MINIMIZING GEOTECHNICAL SURPRISES

by

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Will examine two case histories involving geotechnical failures or special problems and evaluate each in terms of whether it should be considered unexpected (an act of God) or could/should have been anticipated.

If it is the latter, then how minimize such adverse outcomes in the future?

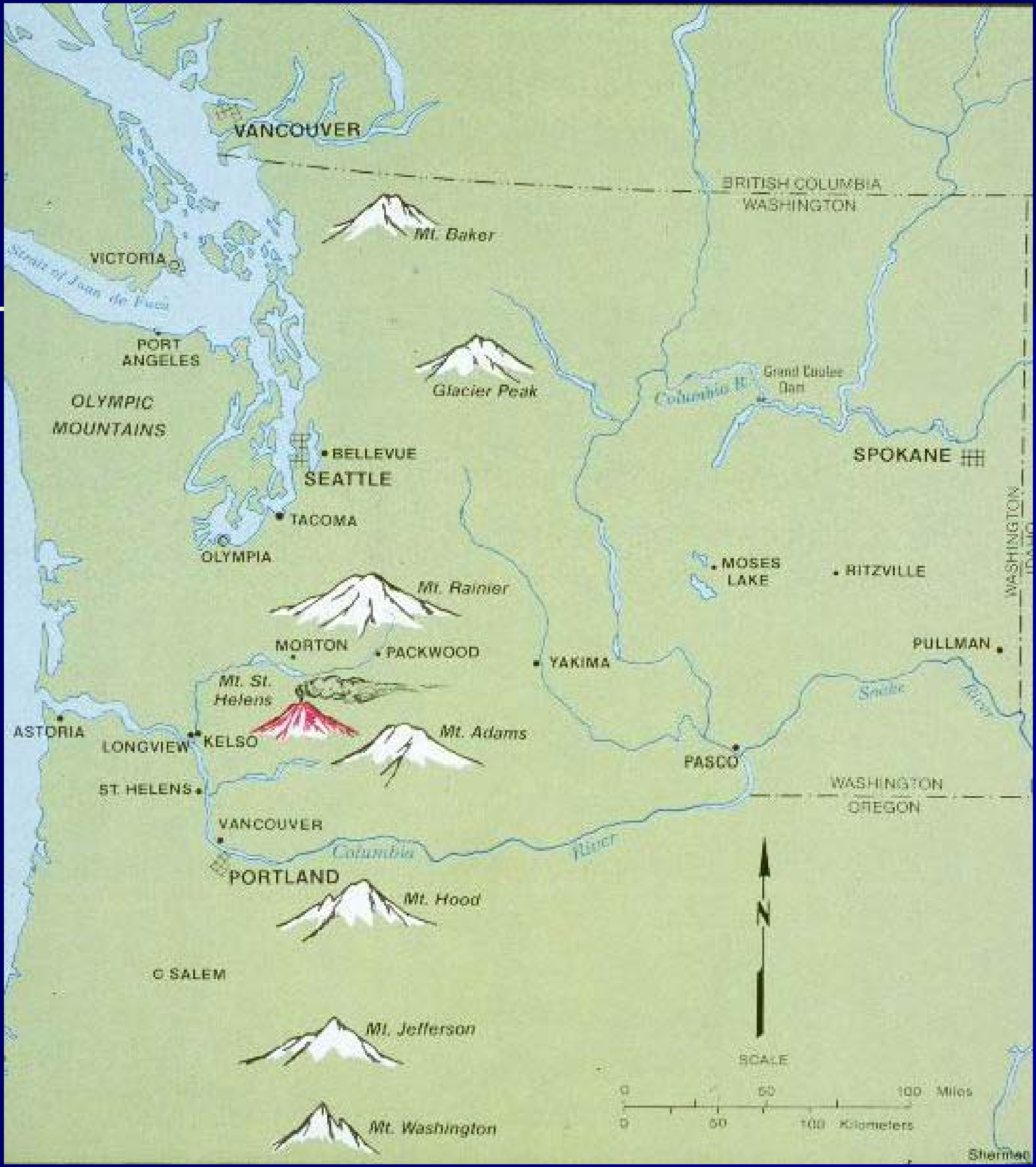
THE CASES:

- Unusual soil types leading to difficulties in embankment dam construction
- Slowly moving landslide damage to a roadway and a bridge

