Structural Instrumentation and Monitoring Services

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OPEN SYSTEMS & SERVICES
KINEMETRICS

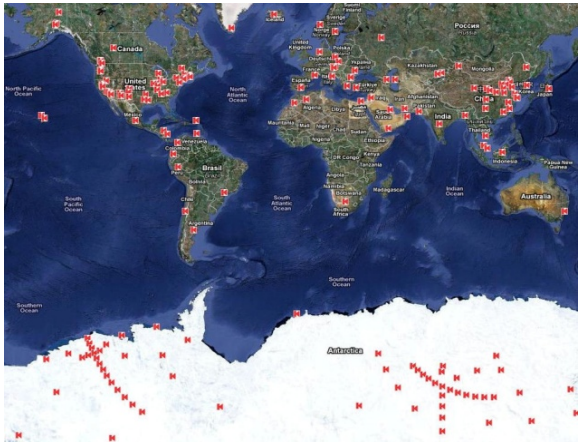
OUTLINE

- Introduction
- Enhanced Rapid Post-Earthquake Assessment
- Seismic Monitoring for Large Facilities
- Structural Health Monitoring
- Summary

INTRODUCTION - KMI

Kinemetrics, Inc.

- Founded in 1969
- OYO Corp owned in 1991
- ISO9001 since 1999
- $35M FY2012 revenue (mostly international)



HQ's in Pasadena CA with Sales and Project offices in Switzerland & Abu Dhabi

INTRODUCTION - KMI

KINEMETRICS

Designs and manufactures sensors, digitizers and software

QUANTERRA®

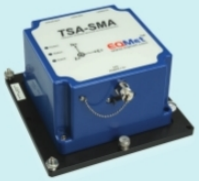
Designs High-End Digitizers

metrozet

Designs High-End Sensors

EQMet

Cost-Effective Products



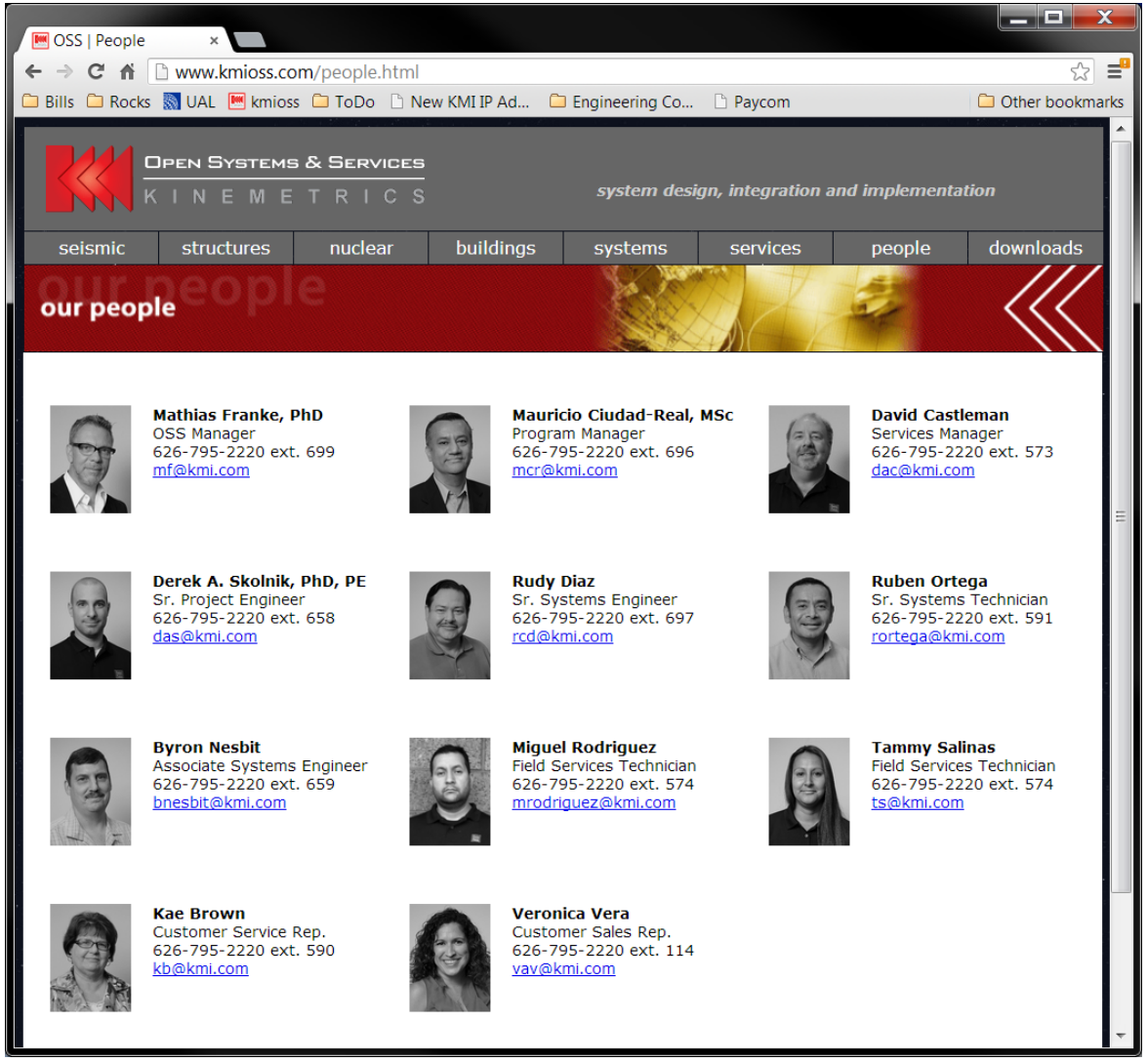
INTRODUCTION - OSS

Open Systems Services

Specialized team of experts in:

- Geosciences
- Earthquake Engineering
- IT & Telemetry
- KMI & Other Technology

Comprehensive application-driven solutions & services



INTRODUCTION - OSS

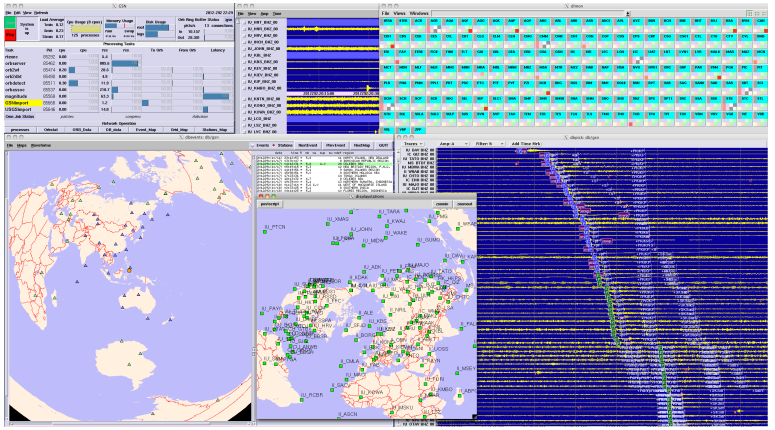
Seismic Monitoring

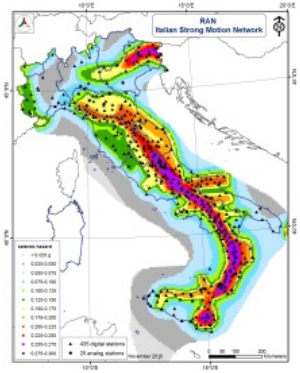
Seismic Networks

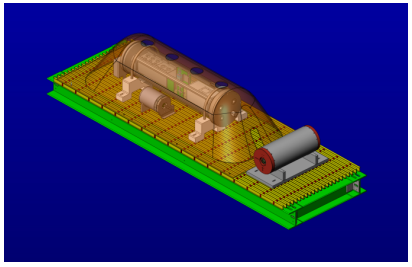
Ocean Bottom Seismometers

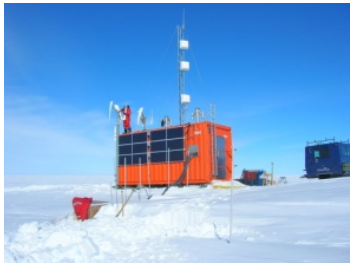
Volcano Monitoring

Environmental Monitoring









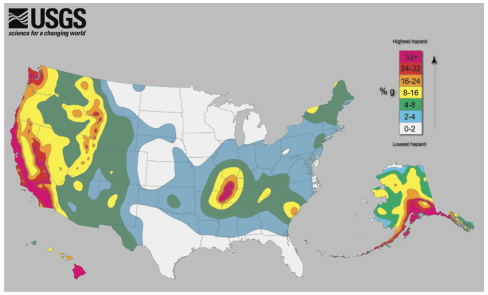
ENGINEERING

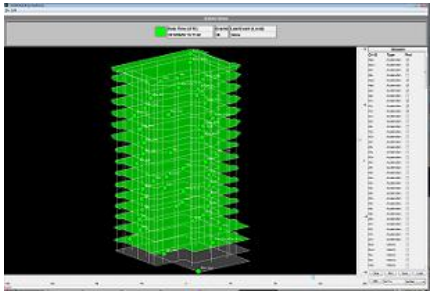
Strong-Motion Networks

Structural Monitoring

NPP & Nuclear Treaty Verification

Construction Monitoring



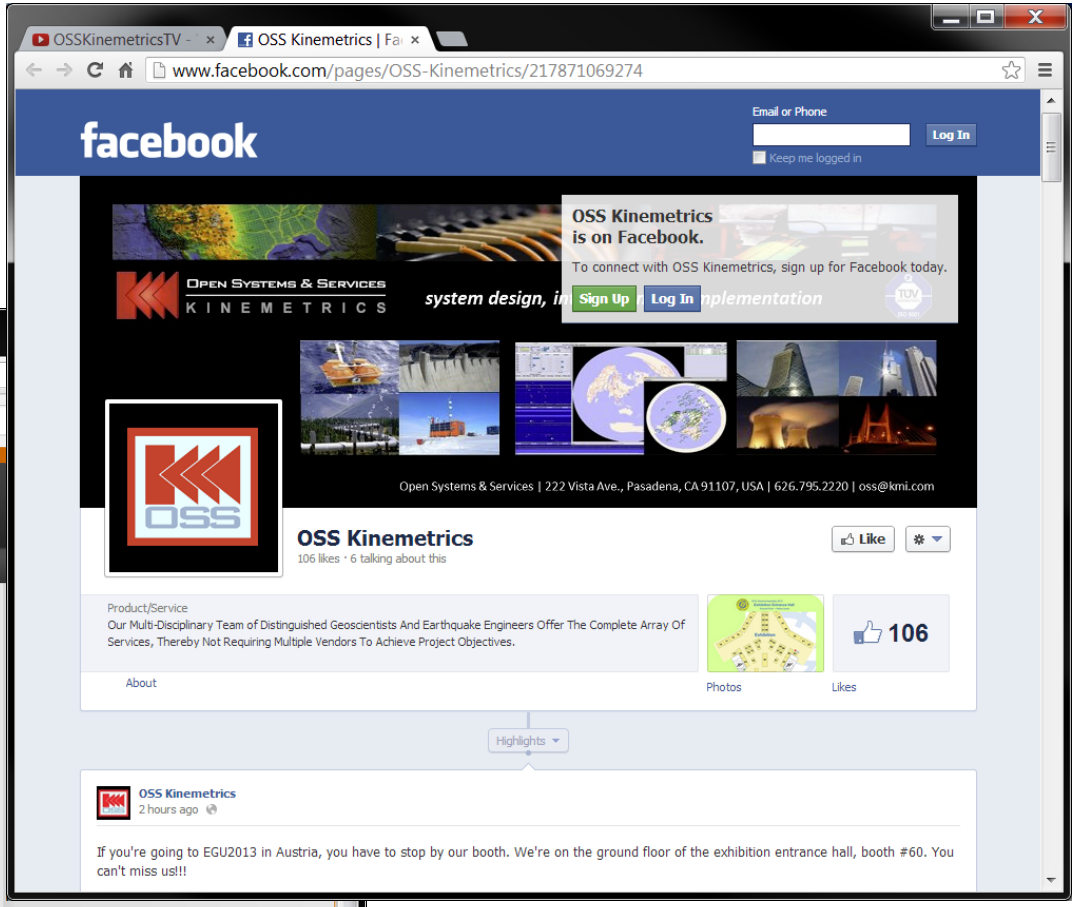


EMERGENCY RESPONSE

- Emergency Management
- Real-time loss estimation
- Response Planning
- Processing & Visualization
- Data/Display Center(s)
- Telemetry
- Equipment (sensors)

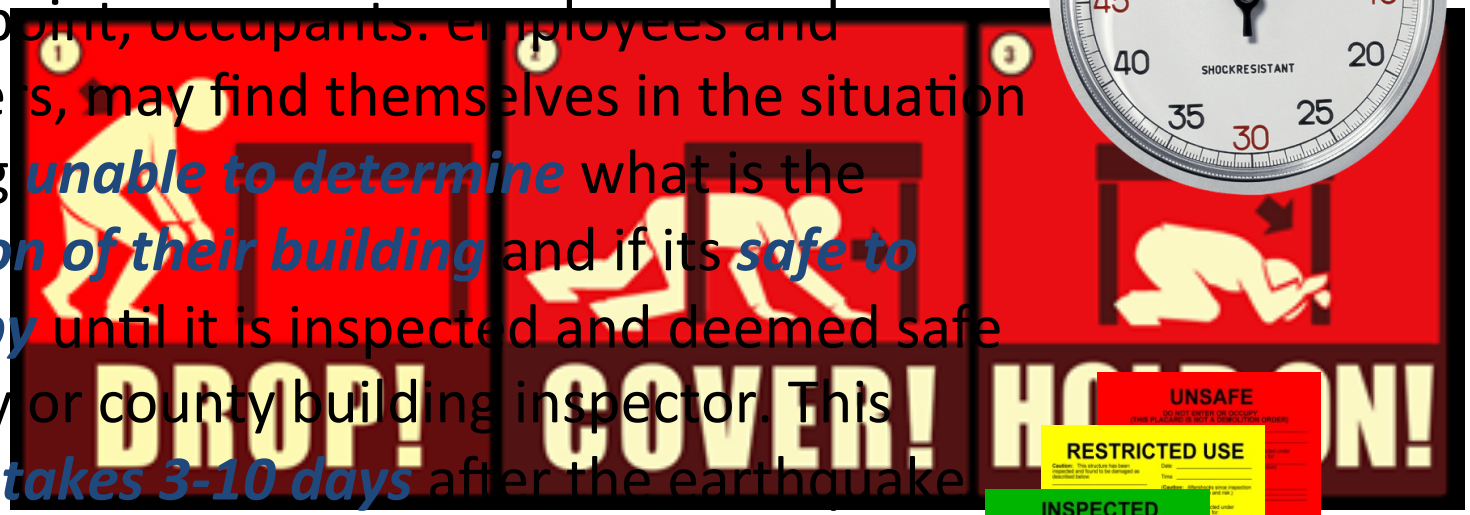
SOCIAL MEDIA

We're everywhere



THE PROBLEM

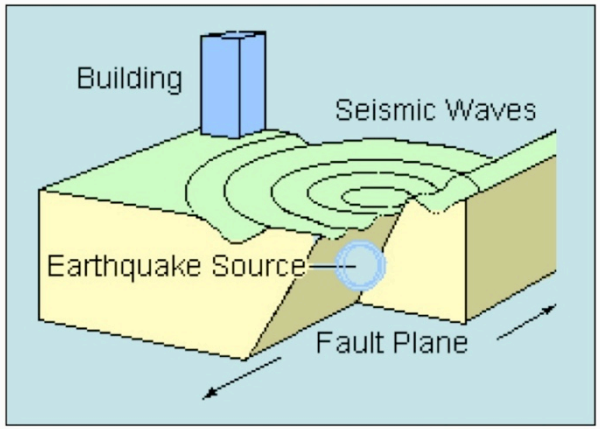
- In the US, the typical business emergency plan calls for employees to ***Drop, Cover, and Hold*** during an earthquake, and then to ***evacuate*** the building if it is damaged and safe to do so.
- At this point, occupants: employees and managers, may find themselves in the situation of being ***unable to determine*** what is the ***condition of their building*** and if its ***safe to reoccupy*** until it is inspected and deemed safe by a city or county building inspector. This ***usually takes 3-10 days*** after the earthquake.
- Even when a building inspector has reached the building, it could take ***a lot of time*** to complete a visual inspection and often is recommended a ***more detailed structural evaluation***.



