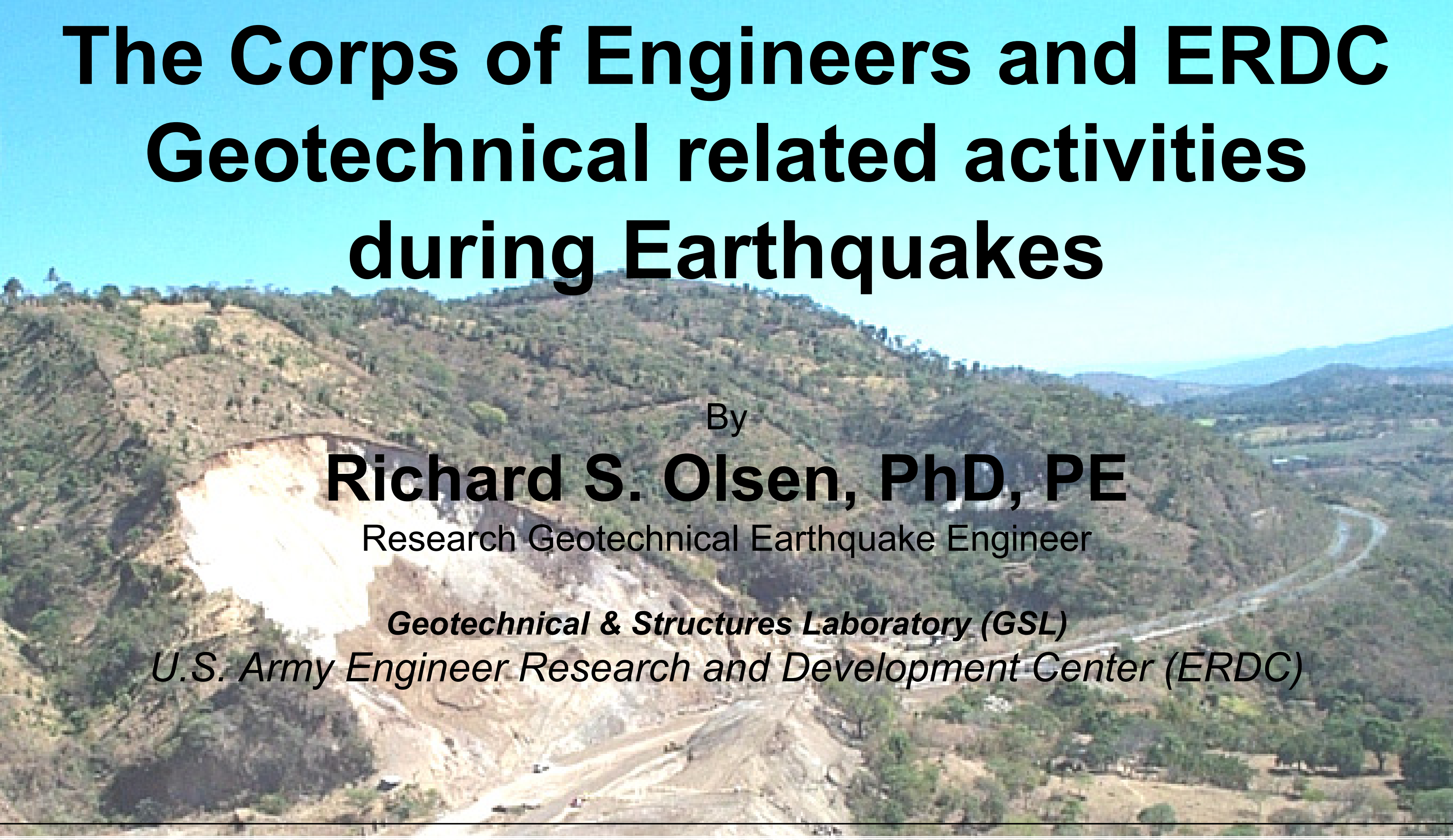
The Corps of Engineers and ERDC Geotechnical related activities during Earthquakes



By

Richard S. Olsen, PhD, PE

Research Geotechnical Earthquake Engineer

Geotechnical & Structures Laboratory (GSL)

U.S. Army Engineer Research and Development Center (ERDC)

NSF sponsored

Geotechnical Earthquake Engineering Reconnaissance (GEER)

Joint Advisory Panel and Working Group Meeting

Berkeley, CA

October 7, 2004

USACE and ERDC past work during earthquakes

- Ground Failure mechanisms evaluation
- Embassy consulting in foreign countries
- Consulting with other US federal and state agencies
- How to perform rapid evaluation

Emergency reconnaissance in general

- data sharing between federal agencies
- Not just data or reports
- Reconnaissance needed for initial field planning and field people
- Information gathering – different means of data communication
- Flow of data with no post processing

Future work

- helicopter recon project
- web based recon reporting
- Emergency data research

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Moving data during emergencies

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Information Fog *occurs*
during the initial 24 to 48 hours after major disasters (that cover large geographic area)

- ✓ Real-time information is critical
- ✓ Efficiency of field personal is critical
- ✓ Gathering data is difficult when people are injure
  (data gathering must therefore not require people input)
- ✓ New technology development is needed
  to decrease information FOG

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Why is Data flow so important?

- *Or is it information flow?*
- *Information follows data*

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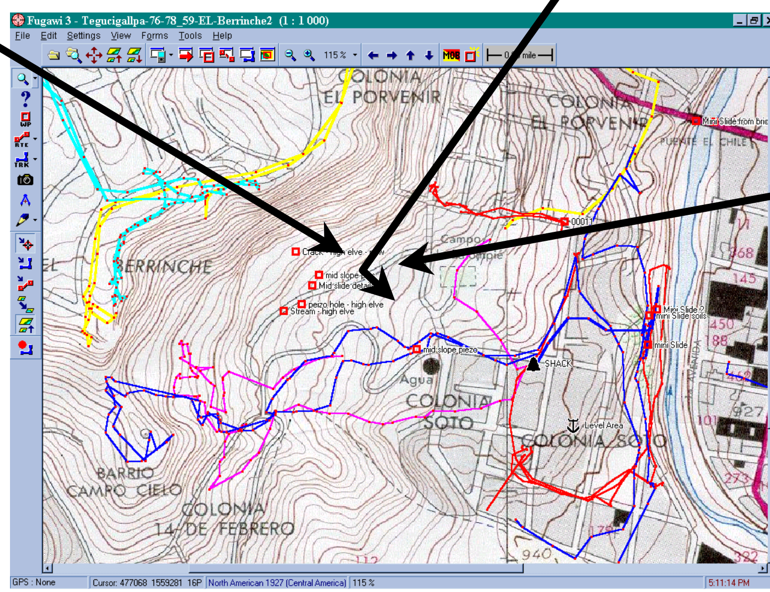
Recon System for the previous 4 years

Combining GPS and digital photos with off the shelf software

Paper note taking



Combine using Grapher and Fugawi software

This is what I use now,
a paper task card (simplified)

Data and information must flow in near real-time

- ✓ GIS systems must be updated in real-time
  (the GIS is the eyes of emergency management)
- ✓ Post processing of data is a “no no”
  (data should be collected and processed with
  as little to no human interaction)
- ✓ Using paper forms in the field is a “no no”
- ✓ Every major disaster is unique
  (plan for the need to use unique sensors and different data formats)
- ✓ Real-time data decreases the potential for data holes

TOWNS helicopter recon project

Dr. Richard Olsen
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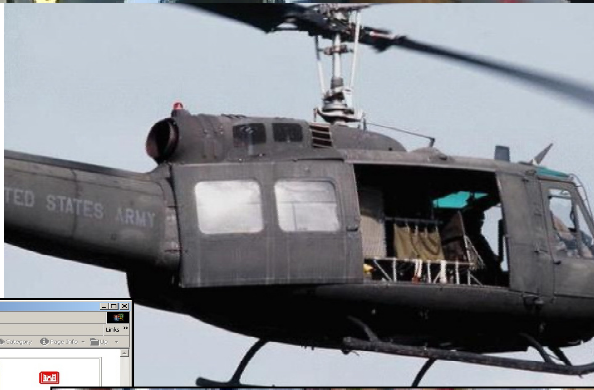
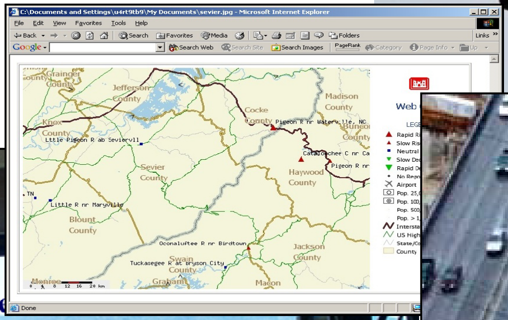
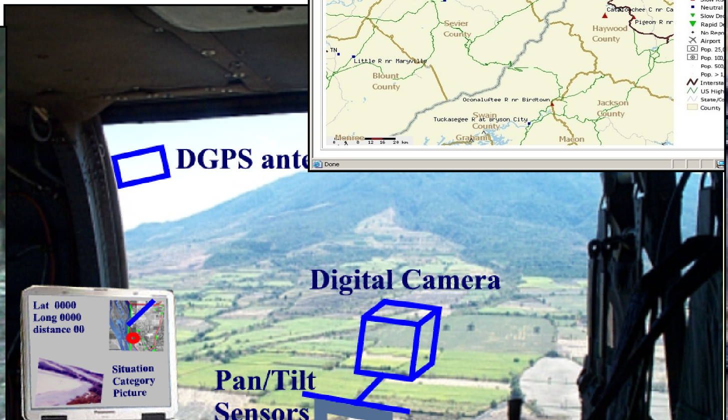
US Army Engineer Research and Development Center (ERDC)

Research Project: Real-time information retrieval from Helicopters during emergencies

Emergency Managers need fresh real-time information to keep GIS updated in order to make good command decisions







Real-time information is needed during emergencies

What is needed?

1) Lots of information (inside the total disaster area)
2) Good descriptions based on good observations
2) Observations backed up with photo images
3) Timely information; Get the info and drop it into GIS within hours

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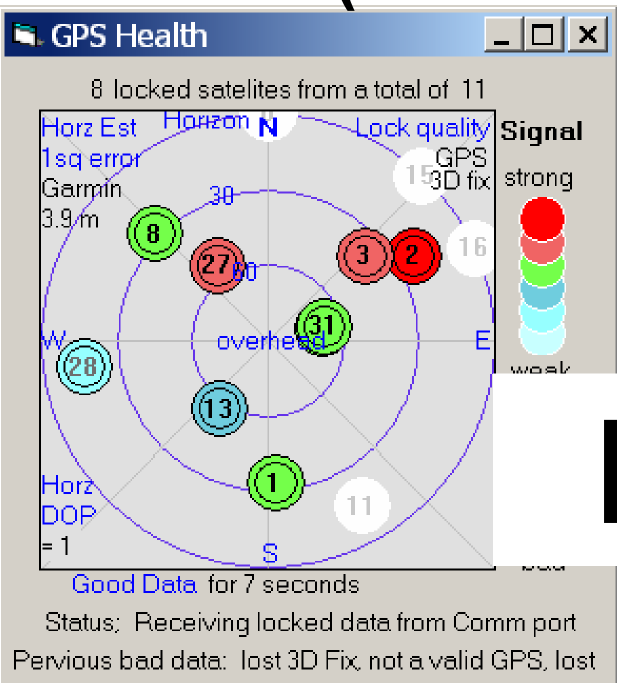
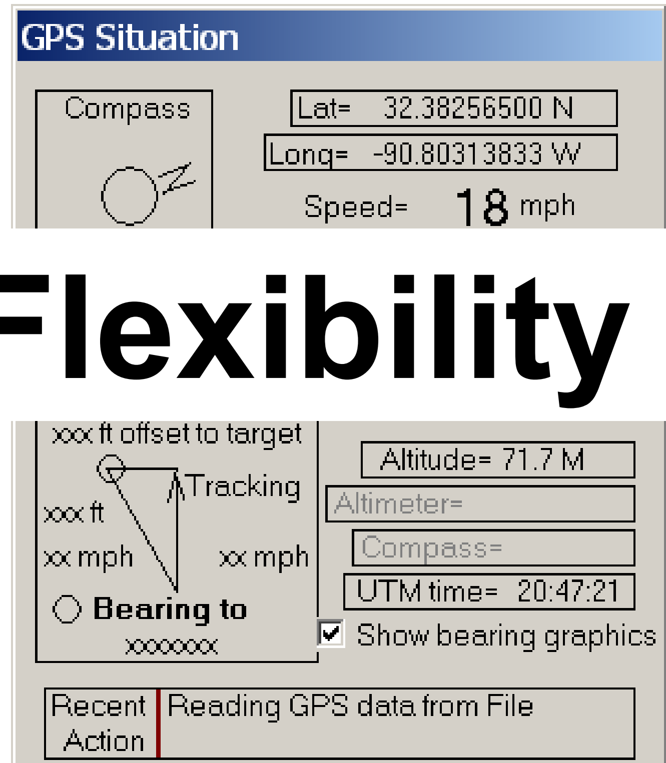
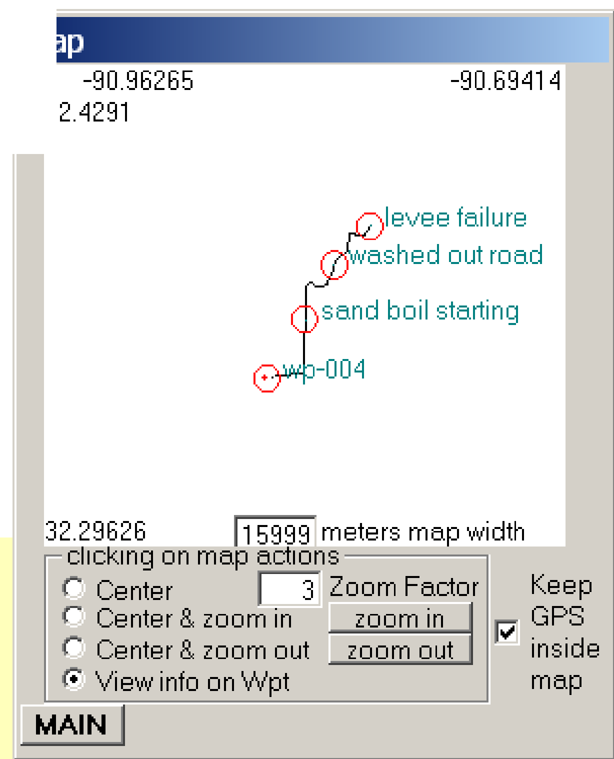
ERDC developed custom software for GPS satellite health and location gathering (Pocket PC and portable computer)





Flexibility



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Hardware Parts

Hardware Parts and software interface

Tilt and bearing measurements

Pan tilt magnetic bearing

GPS devices

Laser distance device (vertical height)

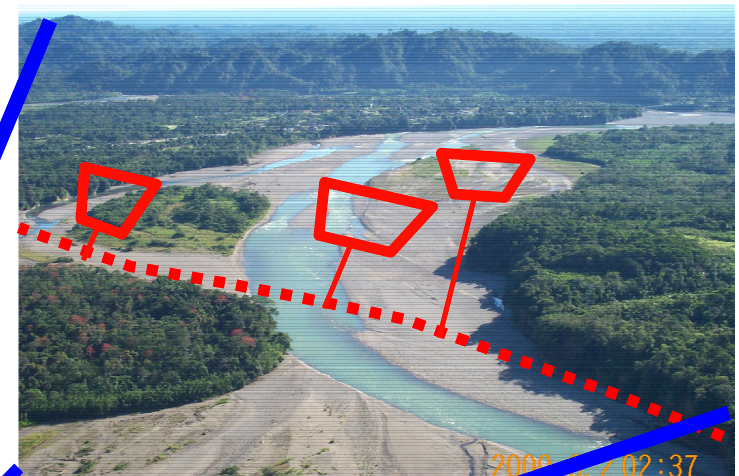
Digital Cameras;

high speed real-time images and
high resolution pictures

Eye viewable VGA screen

monitor

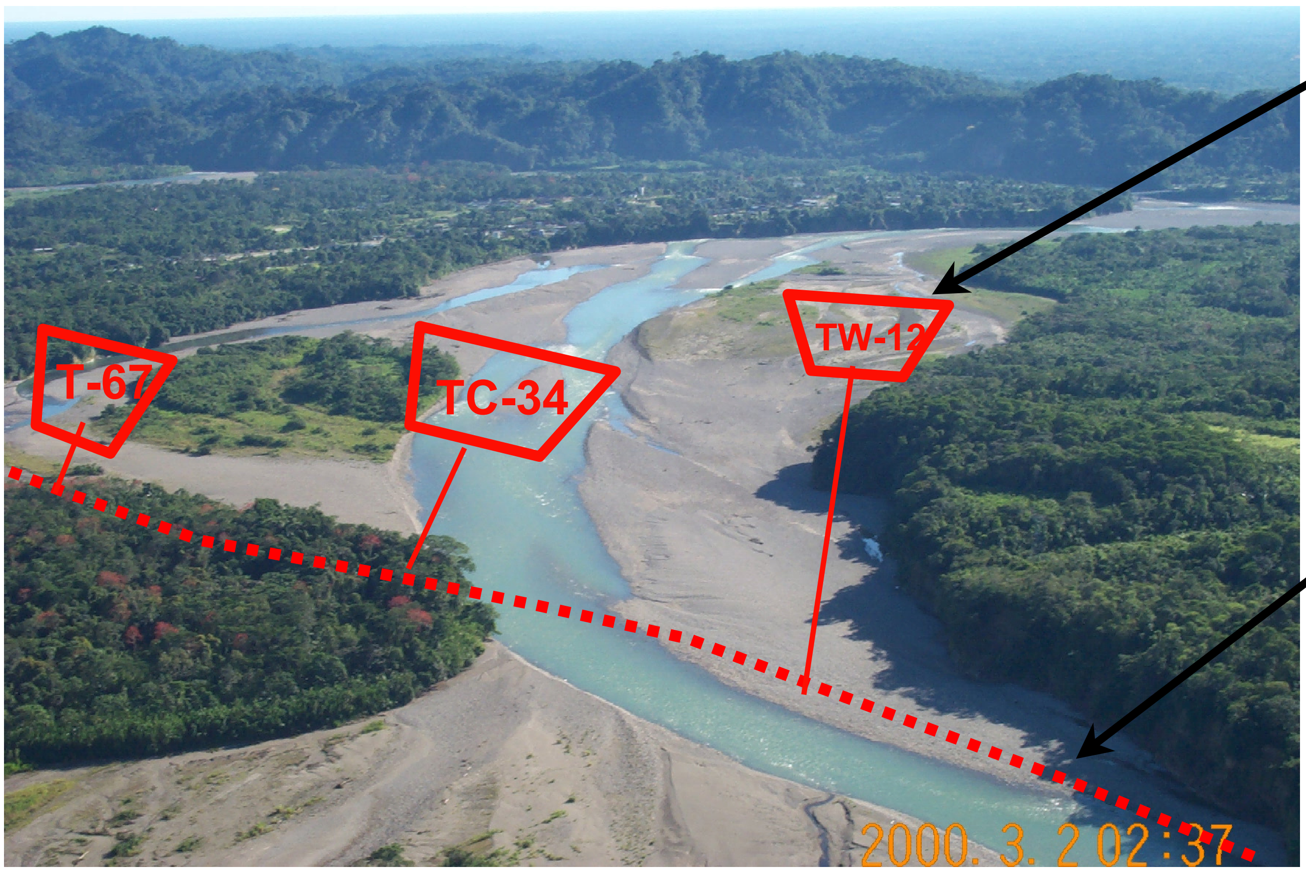
State-of-the-art off the shelf VGA display



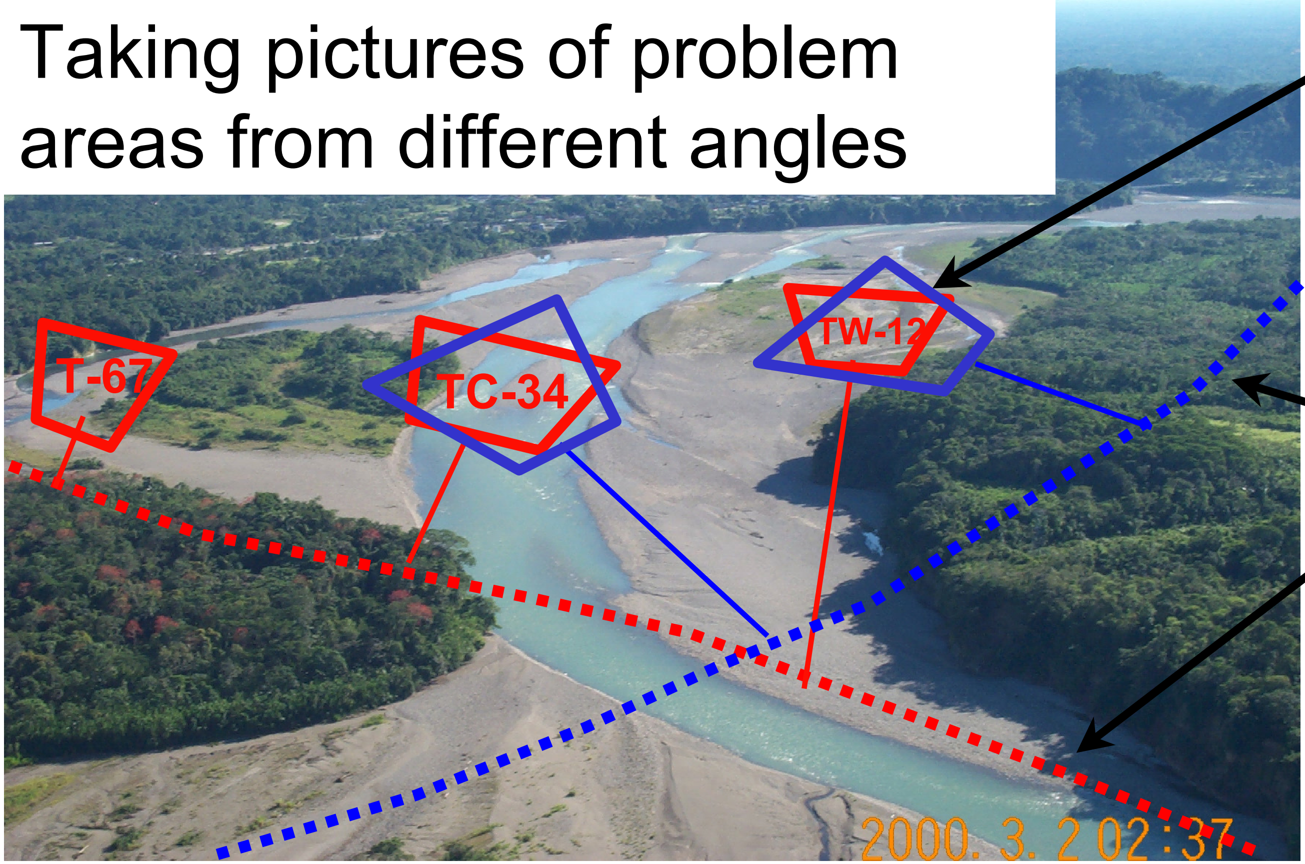
Sony VT-500Camera

Real-time Image Processing

A real-time display of
camera images and a database problem areas



Taking pictures of problem areas from different angles



Previous camera image foot prints

Another helicopter path

Previous helicopter path

Real-time camera image

Past efforts

The best time to capture critical details of a landslide or ground failure is “immediately” after the failure.

If you don’t know what to look for, you will miss it.

(walk everywhere, look for reactions & behaviors, and know how to interview people)

Pictures are only good if you know what to look at.

(Don’t expect pictures taken by “others” to show important details)

Know how to take pictures that can explain the total story.

(not all pictures are equal to a 1000 words – getting good pictures is an art form)

You must be able to explain all actions of a slide mass.

