried-out peat can sag. Because peat sometimes occurs locally, this type of subsidence also occurs locally. The subsidence in the province of Groningen causes an increase in the groundwater level compared to the ground level. This high level can be restored/lowered by pumps and weirs.

Also see: Subduction and Settling.

Figure 63. At this historic end house of this farm in Garrelsweer, cracks appeared in the foundation and basement in 2006 and 2012 due to the earthquakes. In combination with the already occurring land subsidence and the resulting increased groundwater level, the groundwater ran into the basement.
Finally, in 2020, this old building was placed on Base-insolation, a job that was not completed until the end of 2021.

HAS, Helical Application System

This abbreviation HAS (Helical Application System) is common in damage reports and refers to the bonding with an epoxy mortar of stainless steel spirally formed (helical) reinforcement bars in the horizontal joints of the cracked brick masonry. These connect the wall sections on both sides of a crack and increase or introduce tensile strength in the plane of that wall. It is one of the most effective methods of light structural seismic reinforcement. Also: Spiral reinforcement, stainless steel stirrups and ribbon joint reinforcement.

Figures 64. A stainless-steel spiral-shaped (helical) wall reinforcement is glued into a deeply milled horizontal masonry joint. The horizontal joint is then fully glued and finished. Given the light tremors in the province of Groningen, this is the most relevant and important method for wall repair and strengthening.
Right: The longitudinal reinforcement above the lintels is interrupted here. This means that with a new earthquake there will be a new crack between the ends of the reinforcement. In the early period after 2012, the method was often incorrectly applied.

For seismic reinforcement it is necessary that this horizontal joint reinforcement continues all around the building, and not just a small piece to the right and left of the crack. In the initial phase of building repairs in the province of Groningen, short pieces of spiral (helical) reinforcement were often used to keep costs low. By consistently connecting all inner and outer walls together and connecting the floor joists to the walls (making diaphragms), many buildings can be made sufficiently seismic resistant, and large cracking can be prevented.

There exist several companies[79] that implement this system, or have it licensed by contractors or sell the necessary materials. When the foundation of a building is good and only light repair of walls is required, without large scale seismic repair or reinforcement, costs can be kept low. More in Chapter 6 Reinforcing walls.

High-Risk Elements

The removal of high-risk elements from a building, or from building components is important. Securing these elements prevents them from falling off the building in the event of an earthquake and cause damage. An initial identification of these high-risk components is done by means of Rapid Visual Screening, (RVS) [80]. When a potential problem is observed during a superficial examination, a further analysis follows by means an Extensive Visual Screening (EVS).[90]

Removing a heavy brick masoned chimney from a flexible timber roof is also removing a high-risk element. In seismic terminology this is strengthening the building.

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[79] See: https://www.abcadamas.nl/ and https://www.totalwall.nl/nieuws/de-herstel-methode-van-total-wall-concept.html
[80] These methods are adopted from the FEMA. Oly slightly modified to suit Groningen circumstances.

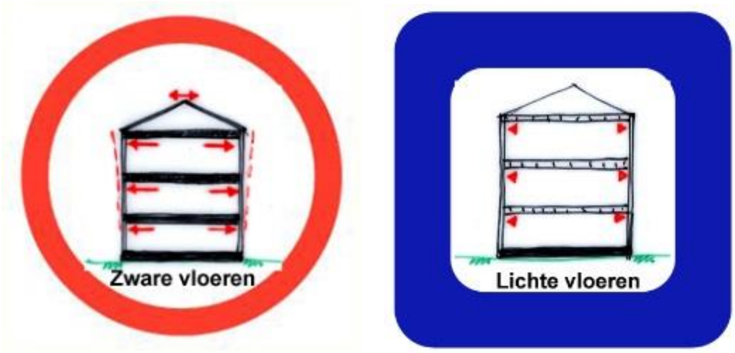
Figures 59. High-risk elements include heavy chimneys on a flexible timber roof structure, balconies wedged into brick walls, and spandrels or free-standing gable ends that sit on buildings and above sidewalks. While falling, they can cause casualties in the public space. Middle and right. Building with high-risk elements: heavy chimney on a weak roof, wedged cantilevered balcony (red), and a building without these high-risk elements (blue).[81]

High-Risk Buildings

Buildings can be identified through an RVS or EVS. Each type of building, in combination with the strength of the earthquake zone (max. PGAg) has its own risk profile. Heavy mezzanine floors pose a high risk because they place great loads on the walls; light wooden floors are less risky.

Figures 60. Left. Heavy concrete floors (high risk, red) and Right. light wood floors (low risk, blue).

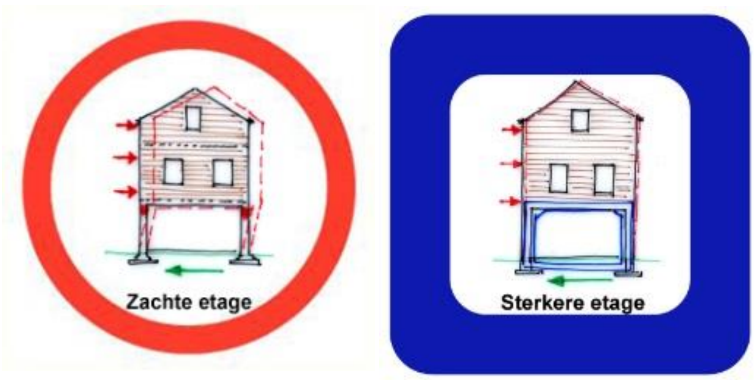
Wooden floors in combination with narrow window piers can pose a high risk if they do not have an especially strong reinforced aperture.



As one of the riskiest buildings, the terraced houses (stacked construction method) with large window frames in the facades and heavy concrete floors can be regarded as one of the riskiest buildings. The ground floors with large window openings are considered weak floors. If there are no transverse walls inside terraced houses that can absorb the earthquake loads in the longitudinal direction of the building block, these are very risky. Strengthening these buildings can be done, for example, by adding strong portals, strong constructive glass panels that sit tightly in the window frames and transfer the floor load from the storey in the plane of the facade walls to the foundation.

Figures 61. Left: Soft/weak ground floor (shops, terraced houses) with a lot of deformation (high risk).

Right: Strong ground floor due to a reinforced portal with less horizontal displacement (low risk).



[81] A more extensive overview of poor and good solutions is indicated in the document 'Basis Regels voor Aardbevingsbestendig Bouwen' (Base rules for earthquake resistant construction) on www.nienhuys.info ,.

Figure 62. The town hall in Leermens is a high-risk building because of the extra narrow window piers (width/ height = < 1/7) and the lack of lintels over the full length of the façade, or the presence of a connecting floor diaphragm.

By replacing at least one window in each side with a structurally strong glass panel, the piers are structurally widened.

It is not always possible to see from the outside whether a building has a high-risk profile. Studying the building plans and the construction method then provides more insight. Similar risks are often present for similar buildings.

Hypocentre

The area below the epicentre where the earthquake originates; also known as the heart. The focal depth of a tectonic earthquake can reach tens of kms. Recent major earthquakes in Christchurch (New Zealand) and Nepal had their hypocentres only 5 – 15 km deep respectively, making the shocks at the epicentre extra strong.

The hypocentre of Groningen earthquakes is very shallow at 3 km. For relatively small earthquakes, they are therefore strongly felt compared to tectonic earthquakes. *Figure 50.*

The total energy released in the hypocentre in all directions is expressed and measured on the Richter scale. Because all earthquakes in Groningen come from the same 3 km depth, the Richter values can be compared with each other, but not with the Richter values of tectonic earthquakes. The accelerating ground motion at the earth's surface (the PGA), combined with the building's own mass, determines the earthquake load on buildings and is measured in three directions. Two horizontal axial perpendicular and one vertical. The amplitude of each of the three movements (horizontal X and Y, and vertical P) is the amount of horizontal or vertical acceleration of the building's foundation. The vibrations felt have to do with the building response. An elastic building may longer continue to vibrate.

IMG, Instituut Mijnbouwschade Groningen, Institute for Mining damage in Groningen.

On 31-01-2018 it was decided to set up the Temporary Commission for Mining Damage Groningen, which, as an administrative body, would be allowed to decide on applications and compensation for mining damage completely independently and without interference from the NAM. Damage that was and would still be caused by soil movement that was the result of gas extraction in the Groningen field and the village of Norg underground gas storage by the NAM.

Minister Wiebes (Economic Affairs and Climate) took the Groningen Mining Damage Decree in consultation with the regional administrators in Groningen. With this decision he responded to a long-cherished wish of civil society organizations and the region to bring the claims settlement under 'public control'. The start was March 19, 2018. Then 13,476 reports came from Centrum Veilig Wonen (CVW, centre for safe housing), which handled claims under the previous claims protocol. Of those 13,476, approximately 12,500 damage reports were not yet processed.[82]

[82] The following information was added since early 2023.

Immediate occupancy, IO

Although minor damage affects the quality of life and the value of the house, this does not mean that the building's strength is reduced. Only in the case of cracks larger than 2 mm should the integrity of the (masonry) construction and the connections be examined. Minor building damage, both structural and non-structural, can occur during a small quake or one that is larger but occurs at a great distance from the epicentre. This may apply to the lowest form of building damage (Damage State 1, DS1). The building, after inspection, can be immediately occupied.

In such a case, the vertical and horizontal strength and stiffness of the building are still intact. Brick walls have then lost their tensile strength at the location of the crack, but these brick walls have never been designed for tensile strength. Although minor repairs are necessary, the building can remain inhabited (direct occupation or use). However, if the repairs are only cosmetic, they will reappear in a similar future quake.

More than 98% of the buildings in the province of Groningen fall into this category and there was no risk of collapse for the residents.[83]

In buildings that already suffered damage before the perceptible earthquakes (PGAg 0.03 = < Richter 1.5), this damage will often worsen with other and more frequent intangible earthquakes that can be felt by humans. Foundations on solid ground on the principle of equilibrium have been subject to settlement since 1980 due to the light vibrations that could not be felt. With the palpable quakes (PGAg >0.04 = > 2.4 Richter) these settlements and cracks will increase.

To reduce the pressure differences inside the gas reservoir, spreading of the speed of the gas extraction has been applied since 2014. However, the further the depletion of the gas supply and lowering the internal pressure in the sandstone layer, the more often sudden compaction occurs with a resulting quake. By extracting the gas more slowly, the frequency, strength and number of the quakes can be kept low.

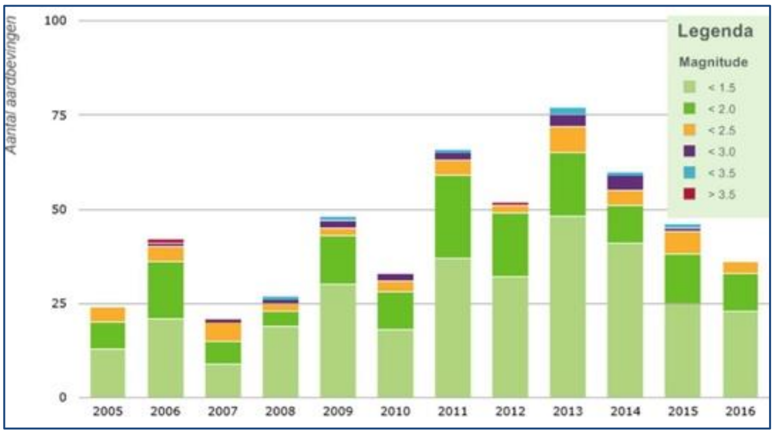
In 2022, more claims for physical damage will have been processed than received (45,800 submitted, 58,500 settled). At euro 362.5 million in 2022, the total compensation awarded for physical damage, decrease in value and immaterial damage is higher than the implementation costs of euro 224.6 million for those schemes.
For example, the reporting costs for all schemes together are now euro 0.62 on every euro of reimbursement. Last year (2022) it was euro 0,43 on every euro. For 2022 on physical damage, there was spend euro 0.72 on every euro. In 2021 this was euro 0.74 reporting expenses on every euro construction. However, in 2022 the implementation costs for handling via customization were rising relatively quickly, to euro 1.42 reporting per euro compensation by construction.

[83] Because the KNMI predicted very large earthquakes with a PGA that was 5X larger than had occurred in Huizinge, without indication the specifications of that calculation, the residents became nervous/scared and psychologically stressed about the projected collapse of their buildings. PGAg 0,42 (= 5X Huizinge PGAg 0,085) or Richter 6 to 6,5. Although people can continue to live safely in their homes, even though there are cracks in the brick facades, many residents have become anxious because of the exorbitant forecasts about future earthquakes between 2015 and 2018, which have since been revised.

Figures 63. Numerous cracks arise from the foundation due to small settlements in foundations on solid ground. These cracks extend to the window openings on the ground floor. These are very common even without earthquakes, especially in brick buildings with cellars. These cracks are aggravated by (earthquake, traffic) vibrations.

Figures 64. Thes NAM-platform graphs[84] about the number of quakes < Richter 1,5 shows a reduction of shocks per 2014, both in number and strength. This decline has continued.

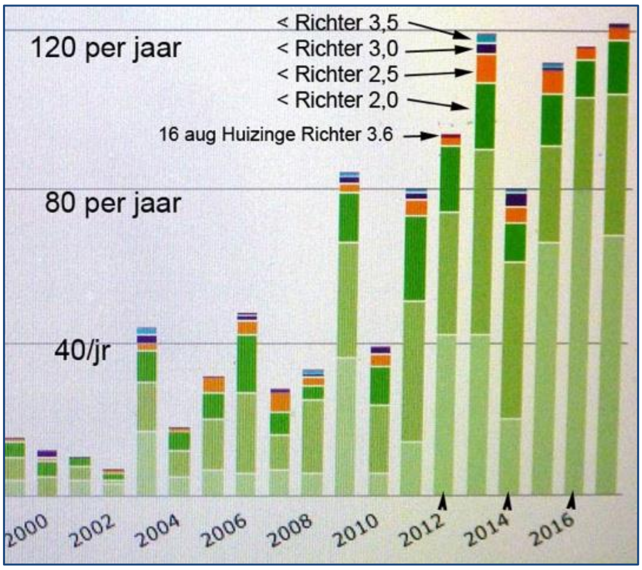
After the bang on 16 August 2012 Huizinge (Richter 3.6) the NAM <u>increase</u>d gas production, resulting in a larger number of shocks in 2013/2014.



This NAM-graph is until 2017. In the 2012 column the Huizinge shock is indicated [85].

After 2013, a sharp reduction in production was introduced, from 54 billion m³/year to 24 billion m³/year in 2017, which greatly reduced the number of shocks in 2014.

In the years 2015 to 2017, the total number of earthquakes will again increase due to the lower pressure in the gas field, while 2017 also indicates an increase in the number of Richter earthquakes < 1.5.



[84] https://www.nam.nl/feiten-en-cijfers/aardbevingen.html#iframe=L2VtYmVkL2NvbXBvbmVudC8/aWQ9YWFyZGJldmluZ2Vu

[85] For 2020 see*:* https://www.nam.nl/feiten-en-cijfers/aardbevingen.html#iframe=L2VtYmVkL2NvbXBvbmVudC8_aWQ9YWFyZGJldmluZ2Vu

The SodM shows in her advice[86] of April 2017 that the number of shocks that were larger than Richter Mw 1.0 has decreased since the interventions after 2013. Due to these measures, the 'immediate occupancy' and use of buildings in the province can remain high **and there was no increased risk of collapse**, while repairs and adjustments have been made to the strength of the most fragile buildings.

After the 2006 and 2009 earthquakes, NAM reduced gas production so that the number and strength of the earthquakes was lower for a year. To see what would happen with the number and strength of the shocks, the NAM increased the gas extraction in 2013[87].

Because natural gas extraction continued and was increased immediately after 2012, both the number and strength of the shocks therefore also gradually increased. As a result, the gas pressure in the sandstone layer dropped extra quickly, causing extra compaction (and shocks).

In 2017, the SodM recommends a further reduction of gas production of 10% to a maximum of 21.6 billion m^3/yr. On 10 Sept 2019, Minister Eric Wiebes (Economic Affairs) reported that before 2020 gas extraction must be reduced to below 12 billion m^3/yr instead of the previously planned 15.9 billion m^3/yr. The minister also stated that the gas tap of the Groningen gas field should be closed in October 2022. The resulting reduced gas production for the Netherlands has, among other things, stimulated better building insulation standards to be drawn up [88].

Importance factor. Building classification. {Eurocode 8: 1.4.2.11}

This is indicated by factor ϒ1 (gamma), by which the load is multiplied at higher or lower importance of the building structure compared to the standard. This classification roughly corresponds to the importance classes of NEN-EN 1998-1. The more important a building is, the greater the multiplier.

Consequence classes (=CC) [89]	**Importance factor *ϒ1***	
	New building	**Reconstruction and rejected buildings**
CC1A. Small risk and small or neglectable effects such as with agricultural buildings <u>without</u> human occupation.[90]	a	b
CC1B: As above but <u>with</u> human occupation.	1,3	1,2
CC2. Average risk of considerable consequences, housing or office buildings.	1,5	1,4
CC3. Large risk of large consequences, important buildings, stadiums, public buildings (schools).	1,7	1,6

a. For CC1A the earthquake loads are not supposed to be determining. If required, the importance factor ϒ1 = 0,8 can be used.

b. *For CC1A the earthquake loads are not supposed to be determining. If required, the importance factor ϒ1 = 0,6 can be used.*

[86] See annex to: https://www.sodm.nl/onderwerpen/aardbevingen-groningen/nieuws/2017/04/18/xxxxxxx

[87] This shows that the NAM was following/experimenting with the gas pressure and its effect on the shocks.

[88] To prevent the Netherlands from becoming too dependent on Russian gas imports. The Paris environmental agreement also demands less CO_2-emissions. Buildings must therefore be better insulated, because existing buildings are one of the largest energy loss items (consumption 30%) of today's society.

[89] See: http://www.stufib.nl/images/bestanden/presentaties/verg%2070%20-%2011-003-2009%20(TU%20Delft)/stufib_11_maart_2009_ECO_Braam.pdf and http://www.stichtingibk.nl/wp-content/uploads/2013/12/iBK-2014-04-Definitie-Risicoklasse-1.pdf

[90] With a large number of cattle in an agricultural building it can be defined as consequence class CC1B with importance class of respectively $ϒ_1$ =1,3 and $ϒ_1$ =1,4. There is no definition of 'large number' but current political attitude is that cattle requires more protection and wellbeing.

