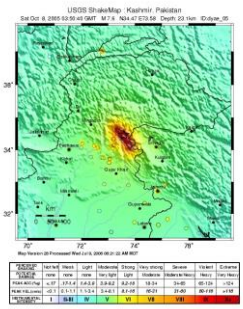

## Overzicht

- De impact van aardbevingen
- Hoe ontstaan aardbevingen?
- Wat is een aardbeving?
- Hoe worden aardbevingen gemeten?
- Wat zijn de effecten en gevolgen?
- Hoe bepaal je het gevaar van aardbevingen?
- Hoe bepaal je de grondbeweging?
- Hoe ontstaan aardbevingen in Nederland?
- Wat is er aan de hand in Groningen?



## De impact van aardbevingen

- Balakot, Pakistan
- Kashmir aardbeving M 7,6 - 8 oktober 2005










7

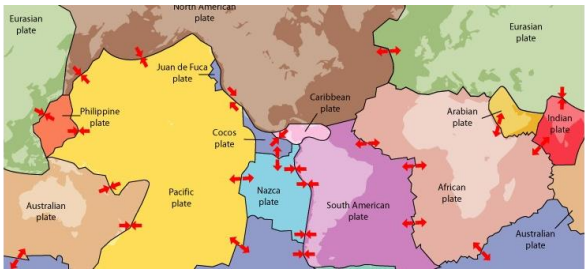
8

9

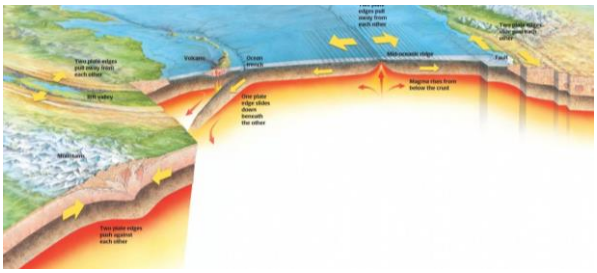
## Hoe ontstaan aardbevingen?

- Door plaattektoniek en vulkanische activiteit
- Door menselijke activiteit

10




11



12

## Menselijke activiteit

- Geïnduceerde aardbevingen
  - Verschuiven van breuken die niet op spanning staan
  - Gaswinning
  - Vullen van grote waterreservoirs
- Getriggerde aardbevingen
  - Verschuiven van breuken die al op spanning staan
  - injectie van afvalwater en stimulatie tbv geothermie en schaliegas

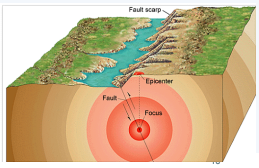
13

14

15

## Wat is een aardbeving?

- Een voortplantende golfbeweging die wordt veroorzaakt door beweging langs een breuk (Eng: Fault)
- Aardbevingsgolf bestaat uit:
  - Body waves
  - Surface waves

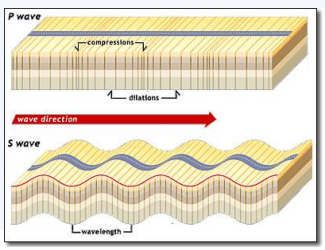




17

## Bodywaves:

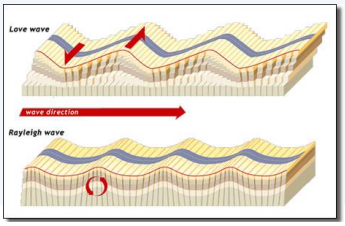
- Drukgolf: P-wave
- Schuifgolf: S-wave




18

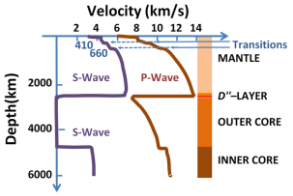
## Surface waves (oppervlaktegolven)