(visualize the movement and reaction of the landslide to where you see it today)

Take preliminary survey measurements during the first visit

(The slide might move again before a high level survey is performed)

Field test the soil strength of exposed soils during the first visit

(exposed soils of a landslide are a rare opportunity that should not be missed)

Landslides are not as simple as we learn at school

The larger the slide mass the more complex the behavior

- Triggering mechanism (for large landslides) is generally the big issue
  (triggering will decrease the apparent stability FS to below one)
- High generated pore pressures can be very important
  (pore pressures can be extremely high at the toe)
- The shape of a landslide mass will affect how it moves
- Cracks can be an indicator only of modulus difference
  (bulging and displacements are generally more important)
- Large landslides generally moves in segments and with time lags
  (Small landslides in homogenous material fail predictably)
- Man-caused changes to a hillside generally decreases stability
- Small details can lead to big discoveries
- Toe stability becomes more important as the slide mass increases
- Hillside geometry can concentrate seepage & cause high pore pressures

etc

Triggering Events

Large landslides are normally **triggered as a result of localized events**, such as small landslides at the toe of the hillside.

Cultural changes to a hillside within developed areas (especially marginally developed areas) **can act as the triggering event**. Minor changes to a hillside can influence local stability.

These changes can be: streambed changes, changes to vegetation load (and type), broken lined drainage ditches, malfunctioning of underground water/sewer/drainage pipes, diverted surface runoff, cleaning/repairs to infrastructure, ignoring recommendations, etc.

Actions (and sometimes multiple actions) will lower the slope stability until failure occurs.

A slope will show physical changes before a landslide occurs. These surface physical changes are in addition to measured pore pressures and inclinometer measurements (if they were placed in the correct location). Each slope is unique and it's difficult to specify generalizations about indicators to look for.

Field Observations

- The best time to capture critical details about a landslide is "**immediately**" after the failure. Minor details can lead to big discoveries and provide the only clues about the landslide triggering mechanism.

- This type of fieldwork is not about collecting data. It's about **looking for answers** and collecting support data.

- **Observe the landslide from all sides** and inside the landslide area (if possible) in order to look for reactions and behavior. Revisit the site within 24 hours to get a second perspective.

- Do not focusing your attention on **tension cracks** at the top of a hillside, they will not lead you to the landslide triggering mechanism. These cracks are normally the last part of a total slip surface to move.

- **Examine exposed landslide segments** inside a landslide mass for sandy layers because elevated pore pressures are always important.

Pictures tell a 1,000,000 words
BUT only if done properly

- ✓ *Picture attachments to E-mails is a "no-no"*
- ✓ *Photos without orientation are also a "no no"*
  (orientation can be maps or an annotated overall photo)
- ✓ *Web based photos (and descriptions) can be generated in minutes – Just do it*
- ✓ *Development is now underway to help*

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US Army Engineer Research and Development Center (ERDC)

How important are cracks?

- Cracks are not the most important factor.
- Cracks are like the “wagging tail of a dog,”
- Cracks don’t point to failure mode – they are only the resultant.

1964 Good Friday Alaska earthquake – massive sliding into the Bay

San Salvador Landslide Recons (2001 Feb)

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

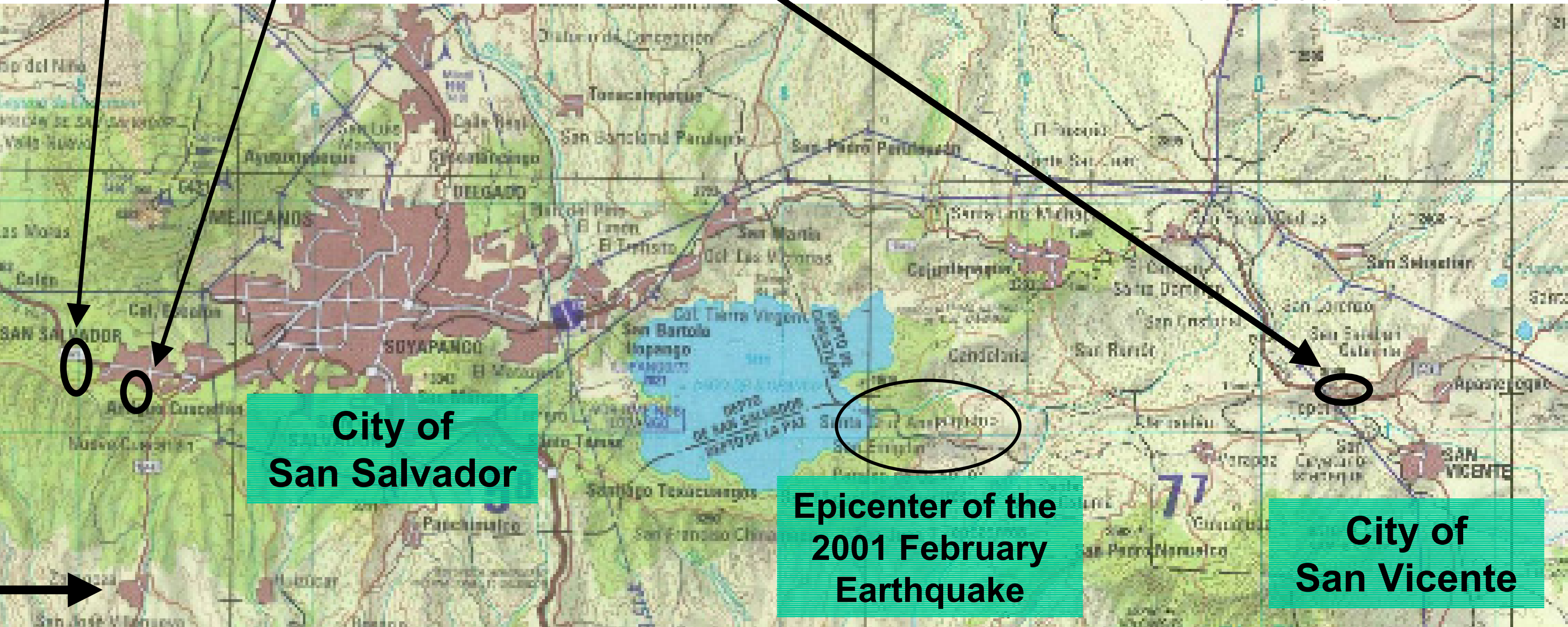
Landslide Recons
2001 El Salvador Earthquake

Los Chorros
"Chute" Landslide

Santa Tecla
"Destructive"
Landslide

San Vicente
"Massive" Landslide

Dr. Richard S Olsen   ERDC



Landslide observations along the Pan American highway

UTM NAD27
249952 1513054

The "chute" landslide

Traveled at 50 mph plus – several deaths

Closed Pan American highway for a week

The main landslide was triggered because of a 20 year old dirt road. The initial failure jumped the road and started the debris chute slide.
Was NOT an easy answer to Find

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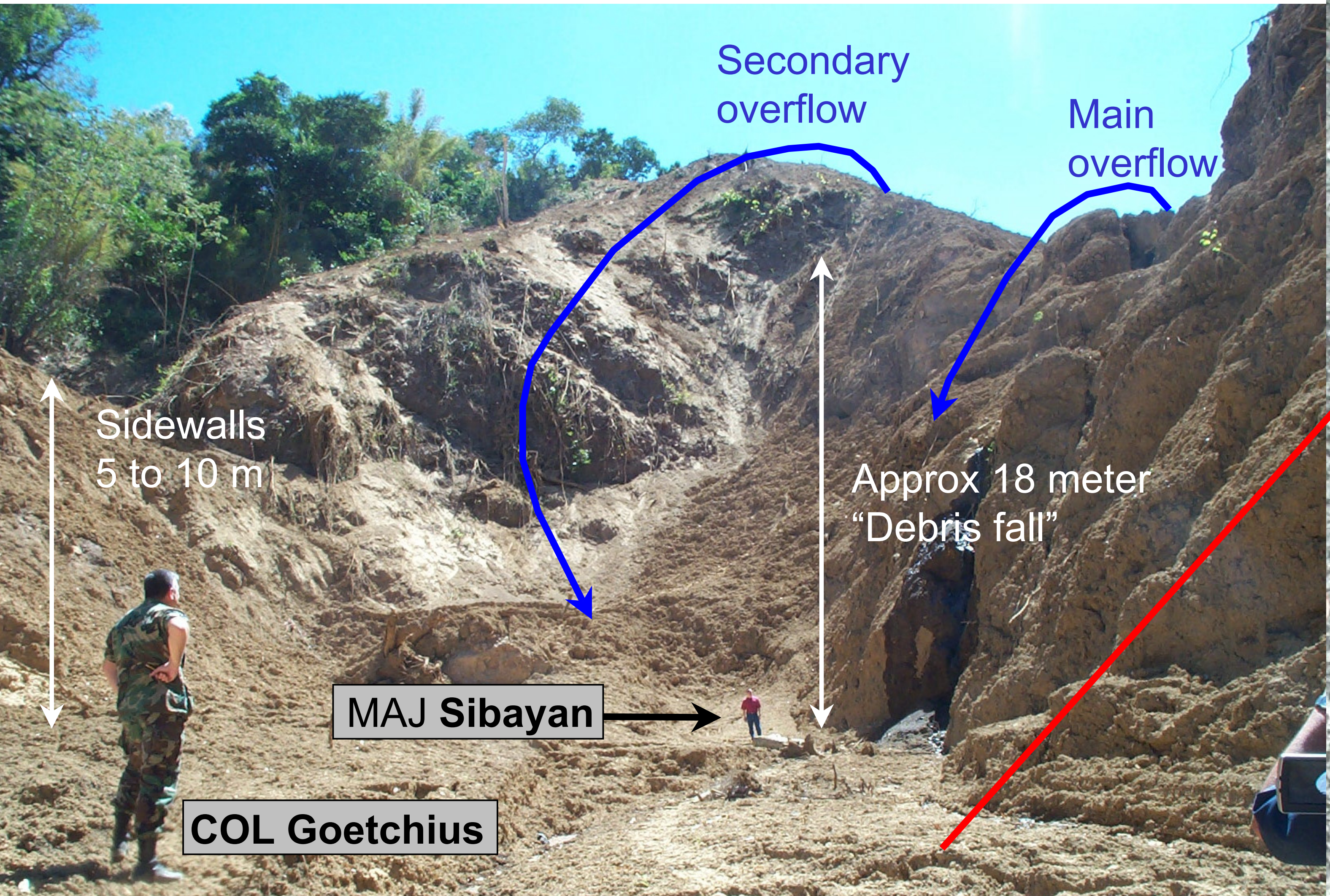
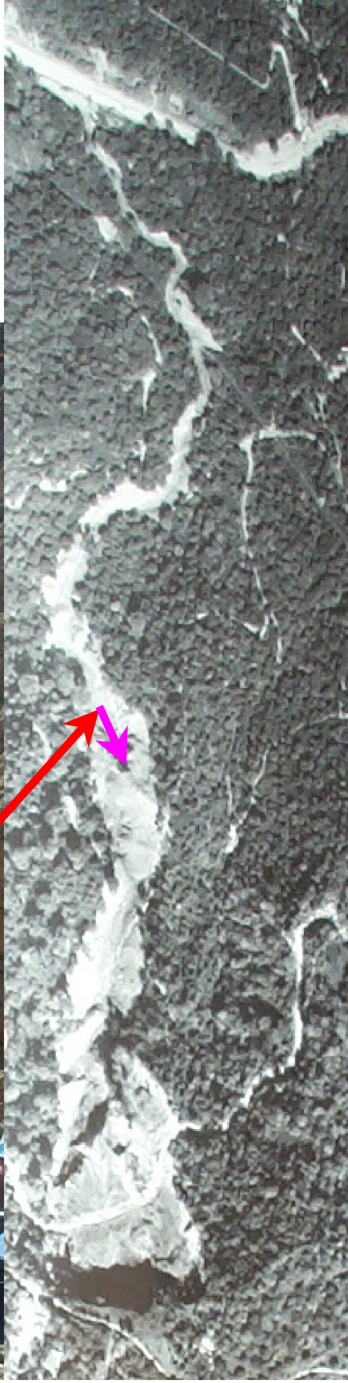
OlsenR@WES.Army.mil

Landslide observations along the Pan American highway

UTM NAD27 250028 1512355

The “chute” Landslide





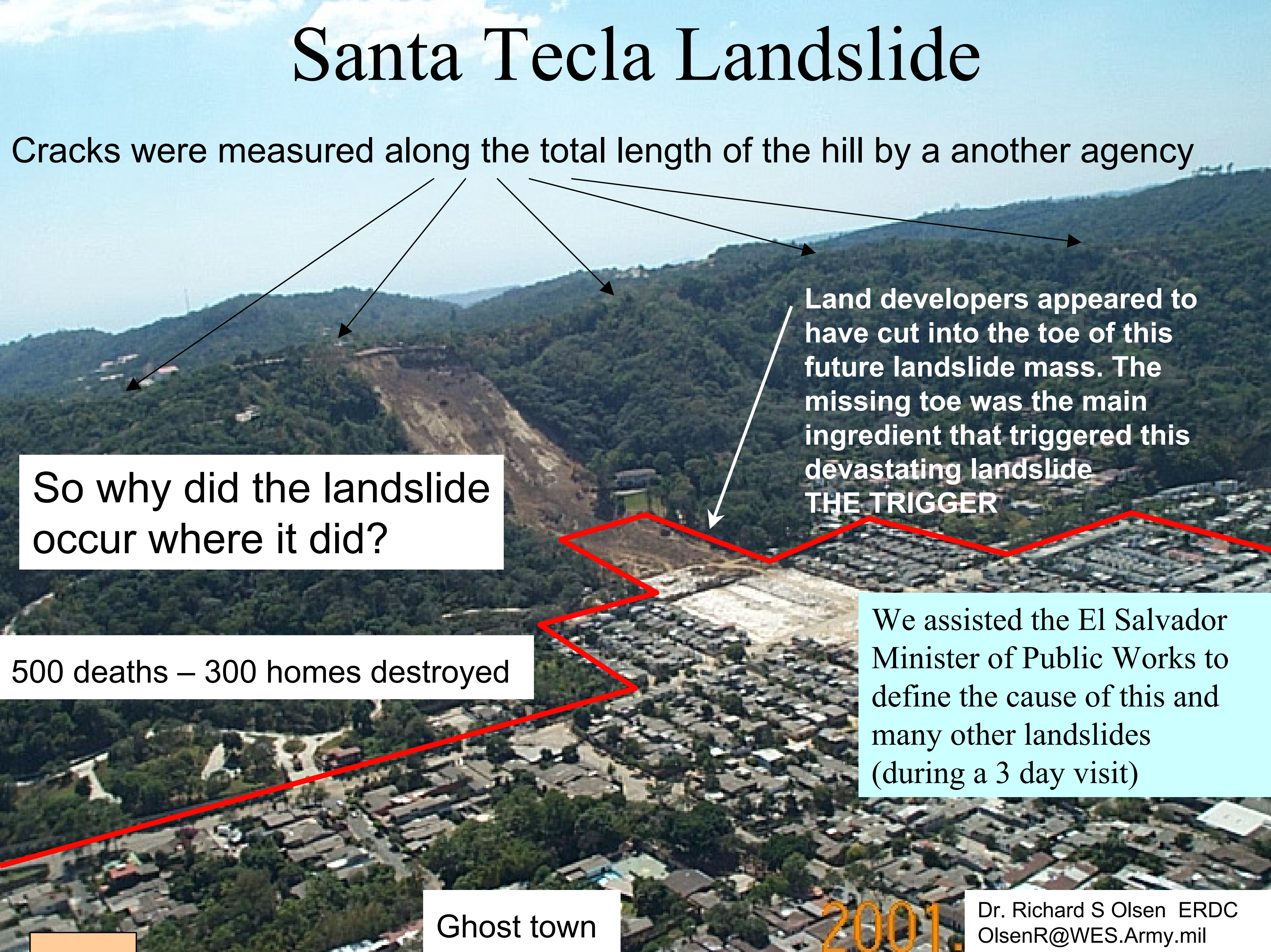
Los Chorros "Chute" Landslide

The headwall

Pre Slide shape

Road cut (40 years ago) removed the toe from the future landslide

The landslide, triggered by the earthquake "jumped" the road


Santa Tecla Landslide
Cracks were measured along the total length of the hill by a another agency
Land developers appeared to have cut into the toe of this future landslide mass. The missing toe was the main ingredient that triggered this devastating landslide
THE TRIGGER
So why did the landslide occur where it did?
500 deaths – 300 homes destroyed
We assisted the El Salvador Minister of Public Works to define the cause of this and many other landslides (during a 3 day visit)
Ghost town
2001.
Dr. Richard S Olsen ERDC
OlsenR@WES.Army.mil

The San Vicente Landslide

Recommendations to decrease the risk of short-term future landslides - San Vicente Landslide site

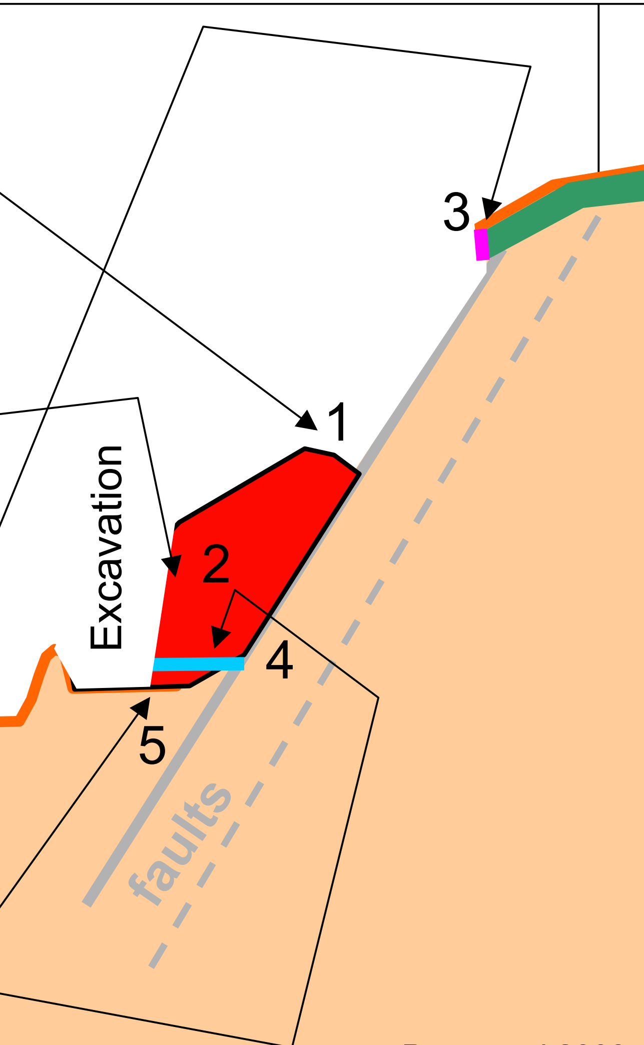
1) Recontour the soil at the top of the landslide mass next to the fault slope to reduce rainfall infiltration. Install a surface drainage system to reduce the potential for rain water seepage into the landslide mass.

2) Dramatically reduce the slope angle of the cut into the landslide mass next to the highway because of potential instability during the rainy season

3) Remove the residual soil escarpment at the top of the exposed fault. This can be accomplished by explosives from shallow holes.

4) Drill horizontal holes from the highway into the landslide mass and intersect the fault. This will provide pore pressure relief of generated pore pressures at the toe of a potential landslide.

5) Provide an area next to the landslide to contain any future small landslide movement.



Presented 2003
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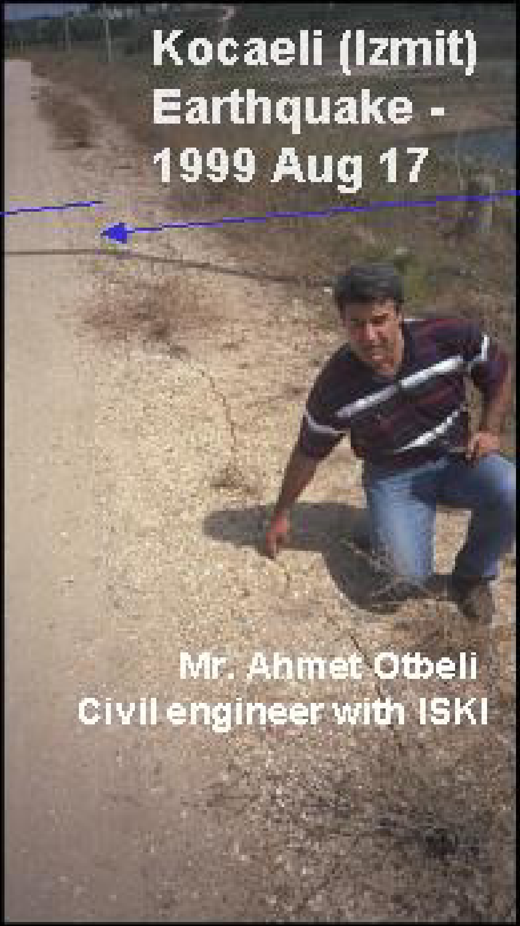
EQ recon in Turkey

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

N40.598 E29.204 Near the City of Yalova, Turkey



A single 9 mm wide crack the length of the dam was observed on the upstream side of the crest gravel road. The upstream side of this crack was 2 mm lower than the downstream side.

Gokce Dam, 30m earth/rock dam - views from the gravel crest road

What does the observed crack at Gokce Dam represent?

