WV VRS Integrity Manager Proposal

Coal Slurry Impoundment, Bridge, and DamMonitoring

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Agenda

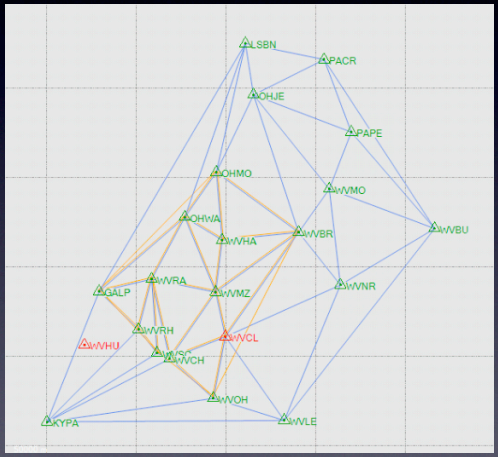
- Introduction
- System Overview
- Case studies & other applications
- Questions/Discussion

Terms

- GNSS: Global Navigation Satellite System
  - GPS, GLONASS, Galileo, Compass
- CORS: Continuously Operating Reference Station
- VRS: Virtual Reference Station server software
- WVCORS/VRS: WVDOH funded, RTI managed network of CORS and VRS software
- Kalman filter: a mathematical method using measurements observed over time with random variations to produce values that tend to be close to the true value of the measurement

WVCORS/VRS Status

- 26 June 2010
- Additional 25 CORS
- Permit GNSS RTK statewide
  - ± 1 cm horizontal
  - ± 2 cm vertical



WV VRS
Network Motion Engine

Map 2D | Current Displacements | Adjustment | Displacement Chart | Axis Rotations | NMEA Output

Station Name	Station Code	Axis Rotation	Δ Northing [m]	Δ Easting [m]	Δ Height [m]	Δ 2D [m]	Δ 3D [m]
Harrisville, WV	WVHA	☐	-0.010	0.172	-0.056	0.173	0.182
Elkins, WV	WVNR	☐	0.003	0.137	0.068	0.137	0.153
Clay, WV	WVCL	☐	0.009	-0.042	-0.143	0.043	0.149
Red House,...	WVRH	☐	0.005	0.067	-0.031	0.067	0.074
Lewisburg,...	WVLE	☐	0.014	-0.003	-0.058	0.014	0.060
Bridgeport,...	WVBR	☐	0.008	0.058	-0.006	0.058	0.059
Cranberry, PA	PACR	☐	0.010	0.058	-0.002	0.059	0.059
Paintsville, KY	KYPA	☐	0.017	0.048	-0.024	0.051	0.057
Perryopolis,...	PAPE	☐	0.006	0.053	-0.002	0.054	0.054
Charleston,...	WVCH	☐	0.008	0.049	-0.013	0.050	0.052
Mount Zion,...	WVMZ	☐	-0.013	0.041	0.027	0.043	0.051
Oak Hill, WV	WVOH	☐	0.026	0.030	-0.017	0.040	0.043
South Charle...	WVSC	☐	0.005	0.023	-0.009	0.024	0.026
Burlington,...	WVBU		0.000	0.000	0.000	0.000	0.000
Wintersville,...	OHJE		0.000	0.000	0.000	0.000	0.000
Ravenswood...	WVRA		0.000	0.000	0.000	0.000	0.000
Gallipolis, OH	GALP		0.000	0.000	0.000	0.000	0.000
Marietta, OH	OHWA		0.000	0.000	0.000	0.000	0.000
Lisbon, OH	LSBN		0.000	0.000	0.000	0.000	0.000
Morgantown,...	WVMO		0.000	0.000	0.000	0.000	0.000
Woodsfield,...	OHMO		0.000	0.000	0.000	0.000	0.000

VRS Integrity Manager

- Add-on package to the WVDOH Virtual Reference Station (VRS) server software
- Detects changes in GNSS/GPS antenna positions versus reference coordinates over time
- Measures these changes and keeps records to allow trend analysis
- Automated alarms and reports based on user defined thresholds

Types of network dynamics

- Acute, Localized
  - Affects a small portion of the network
  - e.g., Roofing; vehicle collision with pillar
- Acute, Widespread
  - Affects the overall network
  - e.g., earthquake
- Chronic
  - Affects smaller & larger portions of the network
  - e.g., Subsidence, tidal loading, continental drift

What does an Integrity Monitor offer?