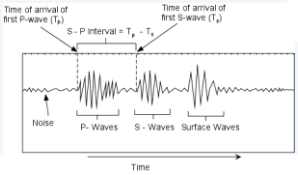
- Love waves
- Rayleigh waves




19

## Snelheid van P- en S-waves



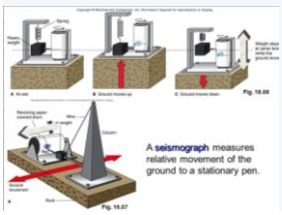

20

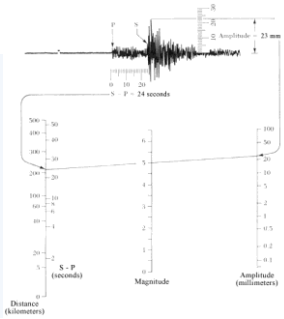
## Hoe wordt de kracht van een aardbeving gemeten?

- Magnitude schaal: instrumentaal (seismograaf)
  - Richter (Local) Magnitude (ML), Moment Magnitude (MW)
  - Maat voor hoeveelheid energie die vrijkomt
  - Logaritmische schaal
- Intensiteit schaal: op basis van ervaring en schade
  - European Macroseismic Scale (EMS-98)
  - Modified Mercalli Intensity (MMI)
  - Medvedev–Sponheuer–Karnik Scale (MSK-64)

21

## Magnitude schaal

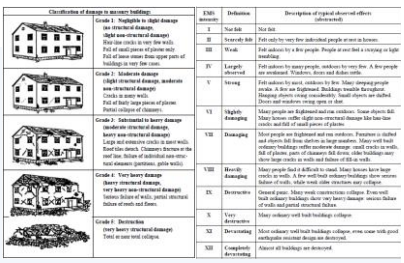



22

## Intensiteit schaal

- EMS-98



| EMS-98 intensity | Definition | Description of typical observed effects (abbreviated) |
|---|---|---|
| I | Not felt | Not felt. |
| II | Scarcely felt | Felt only by very few individual people at rest in houses. |
| III | Weak | Felt indoors by a few people. People at rest feel a swaying or light trembling. |
| IV | Largely observed | Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle. |
| V | Strong | Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut. |
| VI | Slightly damaging | Many people are frightened and run outdoors. Some objects fall. Many known reliefs slight non-structural damage like hair-line cracks and fall of small pieces of plaster. |
| VII | Damaging | Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well built ordinary buildings suffer moderate damage: small cracks in walls, fall of plaster, parts of chimneys fall down, older buildings may show large cracks in walls and failure of fill-in walls. |
| VIII | Heavily damaging | Many people find it difficult to stand. Many houses have large cracks in walls. A few well built ordinary buildings show serious failure of walls, while weak older structures may collapse. |
| IX | Destructive | General panic. Many weak constructions collapse. Even well built ordinary buildings show very heavy damage, serious failure of walls and partial structural failure. |
| X | Very destructive | Many ordinary well built buildings collapse. |
| XI | Devastating | Most ordinary well built buildings collapse, even, some with good earthquake resistant designs are destroyed. |
| XII | Completely devastating | Almost all buildings are destroyed. |

23



24

## Wat zijn de effecten en gevolgen

- Directe effecten
- Indirecte effecten

25

## Directe effecten van aardbevingen

- Beweging aan het maaiveld en in de ondergrond
  - Vaak treedt amplificatie op door grondopbouw
  - In sommige gevallen treedt resonantie op
  - Uitgedrukt/gemeten in PGA, PGV, Sa, Sv
- Verweking van zand en silt – liquefaction
  - (Tijdelijk) verlies van draagkracht - hellinginstabiliteit
  - Opdrijven van ondergrondse ojecten
  - Permanente grondverplaatsing: zetting, squeezing
- Verplaatsing (lateraal/vertikaal) langs de breuklijn

26

## Indirecte effecten van aardbevingen

- Vloedgolven (Tsunami, Seiche)
- Helling instabiliteit – vaak in relatie met verweking
- Lateral spreading – vaak in relatie met verweking
- Topografische amplificatie