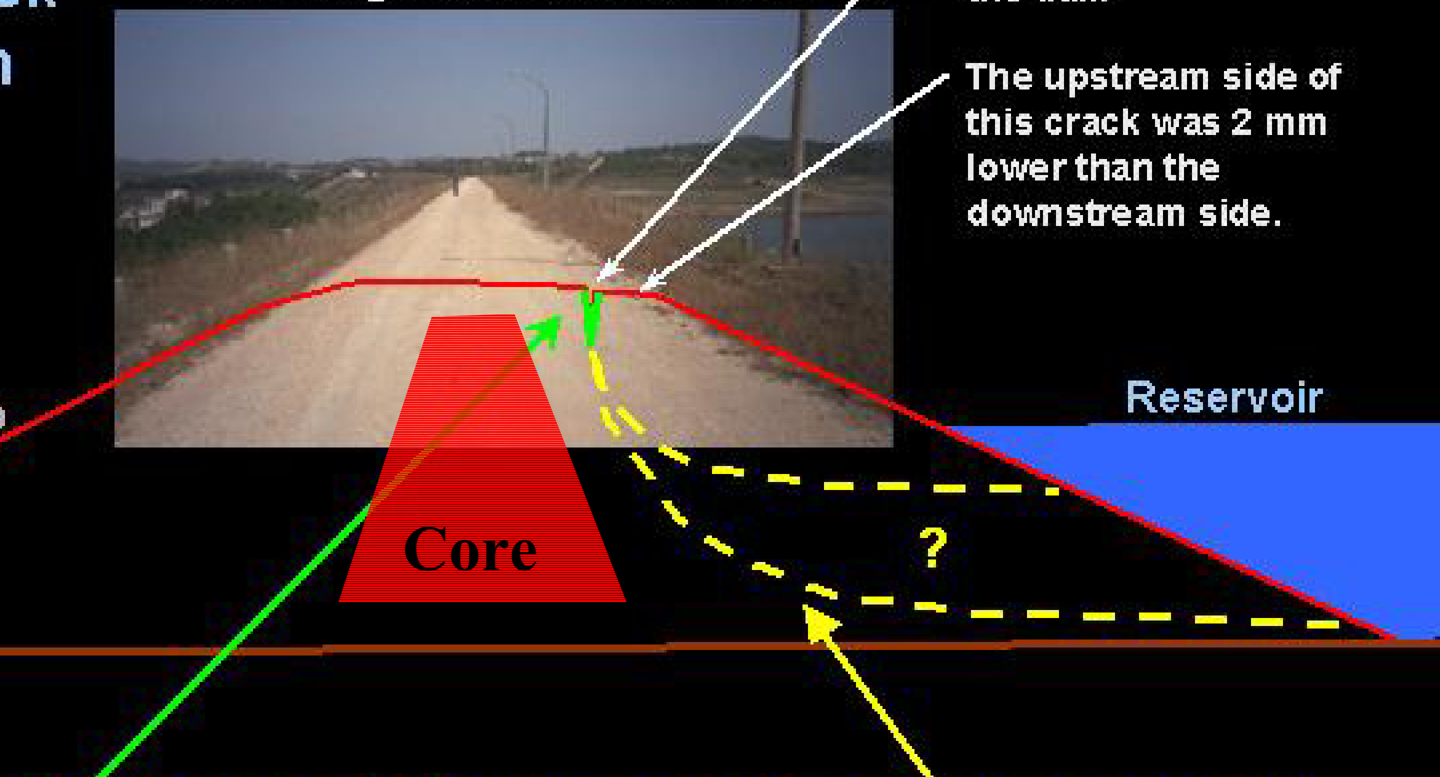
Izmit Earthquake
August 17 1999

Richard S. Olsen, PhD
ERDC-WES
www.liquefaction.com/eq99

Gokce Dam
30m high earth/rock dam

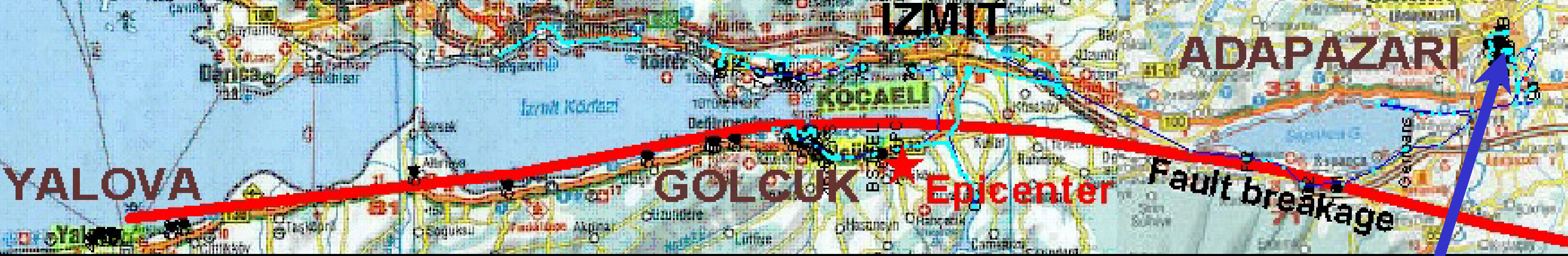
A single 9 mm wide crack the length of the dam

The upstream side of this crack was 2 mm lower than the downstream side.



A 7mm wide crack (and 2mm drop) over a potential 150 m slip length represents 0.005% slippage. This dam experienced minor elastic based movement to reestablish the static strength – excellent performance.

This type of crack and crack width should be expected for a magnitude 7+ earthquake event because a stiffer compacted dam is bad for many other reasons.



Silt liquefaction caused bearing failure
(no liquefaction boils were observed)

N40.775 **E**30.4045
City of Adapazari, Turkey

EQ recon in Taiwan

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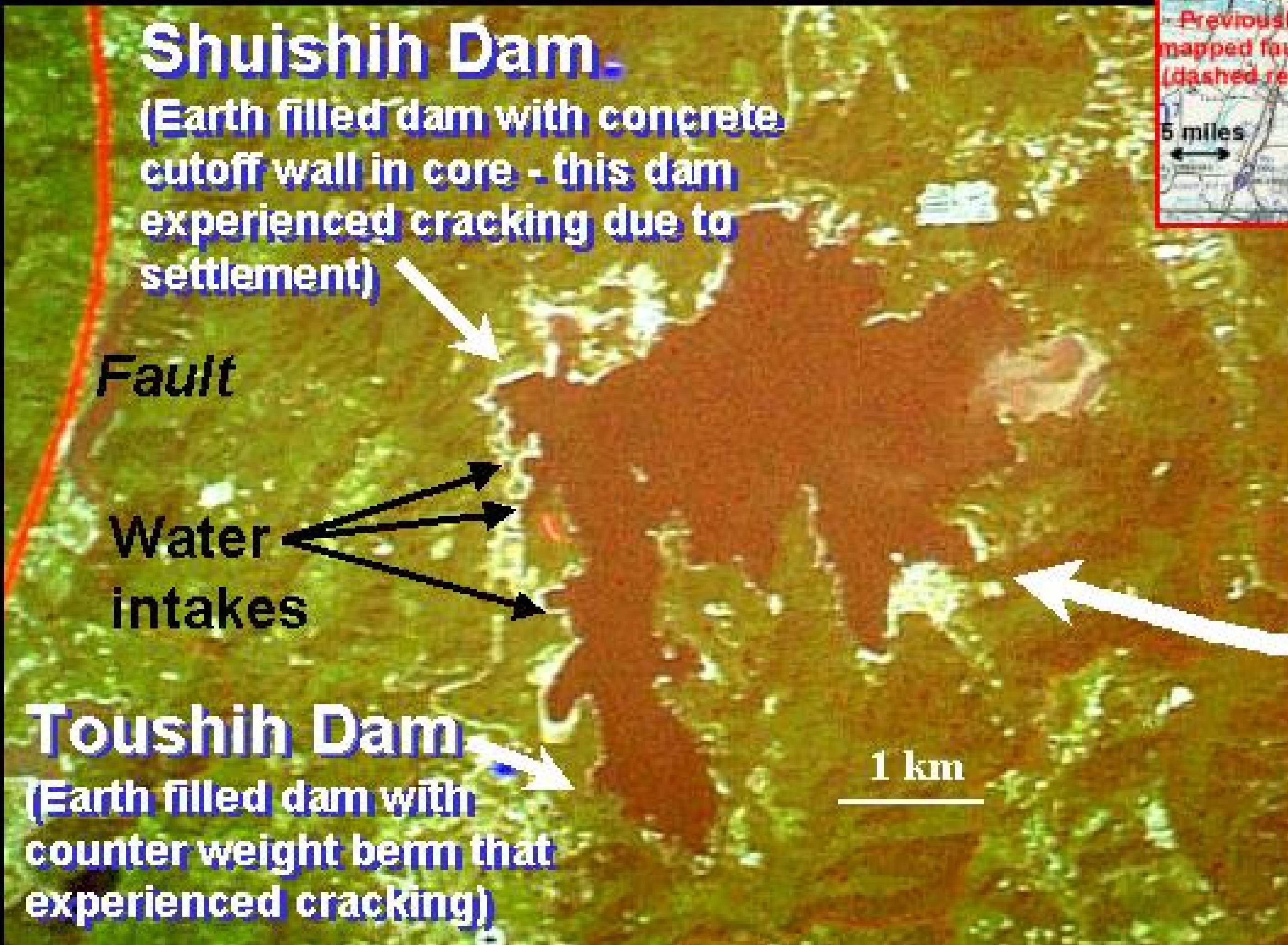
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

Sun Moon Reservoir

This reservoir is the
major water supply for Taichung



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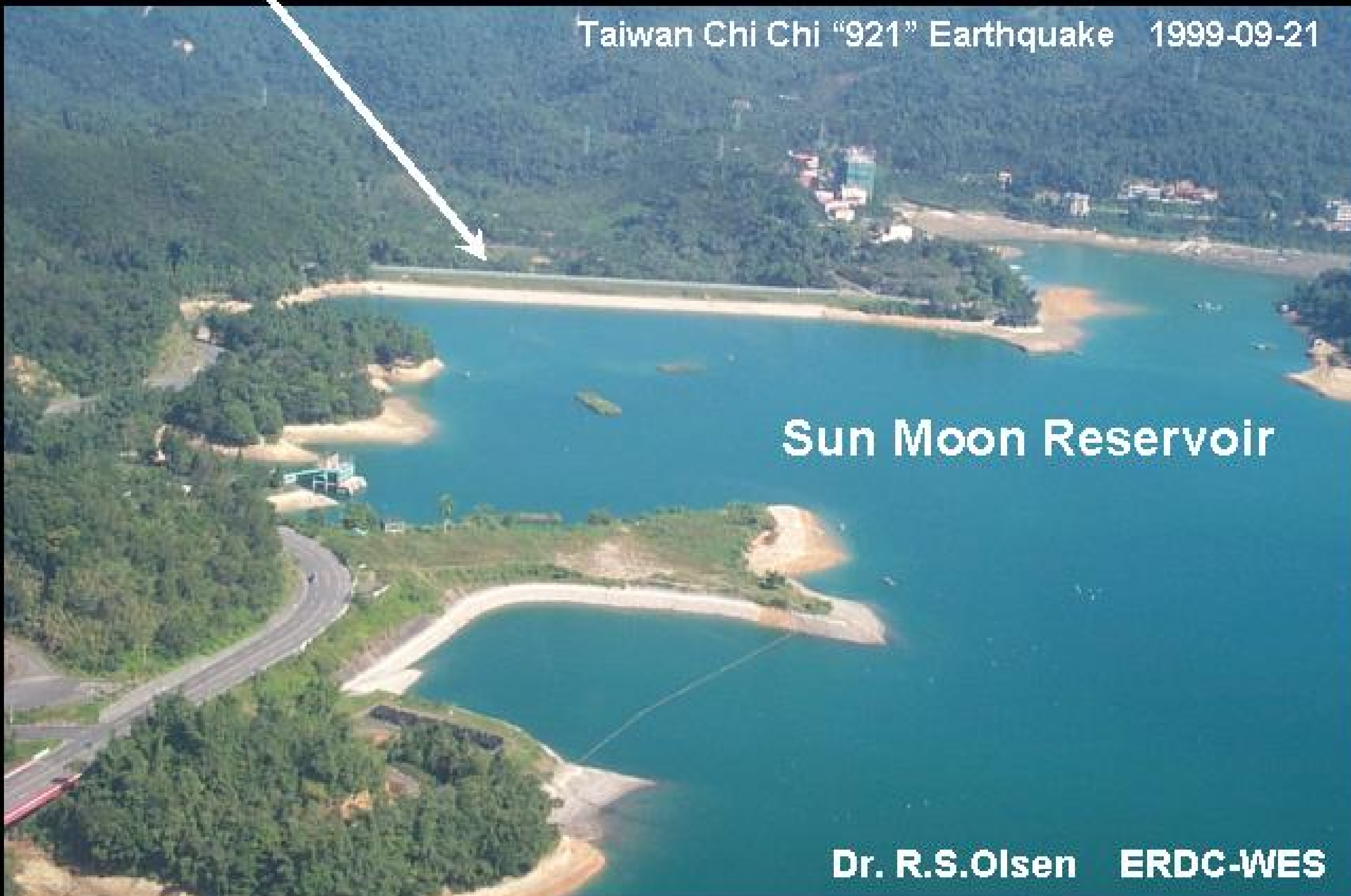
ERDC- WES

Taiwan Chi Chi
Earthquake 1999-9-21

Shuishih Dam

Earth dam on a rock foundation with a concrete wall in the core

Built in 1934 by the Japanese

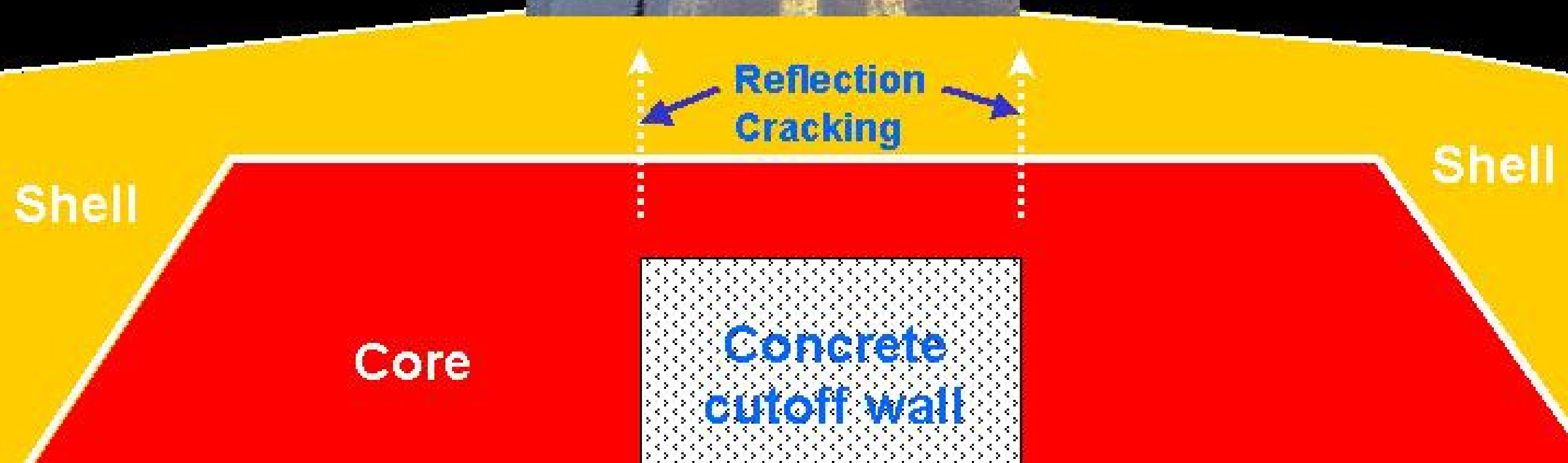


Shuishih Dam

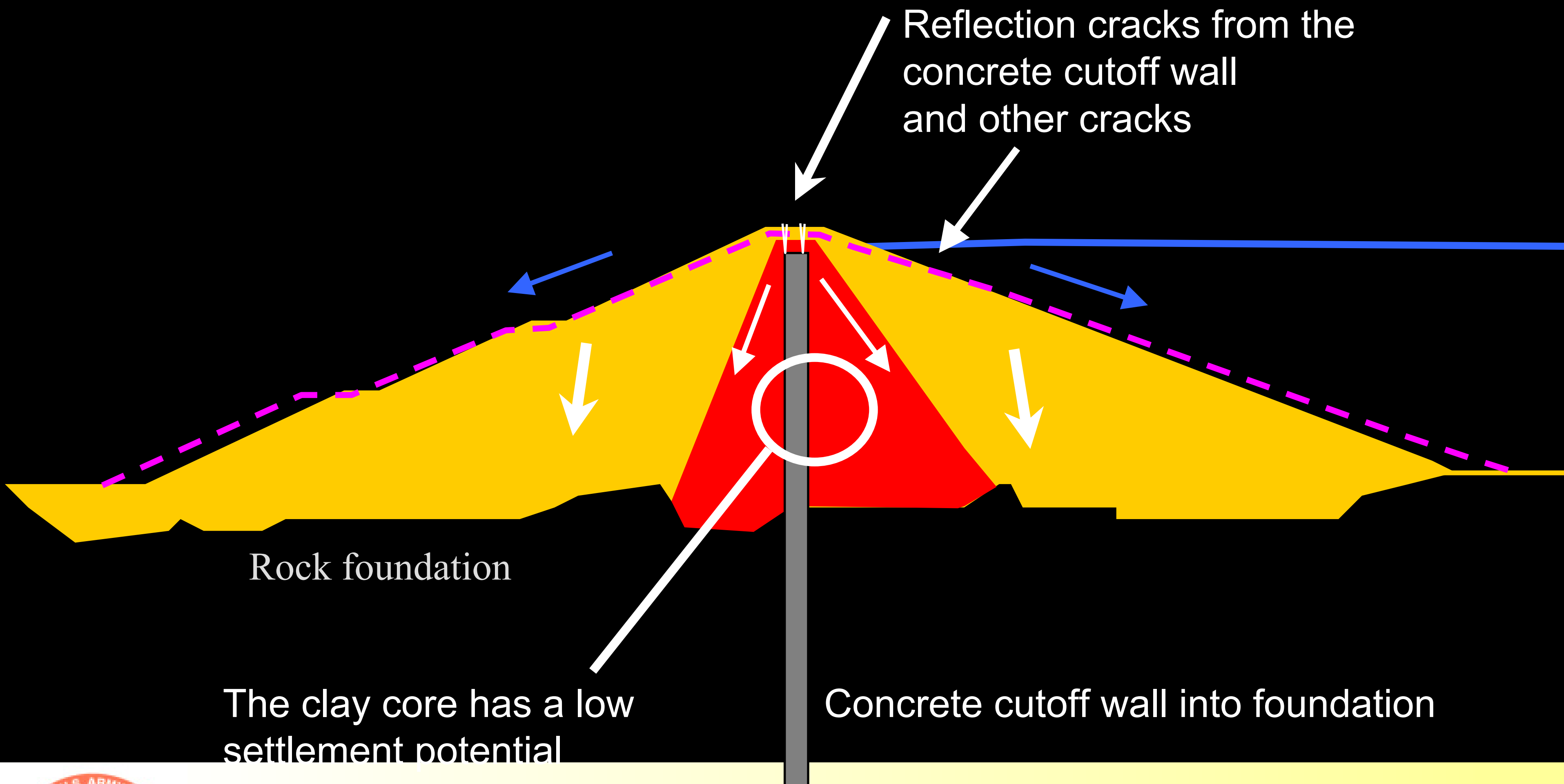
Taiwan Chi Chi
"921" Earthquake
1999-09-21

Dr. R.S.Olsen - ERDC

Shuishin dam, build in 1934, experienced 30 cm of settlement within the shell during the Chi Chi earthquake. This shell settlement caused the shell to move away from the concrete cutoff wall resulting in reflection cracks, as shown.



Shuishih Dam – Sun Moon Reservoir
What causes the settlement and cracks?



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Taiwan Chi Chi "921" Earthquake 1999-09-21

Tsao-Ling landslide dam

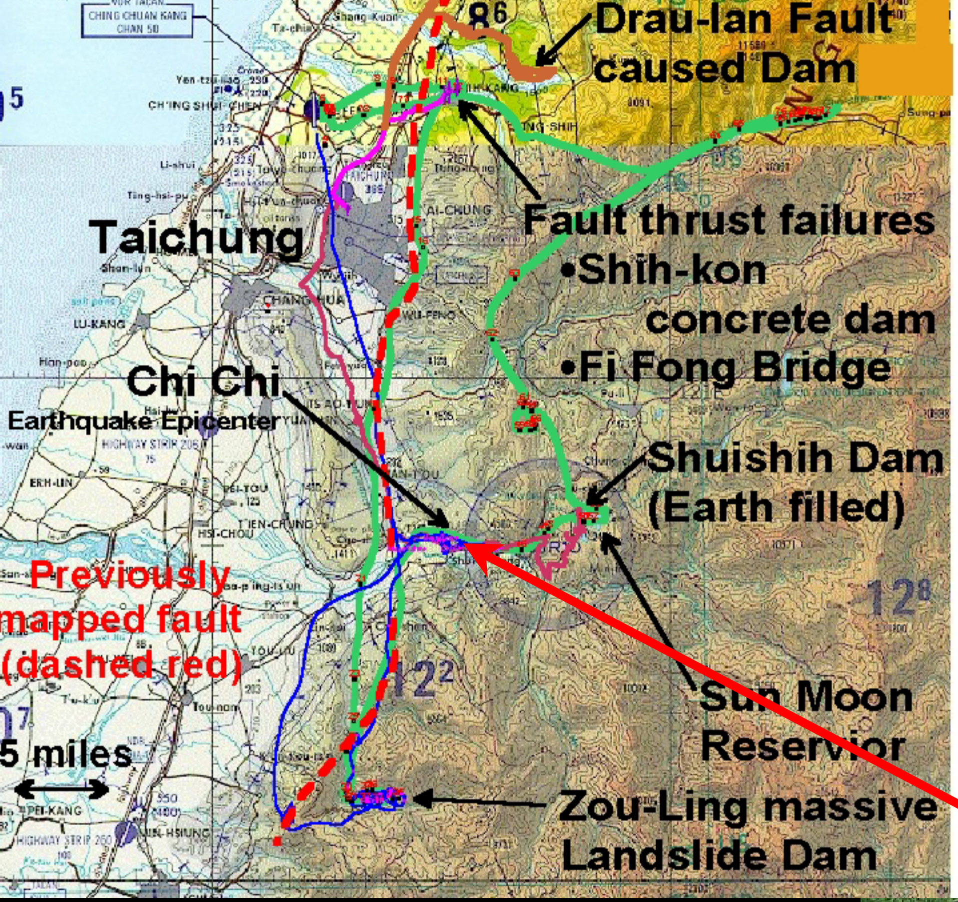
Taiwan Chi Chi "921" earthquake

Dr. R.S.Olsen
ERDC-WES

Liquefaction observations in Taiwan

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

Ground Liquefaction Observations



Taiwan Army base near the town of Chi Chi

Liquefaction and lateral spreading were observed

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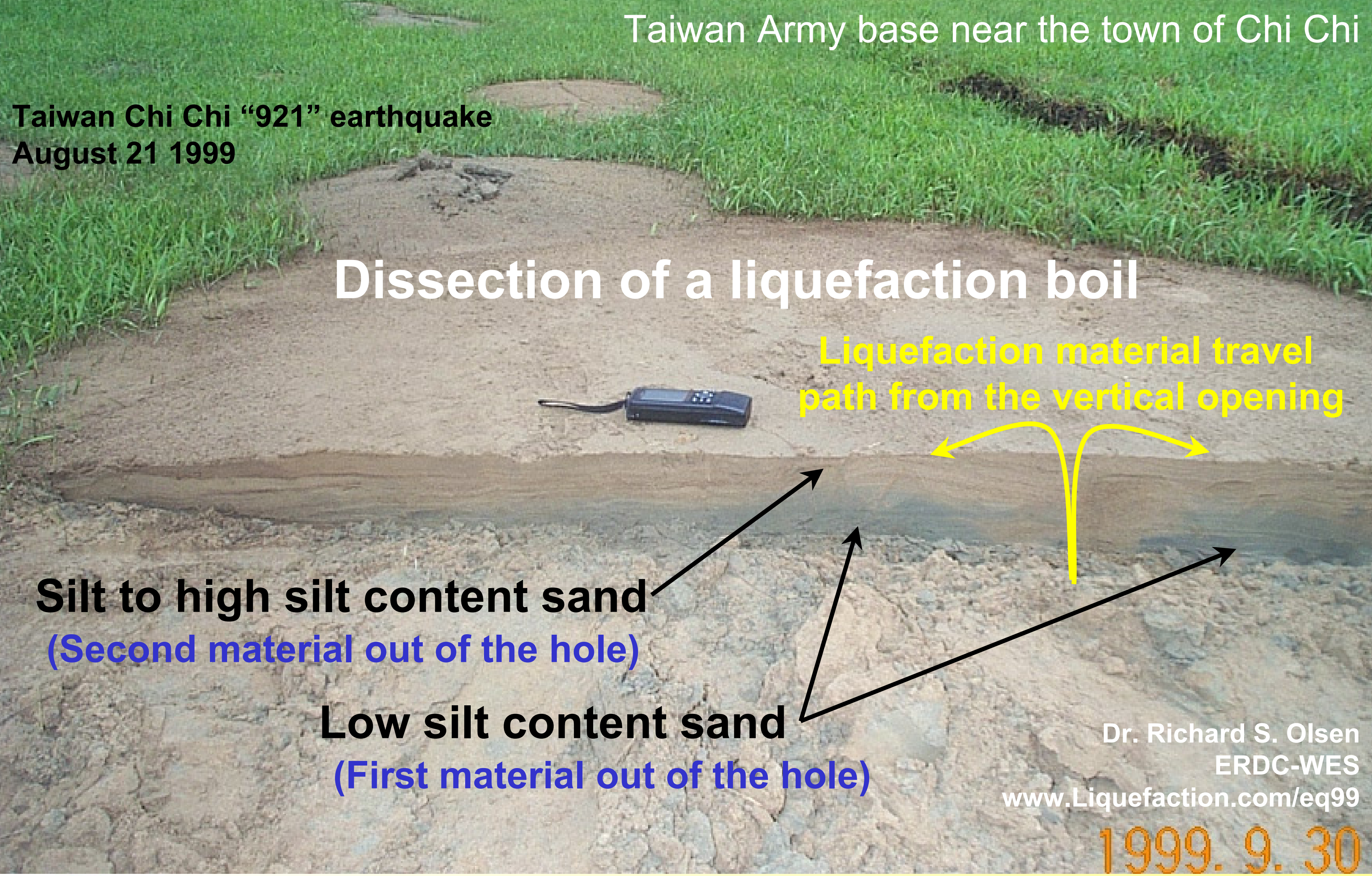
US Army Engineer Research and Development Center (ERDC)