- The use of GNSS for monitoring a site of interest
  - i.e., dam, mine wall, CORS, coal slurry impoundment
- Ensures quality geodesy
  - Tie the WVCORS network to the national/ regional network
- Discover & compensate for trends in station motion
- Reporting to provide indications of station stability or movement

Software Conceptual Model

Raw GNSS

Reports

Engines

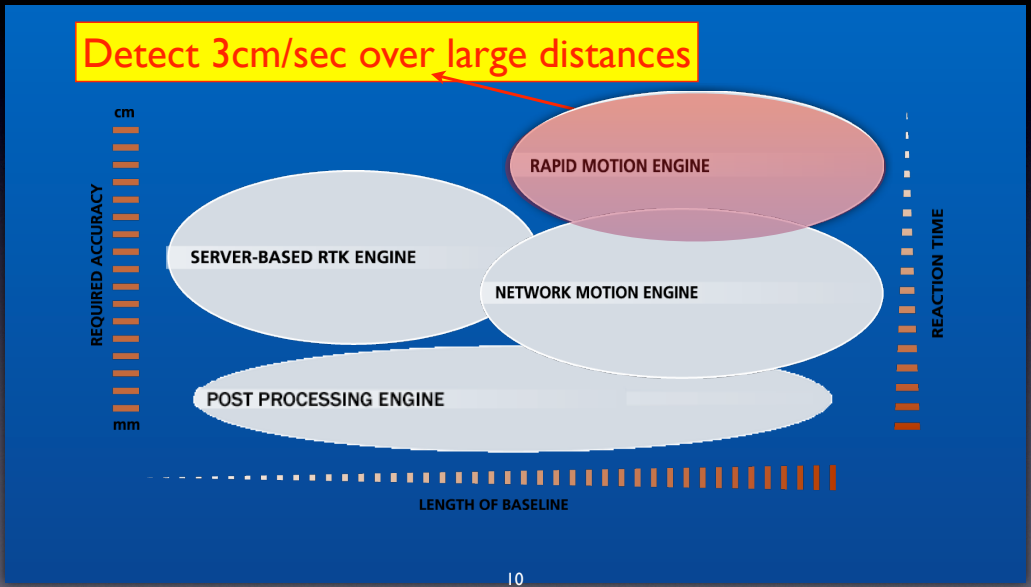
Alarms

Filters

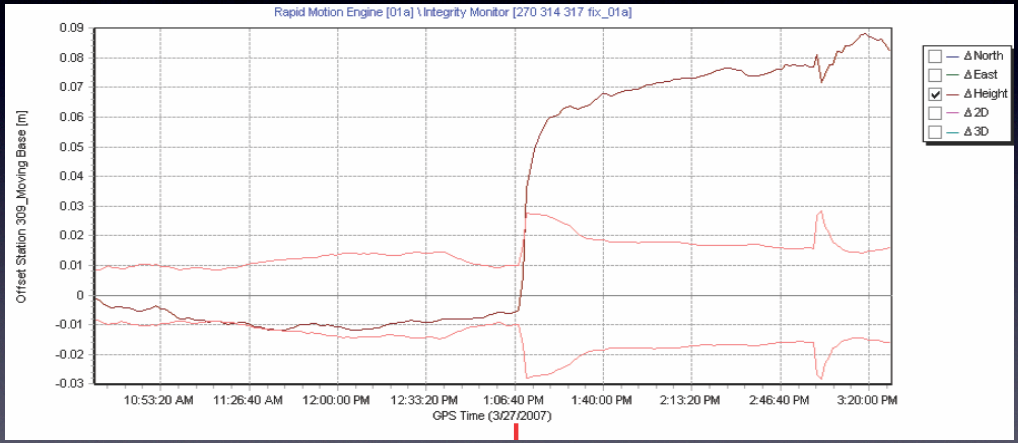
Integrity Manager

Database

Comparing the Engines

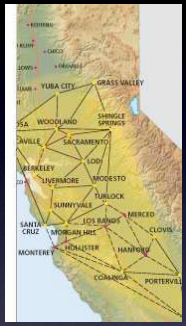


System reaction time



Red line shows time of movement

CSDS Installation



California Survey & Drafting Supply

Uses Integrity Manager software to:

