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Petroleum Storage and Seismicity: A Presentation to OSPE

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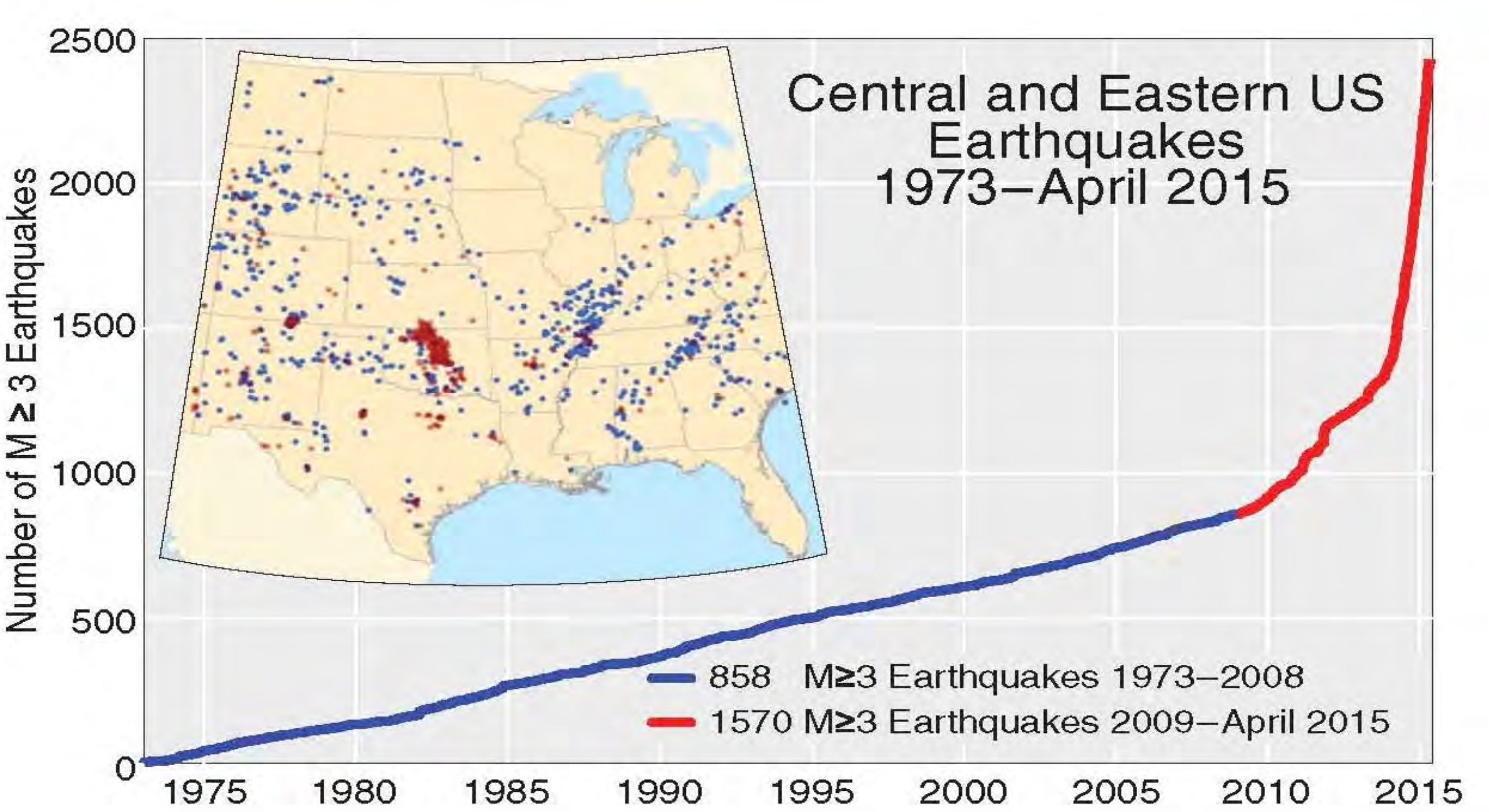
Agenda and presentation outline

- Introduction
- Seismic Design Process
- Selection of Seismic Parameters
- Evaluation: October 10, 2015 M4.5 Earthquake
- Earthquakes Effects - Aboveground Storage Tanks (ASTs)
- Infrastructure Considerations
- Disaster Preparedness

Central and Eastern U.S. earthquakes

1973 to April 2015



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OKLAHOMA | Economy, Energy, Natural Resources: Policy to People

ENERGY ▾ NATURAL RESOURCES ▾ ECONOMIC DEVELOPMENT ▾

Oil Company Makes New Quake Plans After Shaking Near U.S. Storage Hub in Oklahoma

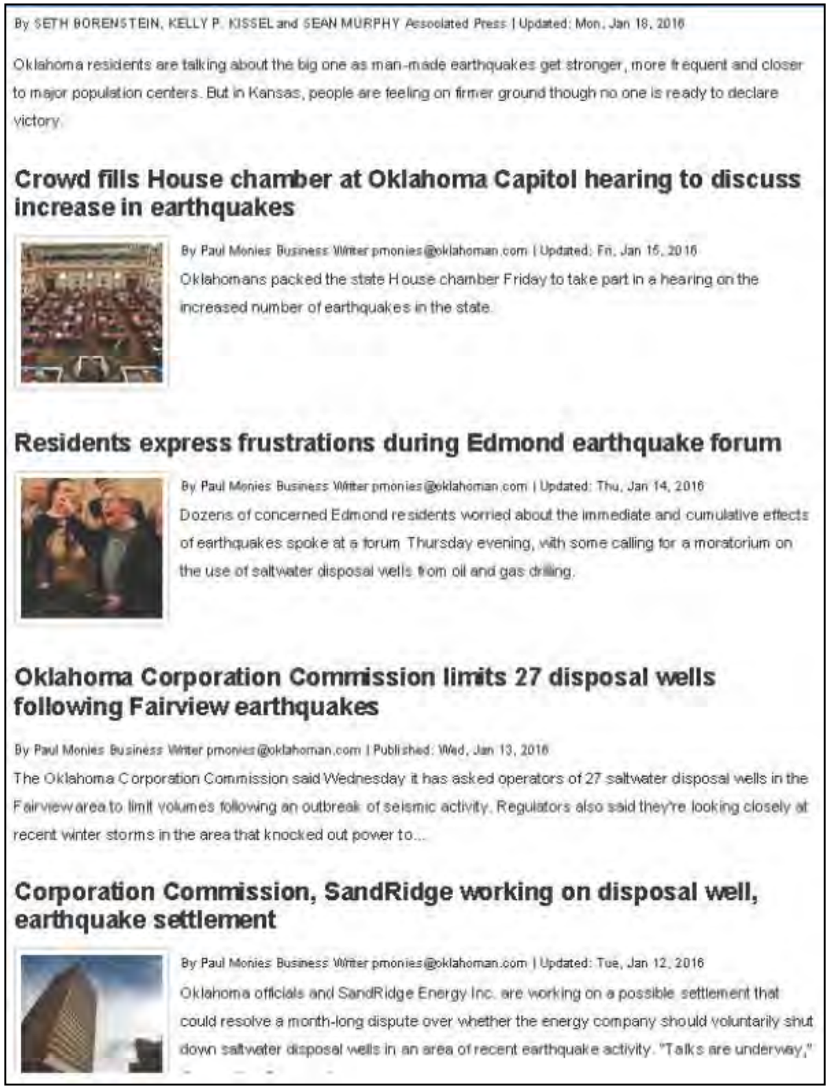
NOVEMBER 24, 2015 | 10:49 AM
BY JOE WERTZ

1 Comment · Email · Tweet · Recommend 46

JOE WERTZ / STATEIMPACT OKLAHOMA

Tanker trucks unloading oil at a Phillips 66 terminal in Cushing, Okla., home to the largest commercial crude oil storage in the U.S.

Phillips 66, a refiner with 700,000 barrels of storage capacity in Cushing, Okla., "has overhauled how it plans for earthquakes, a sign U.S. energy companies are starting to react to rising seismicity around the world's largest crude hub," Reuters' **Liz Hampton**



By SETH BORENSTEIN, KELLY P. KISSEL and SEAN MURPHY Associated Press | Updated: Mon, Jan 18, 2016

Oklahoma residents are talking about the big one as man-made earthquakes get stronger, more frequent and closer to major population centers. But in Kansas, people are feeling on firmer ground though no one is ready to declare victory.

Crowd fills House chamber at Oklahoma Capitol hearing to discuss increase in earthquakes

By Paul Monies Business Writer pmonies@oklahoman.com | Updated: Fri, Jan 15, 2016

Oklahomans packed the state House chamber Friday to take part in a hearing on the increased number of earthquakes in the state.

Residents express frustrations during Edmond earthquake forum

By Paul Monies Business Writer pmonies@oklahoman.com | Updated: Thu, Jan 14, 2016

Dozens of concerned Edmond residents worried about the immediate and cumulative effects of earthquakes spoke at a forum Thursday evening, with some calling for a moratorium on the use of saltwater disposal wells from oil and gas drilling.

Oklahoma Corporation Commission limits 27 disposal wells following Fairview earthquakes

By Paul Monies Business Writer pmonies@oklahoman.com | Published: Wed, Jan 13, 2016

The Oklahoma Corporation Commission said Wednesday it has asked operators of 27 saltwater disposal wells in the Fairview area to limit volumes following an outbreak of seismic activity. Regulators also said they're looking closely at recent winter storms in the area that knocked out power to...

Corporation Commission, SandRidge working on disposal well, earthquake settlement

By Paul Monies Business Writer pmonies@oklahoman.com | Updated: Tue, Jan 12, 2016

Oklahoma officials and SandRidge Energy Inc. are working on a possible settlement that could resolve a month-long dispute over whether the energy company should voluntarily shut down saltwater disposal wells in an area of recent earthquake activity. "Talks are underway,"

Earthquake felt throughout most of NW Ohio, SE Michigan upgrade - Toledo News Now, News, Weather, Sports, Toledo, OH

Ask the Expert | Birthday Club | Community Track | Obituaries | Contests | 41911 Deals

Earthquake felt throughout most of NW Ohio, SE Michigan upgraded to 4.2 magnitude

Published: Saturday, May 2nd 2015, 11:03 am CST
Updated: Saturday, May 2nd 2015, 1:50 pm CST

By Abby Bryson CONNECT

(Toledo News Now) - The USGS website has updated the magnitude of the earthquake felt throughout most of northwest Ohio and southeast Michigan from a 4.0 to a 4.2, making it the second largest earthquake in Michigan history.

The earthquake was located approximately 8 kilometers south of Galesburg, MI around 12:23 p.m. Saturday.

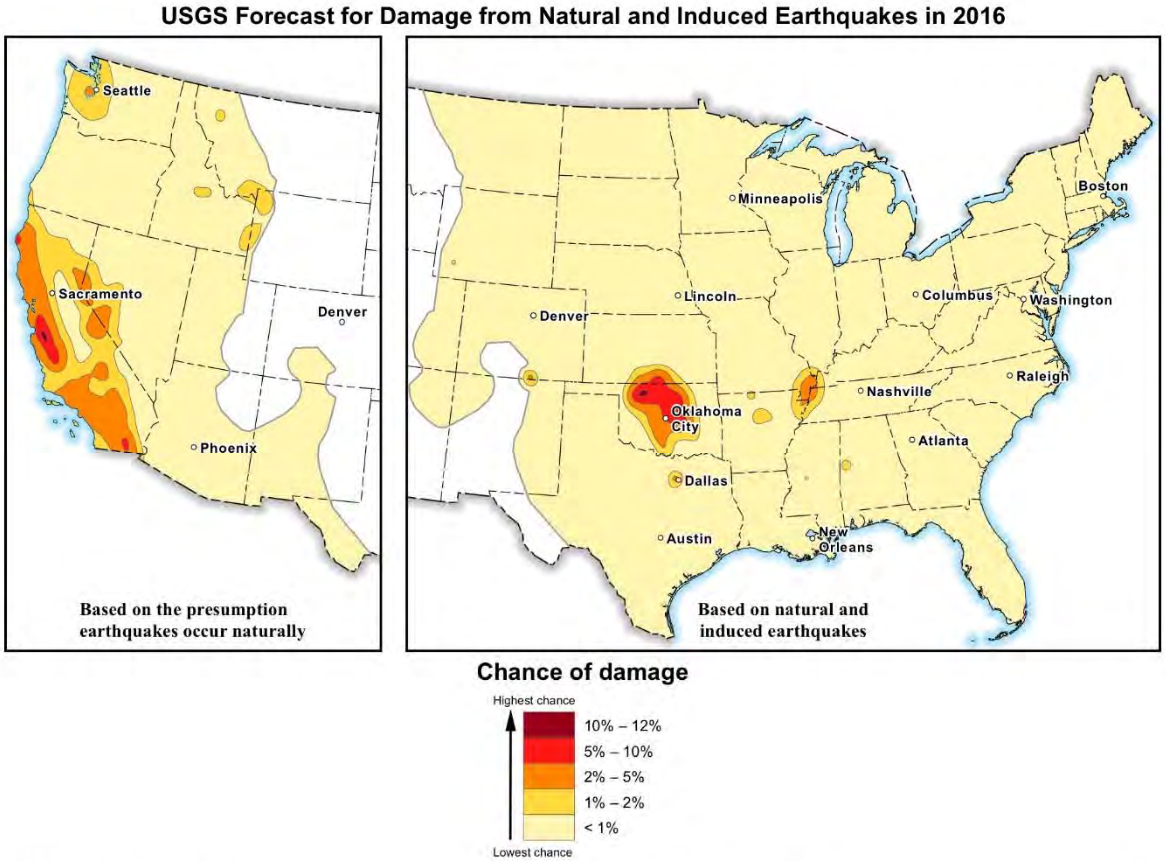
No reports of any damage or injuries have come in, though the earthquake was felt from several miles away in parts of Ohio, Indiana, Illinois, and Wisconsin.

Tune into WTOL 11 News Now at 6 for more.

Why is this a big deal?

Why is this a big deal?

Potential - Earthquake damage, 2016 prediction



USGS map displaying potential to experience damage from natural or human-induced earthquakes in 2016. Chances range from less than 1 percent to 12 percent.

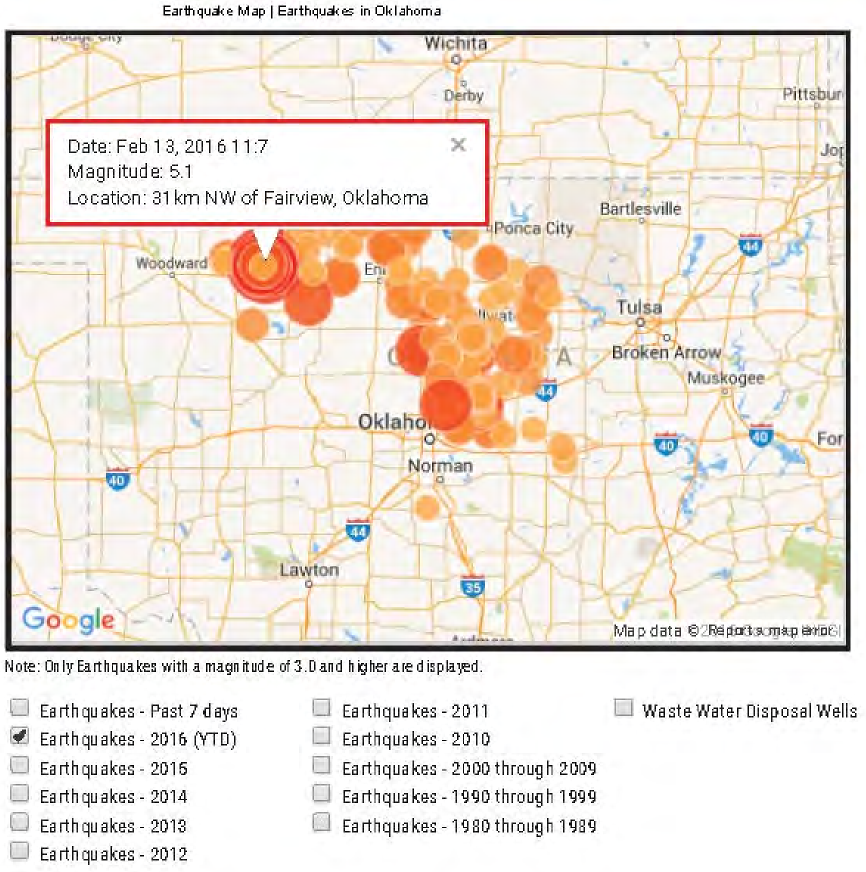
http://www.usgs.gov/blogs/features/usgs_top_story/induced-earthquakes-raise-chances-of-damaging-shaking-in-2016/?from=title

OBJECTIVE

FRAME	The Earthquake Effects on Storage Tank Infrastructure
COMMUNICATE	Seismic Design Process For Storage Tanks
IDENTIFY	Potential Issues
PROPOSE	Mitigation Measures

Reporting of Earthquakes

Typically Reported as Magnitude



Earthquake Map | Earthquakes in Oklahoma

Date: Feb 13, 2016 11:7
Magnitude: 5.1
Location: 31 km NW of Fairview, Oklahoma

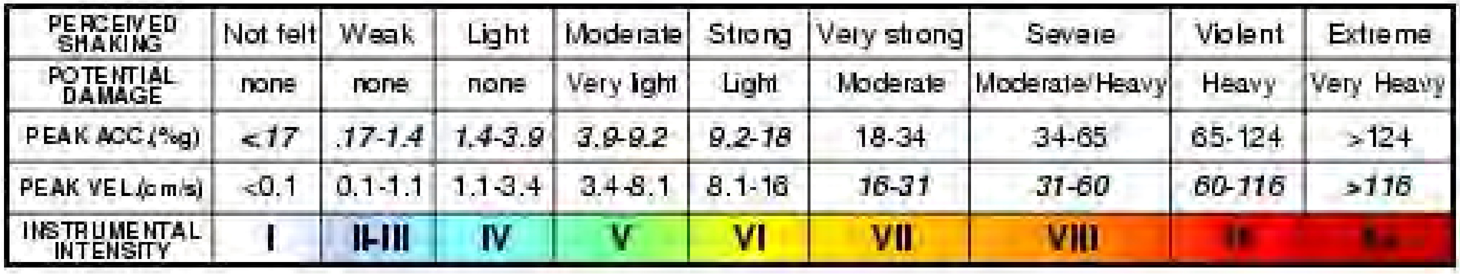
Note: Only Earthquakes with a magnitude of 3.0 and higher are displayed.