The multiplier increases the safety of the building. This is important for buildings where many people or animals may be present, and in combination with tectonic earthquakes, because with tectonic quakes it is not possible to say with certainty how strong the maximum earthquake will be.

Appartement buildings such as with a communal entrance, having maximum two storeys of three floors are categorized under CC1B. With four floors these appartement buildings are CC2.

Buildings and installations that have an important function during and immediately after an earthquake also have a high category. Communication equipment is one such example. Also, installations that can cause a lot of damage, e.g., chemical installations with hazardous substances.

Not only is the safety factor CC increased, but for many buildings the risk factor is also reduced from 10^{-5} to 10^{-6} (= safety factor increased), such as for chemical companies and sea dikes. Large residential buildings, according to the list above, also have an increased factor, which means that they must be made stronger.



Figures 65. Left: CC1B, three floors. Middle: CC1B three floors. Right: CC2, four floors
In the middle picture there are four floors, but the bottom floor is not inhabited (garage boxes), therefor only three floors apply with CC1B qualification.

Induced earthquake.

Induced earthquakes have been recorded in the province of Groningen since 1986 and are caused by the relief of stresses in the deep subsurface that have built up during gas extraction since 1963. Due to the pressure drop of the gas in the reservoir rock at the location of the gas extraction, the differential stress in the surrounding rock is so large that sudden shifts occur along existing fracture lines. Many vibration meters have been installed by the KNMI and the NAM.

The methane gas (CH_4) rose from the underlaying coal seam a few hundred million years ago and was trapped in the porous sandstone because of the deposited and closing rock salt layer (Zechstein) on it. As a result of gas extraction, gas pressure drops inside the sandstone layer and compaction of the sandstone occurs, resulting in soil subsidence and bowl formation at the surface.

With uneven and rapid extraction of the natural gas, taken over the entire Groningen field, pressure differences will arise in the sandstone layer (the reservoir). With a reduced internal pressure, the sandstone can or will suddenly be crushed.

Sudden vertical shifts can then occur along the many existing fault lines; these are earthquakes in the hypocentre. Subsequently, small settlements also occur in the areas between the fault lines and above the salt rock (usually not perceptible to humans). All these shocks are therefore induced by the extraction of the natural gas.

Induced earthquakes are significantly different from tectonic earthquakes. See, for example, the Figure under 'Duration of the earthquake'.

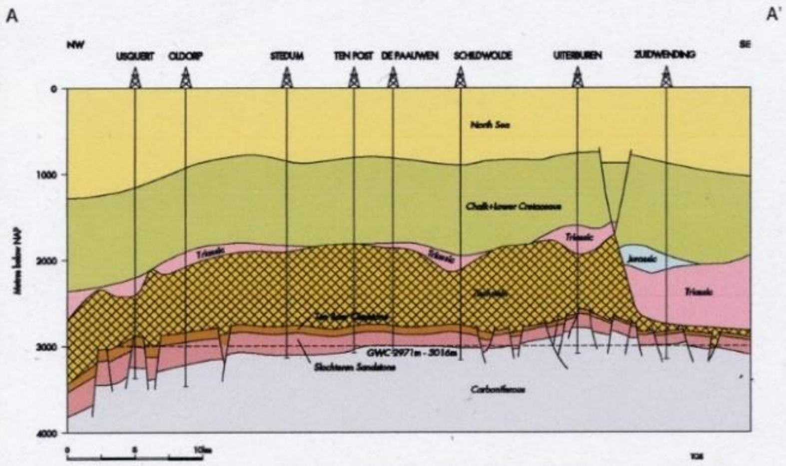
B2.1) Geologische doorsnede van het Groningen veld = Geological cross section of the Groningen field.
De onderstaande tekening geeft de geologische doorsnede weer van het Groningse veld in een noordwest – zuidoost oriëntatie (zie Figuur B2 voor structuur kaart). = The drawing below indicates the cross section of the Groningen field in a northwest – southeast orientation. (see Figure B2 for structure map).
NB. Verticale schaal = ongeveer 7 x horizontale schaal = Note. The vertical scale = about 7x the horizontal scale

Figure 66. Deltares report. Section from Winningsplan 2013: Vertical is 4 km, horizontally 50 km. From Warfum N-W (left) to Oude Pekela S-E (right).

From the top down:
North Sea = clay soil deposits;
Calcareous strata ≈1-2 km thick;
Shaded = Zechstein rock salt deposits up to ≈1 km thick.
Pink = Slochteren Rotliegend sandstone of ≈ 100-200 m thick also called the 'reservoir rock'.
Grey below is the Carboniferous layer = coal bearing layer and the rest of the 40 km earth crust.

B2.1) Geologische doorsnede van het Groningen veld

De onderstaande tekening geeft de geologische doorsnede weer van het Groningen veld in een noordwest-zuidoost oriëntatie (zie Figuur B2 voor structuur kaart).



Figuur B1: Geologische doorsnede van het Groningen veld. Zie sectie A-A' in Figuur B2

NB: Verticale schaal = ongeveer 7x horizontale schaal

The main differences between tectonic earthquakes and induced earthquakes are listed below.

#	Tectonic earthquakes	Induced earthquakes (Groningen)
1	Caused by natural movements of large tectonic earth plates (continents) away from each other, or towards each other.	Caused by people because of mining (gas extraction Groningen), large water reservoirs, construction activity, heavy traffic and bombs.
2	Derive from great depths, 15 km to 80 km.	Are superficial, only 3 km in Groningen
2a	Vertical displacement and deformation of all connected and massive earth layers starting at great depth.	Only compaction of the sandstone reservoir rock, no movement of the underlaying carboniferous rock.
3	Tectonic earth shelves continue to float about ≈ 4 cm/year	No horizontal displacement from continental shelves.
4	Because of great depth, large spreading over a wide area. Felt over 50 to 100 km.	Because of shallow depth, small but violent shocks and less horizontal spreading of the shock waves.
5	Horizontal movements up to 50 cm, and locally possible large subductions.	Mainly small subductions < 1 cm.
6	Vertical building movements can be few to several cm's. Soil collapse can be in meters and deep crevices can occur.	Vertical movements are in mms. Soil collapse is very slow and over lime due to compaction and slight surface bowl formation over many kms wide area.
7	Soil and landslides in the mountains and blocking of rivers and breaking of dams.	No visible changes, apart from slow surface subduction causing change in (ground)water levels..
8	Duration of several seconds up to several minutes in the hypocentre per event.	Duration of a fractions of seconds in the hypocentre and often one single shock.[91]
9	Earthquakes longer than several second can cause liquefaction of wet soils.	No long and continuing vibrations and no soil liquefaction.
10	Long duration horizontal vibrations can cause vertical amplification of the shock wave over longer distances, depending on the soil structure.	Vibrations are too short to cause amplification in soft soils.
11	Within days and weeks many large aftershocks that usually are less strong but can cause further collapse	Only few small aftershocks which are not perceptible by humans.

[91] No counting the post shoch reverberation of the building due to the soil movement and elasticiyy.

#	Tectonic earthquakes	Induced earthquakes (Groningen)
	of already damaged building.	
12	Aftershocks are large and frequent, directly after the main event and cause extra damage and collapse of weakened buildings.	Aftershocks are tiny (not perceptible) and hardly cause progressive damage.
13	Appear periodically and with large periods in between in the same area. This varies from dozens of years to over 100 years. For example, the large Kathmandu earthquakes appear every 75 to 80 years.	Appear weekly monthly and yearly, depending on the human activity. The earthquakes will increase in strength and frequency with the lowering of the internal gas pressure.
13a	After very large earthquakes the cycle of the Gutenberg-Richter constant starts again from zero.	After small earthquakes the Gutenberg-Richter constant for that hypocentre starts again, but for other area's it will continue. There is an overall limit to the constant.
14	Worldwide a lot of knowledge has been accumulated and international building regulations have been developed.	Less international knowledge obtained and dependent on mining type. Reason for excessive uncertainty margins in the calculations.
15	Seismographs register earthquakes worldwide.	Additional seismographs are added in Groningen.
16	Mw- or Richter-values of the earthquakes from different areas and are NOT related or can be compared to each other or for the PGA-values.	Because all earthquakes in Groningen originate from a depth of 3 km, the Mw- or Richter-values can be compared to each other, but not with those values from other earthquake areas.
17	Detailed construction information is available in Engels or the language of the country and freely available for everybody.	No Dutch language information was available until 2015 and after that hardly available for citizens.[92]
18	Active promotion of construction knowledge and legislation about seismic resistant construction.	In Groningen, by the NAM or government, no public promotion of seismic resistant construction methods.
19	Seismic knowledge required for all architects and engineers as well as practical training at vocational schools.	Hardly any technical education available, only commercially for HBO at the Groningen university. RUG.
20	Simple static calculation methods generally applied for common housing and low buildings.	Very complicated and expensive calculation methods used for all buildings, also when such was not relevant.
21	Training material for low literacy, such as 3D drawings are freely available.	Drawings and calculations are not available for citizens. Commercial earning model for business.
22	Generally, no insurance against earthquake damage. Commonly emergency aid by national and international organisations.	Causer of damage is by law obliged to compensate for damage. Lengthy arguments about what earthquake damage is and what not.
23	Limited insurance against collapse is possible when the building is constructed according to the seismic code.	Long juridical and expensive processes can be resulting from differences between technical assessment reports.
24	Acceptation by population as faith about damage and victims and large economic losses. .	No acceptation by the population of more damage. Demands for economic and emotional compensations.
25	Population is often visibly glad about the aid supplied.	Population remains suspicious about the measurements and demands more compensation.
26	Psychological acceptation by faith. Normal mourning period for the deceased.	Traumatic developments because the sociological problems, fears, stress and economic damage. [93]
27	When it appears that buildings were not adequately designed according to the seismic codes, improvement of the inspection or adaption of the code may result. Also, building contractors that were at fault during the construction period for not following the seismic code may be prosecuted.	When in 2016 it was concluded that the maximum 2014 PGA was far too high and subsequently was lowered, the need for seismic strengthening was also reduced. This was an argument for the NAM to limit the number of building strengthening. This caused widespread discontent among the population.

[92] When the information was produced by me in 2015, that information was not made readily available by the NAM. Moreover, the technical college in Groningen did not wat to use that information, mainly because their training structure was not adaptable, and they argued that the curriculum was not yet certified by the Ministry of Education. Only in 2022 (7 years later) some limited technical information was released by the NCG to contractors (possibly partly based on my 2015 information), but not widely promoted.

[93] In the absence of proper government support (including finances, loss of pension) long-term stress, anxiety and exhaustion can result with consequent health problems.

Due to the large number of differences, the two types of earthquakes cannot be properly compared. Images from the press of major tectonic earthquakes (Mw 6 or 7) are therefore **not representative** about what could be expected in Groningen. The 2011-02-22 Christchurch quake is also not representative but show the effect on residential houses [94].

Figures 67. Left. This building is in the DS4 (just failed to collapse completely). Middle. This building is in the DS5 (collapsed) phase, while they were built seismically resistant according to the code.
This earthquake was Mw 6.2 and depth of only 5 km and for a 15 km long zone with PGAg ≈ 0.22 vertically and PGAg 0.17 horizontally at the epicentre. In the city itself, the PGAg 0.08 vertical and PGAg 0.07 horizontal, comparable to the 16-08-2012 Huizinge earthquake, but much longer in duration.

This 2011 Christchurch quake lasted only 10 seconds and caused soil softening (liquifying) in some locations. The total economic damage was estimated at >20 billion euros. Buildings that are very similar to those in the province of Groningen but complied with the seismic code; 20,000 buildings damaged and 10,000 beyond repair; 50,000 people moved. Almost half of the 186 victims were caused by falling debris from gable ends in the shopping streets.

In an induced earthquake in Groningen there is usually only a single bang, or on 16-08-2012 in Huizinge a double blow with a period of < 1 second.[95] The Christchurch quake was >10X as long as the Huizinge quake with a comparable PGAg in the city centre. The longer duration is therefore one of the reasons why the damage was so great. If one would get at least 10X the Huizinge quake directly in succession, it would be comparable. In Groningen the quakes were > I year apart.

In New Zealand, new construction must comply with the seismic code, but the quakes in the epicentre (15 km outside the city) were significantly higher than the maximum PGAg value stated in the New Zealand code. Most likely the seismic map will be adjusted.

When determining the building strength in Groningen using the NLTHA method, the building is usually calculated with a greater shock strength and each time based on a single shock. This first shock therefore indicates the initial building strength. When new shocks are released on the damaged building, that building will be initially be weaker and progressive damage will occur.

Inherent defect or construction fault by owner.

Inherent defect is the translation of a legal concept/terminology indicating that the root cause of a damage to a building is not directly external, such as an earthquake, but is mainly due to the actions or inaction of the building owner. For example, if the horizontal tensile beams in the large roof trusses of the barns are cut through (to make room for high agricultural vehicles), the side walls get extra sideway pressure from the rafters (this was regularly encountered).

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[94] See for more data https://www.britannica.com/event/Christchurch-earthquakes-of-2010-2011

[95] People claim that they have felt the earthquake for several seconds, but that was including the reverberation of the buildings they were in.

In the event of an earthquake, the outer walls can then be pushed away and collapse or fall over to the outside. The primary cause of the collapse is the sawing through of the trusses and not the earthquake [96].

A building erected before 1902 no longer complies with current 2015 building standards, but probably complied with the then prevailing building practices of that time. The first new building standards were from 1901. Building regulations do not oblige the owner to reinforce the building according to the latest standard. If damage occurs in a severe storm because of the older building standard, this will not be regarded as an inherent defect by an insurance company. The NAM followed this principle and strengthened many old buildings.

Figure 68. In this converted garage, the contractor has removed the tie rods from the trusses to create more space inside (own construction error). The roof load and the arch push the side walls outward causing the arch to split and sag in the middle. If the arc is already under tension, an extra vibration from an earthquake can cause a larger crack.
The primary cause of the crack is the construction defect (inherent defect).

In terraced houses (with large windows front and rear), the front and rear facades on the ground floor have windows without any shear strength in the plane of that long façade of the building block. Only short inside cross walls may provide some resistance. Someone who has removed a small inner load-bearing cross wall between the living room and kitchen in such a terraced house to create an open kitchen, weakens the horizontal longitudinal resistance of the entire building block. Without an earthquake, the building will remain standing, but an earthquake in the longitudinal direction of the block can cause significant cracks; even collapse risk of the entire row. See 'Building Directive'.

The legal question is whether a home with its own defect must be repaired by the person who caused the earthquake (the NAM) or whether it is the homeowner's own fault. In principle, the Municipal Building and Housing Inspectorate should not have allowed this internal renovation and change to the supporting structure of the building. However, building inspection was/is often inadequate in the province[97]. The houseowner is correct when stated that the cracks would not have appeared if there were no earthquakes. However, the NAM also, when it is stated that the building was considerably weakened by the "renovation" by the owner with making construction faults.

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[96] Most conflicts and counter-assessment damage reports and arbitration procedures have arisen on this theme. Light tremors revealed not only subsidence of foundations but also old construction errors. The NAM tried to make a fair assessment and not financially reimburse or repair damage that was old or caused by the building owner or a former building contractor. The house owners argued that the damage would not have shown without the earthquakes. Although the NAM promised since 2012 generous compensation, they became tight-fisted about compensations, while the gas exploitation had generated over 400 billion euros of profit. The large costs of arbitration that were the result, as well as the time delay in repairs or strengthening, caused widespread discontent, and costed three times more money than the repairs. After 2020 it was decided by parliament to really generously compensate the inhabitants, causing a many-fold increase of the overall repair and compensation cost as compared to just repairing all the damage since 2013 in the first place.
[97] Practice was/is that the inspection is often not informed about owner directed constructions. The administrative capacity does not exist in a rural area to monitor all activities.

Figure 69. Left: If the floor-wall connections of the storey floors are not moment-strong enough to withstand an earthquake load in the longitudinal direction of the building block, and there are no internal transverse walls that can withstand loads, the block can collapse as a house of cards.
Middle: Small inside transverse wall of a house after the 1992 earthquake in Roermond. When this wall would have been removed by the creation of an open kitchen, probably the house would have collapsed. The X crack formation is typical of an in-plane wall overload (shear).
Right: House after an earthquake in Italy. Earth movement to the right causes the // cracks, earth movement to the left causes the \\ cracks.

During building inspections after earthquakes, inherent defects are regularly found. It is also not easy to indicate exactly whether a subsidence (of foundation caused by earthquake shocks) or crack formation is due to an inherent defect. In some situations, the first (older) cracks are the result of settlements, which in themselves can have many different causes. They may also have been caused by the light earth vibrations in the past that were not sensed by the house owner.

For the assessment of earthquake damage several options were possible:

Fault	Type	Description	Responsibility
Unsound (re)-construction	1A	Poorly executed (re)construction in comparison with other buildings that were realised in the same environment and period.	Inherent defect- At the expense of the owner.
	1B	Properly maintained building, built in accordance with the regulations and customs applicable to the (re)construction at the time, but must now be regarded as unsound due to the progress of the quality of the building regulations.	No inherent defect.
	1C	Renovation or extension without approval from the Building Inspection, but not addressed by the Building Inspection to change or demolish and now existing for more than 20 years. (Barred).	No inherent defect. Also, the case when the extension has defects.
Deplorable state of building (near ruin)	2	Structural defects in a building, or the condition of a plot, of such a nature that the government would order repairs under the Housing Act.	Inherent defect – to be repaired ate the expense of the house owner.

Objectively, the root causes of many damages are primarily due to old building codes (1B) and then due to inherent defects. Those weaknesses have come to light through the earthquakes. In case of reasonable doubt, a second earthquake expert can be consulted, and an additional structural and foundation investigation may be necessary. Technical testing or probing was/is also possible. The above regulation was defined by NAM after many (expensive) inspections and re-inspections of buildings and irresolvable conflicts with building owners [98].