- Monitor the integrity of the reference stations in the CSVSN network
- Expand the CSVSN network when stations are added
- Calculate new coordinates when updates are required

*California Survey Virtual Survey Network

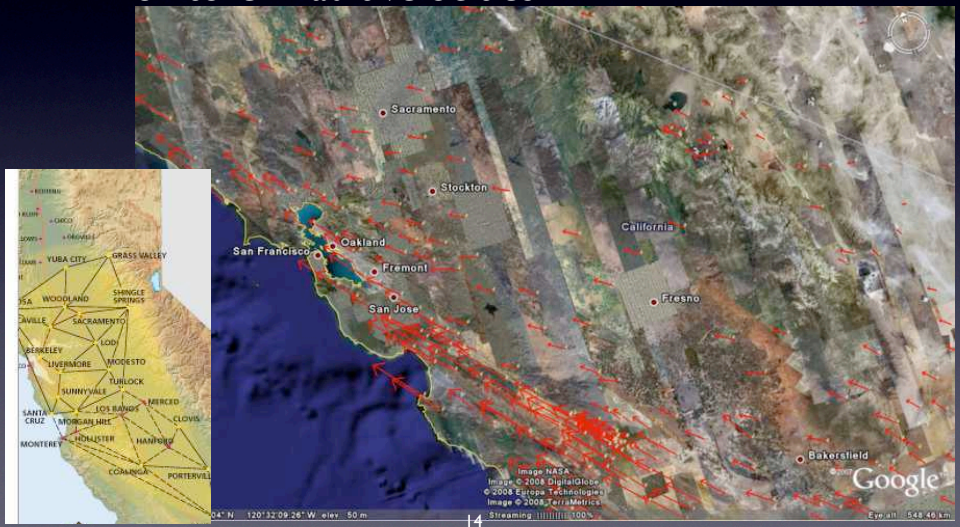
www.csdsinc.com

CSDS IM Installation

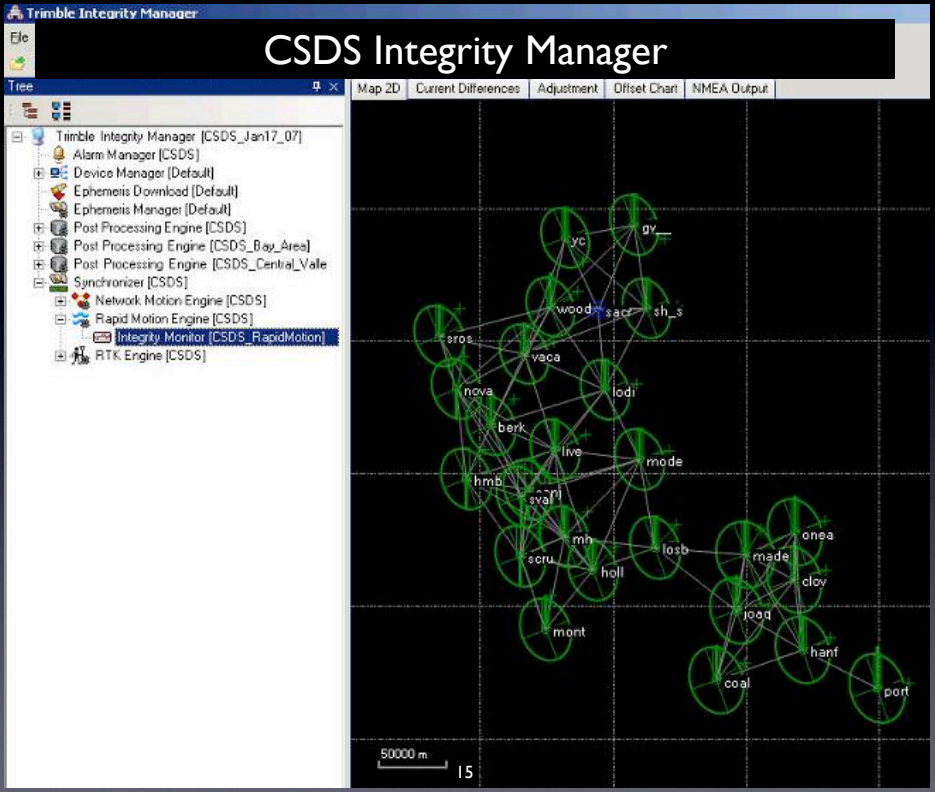
California fault movement cased the displacement in the concrete wall

