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
Moving data during emergencies
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 injured
  (data gathering must therefore not require people input)
- New technology development is needed to decrease information FOG
Why is Data flow so important?

• Or is it information flow?

• *Information follows data*
Recon System for the previous 4 years
Combining GPS and digital photos with off the shelf software

Combine using Grapher and Fugawi software

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

Flexibility

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

Hardware Parts and software interface

Pan tilt magnetic bearing

GPS devices

Laser distance device (vertical height)

Digital Cameras;
- high speed real-time images and high resolution pictures

Hardware Parts

monitor
State-of-the-art off the shelf
VGA display
Real-time Image Processing

A real-time display of camera images and a database problem areas
Taking pictures of problem areas from different angles
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.

Lecture on Landslides – By Dr. Richard S Olsen
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

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
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)
Observed Landslides during this mission

City of San Salvador

Santa Tecla "Destructive" Landslide

Los Chorros "Chute" Landslide

San Vicente "Massive" Landslide

City of San Vicente

Epicenter of the 2001 February Earthquake

City of San Salvador
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.
Landslide observations along the Pan American highway

UTM NAD27 250028 1512355

The “chute” Landslide

Secondary overflow

Main overflow

Sidewalls 5 to 10 m

Approx 18 meter “Debris fall”

MAJ Sibayan

COL Goetchius

Landslide observations along the Pan American highway

UTM NAD27 250028 1512355
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

2001. 2. 7. 17:17
Dr. Richard Olsen  
Geotechnical and Structures Laboratory (GSL)  
US Army Engineer Research and Development Center (ERDC)

Santa Tecla Landslide

Cracks were measured along the total length of the hill by another agency.

So why did the landslide occur where it did?

500 deaths – 300 homes destroyed

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

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

The San Vicente Landslide

Dr. Olsen  ERDC

San Salvador
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
Dr. Richard S Olsen
OlsenR@WES.Army.mil
EQ recon in 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.
Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

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

City of Adapazari, Turkey

N40.775 E30.4045

Kocaeli (Izmit) Earthquake - 1999 Aug

Dr. R. Olsen, USA-ERDC-WES 99-Aug-25
EQ recon in Taiwan
Sun Moon Reservoir

This reservoir is the major water supply for Taichung

Shuishih Dam
(Earth filled dam with concrete cutoff wall in core - this dam experienced cracking due to settlement)

Fault

Water intakes

Toussih Dam
(Earth filled dam with counter weight beam that experienced cracking)

Dr. R.S. Olsen
ERDC - WES
Taiwan Chi Chi Earthquake 1999-9-21
Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)

Shuishih Dam
Earth dam on a rock foundation with a concrete wall in the core
Built in 1934 by the Japanese

Taiwan Chi Chi “921” Earthquake 1999-09-21

Sun Moon Reservoir

Dr. R.S. Olsen ERDC-WES
Shuishih Dam

Taiwan Chi Chi “921” Earthquake
1999-09-21

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.

Dr. R.S. Olsen - ERDC
Shuishih Dam – Sun Moon Reservoir
What causes the settlement and cracks?

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

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

- Reflection cracks from the concrete cutoff wall and other cracks
- Rock foundation
- The clay core has a low settlement potential
- Concrete cutoff wall into foundation

Taiwan Chi Chi “921” Earthquake 1999-09-21
Possible sequence of events that created the landslide dam

Taiwan Chi Chi “921” earthquake

Dr. R.S.Olsen
ERDC-WES

Sequence 1
Sequence 2
Sequence 3
Liquefaction observations in Taiwan
Taiwan Army base near the town of Chi Chi

Liquefaction and lateral spreading were observed

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)
Taiwan Army base near the town of Chi Chi

Taiwan Chi Chi “921” earthquake
August 21 1999

Dissection of a liquefaction boil

Liquefaction material travel path from the vertical opening

Silt to high silt content sand
(Second material out of the hole)

Low silt content sand
(First material out of the hole)

Dr. Richard S. Olsen
ERDC-WES
www.Liquefaction.com/eq99

1999. 9. 30

Dr. Richard Olsen
Geotechnical and Structures Laboratory (GSL)
US Army Engineer Research and Development Center (ERDC)
Taiwan Army base near the town of Chi Chi

The wings of this building complex differentially settled due to liquefaction.
2001 Seattle Earthquake Recon
Assessment of
Howard Hanson Dam
Each crack was caused by modulus differences (i.e. material differences or trenches)

Gravel was not crushed – thus the pier did not repeatedly hit the slab during the earthquake

2001 August 16
Lecture on Landslides
By Dr. Olsen
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
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.

Dr. Richard Olsen  
Geotechnical and Structures Laboratory (GSL)  
US Army Engineer Research and Development Center (ERDC)
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)
Sliding Surface Made up of Several Segments
Borings and intersections with landslide slip plane
Landslide was triggered at the north side of the toe (toe was blown out due to high exit seepage gradient)

From witness interviews:

- Times for maximum landslide movement:
  - 7am
  - 6pm
  - 9pm
  - 2pm
  - 6pm

The two evaluated slip plane locations.
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
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

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
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?

This tube is like a sand layer that extends up the slope but is plugged at the end.

Localized landslide can either block the sand layer or relieve the pore pressure.

Hillside geometry can concentrate seepage & cause high pore pressure.

Inclined sand layers can have extremely high water (pore) pressure.

Artesian water pressure

Lecture on Landslides – By Dr. Richard S. Olsen
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 next break

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?
Liquefaction reduces the shear modulus dramatically

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

Slope movement occurring (keeping a constant shear stress) (ie Sheffield Dam)

No slope movement allowed (Strain softening is reducing the static shear stress level) (ie Lower San Fernando Dam)

Static stress-strain behavior

FS=1.5

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

Lecture on Landslides – By Dr. Richard S Olsen  ERDC  OlsenR@WES.Army.mil
Two Modes of Failure because of modulus & pore pressure
What can happen when cavities in the foundation becomes large?

Cavities formed because of internal erosion.
The cavity can extend to the ground surface and ultimately collapse the total dam (like Teton Dam)

Cavities formed because of internal erosion
Cavities formed because of internal erosion.
The cavity is now releasing the reservoir
Total release of the reservoir
Alternatively the cavity can cause slope instability and total failure.

Deep crack caused by slumping toward cavity zone.

Downstream cracks can develop and extend to the water table (seepage line) and thus removing important soil resistance along a potential failure plane.
Downstream cracks can develop and extend to the water table (seepage line) and thus removing important soil resistance along a potential failure plane.

Deep crack caused by slumping toward slump zone

Potential water escape through the dam

Slide potential
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?