[98] Initially (since the first damages in 2000), NAM had stated that it should generously allocate damages to earthquakes to prevent conflicts of opinion. However, due to the ever-increasing costs of the inspections, re-inspections, and mutual argumentation in the event of doubt and a clear inherent defect (to the opinion of the

For example: A new extension was built years after the old main building and has a different foundation than that under the main building, because the new foundation must comply with new building regulations. Both foundations were constructed in accordance with the building regulations applicable at the time. Due to subsidence, vibrations or an earthquake, a crack will occur between the old and new part. All structural engineers know that new foundations on solid ground will settle somewhat, resulting in tensions and cracks in the masonry above. Hairline cracks or larger along the connection between the two buildings are normal in this case[99]. A structural solution to prevent this is an expansion/dilatation joint between the older main building and the new extension. However, if Building Inspection has not checked the drawings and the execution, or it has seen or accepted the drawings, it is not considered an inherent defect (1C).

No financing structure was set up (not even in collaboration with the government)[100] for repairing the inherent defects or making the home more sustainable (insulating, generating energy). As a result, many buildings experienced scaffolding and props[101]. The images of the struts were widely used in the press as negative imagery and pointing out how important the damage was.

Figures 70. House in the struts/props with side view and front view. The large damage above the double door in the middle indicates a structural problem related to the high windows, narrow piers between the window frames and the distribution of the inner walls, with a lack of a continuous connecting diaphragm under the roof. These are architectural aspects from before 1920 and have nothing to do with inherent defects, because that was how people built at the time.

In refection 2021: After the NAM making mega-profits from the exploitation of natural resources it would have been far less costly to just repair all damages including the so-called inherent defects and including the upgrading of the houses (thermal insulation), than the realised situation with all its juridical dealings. In early 2023 it was decided to overcompensate the inhabitants of the province, adding to additionally high costs.

NAM), the inspection costs ran very high (these were costs for the NAM). Part of the problem was that the NAM had erroneously decided/ordered since 2013 that foundation damage would not be classified as earthquake damage. The various unresolved conflicts regarding inherent defects left a strong negative mark on NAM and the repair work, and delayed building repairs or replacement new construction. The buildings that, whether-or-not necessary, remained in propped-up scaffolding, and are shown in every news article about the slow recovery activities, caused an additional negative image in the press and to the public.

[99] The issue with the NAM criteria was that such cracks were deemed 'inherent defect' and not the cause of the earthquake. Instead of just repairing the building with an adequate dilatation joint under the 'generous repair' concept, millions of euros were spent/wasted on reports and arbitration (3/4th of all expenses).

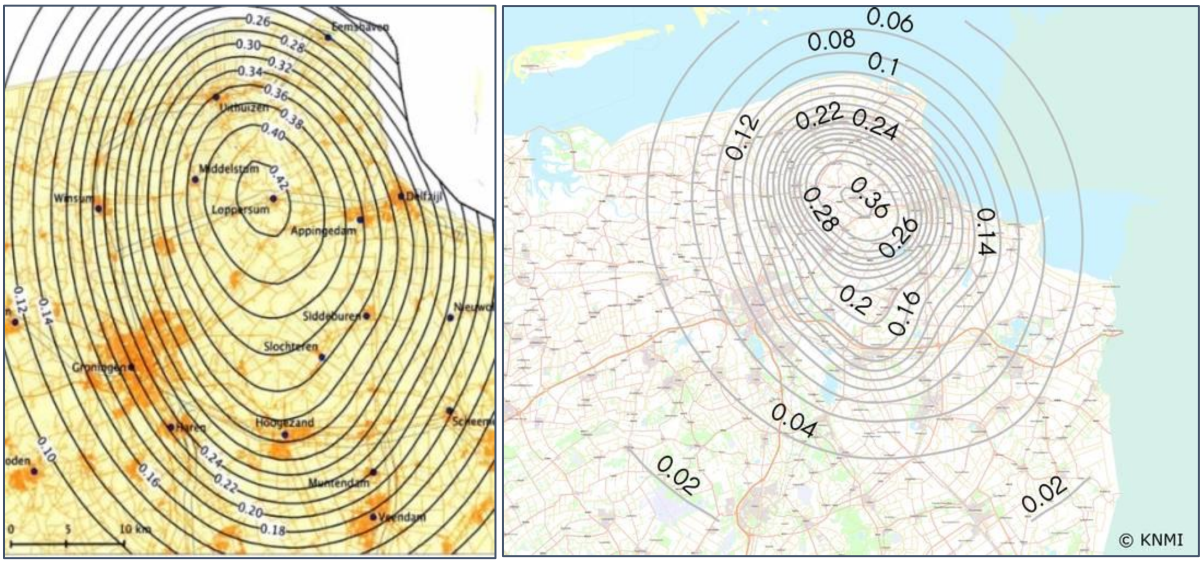
[100] A proposal was made (by me) to create a building fund to finance the additional adjustments and recover the additional expenses at the time of sale of the building. However, the NAM felt it would not want to enter in the building market and long-time fund management as it was primarily an energy company.

[101] Several props were not necessary but were erected by the houseowners to stimulate action.

KNMI, Koninklijk Nederlands Meteorologisch Instituut

The Royal Netherlands National Institute of Weather, Climate and Seismology. Making knowledge, data, and information available at KNMI is a core activity. The KNMI has several seismographs in The Netherlands and studies the different types of earthquakes. The institute is an agency of the Ministry of Infrastructure and the Environment. The tasks of the KNMI are laid down in the KNMI Act. www.knmi.nl KNMI does not provide information about structural or seismic strengthening.

The KNMI is jointly responsible for determining the earthquake strength contour map associated with the Eurocode 8 and the Dutch translation, the NPR9998. Because the KNMI could only study past data regarding the determination of the PGAg threat map and the 2012 production information provided by the NAM about the planning of future gas exploitation, and because there were many uncertainties, the first PGA map can be called extremely conservative (i.e., with very high PGA value).



Figures 71. Left: The first KNMI PGA map from 2014 with a PGAg 0.42 in the epicentre. Right, the second map from 2015 with PGAg 0.36. These very high values were determined based on uncertainties and NAM's wish to continue large-scale gas extraction until the gas field is exhausted. The values of 2020 can now be found on a Home Webtool https://seismischemacht.nen.nl/map.php and is specified per one km location. The KNMI makes earthquake strength calculations according to the Richter scale based on its own data. From this the PGAg loads are calculated, which are then given an incremental factor for the uncertainty.

If a new shock were to occur after 2013, in the order of magnitude of 16 August 2012 in Huizinge (PGAg < 0.1), the population would react strongly and put pressure on politicians to take other measures to prevent multiple shocks. of that order of magnitude. This correct assessment was already made (by me) in 2014 and confirmed in 2017[102]. Additional shocks with a similar and lesser magnitude since 2014 resulted in widespread discontent and political measurements that obliged the reduction of the gas exploitation.

The largely exaggerated and not explained PGA values of the KNMI maps were the cause of increasing fear and stress among the population of Groningen and extensive research activities by the NAM that delayed the repair and strengthening activities.

[102] This is exactly what happened after the earthquake of 8 January 2017 in Zeerijp (PGAg 0.116 with Richter Mw 3.4). The ground acceleration of this one was slightly greater than that of Huizinge, but was judged to be less strong, because it was only a single shock and had less reverberation from buildings.

Moreover, excessive strengthening of many buildings was realised, and hundreds of houses were planned to be demolished as these old buildings would not withstand the enormous PGA predictions of the KNMI.[103]

Lateral Force Resisting System, LFRS

The collection of shear walls, load-bearing walls, portals, and columns, and connected by diaphragms, which together provide resistance to earthquakes. This building system can be calculated in a fairly simple way using the LFRS and provides sufficient certainty for the building strength because the calculations include the usual margins. This is especially the case with low-rise and rigid constructions. For elastic or flexible high-rise buildings (+10 floors), the elastic absorption or ductile deformation is here not considered.

The LFRS calculation method is the classic calculation method for the strength of a building. It is assumed that the earthquake exerts a horizontal force on the building that is related to the mass of the building (PGAg 0.1 = 10% of the mass). These horizontal forces on the building are adjusted according to the applicable earthquake code according to (a) the mass of the structure, (b) the importance factor, (c) the construction type or the behaviour factor of the building, (d) the type of soil, (e) the height and (f) the irregularity of the building.

For simple buildings with a few floors, the LRFS static calculation is sufficiently accurate and can be completed in a short period. The supposedly 100% precise NLTHA method takes weeks and can cost 15,000 euros for a small building.[104]

If a typology is used, a similar building of the same typology can deviate considerably. With the calculation with a PGA that deviates 100%, the result of that NLTHA method is then at most 30% or 40% accurate, and therefore no better than the fast, cheap static LFRS calculation method.

Liquefaction {Eurocode 8: 1.4.2.19}

Liquefaction is the loss of strength and stiffness in moisture in non-compacted but saturated sandy soil, due to vibrations and the associated reduction of effective stress and bearing capacity of that soil. With partial softening, there is still part of the grain tension left (pressure on the sand grains).

Water overpressure consists of temporary extra water pressure in the pores between soil particles, which can be caused by rapid shear stress changes during an earthquake. Due to the low PGA, combined with very short vibration periods and few wet sandy soils, soil softening does not occur in Groningen. This is only possible with PGAg > 0.2 and long vibration periods of tens of seconds.

In the top 10 - 15 m of the soil in Groningen, sand packs can be found that are under/in the groundwater and on which foundations are made with piles, but these sand layers are well compacted and do not give rise to softening. However, it is possible that pile foundations that are overloaded by earthquake vibrations penetrate deeper into the sand layer.

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[103] A separate document was prepared by me, pointing out the wrong PGA map predictions by the KNMI. Available on www.nienhuys.info second page.

[104] This method was extensively used in Groningen, while the PGA parameters were wrong, but it provides a generous income for the companies who were able to apply the complex NLTHA method. The quoted argument was that the NLTHA method was more precise, which in fact it was not because of the wrong PGA. Furthermore it was totally irrelevant for the low rise and stiff masonry brick building.

Figure 72. Example of softening of sandy soil causing the water to rise and lose the soil's carrying capacity. Protracted and severe 2011 New Zealand earthquake.
Because the tremors in Groningen are only short, softening does not occur, but settlement does.

Moment-resistant frame

This is a building structure that resists horizontal forces because its components such as beams and columns resist elastic bending without permanent deformation. After the load, the load-bearing structure returns to its original shape. A moment-resistant main support structure with elasticity has a higher q-factor than a rigid box structure. Beams and columns structures that permanently deform (but do not break) under overload are called ductile. A ductile building has a higher q-factor than a moment-resistant structure.

Magnitude of Intensity

This is the measure of the strength of the earthquake, usually expressed as a number on the Richter scale or as moment magnitude (MMS; also written as Mw). There are different magnitude scales, but **they are not easy to compare.**

The magnitude is based on the moment of the earthquake, which is equal to the rigidity of the Earth multiplied by the average subsidence of the fault and the size of the area that has subsided. The MMS scale was developed in the 1970s as a successor to the Richter scale. The MMS is now the primary scale used by the United States Geological Survey (USGS) to measure any major earthquake. Similar to the Richter scale, the MMS is a logarithmic scale. With an increase of 1 point on the Mw or Richter scale, the earthquake is ≈10x as strong. The KNMI uses the Richter scale for earthquake strength indication, which **cannot be directly compared with the PGA for the seismic building load.**

An earthquake Richter 4.6 (PGAg ≈ 0.22) is **therefore 10x as strong** (amount of energy in the epicentre) as an earthquake Richter 3.6 (PGAg ≈ 0.085 Loppersum). However, the PGA force at the epicentre on the building is about 2.5X as strong. The PGA force is the determining factor for the building. The total energy of an earthquake in the hypocentre goes in three directions and is therefore **31.6 times as strong** with one whole point increment of Richter or Mw. {Eurocode 1.4.2.1} and {Eurocode 1.4.2.3}.

The big problem (for the Press and the public) of the KNMI Richter indications is that the PGA forecasts from 2014 indicated that the earthquakes could reach a strength of Richter 6 and higher. It was indicated that Richter 4.6 is 10X as strong as Richter 3.6 (16-08-2012 Huizinge). A quake of Richter 5.6 would be 10X higher than Richter 4.6, this would be about 100X stronger than Richter 3.6.
At the same time the Press showed worldwide devastating earthquakes of Richter 6 and more, causing fear among the population about imminent collapse of their houses.
That fear was real, based on the Richter 5.6, but that Richter 5.6 was totally unreal.

Although the KNMI always indicated the past earthquake strength in Richter, they are not a good indicator of the building damage. The actual PGA of a past earthquake could only be found through detailed internet search on their website [105].

Richter scale (energy).	Description in the Epicentre	≈ PGA_g
1-4 Light earthquake	Type of induced earthquake in the province of Groningen.	< 0,1
4-6 Moderate heavy quakes	Reinforced masonry is obliged according to most of the earthquake codes	> 0,2
> 6 Large earthquakes	Does not exist in The Netherlands	> 0,3
Scale of Mercalli	Description of the experience of people.	
I. Not felt	Only detected by seismometers	0,01
II. Barely felt	Only felt under optimum circumstances [106]	0,02
III. Weak	Felt by some people. Vibrations as by traffic.	0,04
IV. Moderate strong	Felt by many people. Vibrations as by heavy traffic. Rattling of doors and windows.	0,06
V. Strong	Generally felt. Suspended articles will swing. Sleeping people will wake up.	< 0,08
VI. Light damage	Schrikreacties. Voorwerpen in huis vallen om. Lichte schade aan minder solide huizen.	< 0,1
VII. Schade	Panic. Damage to many buildings. Chimneys break down. Waves in ponds.	< 0,15
VIII. Large damage	General panic and damage to buildings. Weak structures are partially destroyed.	< 0,2
IX. Destructive	Many buildings and foundations heavily damaged. Underground pipelines break.	0,3
X. Extremely destructive.	Destruction of many buildings. Damage to dams and dikes. Ground displacement and cracks in the earth	>0,4

Mercalli intensity is determined retrospectively through damage observations and surveys; the emotional value therefore plays the leading role here. The intensity depends on the magnitude of the quake, the soil conditions and the distance and depth to the hypocentre. This data is displayed on an intensity map.

The different scales such as Richter (Energy, Mw), EMS (damage) with Mercalli (feeling and damage), and the PGA zoning of the Eurocode 8 do not coincide. All PGAs (acceleration) of tectonic and induced quakes can be compared, regardless of the depth of the hypocentre; that is why they are listed in the Eurocode 8 and the NPR9998.

Groningen hypocentrum op 3 km diepte = Groningen Hypocentre at 3 km depth
Waarschijnlijk maximum bij maximum gasextractie = Likely maximum at maximum gas extraction

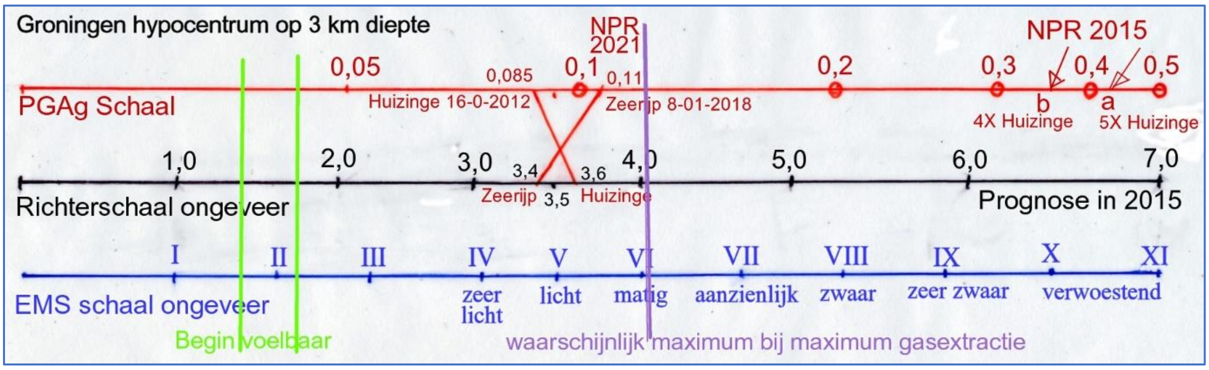


Figure 73. The PGA is strongly influenced by the depth of the hypocentre and the ground layers. The logarithmic Richter scale only has to do with the strength of the earthquake (+1 point = 10X as strong) and cannot get very large in Groningen due to the relatively thin sandstone layer (max 200 meters). The Richter scale has little to do with ground acceleration. The Zeerijp earthquake (8 January 2017, Richter 3.4) therefore had less force, but a larger PGAg (0,116) than the Huizinge earthquake (0,085 Richter 3.6). The Mercalli and EMS scales are both based on feeling.

[105] Because the Richter scale is logarithmic, for most people this could not be properly understood.
[106] For example, during the night when in a relaxed/quiet position. During the day, when people are moving, they will not detect these. However, these light quakes do have influence on constructions.

Only the PGA of the quake is indicative of the building damage and is therefore stated in the Eurocode 8 or the NPR9998, not the Richter scale. There are for each shock three PGA values; vertically, radially horizontally from the epicentre and the S waves horizontally from right to left, also from the epicentre (snake motion).

The Richter scale is used for earthquakes in Groningen because all earthquakes originate from the same 3km depth and are therefore easy to compare. **Only the PGA is used in calculations.**

Main construction {Eurocode 8: 1.4.2.23}

The main or principal carrying construction. The principal building structure or assembly of structural members (primary seismic elements), the failure of which results in damage disproportionate to the cause. These are the load-bearing walls, columns, and floors, with their connections. If some of these parts fail, the entire building will be dragged along and the collapsing building will cause considerably more damage. A rigid and brittle main supporting structure, such as brick masonry, will crack when overloaded and can then collapse suddenly. For structural or seismic reinforcement, the main structure must therefore be reinforced.

Maximum earthquake

The maximum earthquake is the (theoretical) maximum possible earthquake in a certain area, calculated based on data from the past and adjusted on the basis of risk calculations. The strength is increased with tolerances and uncertainties and sometimes with extra “safeties” such as in Groningen for periods up to 2475 years (design model). Construction designs are based on this maximum earthquake value, so that the building ‘just does not collapse’. This design value does not prevent the building from cracking.

When the risks cannot be clearly defined, an additional uncertainty percentage is applied. The more uncertainties, the higher the maximum earthquake PGA value [107].

The theoretical probability of that maximum earthquake occurring is 2% over a period of 50 years, or 10% in 475 years and is indicated in the NPR9998. However, to determine the probabilistic maximum earthquake, you also must take the Dutch socio-political context into account; that was NOT done. It was already clear with the Huizinge earthquake of 16 August 2012, that earthquakes stronger than PGAg 0.1 would not be tolerated socio-politically-legally. Below a PGAg of 0.05, according to the NPR9998, no seismic reinforcement would be necessary.