CSDS IM Installation

Monitored Fault Velocities

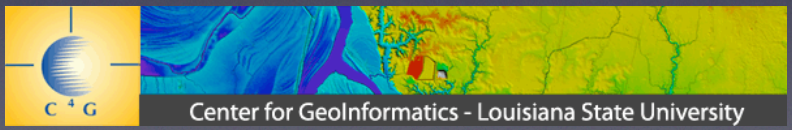


CSDS Integrity Manager



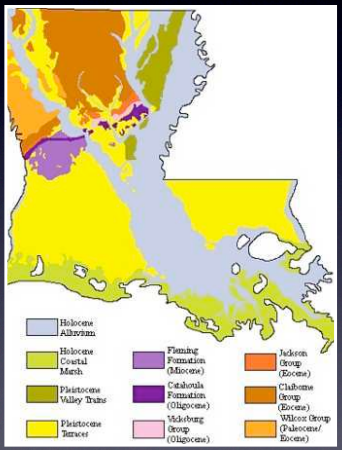
Installation example - Louisiana State University (C4G - LSU)

- Providing critical post-Katrina survey data across LA through GULFNet
  - www.c4g.lsu.edu
- Integrity Manager monitors station integrity
- Provides data for a geologically dynamic part of USA



LSU

- Entire state built from Mississippi River mud
- Natural subsidence caused by sediment/ water loading, faulting, compaction.
- Flood control measures (river levees, dams) are starving yellow/green areas of fresh sediment, consequently coastal LA is now only sinking.
- Mississippi River areas may be loaded by tidal effects



LSU GULFNet

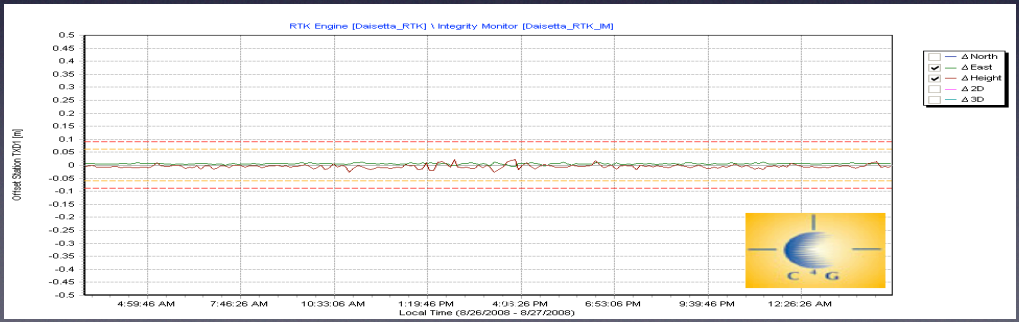
GULFNet / Integrity Manager stations

Daisetta TX sinkhole

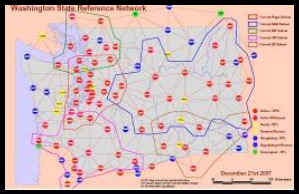
- Special TIM project
  - Salt dome – waste water pumping causes collapse

Daisetta Sinkhole Monitor

- LSU provides near real-time graphs (5 sec delay) of station integrity
- http://www.c4g.lsu.edu/ Click on "Daisetta Sinkhole" for most recent chart



Structure Monitoring Installation Seattle Public Utilities (SPU)