☐ Earthquakes - Past 7 days
☑ Earthquakes - 2016 (YTD)
☐ Earthquakes - 2015
☐ Earthquakes - 2014
☐ Earthquakes - 2013
☐ Earthquakes - 2012
☐ Earthquakes - 2011
☐ Earthquakes - 2010
☐ Earthquakes - 2000 through 2009
☐ Earthquakes - 1990 through 1999
☐ Earthquakes - 1980 through 1989
☐ Waste Water Disposal Wells

Earthquake data provided by the Oklahoma Geological Survey. Disposal well data provided by the Oklahoma Corporation Commission.

Reporting of Earthquakes

Modified Mercalli Intensity scale (MMI) definition



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

From the USGS Website: This scale, composed of increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

http://earthquake.usgs.gov/learn/topics/mercalli.php

While Magnitude or MMI may be meaningful in describing severity to the general public, **tank design engineers use seismic parameters** in the design process.

Magnitude and energy correlation

- Magnitude (M) is based on maximum amplitude of motion recorded by a seismograph for an earthquake

1 unit of Magnitude Change ---> 10 times of change in amplitude

- Structural Response is related to Energy Release (E) NOT Magnitude.

1 unit of Magnitude Change ---> (10)^1.5 times change E, (31.62 times).

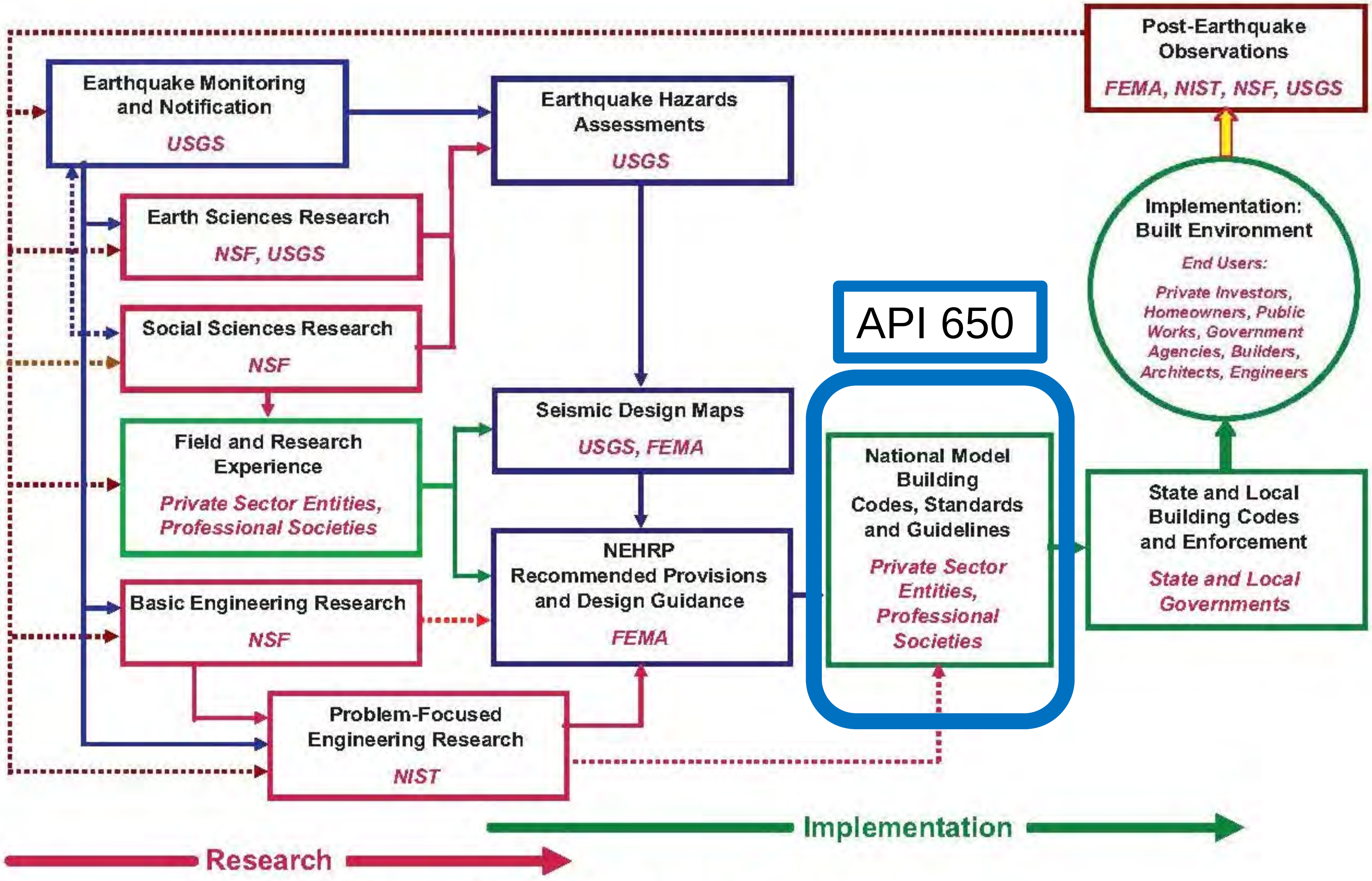
Mathematically, $log_{10} E = 1.5M$

	Earthquake				
Magnitude	**4**	**4.5**	**5**	**6**	**7**
Ratio of maximum amplitude for the earthquake as compared to a M4.0	1	3.16	10	100	1, 000
Ratio of Energy Released for the earthquake as compared to a M4.0	1	6	32	1000	31,623

Cushing,
Oct 10, 2015

HAITI,
Jan 12, 2010

Seismic design map development process



NEHRP Impact on the Built Environment

Seismic Waves, June 2007, The NEHRP “Recommended Provisions” and the National Model Building Codes.

Seismic design process for ASTs

Response is divided into:

1. *Impulsive Mode (Tank and a portion of its contents)*
2. *Convective Mode (Balance of the liquid)*

Vibration modes of AST in an earthquake

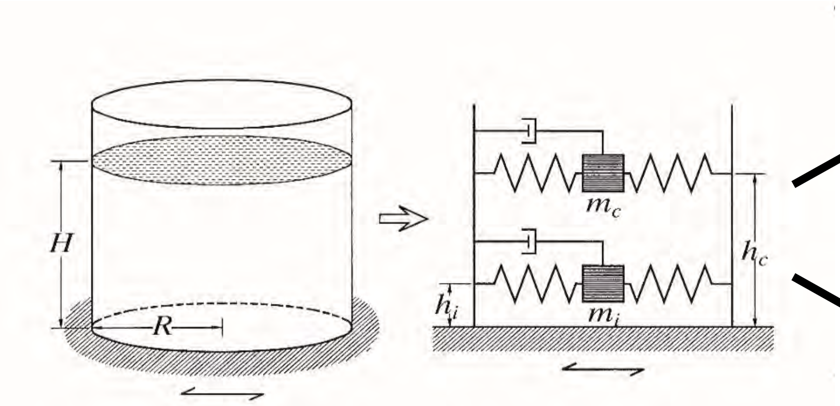
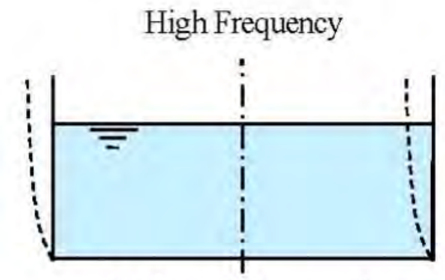
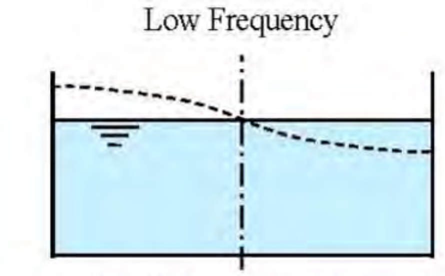


Fig. 3: Liquid-filled tank modelled by generalised single-degree-of-freedom systems



(a) Impulsive motion



(b) Sloshing motion

Yoshida, REVIEW OF EARTHQUAKE DAMAGES OF ABOVEGROUND STORAGE TANKS IN JAPAN AND TAIWAN, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, PVP2014, PVP2014-28116

Seismic design process for ASTs

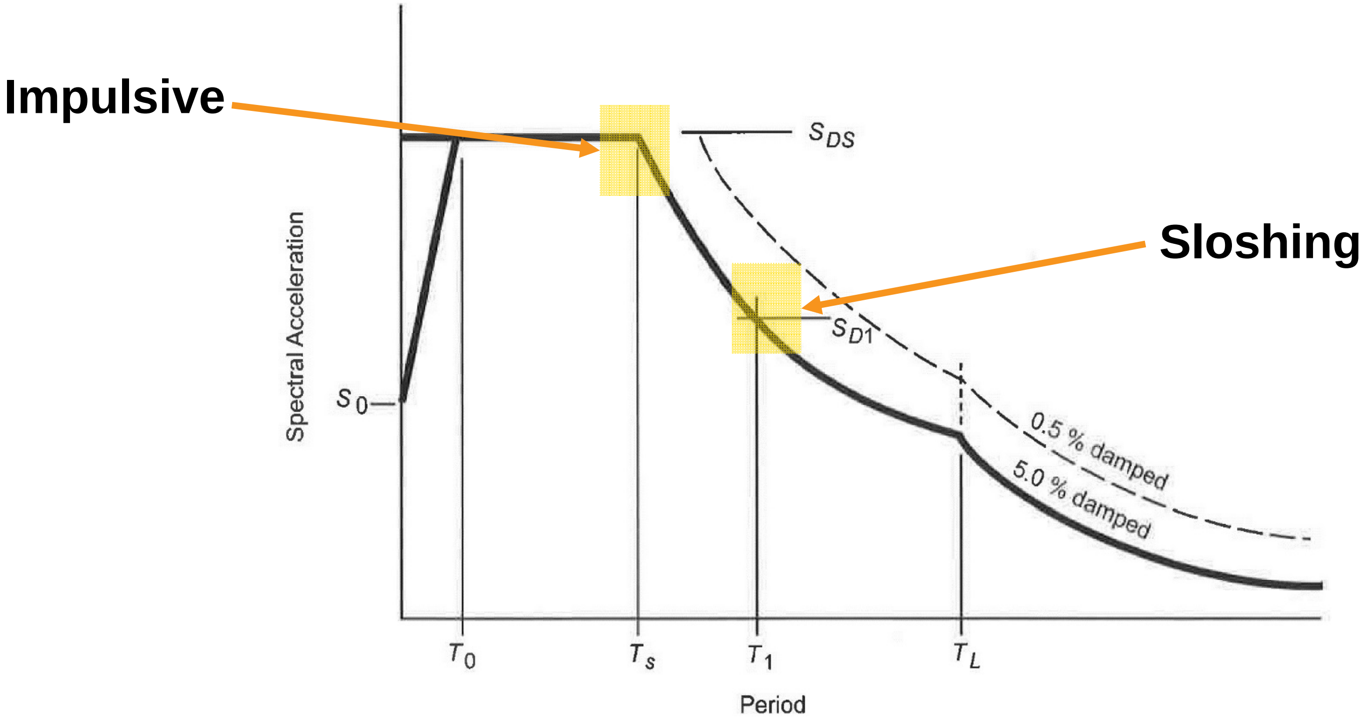


Figure EC.2—Earthquake Response Spectrum Notation

It is these seismic parameters that are used in tank design.

Welded Tanks for Oil Storage, API 650 12th Edition, March 2013 with Errata December 2014

Seismic design process for ASTs

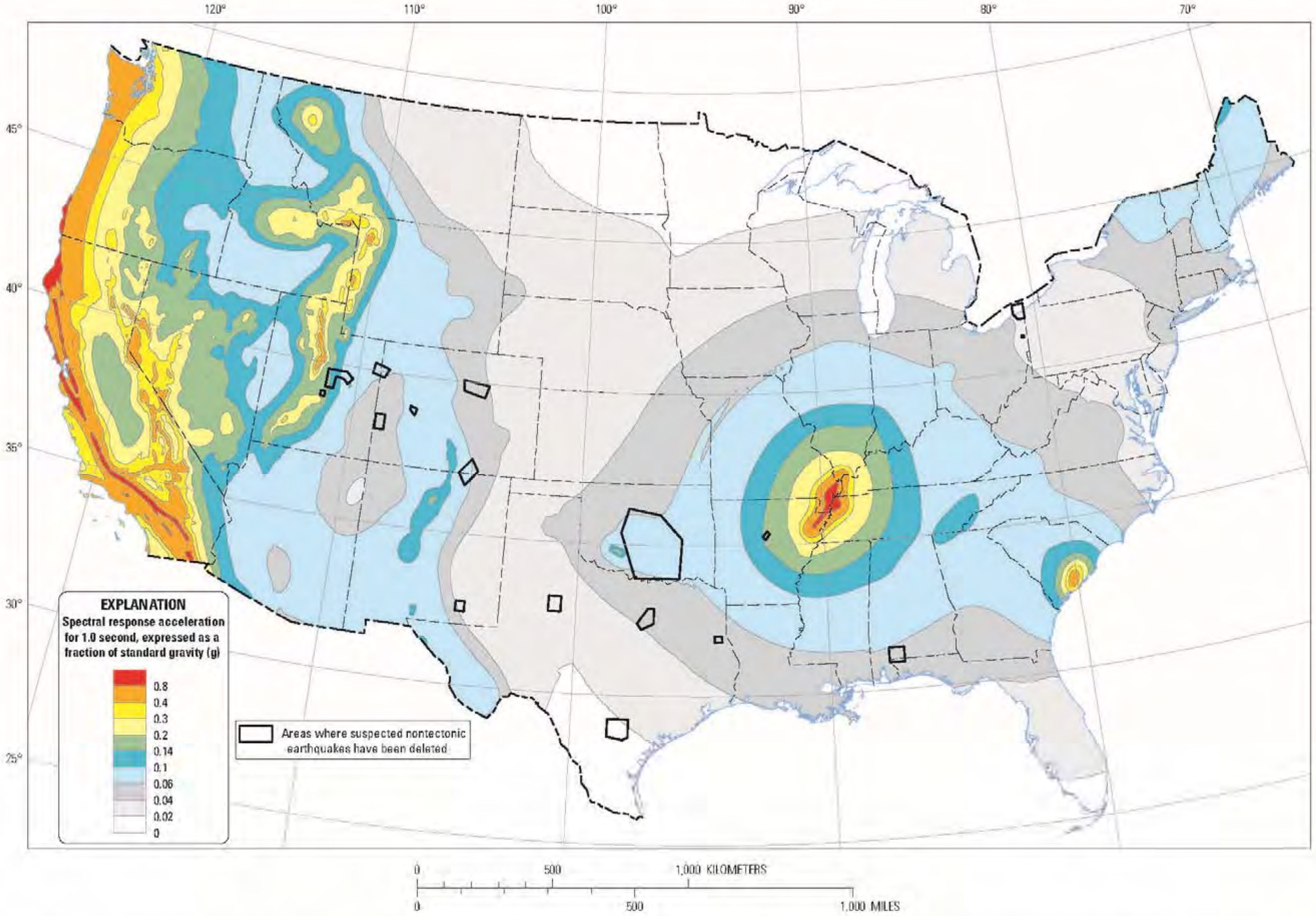
- The USGS publishes the National Seismic Hazard Map (NSHM) with the same POE and recurrence interval. Design Maps are derived from NSHM
- API 650 Standard, Appendix E, defines Maximum Considered Earthquake (MCE) ground motion as the motion due to an earthquake event with:
    - a 2% probability of exceedance (POE) within a 50-year period*

  (recurrence interval of approximately) 2500 years.