The NAM was still legally obliged to realize all repairs. However, they were not legally obliged to prevent damage. Legally they could not (indirectly) kill people because of generating larger earthquakes through gas extraction that would cause building collapse.

When the future earthquakes or shocks are not stronger than the Huizinge earthquake (PGAg = 0.085 or < 0.1), hardly any seismic reinforcements are necessary according to the NPR9998. However, many cracks will continue to appear with small shocks, hence other structural reinforcements are desirable for this to prevent partial collapse of the oldest and weakest buildings.

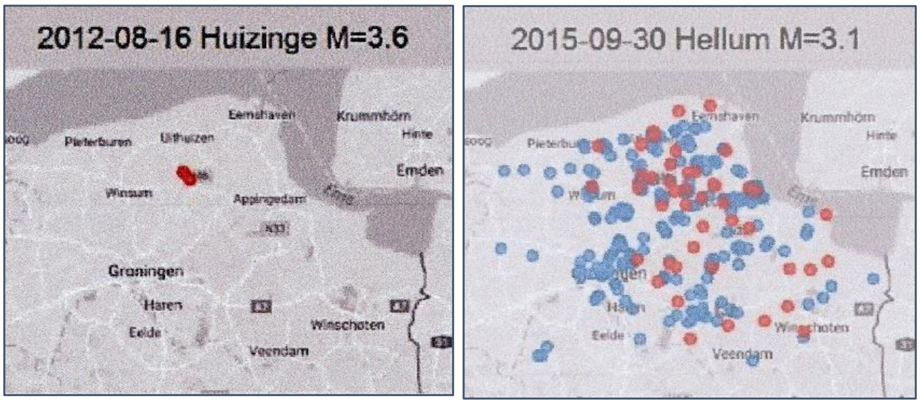
[107] This was the basic issue with the KNMI calculation of the super high PGA for Groningen in 2013. On the one hand, NAM wanted to extract all the gas from the ground at an accelerated pace and had presented the KNMI with the most extreme scenario. On the other hand, it was not known (exactly) what the effect would be of the complete exhaustion. Several uncertainty factors were stacked, or multiplied together, resulting in the very high NPR9998 map figures. The legal or social aspects of this high PGA were not considered.

Soil and foundation settlements can also still occur with the small earthquakes or vibrations, which in turn can lead to cracks in those foundations and higher up in the masonry work. The exaggerated reinforcement advises (made in 2018 based on the very high PGA values) may/will possibly prevent the additional damage.

Measuring network

With the seismological measuring network of accelerometers and borehole seismometers, KNMI and TNO can register earthquakes for the NAM, both on the earth's surface and at great depths. A few hundred accelerometers have also been placed on the foundations of buildings in the province of Groningen. By linking the information from the deep measurements to the measurements at the earth's surface, it is possible to determine the relationship between these two. However, the seismographs on the foundations also show the building response (reverberation) for the different types of structures. The vibration characteristic of those buildings can therefore be determined.

Figures 74. Expansion of the measurement network of the KNMI (red) and TNO (blue) since 2012 up to and including 2015. Thanks to the large measurement network, better data can be collected, and accurate maps can be made.



NAM (Nederlandse Aardolie Maatschappij)

The NAM was founded on September 19, 1947, as a commercial partnership of Shell (25%), Esso (25%) and the Dutch government (50%). The Shell manages on behalf of Esso (ExxonMobil). This establishment was the direct result of the discovery in 1943 of an oil field near Schoonebeek. In 1959, gas was found near Slochteren. Until 2014, NAM produced approximately 75 percent of the natural gas extracted in the Netherlands, from many small gas fields and from the Groningen gas field. NAM's contribution to Dutch petroleum production is approximately 25%.

According to the law, NAM (Shell and Government. www.nam.nl) is liable for damage caused by induced earthquakes. In the period up to 2015, NAM was involved in the interpretation and implementation of earthquake damage dossiers. From 2014 this massive activity to handle thousands damage reports were transferred to the CVW[108].

The NAM (concession holder), together with EBN (Energie Beheer Nederland B.V. = 100% Dutch state), Maatschap Groningen and GasTerra (transport company and trading company for natural gas) together form the 'Gasgebouw' (Gas building), the Dutch organization for extraction and distribution of natural gas.

[108] The transfer of these activities was deemed necessary to create an impartial organisation at distance from the NAM. However, most NAM staff was transferred to the CVW and the directives of the NAM to minimise damage identification were still in place such as negation of foundation damage. In a later stage the damage identification and reimbursement were transferred to the NCG and later again the IMG was created.

National Coordinator Groningen (NCG).

Hans Alders was appointed by decree to direct the NCG in 2015 by the Minister of Economic Affairs because of the gas extraction and damage problems in Groningen, with the task of examining where reinforcement is needed and how this should be tackled. He formed the NCG organization and withdrew in 2018.

This decree was amended on 17 June 2019. At that time, the NCG was the forerunner of an implementing organization that was responsible for carrying out surveys, assessments, and the structural implementation of the reinforcement. From 1 January 2020, NCG will be the implementing organization for the reinforcement task[109].

On 20 May 2019 the ministerial appointment of the NCG and IMG are adjusted.
On 11 September 2019 the NCG and the TCMG sign a cooperation agreement.
In 2023 the first yearly planning was presented by the third NCG, Regina Bouius Remersma.

Natural Gas Groningen

The Natural Gas is a fossil energy source (Methane = CH_4) that was created 350-280 million years ago by the accumulation of a more than hundreds of meters thick layer of plant remains in swamps. The digesting plants, which were deprived of oxygen, produced methane gas through bacteria. This happened all over the world. The large amount of methane caused a very strong warming of the earth climate, resulting in a lot of desertification and sand drifts for millions of years[110]. The digesting plant mass was in the Groningen and North Sea area first covered by a 200 m thick sand layer, through which the methane gas also escaped. Under the sand layer the thick layer of plant fossil remains were gradually compacted into a Carboniferous layer. After flooding by the shallow Zechstein Sea and evaporation of the seawater about a one km thick salt layer deposited over the sand. This locked the methane gas inside that sand. Finally, 200 million years onward a two km thick pack of other soil layers such as sea clay and sand covered the salt layer. The pressure on top of the sandstone rose to 670 bar.

Figure 75. (Internet photo). Artist's impression of the type of vegetation a few hundred million years ago, which is the source of the methane and the formation of coal and oil. That is long before the existence of the dinosaurs or vertebrates.

Due to the great pressure of these 1 km salt rock and 2 km earth layers and the resulting high temperature, this lower plant material below the sand layer has slowly turned into coal. This coal layer lies beneath much of Europe.

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109 https://www.nationaalcoordinatorgroningen.nl/over-ons/instellingsbesluit

110 Methane gas is 21x more potent greenhouse gas than CO_2. The effect was very strong global warming resulting at a global desertification of the earth, melting of the ice caps and rising sea levels.

The escaping methane gas remained trapped in the sandstone under the sealing salt rock layer. The pure natural gas (mainly methane) is odourless, highly flammable, and deadly if inhaled. The natural gas can be mixed with methane gas (CH_4) from biodigesters and with hydrogen gas (from overproduction of electricity). These mixtures will increase in the future when more biogas is produced, and windmills or solar panels have excess of electric power.
See also http://nl.wikipedia.org/wiki/Aardgas

Nederlandse Praktijk Richtlijn, NPR9998 (Eurocode 8)

The Eurocode 8 indicates the calculation method for earthquake-resistant construction. This code applies throughout Europe and has a map appendix per country that indicates the maximum earthquake per region in that country. The Eurocode 8 is again based on the American ACI 318-71 and subsequent refinements with better calculation methods for tectonic earthquakes. The Dutch Practical Regulation or Guideline (NPR9998:year) is primarily a translation of the Eurocode 8. This translation is not essential for most engineers; they can easily use the English language Eurocode 8. For professionals who are not skilled in construction and mathematics, the NPR9998 is a difficult document to understand (240 pages).

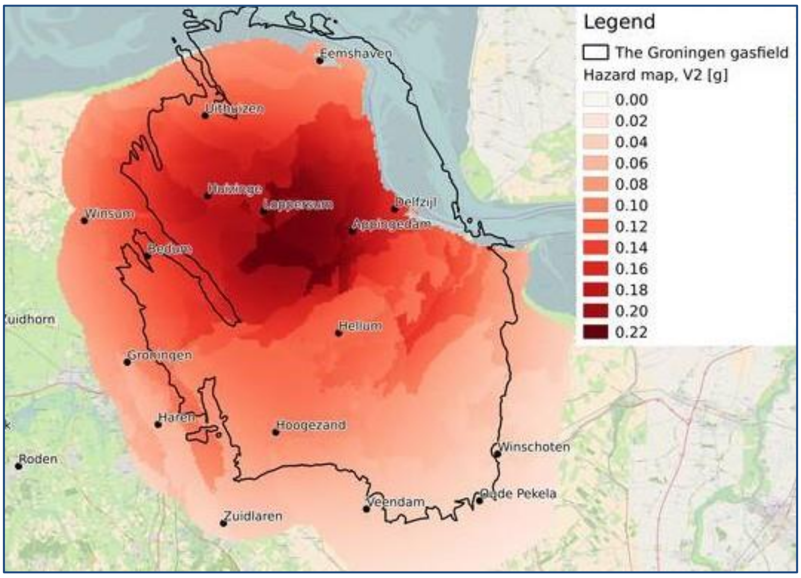
The NPR provides four different calculation methods for buildings. Of these, the static method is the simplest and good for common constructions such as low-rise buildings. The NLTHA is the most complicated and suitable for high-rise buildings (> 10 floors).
The attached national seismic map indicates the maximum earthquake risks for each country.
The first KNMI map of the NPR9998:2014 indicated the extremely high PGAg = 0.42 value

The NPR9998:2020 indicates the PGAg per location and the recurrence period via a new Home Webtool https://seismischemacht.nen.nl/map.php . For a site where the PGAg is <0.05 with a return period of 95 years, no special seismic strength calculation is required.

Before 2012 the NAM had (correctly) estimated that the maximum earthquake because of the gas extraction would be about Richer 3.9 corresponding with a PGAg of about 0.15. After the Huizinge earthquake the NAM requested the KNMI to make new calculations.

Figure 76. This old 2014 Arup threat indicates their estimate of the maximum earthquake at 2.5 X the Huizinge earthquake with PGAg = 0.22 in the epicentre area between Ten Boer, Loppersum and Appingedam.
At the same time the KNMI produced a map with about ***double this value.***

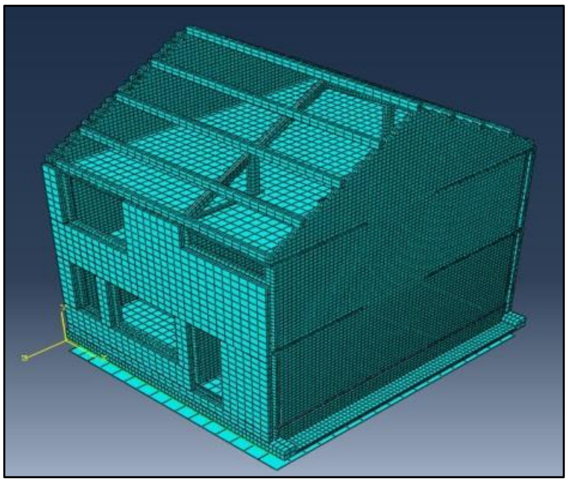
In 2018, when the KNMI lowered their PGA value for the third time, the maximum limit value of PGAg = 0.13 would only be reached in the core area of the region (municipality of Loppersum and south and southeast thereof).

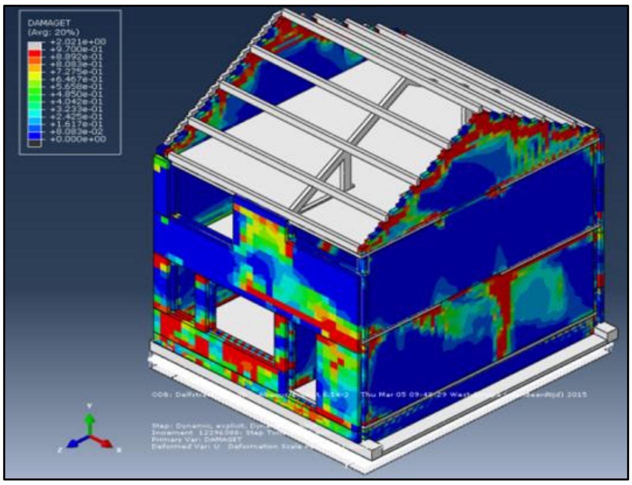


Realistically speaking, the special seismic calculation will no longer be required if the gas tap remains closed. The current KNMI threat map of the NPR9998:2021 is still about 2X higher than the actual occurring earthquake strength in connection with the regular safety factors [111].

NLTHA. Non-Linear Time-History Analysis.

The (Non-Linear Time-History Analysis) calculation method is based on the time-dependent reaction of the building during an earthquake. The vertical and the two horizontal and ground signals of an earthquake are applied to the foundation. To be able to apply and calculate this method, the entire building is calculated in small pieces (for example 30 cm x 30 cm) where the elasticity and strength of each piece and its connections (strength, ductility, elasticity, flexibility) with the connecting piece are entered. This means that tens of thousands of pieces need to be entered; this is specialistic work and takes weeks (and is therefore very expensive).[112]





Figures 77. Example of dividing a terraced house into small pieces of 30 x 30 cm and the result of an NLTHA by Zonneveld Engineers. Red are damage zones such as cracks.

Specially designed computer programs perform the many calculations of each vibration and of all the pieces [113]. This makes it possible to theoretically see which points or zones in a building are the weakest and which are likely to fail. For new or existing buildings, these are the locations where the reinforcements must then be applied, or the design adjusted.

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[111] That in itself is not detrimental. If, according to that NPR standard, new construction is now carried out, such a building will no longer receive cracks with the current light earthquakes, but cracks will still appear in old buildings. To prevent cracks in existing buildings, the typology and the characteristic places where cracks will/may occur will have to be looked at, rather than based on the standard calculations. This requires insight into the building structure and an analysis of the cracks occurring per typology.

[112] The figures below give an example of the calculation of a simple building. It shows where the tensions will appear and the cracks (red). Similar building will have similar damage patterns. However, it is not necessary to use this calculation method instead of the simple Lateral Force Resisting System (LFRS). Both systems indicate at what PGA the building will fail. To analyse thousands of buildings with the NLTHA was good business for the engineering companies, made the reporting extremely expensive, and delayed the repair process. Moreover, with the use of exaggerated PGA values of the KNMI, the results are hardly representative for the reality.

[113] It took several months to enter and calculate the 13-storey Dijkzicht apartment building. In such a case, the construction drawings must be studied, and masonry or concrete tests must be carried out to approach the correctness of the data as closely as possible. The actual calculation must be done with a vibration signal that corresponds to the type of shocks and the type of soil that occur in the province of Groningen. The actual information, however, was derived from tectonic quakes in Turkey in 2015. These were significantly higher than what could occur in Groningen, making the calculations largely irrelevant.

The earthquake signal used for the NTLHA calculation must be the correct ground signal and not the signal from a vibration meter attached to a building foundation. That signal also shows the reverberation response of that building.

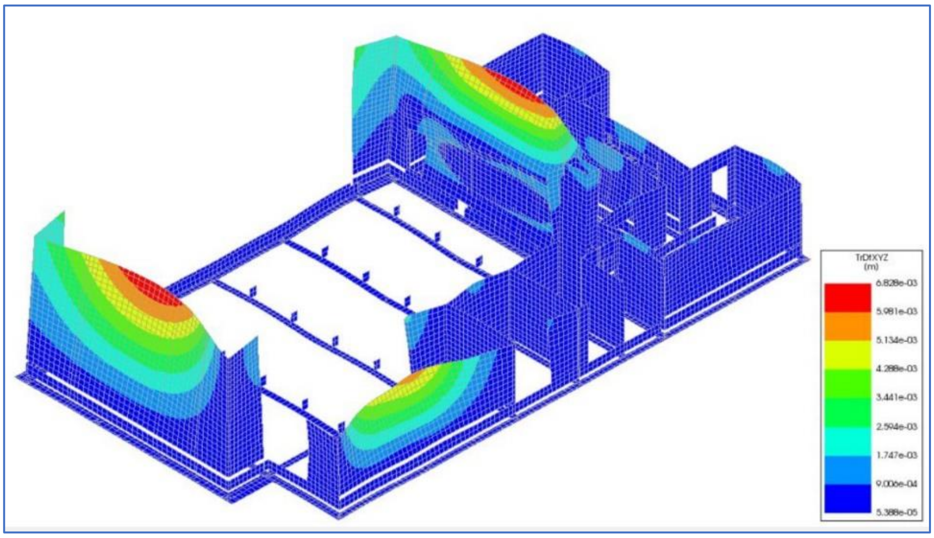
By repeatedly releasing an earthquake shock on the structure, one sees the progression of the damage in exterior and interior walls, until parts or the entire building collapses. By measuring and calculating an example house of each building typology using this method, you get a good idea of where the cracks will occur. Correspondingly, the correct reinforcement measures can then be taken in all similar buildings (cost-saving).

With additional equal shocks in old brick buildings or poor concrete structures, damage patterns can also spread further (damage on damage). This is because crushed and pulverized rocky material or gravel falls into the crack, preventing the cracks from closing and creating new pressure points. This practical detail is not included in the NTLHA method.

The Commission Meijdam gives 14 December 2015 the advice[114] about "Dealing with the risks of induced earthquakes". This advice states that this Committee advocates the use of a precise calculation method, the so-called 'finite elements' method (NLTHA), because this would provide sufficient reliability. That is, when the (1) building data are correctly entered, and (2) the forces applied are correctly applied. However, the first (1) was often a guess, while the second (2) was not correct. To have correct data about the old construction's material tests must be executed.

This recommendation was embraced by the specialized engineering firms. However, the extreme refinement of the calculation method based on a heavily overstated PGA value is also not relevant when a guess must be made about the strength and construction details of old houses. A few weeks of computer calculations yield the same architectural result as half an hour of calculations on one A4. A practical insight into the general building construction is then faster and more reliable.

Figure 78. Image by AVECO of the NLTHA calculation of a school, in which the brick top facades show a lot of deformation and will therefore damage first.