27

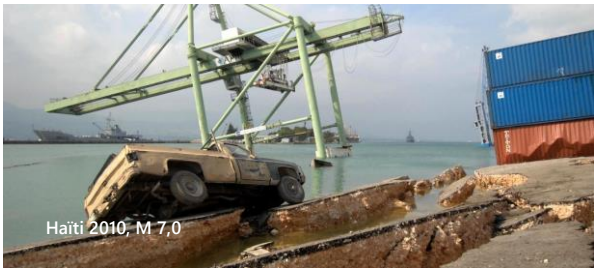
Mexico City 1985, M 8,1

28


29


30

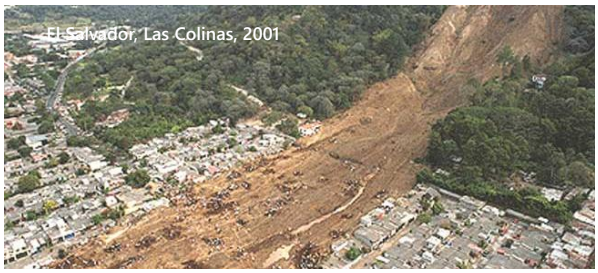

31




32


33


34

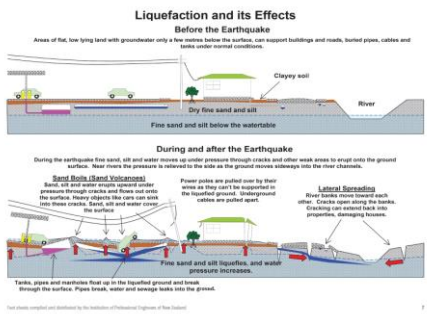



35


36


37


38




## Hoe bepaal je het gevaar van aardbeving?

- Definitie van gevaar (Eng: Hazard): (aanvaardbare) kans van optreden als functie van tijd en locatie
- Hazard analyse:
  - Deterministisch (DSHA: Deterministic Seismic Hazard Analysis)
  - Probabilistisch (PSHA: Probabilistic Seismic Hazard Analysis)

40

## Deterministisch

- Uitgaan van "maximum credible earthquake"
- Effecten van individuele scenario's
- Alleen in seismisch actieve gebieden waar de breukbewegingen goed bekend zijn
- Conservatief
- Meestal voor zeer kwetsbare objecten, zoals kerncentrales

41

## Probabilistisch

- Uitgaan van alle mogelijke aardbevingen ooit opgetreden: catalogus
- Alle onzekerheden worden meegenomen:
  - tektonisch model
  - magnitudes
  - attenuatie
- Voor verschillende herhalingstijden te bepalen, dus geschikt voor alle mogelijke objecten met verschillende kwetsbaarheid

42

## Basis elementen van een PSHA (1)

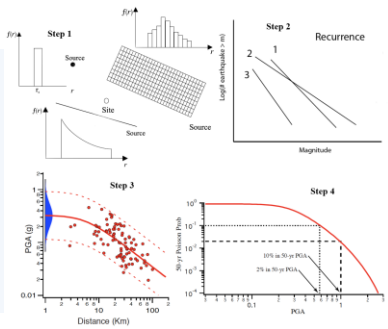
1. Definitie van het seismisch model: bestuderen van de seismo-tectonische setting en aardbevingscatalogus:
   - Identificeer alle seismische bronnen
   - Modelleer seismische bronnen: punt, lijn (breuk) of gebied
   - Karakteriseer elke bron: type breuk beweging, maximum Magnitude
   - Evaluatie van bronnen in termen van frequentie-Magnitude relaties (Gutenberg-Richter)



## Basis elementen van een PSHA (2)

2. Evaluatie en selectie van "Ground Motion Prediction Equation" (GMPE) passend bij de bronnen en seismo-tectonische setting
3. Berekenen (integrereren) van het probabilistisch gevaar met behulp van (computer) modellen
4. Het gevaar wordt vervolgens uitgedrukt in de vorm van seismic hazard curves:
   - Uniform Response Spectra (URS)
   - PGA, PGV, Sa, Sv