  A scaling factor is used to reduce over-strength inherently present in structures built to today's standards
- These maps provide spectral response accelerations for
    - 0.2 Sec (S_s); 1 Sec (S_1)
    - Maps with other POEs are published as well
- These maps **do not include recent seismic activity**

API adopted 1% probability of collapse in 50-years as ASCE 7-10 in May 2016

USGS NSHM areas that identify areas with S_1 (Effects Sloshing)



Two-percent probability of exceedance in 50 years map of 1.0 second spectral response acceleration

Seismic design map for ASCE 7 Standard (2010) showing S_s ground motion

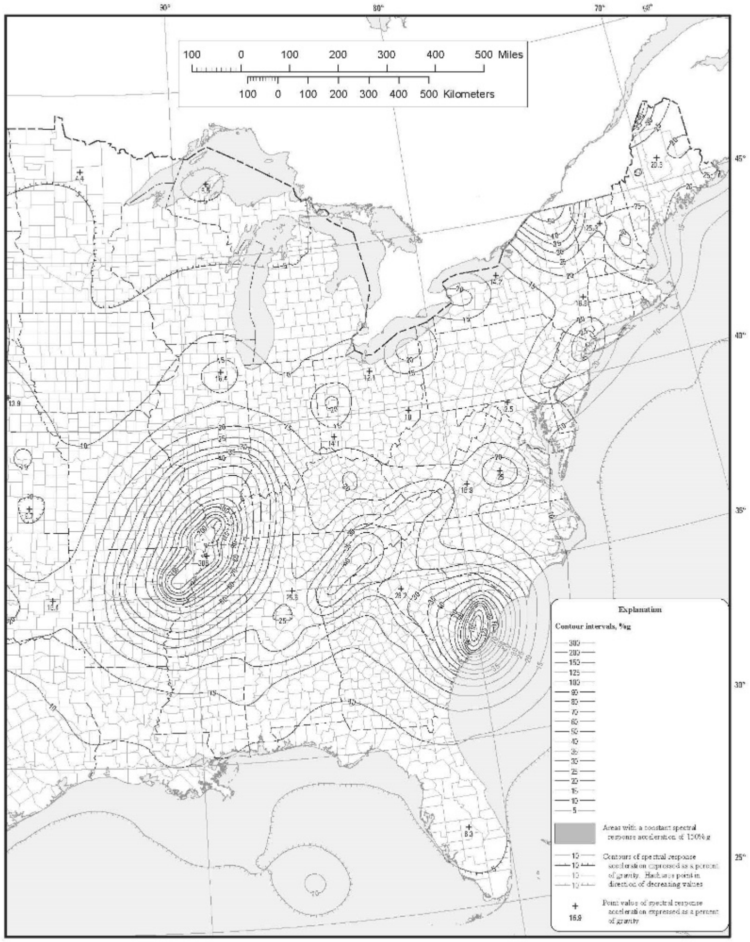
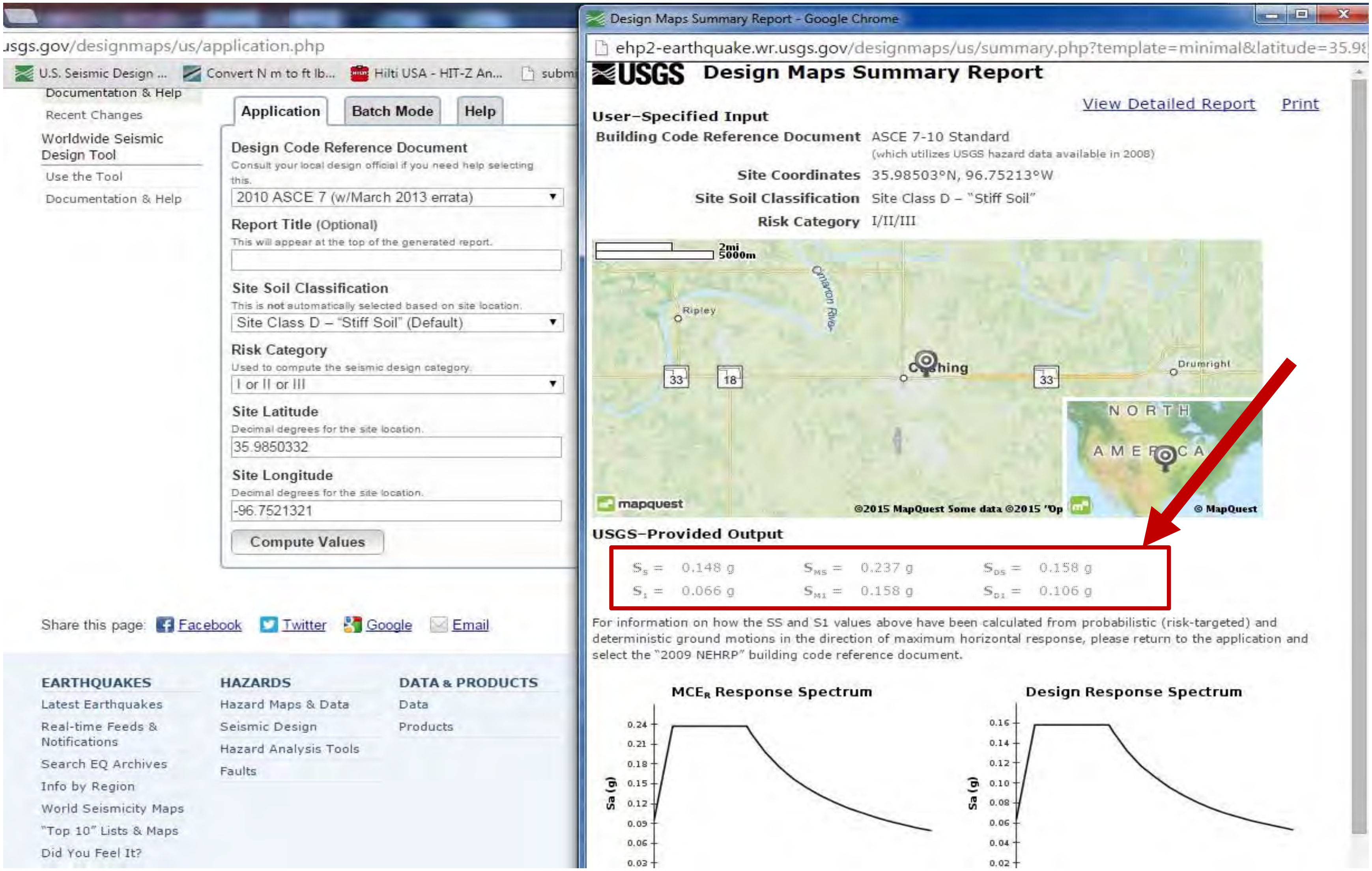


Figure 22-1 *(continued)* **S_s Risk-Targeted Maximum Considered Earthquake (MCE_R) Ground Motion Parameter for the Conterminous United States for 0.2 s Spectral Response Acceleration (5% of Critical Damping), Site Class B.**

- The design code developers decide design practice
- USGS provides seismic design parameters through a design tool

Seismic parameters – USGS tool



Design Code Reference Document
Consult your local design official if you need help selecting this.
2010 ASCE 7 (w/March 2013 errata) ▼

Report Title (Optional)
This will appear at the top of the generated report.

Site Soil Classification
This is **not** automatically selected based on site location.
Site Class D – "Stiff Soil" (Default) ▼

Risk Category
Used to compute the seismic design category.
I or II or III ▼

Site Latitude
Decimal degrees for the site location.
35.9850332

Site Longitude
Decimal degrees for the site location.
-96.7521321

Design Maps Summary Report

User-Specified Input

Building Code Reference Document	ASCE 7-10 Standard (which utilizes USGS hazard data available in 2008)
Site Coordinates	35.98503°N, 96.75213°W
Site Soil Classification	Site Class D – "Stiff Soil"
Risk Category	I/II/III

USGS-Provided Output

$S_S =$ 0.148 g $S_{MS} =$ 0.237 g $S_{DS} =$ 0.158 g

$S_1 =$ 0.066 g $S_{M1} =$ 0.158 g $S_{D1} =$ 0.106 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.

MCE_R Response Spectrum

Design Response Spectrum

Seismic Design Process

$$S_{DS} = Q\ F_a\ S_s \qquad\qquad S_{D1} = Q\ F_V\ S_1$$

Scaling Factor, 2/3 – Structures designed for spectral acceleration at the Design Ground Motion (DGM) have capacity to prevent collapse at 1.5/DGM scaled down, typically 2/3

Modification for soil conditions in (Ss) (default is site class B rock)

$$Ai = S_{DS}\ (I/R_{wi}) \qquad\qquad A_c = KS_{D1}\ (1/T_c)\ (I/R_{wc})$$

An impulsive spectral acceleration coefficient, A_i

A compulsive spectral acceleration coefficient, A_c

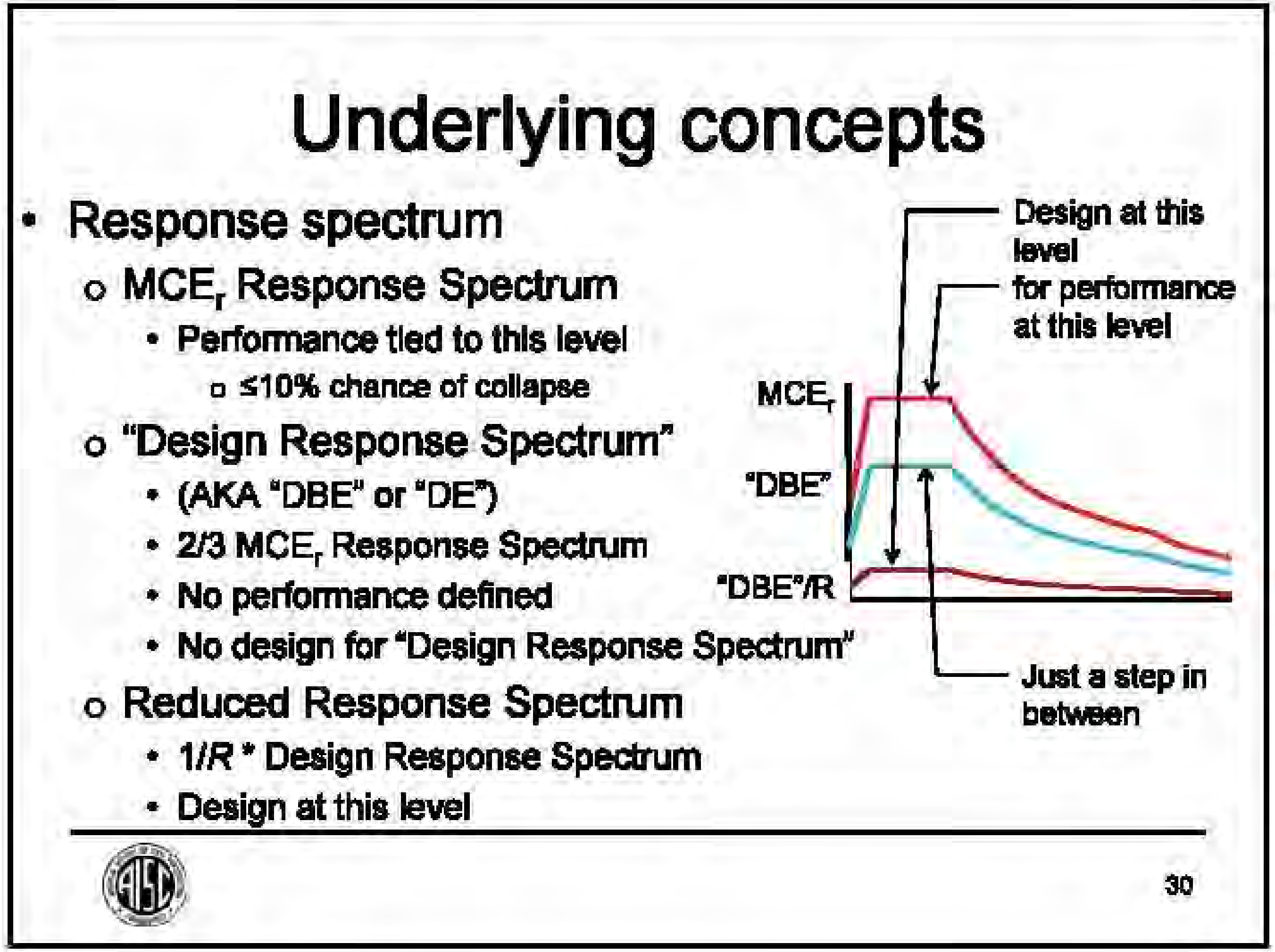
R factor to ensure that the design will perform in inelastic behavior

Equivalent lateral seismic design forces are then determined by: $F = A\ W_{eff}$

The equivalent lateral seismic design forces are applied to the tanks as shears:

$$F_i = A_i\ (W_s + W_r + W_f + W_i) \qquad\qquad F_c = A_c\ W_c$$

Seismic design process for ASTs



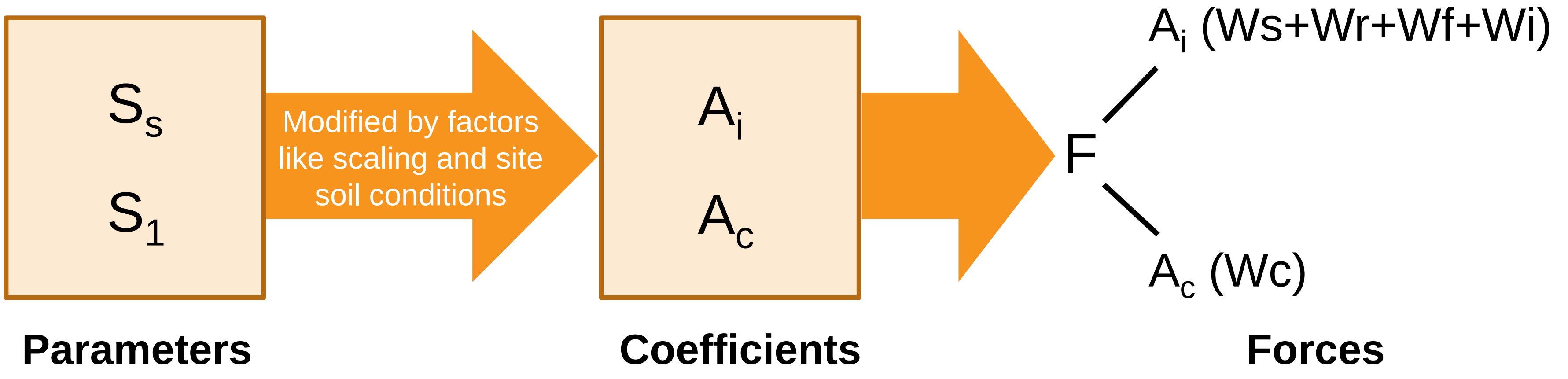
Underlying concepts

- Response spectrum
  - MCE$_r$ Response Spectrum
    - Performance tied to this level
      - ≤10% chance of collapse
  - "Design Response Spectrum"
    - (AKA "DBE" or "DE")
    - 2/3 MCE$_r$ Response Spectrum
    - No performance defined
    - No design for "Design Response Spectrum"
  - Reduced Response Spectrum
    - 1/*R* * Design Response Spectrum
    - Design at this level

Ref: AISC Webinar, "Introduction to Earthquake Engineering Part 3: Building Codes", July 29, 2015

Seismic design process for ASTs

API 650 Appendix E



S_s

S_1

Modified by factors like scaling and site soil conditions

A_i

A_c

F

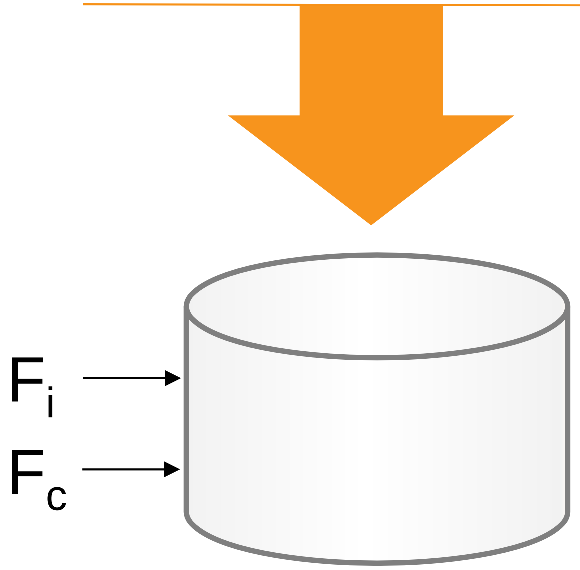
A_i (Ws+Wr+Wf+Wi)

A_c (Wc)

Parameters

Coefficients

Forces



F_i

F_c

Spectral response acceleration parameters are modified and converted to impulsive and compulsive acceleration coefficients.

