Knowledge FOr Resilient soCiEty

SPECIAL MOBILITY STRAND

Teaching Mobility
Open lecture in 2017/2018 at UNS,
8 May 2018, Novi Sad, Serbia

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Earthquake Geotechnical Risks
What we know, What we should know
Lessons learned

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TOPICS

1. **GEOTECHNICAL HAZARDS**
   - **Landslides**
   - **Soil Liquefaction**

2. **Lessons learned – 2004 Mid Niigata Earthquake**

3. **Implementation of lessons into research projects**

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1. GEOTECHNICAL HAZARDS

- ➢ **Landslides**
- ➢ **Soil Liquefaction**

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DYNAMIC SOIL INSTABILITIES

- **Dynamic instability of slopes**

  landslides; rock falls ...

  The instability is due to strength exceedance in potential sliding planes

- **Dynamic instability of soil layers**

  liquefaction; subsidence;

  The instability is primarily related to transformation of soil properties
  specific condition, complex mechanism

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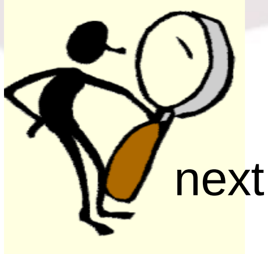
Landslide Types and Processes

The term **“landslide”** describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing.



next Figure shows a graphic illustration

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LANDSLIDE CAUSES

1. Geological causes

a. Weak or sensitive materials
b. Weathered materials
c. Sheared, jointed, or fissured materials
d. Adversely oriented discontinuity (bedding, fault, unconformity, contact, and so forth)
e. Contrast in permeability and/or stiffness of materials

2. Morphological causes

a. Tectonic or volcanic uplift
b. Glacial rebound
c. Fluvial, wave, or glacial erosion of slope toe or lateral margins
d. Subterranean erosion (solution, piping)
e. Deposition loading slope or its crest
f. Vegetation removal (by fire, drought)
g. Thawing
h. Freeze-and-thaw weathering
i. Shrink-and-swell weathering

3. Human causes

a. Excavation of slope or its toe
b. Loading of slope or its crest
c. Drawdown (of reservoirs)
d. Deforestation
e. Irrigation
f. Mining
g. Artificial vibration
h. Water leakage from utilities

4. Extreme natural conditions

a. Heavy rains
b. Floods
c. Earthquakes

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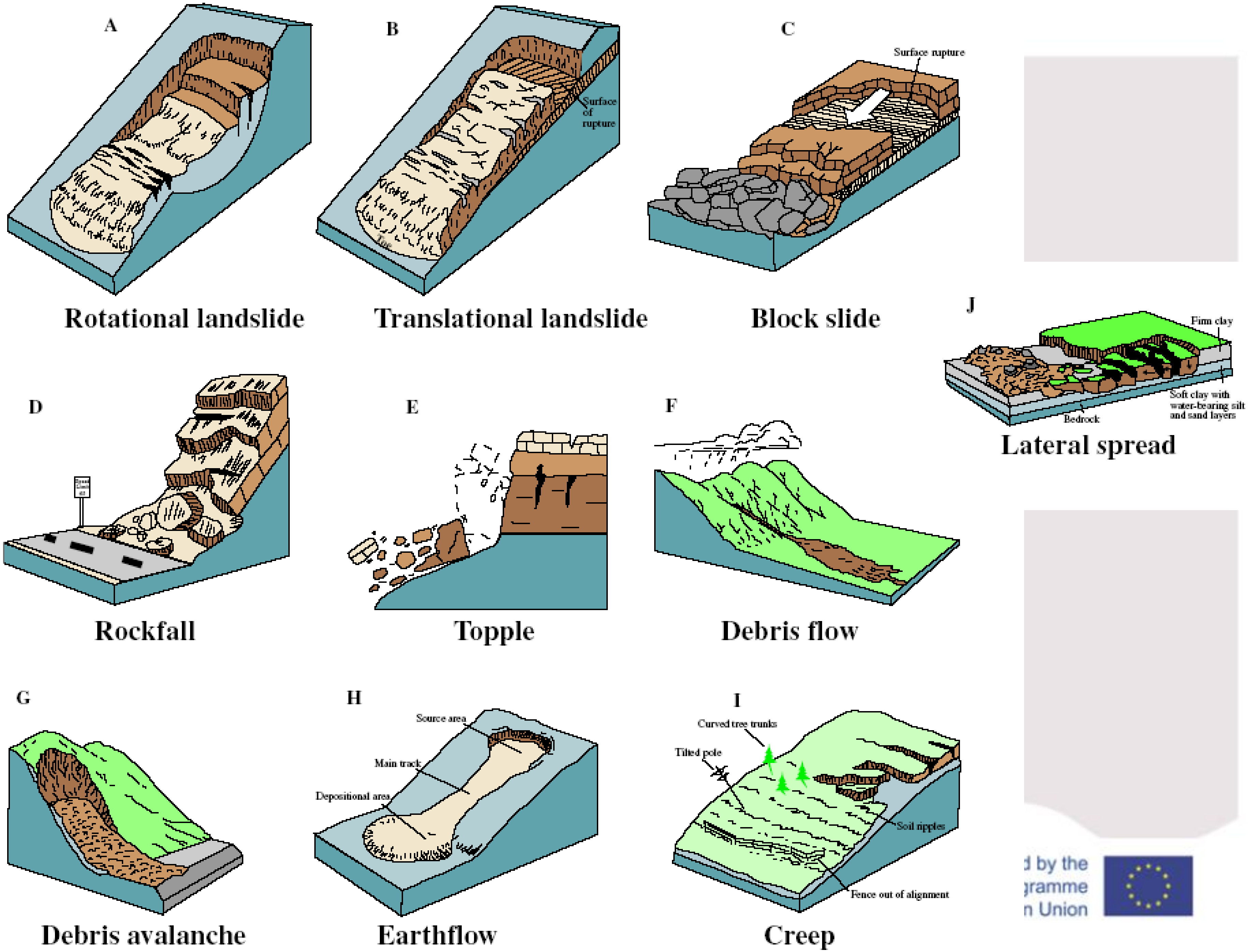
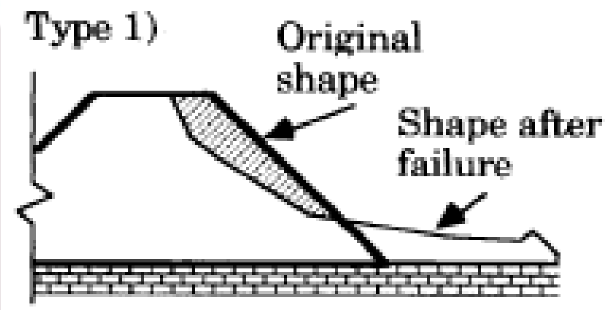
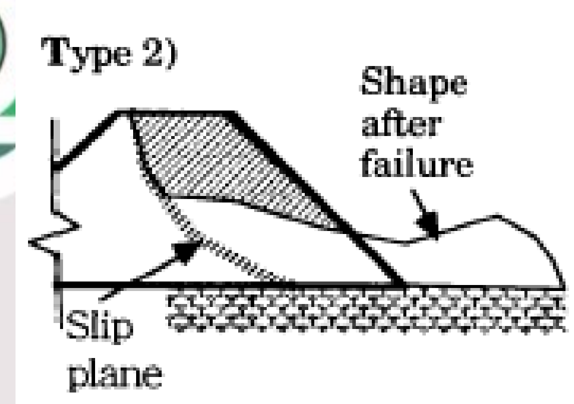

A
Rotational landslide
B
Surface of rupture
Translational landslide
C
Surface rupture
Block slide
J
Firm clay
Soft clay with water-bearing silt and sand layers
Bedrock
Lateral spread
D
Rockfall
E
Topple
F
Debris flow
G
Debris avalanche
H
Source area
Main track
Depositional area
Earthflow
I
Curved tree trunks
Tilted pole
Soil ripples
Fence out of alignment
Creep

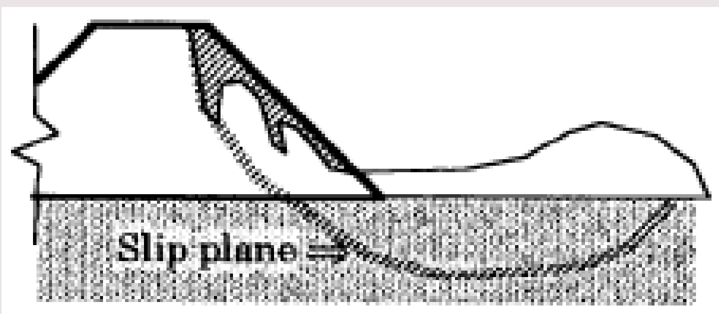
Type 1) Shallow surface sliding of slope



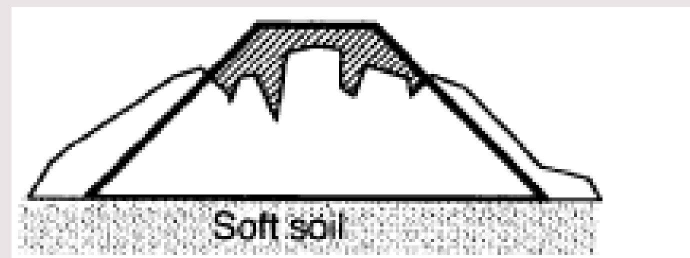
Type 2) Development of slip surface within the body of embankment



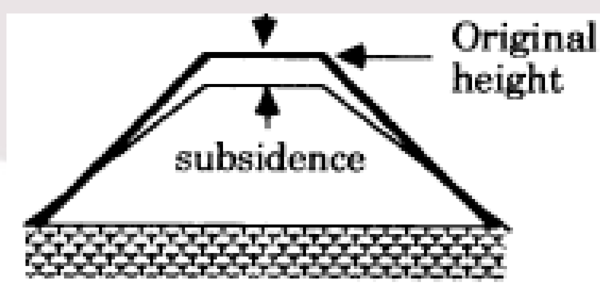
Type 2') Development of slip surface reaching the soft foundation soil



Type 3) Slumping



Type4) Densification



Types of failure of earth fills during past earthquakes (JSCE 2000)

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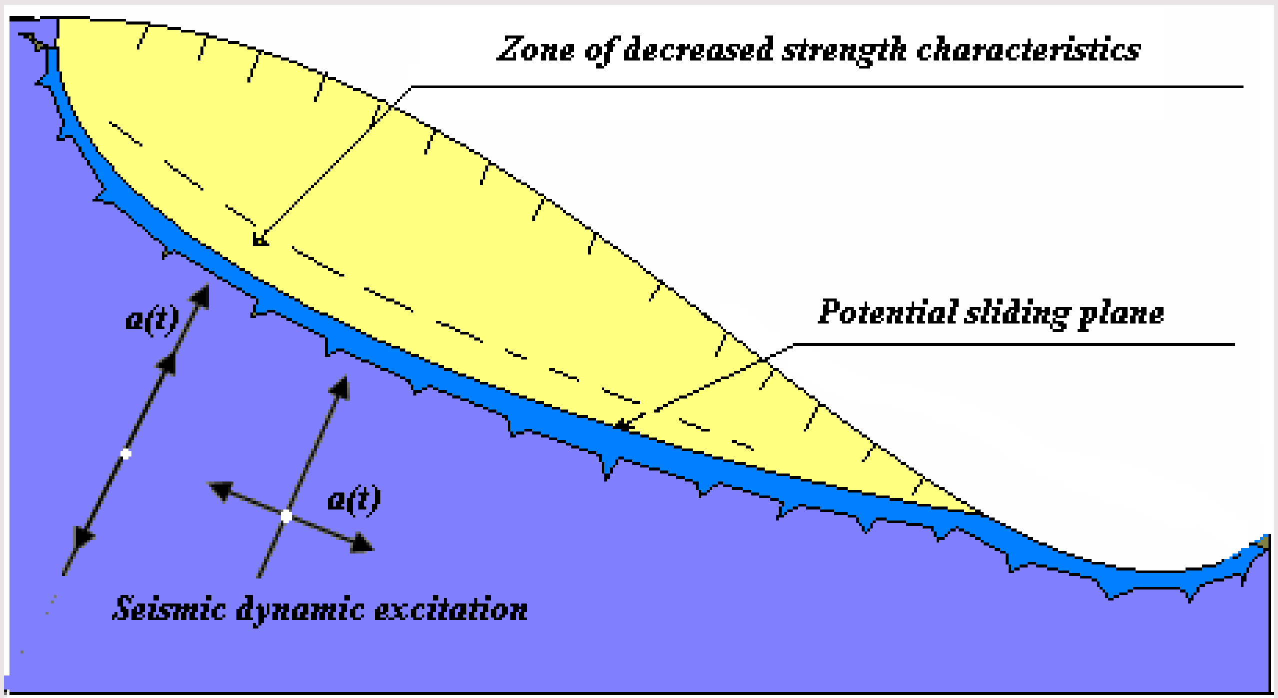
Potential conditions for the instability of the natural slope under seismic dynamic excitation effect