THE DAILY NEWS

www.dailynews.com THE WORLD'S FAVOURITE NEWSPAPER - Since 1879

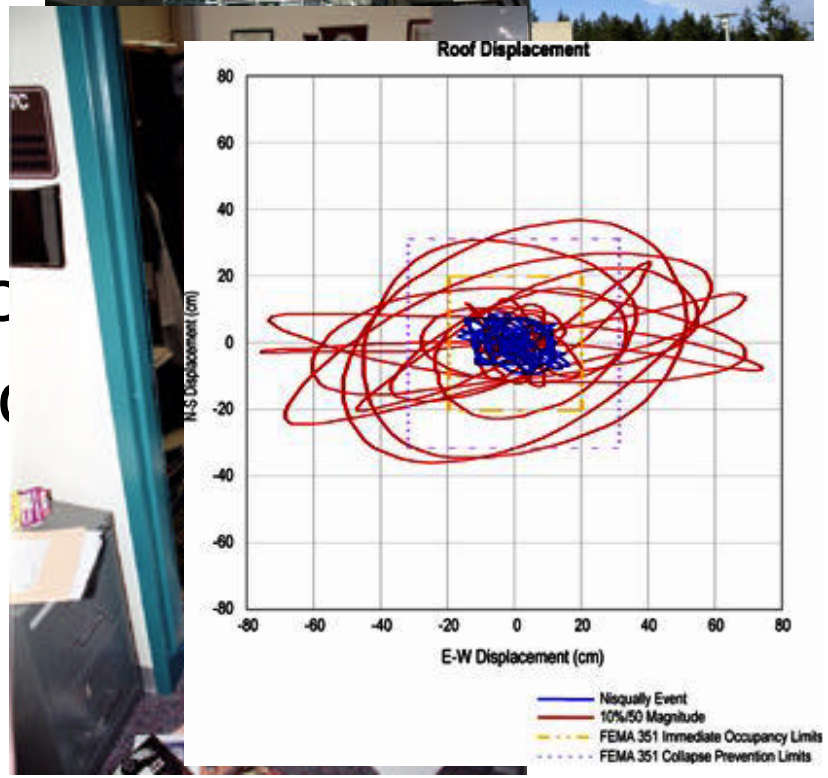
BUSINESS INTERRUPTION: MILLIONS IN LOSSES



After both, the 1989 Loma Prieta and the 1994 Northridge earthquakes in California, private building owners experienced delays in having their buildings inspected for occupancy safety while city and county building inspectors were busy inspecting collapsing structures, critical facilities, and city buildings. Some safe buildings were RED posted in error and others were evacuated awaiting inspection, causing building tenants business interruption.

THE FACTS

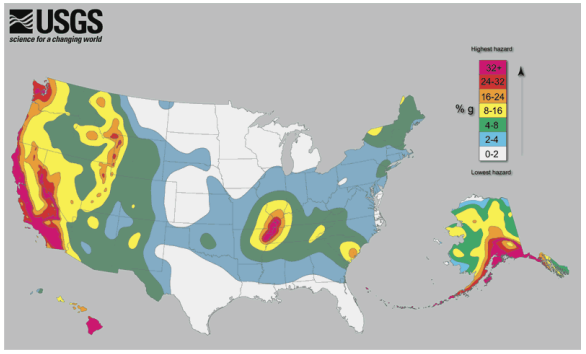
- Naval Hospital Bremerton
- Nisqually Earthquake of February 28, 2001 - 6.8 magnitude
- Evacuation was ordered
- Further Damage inspectic and evaluation: no signifi structural damage
- Patient confidence

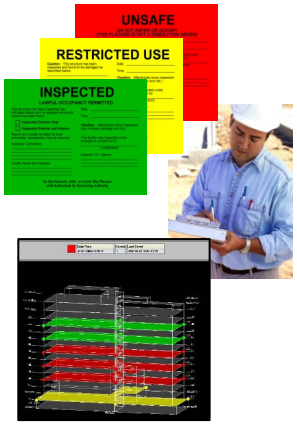


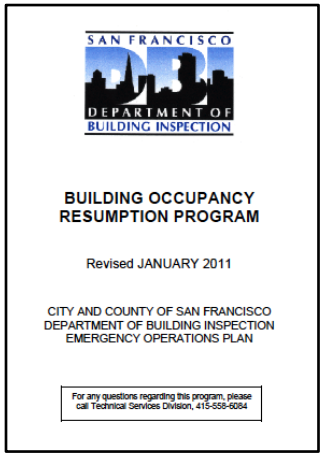
THE SOLUTION

Preparedness

- Understating Seismic Risk
- Pre-Earthquake Assessments
- Monitoring with instrumentation
- Response Plan
- Post-Earthquake Assessments





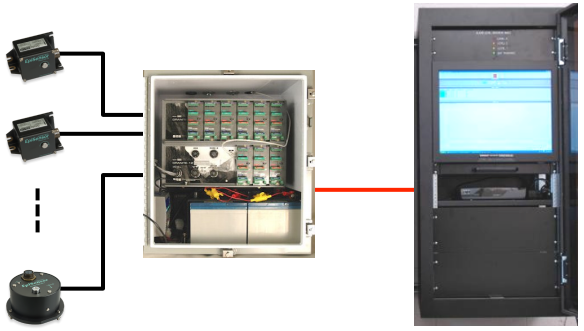

SAN FRANCISCO
DEPARTMENT OF BUILDING INSPECTION

BUILDING OCCUPANCY RESUMPTION PROGRAM

Revised JANUARY 2011

CITY AND COUNTY OF SAN FRANCISCO
DEPARTMENT OF BUILDING INSPECTION
EMERGENCY OPERATIONS PLAN

For any questions regarding this program, please call Technical Services Division, 415-558-6084



- City of San Francisco – BROP
  - Financial Institutions
  - Federal Buildings
  - CALTRANS (CA DOT)

- US Navy – RiedMiddleton's REAP
  - Bremerton Hospital
  - San Diego Medical Center
  - Undisclosed Facilities

REAP
STATE-OF-THE-ART DISASTER RESPONSE FOR HOSPITAL FACILITIES
2011 EERI ANNUAL MEETING
LA JOLLA, CALIFORNIA

THE BROP PROGRAM

- ***What is BORP?***
  The Building Occupancy Resumption Program (BORP) is a program that allows San Francisco building owners to pre-certify private post-earthquake inspection of their buildings by qualified engineers
- ***Why BORP?***
  If you rely on uninterrupted occupancy for your building, BORP could get you back in business sooner after a quake.
- ***How BORP?***
  Within BORP, instrumentation is recommended as part of an Emergency Inspection Program for all highrise buildings. This can provide valuable post-earthquake information about the performance of a building, in addition of reducing the percentage of joints required to be inspected after an earthquake.

THE REAP PROGRAM

REAP

STATE-OF-THE-ART DISASTER RESPONSE FOR HOSPITAL FACILITIES

The Rapid Evaluation & Assessment Program (REAP) empowers facility management to quickly and accurately perform detailed building safety evaluations immediately after an earthquake. The system reduces delay in evaluating and posting essential facilities, gives the assessment team customized building specific information, "pre-engineered" guidance, and minimizes unnecessary delays. An innovative use of state of the art technologies, REAP incorporates ATC-20 and Performance-Based Earthquake Engineering criteria into a system of seismic monitoring of the structure accessible via graphic user interface, post-earthquake evaluation field manuals, and training.

2011 EERI ANNUAL MEETING
LA JOLLA, CALIFORNIA

NAVFAC Naval Facilities Engineering Command
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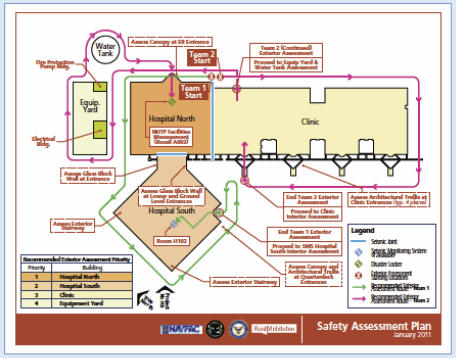
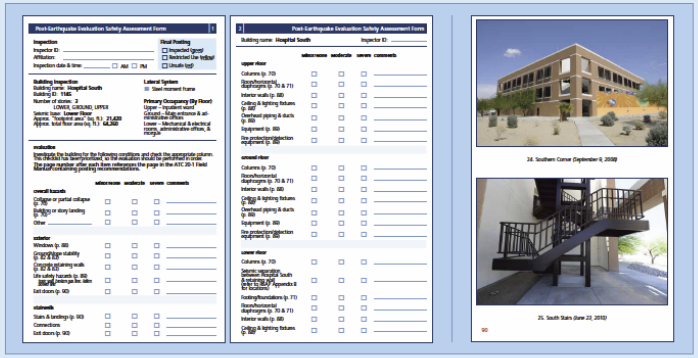
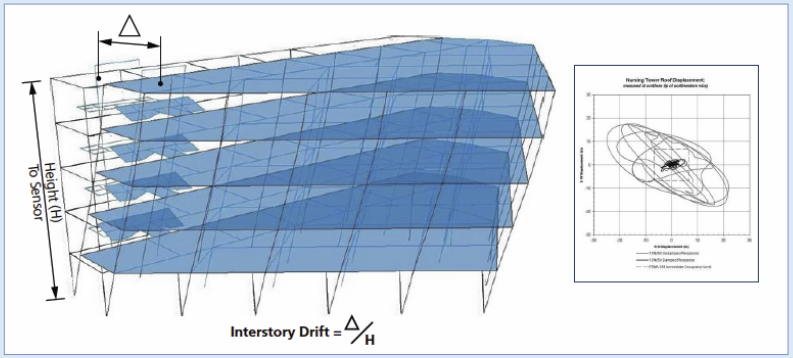


The REAP Field Manual includes inspection tools, including a Safety Assessment Plan (shown above), to guide the assessment team and highlight important features.

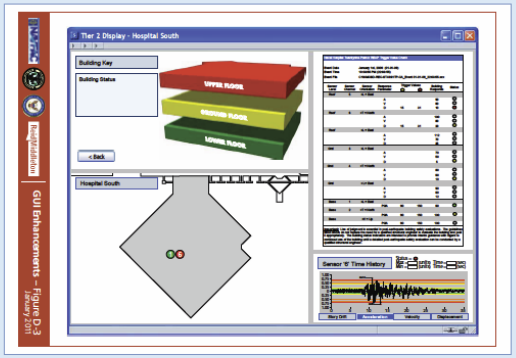


Inspection forms based on ATC-20/45 have been tailored to the specific construction and hazards in the building. Annotated photography documents pre-event conditions.

The SMS provides real-time evaluation of the building response based on pre-engineered performance limits. (The OASIS system by Kinemetrics is shown above.)



This is an illustration on the concept of the SMS, where it measures building accelerations and calculates displacement. Trigger values are entered into the SMS as drift ratios.



Future development of the REAP includes upgrades to the SMS graphical user interface (GUI) to enhance the earthquake performance data available to the assessment team.

** Courtesy of Dave Swanson, Reid Middleton – 2011 EERI Annual Meeting Poster Presentation*

ABU DHABI

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Earthquake shakes UAE, other countries; buildings, hospitals evacuated

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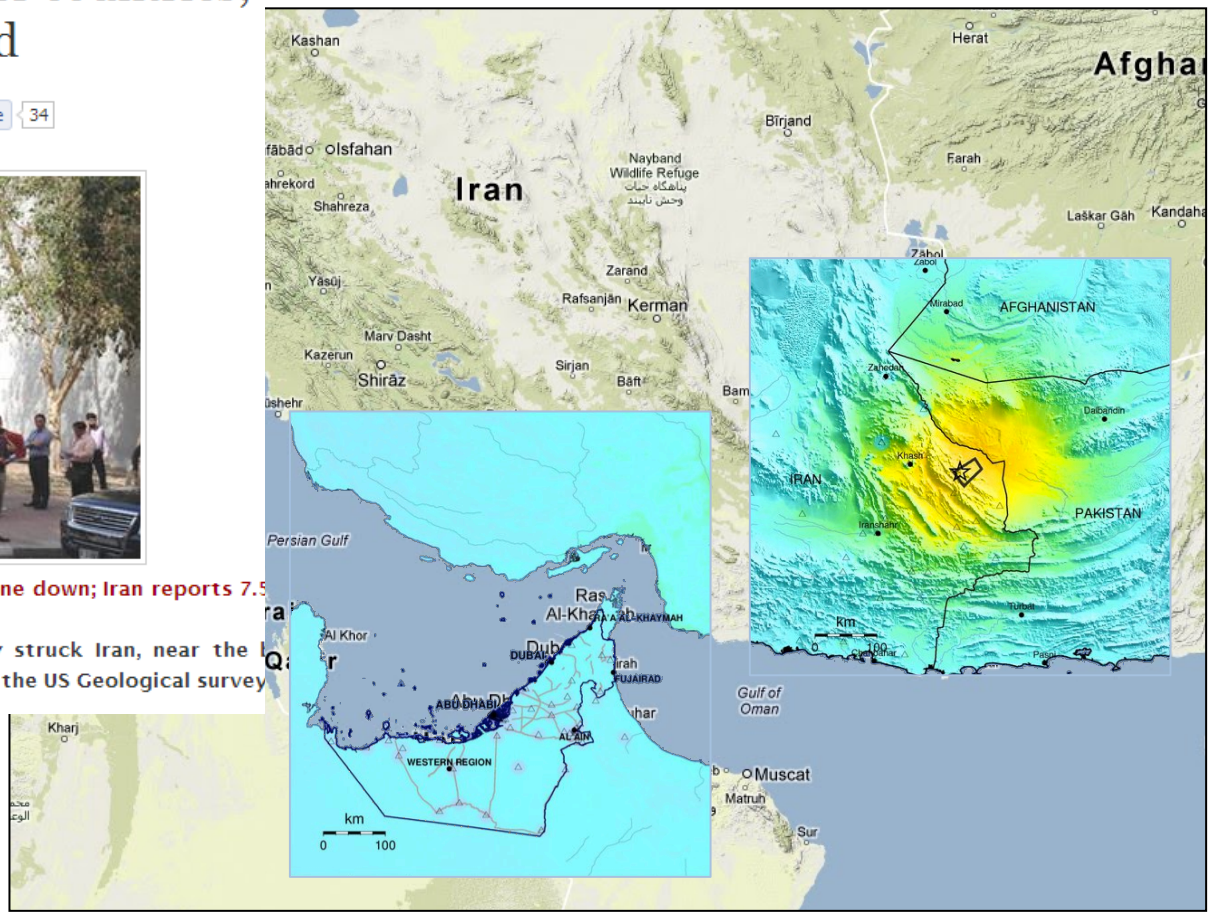
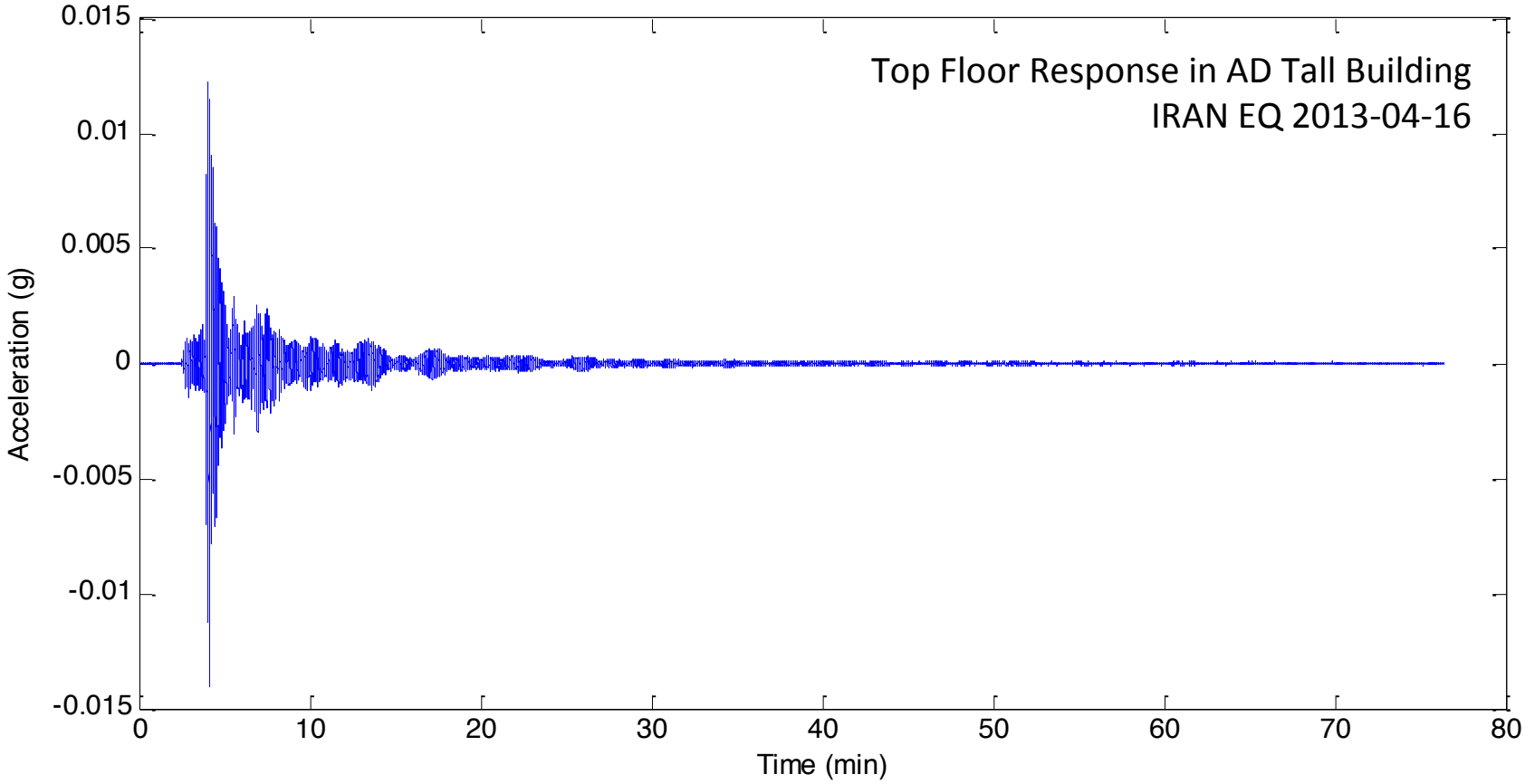
Mobile phone and Internet lines have reportedly also gone down; Iran reports 7.5 earthquake in southeast