CASE 1

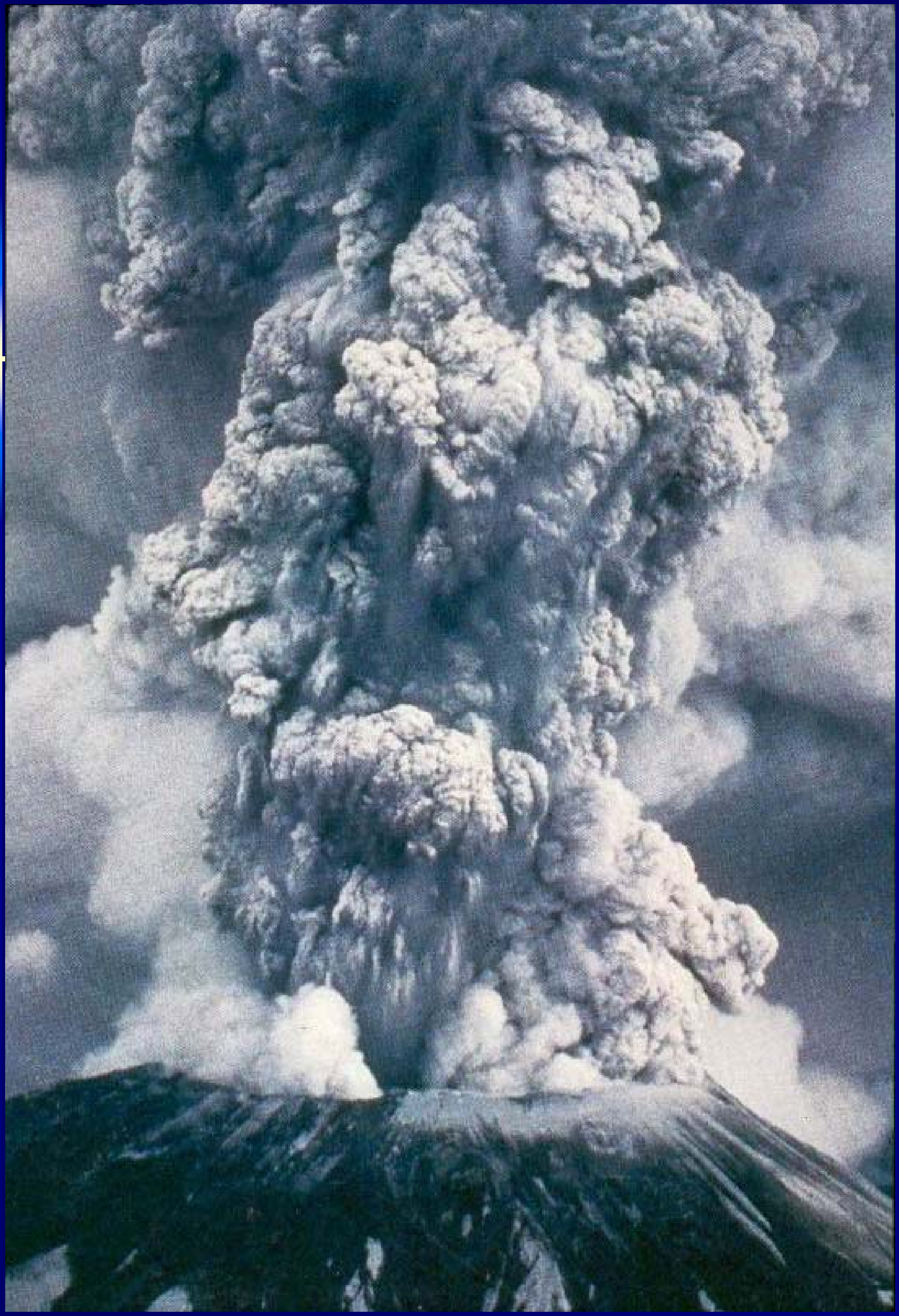
Construction Problems with Unusual Soil Types

THE PROJECT



Major peaks in the Cascade Mountains of the Pacific Northwest

May 18, 1980 Eruption of Mt. St. Helens

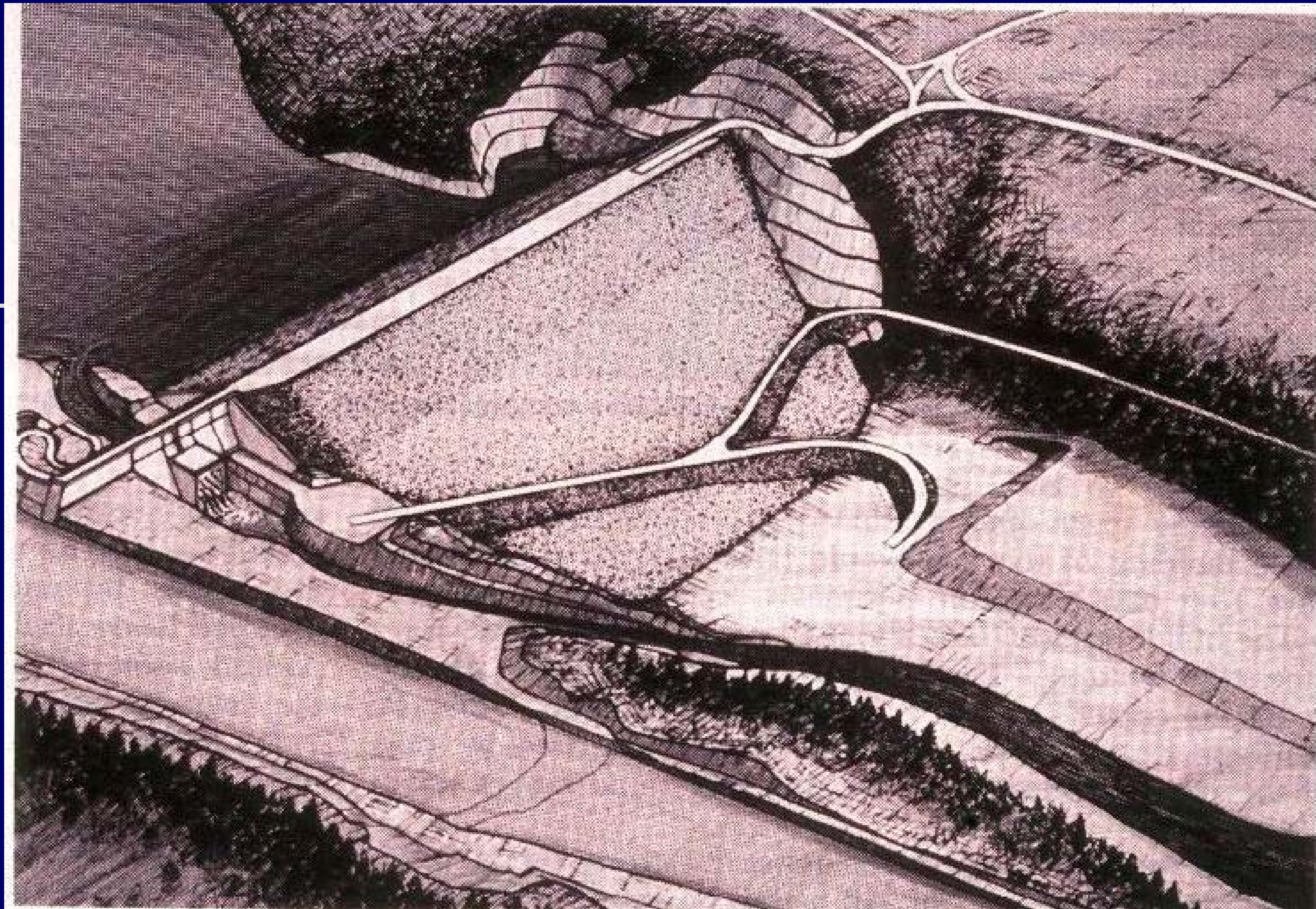


A magnitude 5+ earthquake at 8:32 a.m. set the blast in motion. Huge masses of rock began sliding down the mount's north flank, releasing gas pressure inside. Within seconds the whole north face exploded in a cloud of ash, rock fragments, and hot gases rushing northward at speeds up to 120 miles per hour. Once uncapped, the eruption continued vigorously until late afternoon. The top 1200 feet of the mountain rose in a billowing dark-gray plume of pulverized rock 11 miles high, and began drifting east.