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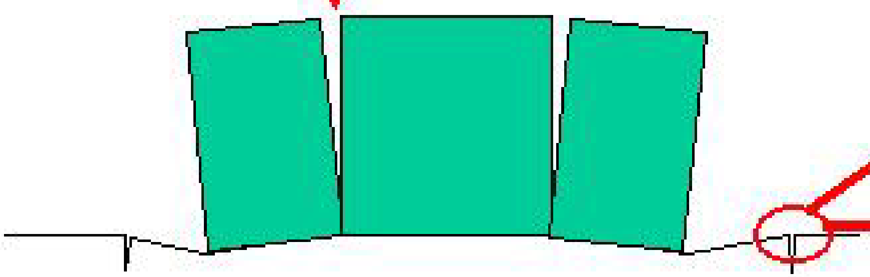
Taiwan Army base near the town of Chi Chi)

Taiwan Chi Chi earthquake



The wings of this building complex differentially settled due to liquefaction

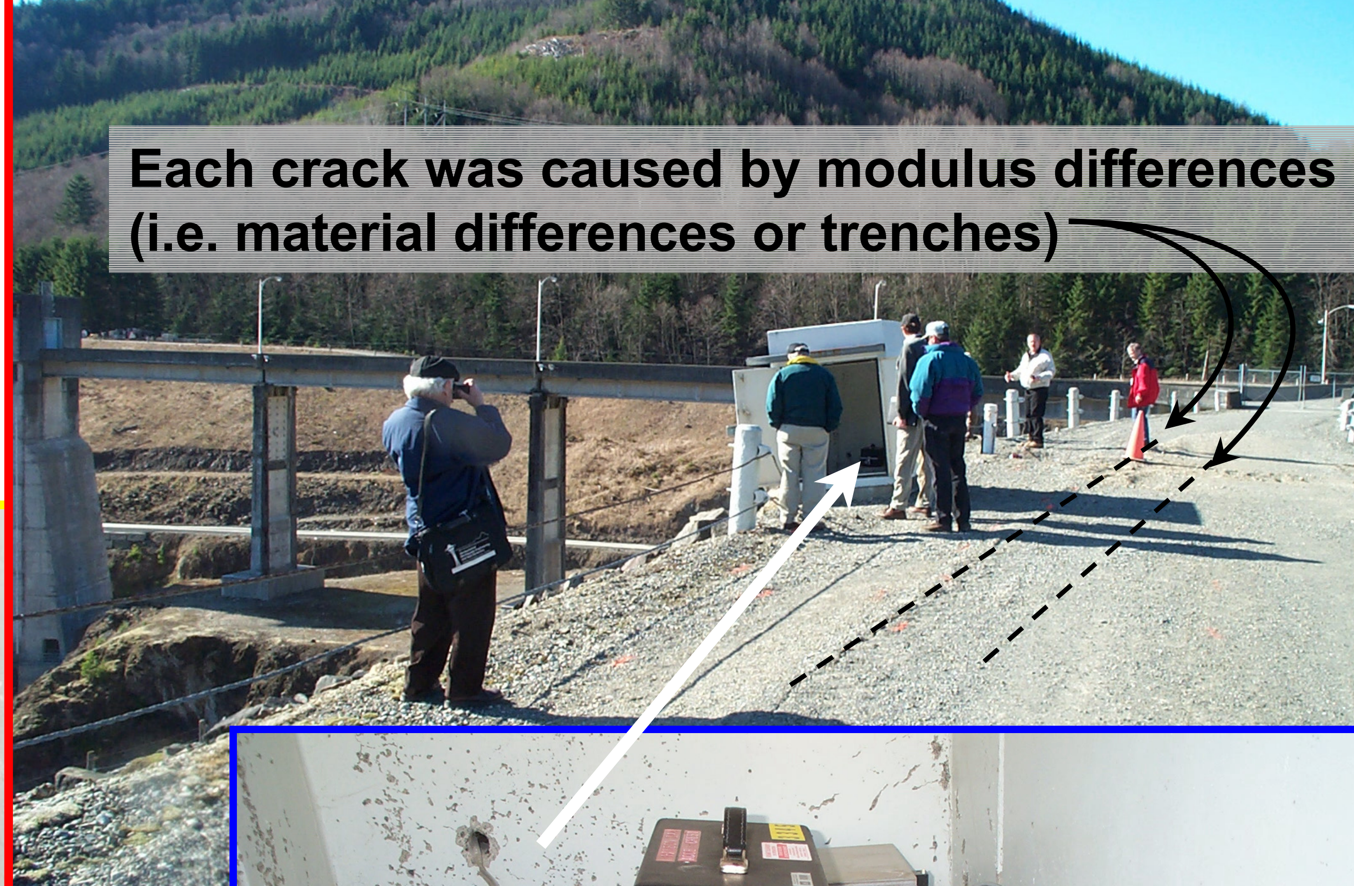
2001 Seattle Earthquake Recon

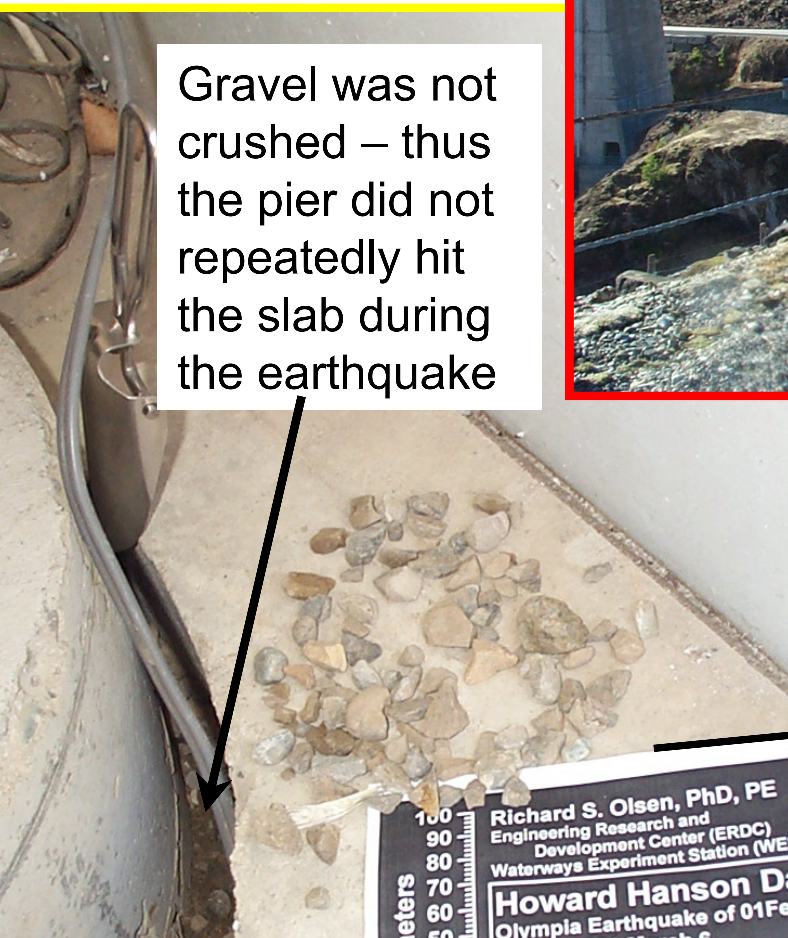
Assessment of **Howard Hanson Dam**

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

Howard Hanson Dam

Damage Recon





2001 August 16
Lecture on Landslides
By Dr. Olsen

Howard Hanson Dam

Seattle Earthquake 2001

Damage Recon

Each crack was caused by modulus differences (i.e. material differences or trenches)

Also, measured temperatures and pore pressures in the shell of the dam reflected dilative behavior

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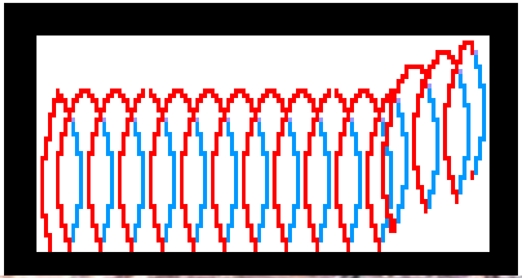
El Berrinche Landslide (during Hurricane Mitch) Tegucigalpa, Honduras

Large landslides generally move in segments with time



The El Berrinche landslide moved in segments based on interviews with people that experienced it

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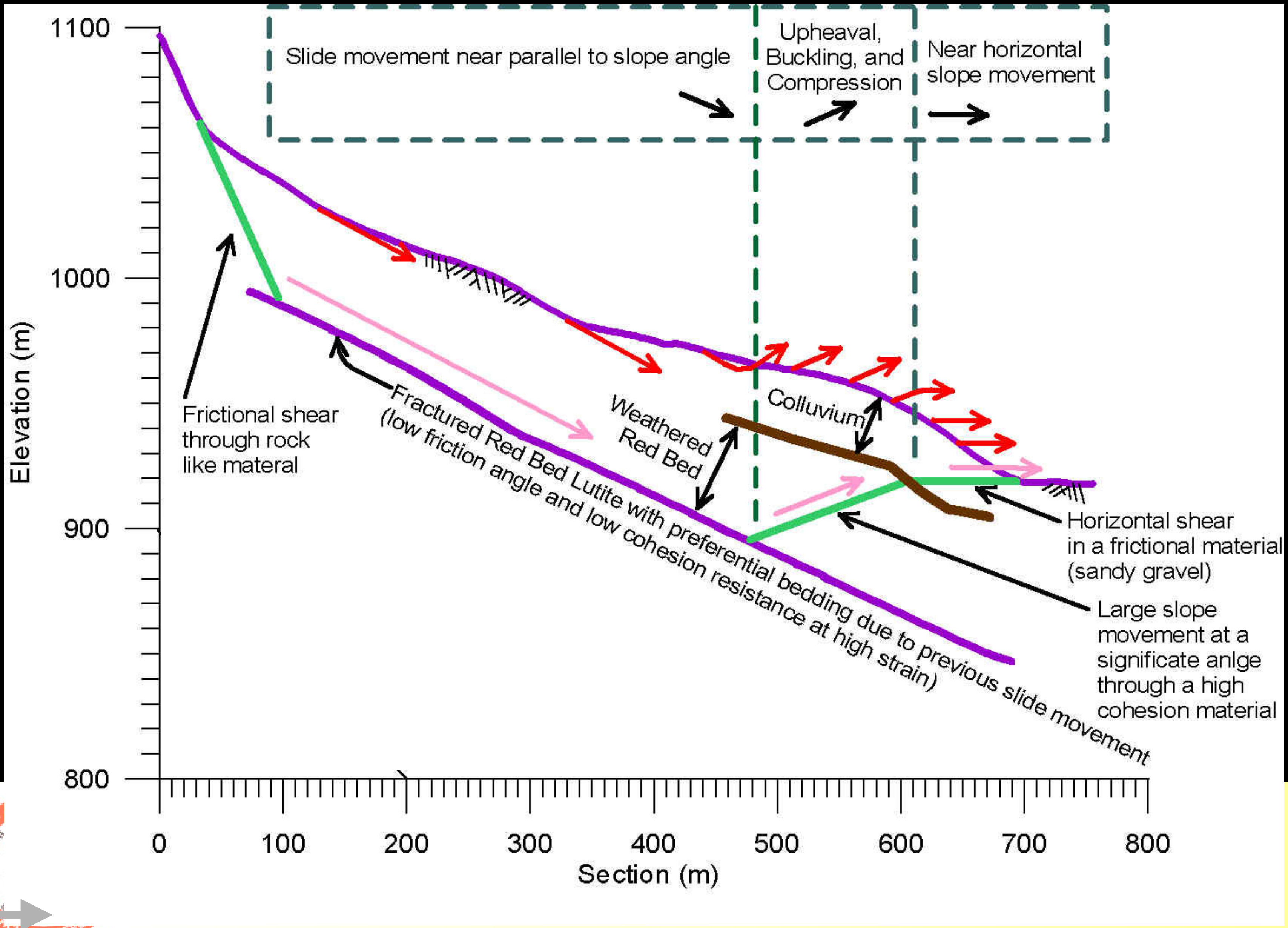
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

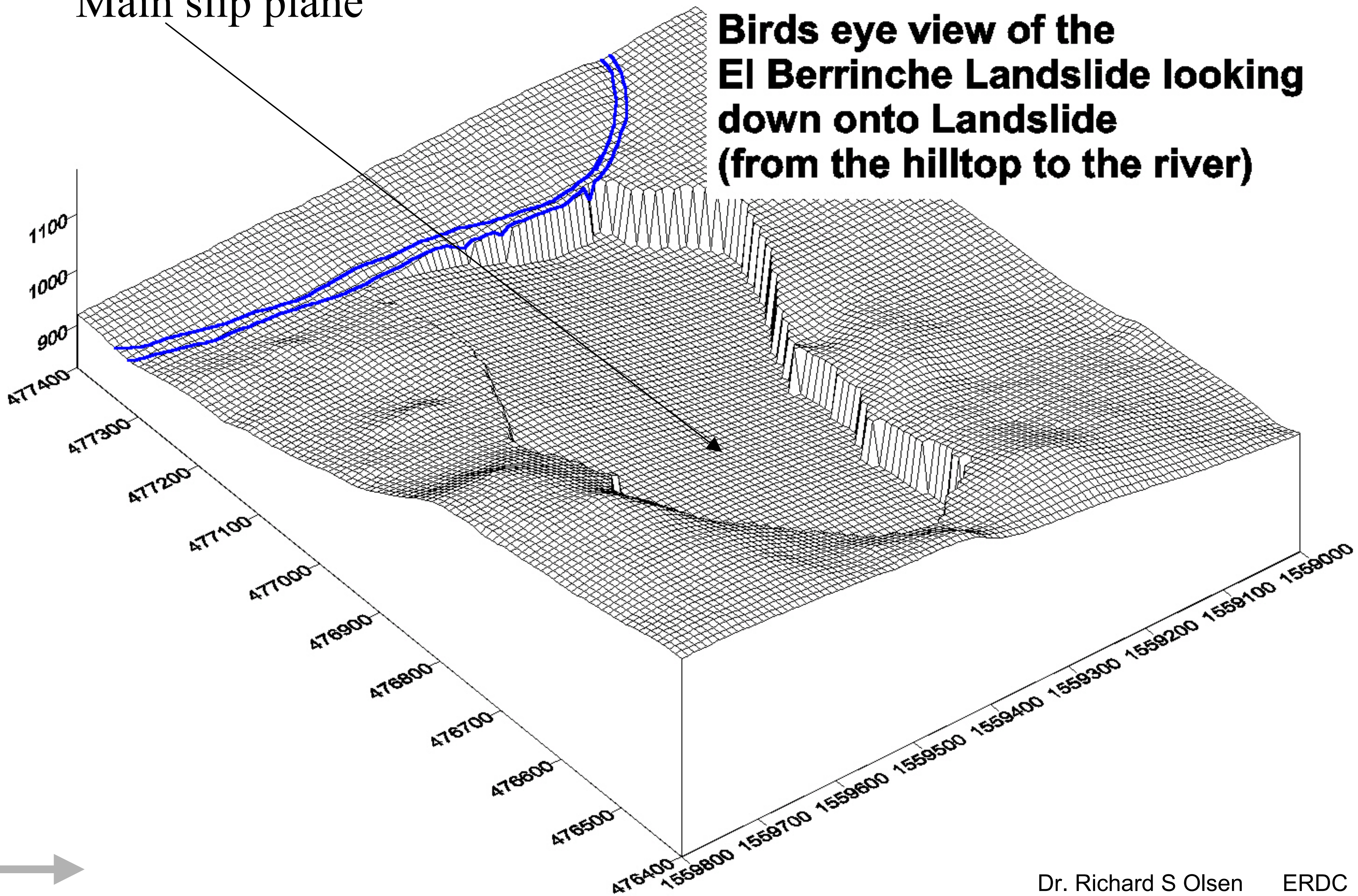
El Berrinche Landslide

Mechanics of Failure of the Main Slide Block



Main slip plane

Birds eye view of the El Berrinche Landslide looking down onto Landslide (from the hilltop to the river)



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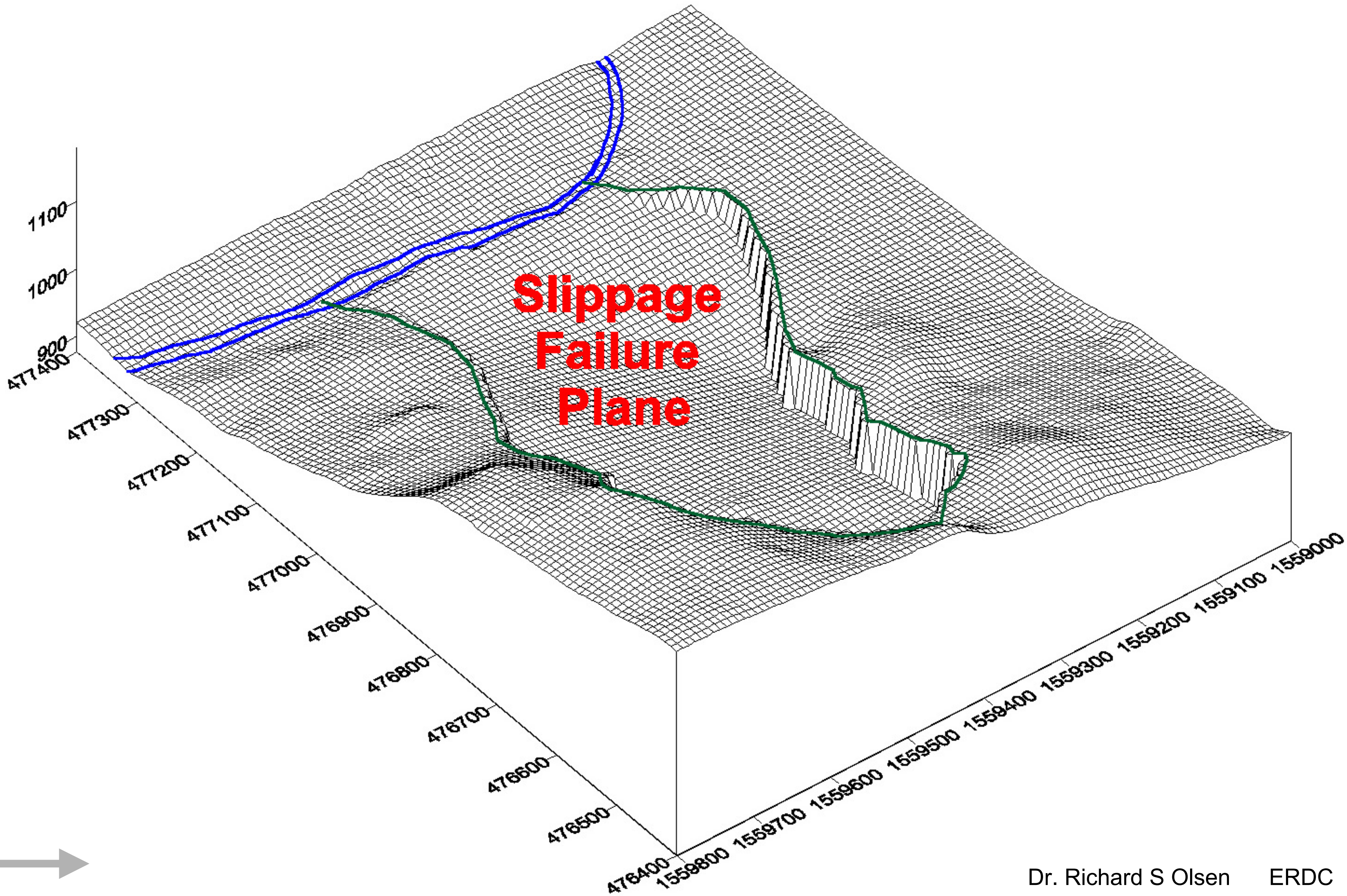

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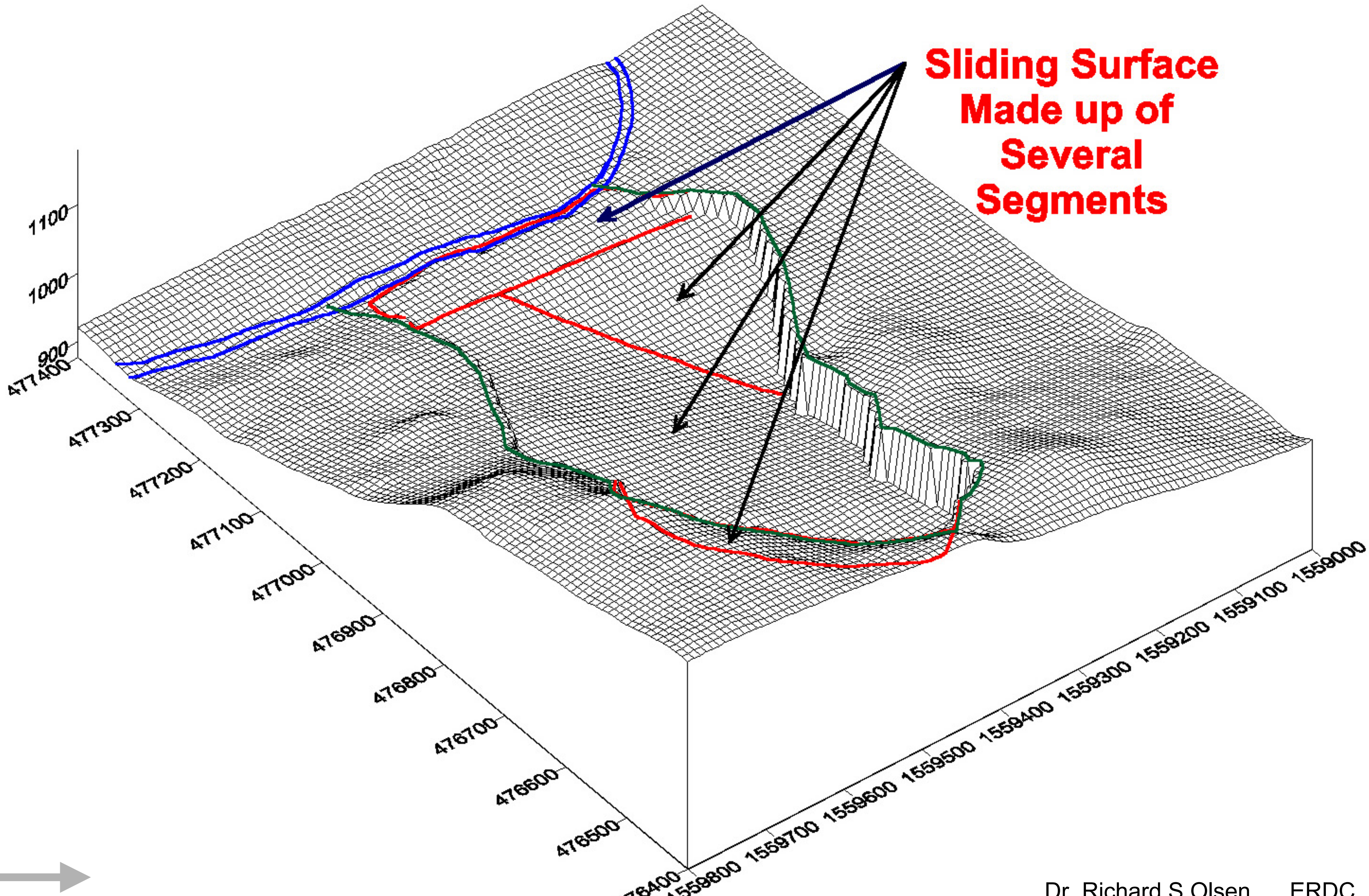