A strong earthquake of 8.0 magnitude has reportedly struck Iran, near the I Pakistan, at 2.44pm UAE time (10:44am GMT) on Tuesday, the US Geological survey

M7.7 - 83km E of Khash, Iran
2013-04-16 10:44:20 UTC

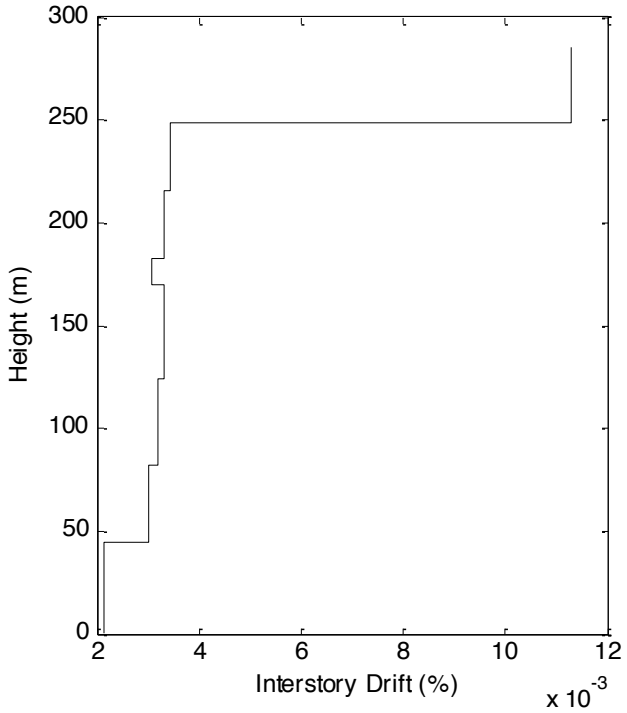


- For UAE buildings, the seismic hazard comes from large distant earthquakes
- These types of events can make occupants feel uneasy during shaking that can last for extended periods of time

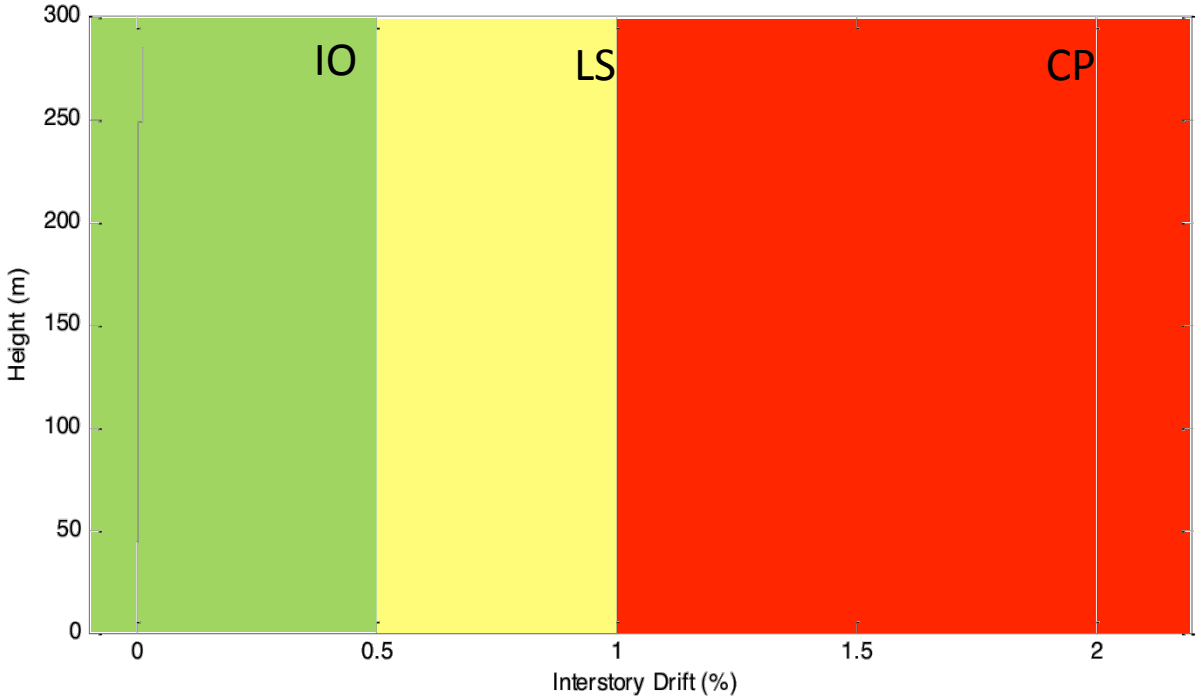


- For example, during recent Iran earthquakes, data from one Abu Dhabi building showed that critical engineering response parameters were well within design limits. The building structure was FINE!

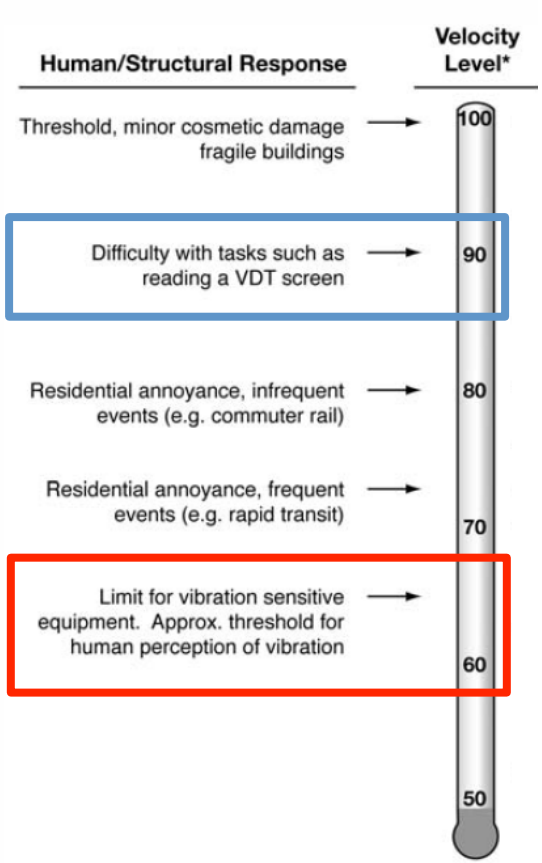
Interstory Drift for tall building, Abu Dhabi – IRAN EQ 2013-04-16



Interstory Drift for tall building, Abu Dhabi – IRAN EQ 2013-04-16 with typical seismic design performance levels: Immediate Occupancy, Life Safety, and Collapse Prevention

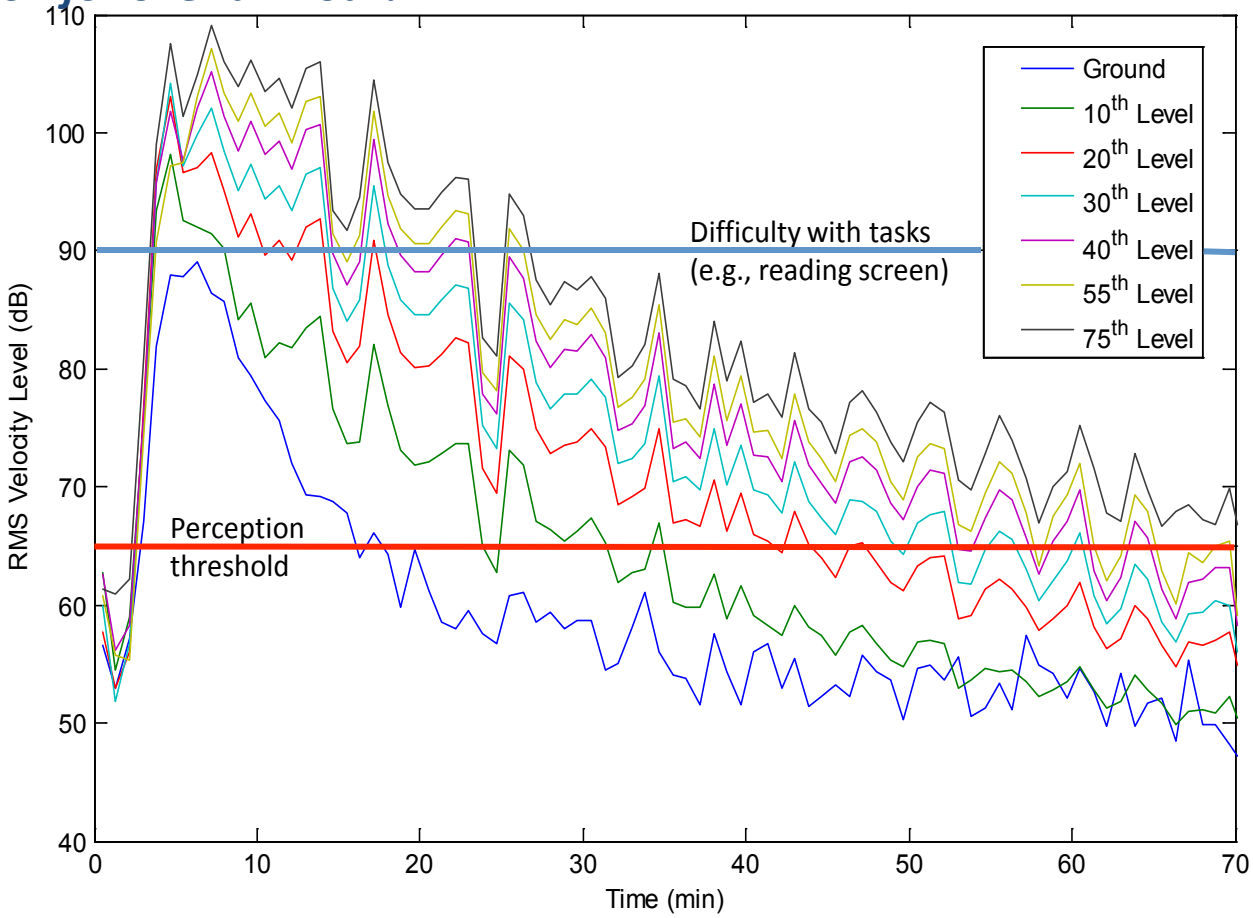


- In this case, data from one tall Abu Dhabi building showed that shaking was ***above the level of human perception for over an hour!***



* *RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second*

Figure 7-3. Typical Levels of Ground-Borne Vibration



Source: US DOT FTA-VA-90-1003-06 Transit Noise and Vibration Impact Assessment

WHAT IS NEXT?

OUTLINE

- Introduction
- **Enhanced Rapid Post-Earthquake Assessment**
- Seismic Monitoring for Large Facilities
- Structural Health Monitoring
- Summary

Post-Earthquake Assessment

- PEA refers to the ***decision making, inspection,*** and ***safety evaluation*** of a structure following a significant earthquake
- Level of enforcement and emergency action will vary, but many buildings will be evacuated and occupants not allowed re-entry until an ***officially sanctioned safety assessment***
- Occupants in essential facilities such as hospitals, emergency operations centers, military installations, critical financial institutions, and nuclear power plants, ***cannot easily evacuate*** or ***sustain expensive downtime*** waiting for a detailed safety assessment

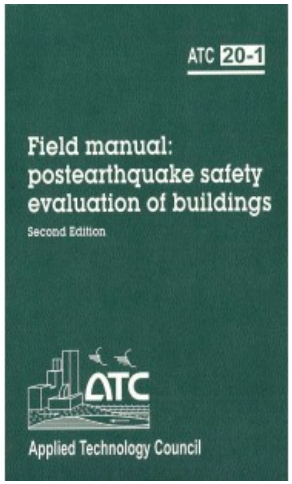
To ***prevent unnecessary evacuations*** and ***minimize downtime***, a proactive solution to performing rapid, detailed, and accurate post-disaster safety evaluations of critical and essential facilities is needed

POST-EARTHQUAKE ASSESSMENT

Rapid Post-Earthquake Assessment

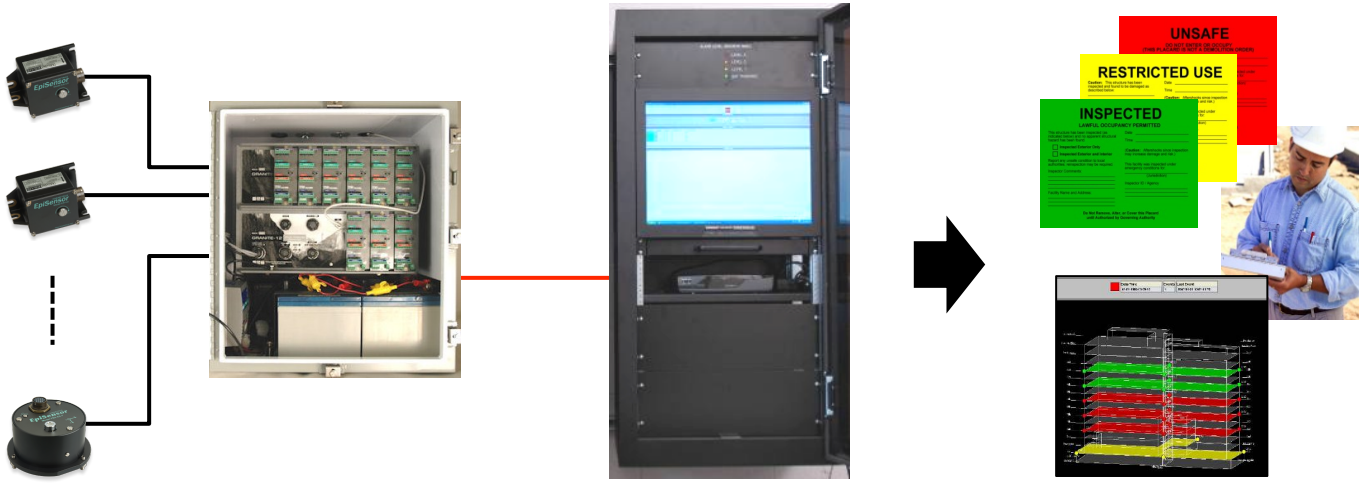
- Rapid PEA refers to a service contracted by engineering consultants that serve as ***'on-call' safety inspectors***
- Possible because of forward-thinking jurisdictions that have established ***Building Occupancy Resumption Programs (BORP)*** that permit engineers-on-call to be pre-deputized to perform ATC-20 tagging in lieu of official inspectors
- However, in large urban areas like San Francisco, 'on-call' engineers can have several building sites under contract and easily become overwhelmed in a declared state of emergency
- Traditional visual-based inspections impose ***high costs and inconvenience*** on building owners and occupants alike because physical access to structural members may require the removal of non-structural components such as interior partitions and fire proofing