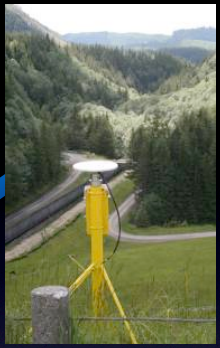


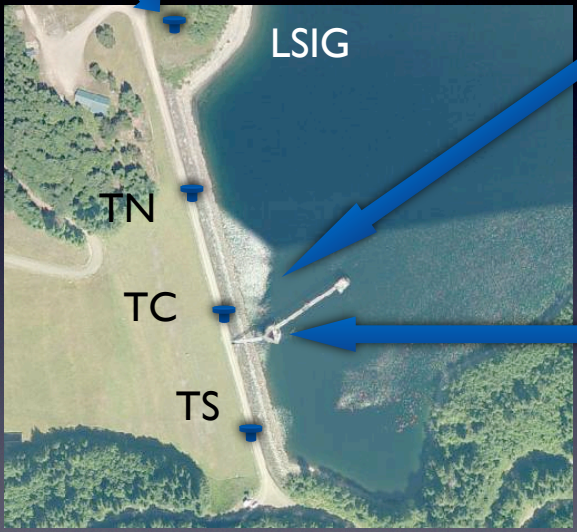
- Washington State Reference Network
  - www.wsrn.org
  - Cooperative statewide real-time Trimble RTKNet VRS and post processing service network
- Integrity Manager software
  - Providing coordinates and integrity management for stations in the WSRN
  - Positioning and status of several antennas located on earthen dam

SPU Tolt dam

- Earthen construction
- Specific engineering requires GNSS tracking of dam status
- Reference stations outside dam operate as site control (LSIG is part of the VRS network)

WSRN
CORS
"LSIG"

