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Technical note on the 1992 Brunssummerheide landslide in Limburg, the Netherlands

P.M. Maurenbrecher, D.G. Price & W. Verwaal
Engineering Geology Section, Faculty of Mining and Petroleum Engineering, Delft University of Technology, Mijnbouwstraat 120, 2628 RX Delft, the Netherlands

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Abstract

The 1992 Roermond earthquake caused two landslides in Brunssummerheide park, South Limburg, the Netherlands. The larger of the two slides is within the area of a large slide which happened in 1955. This area consists of loose, reworked, uniformly graded, fine quartz sands in overall gently sloping ground with a gradient of 1 in 5. At the foot of the slope the ground is wooded and approximately level, with groundwater almost at the surface. The severe and varied tilting of the trees in this area indicates horizontal movement and upward bulging of the soil. High water tables persist and springs in the area are the source of the Roode Beek, a tributary of the Maas River. Swampy and even quicksand conditions exist.

The smaller landslide also occurred in a slope with a swampy area at its foot. Other slopes not associated with swampy areas were not affected by the earthquake. The association of loose, reworked and water-saturated sands with slope failure suggests that the slope failures may have taken place by liquefaction of these sands removing support from the toe of the slope. This paper presents a description of the failed slope; a detailed discussion of the probable cause of failure awaits further research.

Introduction

During the 13th April 1992 Roermond earthquake, two landslides occurred at Brunssummerheide. The failed slope discussed in this study, the larger of the two slides, took place in loose sands with an overall gently sloping, but locally stepped, surface profile having a gradient of 1 in 5. In front of the slope the ground is wooded and approximately level, with groundwater almost at the surface. The severe and varied tilting of the trees in this area indicates horizontal movement and upward bulging of the soils. The area has been subject to brown coal mining and sand extraction in the past. The sands are Miocene and normally relatively dense and partly cemented. The loose state of the sands at this particular site may be attributed to reworking during mining operations and/or to a previous slope failure.

The smaller landslide also occurred in a slope with a swampy area at its foot. Slopes not associated with swampy areas were not affected by the earthquake.

The association of loose, reworked and water-saturated sands with slope failure suggests that the slope failures may have taken place by liquefaction of these sands. The liquefaction removed support from the toe of the slope. This paper presents a first description of the failed slope; a detailed discussion of the probable cause of failure awaits further research.

Landslide description

Soon after the 1992 earthquake, press reports mentioned dike failures along the Maas River and a slope failure at Brunssum. The location of the slope failure is about 30 km SSE of Montfort, the earthquake epicentre. The failure occurred in gently sloping, wooded, sandy ground in the recreation area of the Brunssum-

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Fig. 3. Geological map of the Brunssummerheide showing the locations of the two 1992 landslides (indicated by 1 and 2). Geology based on Felder et al. (1988).

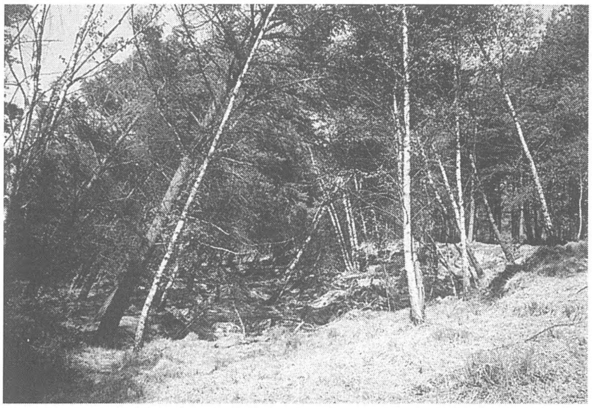


Fig. 1. Brunssummerheide larger landslide: tilted stands of trees at location 1 of Fig. 3. April 1992.

Fig. 2. Brunssummerheide smaller landslide: scarp features at location 2 of Fig. 3. April 1992.

merheide park. The trees were tilted at various angles, suggesting loss of subsurface support due to liquefaction (Fig. 1).