## Onzekerheden in PSHA

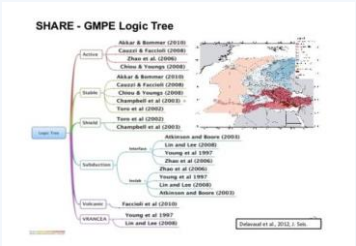
- Aleatorische variabiliteit
  - de natuurlijke willekeurigheid van een proces
  - voor discrete waarden: de kans van optreden van elke waarde
  - voor continue variabelen: kansdichtheidsfunctie
- Epistemische onzekerheden
  - onzekerheden als gevolg van onvolledige kennis van het proces
  - de wetenschappelijke onzekerheid over het model
  - alternatieve modellen



## Vastleggen van de epistemische onzekerheden

- Met een logische beslisboom (Eng: logic tree)
  - Onzekerheden over seismische zones
  - Onzekerheden in GMPE
  - Bij elke onzekerheid worden alternatieve opties gepresenteerd.
  - Subjectieve waarden worden vervolgens toegekend aan elke vertakking



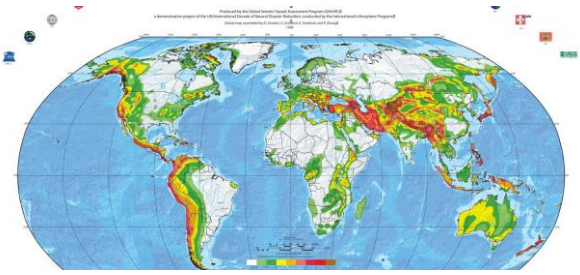


## Resultaat van een PSHA

$$T_R = 1/(1-(1-p)^{1/t_L})$$

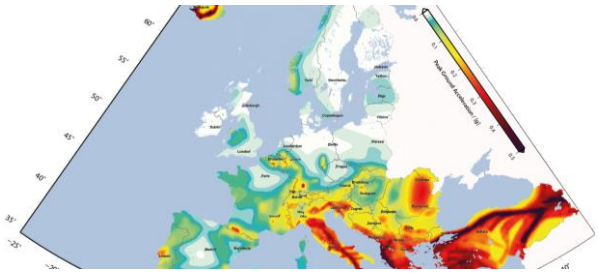
- (acceptable) probability of exceedance ($p$) within a design life ($t_L$)
- return period (herhalingstijd) ($T_R$) 1 % 1 jaar: 100 jaar herhalingstijd
- Voorbeelden
  - 10% probability of exceedance within 50 years: 475 year return period
  - 5% probability of exceedance within 50 years: 975 year return period
  - 2% probability of exceedance within 50 years: 2,475 year return period
  - 0.5% probability of exceedance within 50 years: 10,000 year return period

49



50

10% probability of exceedance in 50 years (475 yr)



51

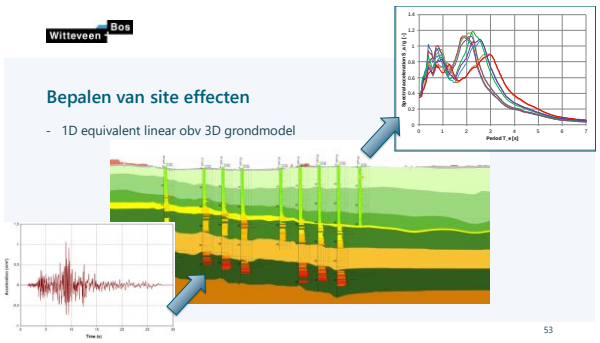
## Hoe bepaal je de grondbeweging en impact op object?