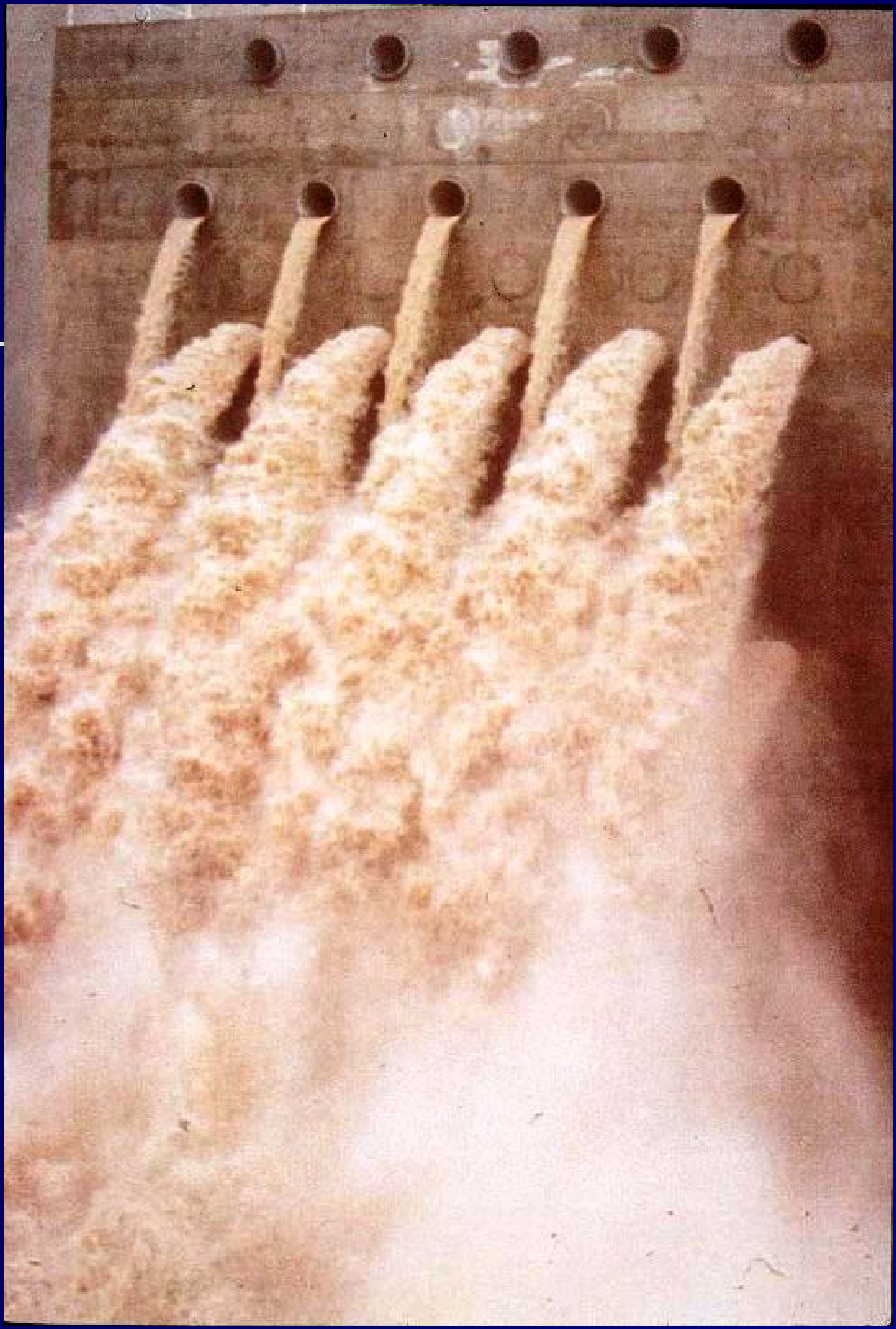
(https://www.nwp.usace.army.mil/op/srs/crisis.asp, accessed January 5, 2006)

--- the avalanche of rock, mud and ice released by the earthquake roared down the mountain, turned westward and surged 17 miles down the North Fork Toutle river valley; one of the largest landslides in history. Another part of the slide pushed north across the valley, overtopped the ridge and flowed down South Coldwater canyon. The eastern part rammed into Spirit Lake, raising the lake level about 200 feet and blocking its outlet with debris hundreds of feet deep. Massive mudflows choked the Toutle and Cowlitz rivers and brought shipping to a halt on the Columbia River.