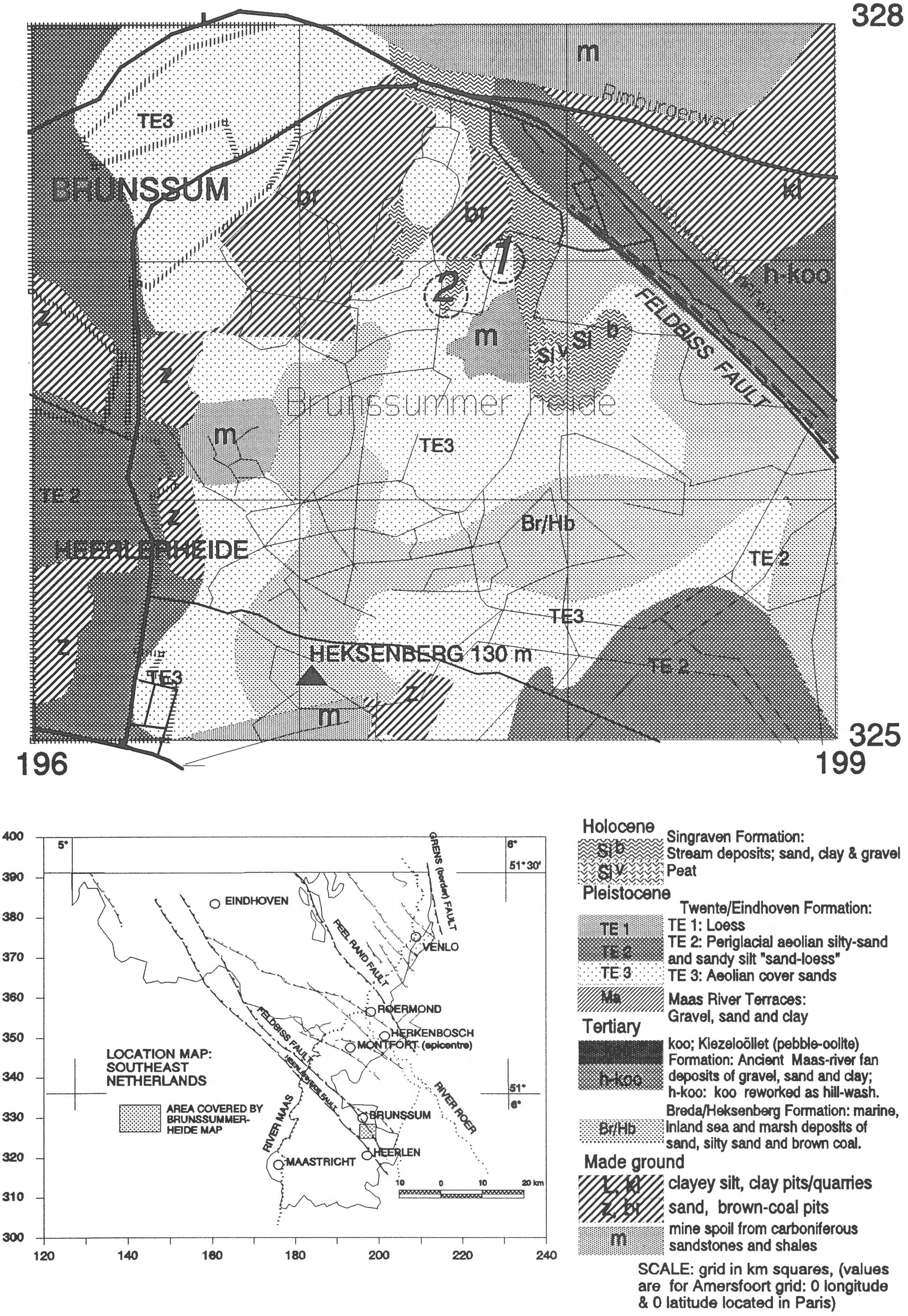
On a site visit one month after the earthquake, a second failure was seen about 300 m from the first. This failure consisted of several steps of semicircular scarps (simulating the seating arrangement in a Roman amphitheatre; Fig. 2). Figure 3 shows the location of both landslides on the geological map (Felder et al. 1988). The fault at the surface nearby is the Feldbiss, the principal southwestern boundary fault of the Roer Valley Graben. The earthquake hypocentre was located on the Peel Boundary Fault on the other side of the graben.