Sliding Surface Made up of Several Segments
1100
1000
900
477400
477300
477200
477100
477000
476900
476800
476700
476600
476500
476400
1559800
1559700
1559600
1559500
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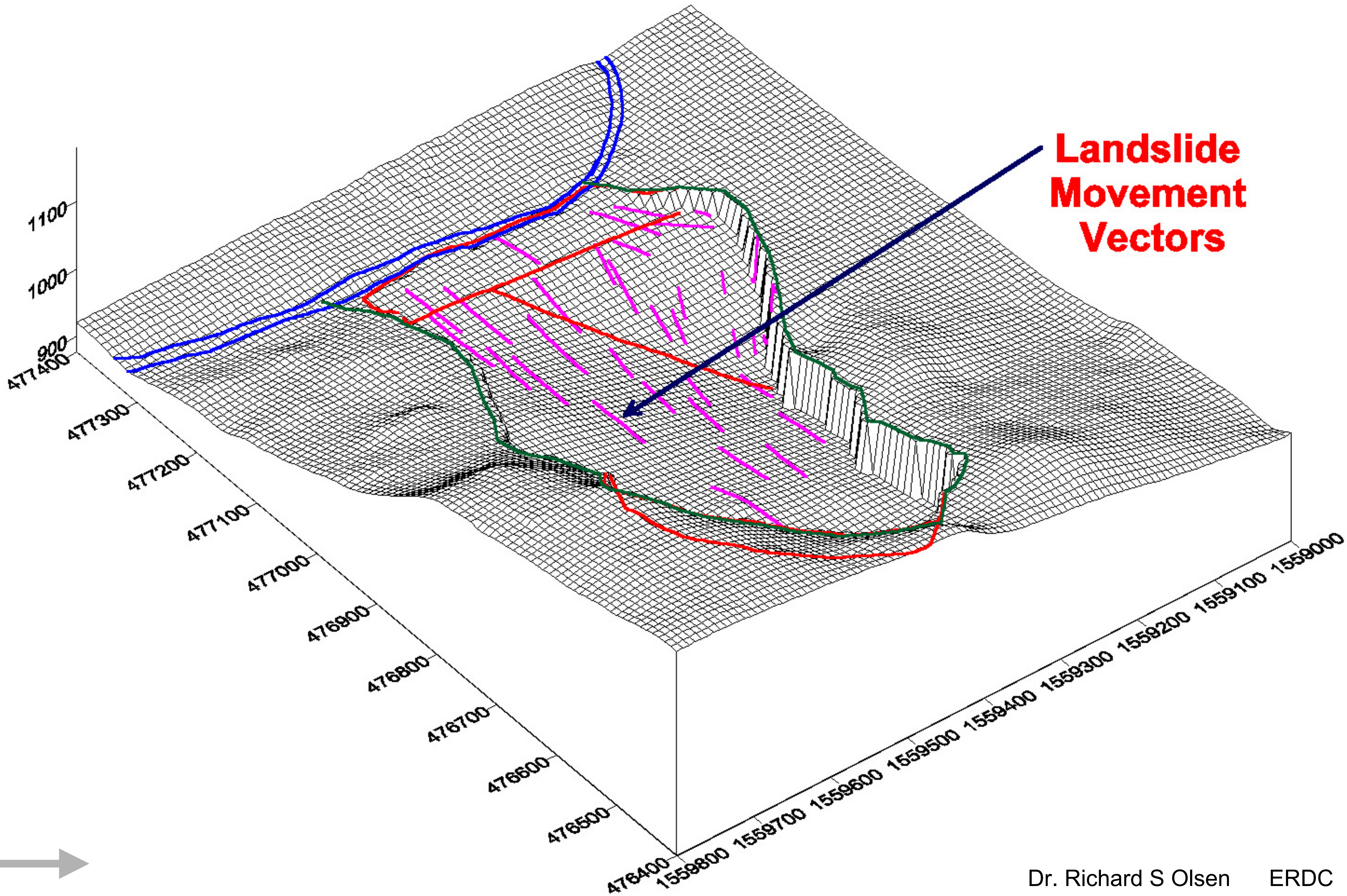
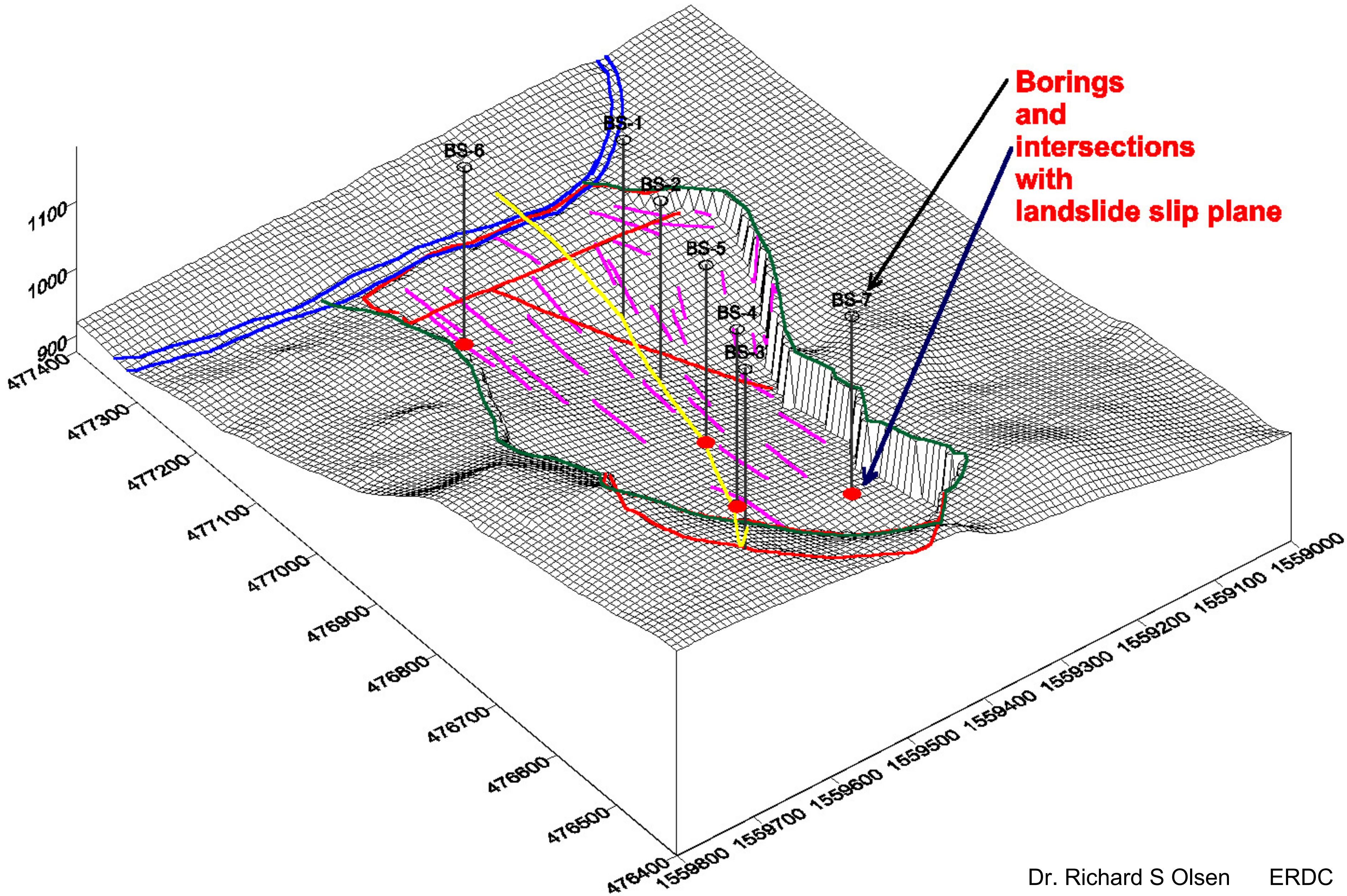
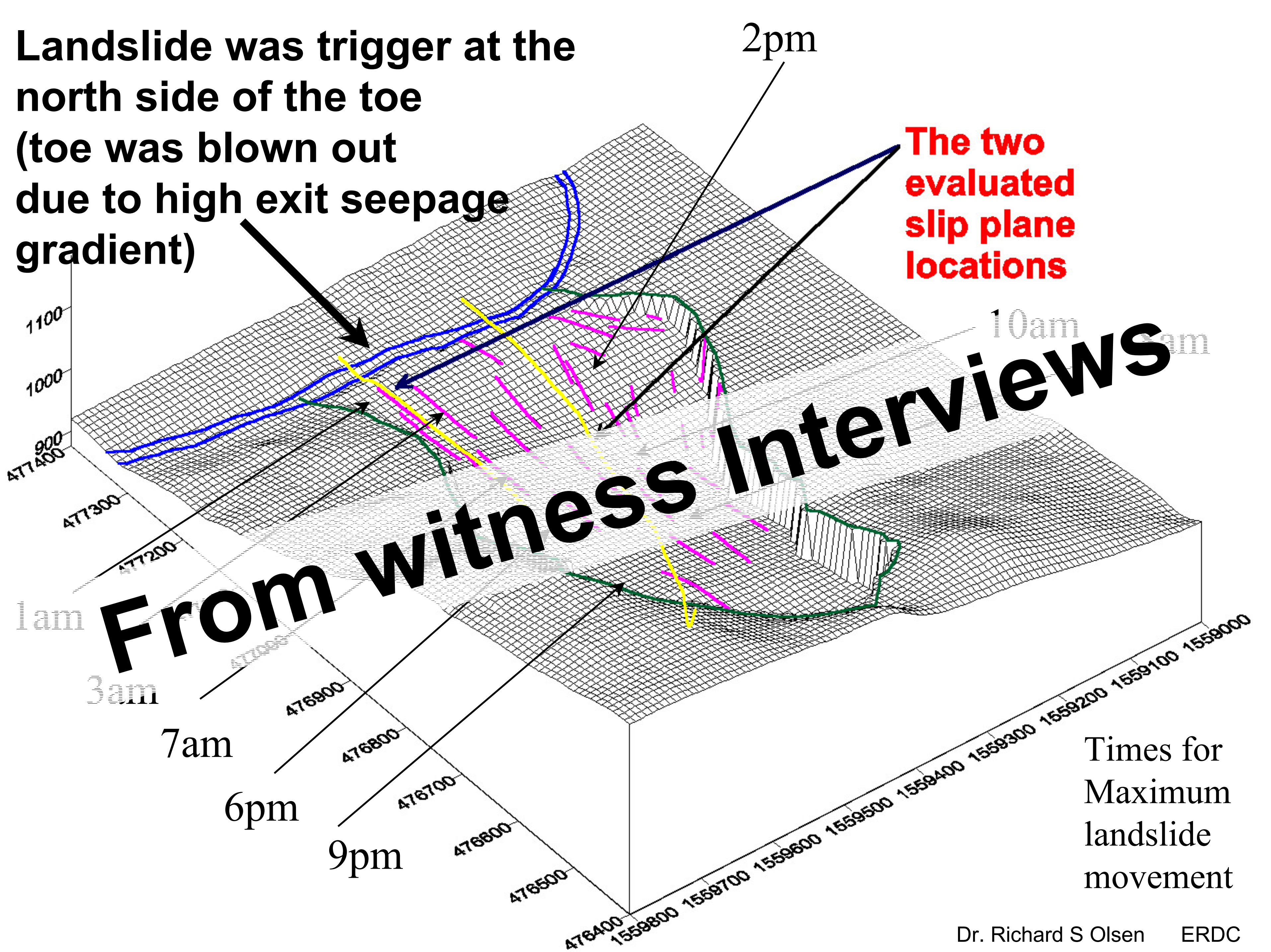
1559200
1559100
1559000



Dr. Richard S Olsen ERDC



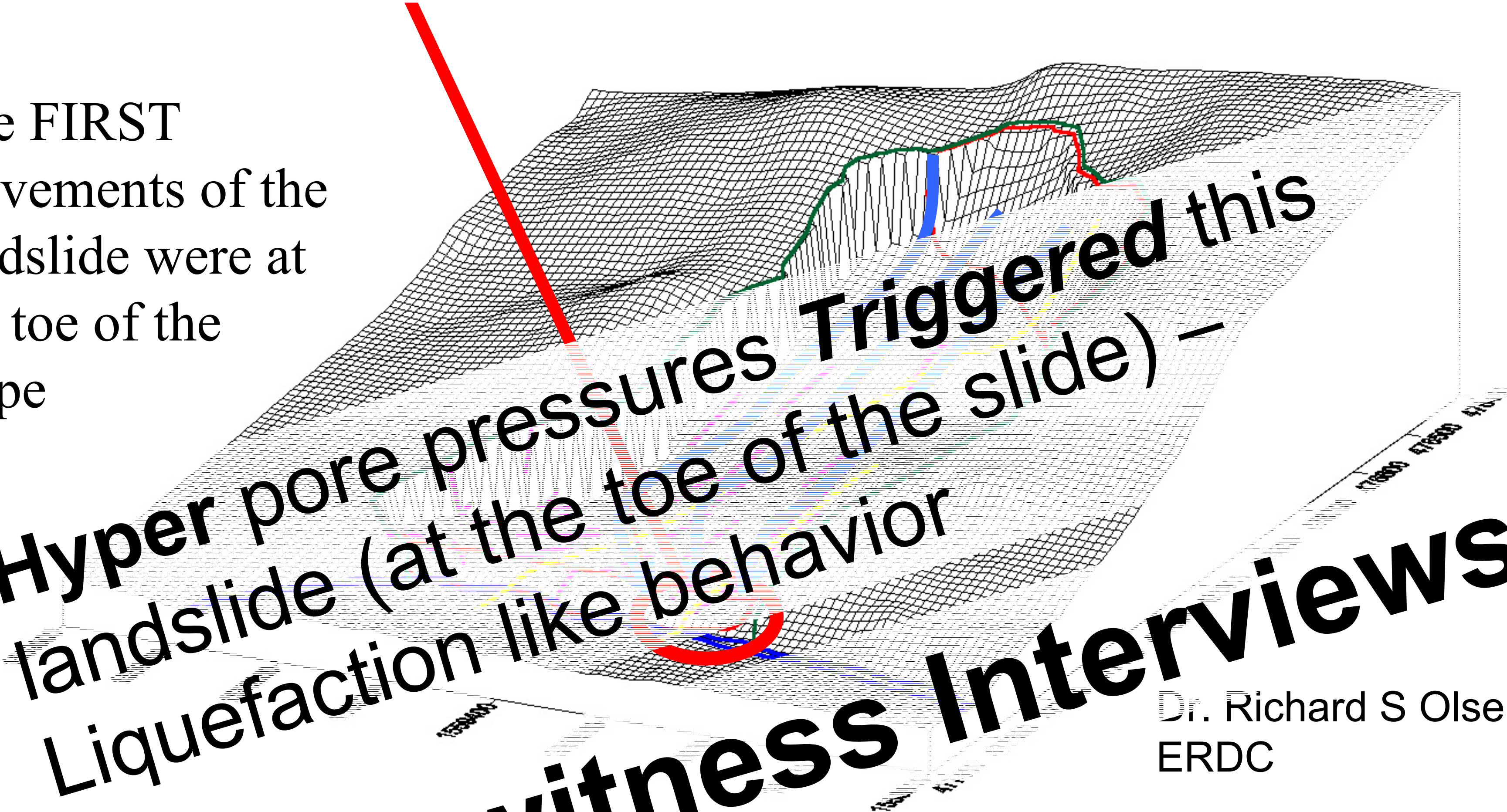
Dr. Richard S Olsen ERDC



Landslide was trigger at the north side of the toe (toe was blown out due to high exit seepage gradient)
2pm
The two evaluated slip plane locations
10am
From witness Interviews
1am
3am
7am
6pm
9pm
1100
1000
900
477400
477300
477200
476900
476800
476700
476600
476500
476400
1559800
1559700
1559600
1559500
1559400
1559300
1559200
1559100
1559000
Times for Maximum landslide movement
Dr. Richard S Olsen
ERDC

Trees were falling over (uphill from the river) due to high pore pressures causing a liquefaction like behavior
- Based on witness interviews

The FIRST movements of the landslide were at the toe of the slope



Hyper pore pressures **Triggered** this landslide (at the toe of the slide) – Liquefaction like behavior

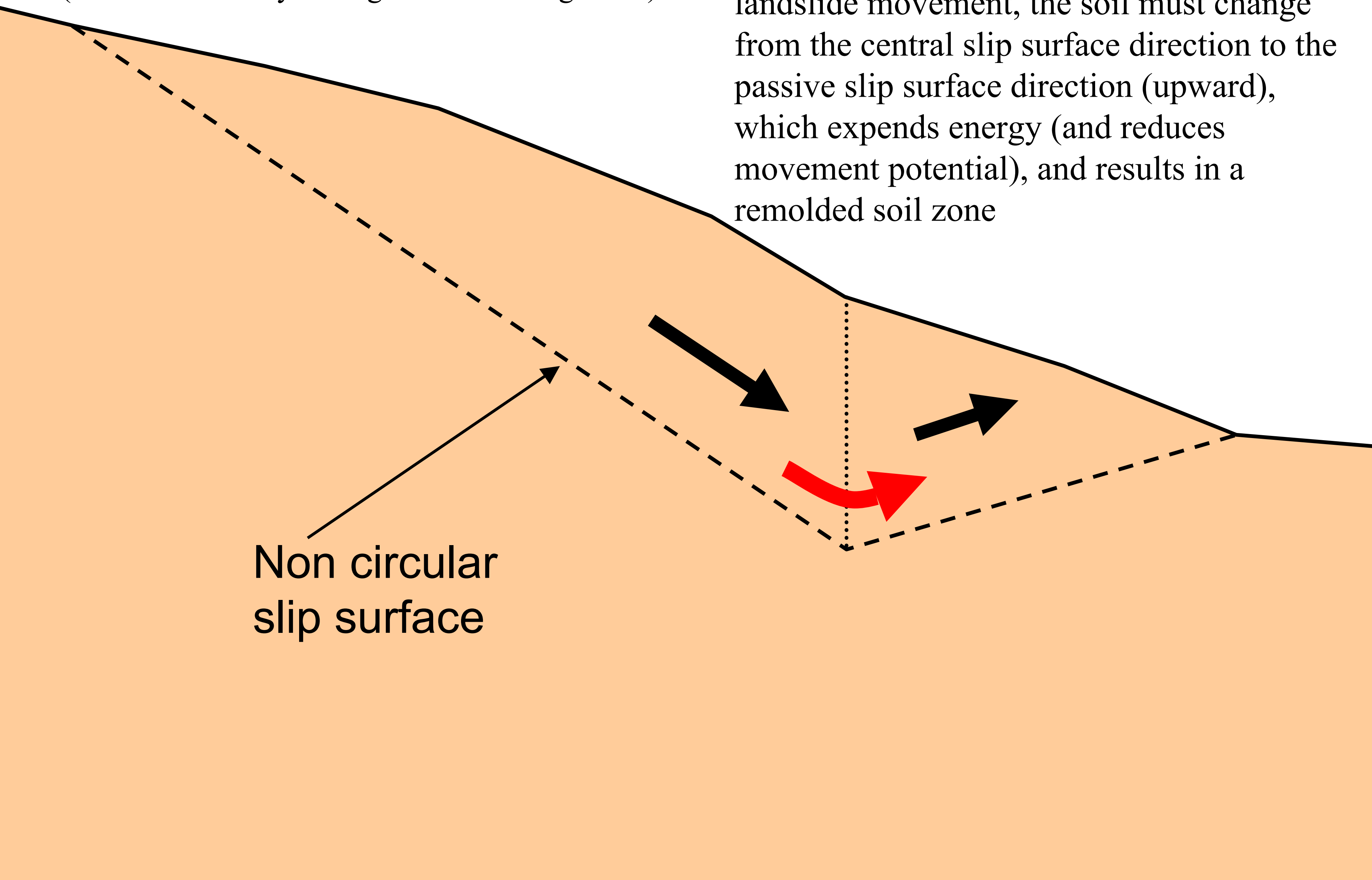
From witness Interviews

Dr. Richard S Olsen
ERDC

Non-circular landslides have complex behavior

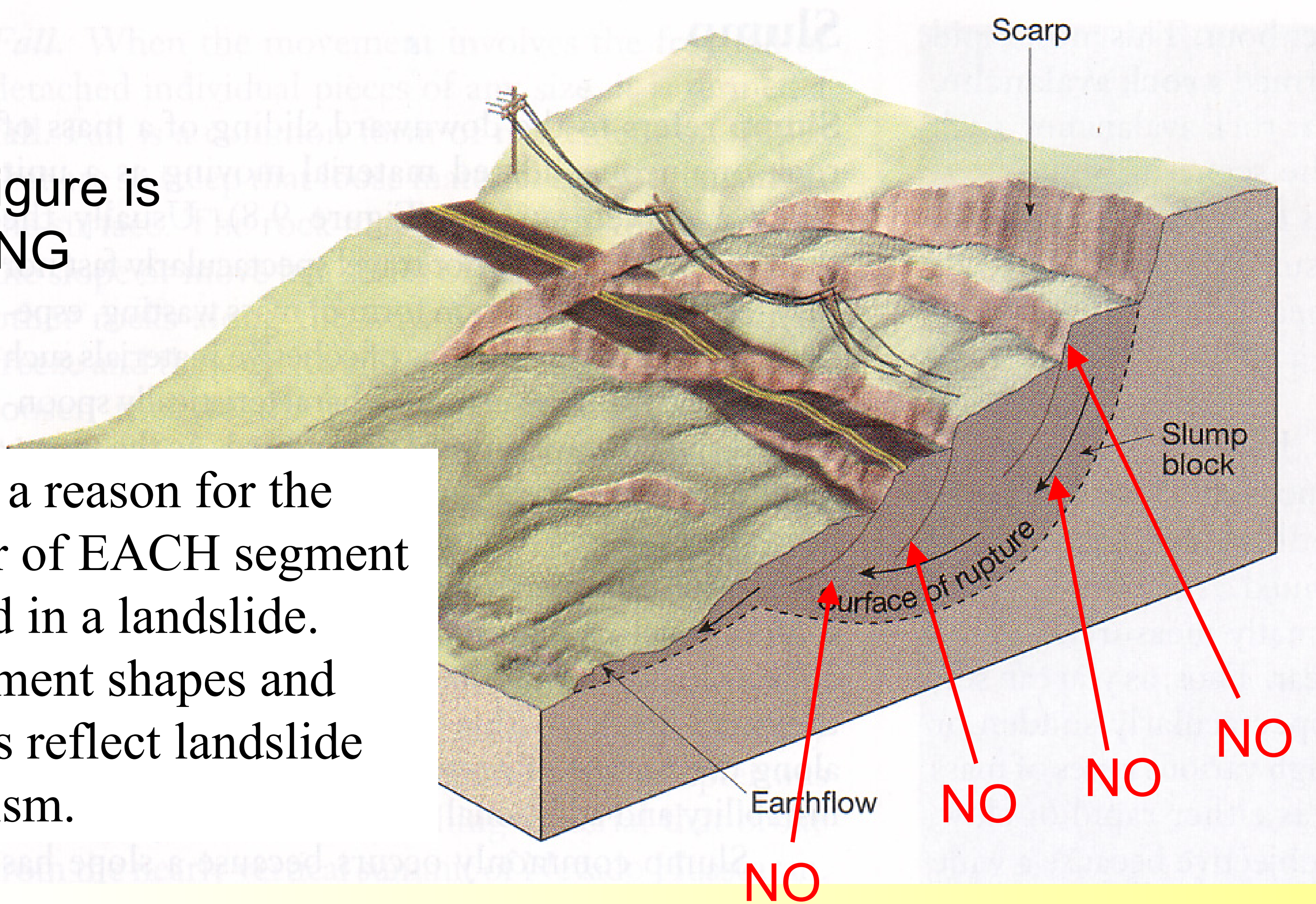
(not understood by most geotechnical engineers)

A non-circular landslide having both a central and passive block will generally have limited potential for movement. During landslide movement, the soil must change from the central slip surface direction to the passive slip surface direction (upward), which expends energy (and reduces movement potential), and results in a remolded soil zone



Over generalization of landslides in textbooks and specialty books

This figure is WRONG



There is a reason for the behavior of EACH segment observed in a landslide. The segment shapes and locations reflect landslide mechanism.