(https://www.nwp.usace.army.mil/op/srs/crisis.asp, accessed January 5, 2006):



Sediment Retention Structure built by USACE to capture 650 million cu yd (500 cu m) ash and sediment over next several decades. Dam is 1800 ft (550m) long and 184 ft (56 m) high



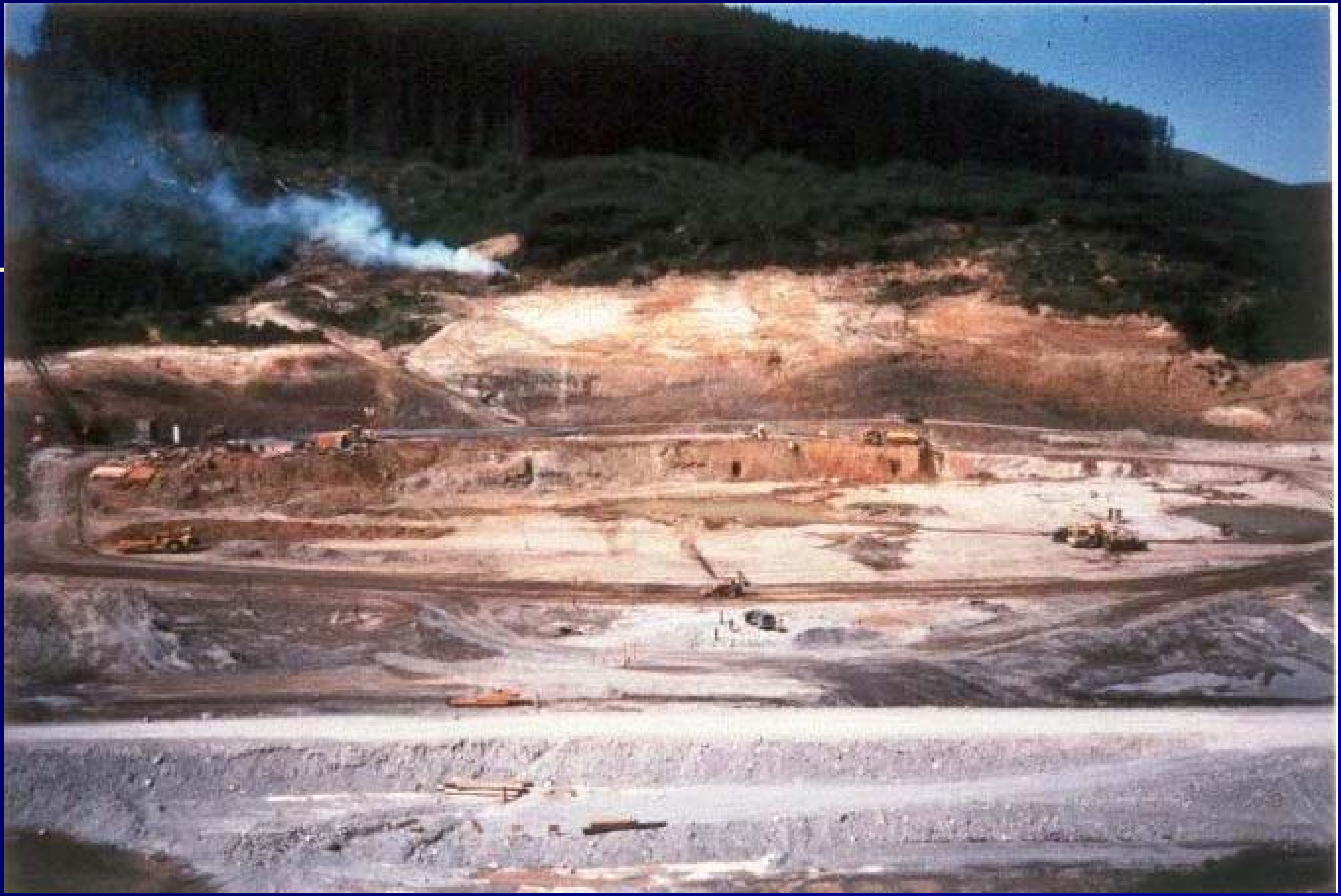
SRS Outfall Structure on right abutment.

30 three ft (1 m) dia, 122 ft (37 m) long pipes in six rows. Progressively close off rows as sediment level rises.

THE PROBLEM

Unanticipated soil conditions during construction caused difficulties in excavation, handling, stockpiling, and compaction. Five material types caused problems:

- Old glacial drift and pre-eruption alluvium ("gravels") on left abutment
- Fine-grained sediment over the gravels
- Surficial layer ("slimes") below topsoil in both abutment areas
- Impervious overburden under slimes on right abutment
- Flow breccia underlying impervious overburden



Left abutment area on June 30, 1987. Gravels and overlying fine-grained materials on cut slopes were source of handling and stockpiling problems during initial excavation.

Right abutment area on June 30, 1987. Dark material at top is the "slimes", lighter material beneath is the impervious borrow, and the lower dark zone is the flow breccia.


Mt. St. Helens
Reclamation Project

The Contractor's Problems:

- Glacial drift gravel was soft and unstable during excavation and wet weather (had hoped to use it as a stable base) – would not support construction equipment.
- Stockpiled excavated material was unstable – flowed up to 500 ft (152 m) until stable slope at 2 – 5 degrees.
- Fine-grained sediments above gravels were unstable.
- Slimes in right abutment area unable to support construction equipment.
- In-situ water contents well above optimum.
- Right abutment impervious overburden, designated for use in core, softened during compaction and appeared wettest in areas subjected to heaviest construction traffic.
- Flow breccia exhibited slaking.

Unstable stockpile slope of old glacial drift gravels excavated from the left abutment area of the Mt. St. Helens Sediment Retention Structure.

THE CAUSE

Soils from volcanic ash in wet environments are referred to as andisols.

"Andisols are soils developed from volcanic ash. ------- Mt. St. Helens recent eruptions resulted in huge outpourings of volcanic ash. Mt. St. Helens falls on the 'circle of fire' that rings the Pacific. ----- These soils possess unusual properties and therefore attract the attention of agronomists and engineers alike.

The unusual properties of Andisols are related to the extreme fineness of the weathering products of volcanic glass. ------ These high specific surfaces result in soils with low dry densities (< 0.5 gm/cm3) and high water retention capacities."

(from Uehara, 1982)

"These soils have unusually high natural water contents, high liquid limits and plastic limits, and low plastic indices. They show different moisture density relationships before and after drying. Optimum water contents for these soils are usually below the natural water content."