These coefficients can be used to determine equivalent lateral seismic design forces which can be applied to the tank as shears to simulate earthquake effects.

Seismic design process for ASTs

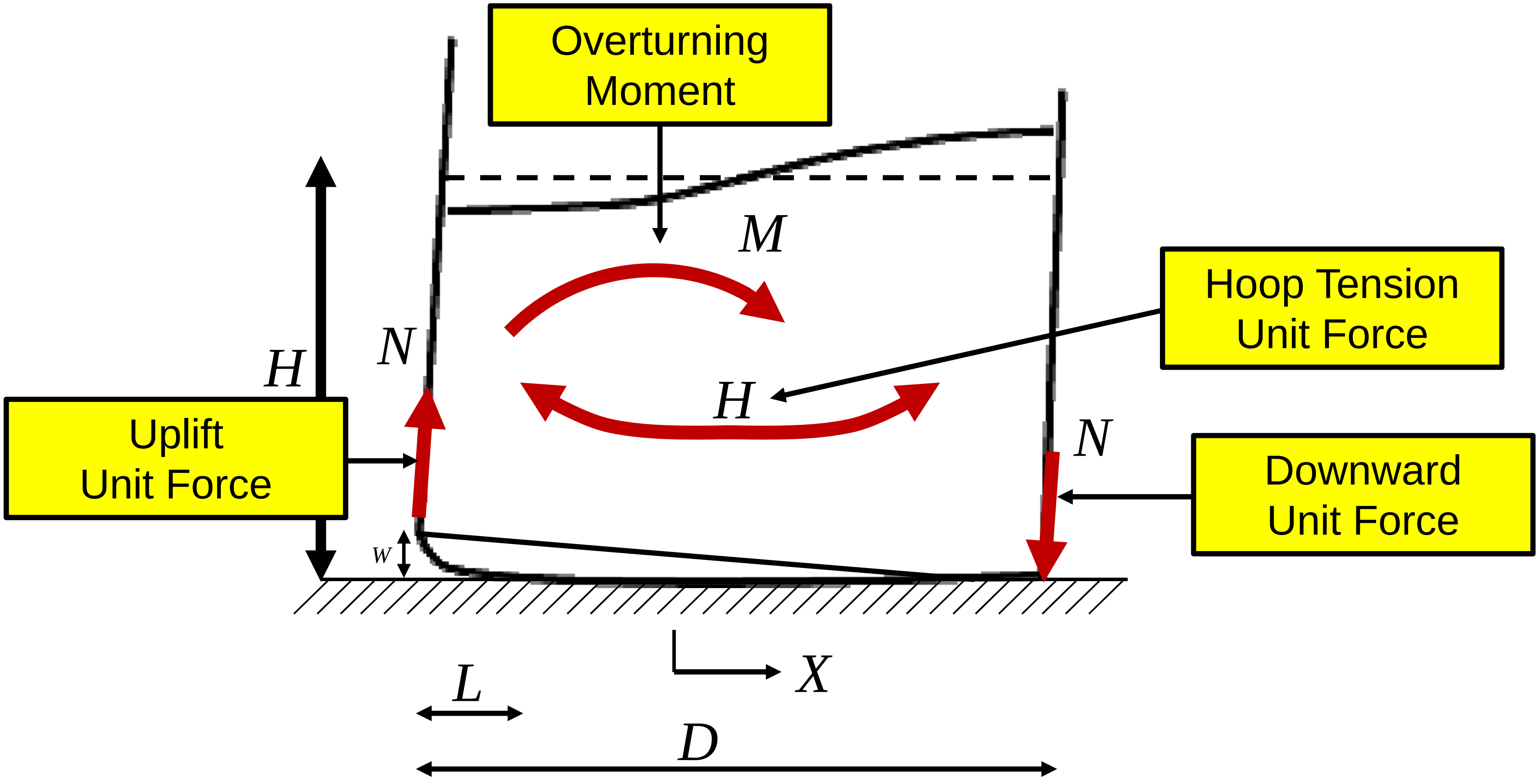
These forces are applied on the tanks and calculations are made for design conditions:

- **Dynamic hoop tensile stresses**
- **Lateral Stability**
- **Overturning Moments**
  - Compressive stresses in tank shell
  - Tank Uplift and Anchorage Requirements
- **Sloshing**
  - Freeboard
  - Effect on columns
  - Roof loading

Key is the definition of seismic parameters, S_s and S_1

Seismic design process for ASTs

Design parameters for an unanchored tank



Vathi, et.al, SEISMIC RESPONSE OF UNANCHORED LIQUID STORAGE TANKS, Proceedings of the ASME 2013 Pressure Vessels and Piping Conference, PVP2013, PVP2013-97700

AST design conditions

Shell Compression; Uplift

Hydrodynamic Hoop Stress

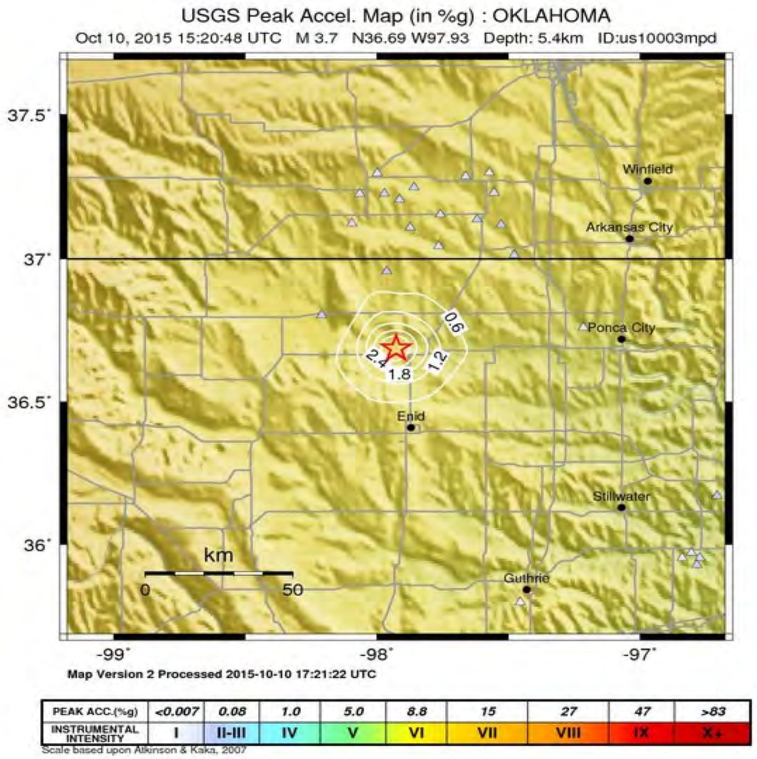
Lateral Stability

How do S_s and S_1 accelerations effect the

Redacted

Selecting a (S_s, S_1) pair for a given earthquake in absence of published data

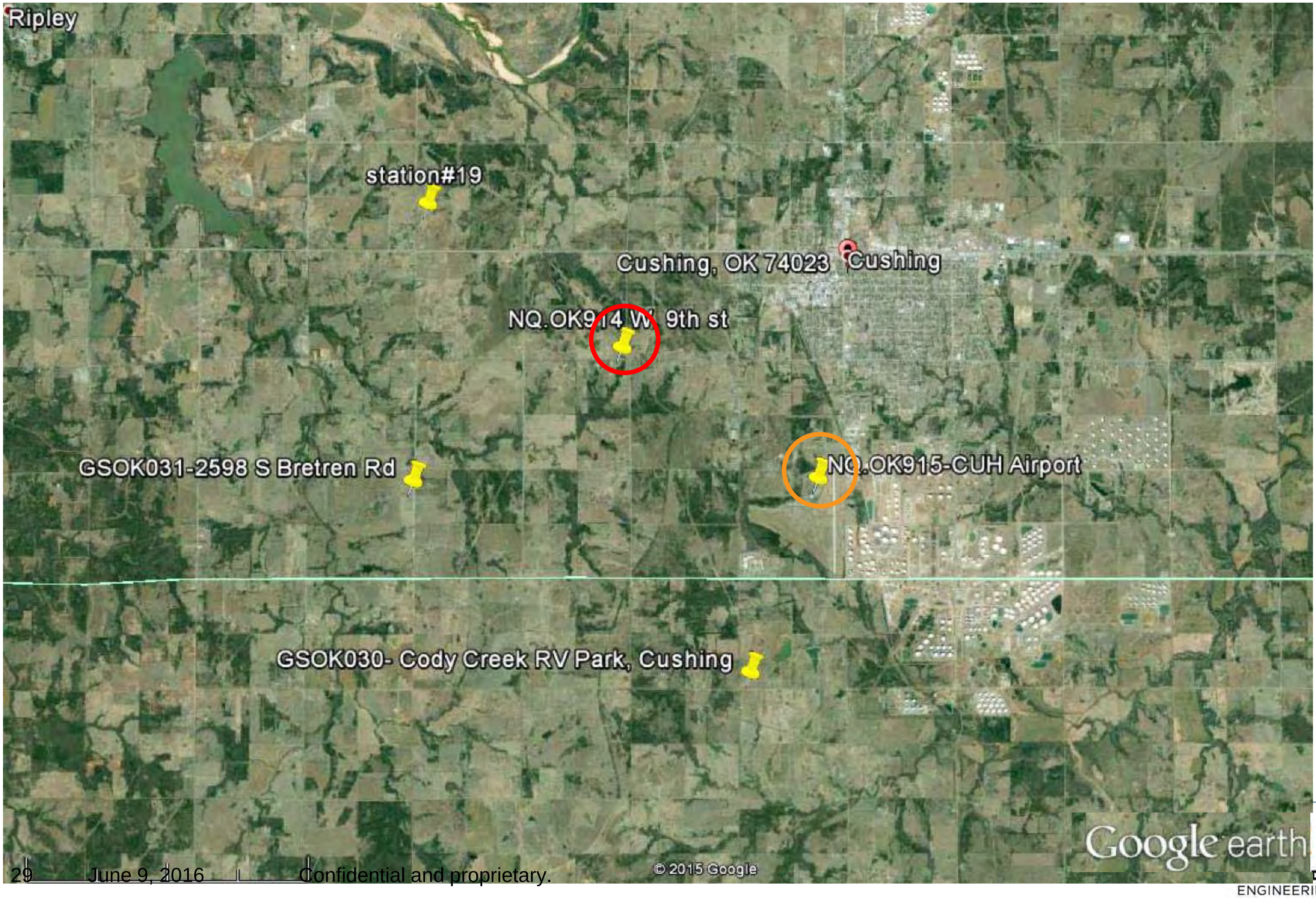
- One option is to use a shake map at a given site
- Per API 650 Standard E.4.3.1 if no response spectra shape is prescribed and only the peak ground acceleration (PGA), S_P, is defined, then the following can be used to estimate seismic parameters for evaluation:
- $S_S = 2.5\ EPGA$; $S_1 = 1.25\ EPGA$



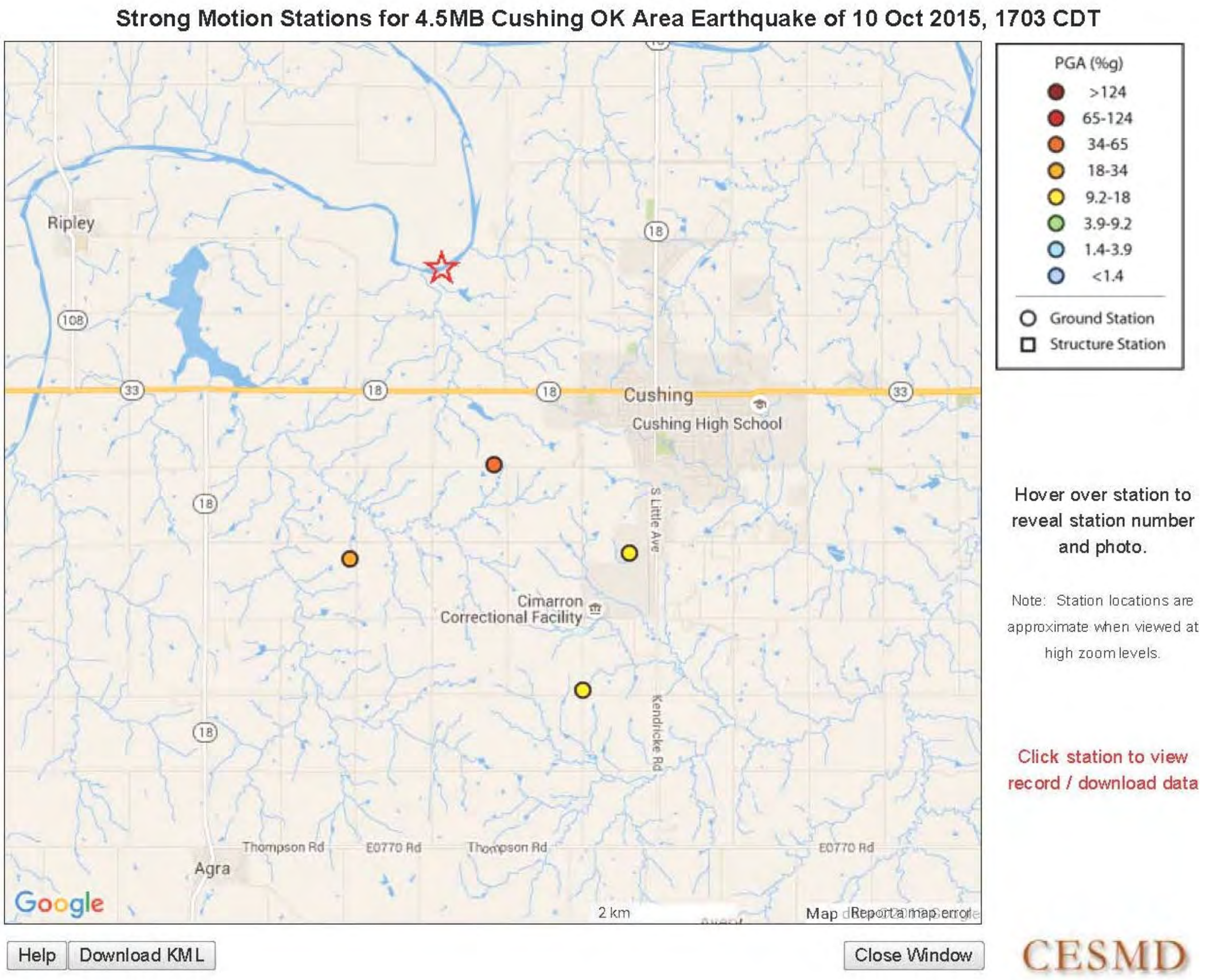
Shake Maps are found at http://earthquake.usgs.gov/earthquakes/shakemap/

Cushing tanks/stations USGS/NEIC

October 10, 2015



Cushing map showing recorded PGAs



Strong Motion Stations for 4.5MB Cushing OK Area Earthquake of 10 Oct 2015, 1703 CDT

PGA (%g)

●	>124
●	65-124
●	34-65
●	18-34
●	9.2-18
●	3.9-9.2
●	1.4-3.9
●	<1.4
○	Ground Station
☐	Structure Station

Hover over station to reveal station number and photo.