Movement follows action

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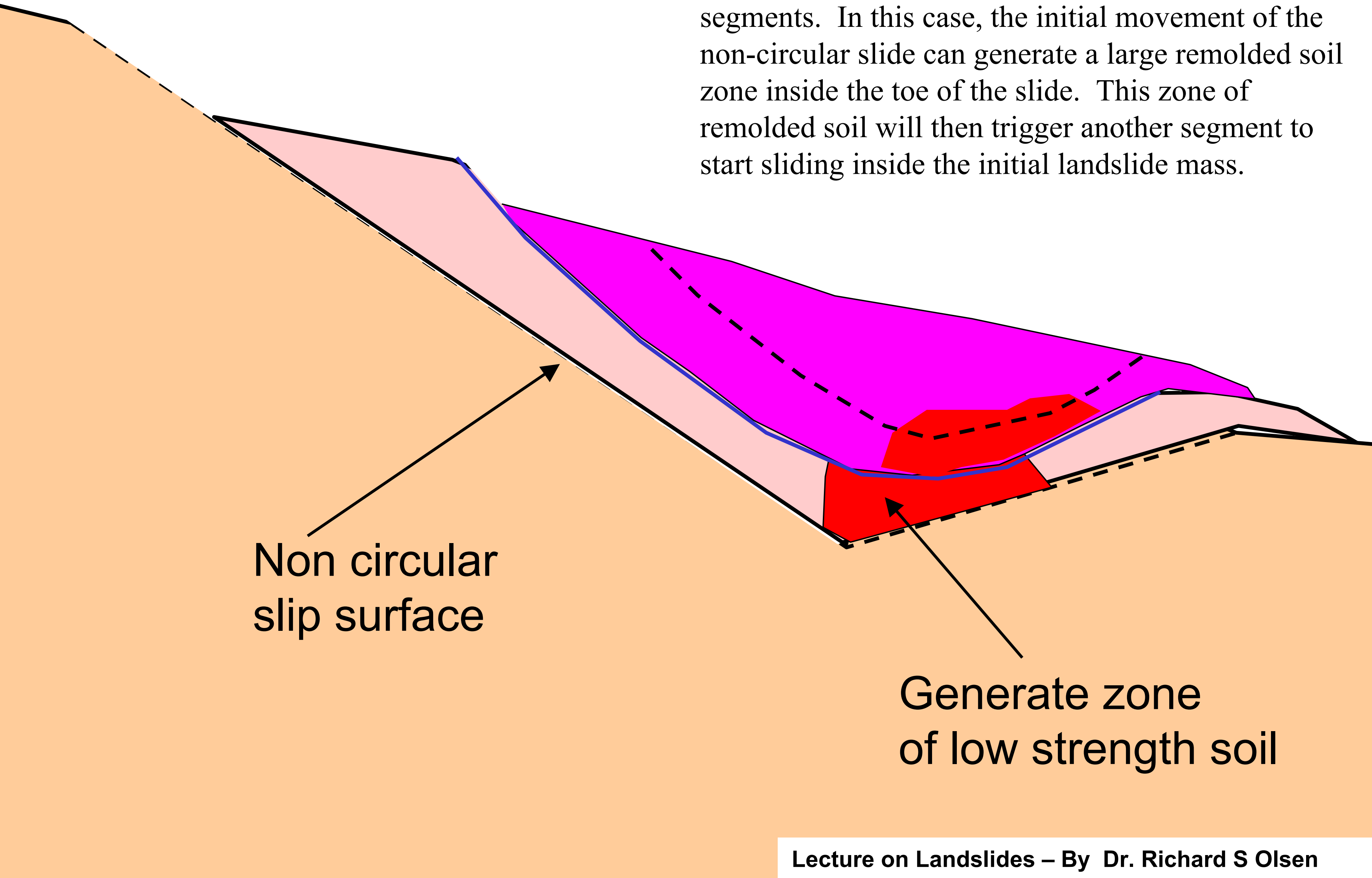
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

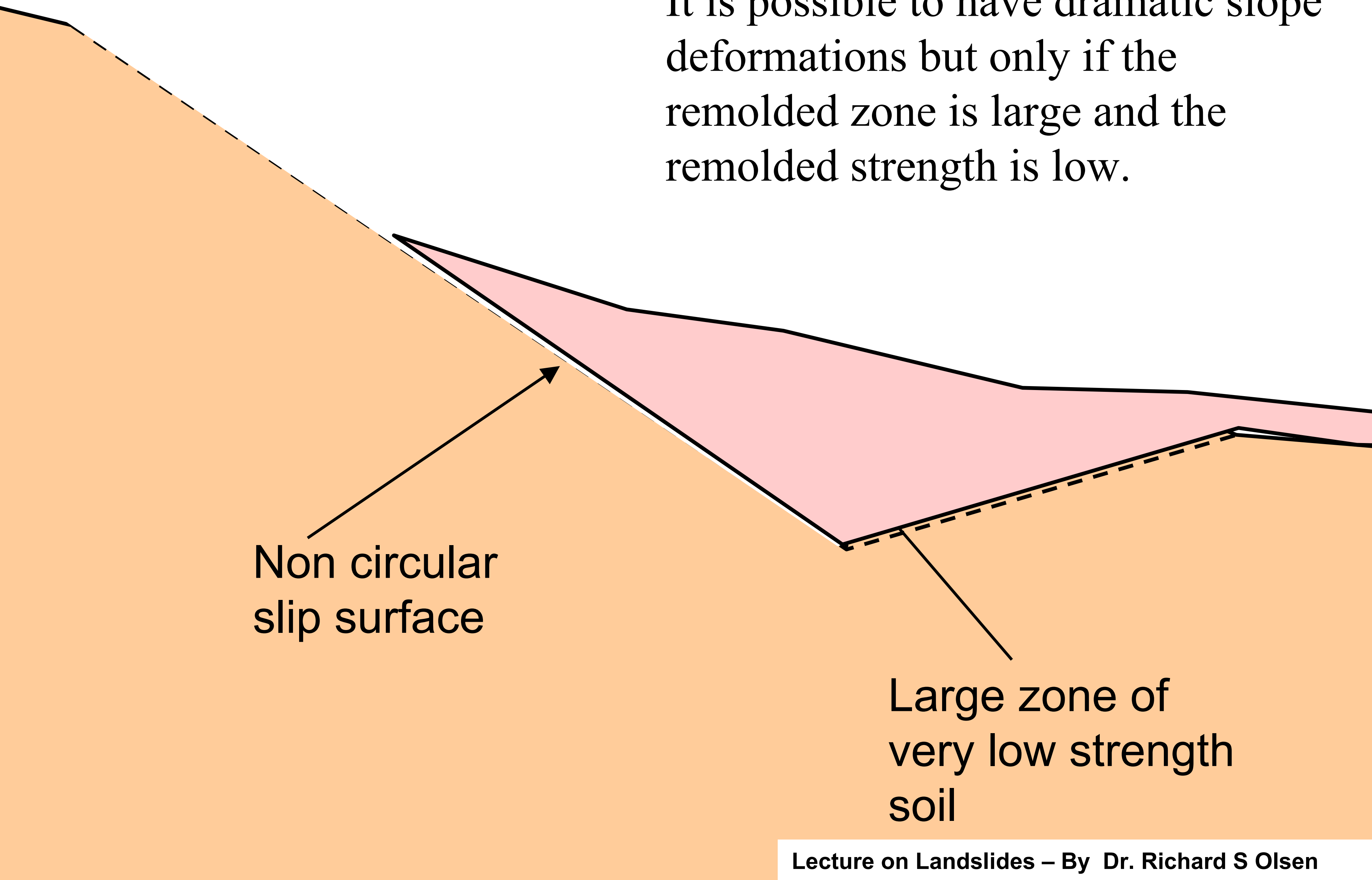
Complex behavior of non circular slip surfaces

Many landslides have a stair-step appearance where the soil mass traveled downward as different segments. In this case, the initial movement of the non-circular slide can generate a large remolded soil zone inside the toe of the slide. This zone of remolded soil will then trigger another segment to start sliding inside the initial landslide mass.

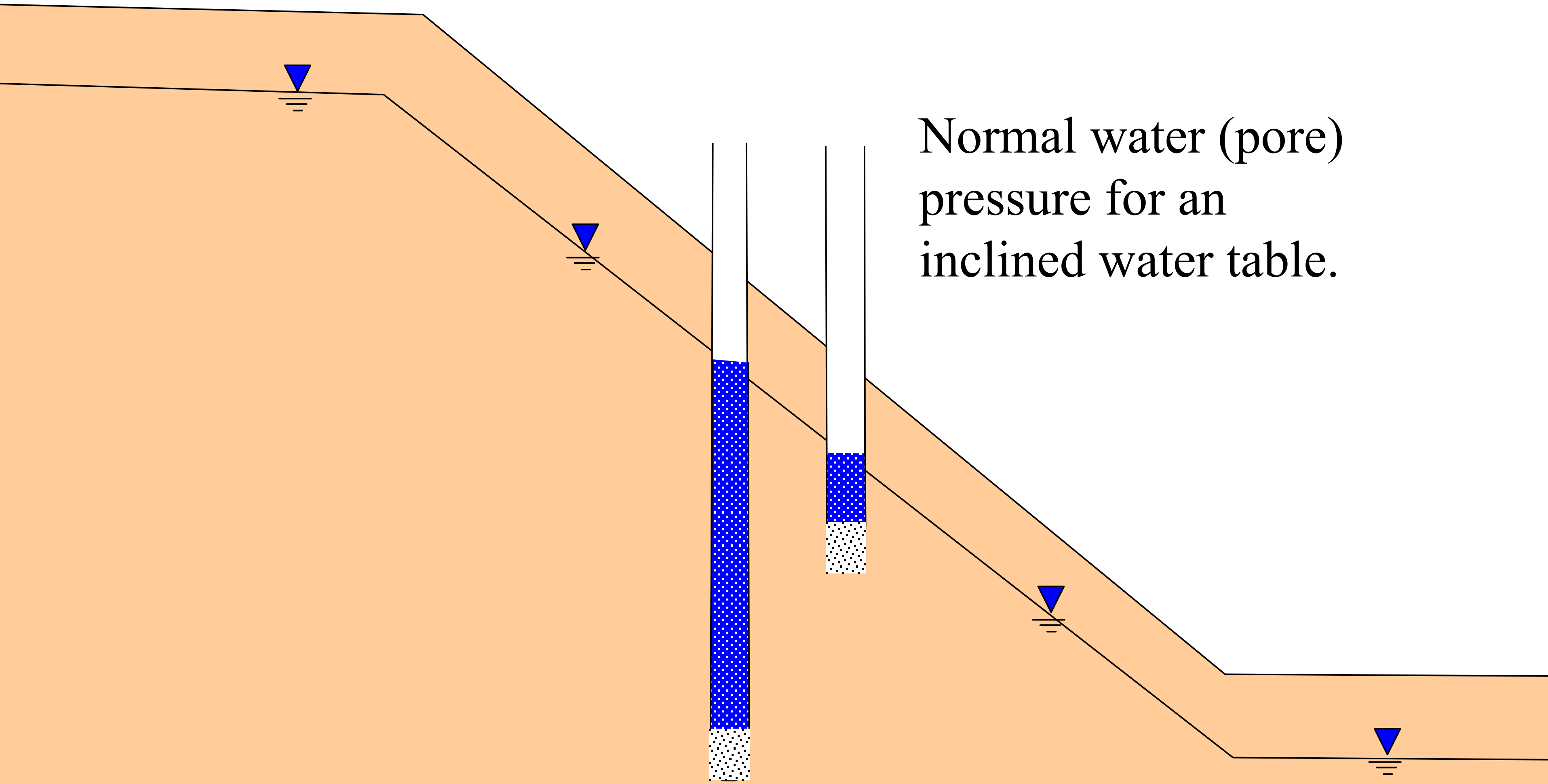


Complex behavior of non circular slip surfaces

It is possible to have dramatic slope deformations but only if the remolded zone is large and the remolded strength is low.

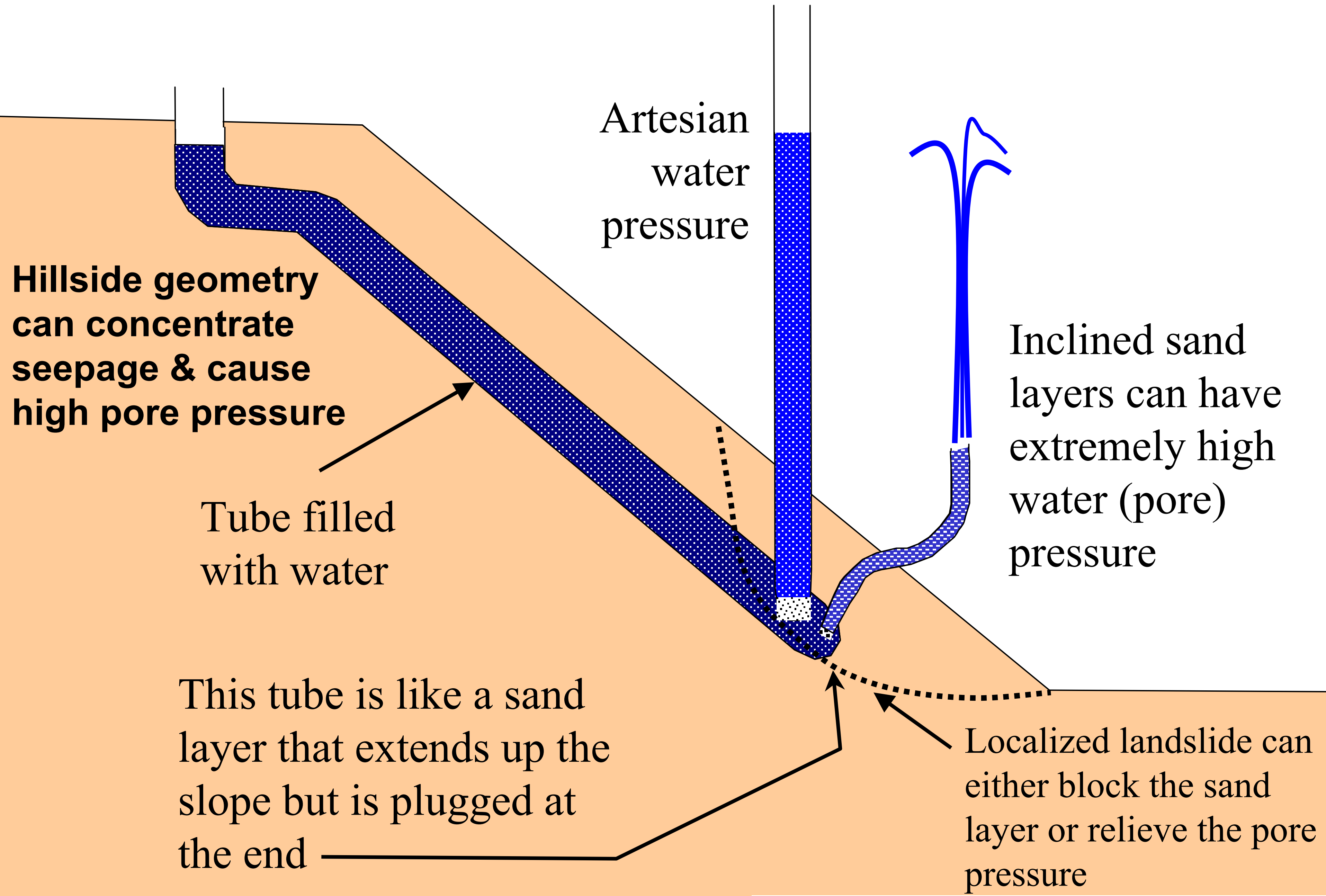


Conventional thinking about pore pressure in slopes



Normal water (pore) pressure for an inclined water table.

How high can the water (pore) pressure get ?



Upstream failure of the Lower San Fernando Dam - 1971

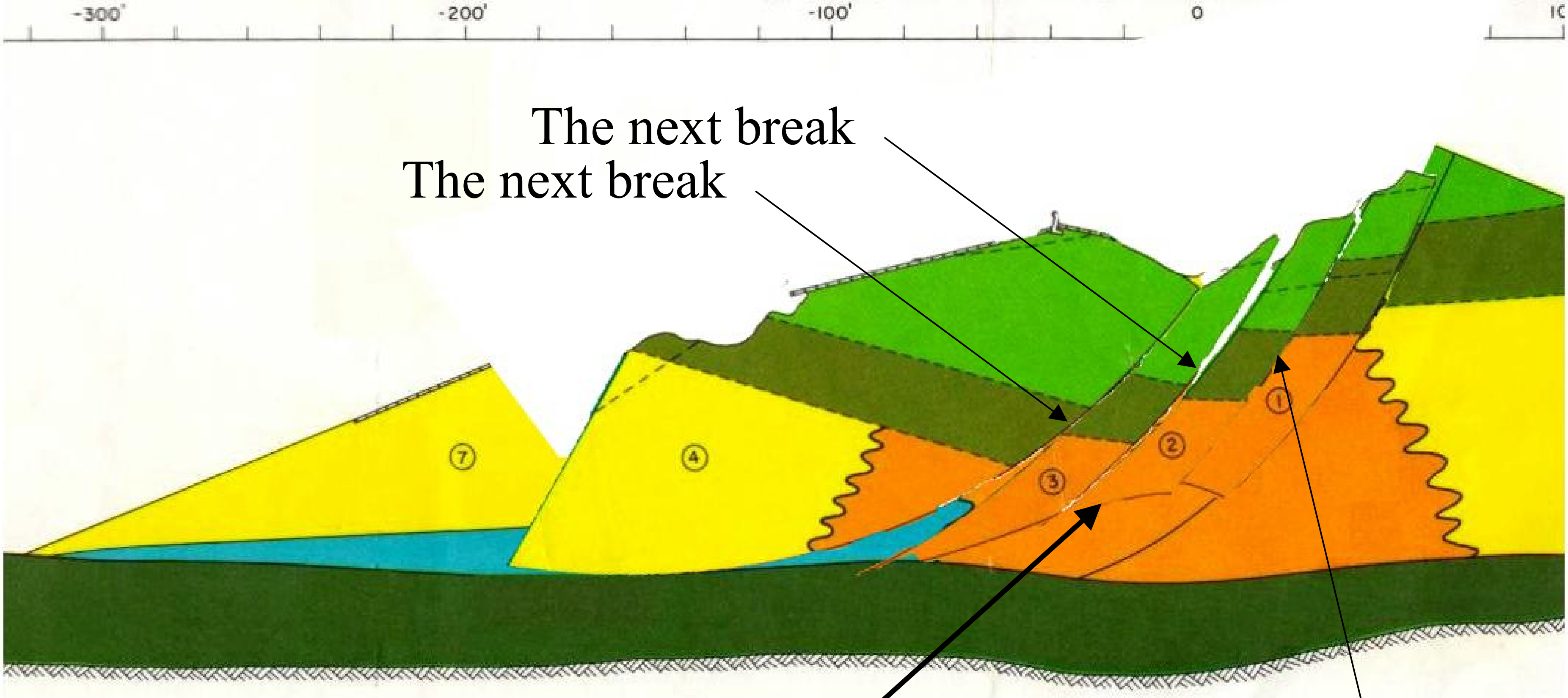
The most famous embankment failure due to an earthquake is the upstream slide of the Lower San Fernando Dam as a result of the Imperial Valley Earthquake of 1971

At the end of the earthquake shaking the on-grounds dam manager looked at the dam and saw no damage (about 3 minutes after shaking). Within about 20 minutes a massive upstream slide occurred.

This dam has been evaluated twice (1972 and 1986). We, as a profession, still have not properly characterized the failure nor have we extracted the correct observations about how to evaluate embankment dams. Stability evaluation of embankments subjected to earthquake is not yet a mature science.