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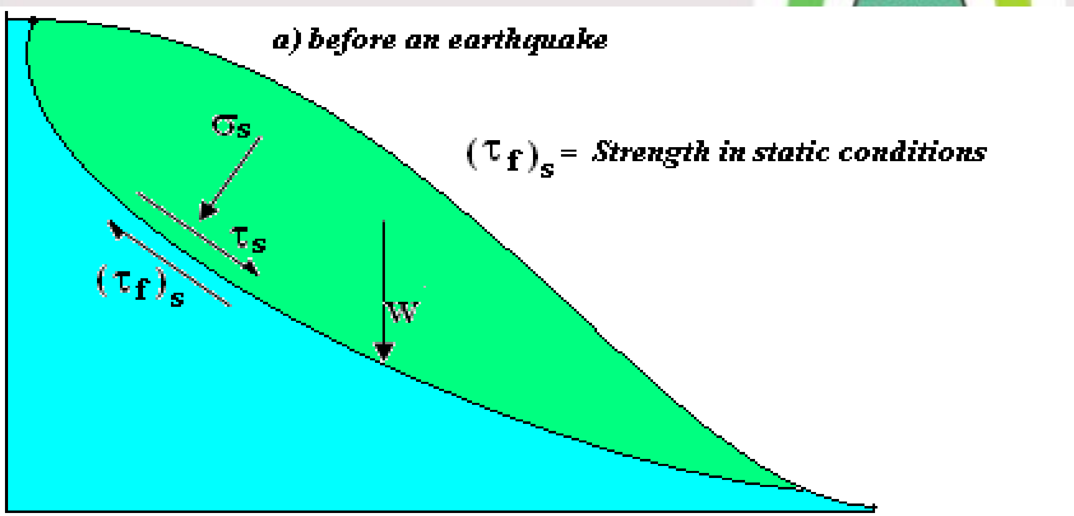


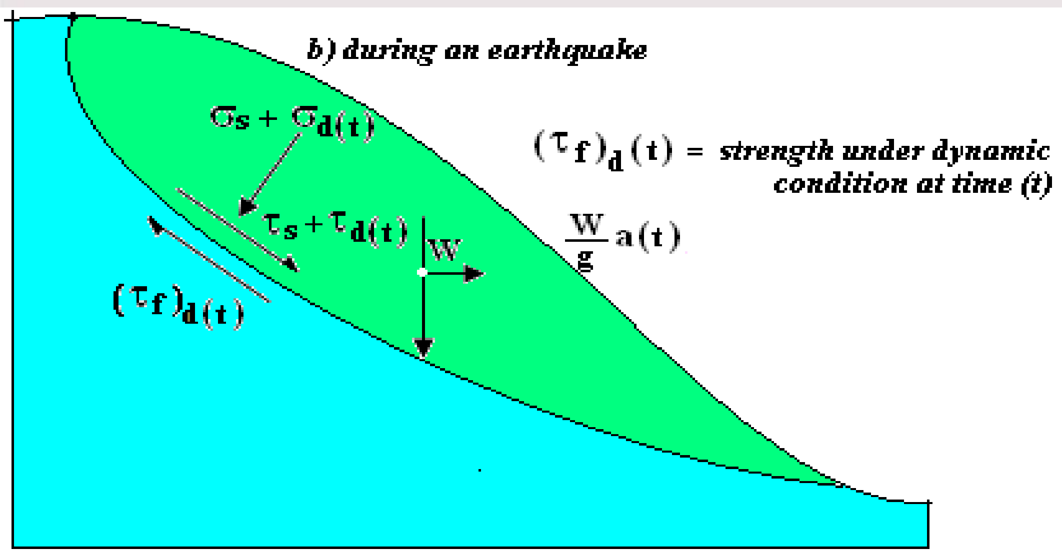
As general case, in static conditions, the soil mass of the slope, above the potential zone or a sliding plane is under the effects of the **gravity load (w)** in vertical direction.

(σ_s **)** - normal stress

(τ_s **)** - shear stress

$$(\tau_f)_s = f\ (\sigma, c, \phi)$$

$$\tau_s < (\tau_f)_s \qquad \textit{equilibrium}$$



Under dynamic conditions caused by an earthquake, an additional effect is involved - the additional dynamic force proportional to the potentially unstable soil mass and the acceleration **(a (t))**

$(\sigma_d\ (t))$

$(\tau_d\ (t))$ $\qquad (\tau_s + \tau_d\ (t))$

$$(\tau_f)_d(t) = f((\sigma_s + \sigma_d(t), c, \phi)$$

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$$(\tau_s + \tau_d(t)) \longleftrightarrow (\tau_f)_d(t),$$

the soil mass remains stable for $(\tau_s + \tau_d(t)) < (\tau_f)_d(t)$

or it has a disturbed stability for $(\tau_s + \tau_d(t)) > (\tau_f)_d(t)$

STATIC

Factor of safety **Fs**

Fs =Rs / As

DYNAMIC

Factor of safety **Fsd**

Fsd =Rsd / Asd

R – resisting forces

A – active forces

Factor of Safety is conventional concept ,

very well worked for static , but outdated for dynamic case !!!

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Critical acceleration a_{cr}

It is a special interest to define acceleration which brings the potentially unstable part of the slope to point of failure.

Acceleration ***'a'*** which resulted the factor of safety *FSd=1* is called *critical acceleration*

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Concept of permanent displacement (residual deformations)

$a_{max} < a_{cr}$; Fsd > 1

$a_{max} > a_{cr}$; Fsd < 1

good starting point , not enough **WHY ?**

if $a_{max} > a_{cr}$ *soil will start to move*

do we have enough information to define stability of the slope? **NO !**

- how much deformation will accumulate at the end of earthquake (residual) ?
- what is the volume of unstable and moving soil mass ?
- what does it mean that deformation for the integrity and performance of the earth structure

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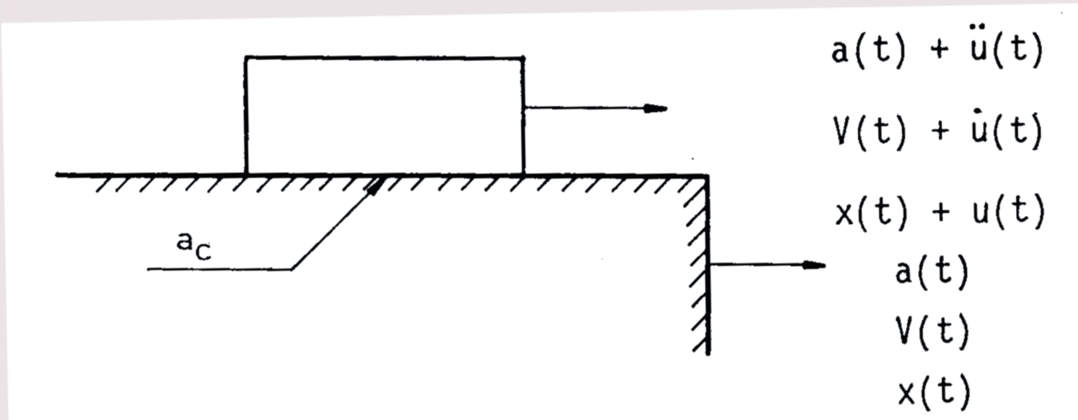
Newmark’s model – evaluation of displacement of rigid block



ü – relative acceleration

ú – relative velocity

u – relative displacement

If a(t) < a_{cr} then ….. ü = ú = u = 0

If a(t) > a_{cr} then ,

$$\ddot{u} = \mathrm{a}(\mathrm{t}) - \mathrm{a}_{\mathrm{cr}} > 0$$

$$\dot{u} = \int \ddot{u}\, dt = \int \left(a(t) - a_{cr}\right) dt$$

$$u = \int \dot{u}\, dt = \iint \left(a(t) - a_{cr}\right) dt\ dt$$

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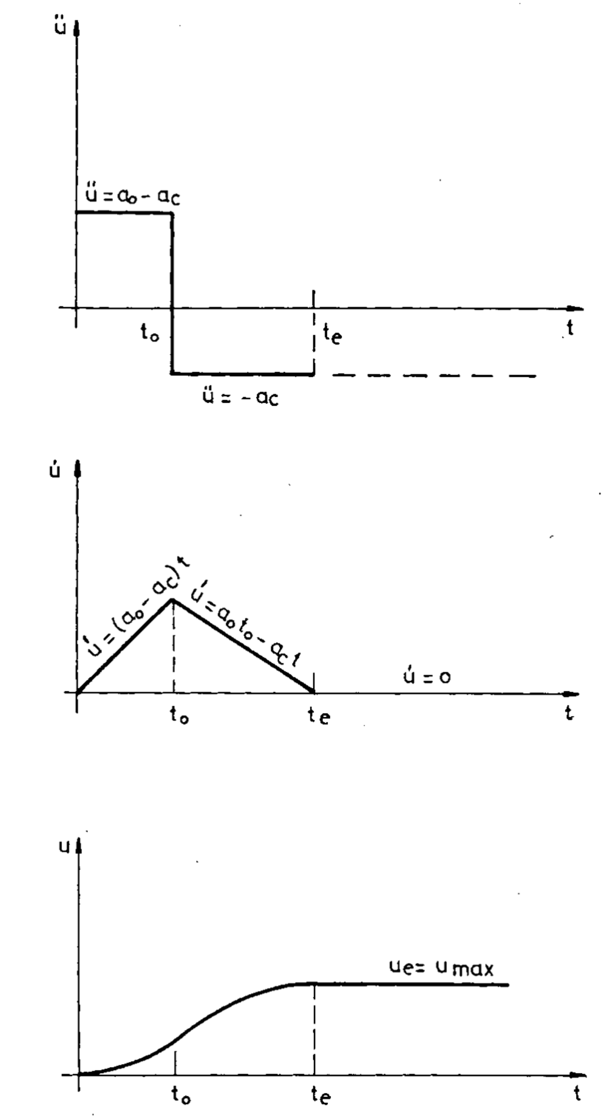

Assumption :

Motion caused by the acceleration in the direction of the slope caused permanent displacement.

Excitation with opposite direction of the slope is considered as unable to move mass backwards.

Since the direction of accelerogram's amplitudes is alternative the procedure is repeated for the positive and negative part of accelerogram, separetly.