The sands in which the failure took place are shown on the geological map as Pleistocene aeolian sands (these form a thin cover) and as reworked sands of the Miocene Heksenberg Formation (Fig. 3). The latter sands are fine to medium graded quartz sands. The Heksenberg Formation also contains lignite deposits which reach large thicknesses about 30 km to the east in Germany. The sands of the Heksenberg Formation are usually dense and often cemented by silica. Locally the sands were loosened as a result of reworking due to lignite and sand extraction. After heavy rainfall an extensive landslide occurred on June 10th 1955 at the site where both present failures are located (Thiadens 1956). Figure 1 shows that trees which have grown since 1955 are bent, indicating movement subsequent to the 1955 failure.

Site investigation

Slope failures are included frequently in the spectrum of ground failure phenomena induced by earthquakes. These features can be used to refine macroseismic intensity estimates and are used increasingly in studies of regional palaeoseismicity (Davenport & Ringrose 1987). Comparison with dated sedimentary sequences enables dating of past slope failures. The failed slopes at Brunssummerheide along with the 1992 sand eruptions at Herkenbosch near Roermond (Davenport et al. 1994) deserve to be evaluated further in this context.

Presently our study consists of a survey to record the profile and areal extent of the disturbed ground, hand penetrometer tests to determine the depth of loose sands, taking of sand samples for laboratory sieve analysis, determination of ground water levels, and digging of trenches to observe geometric features of the disturbed soil mass in cross-section. Results of the site investigations are given in Figs 4–6. Trench results are not yet included as no significant features have been identified so far.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240
5°
6°
51° 30'
51°
6°
EINDHOVEN
VENLO
GRENS (border) FAULT
PEEL RAND FAULT
ROERMOND
HERKENBOSCH
MONTFORT (epicentre)
FELDBISS FAULT
HEERLERHEIDE FAULT
RIVER ROER
RIVER MAAS
BRUNSSUM
HEERLEN
MAASTRICHT
LOCATION MAP: SOUTHEAST NETHERLANDS
AREA COVERED BY BRUNSSUMMER-HEIDE MAP
10 0 10 20 km
Holocene
Si b
Si v
Singraven Formation:
Stream deposits; sand, clay & gravel
Peat
Pleistocene
Twente/Eindhoven Formation:
TE 1
TE 2
TE 3
TE 1: Loess
TE 2: Periglacial aeolian silty-sand and sandy silt "sand-loess"
TE 3: Aeolian cover sands
Ma
Maas River Terraces:
Gravel, sand and clay
Tertiary
koo; Kiezeloöliet (pebble-oolite)
Formation: Ancient Maas-river fan deposits of gravel, sand and clay;
h-koo
h-koo: koo reworked as hill-wash.
Breda/Heksenberg Formation: marine, inland sea and marsh deposits of sand, silty sand and brown coal.
Br/Hb
Made ground
L, kl
clayey silt, clay pits/quarries
z, br
sand, brown-coal pits
m
mine spoil from carboniferous sandstones and shales
SCALE: grid in km squares, (values are for Amersfoort grid: 0 longitude & 0 latitude located in Paris)