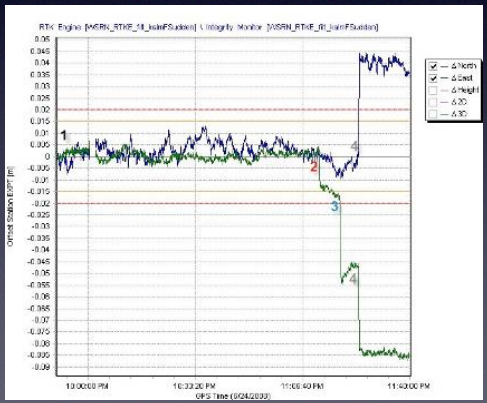


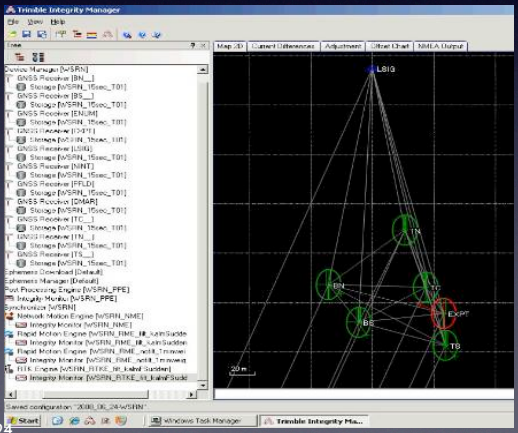


SPU dam

Simulated movement event

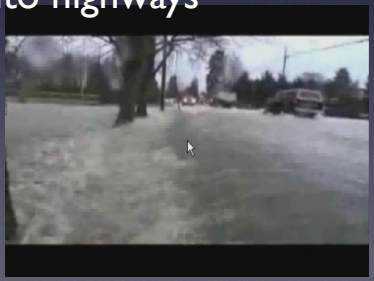
Precision results exceed client need



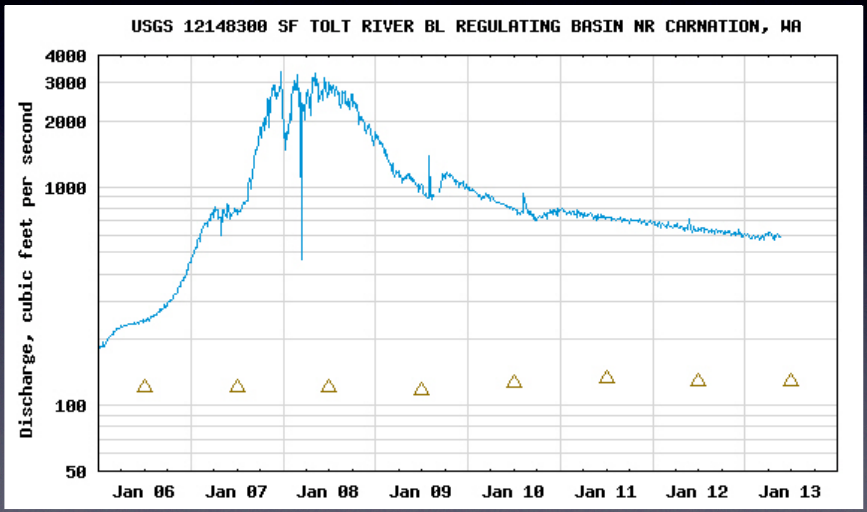


Tolt Dam
High Flow Event

- Jan 7th-10th 2009 weather in WA recorded the Tolt outflow at very high levels
- Downstream
  - River bank overflow onto highways



Tolt Dam High Flow Event



Tolt Dam High Flow Event

- ~ 2000 cfs drop in flow detected at USGS sensors 12-148000 & 12-148300

Sensor 1214800 4:00 am 3640cfs HIGH FLOW

4:15 am 963 cfs ***SUDDEN DROP***

4:30 am 3820 cfs HIGH FLOW

Sensor 12148300 4:30 am 2570 cfs HIGH FLOW

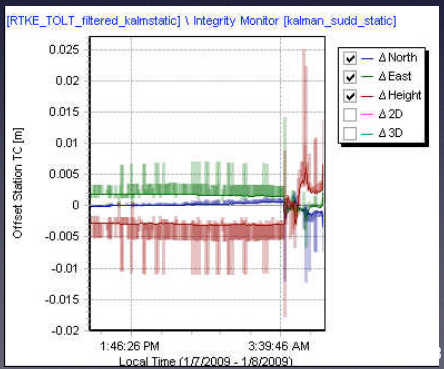
am 467 cfs ***SUDDEN DROP***

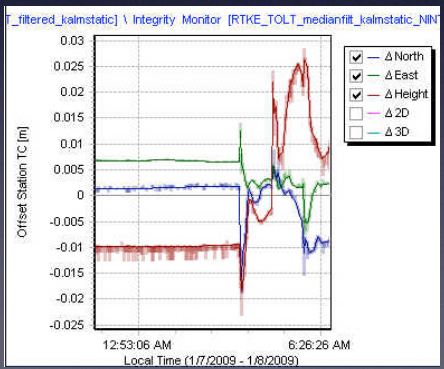
am 2430 cfs HIGH FLOW

01/08/2009 03:30	6.27	3,566
01/08/2009 03:45	6.30	3,620
01/08/2009 04:00	6.31	3,640
01/08/2009 04:15	4.34	963
01/08/2009 04:30	6.40	3,820
01/08/2009 04:45	6.41	3,840

Tolt Dam
High Flow Event

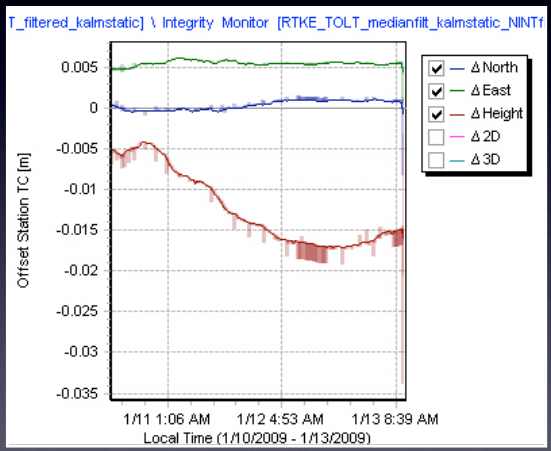
- TIM registers sudden change
- Undulations when >1000 cfs flow
- Dam crest rises as expected