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	Performance Based Design	Conventional concept (factor of safety)
Earthquake effects	Time history of acceleration	Static inertia force
Soil model	Nonlinear, plastic	Rigid-perfectly plastic
Method of calculation	Dynamic analysis	Static calculation on limit equilibrium
Criteria of design	Residual deformation < prescribed value	Seismic factor of safety > 1 (>1.05 ?)

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LIQUEFACTION

WHAT IS SOIL LIQUEFACTION ?

- During an earthquake, the application of cyclic shear stresses induced by the propagation of shear waves causes the loose sand to contract, resulting in an **increase in pore water pressure**. Seismic shaking occurs so quickly, the cohesionless soil is subjected to an **undrained loading**.
- The increase in pore water pressure causes an upward flow of water to the ground surface, where it emerges in the form of mud spouts or sand boils. The development of high pore water pressures due to the ground shaking and the upward flow of water may turn the sand into a **viscous condition**, which has been termed **liquefaction**.

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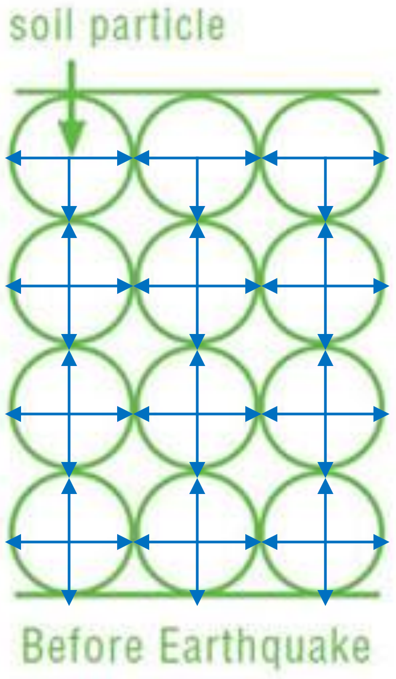

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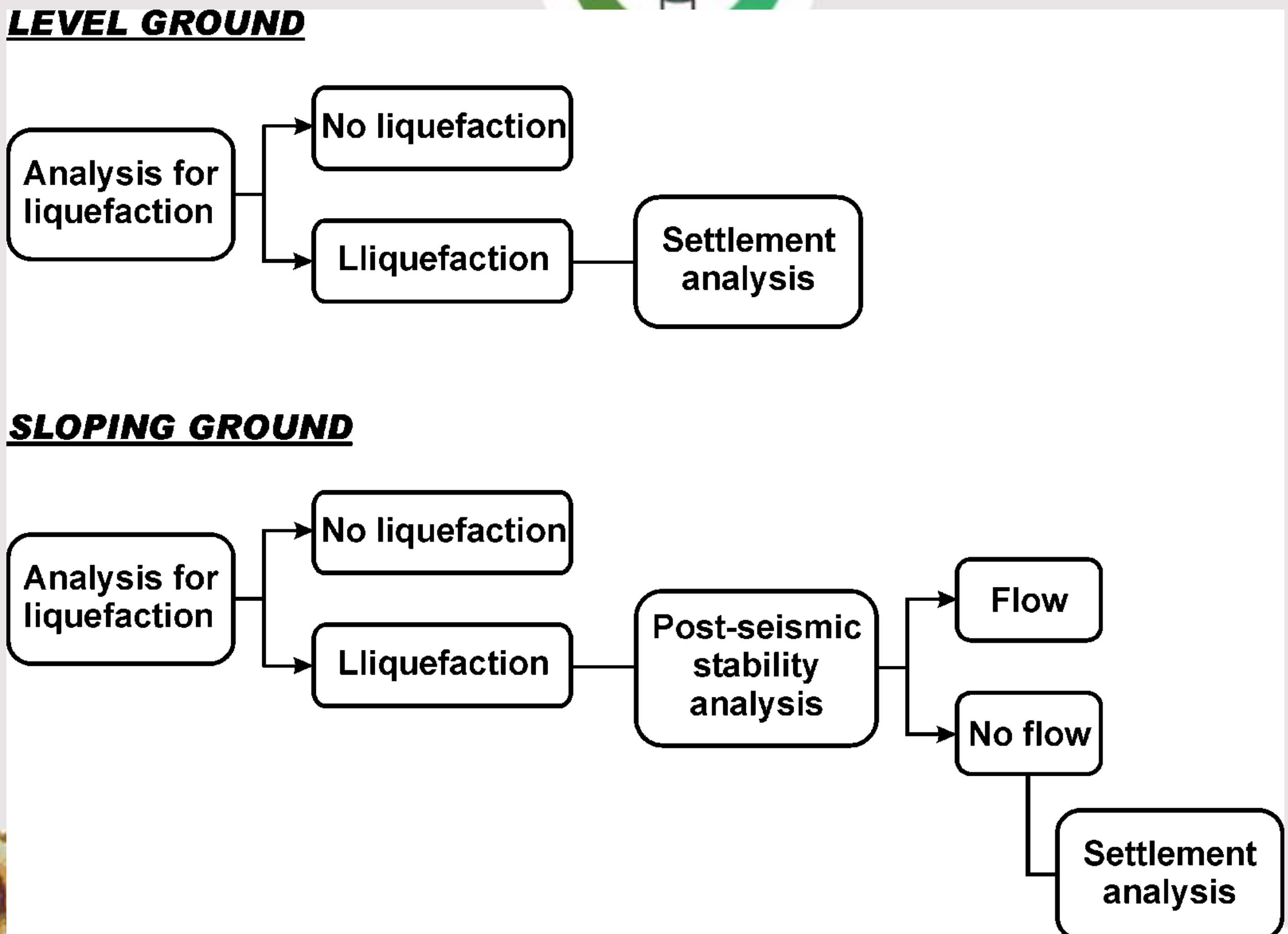
Liquefaction-Related Phenomena



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WHERE and WHEN LIQUEFACTION HAPPEN ?

The occurrence of liquefaction is affected by various factors, which can be classified into three categories

- **<u>Ground motion characteristics</u>**
- **<u>Geological conditions</u>**
- **<u>Soil properties</u>**

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WHERE and WHEN LIQUEFACTION HAPPEN ?

Soil properties	Unit weight, grain size distribution, fines content, average grain size, clay content, plasticity index, relative density, structure of skeleton, shear modulus, damping ratio, coefficient of volume compressibility, degree of saturation, specific gravity of soil particle
Geological conditions	Water table, geological age, total stress, effective stress, overconsolidation ratio, earth pressure at rest, initial static shear stress, deformation constraint condition, boundary condition against seepage: drainage conditions
Ground motion characteristics	Horizontal acceleration, magnitude of earthquake, intensity of seismic shear stress and number of cycles or duration, strain level, direction of shearing

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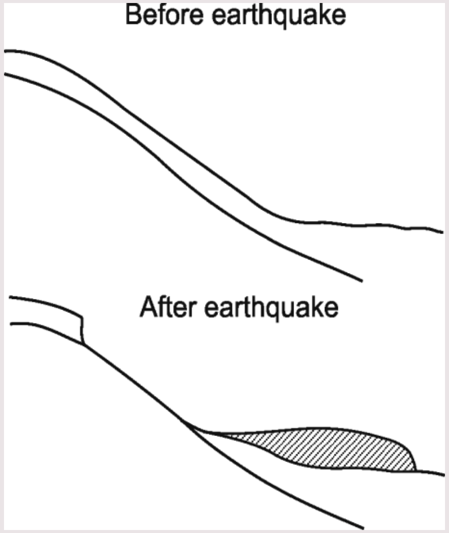
LIQUEFACTION INDUCED DAMAGES

Flow Failures **- Flow failures are one of the most catastrophic ground failures**

displacing large masses of soil laterally tens of meters and at times, large masses of soil have traveled down long slopes at velocities ranging up to tens of kilometers per hour.



Flows may be comprised of completely liquefied soil or blocks of intact material riding on a layer of liquefied soil.

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Liquefaction induced damages

Lateral Spreads. **Lateral spreads involve lateral displacement of large, superficial blocks of soil as a result of liquefaction of a subsurface layer . Displacement occurs in response to the combination of gravitational forces and inertial forces generated by an earthquake. Lateral spreads generally develop on gentle slopes (most commonly less than 3 degrees) and move toward a free face. Horizontal displacements commonly range up to several meters.**

Lateral spreads commonly disrupt foundations of buildings

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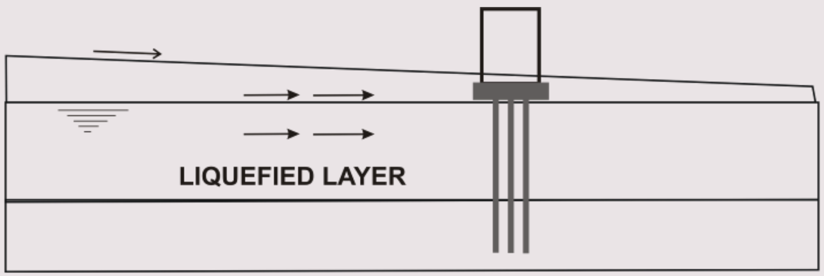
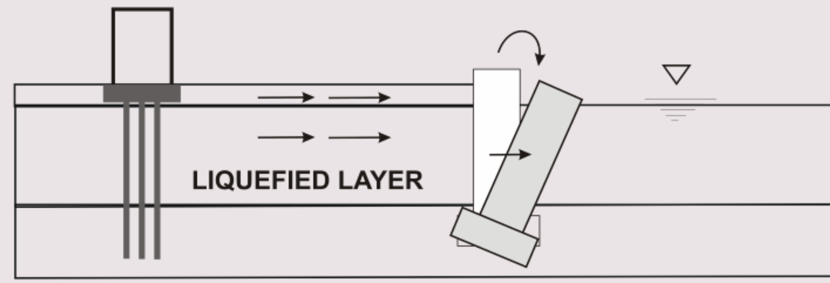
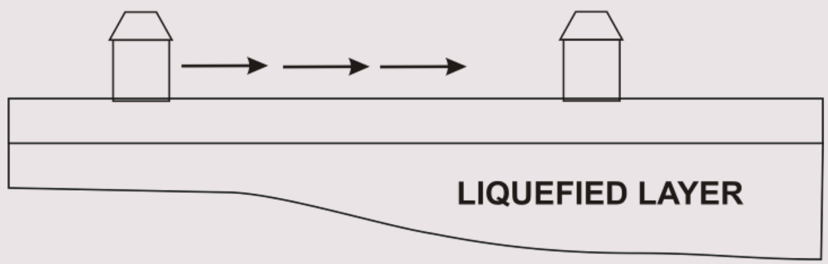
Lateral Spreads - types



Type A – ground surface slightly inclined



Type B – flat surface , abrupt discontinuity by revetments



Type C – ground surface flat but lower boundary is inclined

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Liquefaction induced damages

Loss of Bearing Strength. **When the soil supporting a building or other structure liquefies and loses strength, large deformations can occur within the soil which may allow the structure to settle and tip**

Niigata Earthquake 1964

Adapazari, Izmit Earthquake, Turkey 1999: August 17

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Ground Settlement. **In many cases, the weight of a structure will not be great enough to cause the large settlements associated with soil bearing capacity failures described above. However, smaller settlements may occur as soil pore-water pressures dissipate and the soil consolidates after the earthquake.**

Buoyant rise of buried structures. **Soil liquefaction can also induce buoyant rise of underground structure. Normally, the uplift of the buried structure is prevented by resistance from the adjacent soil. However, when soil liquefies, the soil loses its resistance and starts to behave like liquid with unit weight almost twice that of water. When the unit weight of the buried structure is less than that of the liquefied soil, floating of underground structures can occur.**