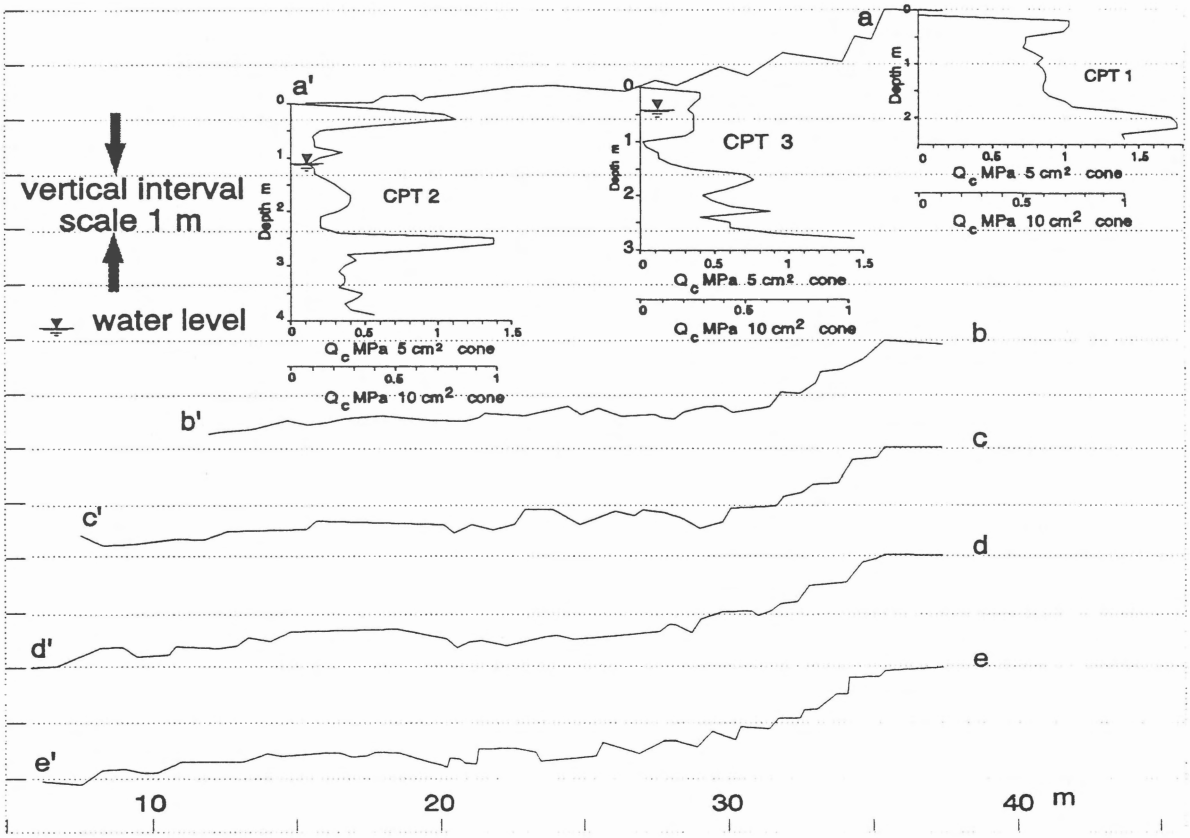

Fig. 5. Surface level profiles along lines aa' to ee' (see Fig. 4) and logs of hand-pushed cone penetration tests (CPT 1, 2 and 3) (cone resistance Q_c scales: 5 cm^2 cone = hand-pushed CPT, 10 cm^2 cone = equivalent scale for the most common machine-operated cone test; the scale is reduced by the ratio of the diameters of the cone, from Hergarden 1990).

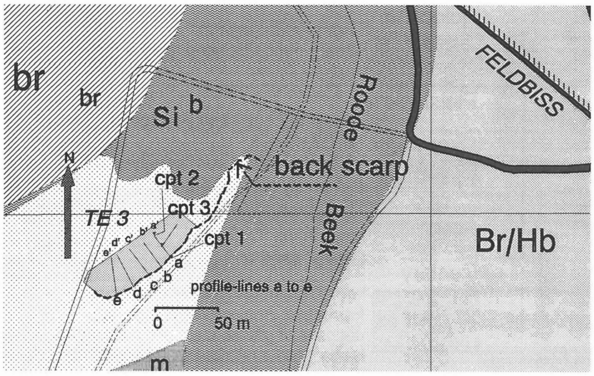

Fig. 4. Map of the large Brunssummerheide landslide (location 1 in Fig. 3) showing the location of profile lines and cone penetration tests (CPT) with respect to local geology (for legend see Fig. 3a).

Appraisal

Earlier work in the southern Netherlands on the susceptibility of ground to liquefaction during an earthquake of magnitude 6 along the Peel Boundary Fault concluded that no liquefaction was to be expected in the area of Brunssum (Lap 1987). However, the locally reworked nature of the ground would suggest an ideal situation for liquefaction. The sands are fine-grained and marshy conditions indicate that they must be generally water-saturated to within one metre of the surface. Hand cone penetration tests proved thicknesses to a depth of 4 m, with very low relative densities. Additional cone penetration tests (CPT) are being prepared to investigate the presence of sand below 6 m depth with a view to satisfy liquefaction conditions such as those given by Seed & Idriss (1971).