- horizontale grondbeweging (Eng: site effect) grootste veroorzaker van schade
- Bepalen van ontwerp spectra mbv nationale en internationale normen
- Site-specifieke dynamische (numerieke) analyse
  - 1D Equivalent Linear
  - 1D/2D Non-linear
  - 3D
  - coupled/uncoupled

52

## Bepalen van site effecten

- 1D equivalent linear obv 3D grondmodel



53

## Normen en standaarden

- De internationale norm: performance-based approach
  - Eurocode 8: Nationale annexes
  - IBC: International Building Code (USA)
  - ISO 19901-2:2004/API: petroleum industrie
  - PIANC: havens/waterbouw
- Amerikaanse normen:
  - ASCE 7 (2010) : http://www.asce.org/structural-engineering/asce-7-and-sei-standards/
  - NEHRP (2009): http://www.nehrp.gov/
- Nationale normen

54

## Performance-based approach

Engineering judgement (codes)

Hazard

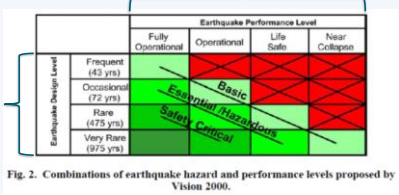
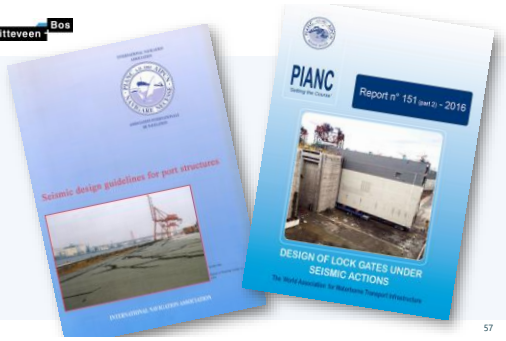



Fig. 2. Combinations of earthquake hazard and performance levels proposed by Vision 2000.

55

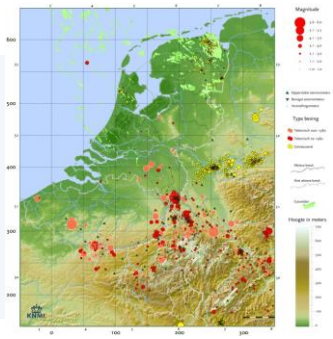

57


58

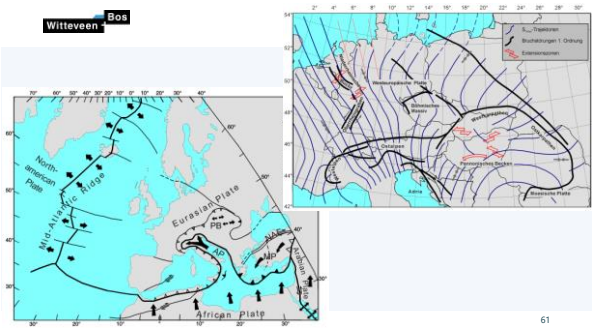
## Hoe ontstaan aardbevingen in Nederland?

- Tektonisch: Limburg en Noord-Brabant
- Geïnduceerd: Groningen (Drenthe/Noord-Holland)

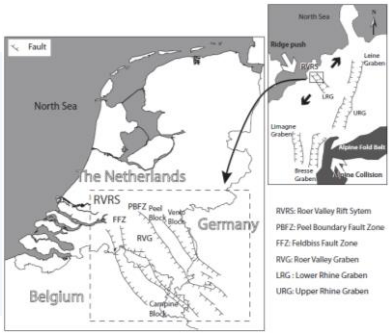
59



60

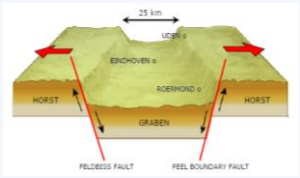



61




## Roerdal Slenk structuur

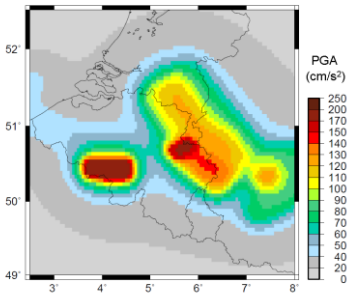
- Extensie, "normale" breukbeweging
- Actieve breuken:
  - Peelrand
  - Feldbiss
  - Heerlerheide
  - Benzenrader, Kunrader
- Grootste aardbevingen:
  - 1930 Uden (M 5,0)
  - 1992 Roermond (M 5,8)