The above is an analysis of a school building, but the top facades are not (in the calculation) connected to the roof construction. The effect is that these top facades start to sway and break off. A well-designed roof diaphragm can avoid this. The earthquake loads must also be applied in the perpendicular direction.

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[114] Commission Meijdam Final advice 14-12-2015 https://zoek.officielebekendmakingen.nl/blg-646523.pdf It is possible that the commission did not understand the differences of the calculation methods or had vested interest in the engineering companies that performed the calculations.

Non-structural building component {Eurocode 8: 1.4.2.12}

Two components must be distinguished:

a. Structural part, not belonging to the main supporting structure of the building. Structural part, which, either because of its lack of strength or because of the way in which it is connected to the main structure, should not be considered as a supporting structure that can withstand an earthquake load to prevent progressive collapse. See also {Eurocode 8: 4.3.5}.
b. Non-structural part. Architectural or electrical part, which, either because of its lack of strength or because of the way it is connected to the building structure, can lead to one or more victims in an earthquake. See also {Eurocode 8: 4.3.6}

The non-structural parts **must not cause any adverse loads to the structure**.

These parts therefore no longer count for the strength calculation of the building and are also building parts that can or may collapse / fall off at the maximum earthquake. Because this is the case, the non-structural (smaller) building elements that can fall of during an earthquake need to be detected and classified as high-risk elements and secured. For example, heavy chimneys.

Before 1960, all parts of a building were rarely calculated for strength and connection. Before 1940 and well before 1900, building was mainly based on experience regarding foundations, wall thickness and window spans such as lintels, also in the city of Groningen. Later it became mandatory that the connections between non-structural elements and structural parts were more than sufficiently strong and where necessary also ductile (deformable in case of overload).

Figure 79. (Internet photo) In Christchurch, New Zealand, the collapse of the non-structural elements of older buildings that were not built according to the seismic code, such as façades, gables over shopping arcades, was the leading cause of public deaths.
Particular attention should be paid to infill panels in space-frame buildings or reinforced concrete structures so that they are ductility connected to the main structure.

Peak Ground Acceleration {Eurocode 8: 1.4.2.2}

The Peak Ground Acceleration (PGA) is the highest value of ground level acceleration during an earthquake. It is expressed in PGAg or PGA(g), where g is the gravitational acceleration of 9.81 m/sec^2. Sometimes the value is given in pga or pga m/sec^2; in these latter notations the value is therefore approximately 10 times the PGAg value. If the strength is notated in PGA, the denomination of m/sec^2 must be stated.

Because the official PGA value as proposed by the KNMI in 2013 has continued to decrease over the years since 2014, the area of influence where new earthquakes would be felt became increasingly smaller (shakes palpable by humans). However, buildings will continue to be affected by the smaller quakes that cannot be sensed by humans. In connection with this period reduction of the PGA, the preventive reinforcements according to the NPR, would also be less necessary. The province area of application of these reinforcements would therefore be smaller.

The magnitude of the earthquake of August 16, 2012, in Huizinge was estimated at PGAg = 0.085 (or pga 0.0085 m/sec^2) slightly less than PGAg = 0.1. The design earthquake from the NPR9998 gives the design loads per location in the province of Groningen [115].

In the newest 2021 KNMI maps, the peak ground acceleration agS at ground level includes the soil factor of the top 30 m and the soil types and groundwater present in those layers. Elastic (clay) soils and soft peat soils have a different influence on the soil factor than firm sandy soil and can cause extra and longer reverberation.

In the press and other texts about Groningen, the Richter value is always used to indicate the strength of an earthquake. This is a good comparison value for Groningen alone, because all earthquakes come from the same depth, but not compared to tectonic earthquakes. By comparing these Groningen Richter values with other tectonic earthquakes all over the world, the fear of the people in Groningen will be enhanced.

The actual strength of the earthquake with respect to buildings is indicated in PGA only. That is why the NPR's threat map is only shown in PGAg.

Peat soils

Peat is a type of soil consisting mainly of partially decomposed plant material such as peat mosses and has a moisture content of more than 75%. When a load is applied (building), the peat will compress, and the water will be squeezed out. This causes settling, and in the case of a foundation on undisturbed soil, building subsidence. Peat that becomes dry, for example due to the lowering of the groundwater, it will start to oxidize, causing it to lose volume, and cause the foundation above it to sag/settle. This will lead to cracking in masonry buildings with structurally weak foundations. Lowering of the groundwater is caused by drought and drainage. When the ground level subsides due to compaction, the groundwater level then rises[116].

For buildings on peat soils, extra wide foundations are desirable, or foundations on piles that bear on a deeper layer of sand. Old houses on peat soil can often be economically placed on a platform foundation. See Chapter 4, Foundations.
Also see ‘Groundwater’.

Period of an earthquake

The duration of an earthquake [117] is described in different ways. What people feel on the surface of the earth is a subjective perception and depends on whether these people are at rest, or whether they are low or high in a building, in combination with the elasticity of that building. In a tall building, the construction will continue to sway horizontally for some time, so that the people at the top of that building will feel the earthquake for a longer period.

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[115] That is, to prevent collapse, according to NPR9998. Because the PGAg values were completely exaggerated in 2013, the new values were only seen by the population as a method of NAM to avoid the repair costs in the outward lying areas (further away) from the epicentre. In 2020, the PGAg values of the KNMI threat maps still have approximately a 100% safety margin. Strengthening of houses against collapse will not prevent cracks.
[116] Because of the general subsidence of the entire province (flat bowl development) due to the gas extraction and compaction of the gas field, the ground water and canal water levels rose in the central part in the province. This needed to be corrected by drainage, causing foundations on peat and clay soils to settle.
[117] For a more detailed explanation see: http://www.usgs.gov/faq/node/3359

Voelbare aardbeving tot ongeveer 4 seconds = Noticeable earthquake up to about 4 seconds (at ground level)

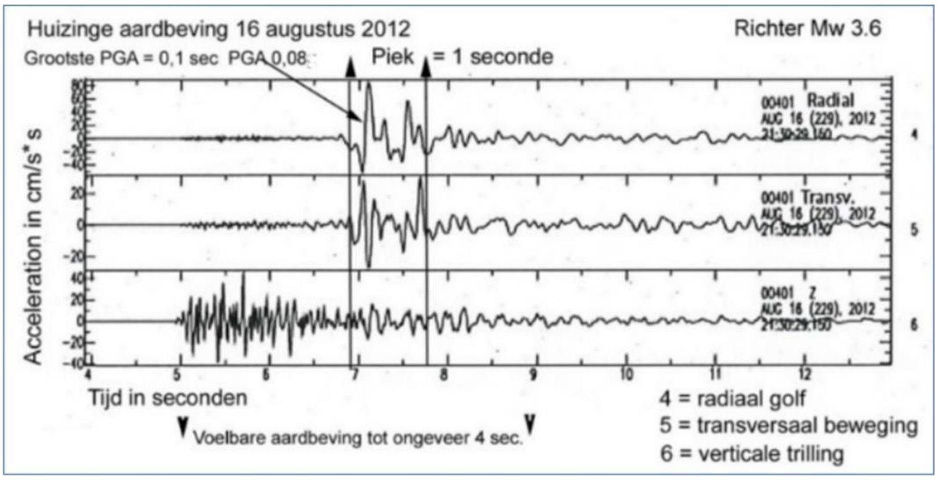


Figure 80. The graph shows the three measurements made by a seismograph. Depending on the horizontal distance between the epicentre and the building, in combination with the subsurface, the duration of the earthquake can increase, but the intensity decreases.

The duration of this earthquake of August 16, 2012, in Huizinge starts at second 5 (in the graph), but it is not recorded when it ends. For people who only felt the horizontal movement, it may have lasted 1-5 seconds depending on their location and building post-shaking (low building).

Iets Kleiner dan epicentre = A little smaller that at the epicentre. Langer = Longer.
Vaste grondlagen = solid or firm soil layers. Zoutlaag = Salt-stone layer. Zandsteen = Sandstone. Zout bult = salt hill.
Drenthe/zuiden = Drenthe province, south of Groningen. Schok grafiek op breukvlak = Graph of shock at fracture zone
Zwakker maar veel langer en meer horizontaal = Weaker but more duration and more horizontally
Wadden = Sea mudflats north of Groningen. Slappe grondlagen = soft soils
Verandering door grondlagen en afstand. = Changes caused by soil layers and distance.

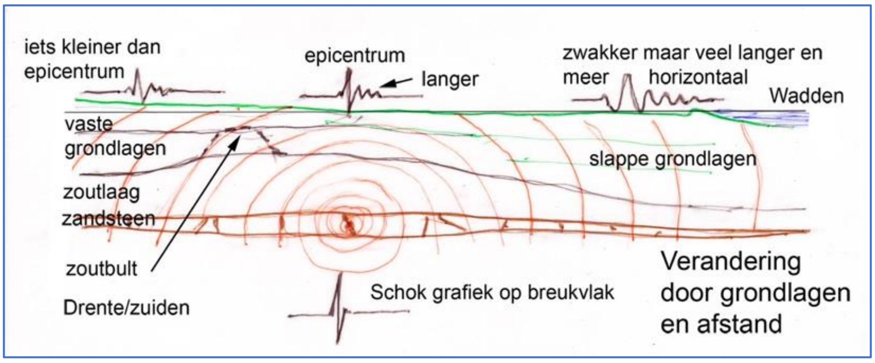


Figure 81. With a high and hard salt bump, the shock can be felt more directly and strongly. With weak soil layers, the post-vibration will last longer. Farther from the epicentre than the depth to the hypocentre (3 km), the horizontal amplitude will be greater than the vertical.

With the Groningen induced earthquakes, the duration of the vibrations in the hypocentre is very short (0.1 - 0.3 seconds) compared to tectonic earthquakes (tens of seconds to minutes). This is due to the small thickness of the sandstone layer (200 m) and the small vertical displacement (< 1 cm) compared to tectonic earthquakes[118]. With tectonic earthquakes the vertical and horizontal displacements can be decimetres. See also 'Induced earthquakes.'

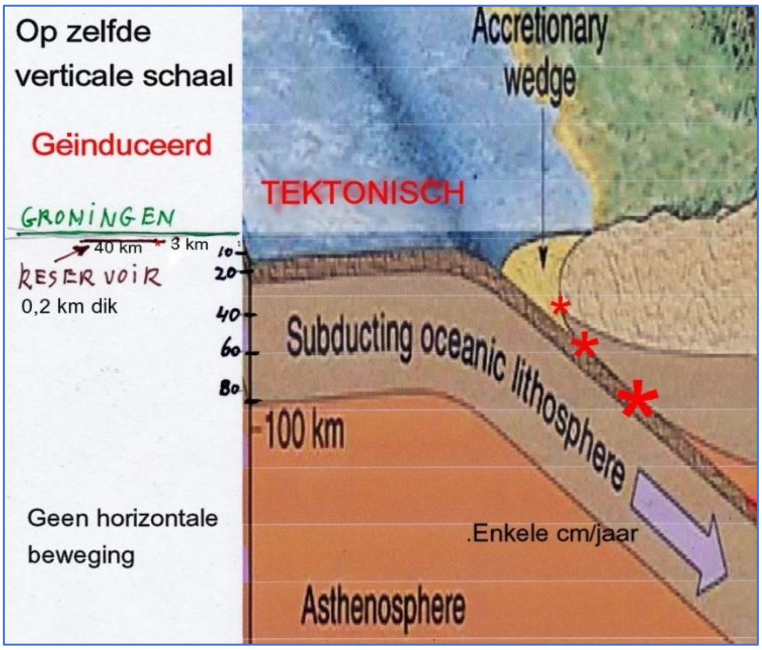
In Nepal, Kathmandu earthquake (2015-04-25, Mw 7.9 and 15 km deep), there was up to 30 cm horizontal displacement. Because of the ground and building effect (reverberation), some people felt the quake in Huizinge for 10 seconds. The above graph only shows between the points of second 5 and second 8 only three seconds vibrations. After that, only the reverberation of the building is felt.

[118] With the Groningen earthquakes there are hardly horizontal displacements (maximum estimated 3 cm).

Op zelfde verticale shaal = On the same vertical scale.
Geen horizontale beweging = No horizontal movement (with Groningen induced earthquakes.)
Subducting oceanic lithosphere is a few cm per year (as fast as a toenail grows).

Figure 84. There are major differences between induced and tectonic earthquakes.

In tectonic quakes, the tectonic plate suddenly shifts diagonally downwards or/and the other upwards for several decimetres.
In induced quakes, there is a compaction of maybe a few cm.
The Mw or Richter values between tectonic and induced earthquakes are hardly comparable. The PGA values are comparable, which is why the NPR only indicates the PGA values and calculation.



Permeability

Permeability of a material (related to porosity). This is related to the number and size of the channels or spaces between the sandstone kernels. Although the sandstone has some porosity, it is not very large. Rapid gas exploitation from one zone therefore creates a pressure difference between the exploited part and the adjacent part, because the gas needs time to flow from one area to another.

There are many boreholes (300) for natural gas extraction in Groningen. The gas from the vicinity of those boreholes flows slowly to those extraction points due to its permeability. When the compaction increases (due to gas extraction), the permeability in the reservoir can also decrease slightly, so that the pressure differences level out less quickly.

Slower extraction of the natural gas will decrease the pressure differentials and spread the compaction over time and reduce shocks on the fracture lines.

Primary seismic building components {Eurocode 8: 1.4.2.13}

Also called support structure. Building elements or parts considered to be part of the structural system that resist the seismic load, the entire support structure. The strength calculation of a building is made for these components.

The primary seismic components (load-bearing walls, columns, portals, diaphragms) must be reinforced to prevent collapse of the building with the maximum earthquake. When the actual quakes have a PGA higher than the maximum of the seismic code, they must be designed to fail ductile. In other words: that they bend (non-elastic) and give way slowly, but do not suddenly collapse. Also see ‘Ductile’.

Rapid Visual Screening (RVS)

RVS is based on the American model (ATC-20) for a fast survey method from the public road. This investigation is used to assess whether a building or elements of a building pose a high risk to residents or the environment. This method was adopted to carry out the first building inspections in the province of Groningen. After establishing a potentially dangerous situation (e.g., low ratio of wall piers), a follow-up investigation is initiated. This follow-up study is called EVS, extended visual screening, according to the same American methods.

Figure 85. A high chimney or detached top facades are high-risk elements anyway and are easy to detect from the outside. The 1930s chimneys are an extreme example of this. At the base, the masonry is also interrupted by the lead flashing. Reinforcement is very expensive and replacement with a lightweight model is then preferred. Open fireplaces are not desirable in energy-efficient buildings or for the environment (poor energy efficiency and high particulate matter emissions). It is therefore preferable to completely remove the masonry chimney unless it is an important architectural element.

Parapets or free-standing gable tops and projecting balconies may also fall under this category. After detecting a potentially high-risk situation, immediate action is taken or a more Comprehensive Safety Investigation (EVS) is initiated.

Figures 86. Left. Example of a gable top as a high-risk element due to lack of connection to the roof and strong erosion of the masonry.

Right. The top needs to be restored and properly connected to the roof.

Reaction diagram'. {Eurocode 8: 1.4.2.5}

Maximum response (reaction) of a structure to an earthquake as a function of its natural period (pendulum period) or natural frequency (depending on height, building mass and elasticity) based on a 5% damping due to the elasticity or tenacity of the soil.

The low and brittle brick buildings in the province of Groningen have an adverse response spectrum and are therefore more susceptible to damage than flexible (wooden) buildings or taller buildings.

The Eurocode 8 (NPR9998) indicates different methods to calculate this own building frequency. A simple method is T_1 = $Ct*H^{3/4}$ Formula (4.6). When the earthquake frequency is equal to the building's own frequency, long-term tectonic earthquakes can cause dangerous building resonance. This is not the case in Groningen because the duration of the shocks is very short (tenths of a second). In a building on Base-isolation, the heavy shock of the earthquake is not transferred to the building above but slowed down and converted to a much smaller movement.

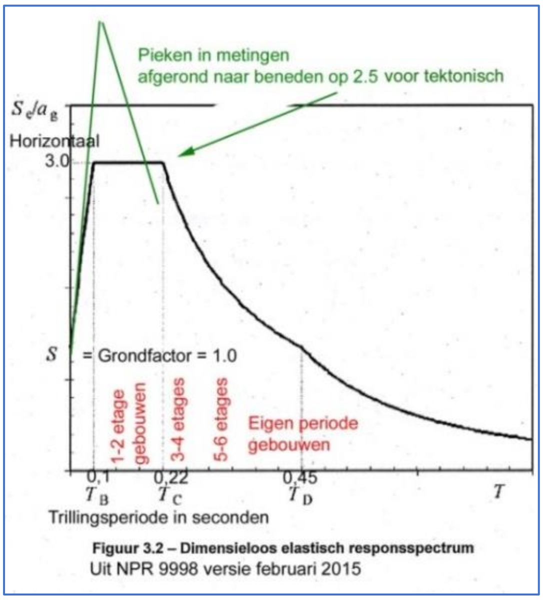


Figure 83. The reaction diagram or response spectrum combines the type of soil with the height and the building's own vibration frequency. Because low buildings have short vibration period, they are therefore subject to higher load than tall buildings.

Elastic clay soils can have a greater damping of the shock, which is favourable for the calculation. The Eurocode 8 or the NPR9998 provides more clarity in the calculations with a soil type map of the top 30 m for the province of Groningen.

Reservoir pressure

By measuring the pressure drop in the reservoir over time at each borehole, pressure differences in the reservoir can be recorded. The greater the pressure differences between adjoining sections, the greater the chance of earthquakes or the more shocks can occur.

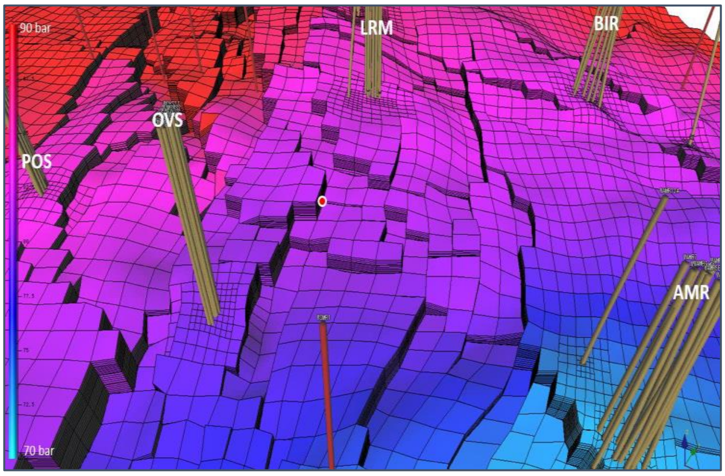


Figure 82 [119]*. The beige lines are the pipes from the drilling sites. Due to faster gas extraction in the AMR zone (bottom right) than from the other boreholes, the reservoir pressure is the lowest there. Minimizing the pressure drift through less extraction will reduce the number and strength of shocks.*
The red line and dot is the hypocentre of the earthquake of 21 August 2017 near Appingedam. The vertical scale of this graph is 10 x horizontal scale.