In the suggested mechanism of failure, schematically shown in Fig. 7, the loss of support in the 'liquefaction zone' caused the soil mass of the higher ground to fail along active shear planes. The lower ground displaced laterally and upwards along passive shear planes to compensate for the slumped higher ground

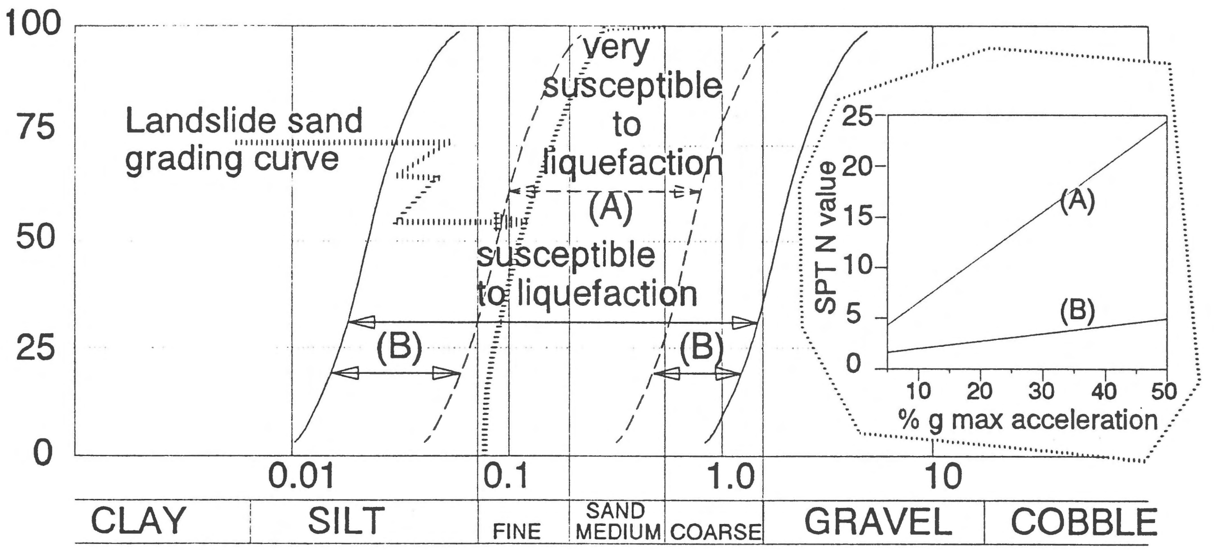

Fig. 6. Particle size distribution curve of the Brunssummerheide landslide sands. Upper and lower bound grading curves for susceptibility to liquefaction are superimposed (A range very susceptible, B range susceptible after Okamoto 1973). Inset shows influence of density in terms of the Standard Penetration Test (SPT) N-values and maximum acceleration values (in %g) required to cause liquefaction.

soil mass. Traditional slope-stability analyses using the slices method for a rotational or translational slip indicate that the horizontal acceleration required to trigger slope failure exceeds by far the accelerations expected to be produced by the Roermond earthquake (Alkema et al. 1994). Figure 6 (after Okamoto 1973) shows that for very low N-values[1], sand type A, which is the Brunssummerheide type, requires a maximum acceleration of about 0.06 g to induce liquefaction. The 5 cm^2 hand cone tests in Fig. 5 suggest equivalent N-values less than 5 using a conversion of

$$Q_c/N\ \mathrm{in MPa} = 0.83\ D_{50}^{\ 0.32} \qquad (1)$$

(based on Robertson et al. 1983), where Q_c is for a 10 cm^2 cone. The equivalent Q_c-values for the 10 cm^2 cone are given in Fig. 5.

Area 1 in Fig. 3 is known as dangerous due to possible quicksand conditions. This, together with the 1955 failure and the movement causing the bent tree trunks, suggests that shear failure is still taking place, possibly along low-shear-strength lignite seams or lignite seat earths combined with high pore-water pressures associated with the springs of the Roode Beek. Such shear may have lowered the density of the sands with depth sufficiently to make the slope susceptible to large movements following earthquake-induced liquefaction.

The purpose of our study is to document in full the slope failure in Brunssum in order to enable a realistic explanation. The study to date has been carried out using inexpensive field techniques. Further investigation is required to confirm ground conditions at greater depth and to establish the cause or causes of the slope failures.