63

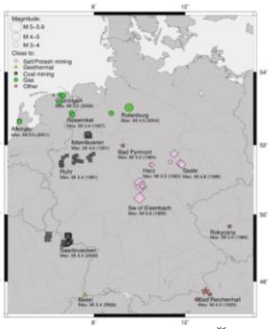
## Seismic hazard map NL

- 10% 50 years (475 yr)




## Geïnduceerde aardbevingen

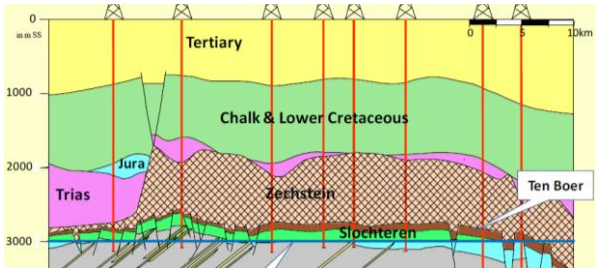
- Door mijnbouw activiteiten
- Niet alleen in Groningen



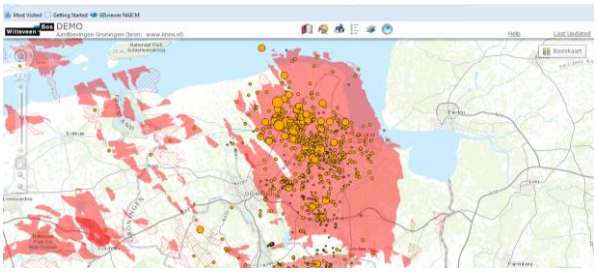
## Mechanisme achter de aardbevingen in Groningen

- meer dan 50 jaar gasproductie, 200 putten
- drukval in het gasreservoir
- (differentiële) compactie (bodemdaling)
- opbouw van rek in reservoir gesteente
- plotselinge beweging langs breuken
- seismiciteit