Return period. {Eurocode 8: 1.4.2.4}

The return period is a measure of the probability of an extreme or maximum event such as the highest water level or the Peak Ground Acceleration (PGAg). Four repeat time options are provided in the Home Webtool: 95 years, 475 years, 975 years and 2475 years. These are based on tectonic earthquakes. The standard return period of NPR9998 is 475 years[120]. However, the original gas exploitation was already planned to diminish per 2015, minimise per 2035 and expire by 2050. To extrapolate the possible earthquake force based on continued high gas exploitation is therefore not correct as the strength and frequency of the shocks will reduce with less gas extraction.

[119] Map with 3D presentation of the pressure differences in the reservoir sandstone rock and along the fracture lines. From NAM website, see: https://www.nam.nl/nieuws/2017/rapport-aardbevingen-gebied-appingedam-loppersum/_jcr_content/par/textimage.stream/1504694438195/cb091a285690c263e3d9cb61f1db6778f3e3668676f20943a8d8226df13e531b/special-report-appingedam-on-27th-may-2017.pdf

[120] It is necessary to develop adjusted return periods for induced earthquakes, considering human activities, increase or decrease with production, and the possible delayed effects of the activities.

The Peak Ground Acceleration agS includes the soil factor. If, with a return period of 475 years, the agS (PGA including the ground factor) is less than PGAg 0.05, no building strength assessment for earthquake loads needs to take place. In the situation of Groningen, a return period of 50 years would be more realistic, because in 2012 it was clear that in a period of another 20 years very little natural gas will be extracted from the central gas field, if policy allows. With that the possible maximum earthquake strength and frequency will drop to below PGAg 0.05.

Richter scale

In 1935, American seismologist Charles Richter designed his magnitude scale. This is based on the strength of the vibrations, as measured on the seismogram at the epicentre and expressed on a logarithmic scale. The magnitude is calculated from the readings of the earthquake recorded by different seismographs. The seismologist (KNMI) applies corrections to this to take the influence of the distance between the epicentre and the seismic station into account. As the travelled distance increases, the seismic waves lose part of their oscillation amplitude due to geometric dispersion and absorption. The Richter scale is logarithmic. This means that one whole point on the Richter scale has a 10X greater deflection on the seismogram.

Richter's amplitude starts at zero, and each subsequent whole number represents a tenfold increase in wave amplitude (logarithmic). This means that a 3 quake on the Richter scale produces horizontal waves that are 10X times as strong as those of a 2-scale quake. An earthquake Richter 4 is therefore 100X as strong as a Richter 2.[121] This ten-fold increase per scale number in wave amplitude represents a >31 X increase in the amount of energy released at the hypocentre. However, that energy from the hypocentre goes in all directions, with only the movement that goes to the earth's surface being relevant.

The Richter scale is not directly related to the PGA scale. The earthquake load on buildings is expressed in PGA. A building damage depends on many factors such as soil type, foundation type, amplitude, frequency and duration of the shocks, and on the stiffness or elasticity of a building, the building shape and other aspects. **The induced earthquakes are NOT comparable to tectonic earthquakes at all**. Richter Mw 4.0 tectonic earthquakes originating from a depth of 15 – 20 km hardly count, while a superficial Richter Mw 4.0 earthquake in Groningen can already cause a lot of damage to old brick buildings. In the Netherlands, buildings were never designed to withstand earthquakes.

Risk calculation and Safety (1)

Risk calculation. Risk and safety are closely related. In the knowhow and statistics about accidents such as traffic accidents, house fires, falling from stairs or scaffolding and the like, the maximum accident risk with fatal outcome is set at 10^{-5}. Reality should be less. This is also applied in European and Dutch laws. This means that a fatal accident of 1 in 100,000 is an acceptable standard within which to stay. The government is therefore trying to set rules and safety requirements so that this value of 10^{-5} is not exceeded. This standard calculation was also applied to the calculation of the risks related to building collapse caused by the induced earthquakes.

[121] The earthquake of 16 Augustus 2012, Huizinge was Richter 3.6 with PGAg 0,085. When the maximum earthquake according to the KNMI could reach PGAg 0,42 or about Richter 5.6, it would mean that the surface earthquake would be about 100X as strong as that Huizinge quake. With this type of excessive quake predictions, the population was briefed since 2014 (also calling it scientifically established). This caused a lot of needles fear among the population, as such heavy earthquakes would cause thousands of houses to collapse.

If the maximum earthquake PGAg were 0.36 (NPR9998:2017) and the deemed acceptable risk of a building collapsing is 1:100,000 or 10^{-5}, the buildings must therefore be reinforced to withstand that seismic load, to avoid collapse. Rather, for induced earthquakes, the risk factor should be 10^{-6}, equal to the risk of collapsing a main sea dike.

With a risk factor 10^{-5} and related to housing collapse (with deadly consequences), that would mean that in the Netherlands (> 17 million inhabitants) there should not be more than 170 deaths per year due to collapsing buildings or nearly 6 deaths per year for the province Groningen (580,000 inhabitants). No one in the Netherlands dies from collapsing houses[122].

In 2015, there were opinions from the Commission Meijdam to increase the risk of building collapses to 1:10,000 or 10^{-4}. The underlying objective of that proposal (not approved) was to minimise the reinforcement requirements, e.g., minimise repair costs[123]. With a risk factor of 10^{-4}, that would mean 60 deaths per year, by earthquake alone, not counting the possible deaths because of construction work or the increased heavy traffic in the small villages. This proposal from the Meijdam Committee was not adopted[124].

Something special is going on in the risk calculation of the number of deaths from Covid-19. With the lock-down, face masks, etc., the death toll in the Netherlands has risen to just over 17,000 in 2020[125], or 1:1000 inhabitants or 1:10^{-3}. By taking vaccination measures, efforts were being made to reduce the death toll to > 1:10,000 inhabitants or >10^{-4}.

Risk calculation and Safety (2)

Safety concerns all interventions that are necessary to improve the safety of the residents in the short term or to remove acute safety problems inside or outside the building (in the direct vicinity). This can be done by shoring up the weak or damaged building, or by securing or removing loose building parts. The residents of the building can also be removed from the house.

The term 'safer' **is a relative term** and an emotional issue for the residents. However, the NPR9998 defines safe as 'just not collapsing', because people can fall victim to collapsing building components. However, the KNMI calculations of the first NPR9998:2015 with **PGAg 0.42** were based on rapid natural gas extraction and complete exhaustion. The NAM/KNMI with their broad assumptions, extrapolations, uncertainties and extra safety margins, the theoretical maximum PGA, when projected over a many-year period, became very high. The KNMI calculated a 100X stronger earthquake than the Huizinge earthquake (Richter 3.6. increasing to Richter 5.6).

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122 From the risk calculations regarding the increased construction activity and traffic movements of the required building strengthening across the province, construction work and traffic could cause a few deaths per year. The number of road deaths in The Netherlands is over 600 per year (3.5 X the ratio 10^{-5}), which is considerably higher than 10^{-5}, if it is assumed that everyone participates in traffic. Measures are being taken to limit the risk for road users to 10^{-5}. According to common law it would therefore be criminal by the NAM to continue gas exploitation that leads to such strong earthquakes that houses will start to collapse. This aspect was never considered by the KNMI when it proposed the exaggerated PGAg 0.42 in end 2013. For unknown reasons the NAM adopted those extremely high KNMI values without further explanations. Their engineering consultants could have told the NAM that such earthquake values were totally not possible, nor likely.

123 Final advises 'Handelingsperspectief voor Groningen' = Management perspective for Groningen by the Advisory committee related to dealing with risks of induced earthquakes. 14-12-2015. https://www.parlementairemonitor.nl/9353000/1/j9vvij5epmj1ey0/vk01ksmvtnzw

124 In the Parliamentary Committee Earthquakes Groningen (2022) this point to propose the increment of the risk factor to 10^{-4} was never discussed, nor the risk factor 10^{-5} was investigated.

125 News information from April 2021 indicates 17.357 direct Covid-19 deaths and another 2673 being related. Such about as many deaths among 19 years and older because of smoking (2018).

With these high KNMI projections, every house would “soon” collapse, as the very high earthquake ground acceleration force would be 5X as strong as Huizinge's PGAg 0.085. By communicating this high PGA value (or Richter value) to the population and suggesting that such earthquakes would be imminent in a few years, a strong feeling of insecurity was created. The details about how they came to this very high figure were not disclosed by the KNMI experts, nor by the NAM.

Whether or not the inhabitants have a safe feeling in their buildings is very subjective[126] based on their knowledge about earthquakes and the effects of the compaction. That knowledge was very little. Earthquakes were an unknown phenomenon in Groningen.

The population believed what they repeatedly were told by the experts and the media. When the NAM proposed in 2013 that these earthquakes would be stronger and stronger over time, everybody believed this, and all official advisory commissions also adopted the same high earthquake values. All testing and engineering were done and calculated on these high values and the media echoed the information. The media and action committees focussed on the impending disaster.

When the cracks in the houses were not timely repaired but became wider with the new shocks that occurred every year, many persons of the population (living in old houses) became ever so nervous about their safety, keeping in mind that the earthquakes would be up to 100X stronger (Richter).

“Safe” by the NPR's understanding is NOT safe by the county's residents. According to the NPR, it is safe when that building “just does not collapse”. According to the residents, it is that a building does not crack or plaster fall from the wall. The safety feeling of the resident is to a very large extent psychological and related to their housing security for the future. With an unknown major earthquake on the horizon, the resident will soon feel unsafe and even less safe without repairs.

Figure 83. Struts around an entrance part of a house. Lack of structural cohesion (floor diaphragm) and an irregular floor plan are often the causes of cracks.

Cracks in the masonry are seldom critically in the sense that the construction of the building is compromised and in risk of collapse.
In terms of the NPR the buildings are not un-safe.
In terms of the house owners, it was unsafe.

Going by the criteria of the earthquake code (‘no-collapse’), the people in Groningen were never at risk, nor was their safety compromised. However, going by the exaggerated NPR9998 maps, their safety would be seriously compromised over many years when the alleged major earthquakes would occur. However, those earthquake projections were totally beyond juridical or political reality. Yet the NAM and its engineering partners continued to operate based on these very high PGA figures.

[126] The feeling of non-safety by the population developed after 16-08-2012 Huizinge and enhanced by the NAM who adopted the KNMI proposal indicating that the earthquakes would become 100X as strong (Richter 5.6 instead of Richter 3.6) while already many houses had developed cracks.

Sandstone

Thick sandstone formations occur all over the world. Millions of years before the formation of that sandstone, large parts of the earth were covered with many plants. The decomposition (rotting) of the gigantic amounts of plant remains also caused a large amount of emission of methane gases (CH_4), which has a very high insulating effect in the atmosphere (> 21 X CO_2). The result was extreme global warming that resulted in desertification everywhere and the displacement of that sand by winds. These dozens and hundreds of meters thick sand packages that were deposited over the rotting plants, were infiltrated with the methane gas. Due to the climatic warming, the polar caps also melted and the sea water level rose, which evaporated due to the great heat. The sea salt deposits blocked the flow of the methane gas so that it stopped in some places.

Figure 84. (Own photo). The Uluṟu Rock in Australia rises over 300 m above the land and has a 1km cross section. This rock shows that next to the general porosity of the sandstone, large holes are present.

If there are no restrictions on CO_2 and CH_4 emissions now, the world will warm up again fast, the sea level will rise sharply, and the deserts will become much larger.

Humanity is now depleting natural resources 1,000,000X faster than they originated.

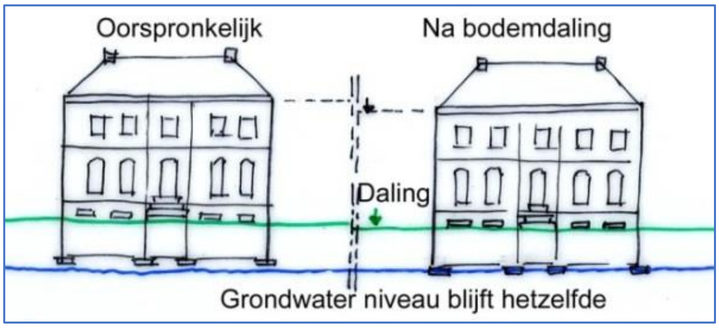
Due to the excessive emissions of CO_2 for our energy supply (e.g. poorly insulated homes) and transport and methane emissions (e.g. from livestock farming), the current world population is engaged in the destruction of our planet.

Settling, setting, settlement

Settling is the subsidence of the ground surface caused by a fall in the water table, compaction or pushing sideways of the soil. Soil settlement is one of the main causes of cracks in brick buildings built directly on the undisturbed ground. Usually, these buildings have light or narrow foundations. Soil subsidence due to compaction initially causes a rise in the groundwater level. The provincial water management must then correct the water table for the benefit of the farmers. Often sewerage systems have to be adjusted as well or fitted with pumps.

Oorspronkelijk = original Na bodemdaling = After soil subsidence Daling = subsidence
Grondwaterniveau blijft hetzelfde = Groundwater level remains the same

Figure 85. In case of subsidence or compaction, all buildings as a whole sink very slowly, while the ground level in relation to the building remains at the same level. This prevents cracks from forming. The groundwater then rises in relation to the ground level.



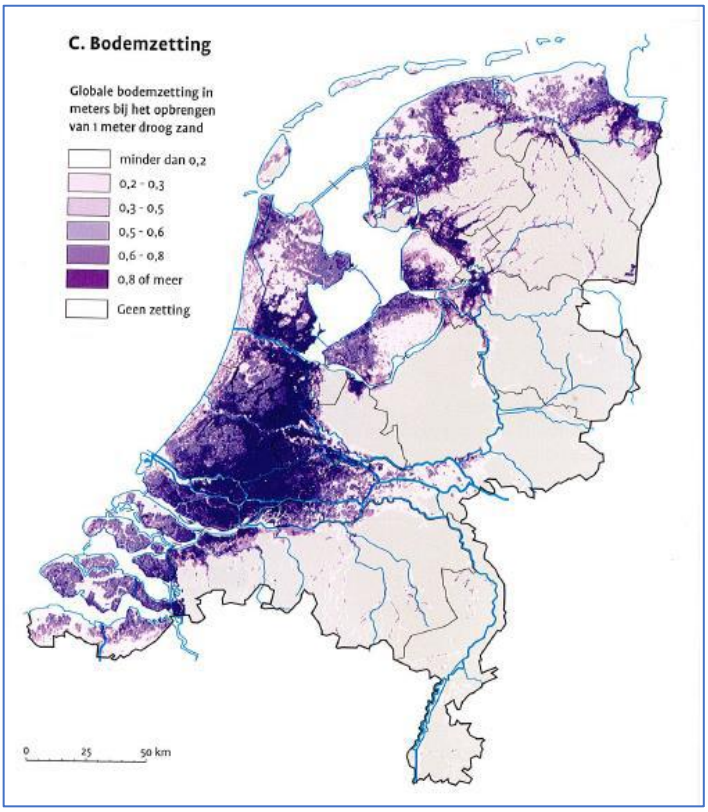
Also see ‘Subduction’ and ‘Compaction’ and ‘Flat bowl shaping’.

<u>Settlement</u> of the soil under foundations is a result of load, vibrations, shrinkage as is the case when peat dries out, and the construction of heavy structures such as dikes, among other causes. When raising the soil locally or applying any other heavy material, settlement can occur over several years; the groundwater can be squeezed out from under this embankment, dike or constructions, whereby foundations that have been laid along the dike slope, are then deformed.

Due to settlement along dikes, dike houses often become quite crooked.

Because since 1970 the foundations were given both a concrete slab and a concrete beam construction, the sensitivity of masoned buildings to settlement in the foundations became less. Because the stronger foundation moved as a whole, and the vibrations were not absorbed by cracked masonry, these vibrations are transmitted upwards in the building, so that from that 1970 period onwards many small cracks manifest themselves in the higher walls.

Figure 86. This map from the Dutch Bos atlas indicates how much settlement will take place if the soil level is raised with 1 m of sand.
This is common practice for new suburbs.
In the province of Groningen this settlement can be up to 0.8 m; this then happens evenly over a long period of time.
In the province of Groningen this occurs in clay soils.



In almost all claims after the earthquakes, there is a combination of building load, foundations on steel and differential settlements of the soil. When the settlement is different between two sides of a building, tensions and cracks can occur in the masonry. Earthquakes can cause new cracks at existing stress zones in the masonry.

Secondary seismic building components

Components that are not considered part of the system to withstand the seismic loads {Eurocode 8: 1.4.2.14}. In the event of collapse, they must not cause damage to the supporting structure or fall so that people can be hit. With an EVS these components must be identified, and problems resolved. Many building codes require the connections between primary and secondary seismic components to meet extremely high requirements. An example is the fixing of concrete facade or balcony plates. However, it is more practical in an earthquake zone if these connections are attached ductile (tough) instead of extra strongly rigidly connected. This way these connections can deform, but not break. With the deformation part of the impact will be absorbed.

Figure 87. Fill-in walls are secondary building components (non-load-bearing walls). During an earthquake, these can contribute strength to supporting column structures (the building's primary load-bearing structure) so that their movement is damped.

In this high-rise apartment building, the brick infill walls contributed to the damping of the horizontal building movements, so that the columns underwent less deformation in their maximum moment zones. Secondary building elements contributed here to the building strength after the deformation of the primary elements (columns).

Seismicity

Seismicity is a measure of the occurrence over time of earthquakes of a certain strength for a certain area or the degree of movement of the soil layers. The surface seismicity is usually presented in the form of a contour map, so that you can see what maximum risk you can expect at a certain location on the earth's surface. The depth seismicity indicates what kind of movements can be expected in the hypocentre. Seismicity can be represented in different ways[127].