A manhole uplifted during the

2004 Mid Niigata Earthquake

***Increased lateral pressure on retaining walls*. If the soil behind a retaining wall liquefies, the lateral pressures on the wall may greatly increase. As a result, retaining walls may be laterally displaced**

Sand Boils. **Although not strictly a form of ground failure because they alone do not cause ground deformation, sand boils are diagnostic evidence of elevated pore water pressure at depth and are indications that liquefaction has occurred.**

Sand boil, during the Loma Prieta Earthqauke

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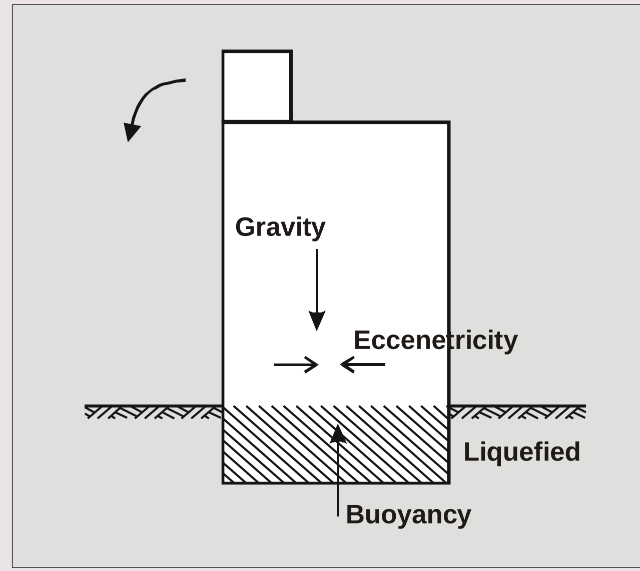
Loss of bearing capacity in foundation



Adapazari, Turkey

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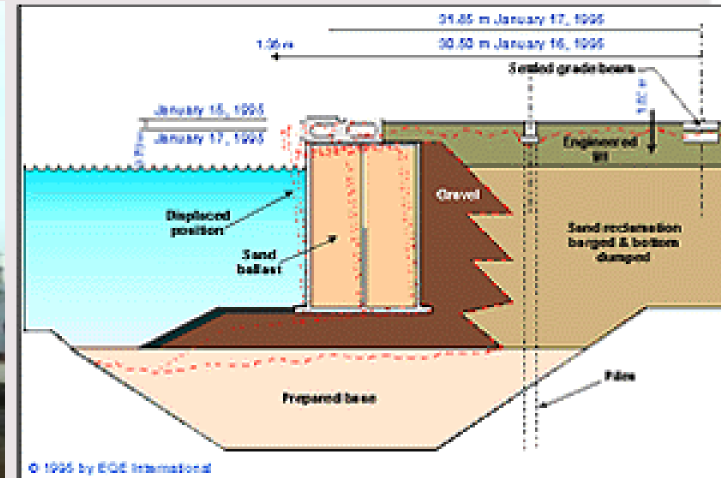
Dislocation of retaining walls



Quay walls - Kobe, Japan

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Lateral movement of soil

Nishihomiya Bridge - Kobe, Japan

Showa bridge - Niigata, Japan

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Los Angeles Dam -1971 , USA

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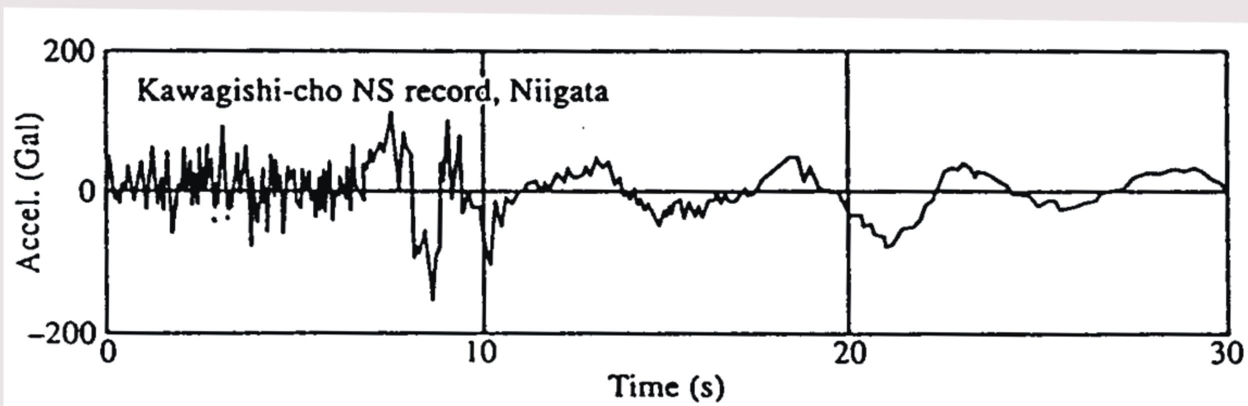
Variation in natural period of ground

Liquefaction induced damages

$$T_g = \frac{4H}{V_s} \qquad V_s = \sqrt{\frac{G}{\rho}}$$

The shear modulus of sand, G, decreases as excess pore pressure rises during shaking, elongating the natural period Tg. Thus, the surface deposit functions as a wave filter; the seismic-motion component of elongated period = Tg is amplified by resonance.



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LESSONS LEARNED

on

GEOTECHNICAL HAZARDS
THE 2004 MID NIIGATA EARTHQUAKE

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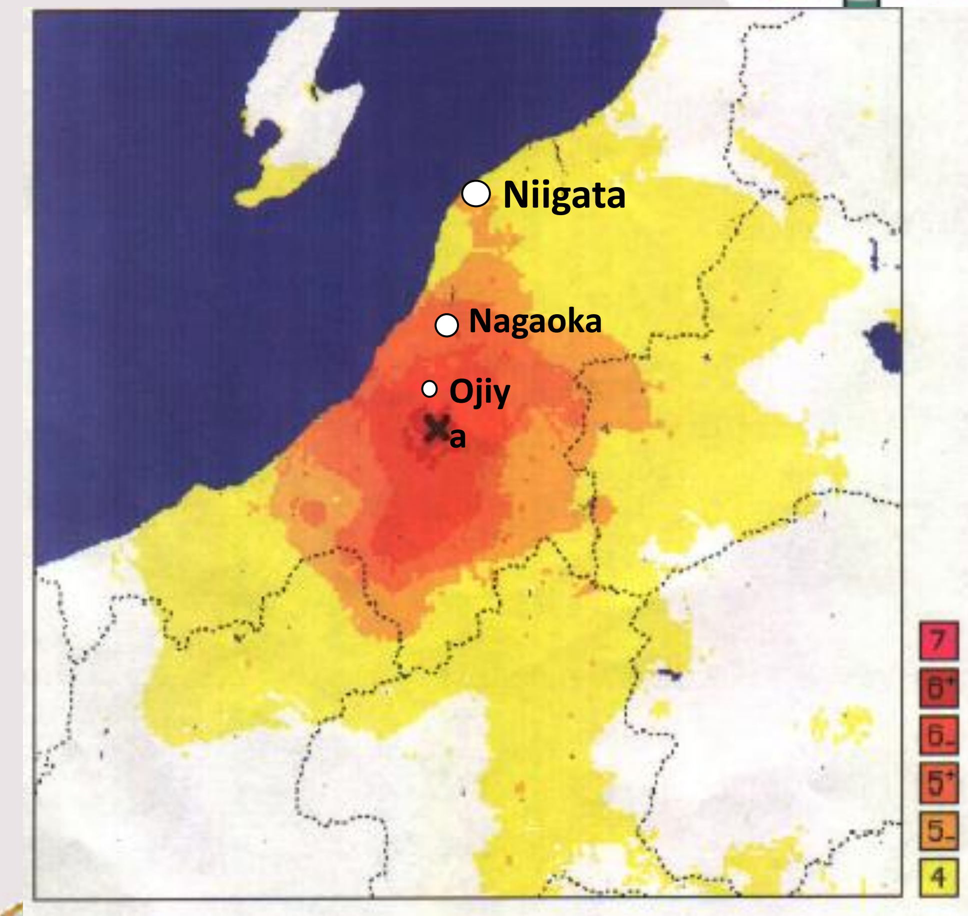
SUMMARY



Intensity distribution (JMA)

Seismic activity :

M=6.8 17:56 pm JST. The intensity is registered 7 on the 7 grade Japanese intensity scale.

The PGA *(1.50g)* is observed at NIG019 (K-NET) station Ojiya, 1995 Kobe earthquake PGA 0.83 g at Fukiai Gas Supply Depot.

Other facts :

Typhoon No.23 passed three days before the earthquake. ***Heavy rainfall*** made the ground ***saturated*** and ***very soft.***

Epicentral area is not densely populated. Ojiya was the city closest to hypocenter.

Topography: hills and mountains.

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GENERAL OBSERVATIONS – <u>GEOTECHNICAL ISSUES</u>

On the basis of the observations, geotechnical instabilities of the 23 October Mid Niigata Earthquake can be classified as:

1) ***Landslides in natural slopes*** ;

2) ***Geotechnical instabilities related to man made ground structures***.

<u>- Landslide in manmade slopes</u>

<u>- Lateral displacements and soil subsidence</u>

<u>- Liquefaction</u>

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LANDSLIDES IN NATURAL SLOPES

Landslides have been one of the dominant geotechnical instabilities occurred during this earthquake. *Saturated soil condition* due to the past rainy days and *steep inclination* of the natural slope made these slopes very vulnerable to earthquake shaking. There were a lot of landslides where *only surface soil layers* from the top of the slope were sliding toward toe of the slope. Sometimes small rocks and mud stones with various dimensions have been seen in the landslide deposit. Landslides in the natural slopes we observed were *small to mid sized* landslides affecting nearby houses, buried road and railways and blocked small rivers with slide debris.

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LANDSLIDES IN NATURAL SLOPES

Landslide in steep natural slope

Surface soil layers from top part of the slopes slide downwards. Place: Nigorisawa

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LANDSLIDES IN NATURAL SLOPES

Middle sized landslide in natural slope occurred and temporary blocked the local road and small river.

Place: Nigorisawa

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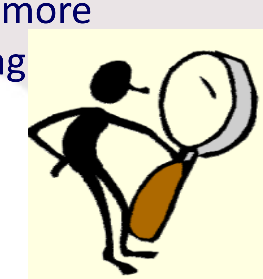
LANDSLIDES IN NATURAL SLOPES

Place: Ojiya-city, Myoken, near Uragara Bridge.

The landslide mass scraped the surface layer more than one meter and moved downward. Sliding surface is almost flat.



Landslides and rockfalls. Place: near Uragara Bridge, Myoken, Ojiya-city

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GEOTECHNICAL INSTABILITIES RELATED TO MAN MADE GROUND STRUCTURES.

- Landslide in manmade slopes

Many of the local roads and railways connecting the villages in the mountain area east of Ojiya-city were built by cutting the natural slopes. Some of these manmade slopes were affected by earthquake triggered landslides and slide debris blocked the traffic. *Mid sized landslide in Nigorisawa village* that destroyed several houses and blocked the local road. The biggest landslide we observed took place *near to Uragara bridge, Myoken*, Ojiya-city. Huge rocks and mud stones completely blocked and destroyed the road in length of more than hundreds meters. Several landslides also took place in residential area in *Takamachi*. Ring road which was passing at the edge of this this residential area was destroyed by several landslides which took place during the earthquake.

photos

GEOTECHNICAL INSTABILITIES RELATED TO MAN MADE GROUND STRUCTURES

Large landslide took place destroying retaining wall and several houses built on the slope. Soil mass moved more than 50 meters downwards.

Place: Nigorisawa village

Damaged retaining wall. Place: Nigorisawa village

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LANDSLIDES AT TAKAMACHI RESIDENTIAL AREA

This residential area was located on *small hill terrace*. A *ring road* at the edge of this terrace was wiped off by the landslides on several places.