Example of a complex failure – Lower San Fernando Dam during the 1971 San Fernando Earthquake

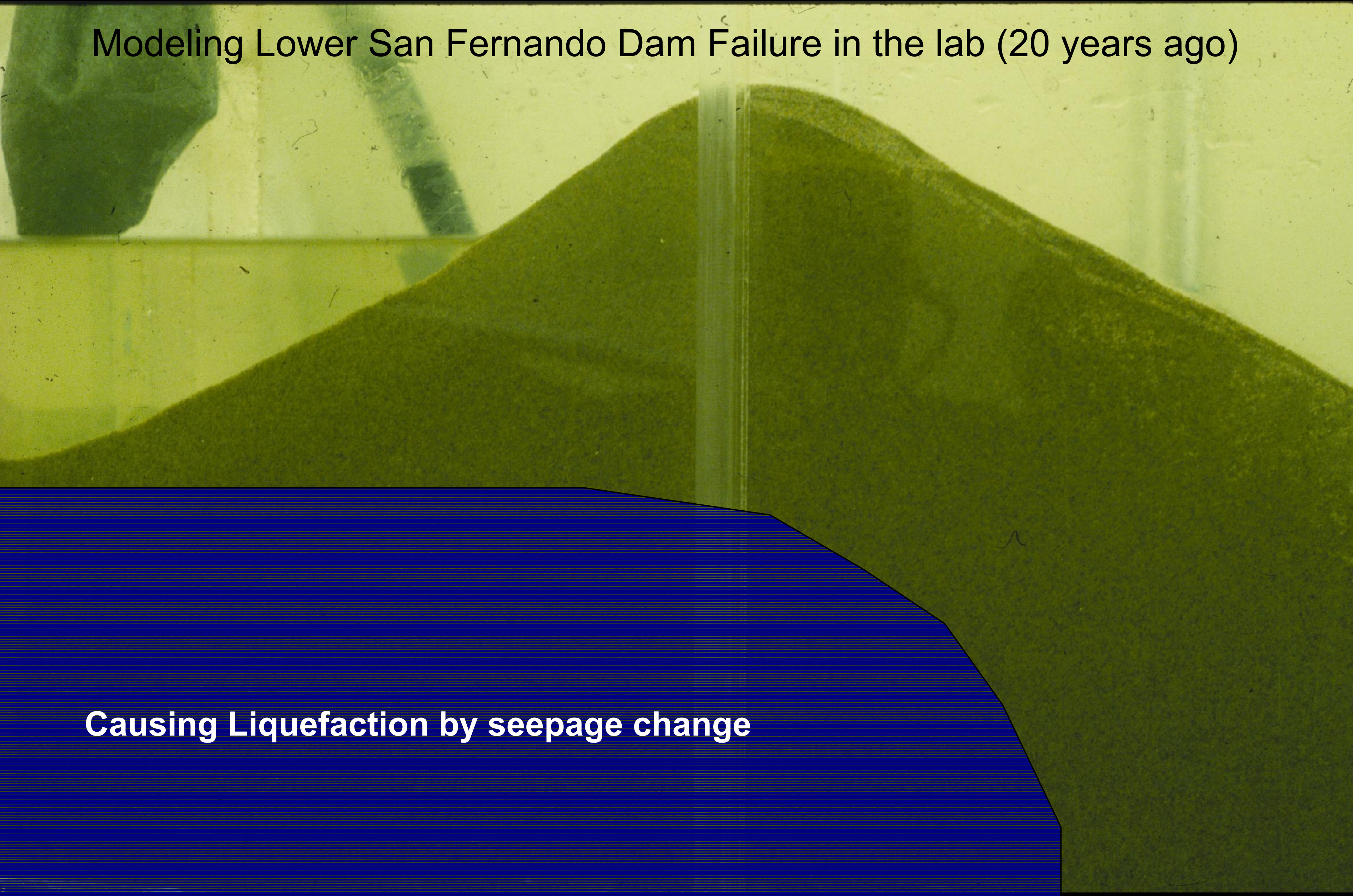
Evaluated and interpreted starting in 1984 by Dr. Richard S. Olsen - Animated in 2001



The segment stops moving because of bearing stress and confinement on the bottom edge of each wedge

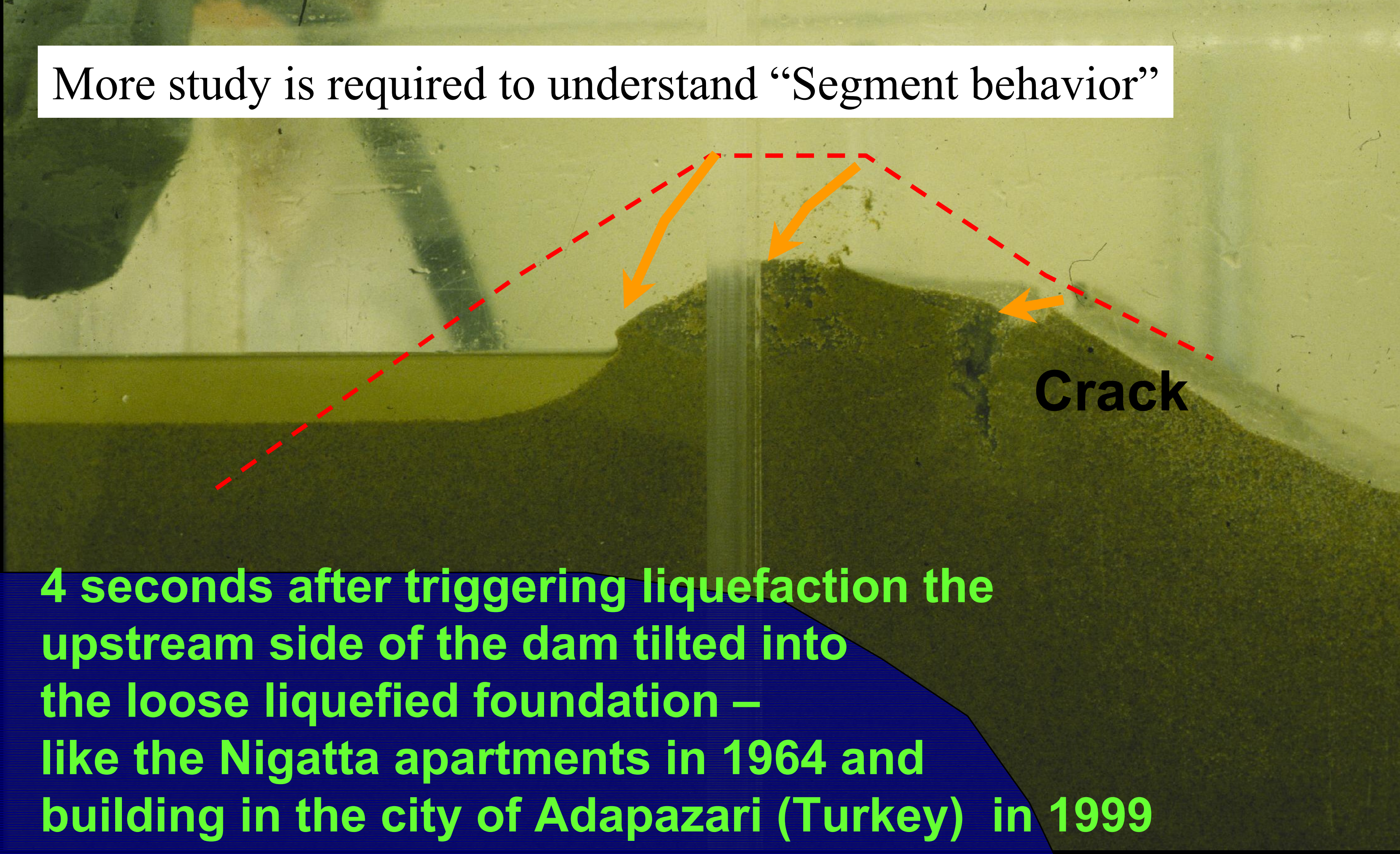
A new slip surface is then broken

Modeling Lower San Fernando Dam Failure in the lab (20 years ago)



Causing Liquefaction by seepage change

More study is required to understand “Segment behavior”



4 seconds after triggering liquefaction the upstream side of the dam tilted into the loose liquefied foundation – like the Nigatta apartments in 1964 and building in the city of Adapazari (Turkey) in 1999

4 seconds in this model = 20 minutes for Lower San Fernando Dam

What is Strength ?

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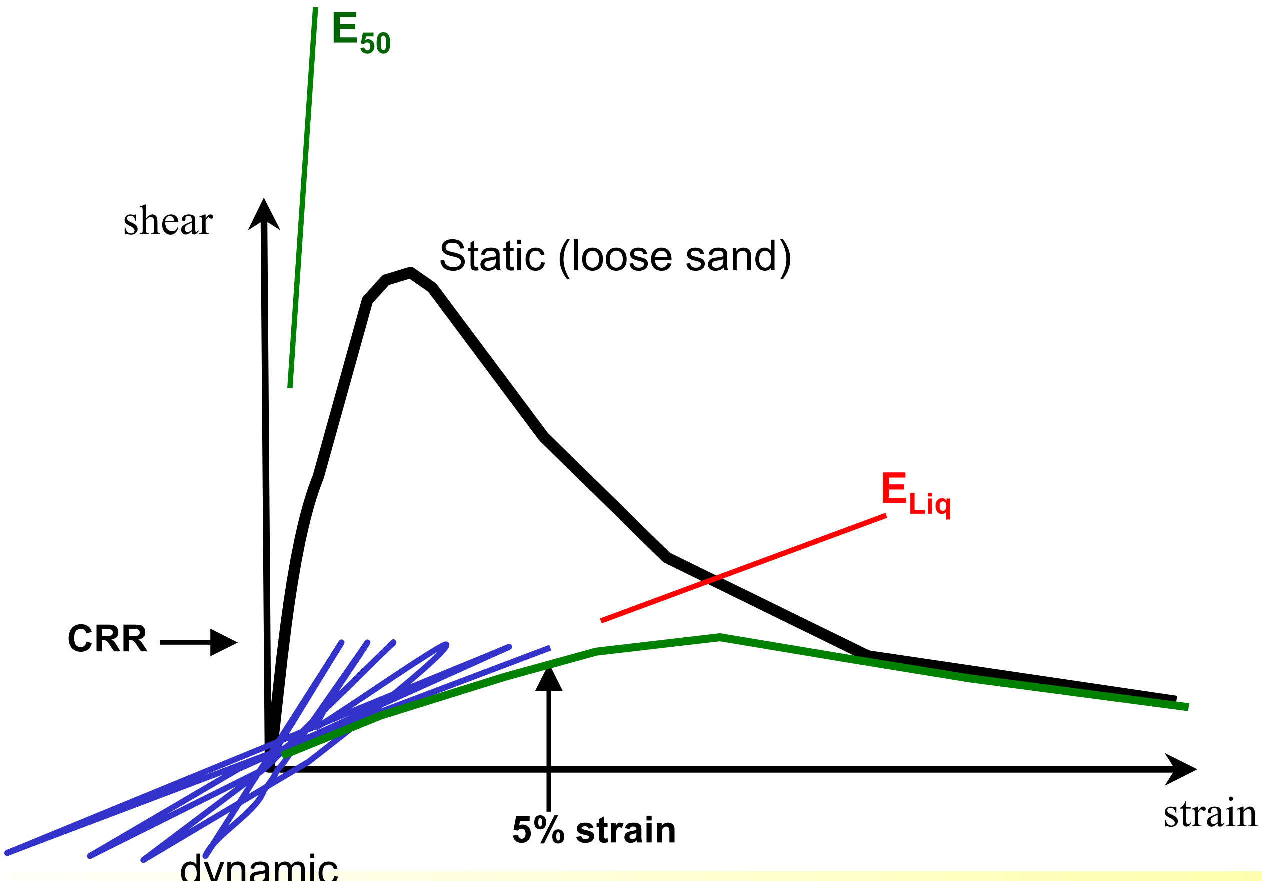
US Army Engineer Research and Development Center (ERDC)

Liquefaction reduces the shear modulus dramatically



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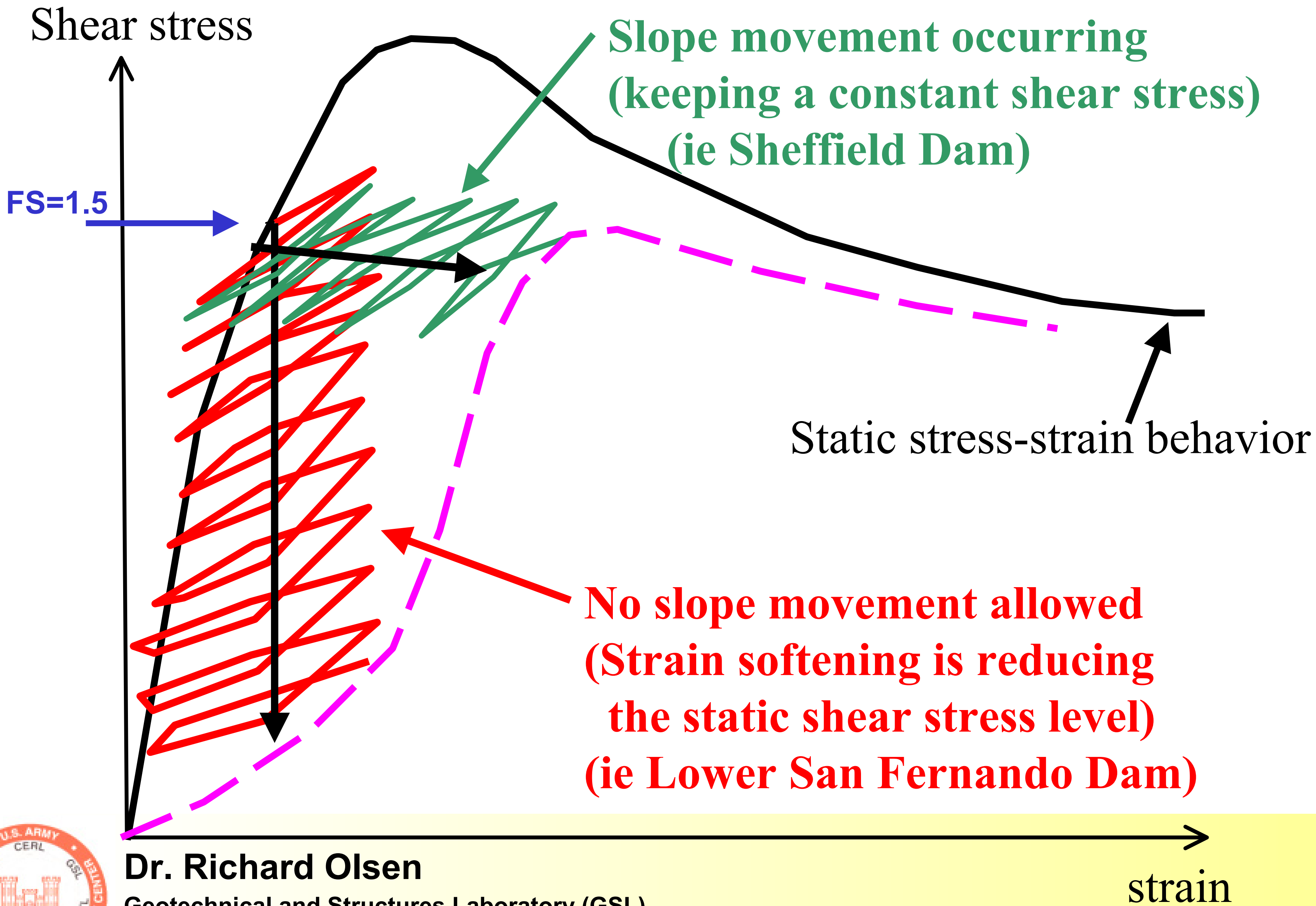

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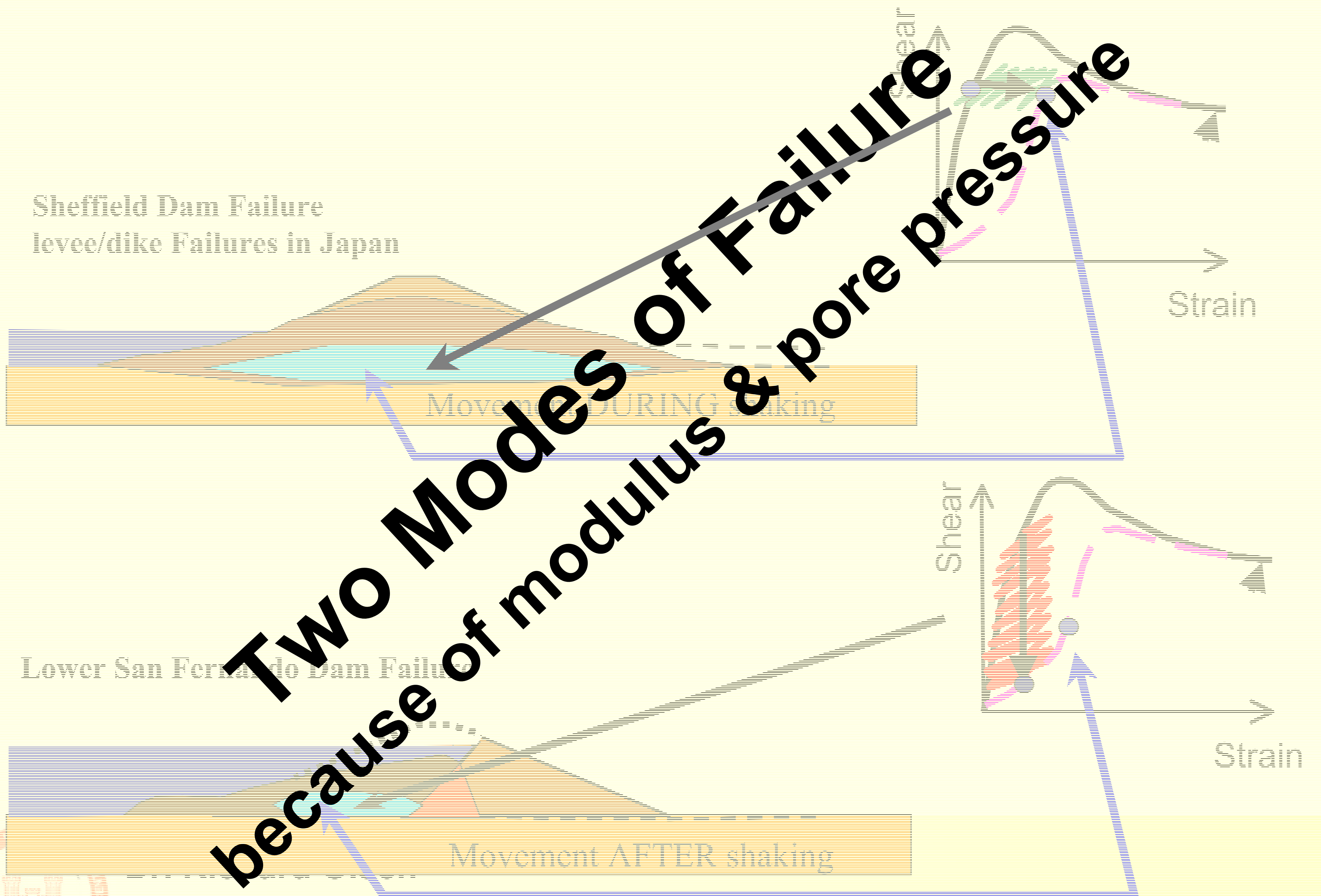
US Army Engineer Resea

Two Modes of Failure

because of modulus & pore pressure



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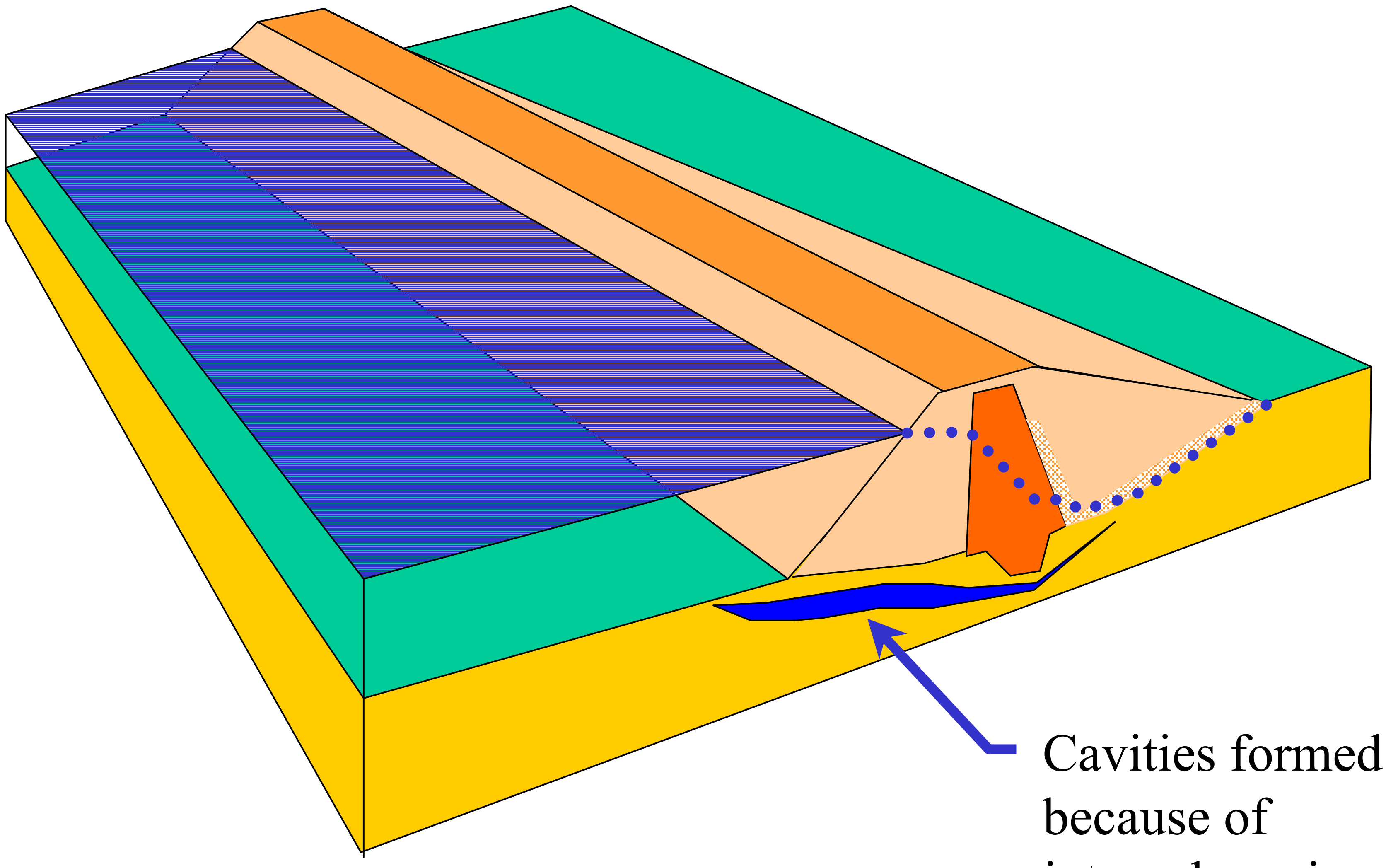
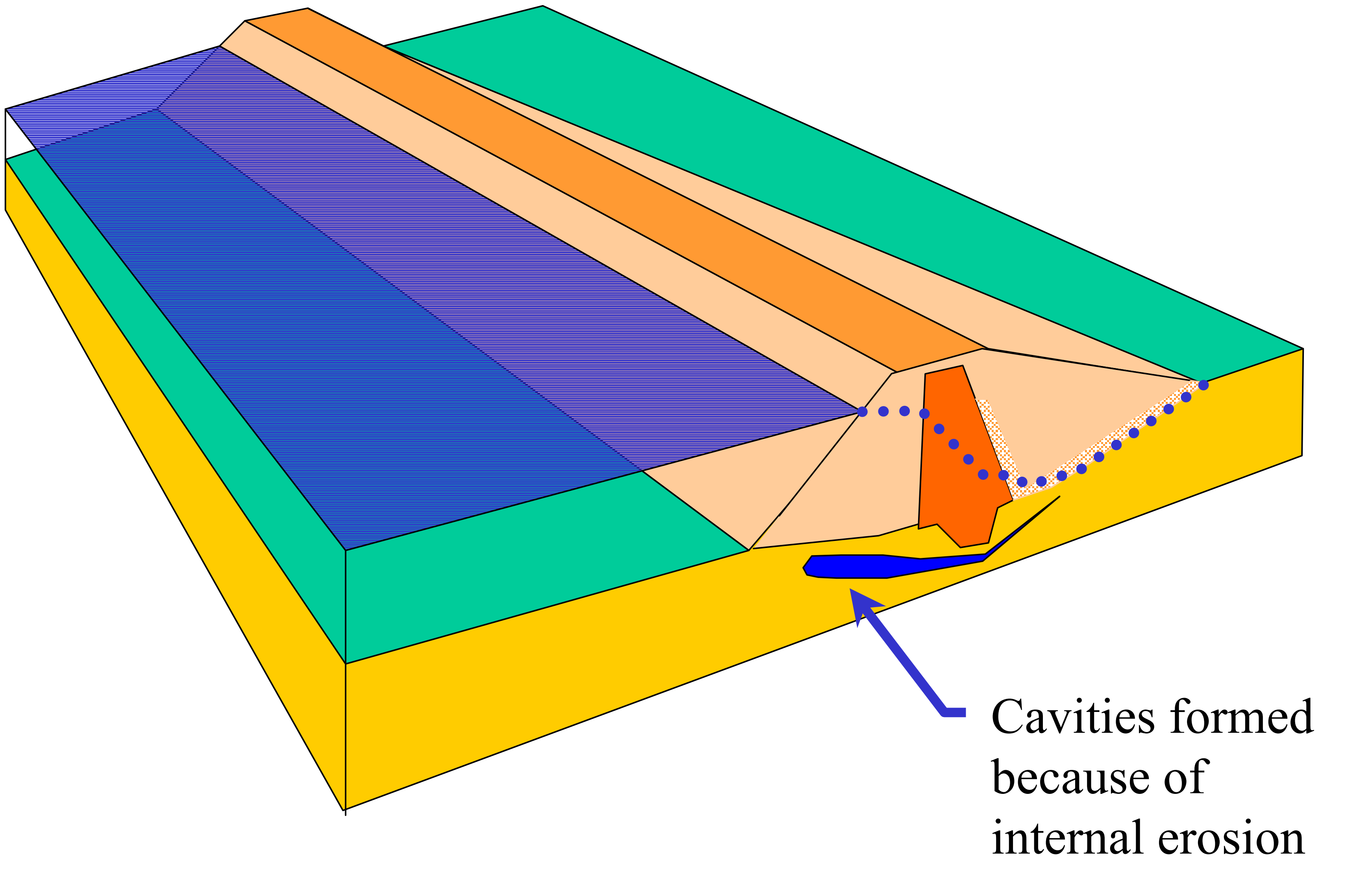
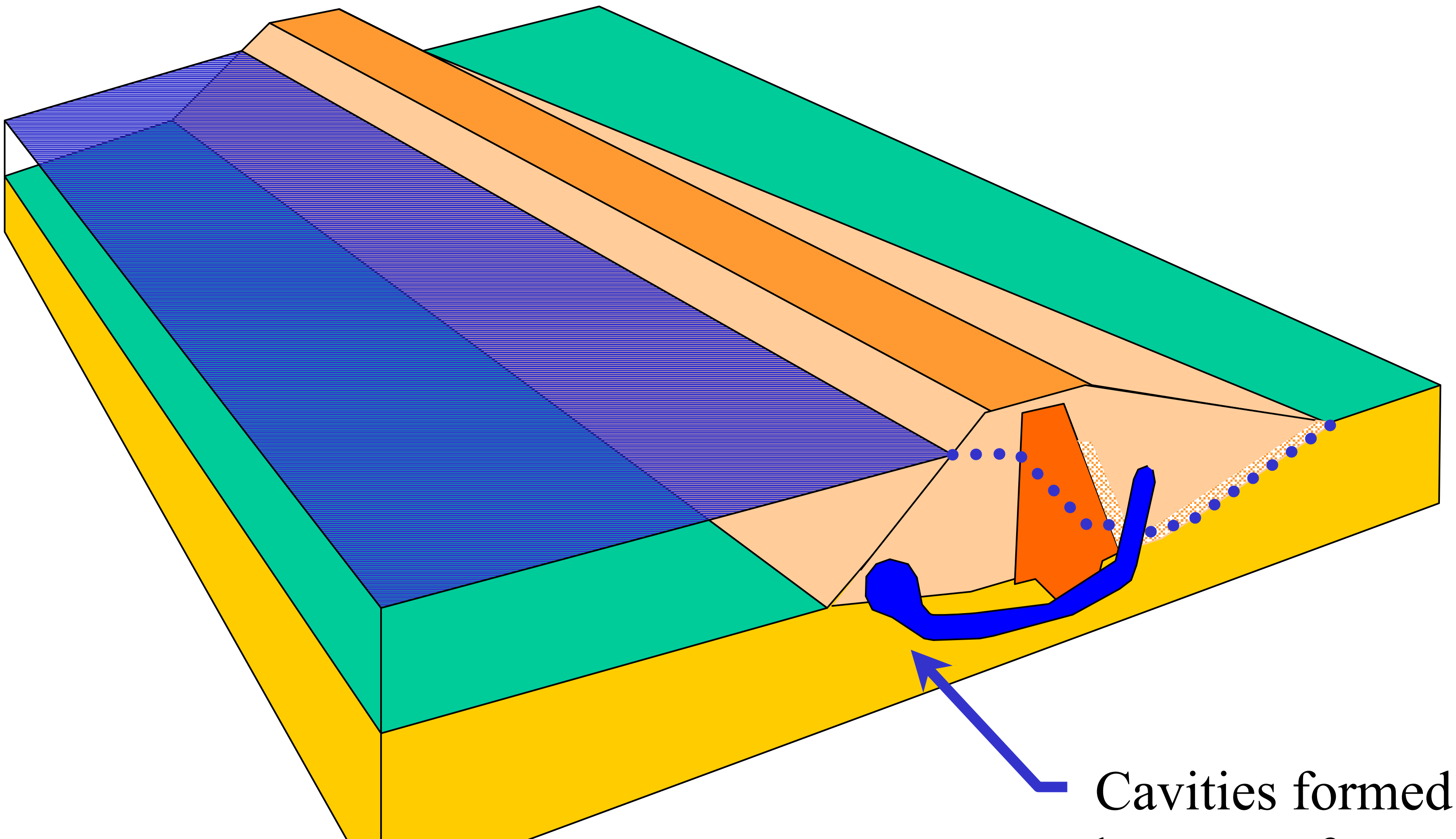
What can happen when cavities in the foundation becomes large?