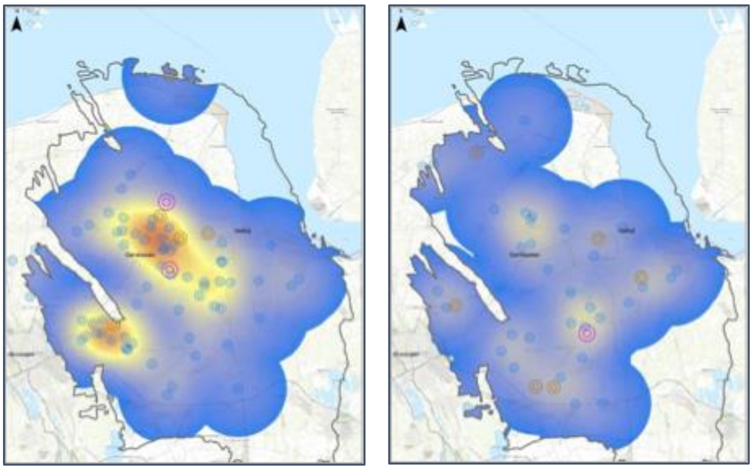


Figure 88. Groningen earthquake field.
Left: March 2013-2014. Major and double circles are major shocks; small circles are small jerks.
Orange indicates a higher density of shocks per km^2/year, and yellow a slightly lower density per km^2/year.
In the central area around the municipality of Loppersum, gas extraction was less in 2014, resulting in less seismicity.
Right: March 2015-2016.

[127] See report: April 13, 2017 - Annex 1. Technical annex. Advice Groningen gas field related to the recent earthquakes in Wirdum and Garsthuizen 2016/2017. Staatstoezicht op de Mijnen (SodM).

Seismic

Seismic as an adjective refers to vibrations, earthquakes, and related phenomena and to the investigation of the construction of the subsurface by natural (tectonic) or man-made (induced) shocks. Seismic soil investigation is done by setting up seismographs along a km-long line and measuring the periods between a shock and the seismographs. This makes it possible to determine where changes in the deeper soil structure take place. By doing this in two directions, a 3D map of the subsurface can be made.

Seismic waves

Seismic waves are a result of an earthquake, different types of vibrations arise that spread out from the source of the earthquake. The vertical P (pressure) or pressure waves are the fastest (about 3 km/sec. in Groningen), and the horizontal S (secondary) waves are half as fast. These S waves are measured horizontally in two directions (radial and zigzag). These vibration waves propagate through the earth as well as along the earth's surface. These pulses are recorded on the seismogram and the strength and frequency can be read. Such pulses are called seismic phases by seismologists. The difference in speed with which the various waves propagate is particularly important. The wave speed is determined by the combination of the elastic properties and the density of the rock or soil layers in which the wave propagates. There are many soft and weak zones in the upper soil layers of the province of Groningen. In many places, the top 10 m has a very soft structure (clay, peat), which slows the waves.

The $V_{s,30}$ velocity refers to the top 30 meters and is an influencing factor for the load on a building. Although the propagation speed P in granite is 6 km/sec, this P in the soil layers above the Groningen sandstone averages 3 km/sec. The propagation speed in the soft Groningen $V_{s,30}$ top layer is only between 100 m/s up to 200 m/s. Because the speed of the waves is a determining factor for the ground acceleration and the resulting building damage, this has been calculated in more detail in the appendix to NPR9998 and shown on the map of the current KNMI Webtool.

Seismograph or seismometer

A seismometer or seismograph is an instrument for recording the vibrations of the earth. It usually consists of a set of three seismometers: one for the vertical movement (Z or V) and two for the horizontal movement (X and Y) from the epicentre. The meter for vertical movement consists of a weight suspended from a spring. The gauge for the horizontal is a pendulum. After a movement, the mass will return to its original equilibrium position. The meter is read electronically, and the signal is forwarded to a central point for analysis.

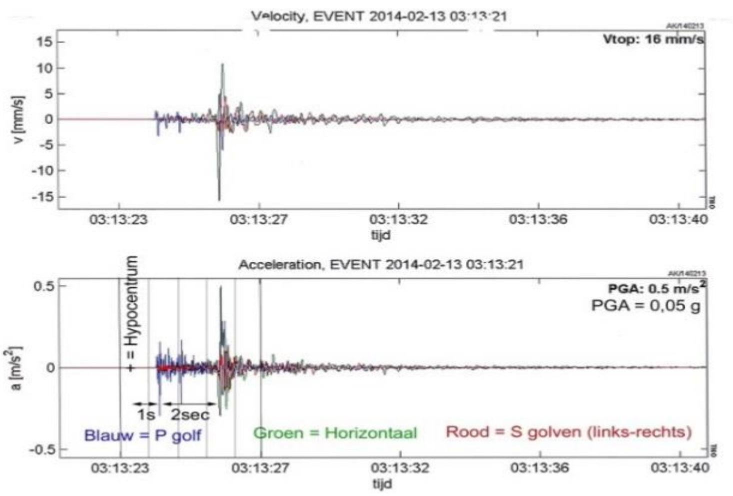


Figure 89. The two seismograms indicate the three movements with the speed (top) and the acceleration (bottom).
This 2014 shock started on second 23 and reached the Earth's surface in second 26.5 and lasted less than half a second.
Depending on its construction, a building will reverberate. A seismometer on a foundation will give an extended vibration reading.

Seismogram

A seismogram (*Figure above*) is a recorded result of a seismic survey by means of a seismograph of generated vibrations in the subsurface. Three movements are recorded. The vertical vibrations (pressure or P-waves), the horizontal radial waves (from the epicentre outwards), and the horizontal transverse S-waves (back-and-forth movement from the epicentre). The PGA is determined based on these horizontal radial waves. For some earthquakes, both the vertical and horizontal PGA are indicated. The horizontal PGA causes the heaviest building load.

Seismograms can reveal the origin of the waves, the seismic source, or the source of the earthquake. Centres of earthquakes caused by gas extraction are in the northern Netherlands at a depth of approximately 3 km. They are in direct relationship with reservoir rocks (sandstone layer) and their fracture planes at this depth.

Huizinge aardbeving 16 augustus 2012 = Huizinge earthquake 16 August 2012   Tijd in seconden = time in seconds
Voelbare aardbeving tot ongeveer 4 sec. = Noticeable earthquake until about 4 seconds.
Top = radial wave.   Middle = Transversal wave   Bottom = vertical wave.

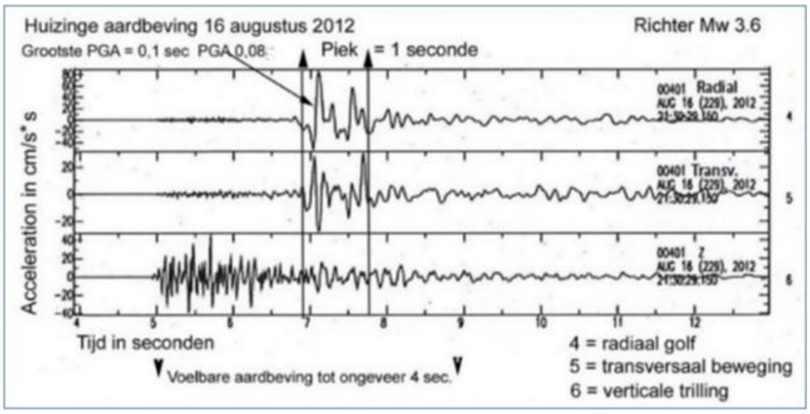


Figure 90. The horizontal radial shock at second 7.2 with PGAg 0.05 towards the epicentre and PGAg 0.08 from the epicentre.

The transversal left-right tremors were considerably less with a PGAg of 0.025.
The vertical PGAg was also half at 0.04, but buildings can withstand these loads. However, subsidence can occur because of the vertical vibrations when the foundations are too narrow.

Shale gas

Shale gas[128] is natural gas trapped in shale or slate, which has a non-permeable structure. The method for extracting shale gas is therefore different from extracting natural gas in Groningen.

Fracking technology to extract gas from shale is used by drilling horizontally through the layers and injecting sand and chemicals. In the Netherlands, attention is being paid to two shale rock formations at a depth of 2 to 4.5 km.

Figure 91. TNO map 2012 of possible shale gas areas. Due to the earthquake damage in Groningen and the possible risk to the quality of the groundwater, there is a lot of civil and political resistance to extracting the shale gas in the blue zone indicated on the map [129].

[128] Source text and map: http://aardgas-in-nederland.nl/de-toekomst-van-aardgas/aardgasreserves-en-verbruik/#3a
[129] Dit heeft te maken met negatieve verhalen uit de USA waar het schaliegas oppervlakkiger wordt gewonnen.

SodM (Staatstoezicht op de Mijnen)

State supervisor on mines. This government organisation supervises compliance with legal regulations that apply to the exploration, extraction, storage, and transport of minerals. The service focuses on the aspects of safety, health, environment, efficient extraction, and soil movement.

SodM is a government inspection service based in The Hague and gives NAM permission for gas exploitation via the Minister. The service falls under the responsibility of the Minister of Economic Affairs. The Minister consults with the SodM for decisions about exploitation.[130]

SodM also works for the ministers of SZW (Social security and working conditions) and Infrastructure & Environment (for environmental and commodity legislation) and for the Public Prosecution Service (for criminal investigations). The service is headed by the Inspector General of Mines. www.sodm.nl

Strong Constructive Glass panel

Walls with large windows and narrow piers are seismically weak constructions. By filling in the window openings with masonry, the walls (in the plane of the wall) will be reinforced. Left photo below. The wall strength can also be improved by making strong window frames or strong frame edges, image bottom centre. For historic buildings or monuments, these are often not acceptable solutions for monument conservation [131].

By placing hardened (tempered), multi-laminated (insulation) glass panels in the window frames and gluing them fixed in a high pressure-resistant manner, the wall piers become much larger and the strength of the building in the plane of the facade increases considerably, image bottom right.

Figures 92. Left. Masoned-up window Middle. Strong window edges Right. Constructive Glass panels

The strong glass panels must be fitted tightly in the window frames of seismically weak buildings with whole brick masoned walls (photo on the right). It must be assured that the ceiling-attic floor forms strong diaphragms and connect all the walls, this way a seismically strong construction is created.

[130] Directly after the Huizinge earthquake, the Minister was alerted to the possibility of larger quakes. The SodM, however, had several years earlier agreed to a gas exploitation maximum over a 10-year period. By 2012 that gas extraction maximum (highly profitable) was not yet reached. The NAM decided to increase from 47.5 to 53.9 bcm in season 2013, which would still fall within the allotment (an increment of 13,5%). In 2013 the new calculations of the KNMI were not yet available. Also, former larger earthquakes of 2006 and 2008 showed that it would take about two years before another larger earthquake would occur. In addition, the gas extraction was actively spread over the reservoir to minimise pressure differences.

[131] Because of lack of local knowledge about this strengthening method, and the unwillingness of the NAM to undertake research themselves, this method was not applied. The unwillingness derived from the position that the NAM did not want to be responsible for product development. The same applied to Base-isolation.

Figure 93. The market hall in Rotterdam is an example with a strong facade of laminated glass panels.
Thermally insulated, laminated glass panels are used in large projects and are therefore not unknown techniques.

Structural strengthening

These are all structural interventions to the foundation or the supporting structure and the roof that make the building stronger, without necessarily complying with the existing Building Directive 2012 or the existing NPR9998 for earthquake-resistant reinforcement or renovation.

Figure 94. Jarino houses from the 1970s, with structural flaws in the facade and foundations, poor thermal insulation, and small rooms.

Due to the construction errors in the façade and foundations, these houses could not be economically strengthened. When insulating on the inside, beds of 200 cm would no longer fit in the smallest rooms.

For example, structural reinforcement was urgent for 57 Jarino homes (photo above) where a major structural defect in the facade lintel supports was exposed due to the Huizinge earthquake. Upon further inspection, it was found that weak foundation beams also caused the interior walls to crack vertically over the pile foundation.

Because of the large front and rear windows, the lateral strength in the façade is low, but with the faulty beam construction it was almost non-existent. In many cases, structural reinforcement is a measure to solve a specific acute problem or to secure an identified high-risk situation.

The reinforcements can be constructive measures that are applied without extensive calculations, such as the placement of props. Structural reinforcement therefore does not necessarily comply with the current new construction standard.

In the situation of the 57 Jarino houses, structural reinforcement was only a temporary necessity, because these houses from the 1970s were generally of very poor quality and the seismic retrofitting, together with the insulation, would cost more than twice the demolition and new construction (of well insulated houses). The short earthquake of 2012 revealed these construction errors. The residents could not be moved immediately, while more shocks were expected within one year. Gas extraction was even increased by NAM in 2013. Supporting steel props were placed in the living rooms of several houses.

Struts or props

Struts or props are used for the temporary support of severely damaged building components as an emergency measure and to prevent further building damage or collapse of that building component.

Figures 95. Different methods of shoring are used including scaffolding inside the buildings. Because of the publicity from these struts by the media, a lot of attention was paid to the buildings with these struts.[132]

The shoring is a temporary safety measure, pending repair or reinforcement or demolition. The shoring up of a structure does not immediately mean that the cause of a foundation subsidence or wall damage is directly attributable to an earthquake. In some cases, there are construction errors and even inherent defects. There was no financing made available for the homeowners to repair their own defects or construction errors, or to strengthen foundations, so the struts were left standing for long periods while arbitration was ongoing.

In many situations, brick buildings built before 1980 fail to withstand the small shocks (PGAg 0.06 to 0.08) and subsequently sustain minor damage. Terraced houses with large front and rear windows, with heavy concrete floors and built in stack construction method, run an increased risk of damage. Homes with high windows, narrow piers and wooden floors that do not form a diaphragm with the walls from the pre-1900 building period are also very weak. In the event of damage, many of these old buildings first had to be propped up and later reinforced before the earthquakes allegedly would increase in frequency and strength from PGAg < 0.1 to a possible PGAg > 0.15.

Subsidence, subduction

Subsidence or subduction of the land is the subsidence of the ground surface due to oxidation (of peat), settlement or geological processes (gas extraction and compaction). The lowering of the level of the soil relative to a fixed reference point, for example the Normal Amsterdam Level (NAP).

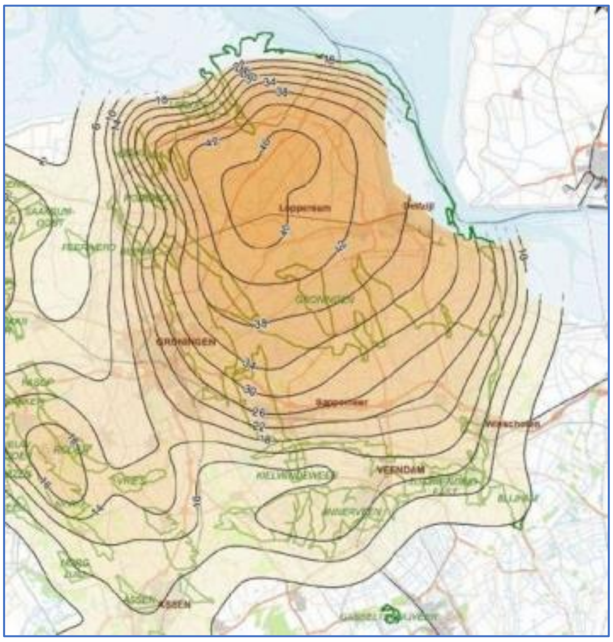
The groundwater level is slowly affected by subsidence, which means that foundations can become wet when the ground sinks with the buildings. To keep the groundwater at the same level, local water is pumped away, which can cause other foundations to run dry.

With wooden pile foundations, periodic drying out can lead to wood rot, which can cause serious damage to the supported masonry foundations. Soil subsidence and subsequent dewatering can therefore indirectly lead to major building damage in the case of wooden pile foundations. Shrinkage can also occur in peat and clay soils, which can cause settlements in the foundation, resulting in cracking of the higher masonry walls.

[132] In some cases, it was claimed that house owners placed struts where no collapse risk was present, mainly to get the attention of the NAM and CVW. On the other hand, with the believe in the very high PGA projections, taking precautions was not unrealistic.

Figure 96. The NRP9998:2015 map shows the 2014 estimated maximum subsidence after 50 years because of gas exploitation, with approximately 60 cm in the municipality of Loppersum.
Here the porosity of the gaseous sandstone is greatest and therefore also the compression when the internal gas pressure is reduced. This decline has been closely monitored for decades, including via satellite measurements.

In addition, there is a national subsidence as a result of peat, drainage and geological subsidence in the Peelslenk (in the south of The Netherlands).



Subsidence Committee

The Soil Subsidence Committee determines which measures are reasonably necessary to prevent, limit or repair damage resulting from soil subsidence due to natural gas extraction in Groningen. This Committee also determined which costs NAM must reimburse[133]. www.commissiegronddaling.nl. See status report 2020 with forecasts up to 2080[134]. This contains a new forecast map for 2030 with a total subsidence of 38 cm in the municipality of Loppersum (estimated uncertainty factor of 2.5).

As a result of soil subsidence, major costs are involved in regulating or restoring the groundwater level for livestock farming and agriculture. In the central area of the province, with the greatest soil subsidence, dikes will have to be raised, dams constructed, the flow direction of sewers changed, and water discharges will be pumped to higher areas, mainly for the agricultural sector.

Sustainability of houses

Sustainability for housing is achieved in four ways.

A. Make the building stronger or otherwise adapt it so that **it lasts longer** and can also be used for other forms of habitation or purposes. As a result, they can be inhabited in a desirable manner for longer and life-course-resistant. The spatial layout, the possibility for life-resistant habitation, or the flexibility are important here.
B. Better thermal insulation (a). This is the intended opinion in many documents, but (b) **energy** consumption/generation also applies (BENG, Nearly Energy-Neutral Buildings). Various organizations mean by sustainability only thermal insulation. However, this is not the complete story.
C. The use of sustainable **materials and constructions**, where many materials as possible are recycled and where the materials used come from sustainably exploited sources such as sustainable forests. The materials for the construction of the infrastructure around the building are also important. When renovating constructions, the maximum reuse and recycling of construction waste is also important.
D. A housing model in which the sustainable **exploitation** and use of the environment is also important (water infrastructure, sewerage, streets, etc.). The realization of residential groups where the common use of services (not everyone has their own car, washing machine and

[133] See report: https://www.commissiebodemdaling.nl/files/nam_bodemdalingsrapport2010.pdf
[134] https://commissiebodemdaling.nl/files/Status%20rapport%202020%20bodemdaling%20Noord-Nederland-final.pdf

leaf blower) and infrastructure is paramount, and the residents can support each other in social and community facilities.