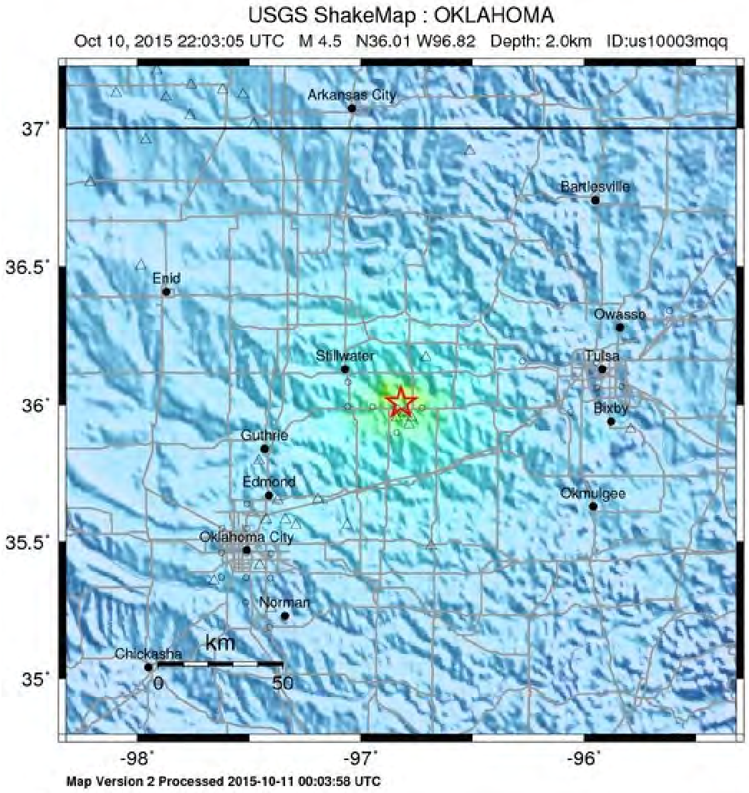
Note: Station locations are approximate when viewed at high zoom levels.

Click station to view record / download data

http://www.strongmotioncenter.org/cgi-bin/CESMD/iqrStationMap.pl?ID=CushingOK_10Oct2015_us10003mqq

Shake map and peak acceleration map

Earthquake October 10, 2015



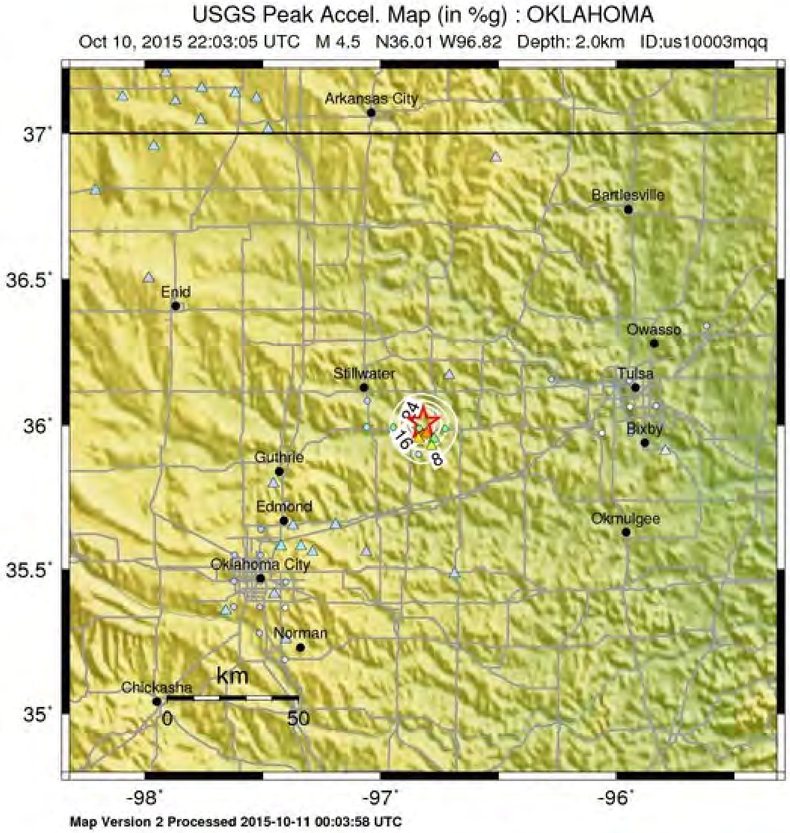
USGS ShakeMap : OKLAHOMA

Oct 10, 2015 22:03:05 UTC M 4.5 N36.01 W96.82 Depth: 2.0km ID:us10003mqq

Map Version 2 Processed 2015-10-11 00:03:58 UTC

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.007	0.08	1.0	5.0	8.8	15	27	47	>83
PEAK VEL.(cm/s)	*<0.003*	*0.04*	*0.5*	*3.0*	*6.5*	*14*	*30*	*63*	*>136*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Atkinson & Kaka, 2007



USGS Peak Accel. Map (in %g) : OKLAHOMA

Oct 10, 2015 22:03:05 UTC M 4.5 N36.01 W96.82 Depth: 2.0km ID:us10003mqq

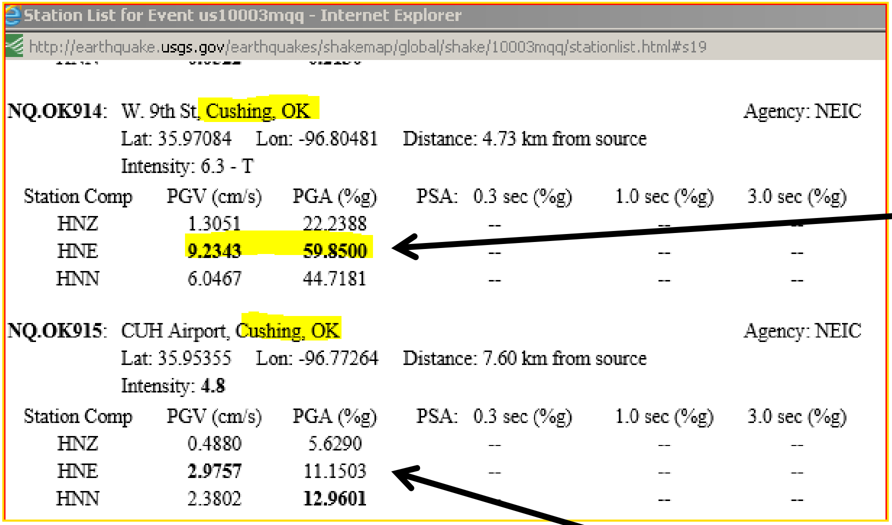
Map Version 2 Processed 2015-10-11 00:03:58 UTC

PEAK ACC.(%g)	*<0.007*	*0.08*	*1.0*	*5.0*	*8.8*	*15*	*27*	*47*	*>83*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Atkinson & Kaka, 2007

Monitored values from shake map

Earthquake October 10, 2015



Station List for Event us10003mqq - Internet Explorer

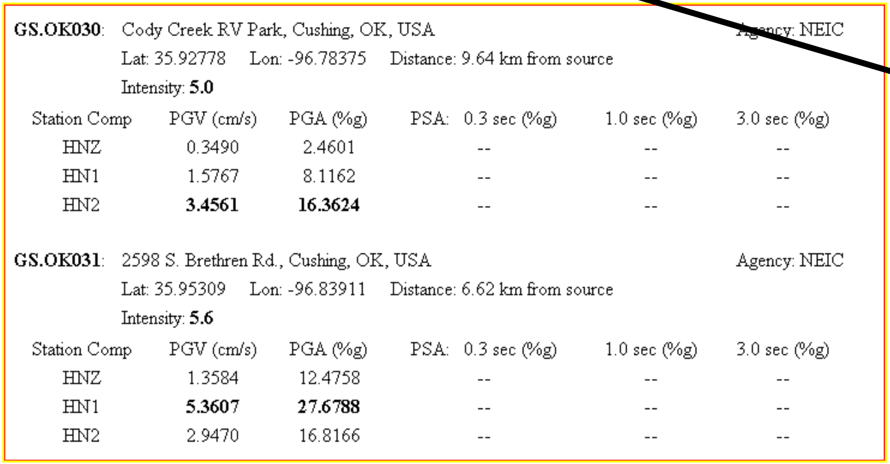
http://earthquake.usgs.gov/earthquakes/shakemap/global/shake/10003mqq/stationlist.html#s19

NQ.OK914: W. 9th St, Cushing, OK Agency: NEIC
Lat: 35.97084 Lon: -96.80481 Distance: 4.73 km from source
Intensity: 6.3 - T

Station Comp	PGV (cm/s)	PGA (%g)	PSA: 0.3 sec (%g)	1.0 sec (%g)	3.0 sec (%g)
HNZ	1.3051	22.2388	--	--	--
HNE	**9.2343**	**59.8500**	--	--	--
HNN	6.0467	44.7181	--	--	--

NQ.OK915: CUH Airport, Cushing, OK Agency: NEIC
Lat: 35.95355 Lon: -96.77264 Distance: 7.60 km from source
Intensity: **4.8**

Station Comp	PGV (cm/s)	PGA (%g)	PSA: 0.3 sec (%g)	1.0 sec (%g)	3.0 sec (%g)
HNZ	0.4880	5.6290	--	--	--
HNE	**2.9757**	11.1503	--	--	--
HNN	2.3802	**12.9601**	--	--	--



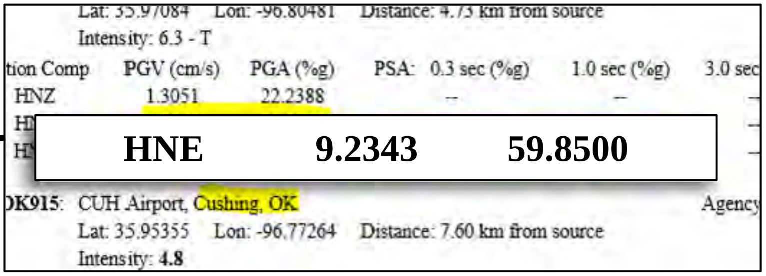
GS.OK030: Cody Creek RV Park, Cushing, OK, USA Agency: NEIC
Lat: 35.92778 Lon: -96.78375 Distance: 9.64 km from source
Intensity: **5.0**

Station Comp	PGV (cm/s)	PGA (%g)	PSA: 0.3 sec (%g)	1.0 sec (%g)	3.0 sec (%g)
HNZ	0.3490	2.4601	--	--	--
HN1	1.5767	8.1162	--	--	--
HN2	**3.4561**	**16.3624**	--	--	--

GS.OK031: 2598 S. Brethren Rd., Cushing, OK, USA Agency: NEIC
Lat: 35.95309 Lon: -96.83911 Distance: 6.62 km from source
Intensity: **5.6**

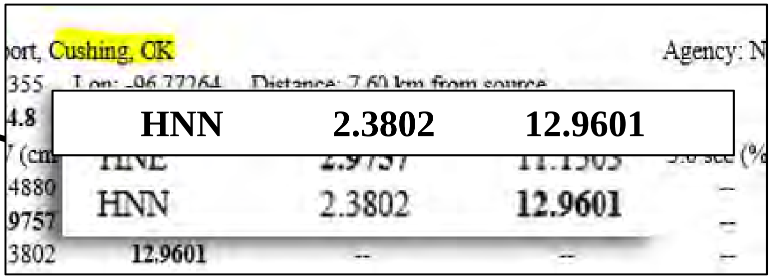
Station Comp	PGV (cm/s)	PGA (%g)	PSA: 0.3 sec (%g)	1.0 sec (%g)	3.0 sec (%g)
HNZ	1.3584	12.4758	--	--	--
HN1	**5.3607**	**27.6788**	--	--	--
HN2	2.9470	16.8166	--	--	--

Highest Recorded PGA Around Cushing



HNE 9.2343 59.8500

Closest Monitoring Device to Tank Farms



HNN 2.3802 12.9601

MATRIX PDM
ENGINEERING

Historical PGAs at the nearest station

No.	Date	Location	Magnitude	Closest Station # To Cushing	PGA @ Station
1	11/06/11	Shawnee, OK	5.6	74023 (35.9970 N, 96.7371 W)	4.91%g
2	12/27/13	Edmond, OK	4.5	126 (36.0120 N, 96.8084 W)	0.24%g
3	07/27/15	Guthrie, OK	4.5	NQ. OK915 (35.95355 N, 96.77246 W)	0.76%g
4	09/18/15	Stillwater, OK	4.1	GS. OK031 (35.95309 N, 96.83911 W)	10.70%g
5	10/10/15	Cushing, OK	4.5	NQ. OK915 (35.95355 N, 96.77246 W)	12.96%g

Note: Cushing is located at 35.9825 N & 96.7642 W.

S_s and S_1 computation based on PGAs

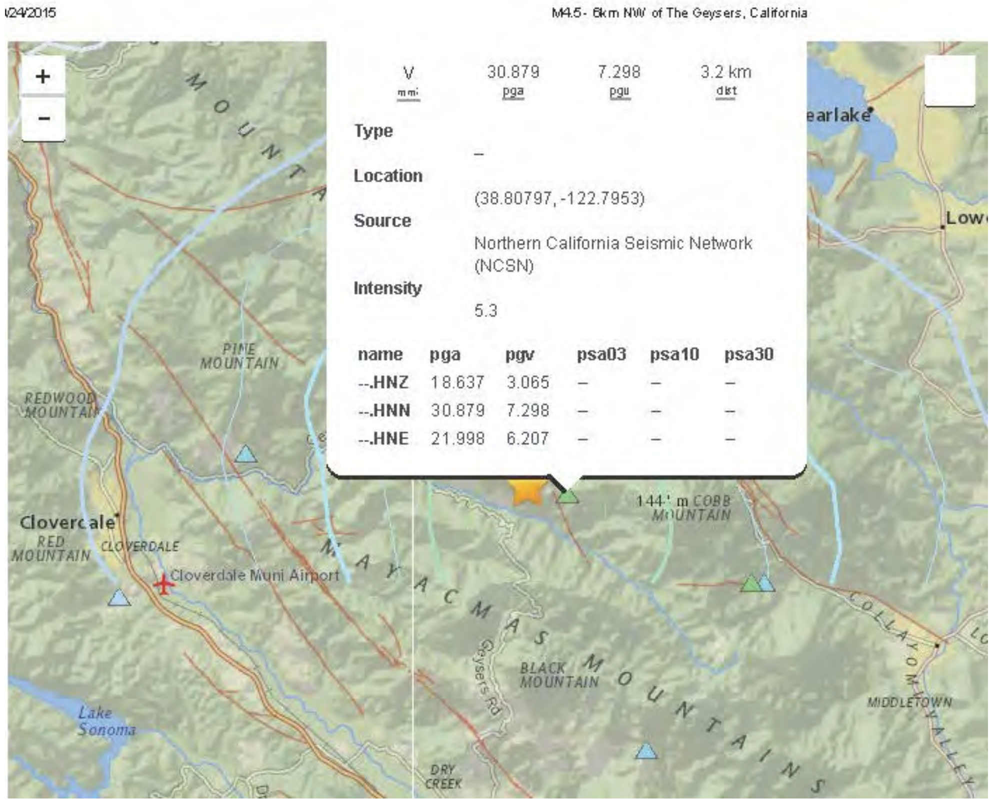
$S_S = 2.5\ EPGA\ ;\ S_1 = 1.25\ EPGA$

	PGA %g	EPGA %g	Computed		Values Used	
		(2/3) PGA	S_s (g)	S_1 (g)	S_s (g)	S_1 (g)
Current Design	N/A	N/A	0.200	0.0625	0.20	0.06
Highest PGA	59.85	39.9	0.998	0.4988	1.07	0.54
Closest PGA	12.96	8.64	0.216	0.108	0.27	0.14
Updated USGS 2016	59.0	39.3	0.983	0.49	1.0	0.14

Parameters From USGS 2016 Map
1% probability of exceedance in 1 Year

Parameters Derived From PGAs

Are these PGAs in the ballpark?