Thrall and Bell (1989)

From ENR, May 7, 1989, in a story on explorations for a new highway between project site and Mt. St. Helens:

"We soon discovered from early drilling results that we were not dealing with standard soils but with 'funny' soils that are full of interesting minerals with high moisture content ---- we soon concluded that much of the excavated material would have to be wasted rather than used in fills as we had hoped."

(Steve Lowell, WSDOT Chief Eng. Geologist

Mineralogy of the Clay Fraction

- In the gravels – expansive smectite
- In the fine-grained units – halloysite
- Lesser amounts of chlorite, vermiculite, and expandable mixed-layer clays
- Iron oxides

CHARACTERISTICS OF THE MINERALS

- Halloysite in hydrated form:
  - Low compacted density
  - High optimum water content
  - Clusters of clay particles cemented by iron oxides
  - Structural breakdown when disturbed
  - Hard to dry
  - Irreversible property changes after drying at T > ~60°C
- Smectite:
  - Swell on wetting; shrink on drying
  - High plasticity
  - Low strength at high water content
  - Small amounts can cause big problems

GEOTECHNICAL SURPRISE – OR WAS IT?

Relevant Considerations

- Bid documents did not indicate unusual soil types
- Schedule required excavation and materials handling during winter and spring (wet)
- Left abutment gravels indicated as (GW), (GP), (SP) and dense. Tests indicated some (GC), (SC), (SM), (CL) and (MH) and some "clay pockets" in the deposit
- Coarse particles susceptible to breakdown

Relevant Considerations (Cont.)

- Fine-grained sediments from left abutment indicated mainly as fine-grained.
- "Some problems will probably be experienced in excavating the fine-grained material due to excess moisture" – but memorandum evidently not provided to bidders.
- One of two sets of compaction test data gave γ_d = 74-75 pcf (1.18-1.20 kg/cu m) and w_{opt} = 43-44%.
- Right abutment impervious overburden had similar characteristics – bid documents did indicate that traction might be difficult in wet weather.

Relevant Considerations (Cont.)

- Owner aware of instability of flow breccia on right abutment, but information evidently not included in plans and specs.
- Unusual characteristics of residual soils in Cascade Mountain areas have been source of problems in the past.
- Could, would, should the contractor have anticipated the difficult construction conditions?

Mt. St. Helens Sediment Retention Structure Today (from USACE Portland District Web Site)

CASE 2

Landslide-Induced Road Failure and Bridge Distress

THE PROJECT

Project is at the Forest City Bridge on the Oahe Reservoir, SD

(Slide courtesy of Vern Schaefer)

Aerial Photograph - 1962

Slide courtesy of Vern Schaefer

After Law Engineering 1976

The Background

- Oahe Dam construction near Pierre, SD in 1950s caused a water level rise of ~100 ft (30 m) at Forest City about 40 miles (64 km) upstream.
- A replacement bridge constructed to provide a crossing for U.S. 212 across the reservoir.
- Bridge is a 4600 ft (1402 m) long steel structure that combines continuous plate girders and cantilever through trusses. Foundation is concrete piers supported by steel H-piles penetrating fill and alluvium into Pierre Shale. Maximum pile depths of 140 ft (42.7 m).
- Reservoir reached normal operating levels in 1968.

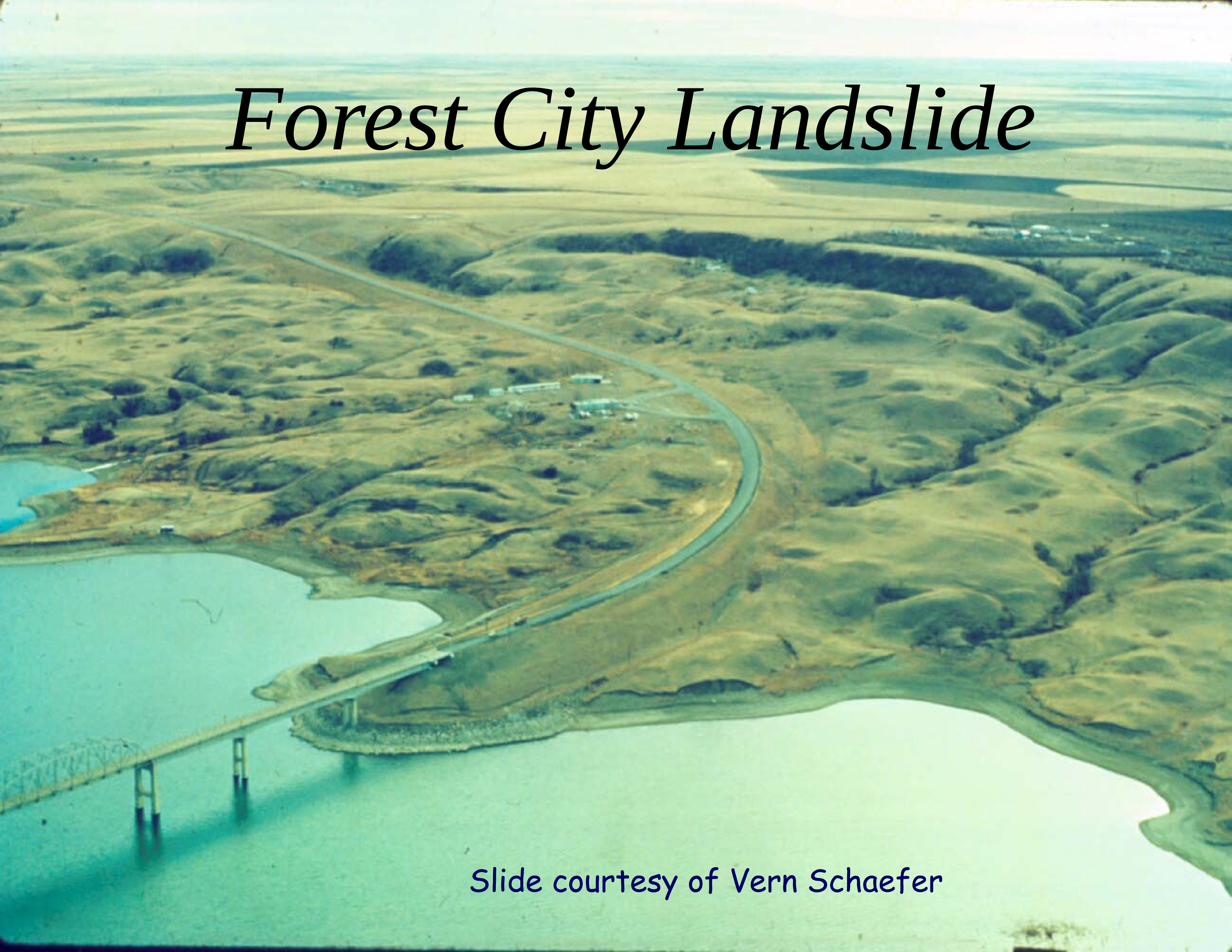
The Background (Cont.)