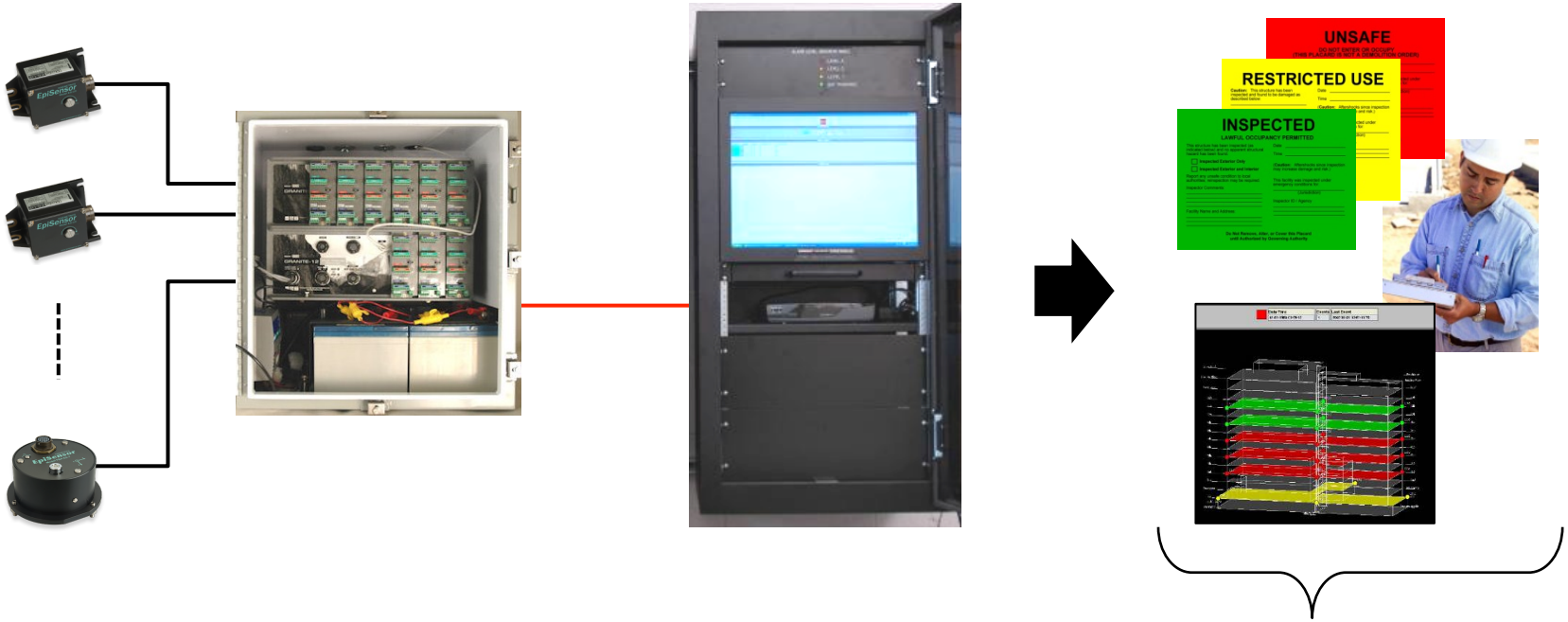
SAN FRANCISCO DEPARTMENT OF BUILDING INSPECTION



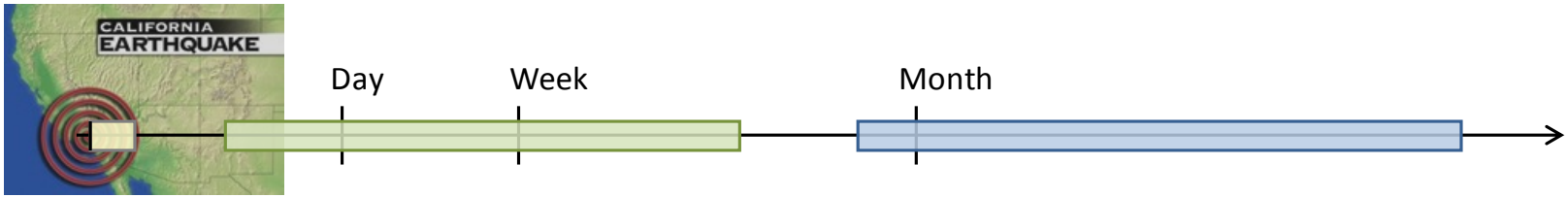
Enhanced Rapid Post-Earthquake Assessment

- Enhanced Rapid PEA refers to the services previously described but enhanced by utilizing information from ***advanced*** strong-motion instrumentation
- This level of service is enabled for buildings with strong-motion instrumentation by two steps:
  1) introducing a system with ***Real-Time Monitoring,*** and ***Onsite Display and Alarm*** capabilities (this is what makes it advanced)
  2) by ***integrating*** the newly afforded information within the overall rapid post-earthquake assessment process

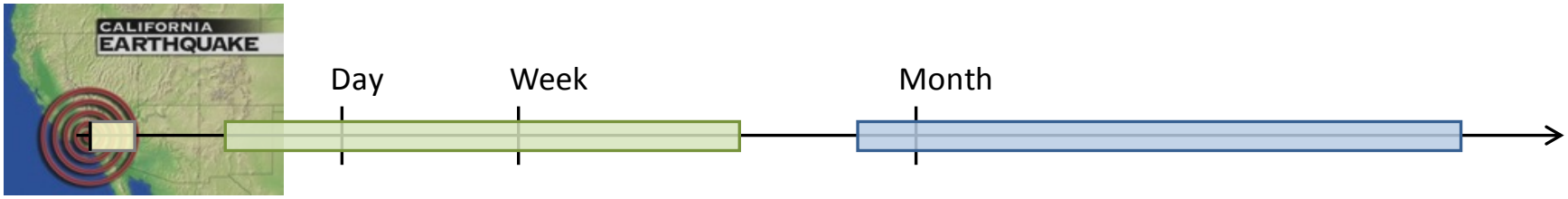




Integration within Post-Earthquake Response Process: use information to make informed decisions across all three phases of post-earthquake response



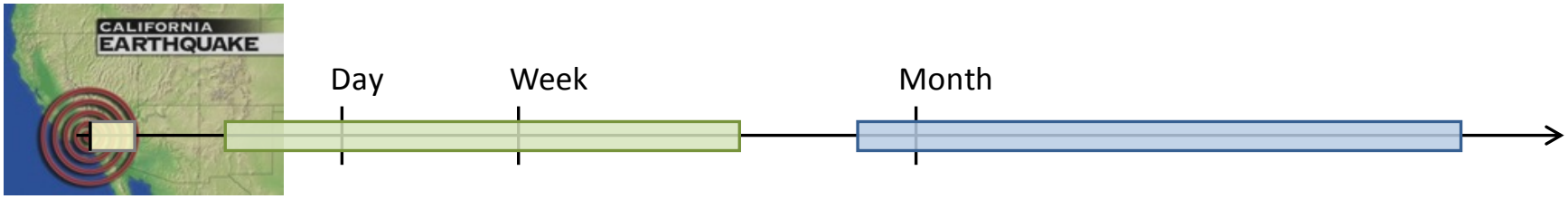
POST-EARTHQUAKE ASSESSMENT



Immediate Response

- Onsite reaction that occurs immediately after shaking stops and "dust settles"
- The natural inclination of occupants is to evacuate after a large earthquake, thus the immediate goal of this phase is to ***enable continued use*** or avoid unnecessary evacuation or facility shutdown
- Onsite alarms provide confidence to operation personnel that it is ***OK*** to stay inside and continue "business as-usual"

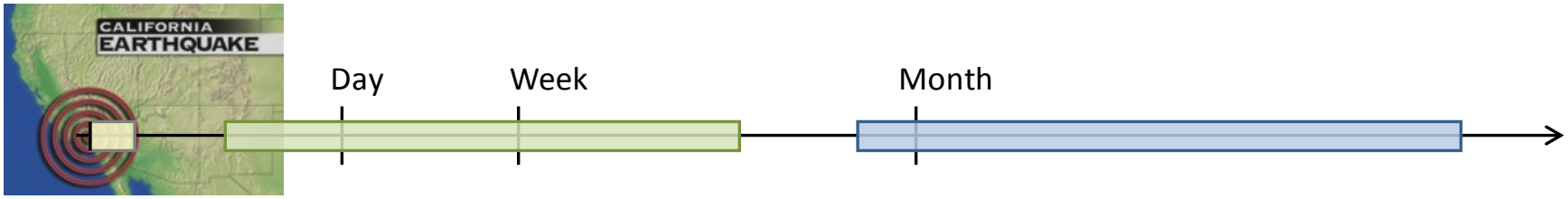
POST-EARTHQUAKE ASSESSMENT



Inspection Phase

- Initiated ASAP, but can be a few days or weeks depending on extent of regional damage and contractual arrangement
- Building Response information are used to aid engineers in the ***inspection and tagging process*** by targeting areas that exceeded predetermined thresholds
- More detailed response analyses can be quickly performed and ***results presented in a brief handout*** to supplement the immediate information provided

POST-EARTHQUAKE ASSESSMENT



Detailed Evaluation Phase

- Extends over a period of months
- earthquake (and aftershock) response information can aid in the subsequent engineering evaluation for assessing potential damage and ***extent of required repairs***. This is particularly applicable for pre-Northridge SMRF's connections which are susceptible to weld fractures that are difficult to detect and expensive to repair
- Computer models of buildings can be calibrated against actual response data increasing confidence in the predictive analysis regarding performance of the repaired/strengthened building in future earthquakes

SIMPSON GUMPERTZ & HEGER

EX2: Critical Financial Institution

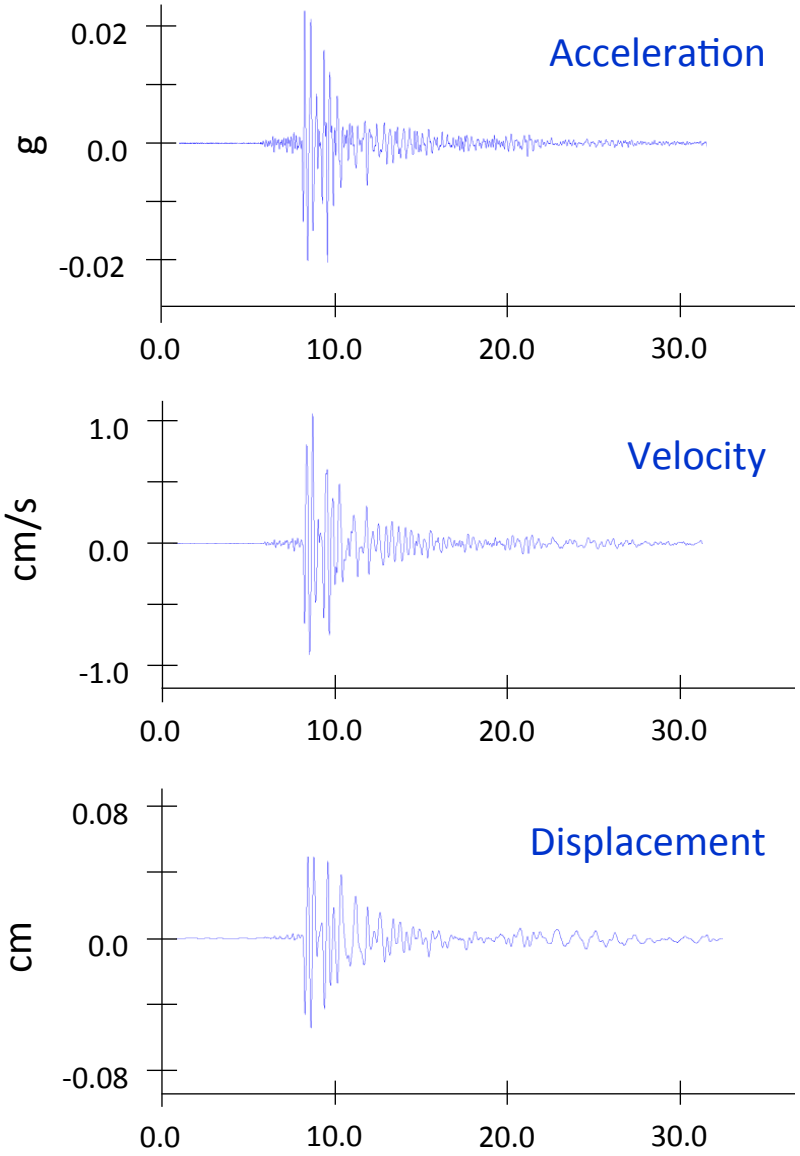
- In 2006, a client located downtown San Francisco opted to implement a BORP program enhanced with a structural monitoring system
- Two separate buildings, 31 and 42 channel systems
- The larger system is installed in a building with two structures seismically isolated by expansion joints

POST-EARTHQUAKE ASSESSMENT

SIMPSON GUMPERTZ & HEGER

EX2: Critical Financial Institution

- In 2011, this particular system captured responses to two small earthquakes of M4.0 and M3.8 with epicenters near Berkeley approximately 10 miles away
- The system triggered on accelerations but not drift
- Small earthquakes help ***to refresh stakeholders of system utility*** and also help to discover minor configuration issues
- Long-term maintenance programs ***maximize uptime*** and assure issues get resolved prior to potential events
- Rights to ownership language should be included in relevant lease agreements



POST-EARTHQUAKE ASSESSMENT

REAP

STATE-OF-THE-ART DISASTER RESPONSE FOR HOSPITAL FACILITIES

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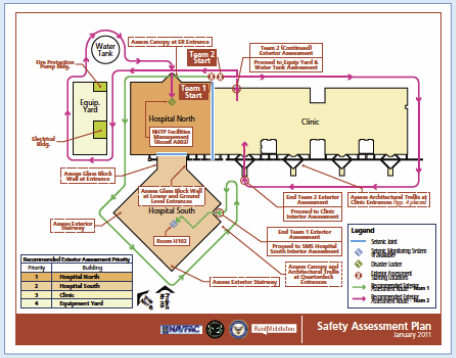
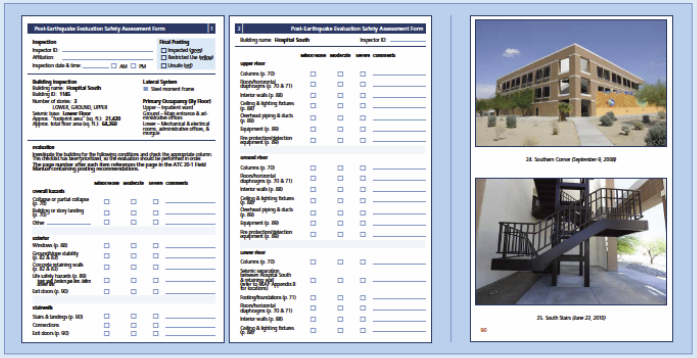
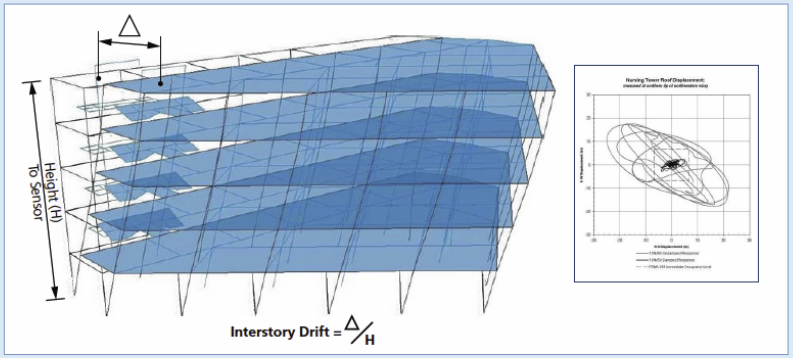


The REAP Field Manual includes inspection tools, including a Safety Assessment Plan (shown above), to guide the assessment team and highlight important features.