/24/2015

M4.5 - 6km NW of The Geysers, California

V	30.879	7.298	3.2 km
mmi	pga	pgv	dist

Type

–

Location

(38.80797, -122.7953)

Source

Northern California Seismic Network (NCSN)

Intensity

5.3

name	pga	pgv	psa03	psa10	psa30
--.HNZ	18.637	3.065	–	–	–
--.HNN	30.879	7.298	–	–	–
--.HNE	21.998	6.207	–	–	–

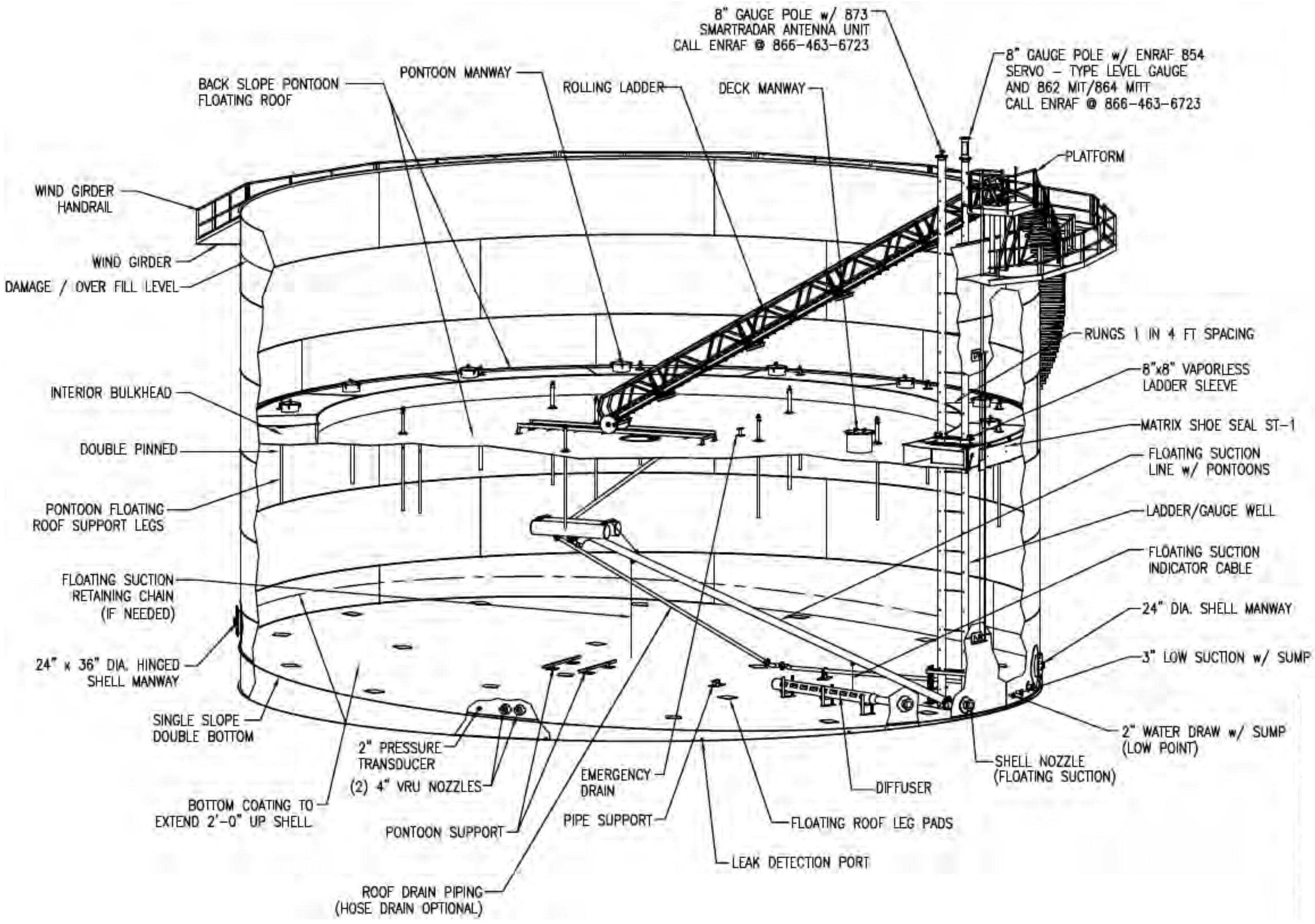
M4.5

- Geysers, Northern CA
  - Max PGA recorded at Epicenter: 30%g
- Cushing, OK
  - Highest PGA recorded in Cushing: 59%g

Both were M4.5 earthquakes.

Comparative? Or, Inexact Conclusions?

Open top storage tanks - descriptions



Distribution of Matrix constructed tanks at Cushing

Redacted

Selected tank dimensions for evaluation

Redacted

Hydro-dynamic hoop stress design condition

Redacted

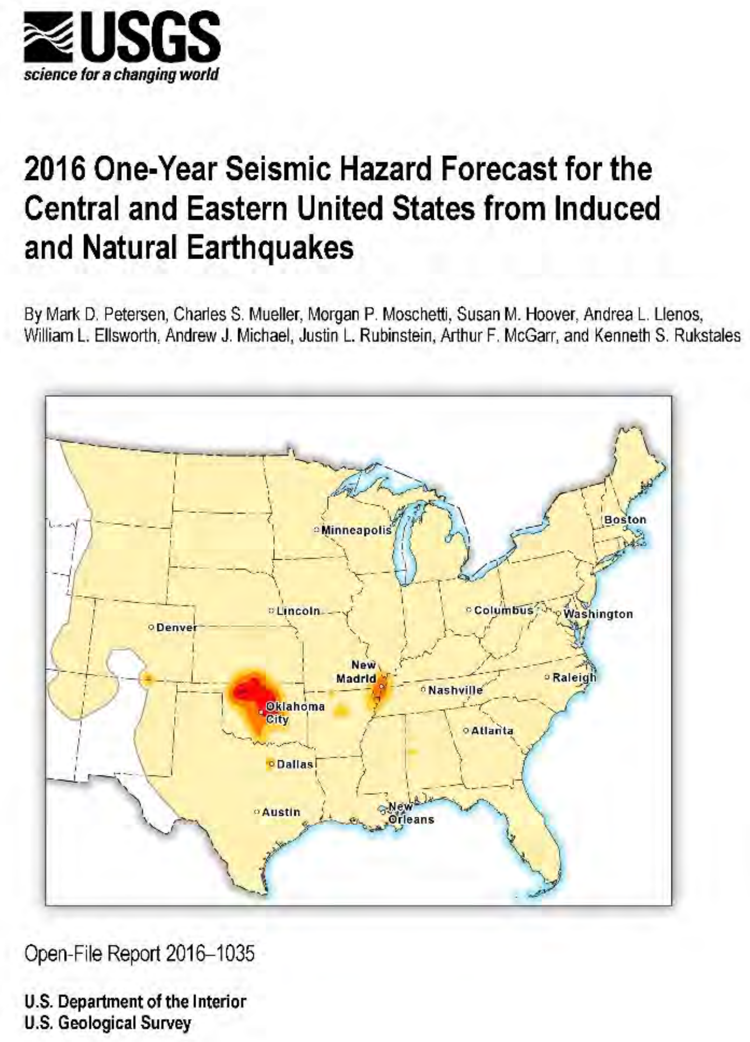
Design Condition for uplift (anchorage

Redacted

If the highest PGAs recorded are used to compute seismic

Redacted

Seismic parameters for increased seismicity



USGS
science for a changing world

2016 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes

By Mark D. Petersen, Charles S. Mueller, Morgan P. Moschetti, Susan M. Hoover, Andrea L. Llenos, William L. Ellsworth, Andrew J. Michael, Justin L. Rubinstein, Arthur F. McGarr, and Kenneth S. Rukstales

Open-File Report 2016–1035

U.S. Department of the Interior
U.S. Geological Survey

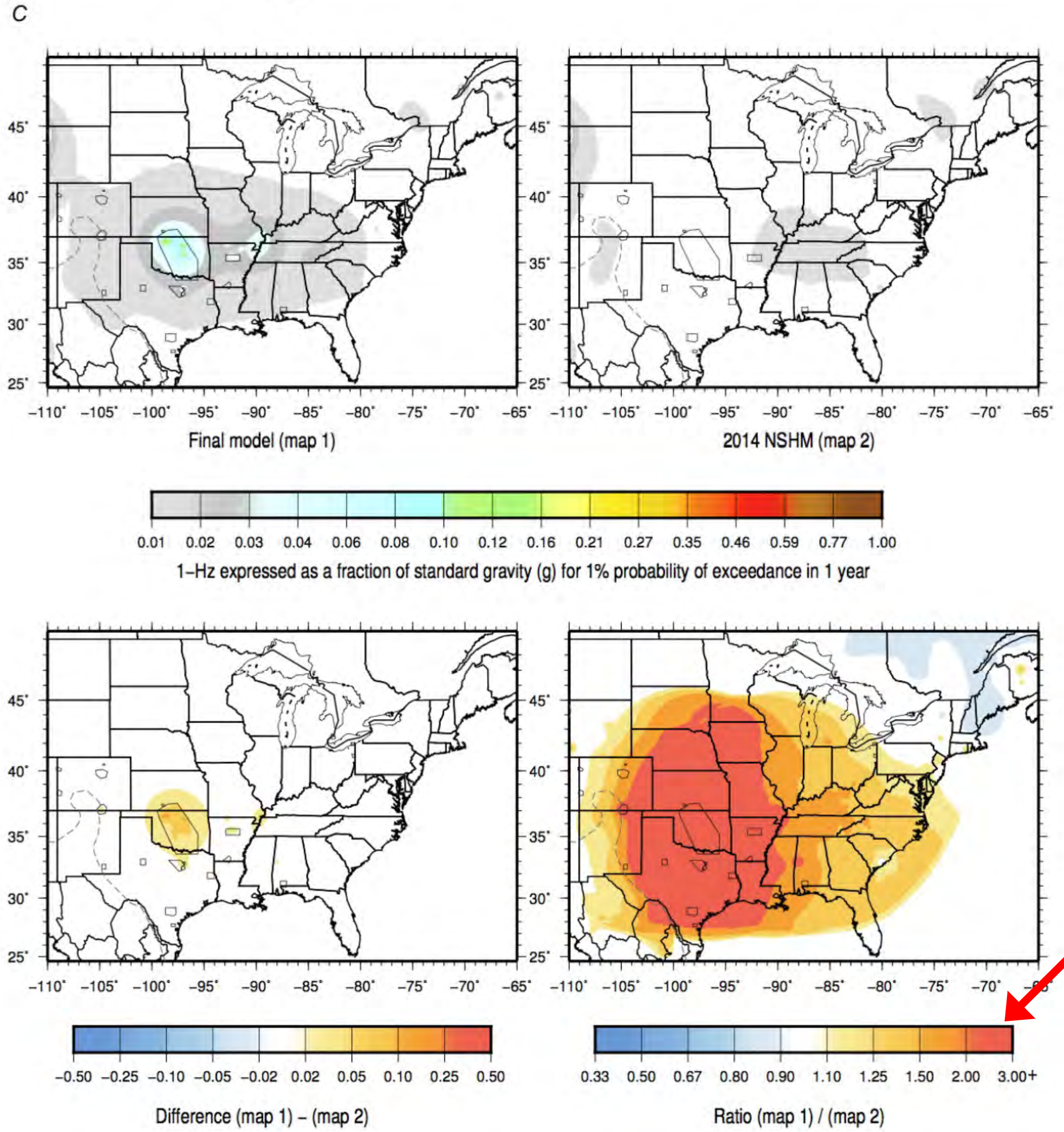
Seismic parameters for increased seismicity

- Maps incorporating are reported in research reference paper below [1]
- First step in developing an operational earthquake forecast for the CEUS
- Assumes
  - earthquake rates calculated from several different time windows will remain relatively stationary
  - Can be used to forecast earthquake hazard and damage intensity
- Multiple maps are available
  - 1 Sec (S_1) & 0.2 Sec (S_s) with a 1% probability of exceedance (POE) in 1 year (Return interval of 100 years)
  - Peak Ground Accelerations

These maps are not incorporated in Codes and Standards.

Confidential and proprietary.

Draft hazard maps for increased seismicity (S_1)



Final model (map 1)

2014 NSHM (map 2)

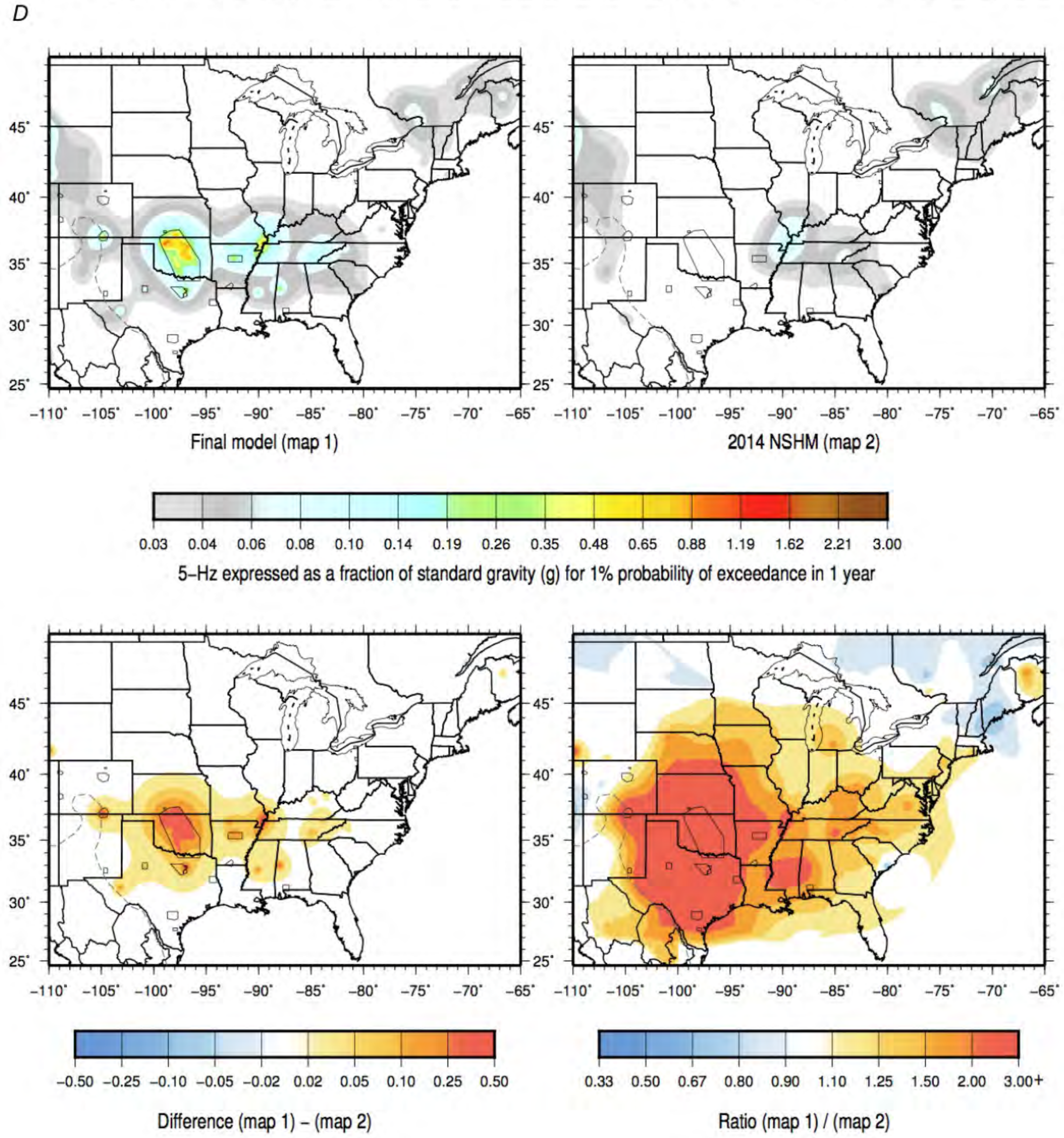
1–Hz expressed as a fraction of standard gravity (g) for 1% probability of exceedance in 1 year

Difference (map 1) – (map 2)

Ratio (map 1) / (map 2)

Factor of Almost 3

Draft hazard maps for increased seismicity (S_s)



Final model (map 1)