66




67

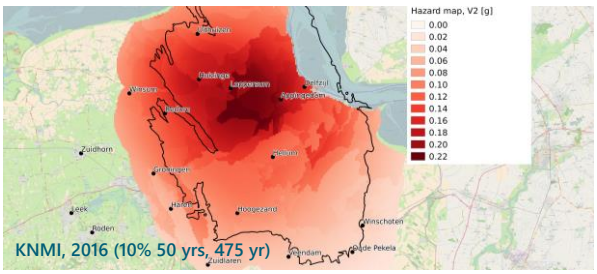


68

## Grootste geïnduceerde bevingen in NL

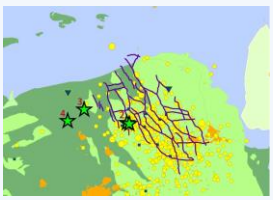
| JJMMDD | Tijd | Locatie | Lat | Lon | Diepte (km) | $M_L$ |
|---|---|---|---|---|---|---|
| 20120816 | 203033,28 | Huizinge | 53,3450 | 6,6720 | 3,0 | 3,6 |
| 20010909 | 065812,52 | Alkmaar | 52,6510 | 4,7130 | 2,0 | 3,5 |
| 20060808 | 050400,05 | Westeremden | 53,3500 | 6,6970 | 3,0 | 3,5 |
| 19970219 | 215350,81 | Roswinkel | 52,8320 | 7,0380 | 2,0 | 3,4 |
| 19980714 | 121202,23 | Roswinkel | 52,8330 | 7,0530 | 2,0 | 3,3 |
| 19940921 | 011258,13 | Alkmaar | 52,6580 | 4,7080 | 2,5 | 3,2 |
| 20001025 | 181034,79 | Roswinkel | 52,8320 | 7,0520 | 2,3 | 3,2 |
| 20010910 | 043015,43 | Alkmaar | 52,6530 | 4,7120 | 2,0 | 3,2 |
| 20081030 | 055429,08 | Westeremden | 53,3370 | 6,7200 | 3,0 | 3,2 |
| 20110627 | 154809,71 | Garrelsweer | 53,3030 | 6,7870 | 3,0 | 3,2 |
| 20130207 | 231908,97 | Zandeweer | 53,3890 | 6,6670 | 3,0 | 3,2 |
| 20111009 | 043342,84 | Noordzee | 53,2810 | 3,8850 | 3,0 | 3,1 |
| 20150930 | 180537,20 | Hellum | 53,2340 | 6,8340 | 3,0 | 3,1 |

69

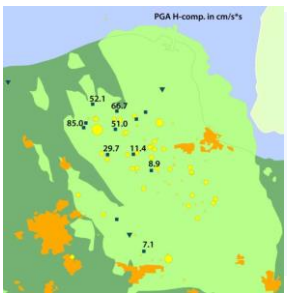


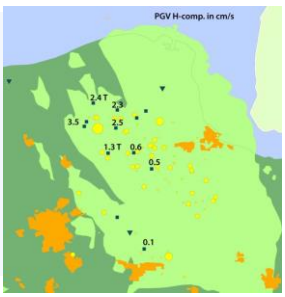

70

## Huizinge beving - 16 augustus 2012, M 3,6

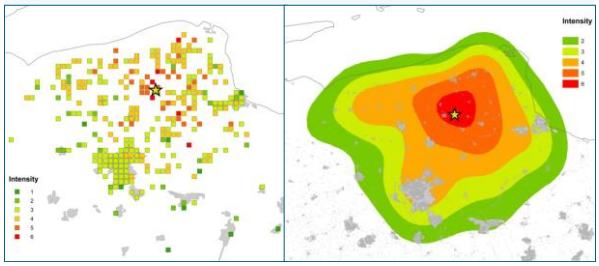


71



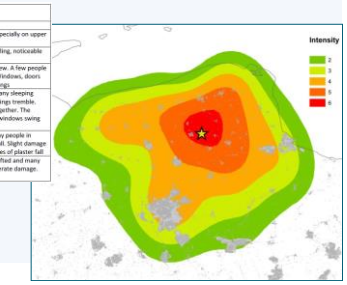



Witteveen Bos




Witteveen Bos

| EMS 98 | Short description | Additional info |
|---|---|---|
| 1 | Not felt | Not felt by anyone |
| 2 | Scarcely felt | Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings. |
| 3 | Weak | Felt indoors by few, people at rest feel swaying or light trembling, noticeable shaking of objects. |
| 4 | Largely observed | The earthquake is felt indoors by many people, outdoors by few. A few people are awakened. The level of vibration is possibly frightening. Windows, doors and dishes rattle. Hanging objects swing. No damage to buildings. |
| 5 | Strong | The earthquake is felt indoors by most, outdoors by many. Many sleeping people awake. A few run outdoors. Entire sections of all buildings tremble. Most objects swing considerably. China and glasses clatter together. The vibration is strong. Topheavy objects topple over. Doors and windows swing open or shut. |
| 6 | Slightly damaging | Felt by everyone indoors and by many to most outdoors. Many people in buildings are frightened and run outdoors. Objects on walls fall. Slight damage to buildings; for example, fine cracks in plaster and small pieces of plaster fall |
| 7 | Damaging | Most people are frightened and run outdoors. Furniture is shifted and many objects fall from shelves. Many buildings suffer slight to moderate damage. Cracks in walls; partial collapse of chimneys. |




Witteveen Bos