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LANDSLIDES AT TAKAMACHI RESIDENTIAL AREA

Several landslides which occurred at this residential area didn’t caused collapse of the houses but heavily damaged the roads and pipe lines. The landslide mass scarped the surface layer just at the edge of the houses.

Soil profile

of the European Union

LARGE LANDSLIDE AT MYOKEN, OJIYA city

LANDSLIDE AT MYOKEN, OJIYA city

Huge rocks and mud stones completely blocked and destroyed the road in length of more than several hundreds meters

LANDSLIDE AT MYOKEN, OJIYA city

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GEOTECHNICAL INSTABILITIES RELATED TO MAN MADE GROUND STRUCTURES.

- Lateral displacements and soil subsidence.

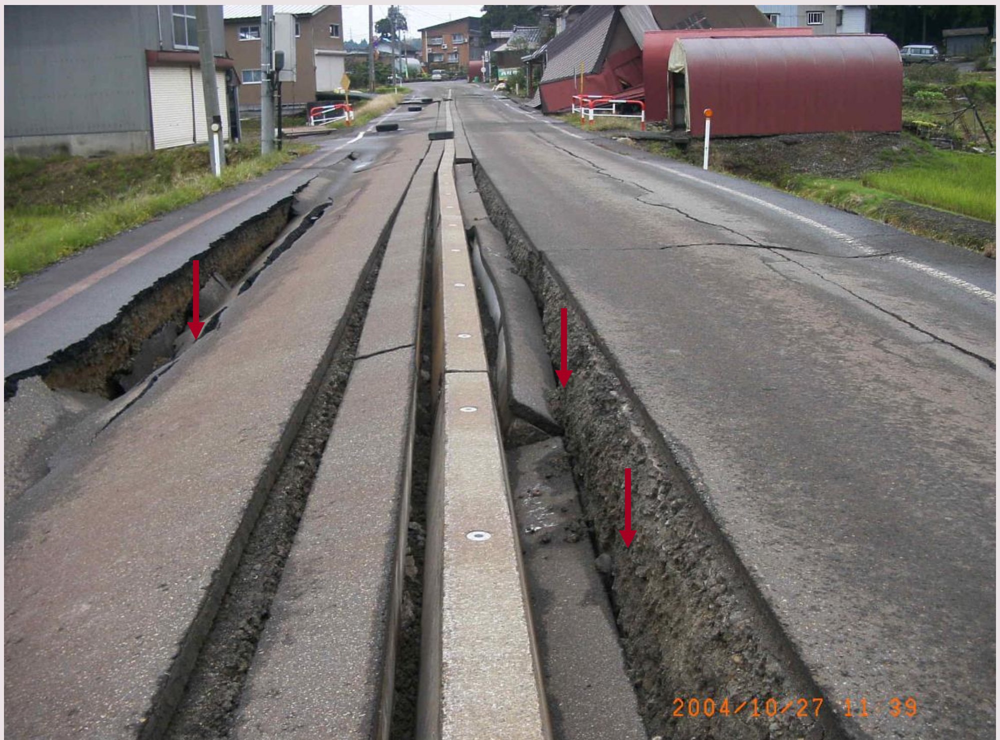
The local roads suffer significant damages due to settlement of the road embankment causing numerous cracks and subsidence of asphalt pavement. Crest settlements of the road embankment frequently occurred with lateral movement of the fill material which produced damages on the retaining wall at the toe of the embankment. Also buried water pipelines located in the middle of the roads were separated from the asphalt pavements.

Connection between the roads and the culverts also between roads and the bridges were particularly damaged by the subsidence of fill material of the road embankment. We observed large crest subsidence on the road approaching the *Yamabe bridge*. The bridge itself performed well during the earthquake no visual damaged could be observe on the steel structure.

Large lateral displacements and ground subsidence we observed at *Nagaoka National College of Technology* which is located on *small hill terrace* in Nagaoka city.

photos

OBSERVED DAMAGES ON LOCAL ROADS



Cracks and subsidence of asphalt pavement.

cracks in asphalt pavement due to lateral displacement

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Approaching road to YAMABA bridge

Road was heavily damaged. Bridge steel structure performed well during the earthquake.

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Approaching road to YAMABA bridge

Big subsidence were observed on the road approaching the Yamabe Bridge

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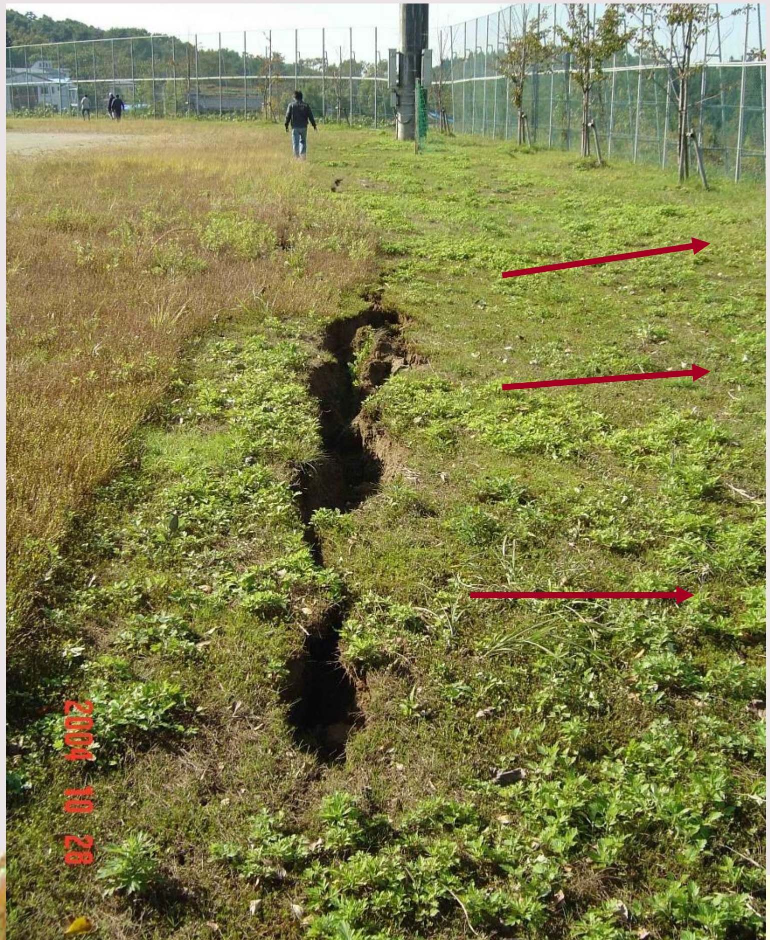
Lateral displacements and soil subsidence

NAGAOKA NATIONAL COLLEGE OF TECHNOLOGY

Lateral displacements and soil subsidence

NAGAOKA NATIONAL COLLEGE OF TECHNOLOGY



Soil moved toward the slope of the hill terrace and large cracks appeared.

Ground subsidence of nearly 1 m at the at college playground.

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Lateral displacements and soil subsidence

NAGAOKA NATIONAL COLLEGE OF TECHNOLOGY

Fill material separated from underground concrete structure due to
large permanent soil displacement

Large ground deformation was observed between two buildings

Lateral displacements and soil subsidence

NAGAOKA NATIONAL COLLEGE OF TECHNOLOGY

Soil settlements up to one meter were observed near to this three stories building which is founded on pile foundation

Tennis courts, on the left side of the photo, were built on small terrace where lateral soil displacements took place toward gymnasium.

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SOIL LIQUEFACTION

There was no evidence for significant soil liquefaction induced damages.

- Up-lifted manholes in Ojiya city and *small sand boils* in their vicinity were the evidence that liquefaction took place. Also small sand boils could be observed in the rice fields.

- Derailment of Shinkansen near Tokamachi Town – tilting of RC column

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photos

SOIL LIQUEFACTION AT OJIYA CITY

Up-lifted manholes in Ojiya city and small sand boils

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Derailment of Shinkansen

Liquefaction occurred at the foot of the piers the boiled sand reached 70 to 90cm. The gap between the pier and the ground indicates the large displacement the pier experienced. Strong motion sensors shut down the electric power supply and prevent bigger catastrophe.

IMPLEMENTATION OF LESSONS INTO RESEARCH PROJECTS

- **Evaluation of landslide risk – multi hazard scenario**
- **Soil liquefaction during small to medium scale earthquakes**

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EVALUATION OF LANDSLIDE RISKS

GIS APPLICATION OF MULTI HAZARD METHODOLOGY

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OBJECTIVE

The main objective of the investigations performed was analysis, distribution and zoning of potential geotechnical instabilities and evaluation of the risk on population and the infrastructure.

APPROACH :

- Systematic analysis and spatial distribution (geo-referenced) of the existing geological and geotechnical data

- Seismic hazard analysis – definition of earthquake scenario

- Different soil water saturation scenario have been pre-determined

-Maps of expected permanent displacements for a pre-selected earthquake scenario combine with different level of water saturation