- Southern approach road (2-lane, asphalt paved) descends on a 6 percent grade from el. 1900 (579 m) to el. 1670 (509 m) in distance of 5000 ft (1524 m).
- It traverses for 2000 ft on fills up to 20 ft (6 m) high.
- Southern bridge approach embankment is about 1000 ft (305 m) long and 20 to 40 ft (6-12 m) thick.

THE PROBLEM

The Forest City Landslide

- Large old slide extends 8000 ft (2440 m) along the Oahe Reservoir and 3000 ft (914 m) inland.
- Bridge about midway along the slide.
- Unstable area covers about 640 acres (260 ha) and involves about 75 million cu yds (57 million cu m) of soil and rock debris.
- No evidence of slope movement for several years prior to bridge construction.
- Slide movement began again during filling of the reservoir (1958-1968).

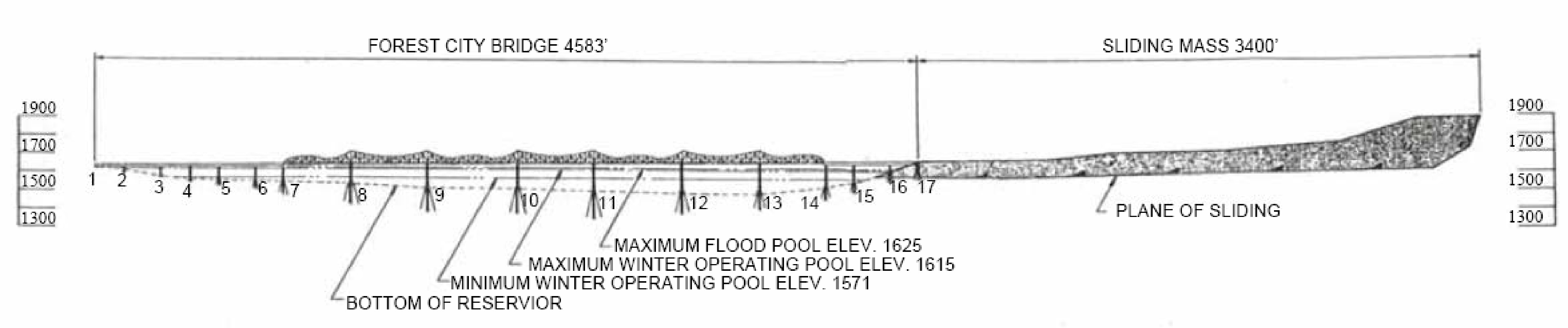

Forest City Landslide
Slide courtesy of Vern Schaefer

Effects on the Bridge

- Minor shortening of the deck observed in 1962.
- Closed expansion device in sill at south abutment discovered in late 1965.
- South end of bridge extended about 35 ft (10.7 m) and bearings and joints modified to adapt to slide movements in 1975.
- Bridge floor system stiffened in 1977.
- South abutment sill at pier 17 rebuilt in 1987.
- Warning system installed to close bridge in event of catastrophic failure

Effects on Roadway and Approach

- Roadway movements and cracking observed in 1968.
- Continuous maintenance required thereafter.
- Seven ft (2.1 m) of additional asphalt by 1973 in some areas.
- In 1980s SDDOT ceased repaving the approach road and simply maintained the grade and a gravel surface.
- Original grade was down onto bridge; it ultimately sloped upward.