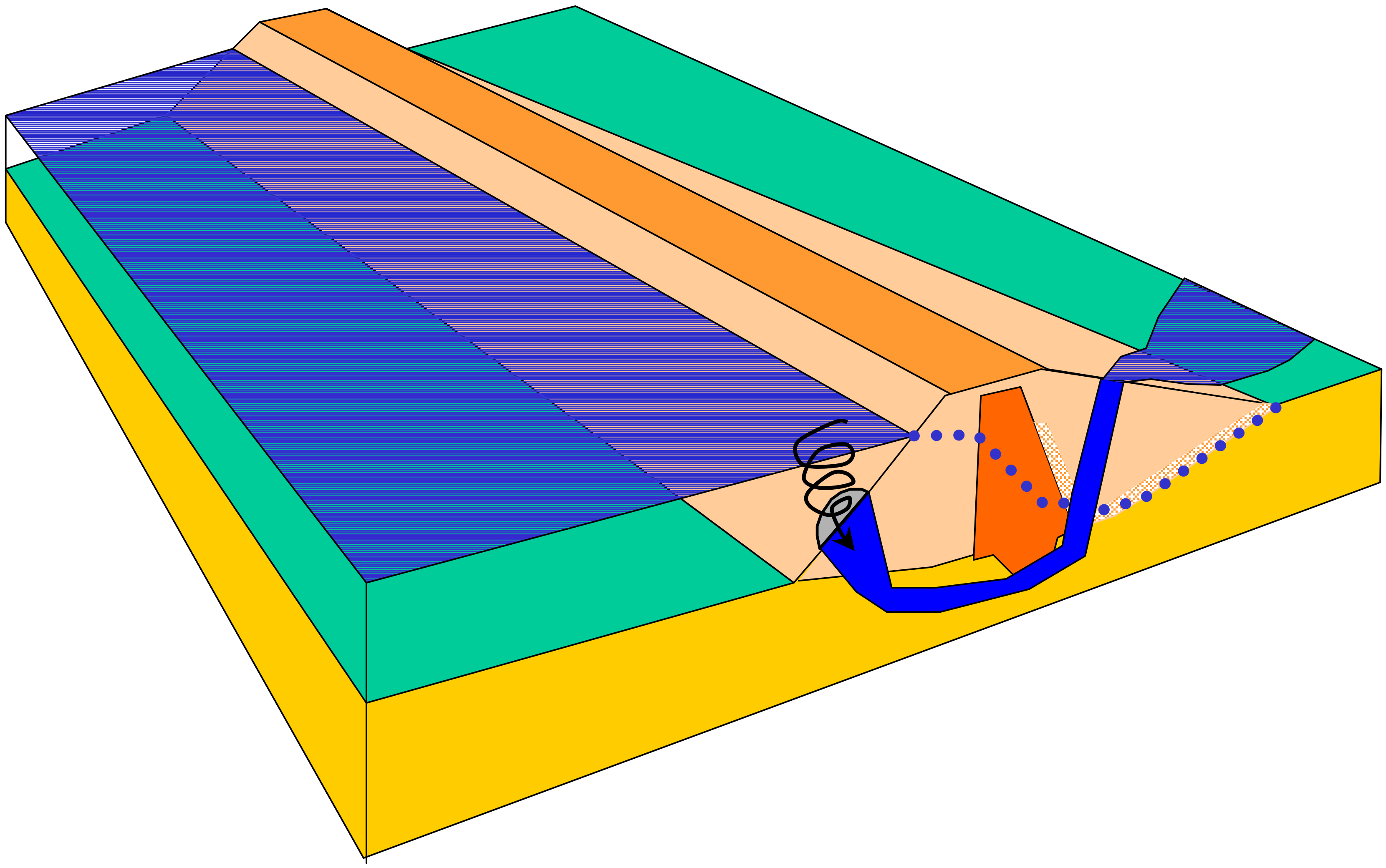
The cavity can extend to the ground surface and ultimately collapse the total dam (like Teton Dam)



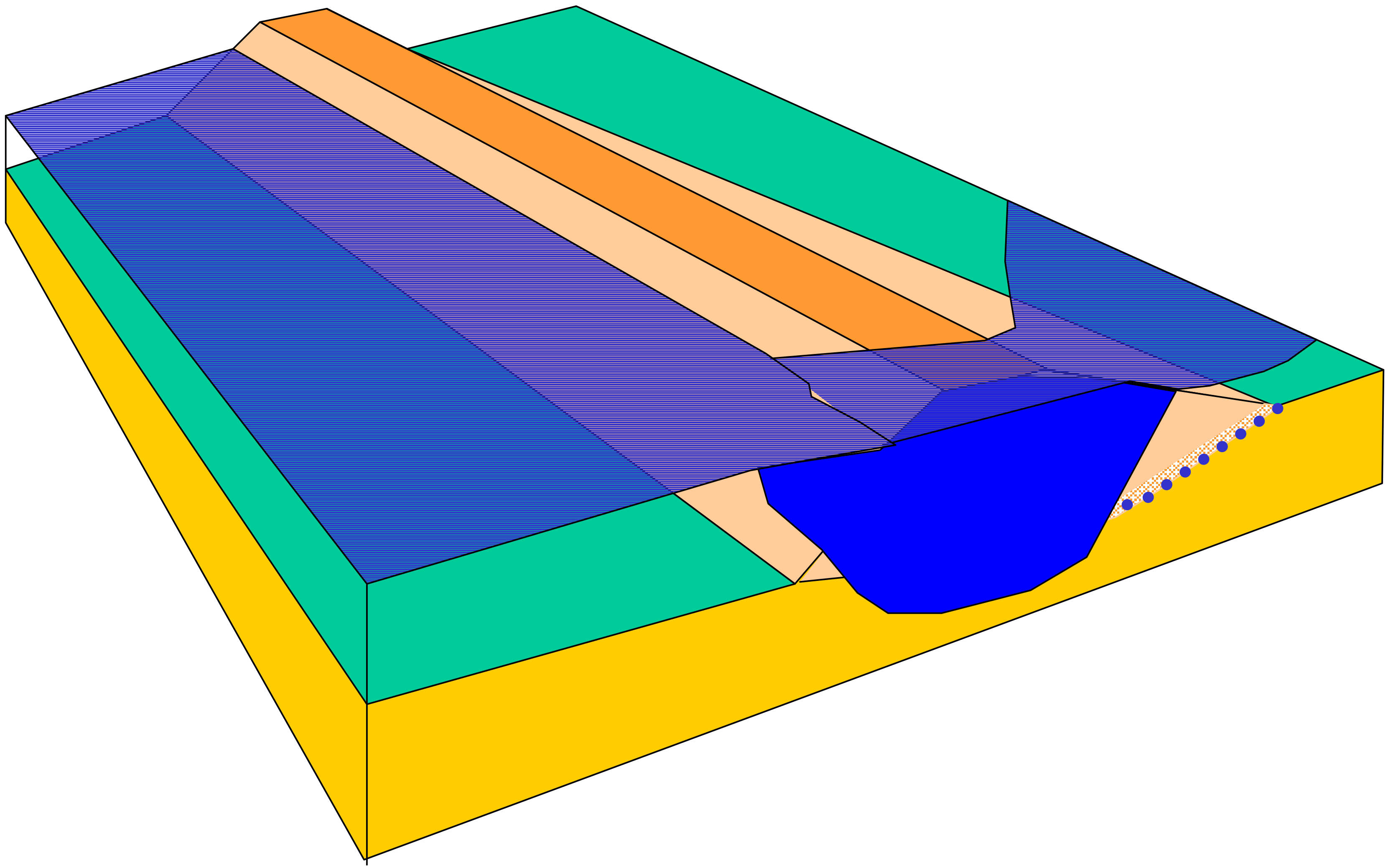


Cavities formed
because of
internal erosion

The cavity can extending the to ground

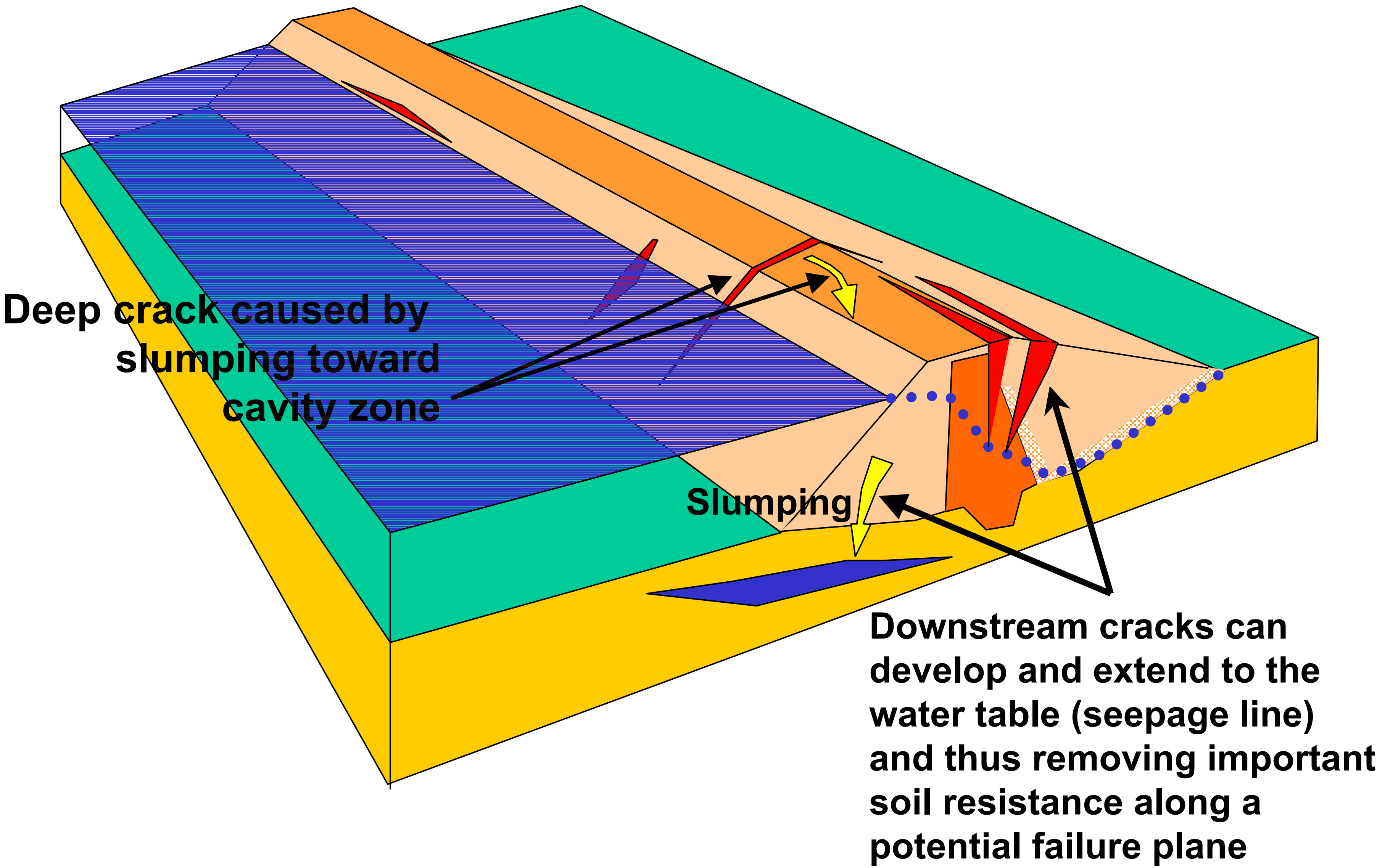


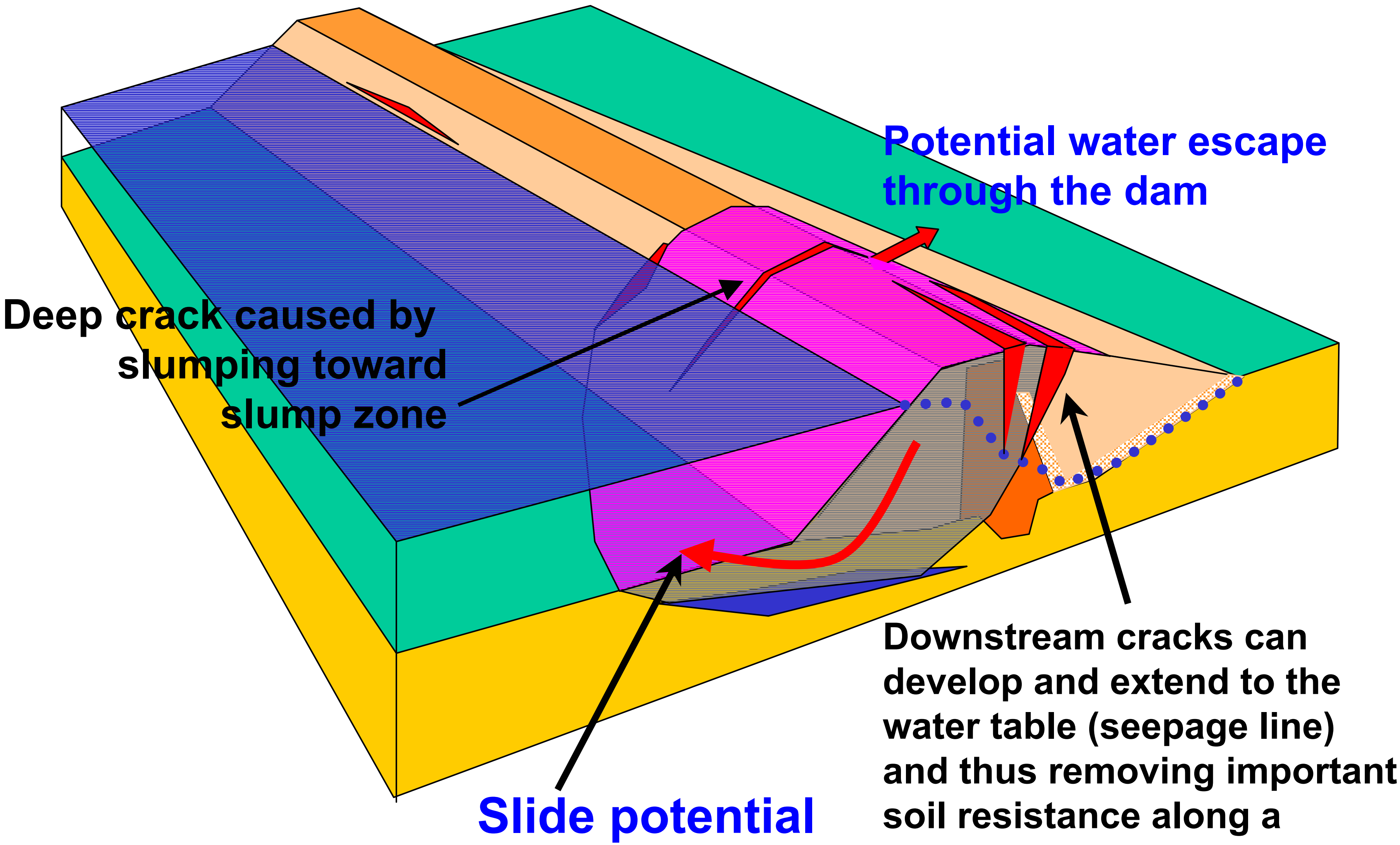
The cavity is now releasing the reservoir



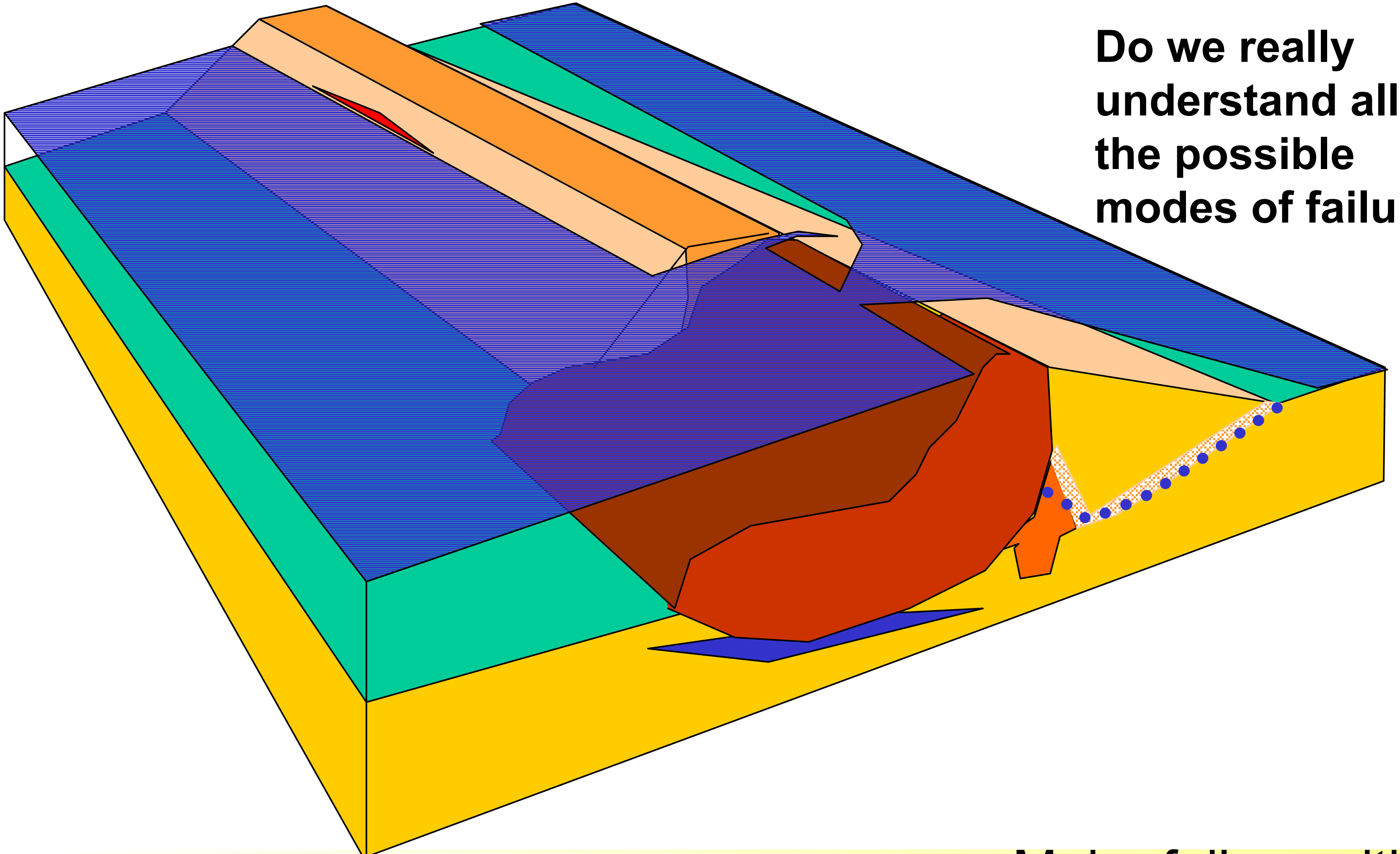
Total release of the reservoir

Alternatively the cavity can cause slope instability and total failure




Potential water escape through the dam
Deep crack caused by slumping toward slump zone
Slide potential
Downstream cracks can develop and extend to the water table (seepage line) and thus removing important soil resistance along a potential failure plane

The next geotechnical based failure of of an earth dam MAY NOT be a simple repeat of Lower San Fernando Dam, Teton dam, or Japanese Levees, etc



Do we really understand all the possible modes of failure

Major failure with water release because of cracks

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Thank You
ERDC GSL