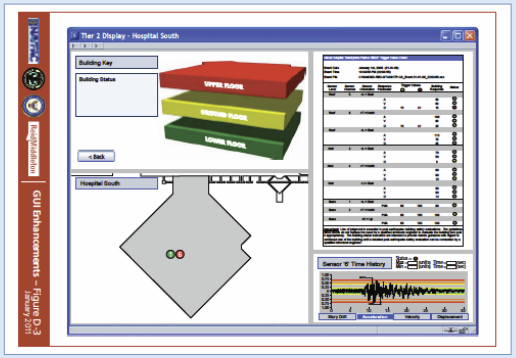


Inspection forms based on ATC-20/45 have been tailored to the specific construction and hazards in the building. Annotated photography documents pre-event conditions.

The SMS provides real-time evaluation of the building response based on pre-engineered performance limits. (The OASIS system by Kinemetrics is shown above.)



This is an illustration on the concept of the SMS, where it measures building accelerations and calculates displacement. Trigger values are entered into the SMS as drift ratios.



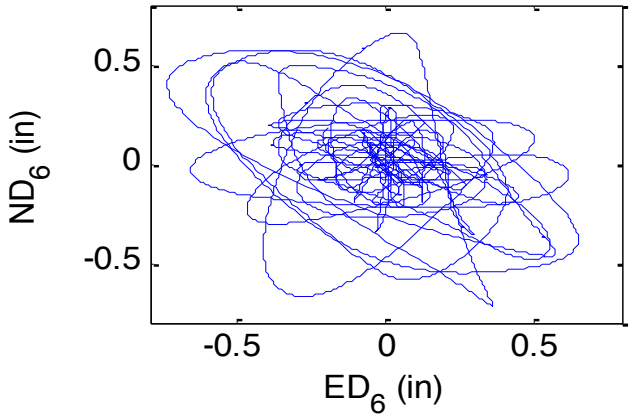
Future development of the REAP includes upgrades to the SMS graphical user interface (GUI) to enhance the earthquake performance data available to the assessment team.

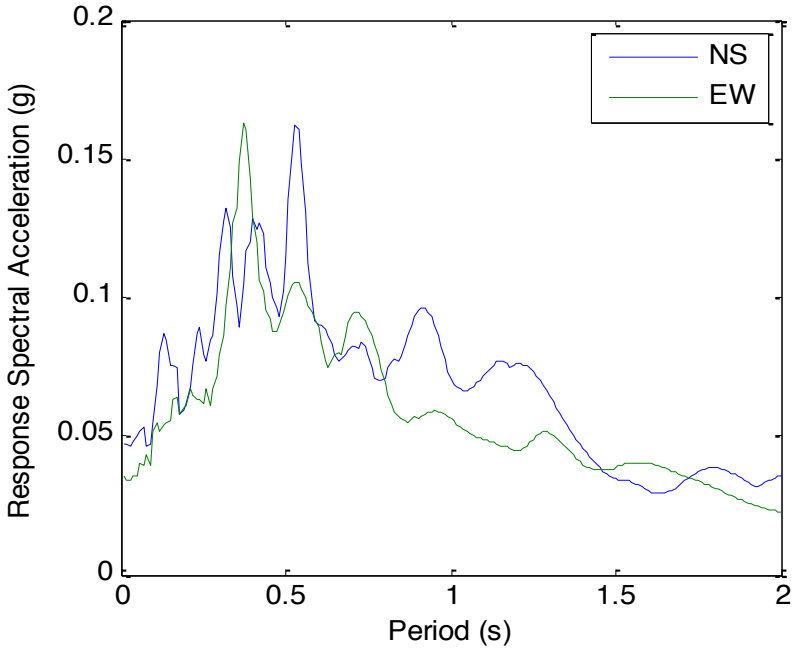
** Courtesy of Dave Swanson, Reid Middleton – 2011 EERI Annual Meeting Poster Presentation*

ReidMiddleton

EX3: US NAVY REAP

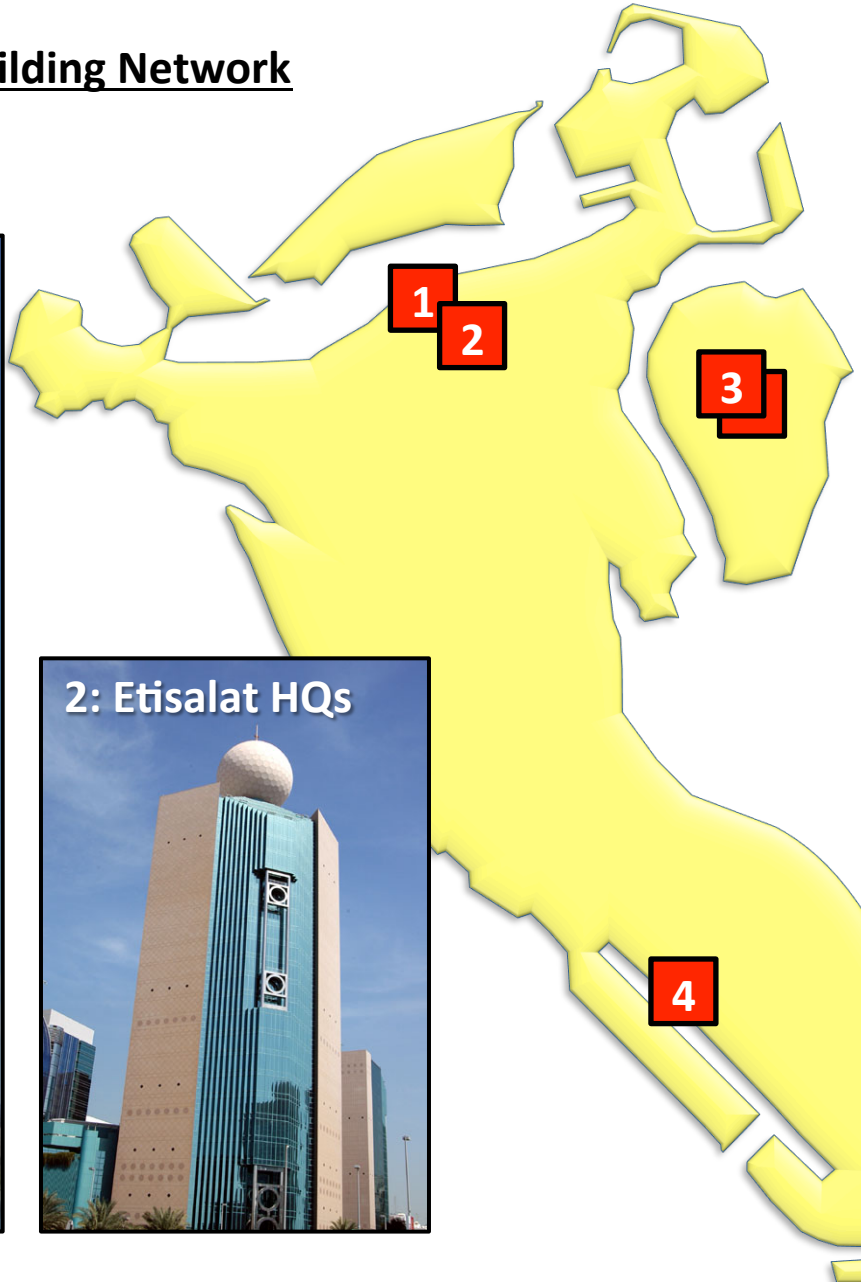
- In 2010, San Diego Hospital system captured responses to the M7.2 Mexicali earthquake approx 200km away
- People felt it, and the system recorded small building movements in nursing towers
- In-depth analysis was quickly done and the report helped to make the decision that a detailed safety evaluation was not necessary
- The analysis included ***response spectra*** at the base and ***XY particle motion*** at the roof

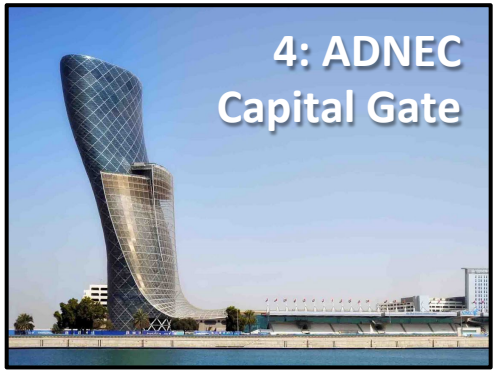




POST-EARTHQUAKE ASSESSMENT

EX4: Abu Dhabi Building Network





POST-EARTHQUAKE ASSESSMENT

EX4: Abu Dhabi

Home » News Article

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Earthquake shakes UAE, other countries; buildings, hospitals evacuated

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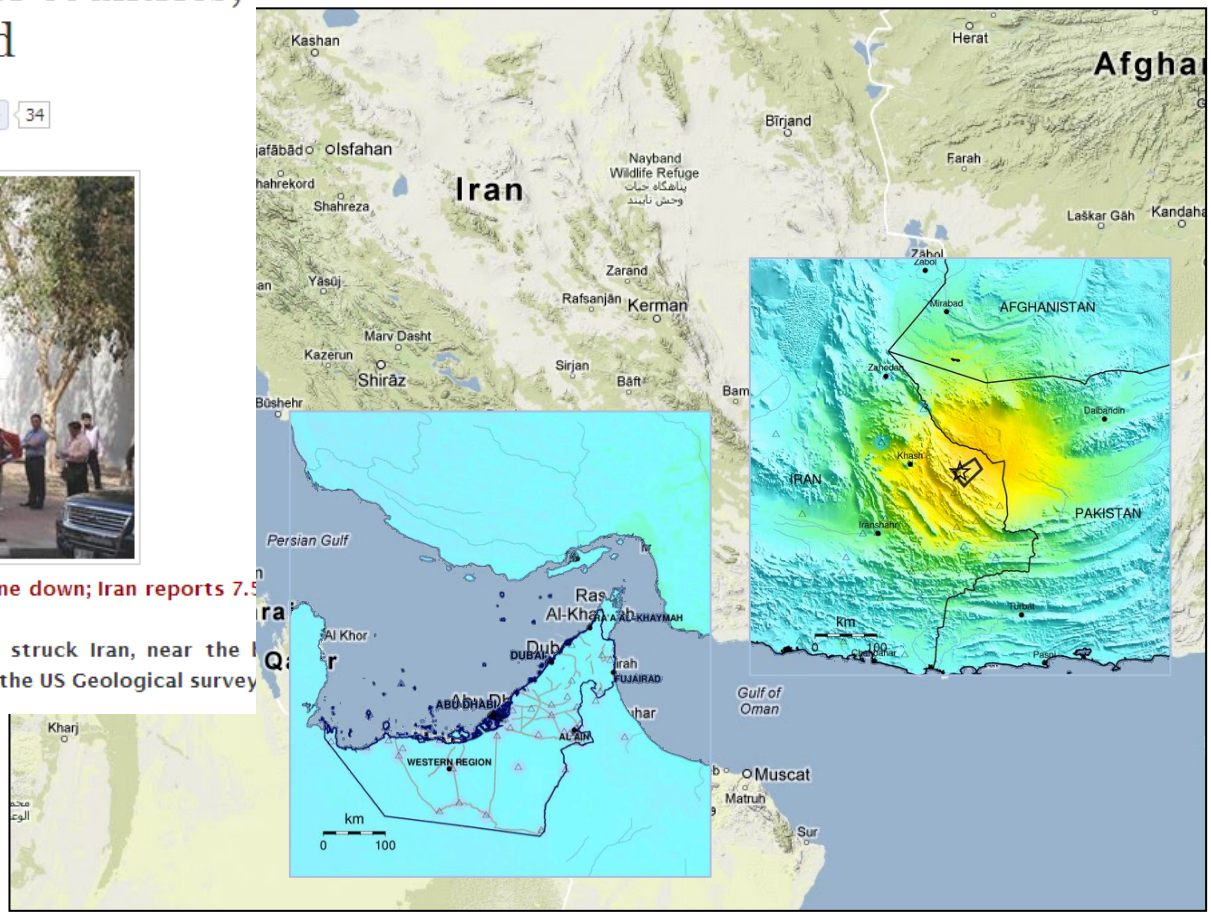
Mobile phone and Internet lines have reportedly also gone down; Iran reports 7.5 earthquake in southeast

A strong earthquake of 8.0 magnitude has reportedly struck Iran, near the I Pakistan, at 2.44pm UAE time (10:44am GMT) on Tuesday, the US Geological survey

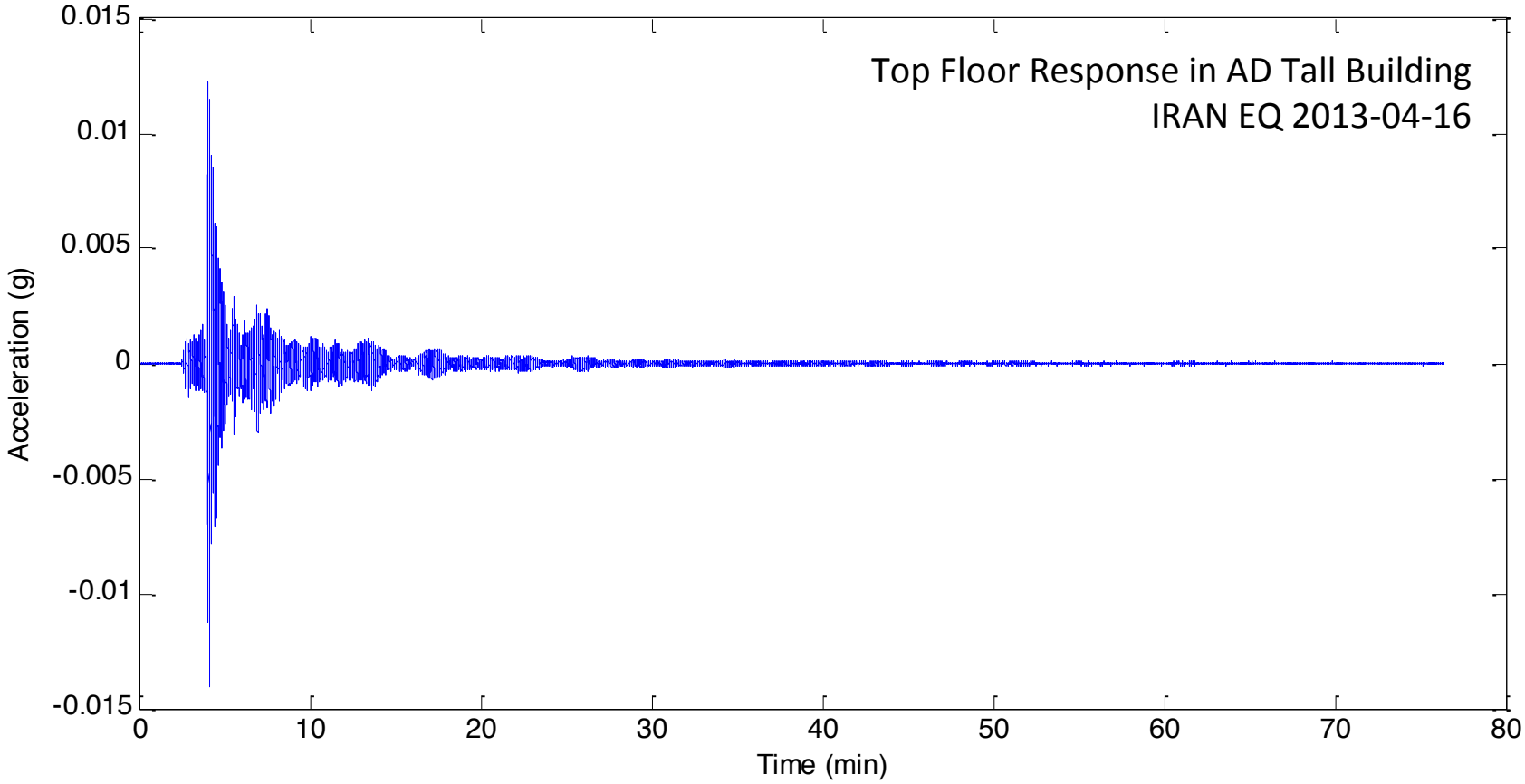
M7.7 - 83km E of Khash, Iran
2013-04-16 10:44:20 UTC