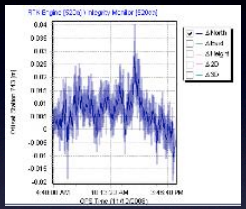


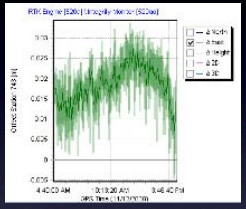
Tolt Dam
High Flow Event

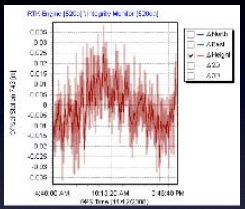
- Excess water in reservoir released by 11 Jan 09
- Dam returns to original position



SPU IM







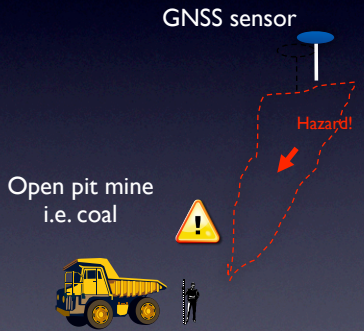
- In a high wind/wave environment, the structure pitches/twists in response about 10cm
- Deck pitches as expected

SPU IM
Bridge Monitoring

- Monitoring an aging elevated expressway
- Providing engineers with structural performance information

Mining Applications

- GNSS monitoring is suited to open-pit mining and where sub-surface deformation could occur
- Manual observation of control marks via RTK/PPS can be supplemented and reduced by installing 24/7/365 monitored GNSS sensors. Streamline field operations.




N
South African Mine
Image © 2009 DigitalGlobe
3°59'24.43" S 31°07'47.30" E elev 3 m
Streaming 100%
Eye alt

South African Mine in 3D


Image © 2008 DigitalGlobe
©2008 Google™
105 m
Pointer 23°59'01.17" S 31°07'42.45" E elev 381 m
Streaming 100%
Eye alt 697 m

Diamond Mine Jwaneng, Botswana

- Deformation Monitoring or slope stability monitoring (SSM) is almost always done for safety reasons
- Makes good economic sense, for example:

  Jwaneng Diamond Mine:

  - Design slopes at 5-10% probability of failure
  - 15-degree increase in one slope angle saves 39 Mt
  - Savings of 39 MT of waste @ $1.5 / ton
- Government Mining Regulator (DME) agreed to steeper slopes providing SSM in place


N
Image © 2009 DigitalGlobe
© 2009 Cnes/Spot Image
©2007 Google™
Pointer 24°31'29.76" S 24°42'18.39" E elev 1109 m
Streaming 100%
Eye alt 5.67 km