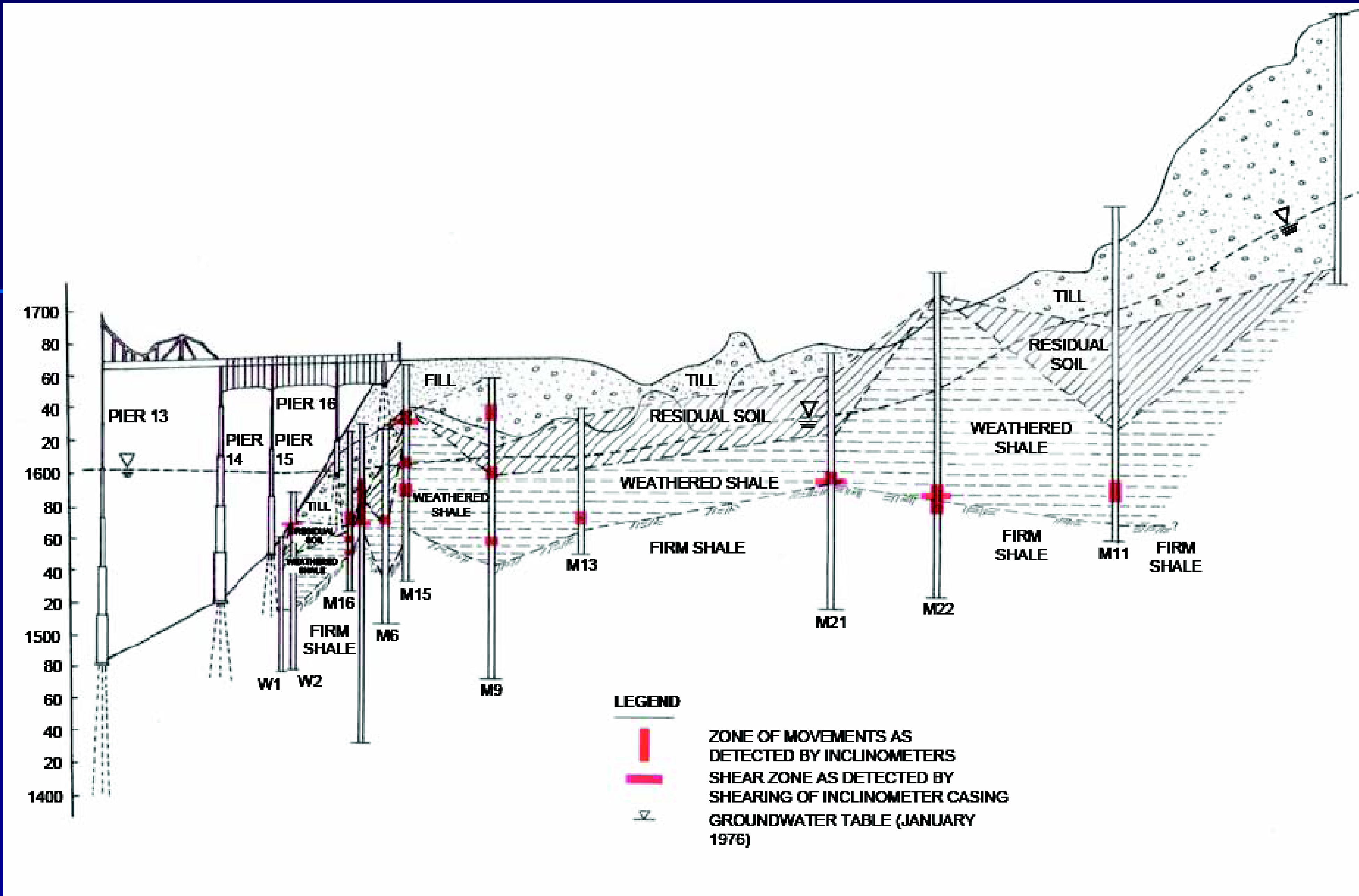
Forest City Bridge and Landslide

No Vertical Exaggeration

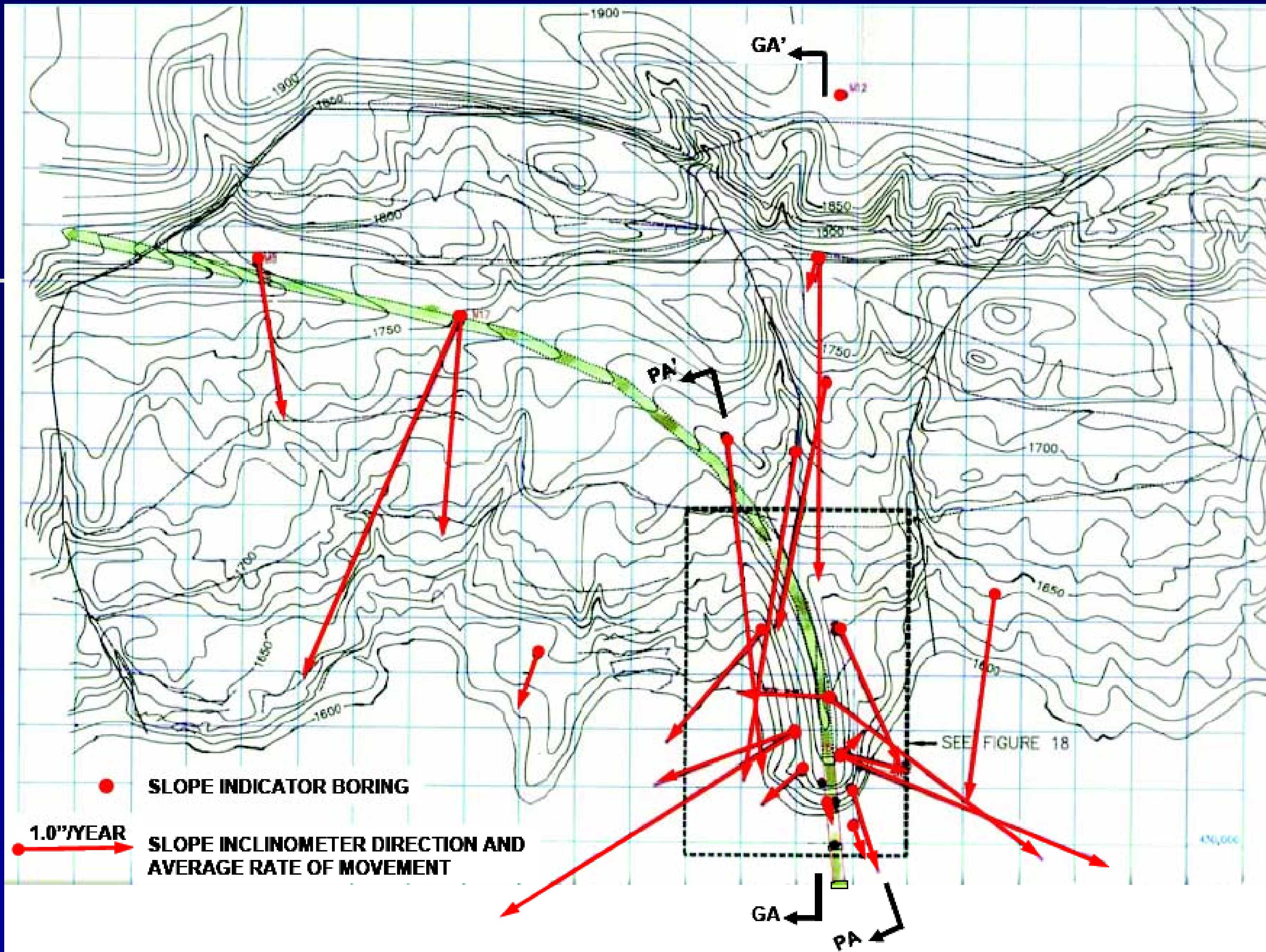
THE CAUSE

Observations

- Water level in slope rose when reservoir filling began.
- Local failures developed along shoreline and under approach embankment.
- Movement velocities up to a few inches per year were recorded.