2014 NSHM (map 2)

5–Hz expressed as a fraction of standard gravity (g) for 1% probability of exceedance in 1 year

Difference (map 1) – (map 2)

Ratio (map 1) / (map 2)

Recommended Reduction in Maximum Capacity (Liquid

Redacted

High Seismic effects on tanks

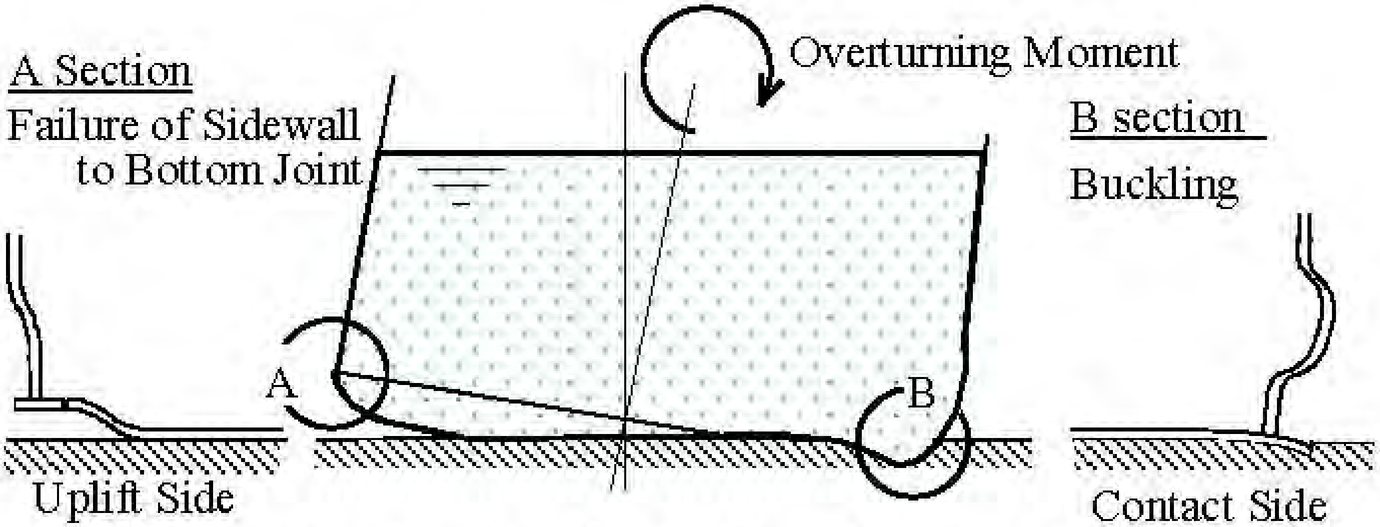


Fig.5 Rocking motion due to high frequency earthquake

Yoshida, REVIEW OF EARTHQUAKE DAMAGES OF ABOVEGROUND STORAGE TANKS IN JAPAN AND TAIWAN, PVP2014-28116, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, July 20-24, 2014, Anaheim, California, USA

Seismic effects on tanks

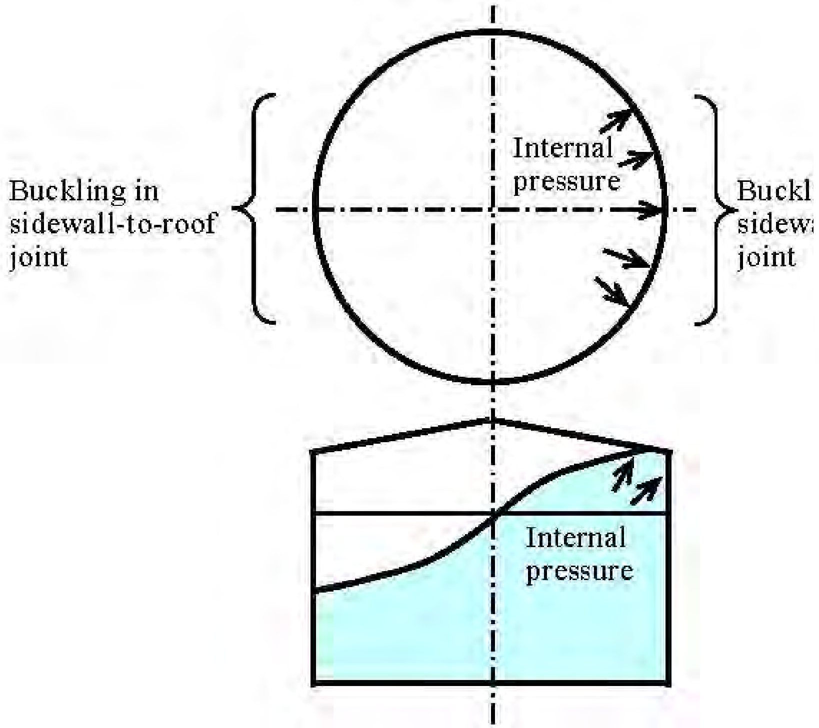


Fig.6 Buckling mechanism of a sidewall-to-roof joint in a fix roof tank due to low frequency earthquake

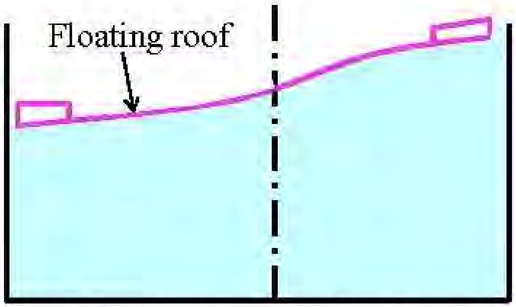
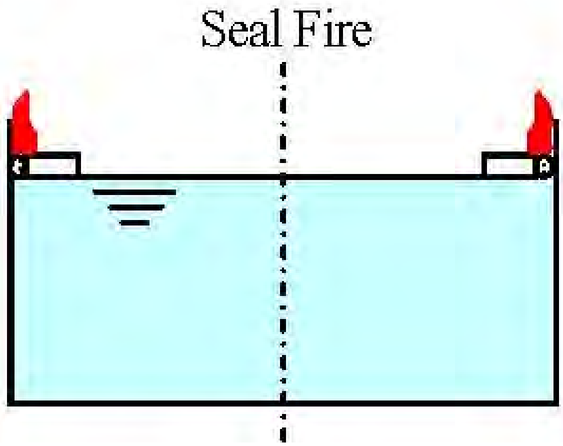


Fig.7 Sloshing of floating roof tanks due to low frequency earthquake



Yoshida, REVIEW OF EARTHQUAKE DAMAGES OF ABOVEGROUND STORAGE TANKS IN JAPAN AND TAIWAN, PVP2014-28116, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, July 20-24, 2014, Anaheim, California, USA

High seismic effects on tanks

Examples of structural effects in high seismic events

Elephant foot buckling of tank shell (bottom shell course)
M_w 9.2 ALASKA U.S.A.

Elephant knee buckling of tank shell
M_w 7 HAITI

Bottom shell course failure due to anchorage effect
M_w 8.8 CHILE

Courtesy of FEMA: Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, FEMA E-74 *et seq*. (2012). Print

High seismic effects on tanks

Lateral movement, anchorage failure and bottom shell buckling

M_w 6.0 NAPA, CALIFORNIA

Erica Fisher et. al. STRUCTURE Magazine, Earthquake Damage to Cylindrical Tanks, Lessons Learned, March 2015

High seismic effects on tanks

Hydro-dynamic stress damage on upper shell course

M_w 7.4 IZMIT, TURKEY

PEER Report, Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey

High seismic secondary effects on tanks

- Examples of Secondary Effects in high seismic events:
  - Rolling ladder on the floating roof falling off the track.
  - Guide pole damage at the bottom
  - Sinking of floating roofs
  - Damage in Seals
  - Foam piping damage inside the tank
  - Foam piping connection damage when the connection is rigid piping

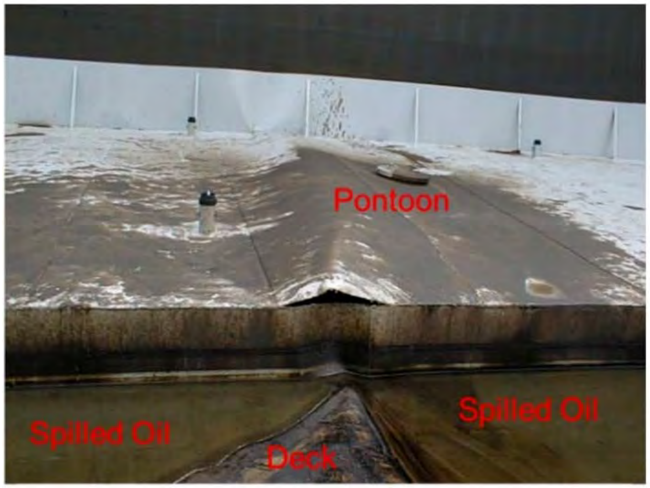
High seismic secondary effects on tanks

Sloshing of liquid
M_w 7.4 IZMIT, TURKEY

PEER Report, Structural Engineering Reconnaissance of the August 17, 1999 Earthquake: Kocaeli (Izmit), Turkey

High seismic secondary effects on tanks

Floating roof pontoon cover plate buckling
M_w 7.3 TAIWAN



Floating roof plate failure
M_w 7.3 TAIWAN

Yoshida, REVIEW OF EARTHQUAKE DAMAGES OF ABOVEGROUND STORAGE TANKS IN JAPAN AND TAIWAN, PVP2014-28116, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, July 20-24, 2014, Anaheim, California, USA

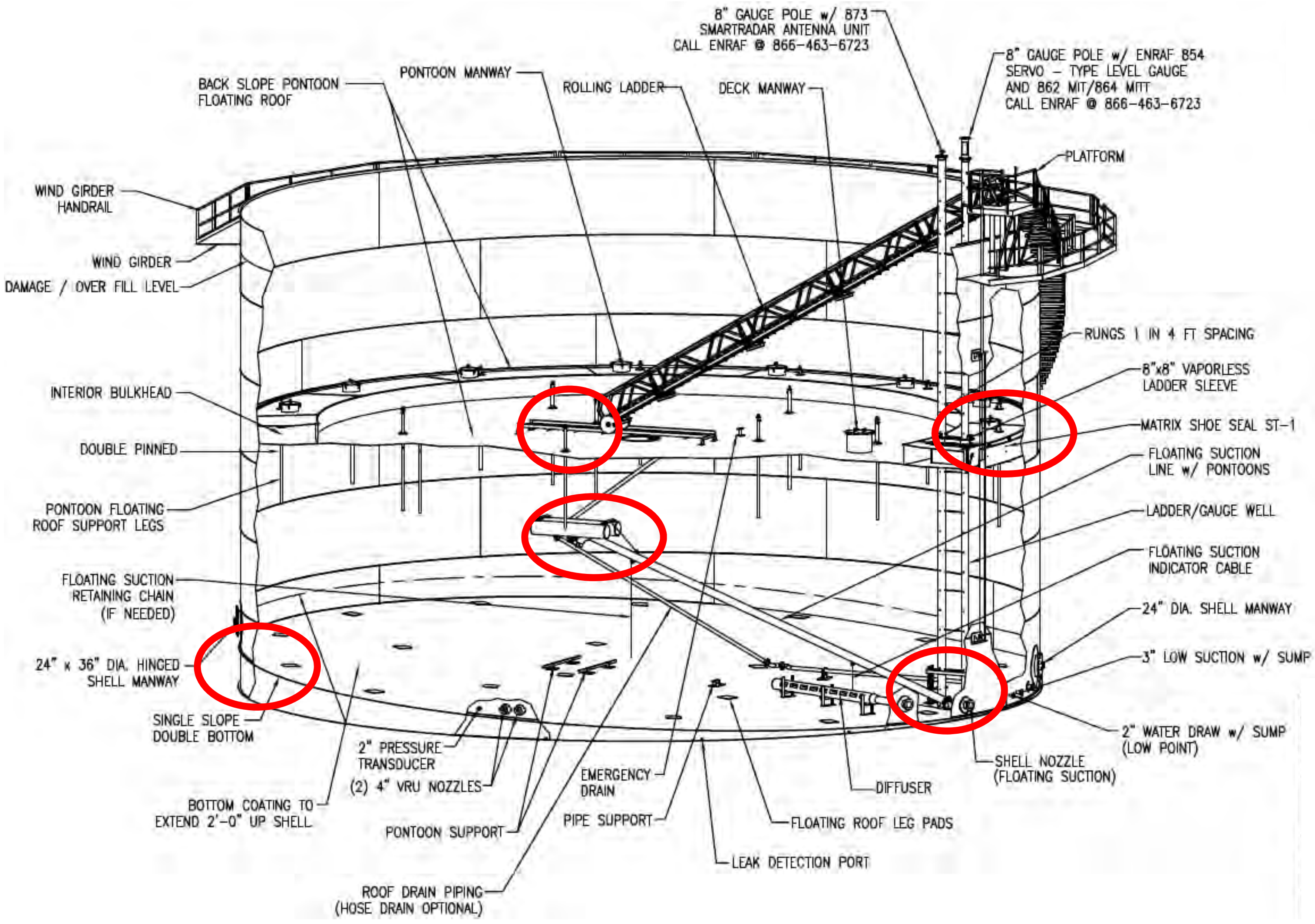
High seismic secondary effects on tanks

Naphtha Tank Fire

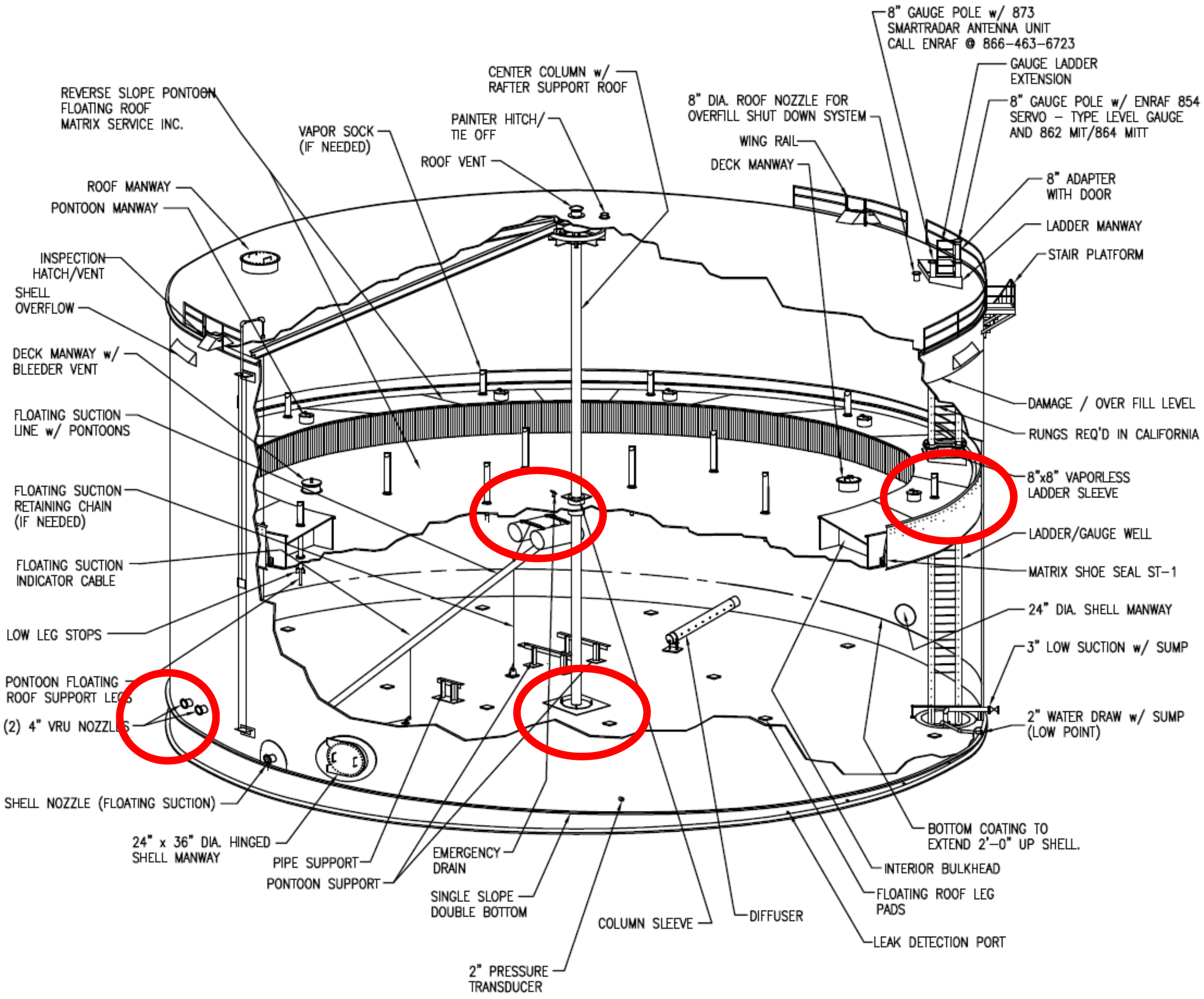
M_w 8.3 HOKKAIDO, JAPAN

Yoshida, REVIEW OF EARTHQUAKE DAMAGES OF ABOVEGROUND STORAGE TANKS IN JAPAN AND TAIWAN, PVP2014-28116, Proceedings of the ASME 2014 Pressure Vessels & Piping Conference, July 20-24, 2014, Anaheim, California, USA

Areas susceptible – open top tanks



Cone roof tank with internal floating roof



Infrastructure considerations

- Areas, other than the tank, which are most susceptible during earthquake are:
  - Piping attached to the tank. Piping inside buildings.
  - Differential movement between piping, connecting structures and platforms
  - Connections for Stairways and Walkways
- Probability of failure of non structural components such as connections should be considered as their failure can be catastrophic.
- Pro-active review of support infrastructure such as fire fighting foam piping, utility lines, power lines is required to reduce risk from major damage
- This review is called, in Seismic Literature, Life Line Engineering

Infrastructure considerations

MITIGATION EXAMPLES

Flexible connections prevented piping damage in 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers)

M_w 8.4 PERU

- Provide Flexible connections at expansion and seismic separation joints to accommodate differential displacements between structures (Refer to Figure 6.4.2.2-5)
- Longevity and resistance to fire considerations for this type of connections

Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, FEMA E-74 *et seq*. (2012).