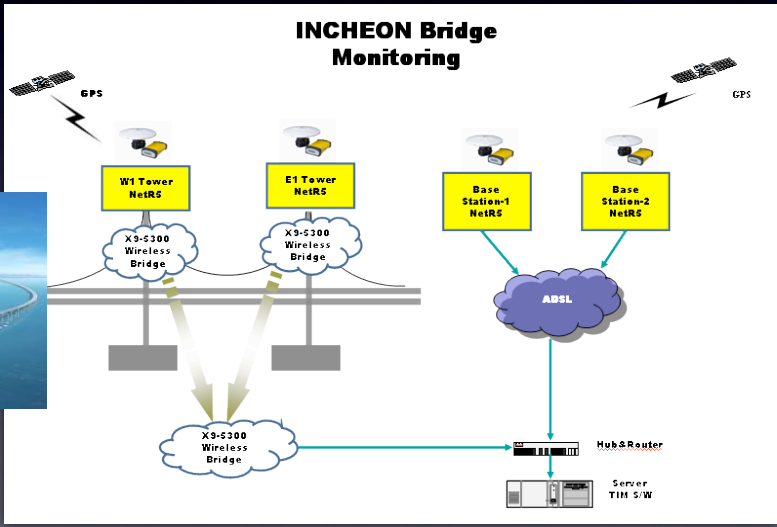
Berg River Dam
South Africa

Berg River Dam

Sensor and Data Communication

Structure Monitoring

- South Korean Incheon Bridge Towers IM plan



Structure Monitoring

- Taiwan legislation requires monitoring of 200+ bridges after >10 fatalities

Coal Slurry Impoundment Construction

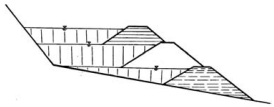


Figure 1: Upstream construction method

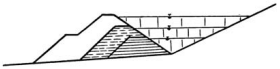


Figure 2: Downstream construction method

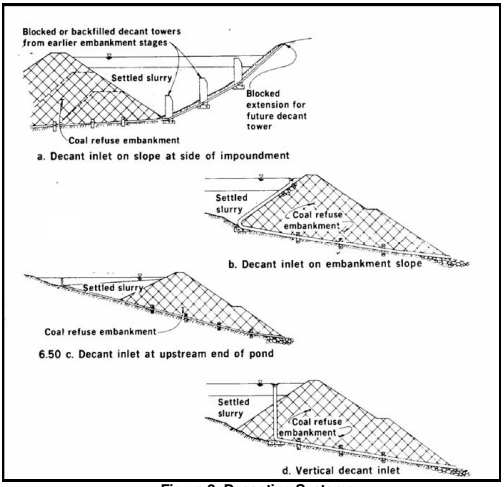


Figure 3: Decanting Systems

Failure Modes

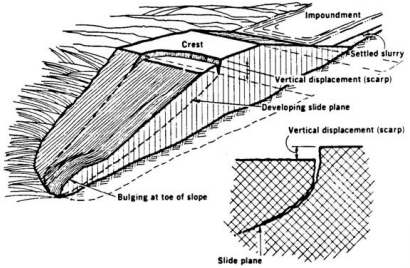


Figure 4: Surface sloughing of material on embankment.

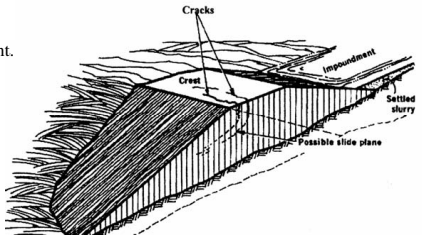
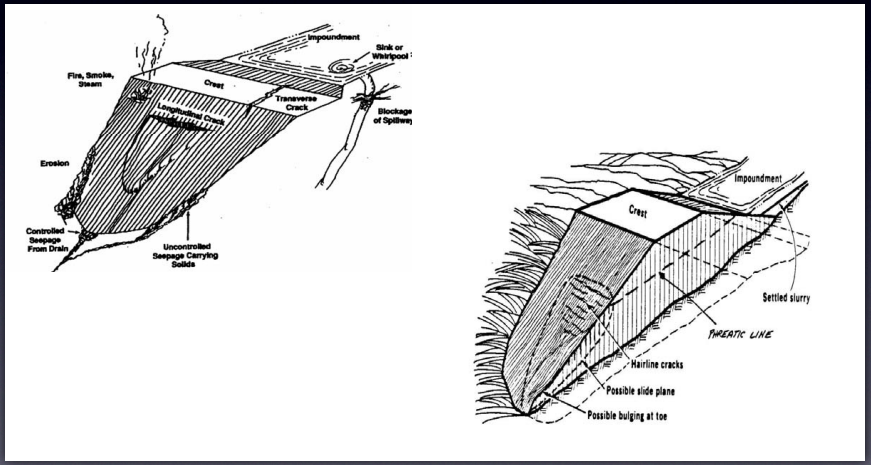


Figure 5: Cracks on Embankment Crest

Indicators


Impoundment
Sink or Whirlpool
Fire, Smoke, Steam
Crest
Transverse Crack
Blockage of Spillway
Erosion
Controlled Seepage From Drain
Uncontrolled Seepage Carrying Solids
Impoundment
Crest
Settled slurry
PHREATIC LINE
Hairline cracks
Possible slide plane
Possible bulging at toe

Site Instrumentation

Data Stream Options

- Slope movement
  - Displacement - GNSS sensor
  - Tilt - 2 axis sensor
- Meteorological Information
  - Rain gauge
  - Temperature
  - Pressure
- Other
  - Decant level

WV IM Hardware/ Software Requirements

✓ Statewide CORS Network

$600,000

✓ Data Center, servers, VRS software

$150,000 + $≈50,000/yr maintenance

× Rapid Motion Integrity Monitor add-on to VRS software

$20,000

× Site GNSS sensors, data communication to Data Center

$15,000-20,000 each + installation + maintenance

2 GPS receivers & antennas available for research ($16,000)