Materials and shear zones in vicinity of the south abutment



Slide movement rates and directions during the mid-1980s

Source and Reasons for the Movements

- Sliding occurred in the Pierre Shale.
- Pierre Shale in vicinity of the bridge is an overconsolidated smectite (montmorillonite/bentonite).
- Unloading and weathering led to internal fracturing, swelling, and strength loss.
- Progressive failures are common.
- Many slopes at F.S. near 1.0.
- Values of residual friction angle at Forest City are from 3.2 to 7 degrees.
- Bridge out to Pier 16, the south abutment, and approach road up to slide scarp were built on old slide initially at F.S.≈1.0.
- Rising water level reinitiated slide movements.

GEOTECHNICAL SURPRISE – OR WAS IT?

Prior Knowledge

- Hummocky ground identified as a glacial end moraine in 1952 preliminary site studies.
- Pierre Shale well known for low strength and expansive behavior.
- Hummocky surface in vicinity of slide is a good indicator of instability.
- Lab tests on bentonitic zones in Pierre Shale gave ϕ_{peak} of 10 - 12° and $\phi_{residual}$ of 6 - 7°.
- Not surprising that initial F.S.≈1.0 given that slope rises at about 6.5° from reservoir to scarp.

What if:

- The marginal stability of the existing slopes had been recognized?
- The Pierre Shale had been identified as the critical formation?
- The role of the increasing water level had been appreciated?

The Rest of the Story

- In-situ reinforcement in 1993 to stabilize approach embankment in vicinity of south abutment.
  - Stone columns
  - RC dowels
  - Rip rap at toe to reduce erosion
- New corridor for the approach road excavated on 5 percent grade in 1994-1995.
- Stone column shear pins installed in 1998 around the approach embankment.
- Structural T's placed to reduce local approach embankment movements at bridge abutment.

Excavation of slide near its head. (Slide courtesy of Vern Schaefer)

View of Cut Six Years Later

Photo courtesy of Vern Schaefer

SOME REASONS FOR GEOTECHNICAL SURPRISES

Poor Communication

- Incomplete and incorrect information
- Failure to define terms and conditions
- *I know you believe you understand what you think I said, but I'm not sure you realize that what you heard is not what I meant.*

- A significant part of the problem at Mt. St. Helens?

Overconfidence

- Experts tend to be overconfident.
- People become insensitive to how much they know.
- *If I hadn't believed it, I never would have seen it.*

- Extrapolation of 8.5 degree friction angle at Oahe to Forest City.

Failure to Consider All Relevant Conditions

- Identification and evaluation of *all* possibilities probably impossible.
- Fault trees and risk analyses can help.
- Lack of knowledge, lack of experience, and lack of precedent result in overlooking key factors.

- Destabilizing effect of reservoir filling at Forest City Bridge.

Insufficient Knowledge of Conditions

- We never have all the data and information we'd like.
- Uncertainty and the need for assumptions.

- Insufficient information provided to contractor at Mt. St. Helens.

Unanticipated Changes

- Can never know exactly what lies ahead.
- *Predictions are very difficult – especially about the future.* (Neils Bohr)
- *"--- experts are no better at making predictions than dart-throwing monkeys or (not to be confused) careful readers of the newspaper. Experts are over-confident, choose evidence that supports what they already believe and are loath to remember, let alone admit, when they are wrong. (Goodman, 2006)*

Wishful Thinking

- If we ignore it, it *won't* go away.
- Prior experience and observations cannot be ignored.
- *Murphy was an optimist*

  (First corollary to Murphy's Law)

- The Forest City topography, old slide, and prior experiences in the Pierre Shale were indicators of potential stability problems.

Lack of Experience or Precedence

- Projects at the frontiers of knowledge are two-edged swords:
  - Can yield quantum jumps in knowledge
  - Lack of knowledge can lead to disaster

The Law of Unintended Consequences

- New technologies, materials, and methods developed to solve problems in one way inevitably cause new problems in another.
- You can never do only one thing.

- Raising the reservoir at Forest City destabilized the slope.

MINIMIZING GEOTECHNICAL SURPRISES

Communicate Clearly

- We don't all speak the same language.
- Marshall's Laws of Perpetual Perceptual Obfuscation:
  - *Nobody perceives anything with total accuracy.*
  - *No two people perceive the same thing identically.*
- Say what you mean; mean what you say.

Make Good Predictions

- Theoretical models should be sufficiently detailed and validated.
- Complete and reliable data about conditions are needed.
- Experiences under similar circumstances should be studied.
- Effects of construction and site alterations must be considered.
- There should be compatibility among different elements of the project.
- The work must be done correctly and consistently.

(from Van Weele, 1989)

Some Guidelines

- Accept only the facts.
- Consider *all* the facts.
- Don't be afraid to say "I don't know".
- Be a good and critical observer.
- *You can observe a lot just by watching.* (Yogi Berra's Law)
- Recognize uncertainties and limitations – and use the observational method to compensate for them.
- Use judgment – *Sound engineering judgment is the best and most versatile computer program that exists – always available, up-to-date, and easy to revise. (from Van Weele, 1989)*

Concluding Comments

- Surprises (and unfortunately some failures) are probably inevitable.
- Aspire to situation that when there is one we can truthfully conclude that it occurred only as a result of circumstances totally beyond our control.

Geotechnical Surprise - Or Was It?