Acknowledgement

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[1] Standard Penetration Test driving hammer blow-count for remaining 300 mm penetration out of a total penetration of 450 mm long split-spoon sampler.

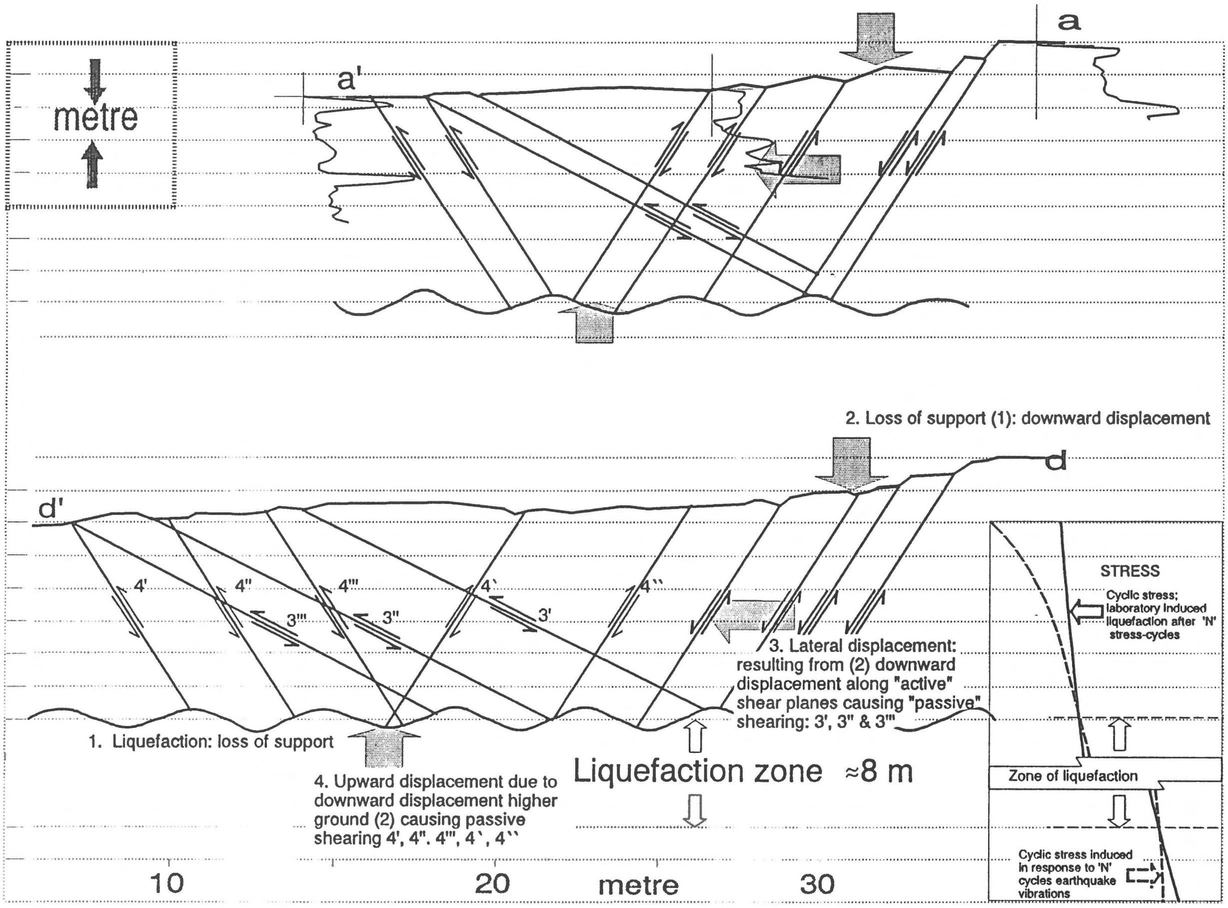

Fig. 7. Schematic sequency of failure mechanisms (stages 1 to 4) of the large Brunssummerheide landslide for cross-sections a'a and d'd of Fig. 4 as a result of loss of support due to liquefaction between 6 and 14 m depth (when cyclic stresses causing liquefaction based on laboratory tests are less than cyclic stresses developed for the equivalent number of cycles by earthquake vibrations as shown in the chart on the right).

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