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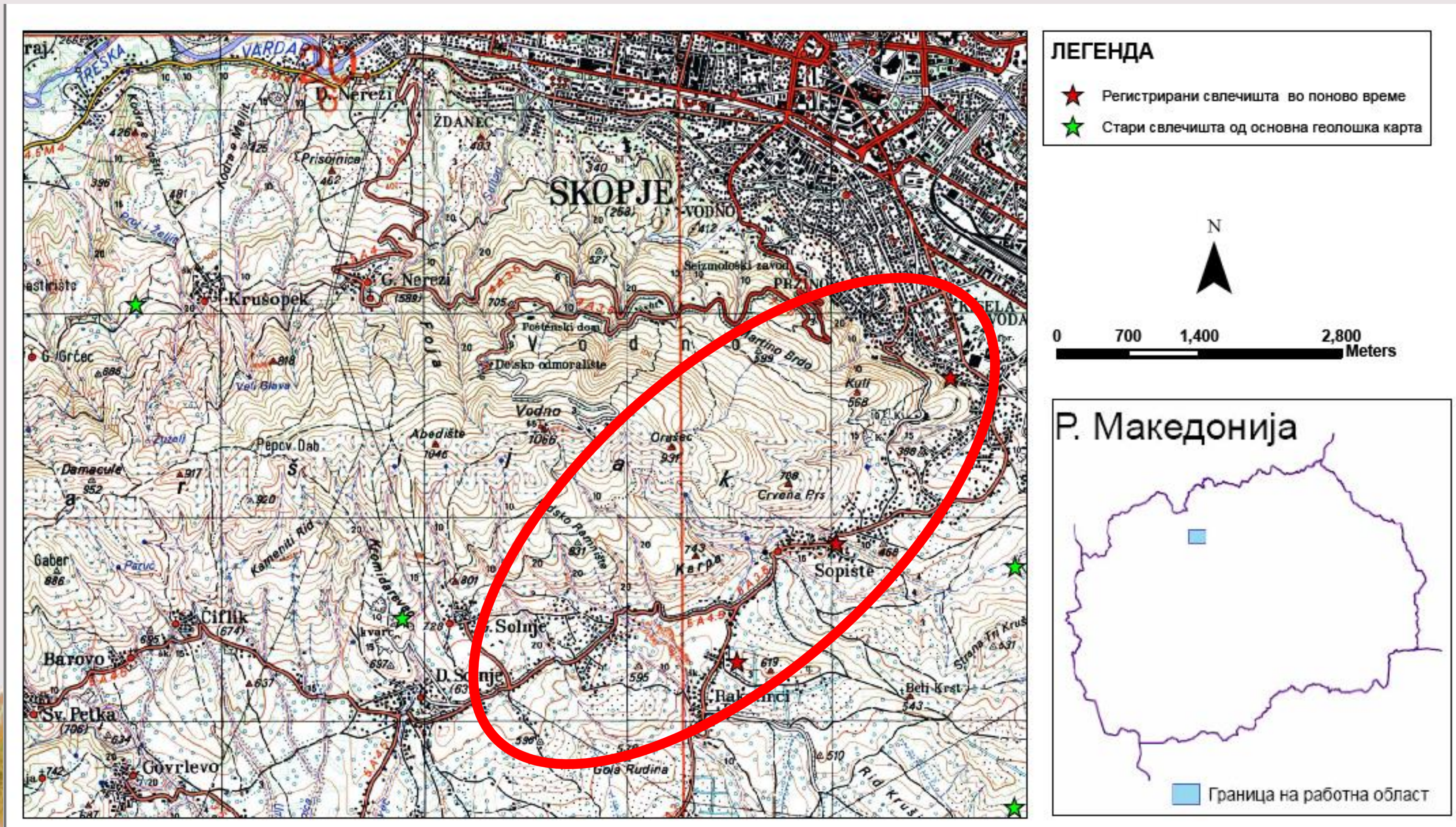
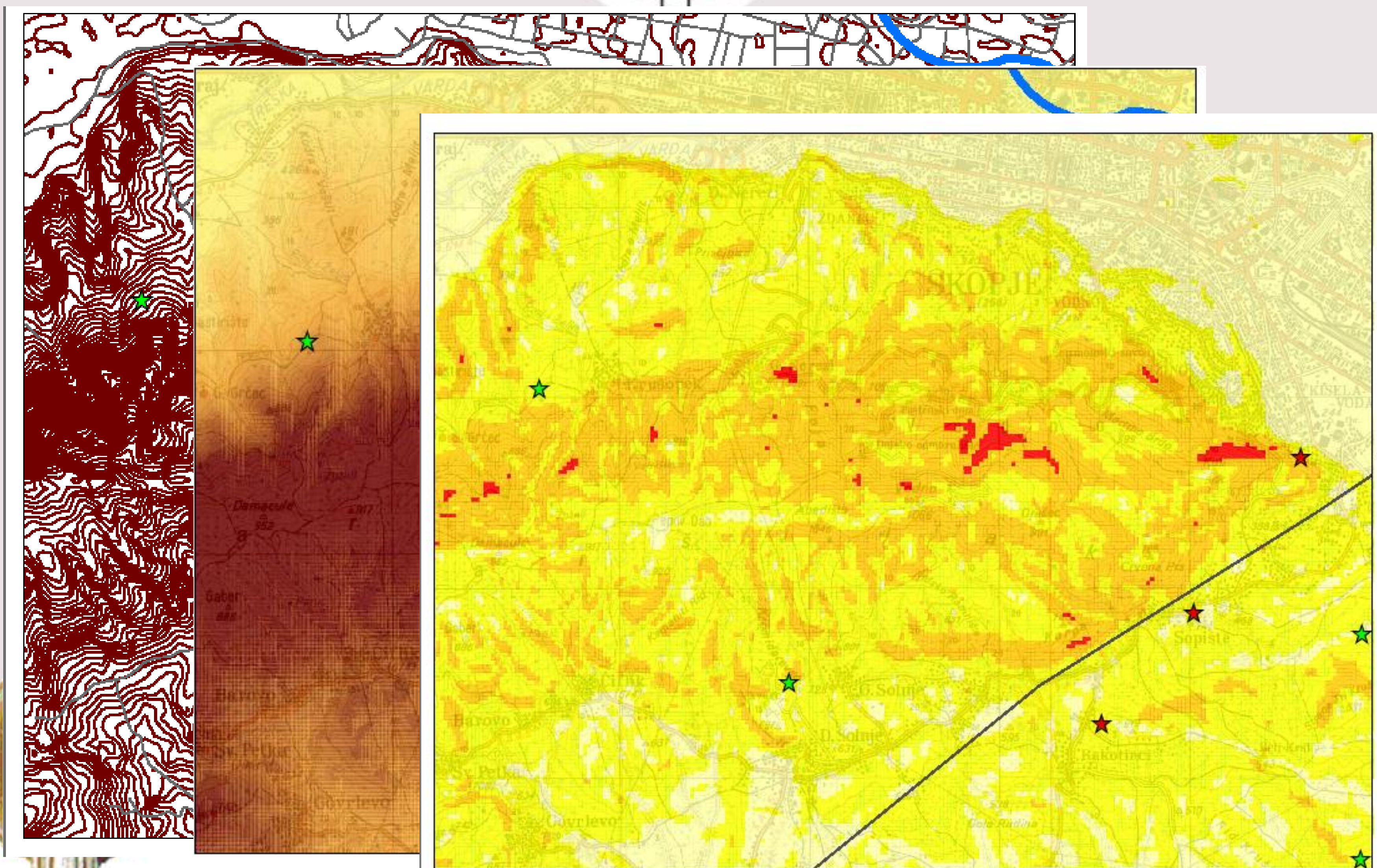
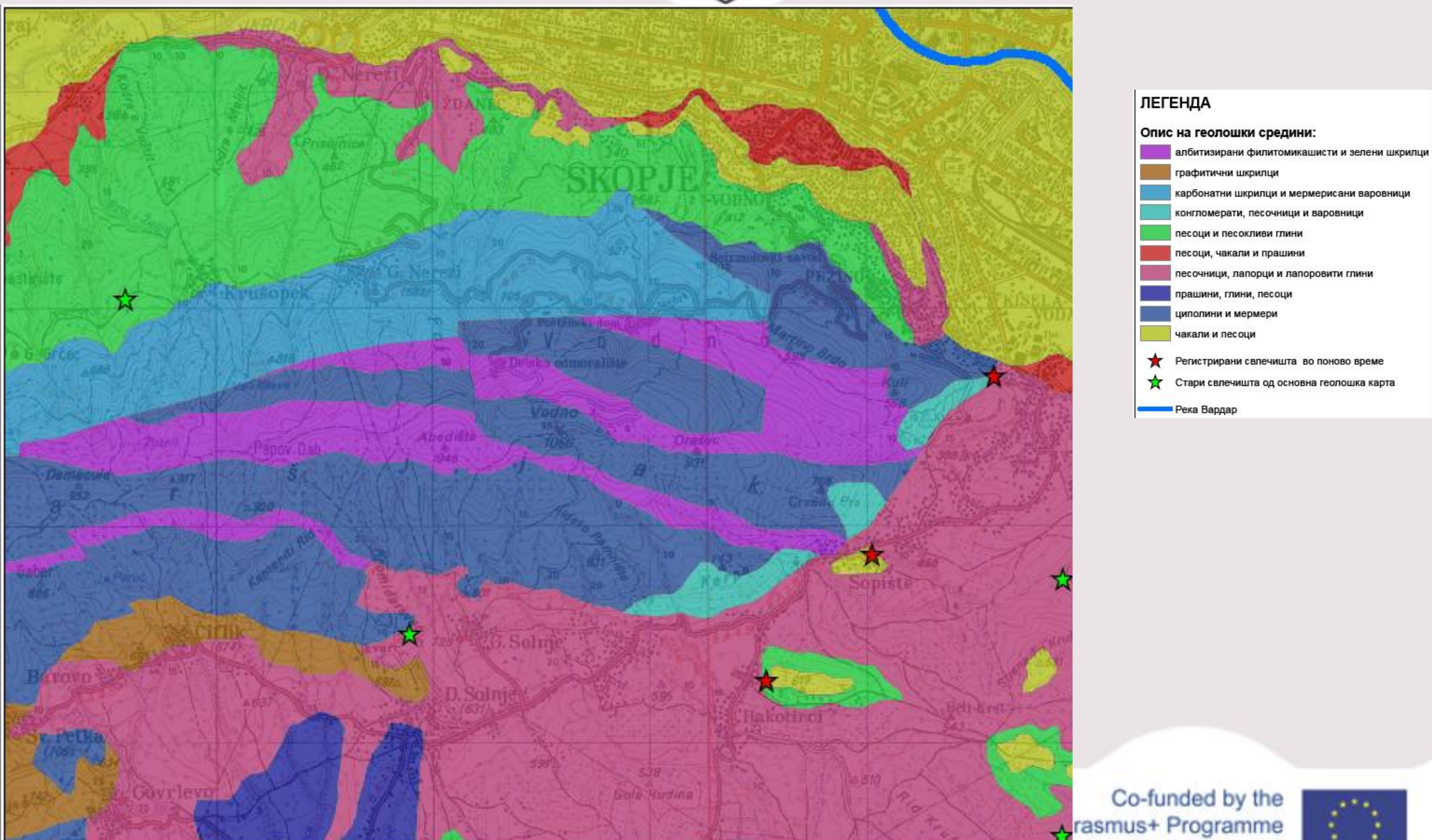
SELECTING WORKING AREA



MAPS – digital elevation model slope definition (GIS)