POST-EARTHQUAKE ASSESSMENT

EX4: Abu Dhabi

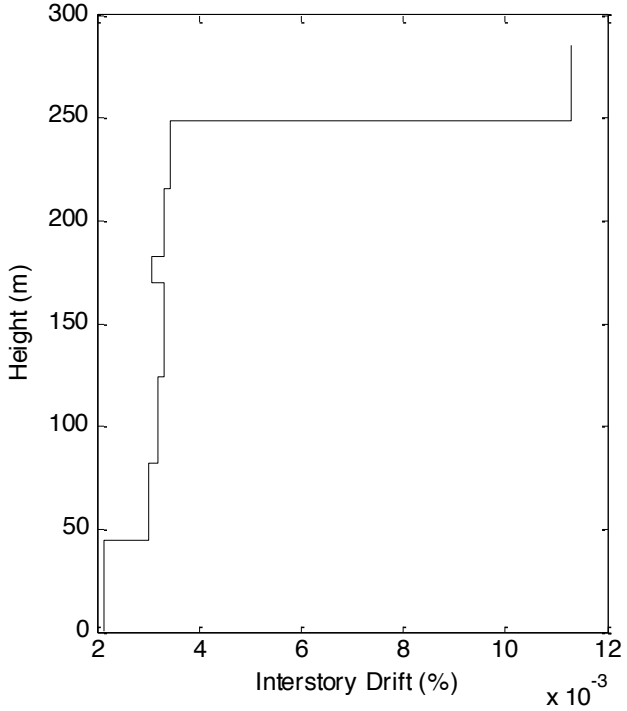
- For UAE buildings, the seismic hazard comes from large distant earthquakes
- These types of events can make occupants feel uneasy during shaking that can last for extended periods of time



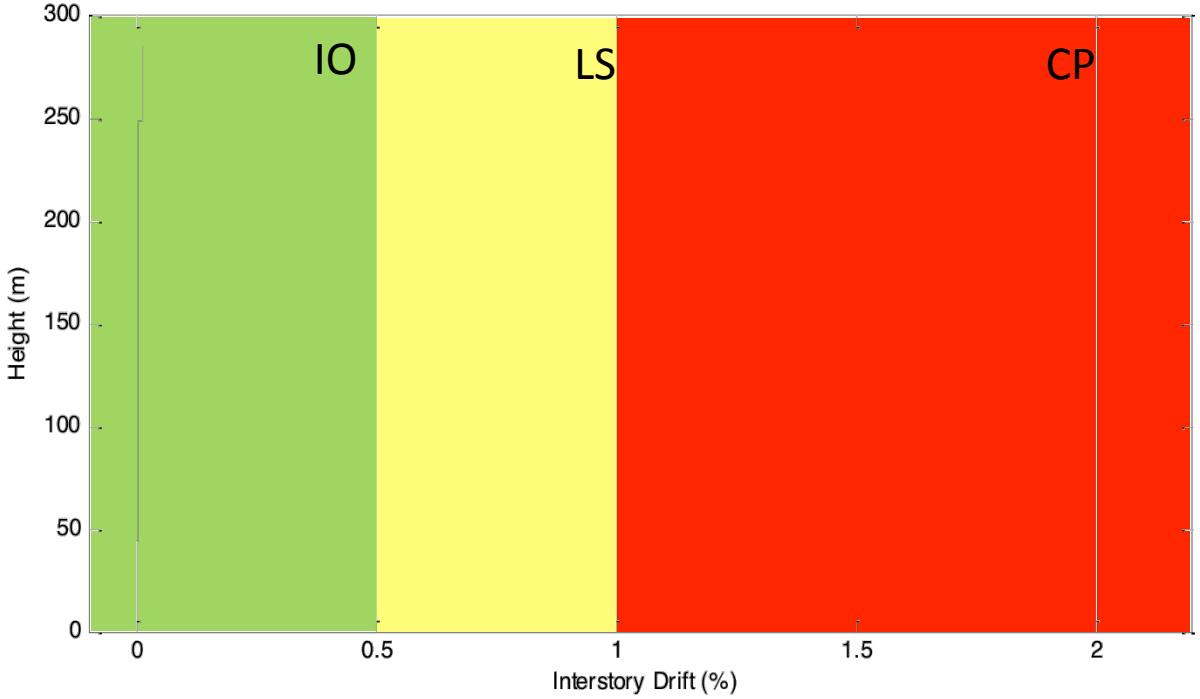
EX4: Abu Dhabi

- For example, during recent Iran earthquakes, data from one Abu Dhabi building showed that critical engineering response parameters were well within design limits. The building structure was FINE!

Interstory Drift for tall building, Abu Dhabi – IRAN EQ 2013-04-16

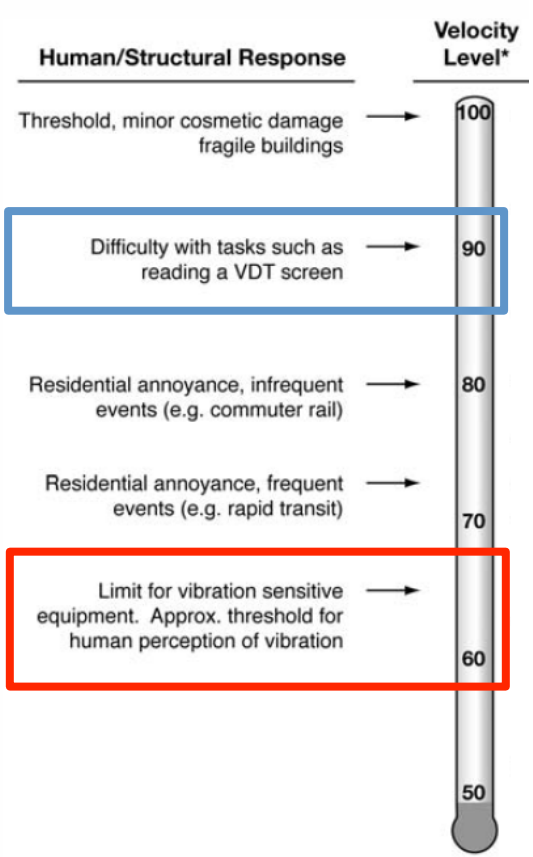


Interstory Drift for tall building, Abu Dhabi – IRAN EQ 2013-04-16 with typical seismic design performance levels: Immediate Occupancy, Life Safety, and Collapse Prevention



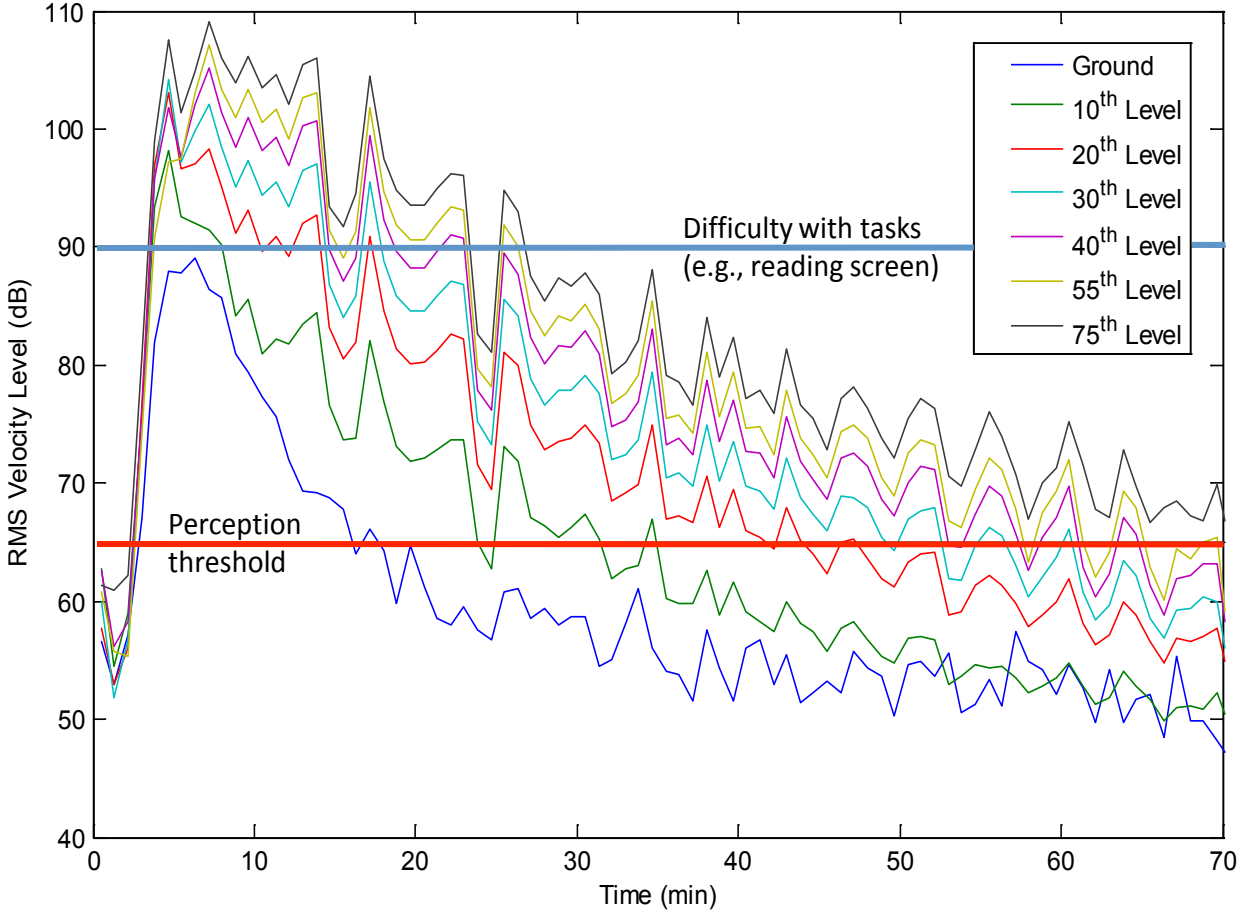
EX4: Abu Dhabi

- In this case, data from one tall Abu Dhabi building showed that shaking was ***above the level of human perception for over an hour!***



* *RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second*

Figure 7-3. Typical Levels of Ground-Borne Vibration



Source: US DOT FTA-VA-90-1003-06 Transit Noise and Vibration Impact Assessment

POST-EARTHQUAKE ASSESSMENT

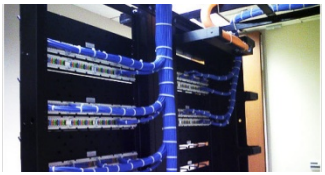
Funding

It's easier to get funding when the system is part of a larger retrofit or new design construction project

Implementation

Engineering implementation work and cost can be significant

** See 15WCEE paper for full list of tasks typically required of design professionals **



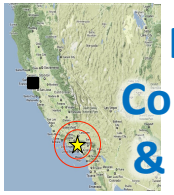
Generally, cabling does not present a significant cost compared to system and implementation costs, however; restricted access and the existence of hazardous materials may change this

Independent Communication

It's simpler to obtain a standalone DSL line for remote access and real-time monitoring than to utilize an existing infrastructure because network admins are reluctant to provide support and access through firewalls

Human in the Loop

While false positives are rare and can be minimized by careful selection of trigger logic, they can happen; so executing evacuations or other actions based on automatically generated system output should be avoided



Remote Command & Control

Real-time remote monitoring is crucial to ensure that the system is always operational and improves the likelihood of the data being available outside the affected region after a large earthquake

OUTLINE

- Introduction
- Enhanced Rapid Post-earthquake Assessment
- **Seismic Monitoring for Large Facilities**
- Structural Health Monitoring
- Summary

Background

- In 1988, EPRI conducted a study (NP-5930) that set out to determine what constitutes ***damaging earthquake motion*** and to develop criteria for determining exceedance of the Operating Basis Earthquake (OBE)
- In this study, several ground motion characteristics were investigated and trends were established based on observed structural damage for over 250 earthquake histories
- The conclusion reached was that a combination of two parameters is best suited for assessing the potential damage of a given ground motion history;

  PSA = peak spectral response pseudo-acceleration

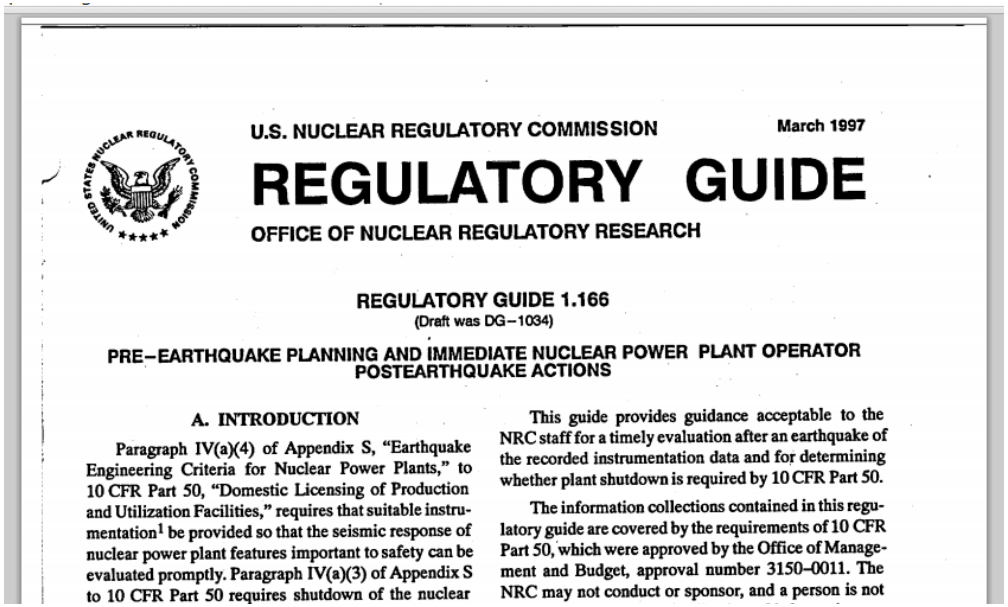
  CAV = cumulative absolute velocity

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Background, Cont

- In 1997 the NRC published a regulatory guide (NRC-1.166) that provided details on implementation of post-earthquake actions for nuclear power plants (NPPs)
- It included PSA and CAV as well as a new exceedance check using velocity response spectra
- If a M5 or greater EQ occurs within a 200 km radius, a NPP must shutdown unless it can reliably advise the NRC, within four hours, that the earthquake's effects on the plant have not exceeded its OBE or CAV design requirements



U.S. NUCLEAR REGULATORY COMMISSION March 1997

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.166
(Draft was DG–1034)

PRE–EARTHQUAKE PLANNING AND IMMEDIATE NUCLEAR POWER PLANT OPERATOR POSTEARTHQUAKE ACTIONS

A. INTRODUCTION

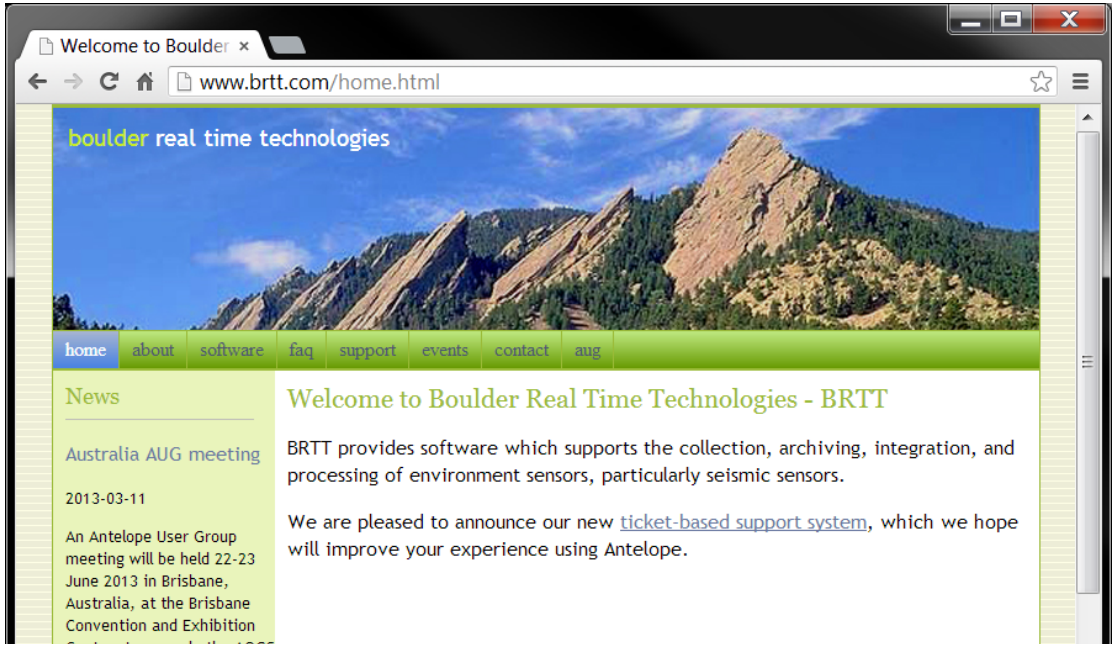
Paragraph IV(a)(4) of Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that suitable instrumentation[1] be provided so that the seismic response of nuclear power plant features important to safety can be evaluated promptly. Paragraph IV(a)(3) of Appendix S to 10 CFR Part 50 requires shutdown of the nuclear

This guide provides guidance acceptable to the NRC staff for a timely evaluation after an earthquake of the recorded instrumentation data and for determining whether plant shutdown is required by 10 CFR Part 50.