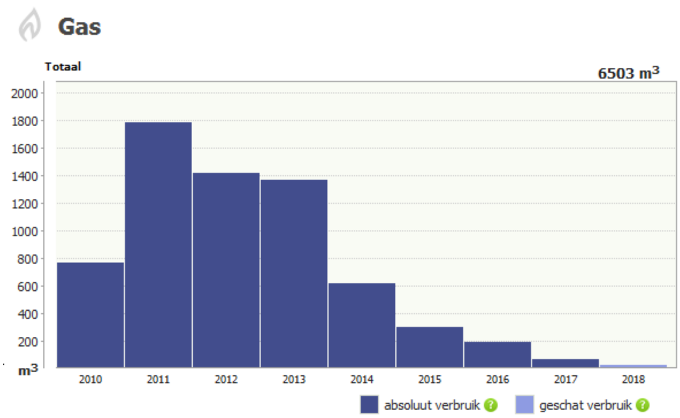
Component C (materials and constructions) can only be achieved if the various waste materials are disposed of separately and offered to companies that can (re)use or upgrade these materials or recycle them. This is possible by keeping the different materials separate on the construction site.

Incineration is the lowest form of recycling. With less natural gas, it is becoming increasingly important that houses are properly thermally insulated and made more sustainable in the other ways. For many houses from the building period 1960-1970 that have small internal dimensions, making them more sustainable is rarely economically feasible when compared to new construction.

By making old houses earthquake-resistant, they are primarily preserved according to A, but that is only meaningful if those houses which have a good foundation and can function properly for another few hundred years. An important element is therefore first to strengthen the foundation and then to thermally insulate it. When earthquake damage is compensated by NAM, in practice the owner will still have to make two investments in the context of sustainability consisting of B (a) the thermal insulation and B (b) the own energy generation via technical installations. In many situations, that owner has no financing options for this. Making an average house more sustainable will cost approximately EUR 50,000.[135]

Those additional financial sources required for sustainability were still to be developed in 2020.

Figure 97. Various types of sustainability were applied to a detached small house for 7 subsequent years (mainly thermal insulation, including PV), as a result of which gas consumption fell substantially.
The gas use of the house is indicated in the graph.
The average citizen does not have the funding for this.



TCBB (Technische Commissie Bodem Beweging)

Technical Committee Ground Movement. This committee examines the relationship between exploration, extraction, and soil movement. The TCBB is an independent committee with several advisory tasks. For example, it advises the Minister of Economic Affairs on the consequences of mining for the movement of the earth's surface and the possible damage caused by this. In addition, under certain conditions, the TCBB gives advice to citizens who have suffered damage due to such ground movement about the amount of compensation to be paid by the mining company.

The TCBB can then conduct a technical investigation into whether and, if so, to what extent the damage was caused by soil movement because of mining. The committee consists of experts in many fields, such as mineral extraction, geology, seismology, soil mechanics, hydrology, structural engineering, and legal affairs. The committee does not make payments or repairs. www.tcbb.nl

[135] With the latest 2023 political measurements it is proposed that the government finances these costs.

Testing

In 2012 there was little Dutch language information available about the propagation of the vibrations in the Groningen type of soil layers and even less information for structural and non-structural engineers about the behaviour of unreinforced masonry buildings in the Netherlands. To gain more knowledge, special survey and test programs were set up about the deep and shallow subsurface, but also about construction methods and materials.[136]

In Italy, e.g., a typical Dutch terraced house was built, based on which the various calculation methods could be calibrated[137]. Test homes were purchased by NAM in which reinforcement methods were tested for practical applicability and cost aspects in, while masonry tests were also carried out by Delft University of Technology. Since the first noticeable earthquakes in 2006, NAM has set up many different types of research and testing. One component is the installation of many building sensors and vibration meters in the deep underground.

Figures 98. Left: A test house (reconstructed row house) was built in Italy on a vibrating table and subjected to series of tests.
Right above. Floor reinforcements were fitted in a purchased house to create floor diaphragms, holding the walls together.
In different types of houses in Groningen various seismic reinforcements were installed in test as a practical test and for demonstrations. These experiences made it clear to what extent these measures were practicable.
Right. The typical low working-class house.

The reconstruction and testing of these types of Groningen homes in Italy were very interesting contracts for the research organizations to calibrate the theory with reality and the very elaborate NLTHA method, but of limited relevance for the seismic strengthening of this type of old houses. In addition, the tests were carried out with earthquake loads that were many times stronger than could ever occur in Groningen, and with shock signals from tectonic earthquakes in Turkey.

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136 Seismic engineer Sjoerd Nienhuys started in 2013 the production of Dutch language and simplified training material for technical schools, allowing building professional to gain knowledge about the cause of earthquake damage and building strengthening. This material has been condensed in the present book chapters 2-12.
137 This exercise was interesting, but the test building was subjected to the extreme high KNMI PGA-projections and on shock waves based on heavy earthquakes in Turkey, not representative for Groningen.

The type of low worker's house (*photo figure 98*) is a common building type from over 100 years old that, because of its shape and layout, is highly vulnerable for seismic loads. By reconstructing the same in new masonry in Italy one overlooks the poor quality of the masonry of the original building, the modifications and extensions that often have occurred, while the one-piece shock table has little relation with the original masoned brick foundation on the clay soil in Groningen.

Test houses

In the province of Groningen, a dozen different building/housing types were bought by the NAM with the purpose to study the application of reinforcements. These buildings were stripped to assess the quality of the masonry work and floor-to-wall connections.

Because the very exact strength of these older houses in the province was not known and because in the past people often built based on experience, or the local contractor built as the neighbours did, many tests were set up. The alleged lack of very detailed knowledge resulted in several investigations such as determining the strength of masonry. Pieces of masonry were sawn out of walls and tested in a Technical University Delft laboratory. [138]

Figures 99. When examining the test houses, it became clear that some wall sections were probably weaker than the standard calculations.
Left. Jointing is often not filled on the inside and over time there have been various facade adjustments. Right.

Figures 100. Left. Old farmhouse. Middle. Terraced house from the 1970s. Right. One of the newer test homes. In these houses, the connections of the floor diaphragms to the outer shell were made or reinforced with different (experimental) new connection methods. The test homes provided insight into the practice of the measure and served also as an information and training location for designers and entrepreneurs.

[138] Those results however, corresponded with what people in the construction world had known for a long time and were already provided in the polytechnic pocketbook 50 years ago. Subsequently, the design and construction strengths were calculated accurately to the percentage, while the basic force values of the NPR were more than 300% off.

In one of these test houses, seismic reinforcements such as wall reinforcement and improved connections between floors and walls (diaphragms) were installed to test the feasibility of the different construction techniques and to evaluate the costs of installation. These test houses were also used to provide information to the press and residents about the possible options for reinforcement, with their advantages and disadvantages.

The test homes were only used to improve the strength and coherence, but not to make the building more sustainable, such as reclassification of user areas or good thermal insulation. The extensive building reinforcements, including some Base-isolation projects, were undertaken as integral test activities to study to what extent the heavy building reinforcements were possible.

Figures 101. In some test houses, a full (reinforced) platform foundation and extra heavy inner and outer wall reinforcements and diaphragms were applied in 2015 to withstand a PGAg 0.36 according to the NPR9998:2015 map. These integral reinforcement operations on old buildings usually cost twice more than the value of the entire house.

The test houses that were purchased had no foundation problems, as this would complicate the analysis. No foundation reinforcements were carried out in houses without a new platform foundation. In 2014, the NAM seismic repair division also ruled that foundation damage was not part of the earthquake damage. This position was carried over to the CVW in 2015, which led to many counter-expertise reports and arbitration[139]. The results of all these studies have not or hardly been (partially) published.

Tilt meter

Movements of a building can be registered very accurately with a tilt meter. These meters are frequently used in the construction of tunnels such as the metro. These make it possible to see whether a building is tilting. For measuring subsidence caused by an earthquake, this is also possible if measurements are taken before and after the earthquake. Vibration meters must send the three-dimensional signal with every vibration. In the case of induced earthquakes, this signal had to be able to handle a frequency of at least 500 Hz. Tiltmeters were not suitable for these three measurements in 2014. Since 2017, several tilt meters have been installed to properly map out the movements of buildings or dikes over time, caused by central subduction in the province or bowl formation.

Trigger aspect

One earthquake can start another, because a new tension difference arises next to the relaxed zone (where the earthquake took place). In the August 16, 2012, earthquake in Huizinge, there were two earthquakes in quick succession, the first apparently causing a second.

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[139] This adoption was under the pressure of the NAM, who still financed all the operations, to minimise the repair or strengthening costs. However, due to the many arbitration cases and re-assessments and additional reports, the final costs far exceeded the possible cost of just generously strengthening the houses.

This, for example, was the reason why that earthquake of August 16 in Huizinge (Richter 3.6) was felt much stronger (by some as long as 10 seconds) than an earlier, almost equal quake on August 8, 2006, in Middelstum with a Richter 3.5 which was only felt for a single second. The longer times felt by the people can include the reverberation of the building itself.

As a result of subsidence and settlement of foundations, elastic stresses will arise in walls. Those built-up stresses can still result in crack damage in the event of additional vibrations or earthquakes. The cracks that then become visible are claimed as earthquake damage, when in fact the previously built-up stress in the wall due to natural subsidence by other causes may have been the main cause. It is also possible/likely that the many small non-human-sensed vibrations since 1970 generated by the gas exploitation have accelerated the settlement of foundations.

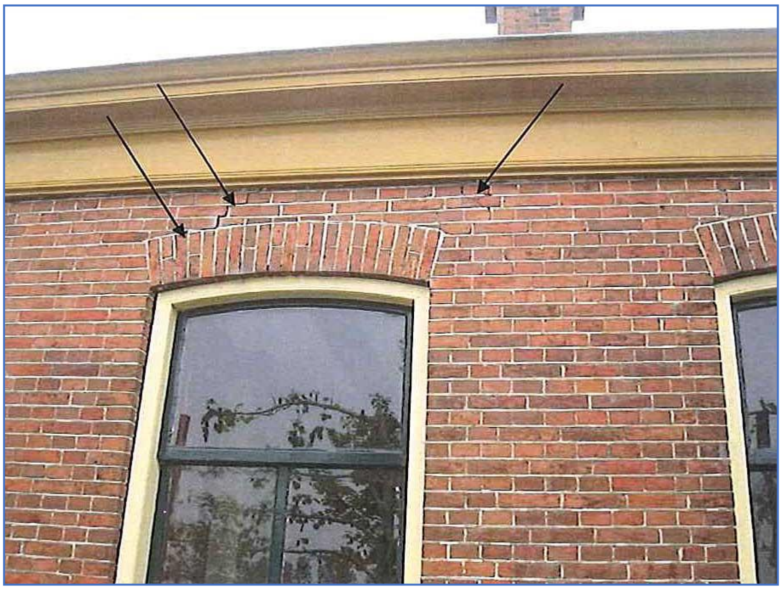
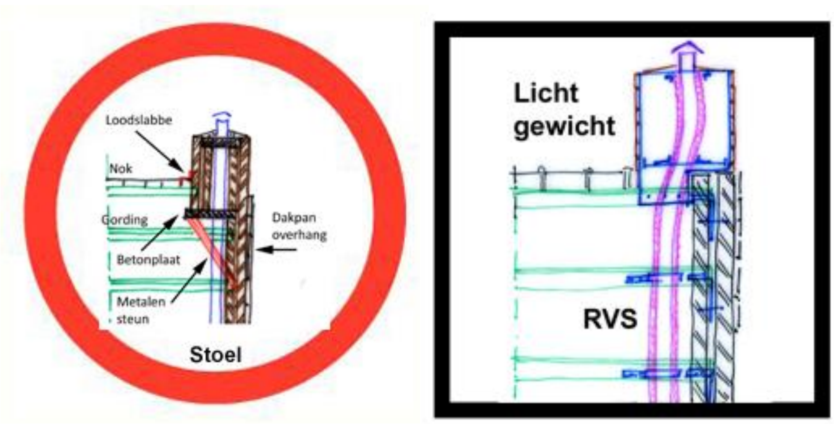


Figure 102. Old buildings on firm soil and without a lintel construction often have stresses in the masonry due to settlements. These stresses can increase with additional vibrations and discharge into visible cracks.
Lateral pressure from a round masoned window arch in combination with a higher side load on the piers can cause the piers to move sideways/outwards.

Unsafe situation

An unsafe situation (in relation to earthquakes) is a situation that, in the event of additional or multiple shocks or more severe earthquakes, can lead to building components falling off or buildings or building components (e.g., chimneys) collapsing or floor and roof structures collapsing.

These unsafe situations can often be observed during an RVS (Rapid Visual Screening), after which an EVS (Extended Visual Screening) can be used to look inside the building. After studying the structural details, this unsafe situation can be eliminated. In a high-risk situation, temporary props can be installed until the unsafe situation has been removed. Removing an unsafe situation is not structural reinforcement.



Figures 103. <u>Left.</u> Heavy brick chimneys on flexible wooden roof constructions and gable ends on thin walls are particularly risky. (RED)

<u>Right</u>. A lightweight chimney. The masonry top facade and its anchoring remain problematic, which is why this second sketch does not have a blue frame.

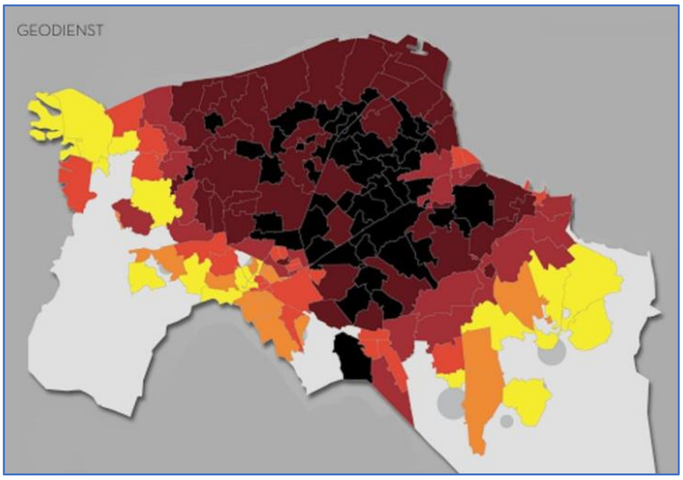
Value compensation

The first value compensation by the NAM for houseowners was discontinued because of too many discrepancies[140]. This was the procedure to determine in the context of a house sold or for sale whether the sales price has been negatively affected by earthquakes, or the risk of future earthquakes. However, the selling price strongly depends on the 'sense of security' that the seller or buyer has, even if there is no chance that the building will collapse during the maximum earthquake.

This feeling of safety is a psychological factor, and it has to do with the proclaimed risks and chance of larger earthquakes. Since 2014, extensive discussions have arisen to determine to which geographical area the value compensation scheme should apply, what happens when building prices rise again (when the vibrations cease), or whether the building owners are entitled to several compensations in addition to building repairs.

It also had to be clear to the people who move to the earthquake area, to what extent they can receive financial compensation. Since the value compensation scheme came into existence, the area in which this scheme applies has expanded considerably in size. For more information on this subject, see: https://www.steunpuntbevingschade.nl/compensation-bij-sales
The scheme has been replaced by the WAG scheme of the IMG: https://www.stwag.gr/img-regeling.

Figure 104. Source: Geodienst.
Value depreciation per postal code.



Value reduction of houses

The possible depreciation of buildings in the earthquake area has been compensated since 2018. The determination of the property depreciation or impairment should be based on a baseline measurement that should have taken place before the earthquakes[141].

However, the valuation of a building is influenced by many factors, including location, age, use value, state of repair, perceived value for the buyer and seller, employment, public facilities, shops, public transport, health care in the region, land price and the like.

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140 The discontinuation of the value compensation: https://www.nam.nl/shared/politics-and-governance/_jcr_content/par/textimage.stream/1453326861342/d18c97a4d8ab0725dd4e01f0bbfea3b331e22375/regeling-waardedaling1.pdf

141 This is rather subjective. In fact, the vibrations started by 1975, although these could not be sensed by the people. Yet these vibrations could have had an effect on the buildings. By taking the time of the start of the vibrations by being what the people could feel, a wrong zero-measurement occurs. No building was measured or analysed on cracks or damage in that early period.

When the population in the region does not feel safe because of the (wrongly) perceived risk of earthquakes or collapse of buildings, the value of that building will decrease. This decrease in value is therefore strongly influenced by the provision of information, the action committees, the press, and the knowledge or understanding of the population about the effect of earthquakes. The general decrease in value in the province of Groningen is, among other things, the result of the very high theoretical maximum earthquake that the NPR9998:2015 published.

With such a high maximum earthquake, the building damage will be very extensive, while many houses that already have considerable damage will then collapse. This perceived risk (by the population) has had a major impact on the cautious behaviour of potential buyers and thus on the fall in property value.

Zechstein

Zechstein translates to 'Salt stone'. This base layer is hard and tough at the same time and therefore has no internal fracture surfaces. The Zechstein under Groningen is on average about one km thick (sometimes with large bulges in places) and trapped the methane gas in the underlying sandstone layer, which originally came from the lower Carboniferous layer under The Netherlands, Germany, Poland and the North Sea.

The thickness of the salt layer varies throughout the area, with ridges or hills of up to 2 km in places. In the province of Drenthe, the salt even reaches the surface of the earth. Salt is mined here, which results in very local subsidence. Natural gas is stored in some of these salt domes during the summer for any peak demand in the winter.

It is possible that these thick salt stone ridges influence the direction and strength of the earthquakes. Due to the hardness and toughness of this salt layer that lies above the gas-containing sandstone, it probably causes a shorter vibration during earthquakes than in the areas where this salt layer is deeper. It can also result in a spread in time of compaction settlements in that sandstone.

Figure 108. (Internet) The Zechstein see was a shallow inland sea that stretched across what is now north-western Europe about 260 million years ago. (Wikipedia)

During the millions of years of the Earth's hot period, the water in this sea evaporated, creating a salt deposit.
So far, the Groningen gas field is the largest that has been found under the Zechstein.
Many small gas fields have been found under the North Sea area.

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