GEOLOGIGAL MAPS – geo-referenced



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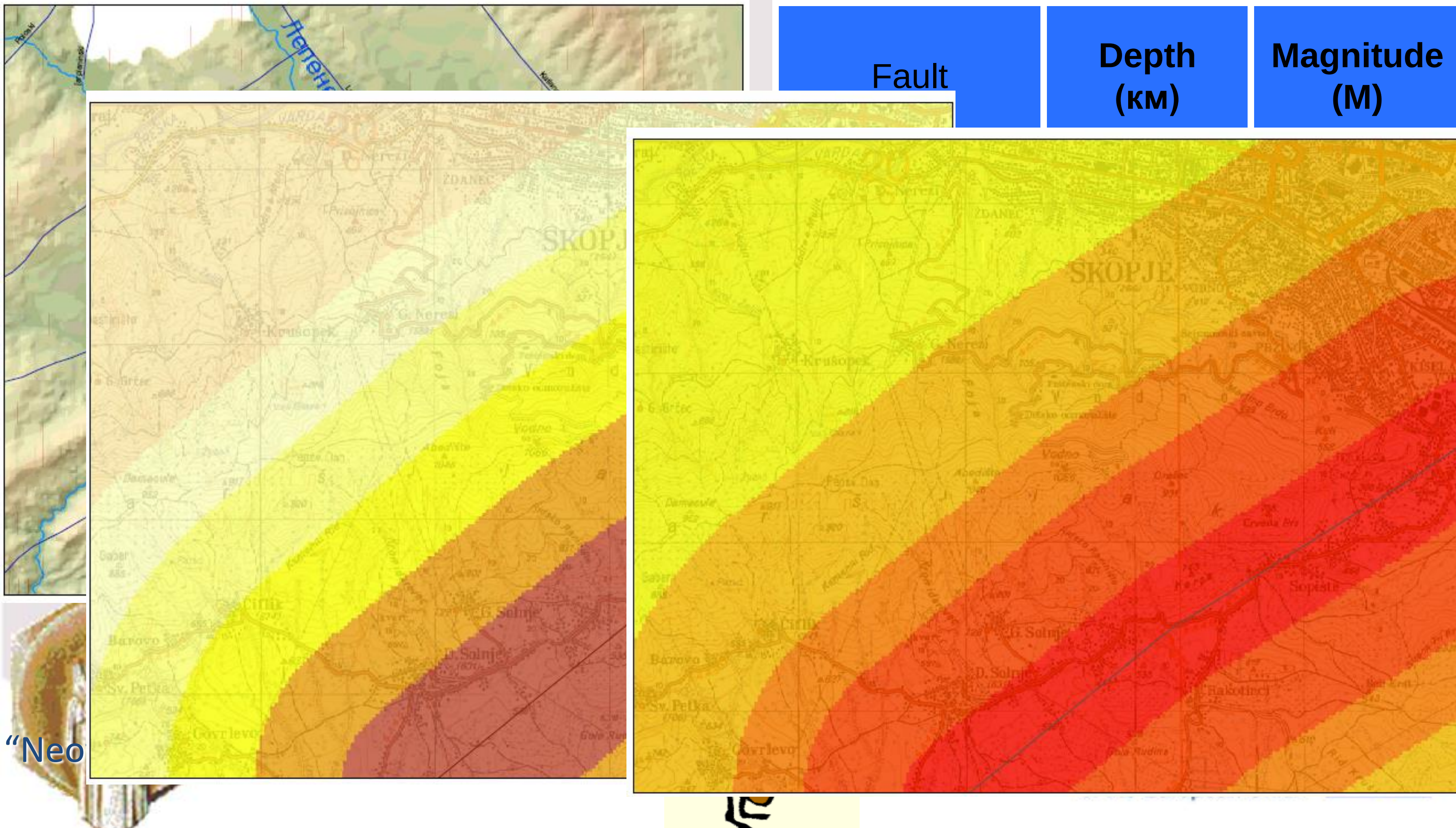
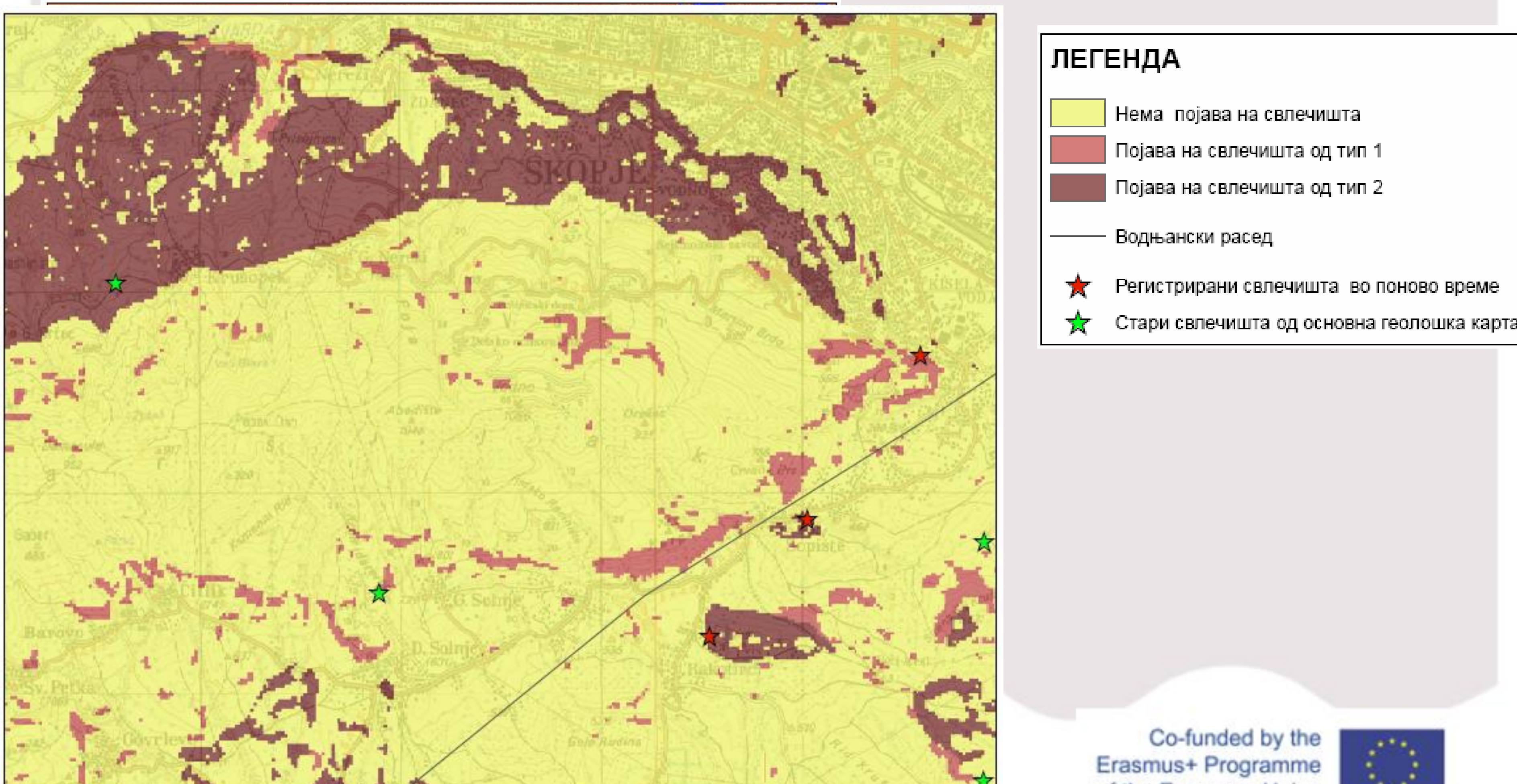
SEISMIC HAZARD ANALYSIS
- Aries Intensity map -

Fault	Depth (км)	Magnitude (M)



“Neo

Landslides potential
- earthquake scenario -



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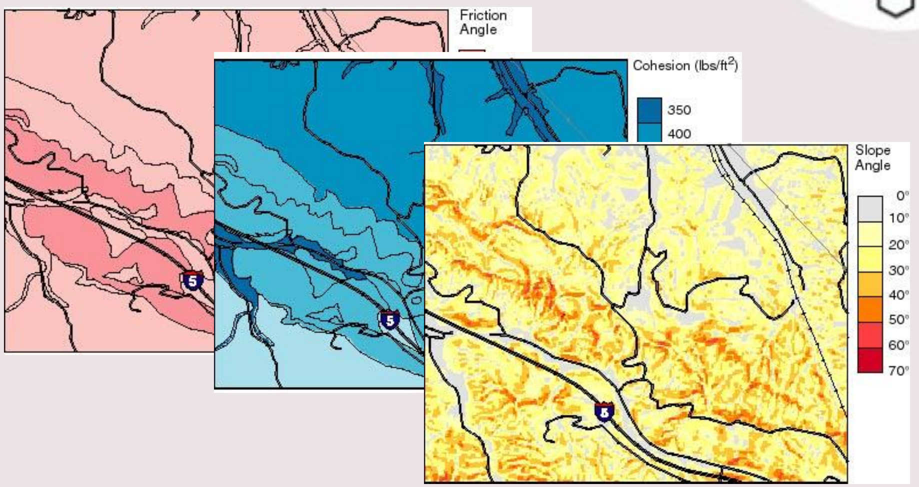
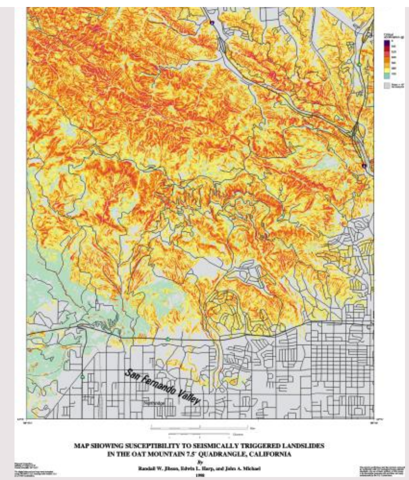
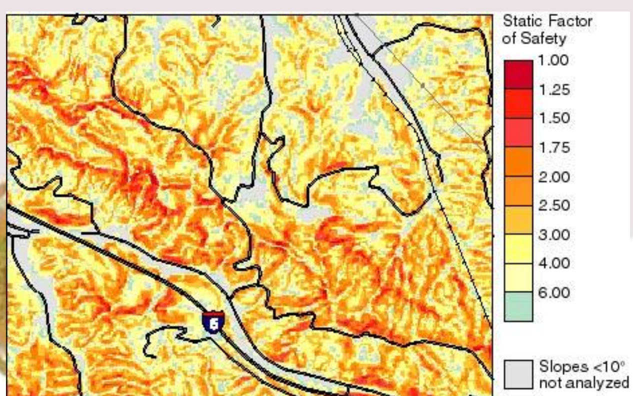
Landslide zonation
- factor of safety , critical acceleration, permanent displacement (Jibson) -



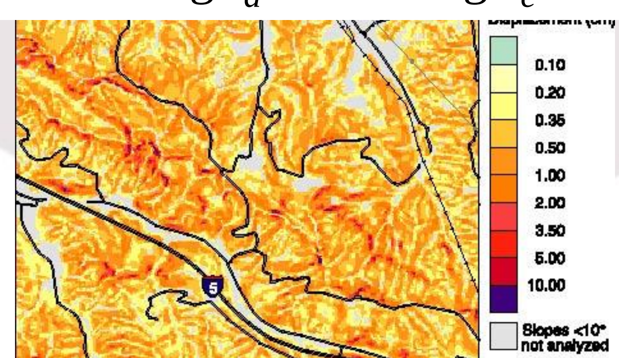
$$a_c = (FS - 1) g \sin\alpha$$



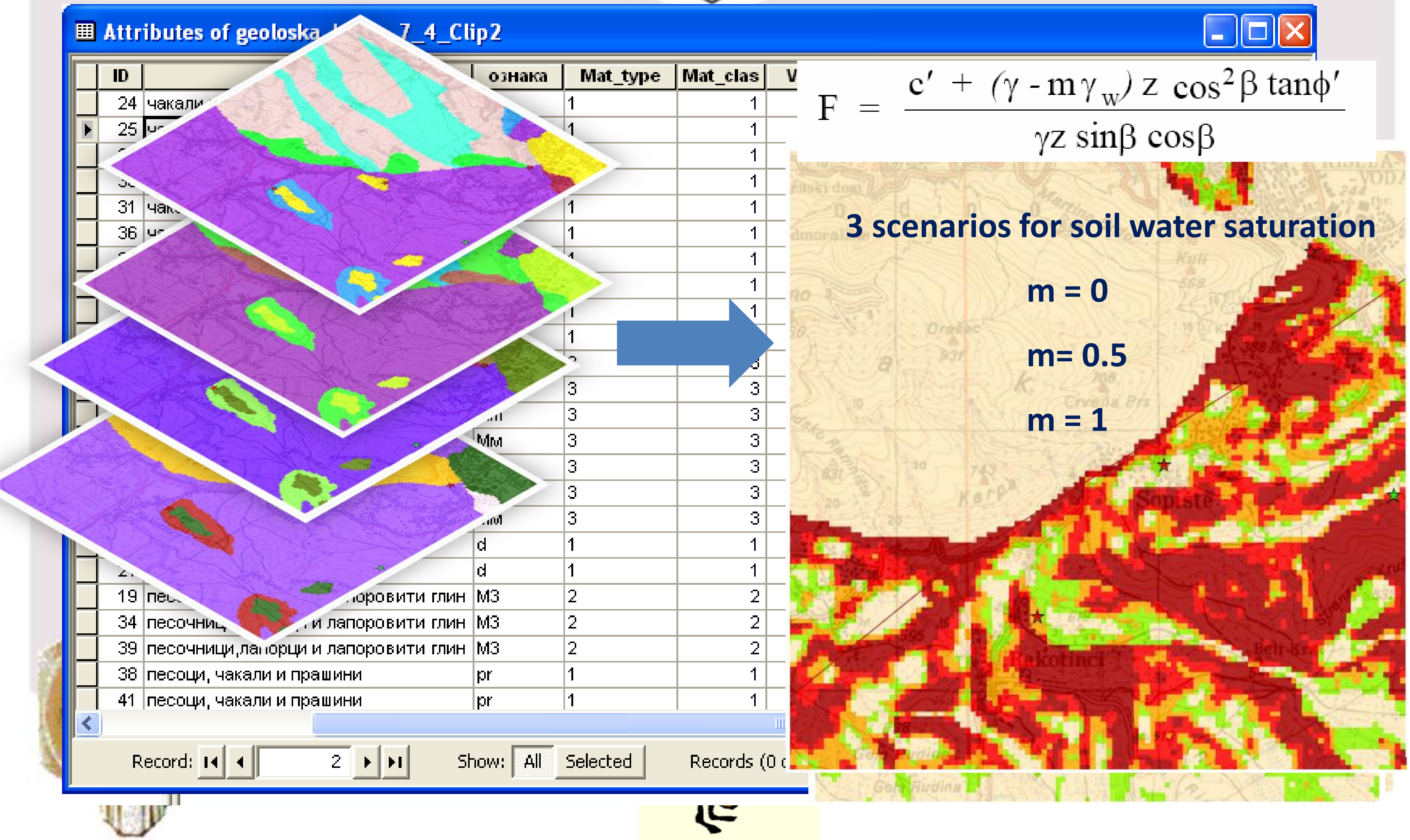
$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$



$$LogD_n = 1.521 \log I_a - 1.993 \log a_c - 1.546$$



Zonation of landslides susceptibility
- Intensive rainfall, sudden snow melt -



$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2\beta \tan\phi'}{\gamma z \sin\beta \cos\beta}$$