The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50, which were approved by the Office of Management and Budget, approval number 3150–0011. The NRC may not conduct or sponsor, and a person is not

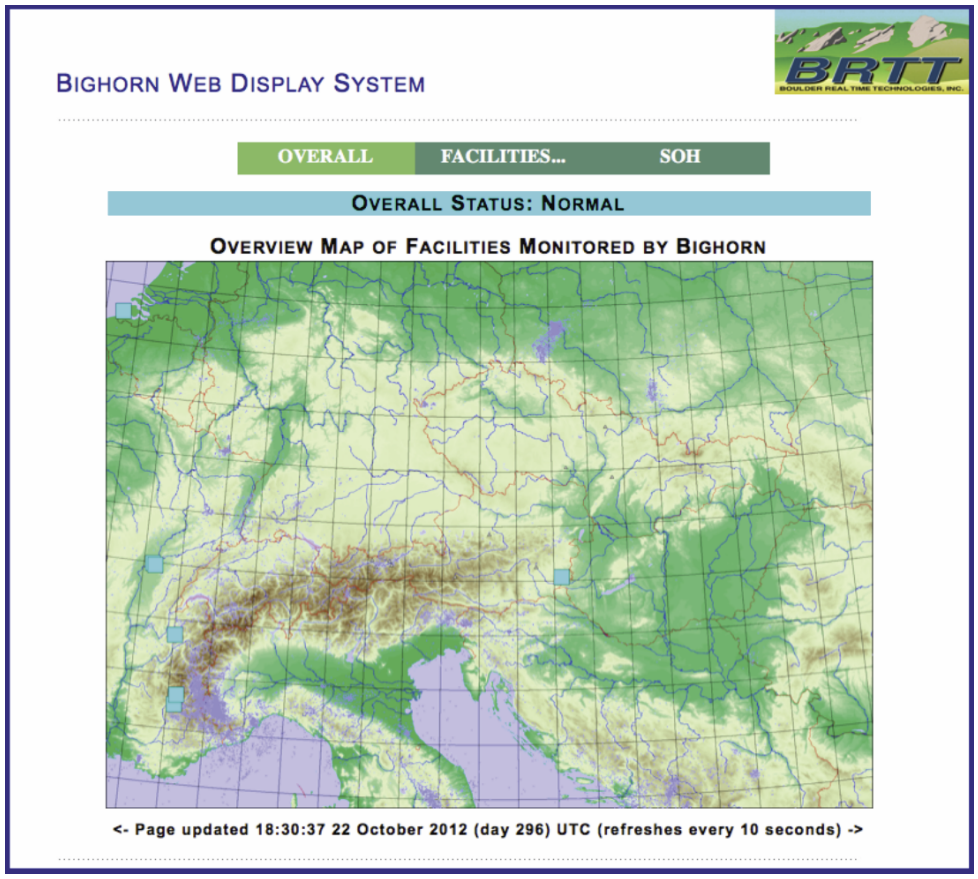
Next-Gen Seismic Monitoring Solution

- Rather than trigger on earthquake, calculate spectra, compare results to design curves, and report on exceedance and issue alarms,...
- Next Generation Seismic Monitoring solution ***calculates response spectra in real-time*** and issues alarms based on exceedance
- BRTT's Bighorn, part of Antelope Environmental Data Collection Software Package (for data collection for very large networks and real-time seismic data analyses)



Bighorn (BRTT)

- Provides a very fast method for computing continuous time-dependent response spectra for large numbers of channels
- Includes built-in web display system



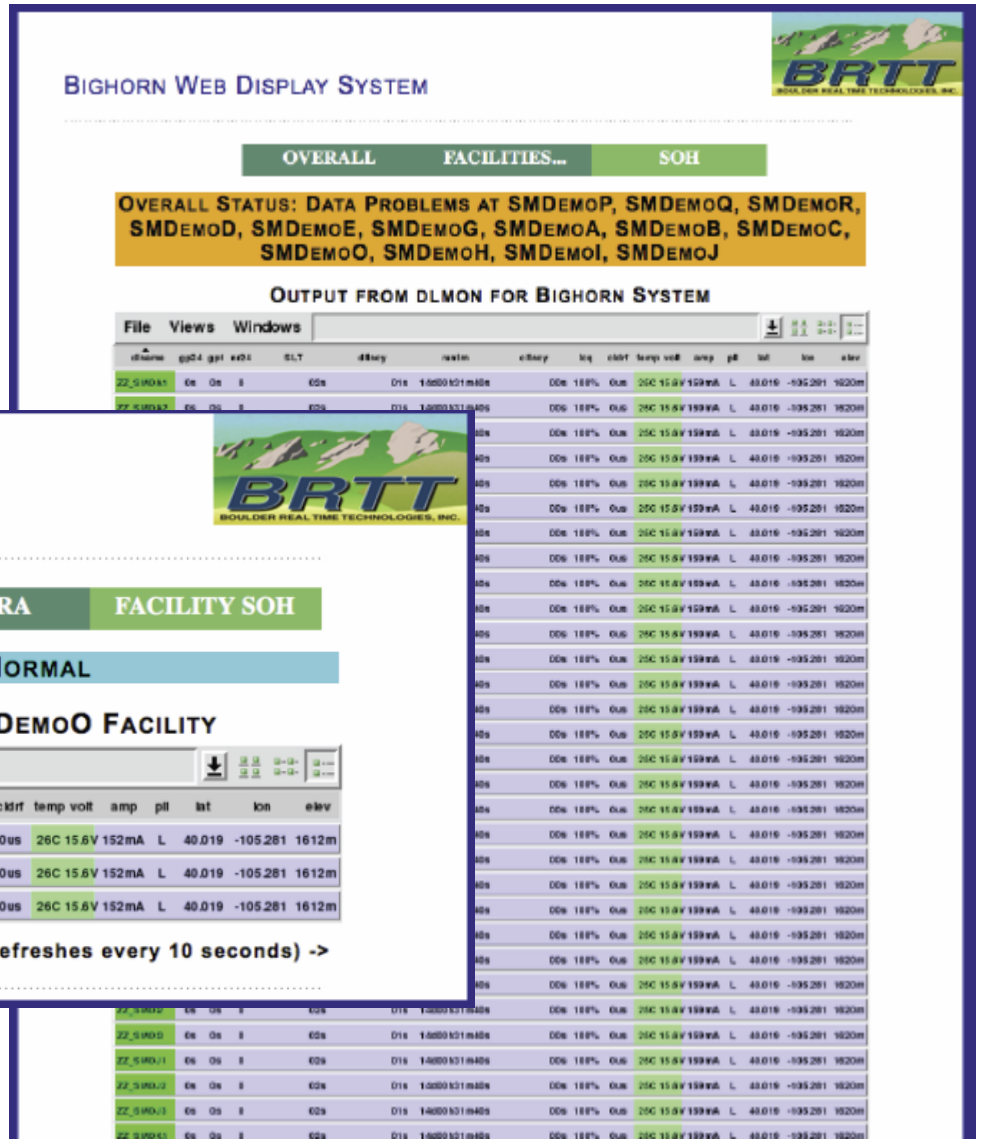
** Courtesy of BRTT*

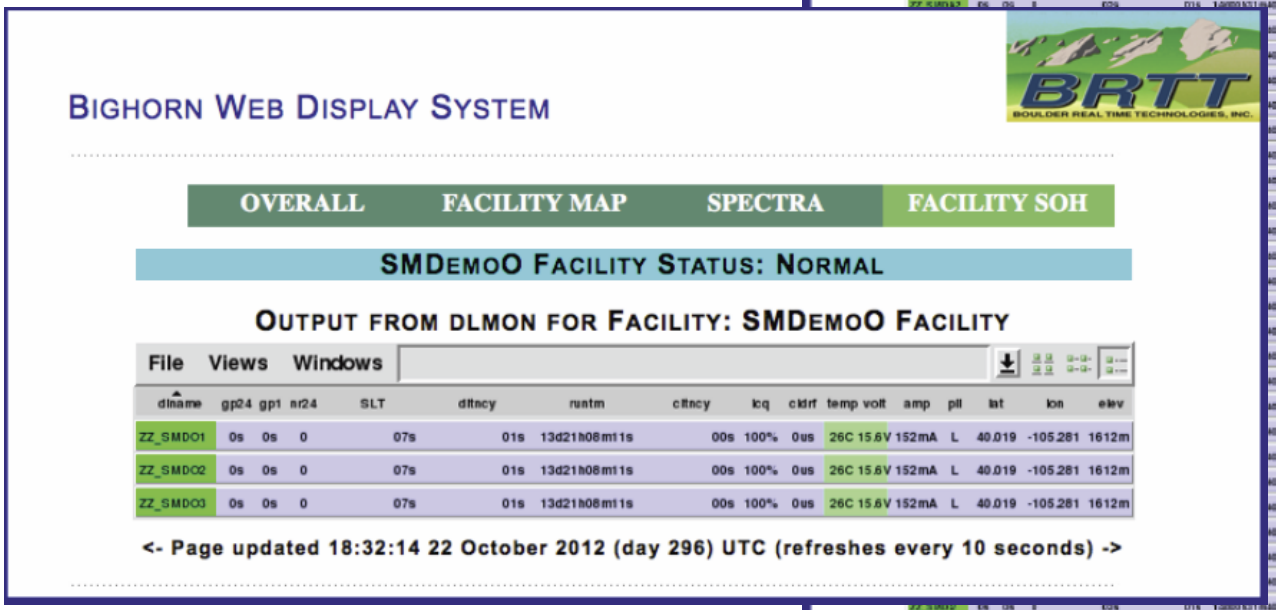
Bighorn (BRTT), cont

** Courtesy of BRTT*

Bighorn (BRTT), cont

- SOH monitoring for each facility and for entire network of plants





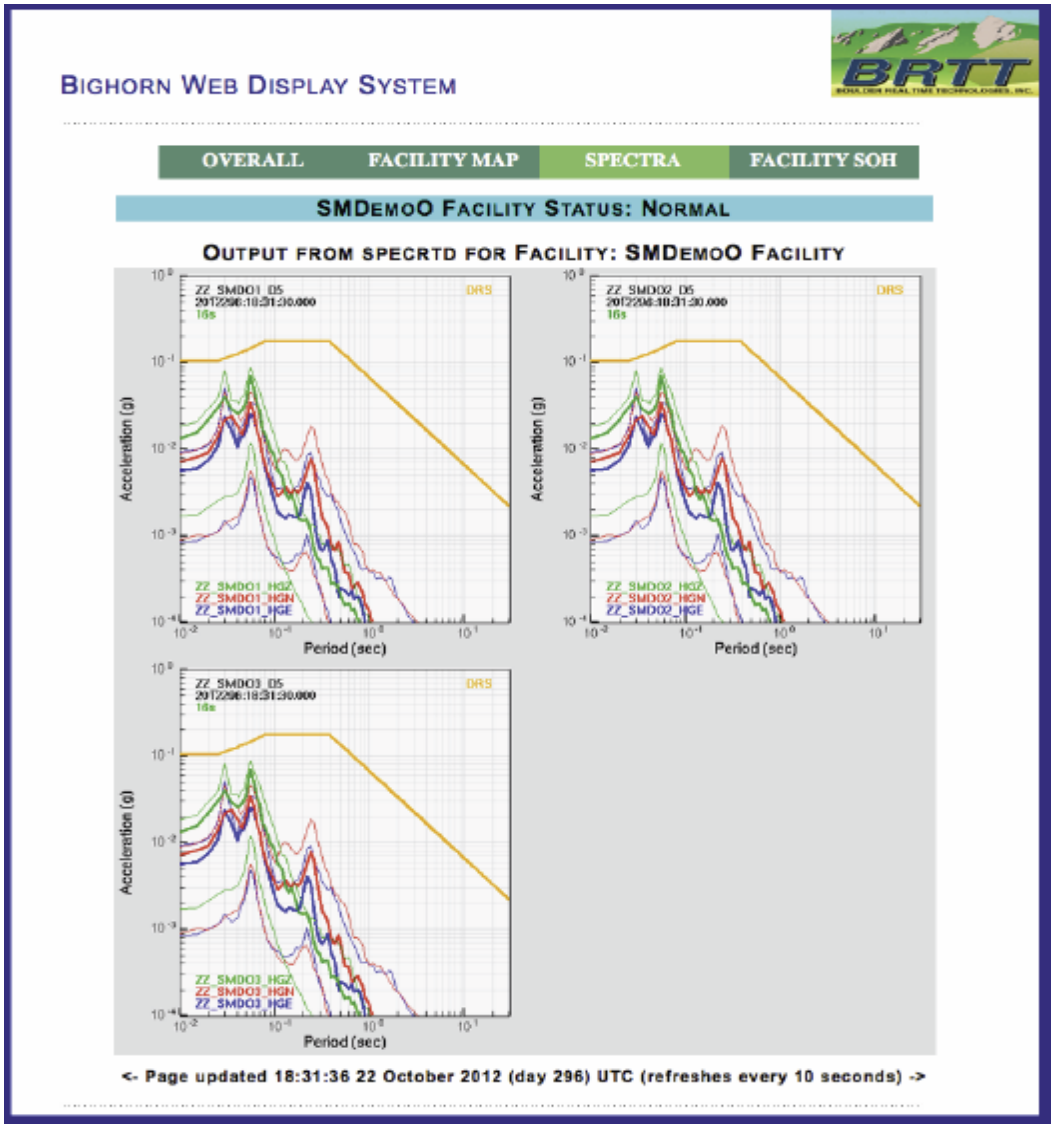
** Courtesy of BRTT*

Bighorn (BRTT), cont

- Real-time calculation of response spectra includes creating frequency-slice waveforms and computing peak values over moving time windows