Infrastructure considerations

Floor-mounted supports for industrial piping in Chile; piping undamaged in 2010 Chile Earthquake (Photos courtesy of Antonio Iruretagoyena, Ruben Boroschek & Associates).

- Brace floor-mounted pipes longitudinally in form of supports
- Anchor steel supports to structural framing or a structural concrete slab.
- Supports can be:
  - cantilevered support member,
  - propped cantilever member, or
  - be built up of multiple elements to form a trapeze or braced frame. (Fig 6.4.3.5-5)

M_w 8.8 CHILE

Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, FEMA E-74 *et seq*. (2012).

Infrastructure considerations

Guidelines - Suspended piping bracing

- Use All directional cable bracing (Fig 6.4.3.1-6)
- Use Sway Bracing with J Hanger and strut (Fig 6.4.3.1-7)
- Do not use Friction connections such as U-bolts
- Always use sway brace in conjunction with horizontal support.

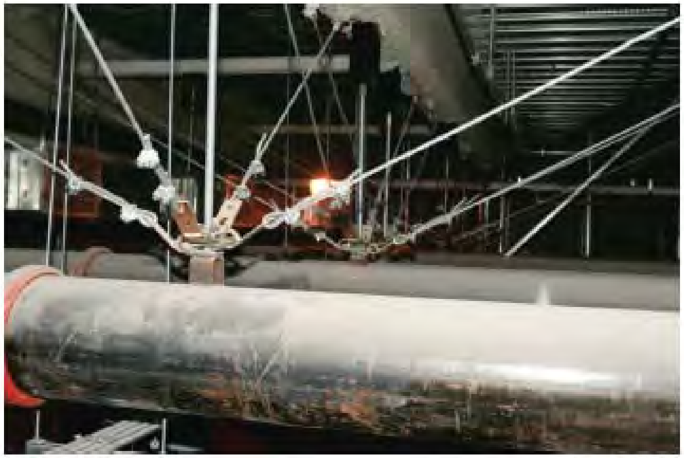


Figure 6.4.3.1-6 All-directional cable bracing of suspended piping (Photo courtesy of ISAT).

Figure 6.4.3.1-7 Transverse bracing with J-hanger and strut at the restraining bolt. Note that longitudinal brace shown is ineffective because the J-hanger can slip along the length of the pipe; a pipe clamp or equivalent is required for a longitudinal brace (Photo courtesy of Cynthia Perry, BFP Engineers).

Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, FEMA E-74 *et seq*. (2012).

Infrastructure considerations

Failure to Conveyor, silo and support structures (Fig. 6.4.1.2-2)

Guidelines

- Do not attach Stairways to both foundation and the tank wall
- Design walkways between tanks to accommodate relative tank movement (Consider a total of 12 to 18 inches of movement).

M_W 8.8 CHILE

Figure 6.4.1.2-2 Damage to silos, conveyors and equipment at a grain operation in the 2010 magnitude-8.8 Chile Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers).

Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide, FEMA E-74 *et seq*. (2012).

What measures can we take?

Reference: http://lamngyeung.blogspot.com/

Earthquake preparedness

Courtesy: Adrian Raeside http://raesidecartoon.com/

Matrix PDM: PROCESS MAP

Earthquake Preparedness

- Identification of vulnerable equipment
- Component Categorization by risk assessment & classification
- Retrofitting vulnerable equipment, structures & components

Seismic Hazard Classification

- Definition of Seismic parameters for defining seismic vulnerabilities and for input into emergency shut down (ESD) protocols

Event Specific Terminal Procedures

- Designing and developing event specific operating protocols
- Selection, installation and set up of seismic monitoring devices

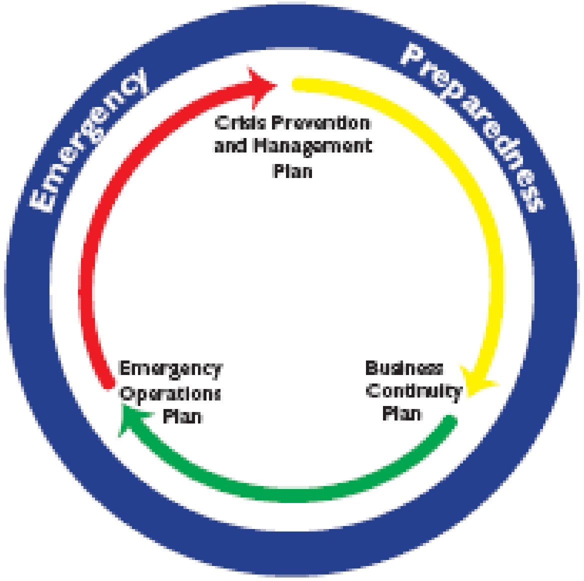
Post Event Inspection & Repair

- Post event inspection of tanks, pipelines, terminal equipment and infrastructure
- Repair and maintenance of tanks, pipelines, terminal equipment other and infrastructure

Earthquake preparedness

COMPONENTS

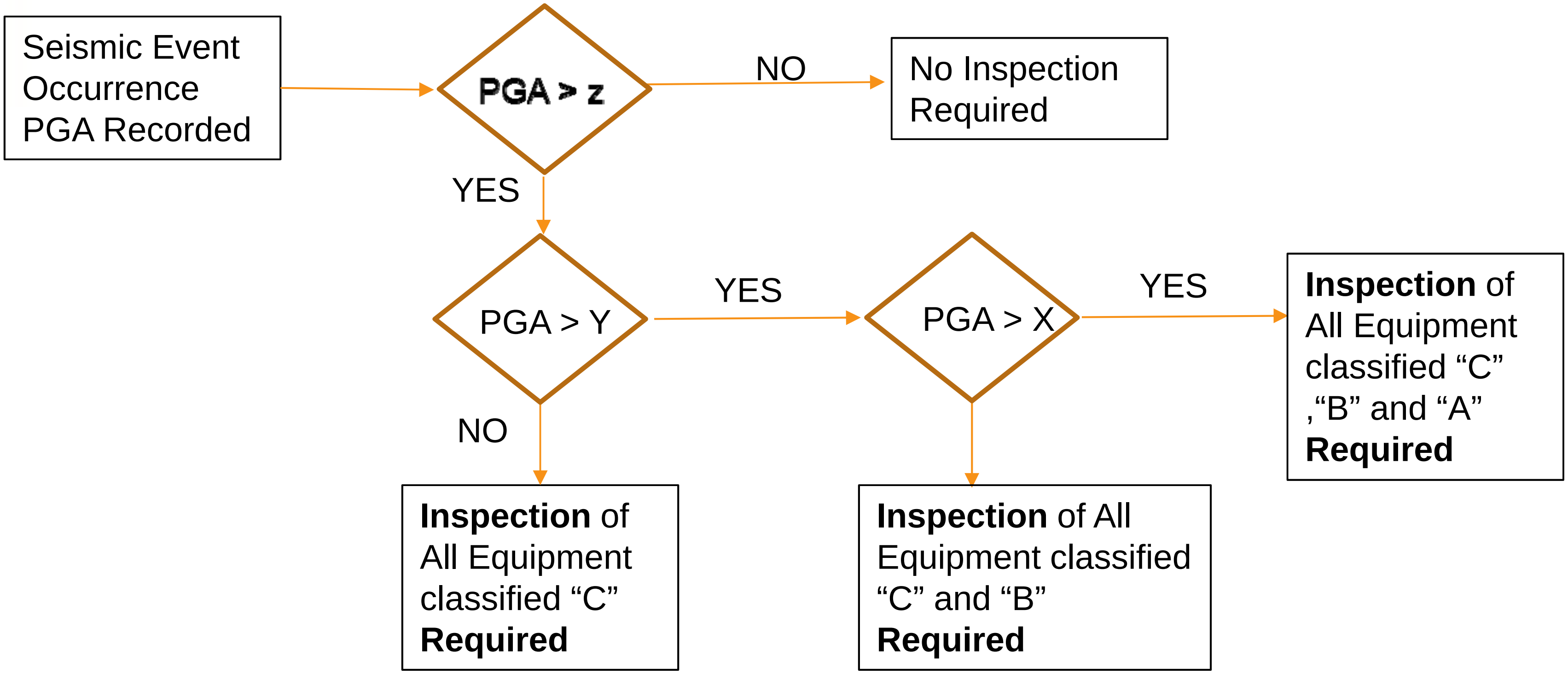
- **Preparedness**
- **Response**
- **Recovery**
- **Mitigation**



https://www.pcc.edu/about/public-safety/emergency-plan.html

Figure 6.4.2.1-2 A vertical tank at hospital overturned due to inadequate anchorage in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).

Seismic hazard classification



Seismic Event Occurrence PGA Recorded

PGA > z

NO

No Inspection Required

YES

PGA > Y

YES

PGA > X

YES

Inspection of All Equipment classified "C" ,"B" and "A" **Required**

NO

Inspection of All Equipment classified "C" **Required**

Inspection of All Equipment classified "C" and "B" **Required**

Seismic hazard classification

- Categorize components based on risk assessment and classification
  - A: Critical Risk
  - B: Moderate Risk
  - C: Low Risk
- Use Seismic parameters for seismic vulnerabilities and Emergency Shut down (ESD) protocols

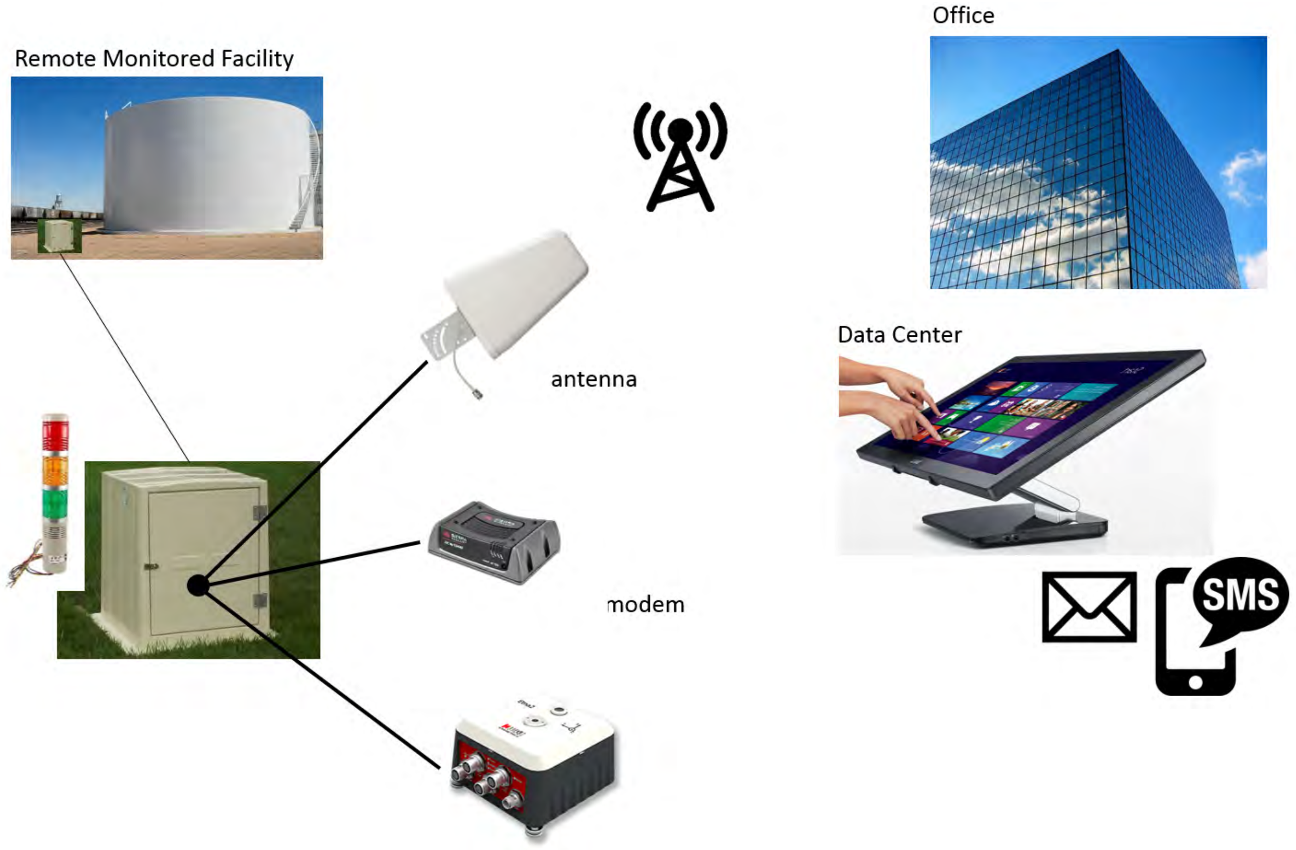
  [Seismic parameters facilitate limiting post-event work to a limited number of components]

A= Critical Risk	PGA ≥ X
B= Moderate Risk	Y ≤ PGA < X
C= Low Risk	Z < PGA < Y
D = No Risk	PGA ≤ Z

Tank Components	**Classification of Risk**
Floating Roofs	
EFR Pontoon	C
EFR double deck	B
IFR Pan roof	C
IFR Bulkheaded Pan	C
IFR Pontoon	C
IFR Double deck	B
IFR Aluminium	C
Seals	C
Guide poles	C
Piping	
Aboveground piping	C
buried piping	B
Fire protection system piping	C
Mechanical Equipment	
Primary Control Valves	A
Pumps/compressors	C
Heat exchangers	C
Rotary equipment	C

Terminal operating protocols

- Develop terminal operating protocols to be used during a seismic event
- For example, a seismic monitoring device for recording PGAs



Post event inspection and repair

- Post event inspection of tanks; equipment and infrastructure in a terminal using checklists
- Processes in place for Repair and maintenance of tanks, equipment and infrastructure after a seismic event

Summary

- Tanks constructed at Cushing are designed per seismic loads based on USGS maps.
- The tanks built in Cushing have performed well based on the acceleration parameters from the recent earthquake from the station closest to the tank farms.
- If higher acceleration parameters are to be considered, liquid levels may have to be lowered.
- Both tanks and surrounding infrastructure should be part of any reviews.

Recommendations

- Owner operators should consider Earthquake Preparedness as part of Disaster Management Plan for their assets.
- Pending USGS data, need an interim solution to define parameters.
- Evaluations for individual tanks, terminals and in based on defined parameters.
- Owners may consider developing post event inspection and repair protocols.
- Reviews should be shared with First Response Providers and Local Regulatory Authorities.

Questions?

MATRIX PDM
ENGINEERING

Thank you!