3 scenarios for soil water saturation

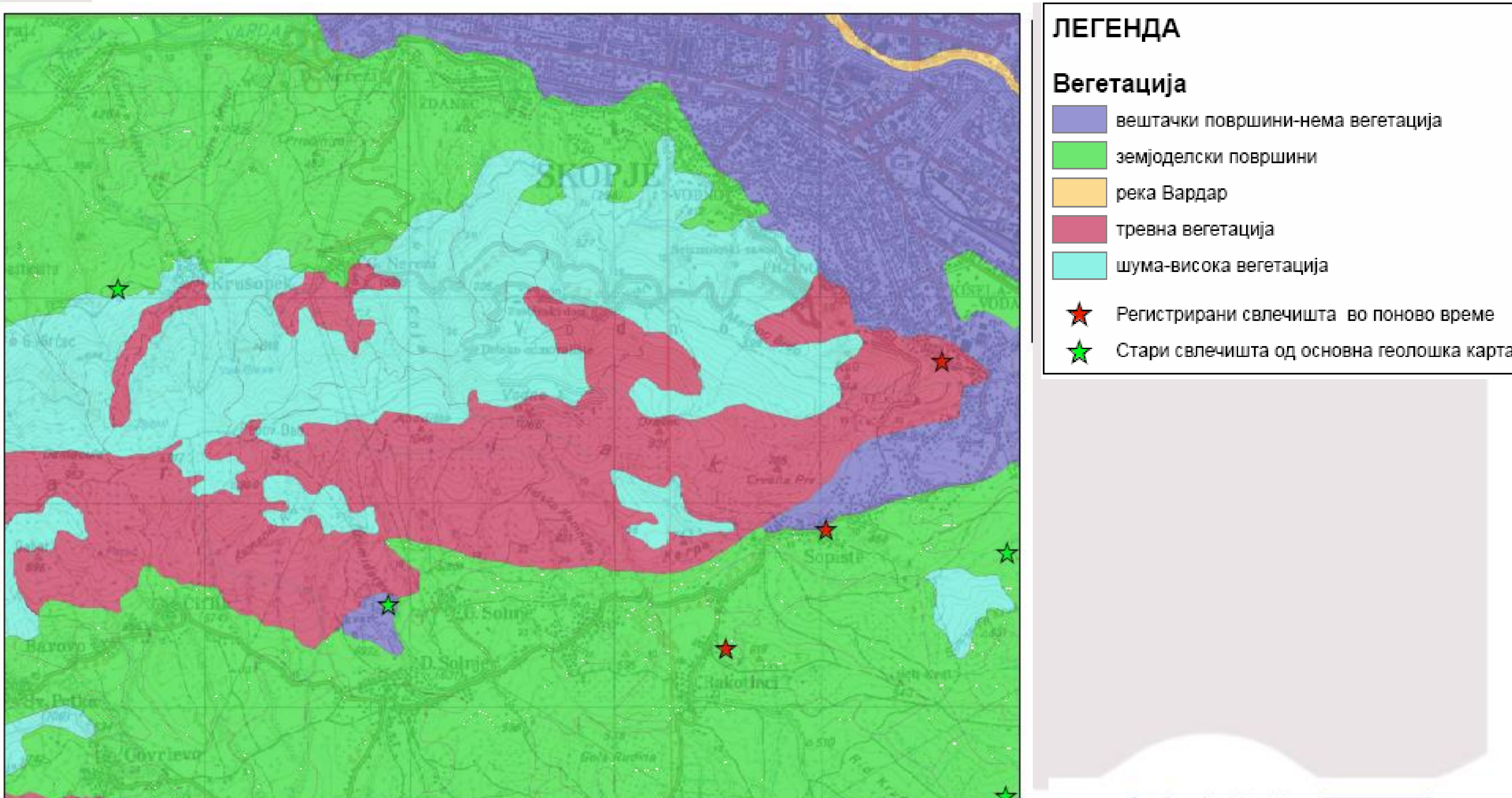
m = 0

m= 0.5

m = 1

“Open Source” geo - database

Spatial distribution of vegetation - erosion scenario – landslide susceptibility



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ASSESSMENT OF SOIL LIQUEFACTION POTENTIAL FOR SMALL TO MEDIUM SCALE EARTHQUAKES

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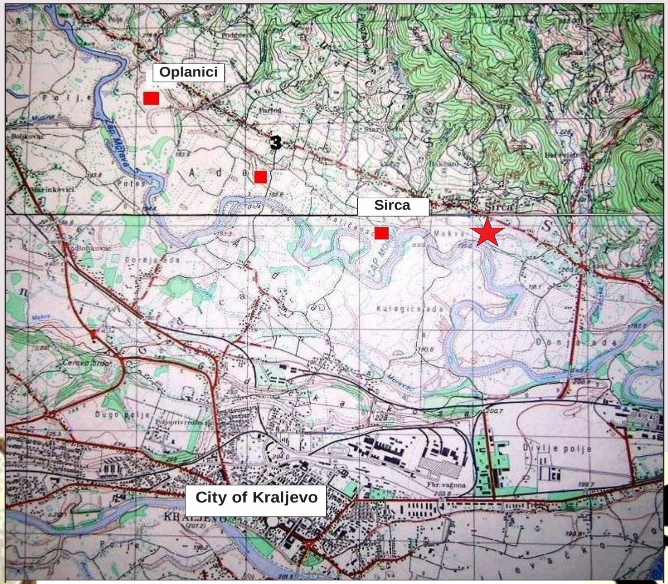
SOIL LIQUEFACTION DURING KRALJEVO 2010 EARTHQUAKE

- Moderate earthquake with M=5.4, November 3, 2010 at 01:56:55 (local time).
- Typical liquefaction manifestations like: ground cracks, sand boils, ejected sand in wells (Seismological Survey of Serbia (2010).
- Agriculture area in the vicinity of Zapadna Morava



Observed Liquefaction at epicentral area

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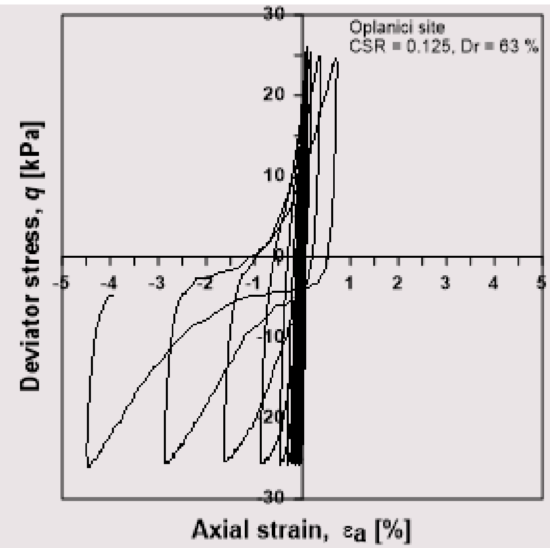
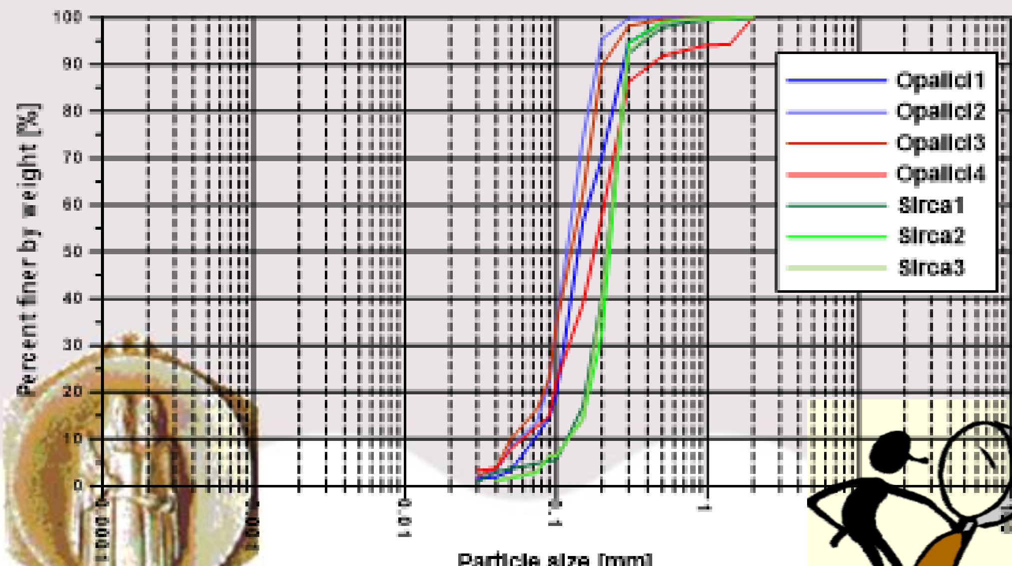
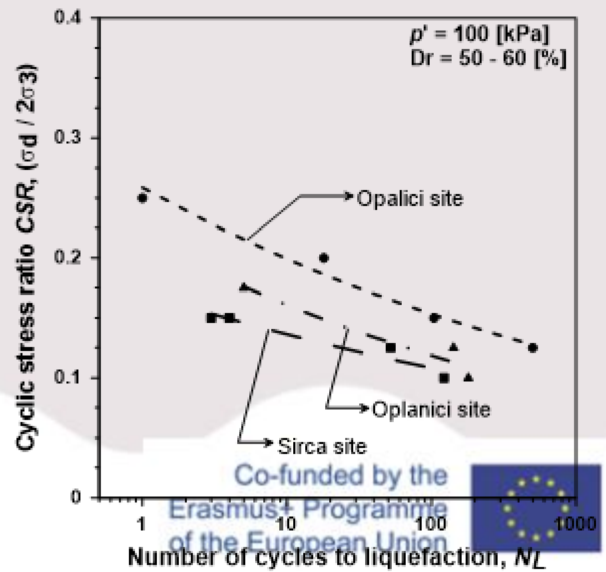
EXPERIMENTAL INVESTIGATIONS ON SOIL LIQUEFACTION DURING KRALJEVO 2010 EARTHQUAKE

- Cyclic tests performed on Cyclic Simple Shear Apparatus (CSSA) and Dynamic Triaxial Aparatus (DTA) IZIIS, Skopje, Macedonia.
- Relatively **low magnitude M=5.4** produced few cases of liquefaction without any reported direct damages to building environment
- Investigated soil samples shows **potential for liquefaction** at low-moderate level of excitation



Stress strain paths during CTUT





Grain size distribution of collected soil material

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Thank you for your attention

Хвала на пажњи

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