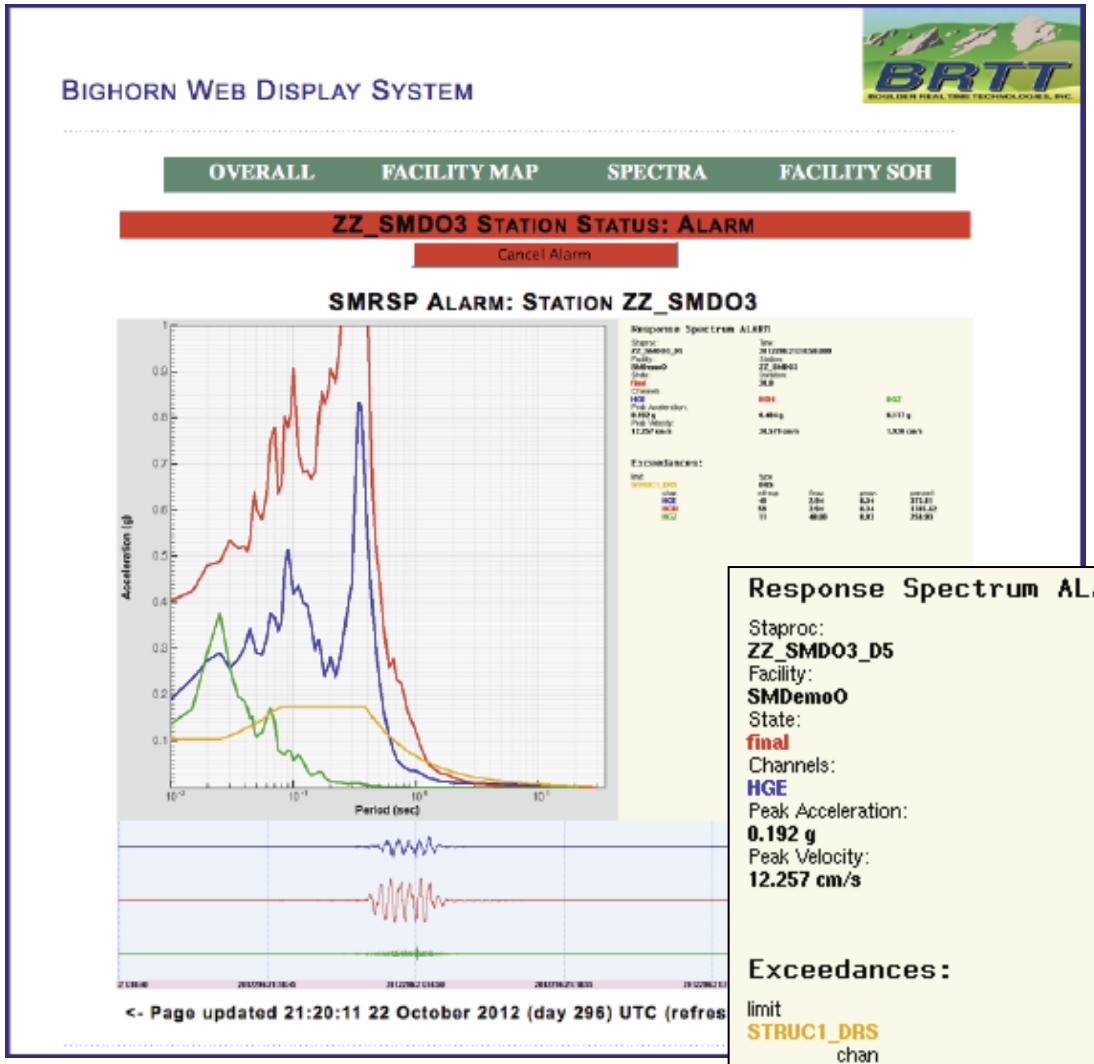
** Courtesy of BRTT*

Bighorn (BRTT), cont



** Courtesy of BRTT*

SEISMIC MONITORING



Response Spectrum ALARM

Staproc:	Time:	
ZZ_SMDO3_D5	**2012296:21:18:50.000**	
Facility:	Station:	
SMDemoO	**ZZ_SMDO3**	
State:	Duration:	
final	**20.0**	
Channels:		
HGE	**HGN**	**HGZ**
Peak Acceleration:		
0.192 g	**0.404 g**	**0.137 g**
Peak Velocity:		
12.257 cm/s	**20.579 cm/s**	**1.920 cm/s**

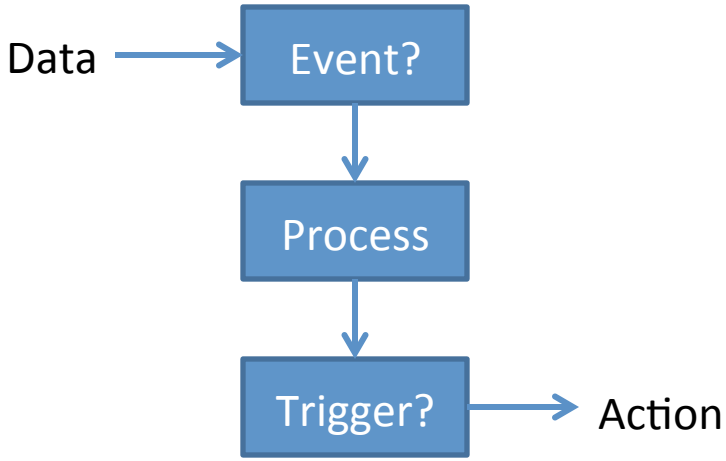
Exceedances:

limit	type			
STRUC1_DRS	**DRS**			
chan	nfreqs	fmax	pmax	percent
HGE	**49**	**2.94**	**0.34**	**373.11**
HGN	**59**	**2.94**	**0.34**	**1385.62**
HGZ	**11**	**40.00**	**0.03**	**258.93**

** Courtesy of BRTT*

Summary

- New Development
- Bighorn represents a paradigm shift in how emergency management of multiple large facilities can utilize advantages of strong-motion networks
- The result is a simpler more robust computation algorithm with less failure points



OUTLINE

- Introduction
- Strong-Motion Instrumentation
- Enhanced Rapid Post-earthquake Assessment
- Real-Time Monitoring for Large Facilities
- **Structural Health Monitoring**
- Summary

What is Structural Health Monitoring (SHM)?

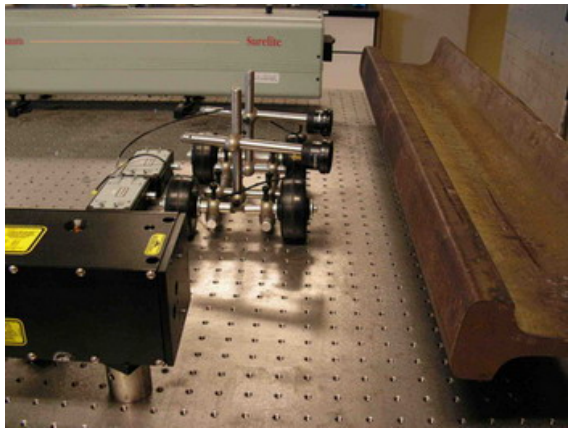
- The ***continuous and automated*** process of assessing a structures' state-of-health, i.e., ***extent of damage***
- The goal is to ***detect damage*** before it reaches a critical state
- SHM implies; permanent instrumentation, real-time processing, damage detection (and location) algorithms, and some online alerting system

Arabdrill 19, UAE

I-35W Bridge Collapse

Types of SHM – Local v Global

- Local SHM measures micro responses and detects localized damage, but usually requires sophisticated equipment (ultrasound, x-ray, piezoelectric actuators) or very dense networks
- Global SHM uses sparse deployments to measure global responses such as acceleration or inter-story drift but requires complex damage detection algorithms and has difficulty to localize damage

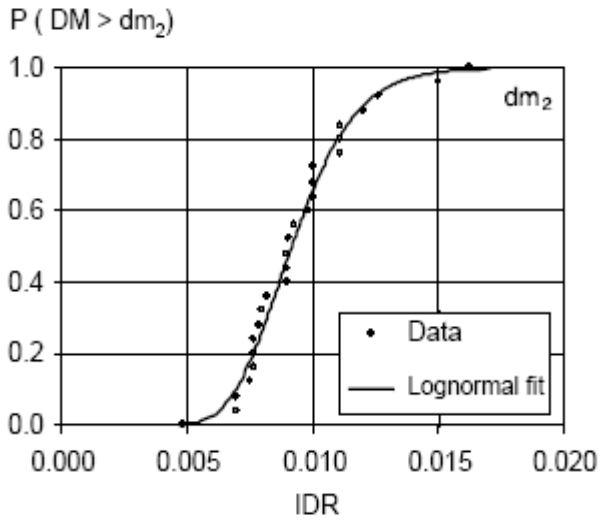


(Scalea, UCSD)

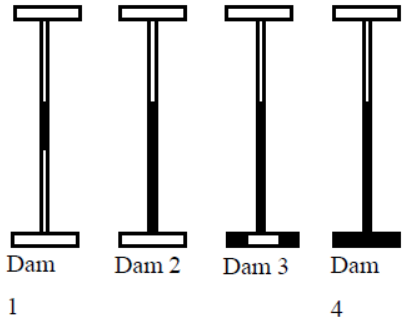
(IRIB SHM System, UD)

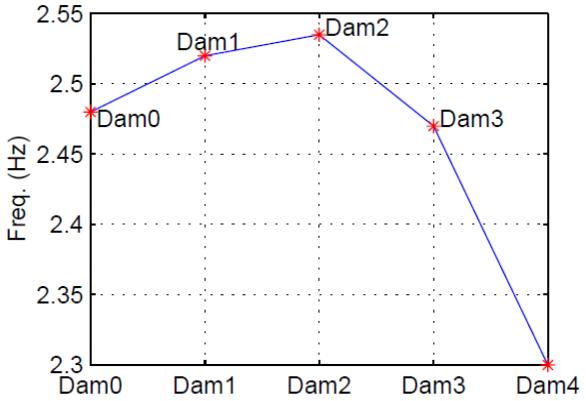
Global SHM Approaches

- Vibration-based (track changes in modal properties or wave propagations)
- Model Updating (automated FEM)
- Combination Suite of Response Quantities (damage index)



(Naeim, JAMA)



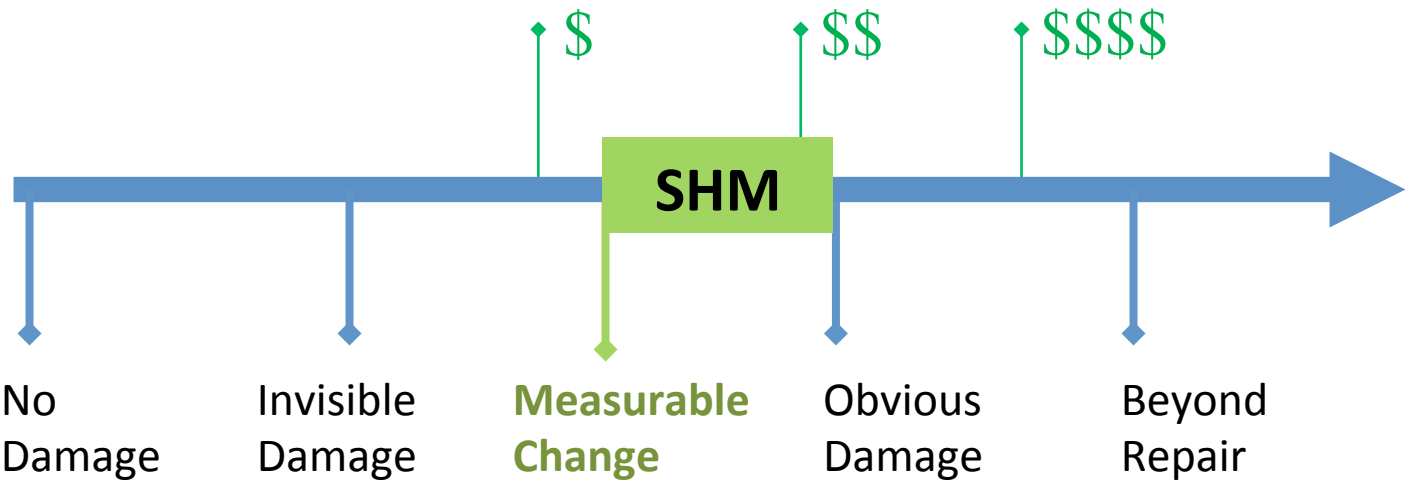


(Farrar, Los Alamos)

SHM Issues – is it worth it?

- Onset of damage can be fast (earthquake) or slow (fatigue, aging)
- For dynamic events, *'Improved Safety'* is generally not the impervious incentive its usually made out to be because if there is dangerous damage in civil structures, you do not need any sensors to see it
- The real benefit of SHM comes when you can reduce repair costs or prolong life of a structure by detecting onset of slow damage before it gets too big.

Challenge: Global SHM algorithms typically require significant amount of damage before its observed



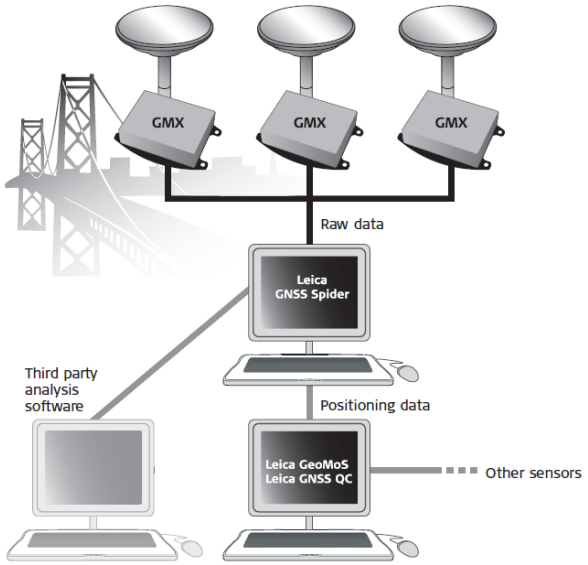
SHM Issues – is it worth it?

- Despite these issues, the civil-engineering community definitely agrees SHM is worthy endeavor
- Academic research efforts are plentiful and solutions consistently proposed
- In industry, SHM specifications are finding there ways onto major project tenders
  - Multiple sensor types
  - Sometimes with big-picture objectives, but not usually
  - Price expectation tied to hardware, not level of service
  - Projects tend to become academic still
- On technology side, our challenge still lies within implementation of a fully integrated SHM system (multiple sensors, common acquisition, different processing approaches, and expert consulting….)

Other Structural Sensors

Biaxial Tiltmeter

Differential GPS



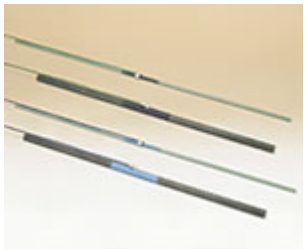
LPR Corrosion

LVDTs

Fiber Optics

Vibrating Wire Sensors

Tensioned wire vibrates (when plucked) at freq proportional to strain



Rebar Strain

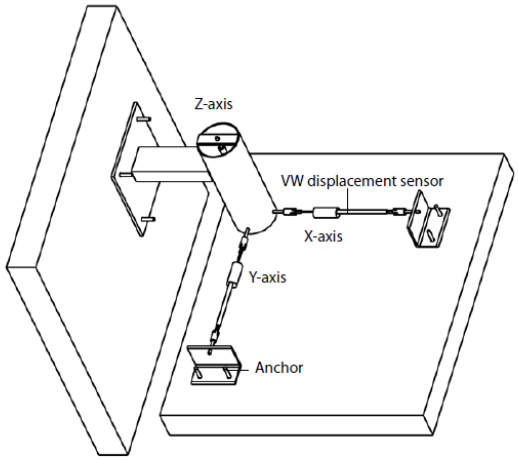
Concrete Strain

Load Cell

Pressure

Displacement

- Static Measurements
- Highly susceptible to temp gradients, built-in temp sensor (thermistor)
- Electromagnet used to pluck wire
- Readout is frequency not voltage
- Manufacturers: Geokon, Starmass, Slope Indicator, Geomechanics



3D-Displacement

Environmental Sensors

Weather Station

Air Duct

Ambient Air

Radar Level Sensor

Precipitation Sensor

OUTLINE

- Introduction
- Enhanced Rapid Post-earthquake Assessment
- Real-Time Monitoring for Large Facilities
- Structural Health Monitoring
- **Summary**

SUMMARY

1. Enhanced Rapid Post-earthquake Assessment is useful for critical and essential facilities
   - Advanced systems with integration into 3-phase response
2. NG strong-motion monitoring for large or multiple facilities using real-time response spectra computations
   - Paradigm shift in SM processing
3. SHM frontiers

THANK YOU

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