On Shaky Ground – Seismicity and Its Impact on Terminal Operations

In October 2015, Cushing, OK, experienced its highest magnitude earthquake to date, raising concern about the impact on terminal facility infrastructure. In response, Matrix PDM Engineering performed a limited analysis of the response of representative tank sets to help identify the effects of these earthquakes. The study was performed to provide guidance to a consortium comprised of terminal owner/operators, regulatory authorities and others based in Cushing. This presentation will present results from the study and share protocols that terminal companies have in place to utilize during and after a seismic event.

ABOUT THE SPEAKERS

Rama Challa is a Director of Engineering at Matrix PDM Engineering, a Matrix Service Company. Challa has more than 25 years of experience in engineering and management related to hydrocarbon, chemical, LNG, industrial and nuclear facilities. He is a subject matter expert in design and detailing, estimating, planning, and scheduling of steel plate structures and turnkey industrial facilities. Challa has a Ph.D. in Structural Engineering from Iowa State University and a certificate in Management from the University of Tulsa. He is registered as a Professional Engineer in multiple states and in Canada.

Warren Cole is Pipeline Integrity Manager with Phillips 66 in Houston, TX. He has worked for Phillips 66 for eleven years with various roles in Field Pipeline Engineering, Terminal Operations, Terminal Automation, Pipeline Control Center and Pipeline Integrity and the Pipeline Control Center. He earned a Bachelor of Science degree in Electrical Engineering from the University of Oklahoma.
On Shaky ground
Seismicity and Its Impact on Terminal Operations
Agenda and presentation outline

• **Seismicity and Effects on Storage Tanks**
  1. Introduction
  2. Seismic design process
  3. Evaluation: Cushing Storage Tanks
  4. High Seismic Effects on storage tanks
  5. Infrastructure considerations
  6. Seismic preparedness

• **Phillips 66 Seismic Response Protocol**

• **Open Discussion & Questions**
Seismicity and Effects on Storage Tanks

Rama Challa
Matrix PDM Engineering
INTRODUCTION
Central and Eastern U.S. earthquakes
1973 to April 2015

Central and Eastern US Earthquakes
1973–April 2015

Number of M ≥ 3 Earthquakes

858 M ≥ 3 Earthquakes 1973–2008
1570 M ≥ 3 Earthquakes 2009–April 2015

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

November 24, 2016 | 10:46 AM
By Joe Wertz

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 Monroe, Business Writer | pmmonroe@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 Monroe, Business Writer | pmmonroe@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 Monroe, Business Writer | pmmonroe@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 Monroe, Business Writer | pmmonroe@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 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

(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.

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Why is this a big deal?
Why is this a big deal?
Potential - earthquake damage, 2016 prediction

USGS Forecast for Damage from Natural and Induced Earthquakes in 2016

Based on the presumption earthquakes occur naturally

Based on natural and induced earthquakes

Chance of damage

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.

<table>
<thead>
<tr>
<th>FRAME</th>
<th>The earthquake effects on storage tank infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMMUNICATE</td>
<td>Seismic design process for storage tanks</td>
</tr>
<tr>
<td>IDENTIFY</td>
<td>Potential issues</td>
</tr>
<tr>
<td>PROPOSE</td>
<td>Mitigation measures</td>
</tr>
</tbody>
</table>
Reporting of earthquakes

Typically reported as magnitude

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

Modified Mercalli Intensity (MMI) scale definition

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, \(\log_{10} E = 1.5M\)

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Magnitude</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of maximum amplitude for the earthquake as compared to an M4.0</td>
<td></td>
<td>1</td>
<td>3.16</td>
<td>10</td>
<td>100</td>
<td>1,000</td>
</tr>
<tr>
<td>Ratio of Energy Released for the earthquake as compared to an M4.0</td>
<td></td>
<td>1</td>
<td>6</td>
<td>32</td>
<td>1000</td>
<td>31,623</td>
</tr>
</tbody>
</table>

Cushing  
Oct. 10, 2015

Haiti  
Jan. 12, 2010
SEISMIC DESIGN PROCESS
Seismic design map development process

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)

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

Vibration modes of AST in an earthquake:
(a) Impulsive motion
(b) Sloshing motion

Seismic design process for ASTs

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

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

$S_{DS} = Q \frac{F_a}{S_s}$

$S_{D1} = Q F_v S_1$

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)

$A_i = S_{DS} \left( \frac{I}{R_{wi}} \right)$

An impulsive spectral acceleration coefficient, $A_i$

$A_c = KS_{D1} \left( \frac{1}{T_c} \right) \left( \frac{I}{R_{wc}} \right)$

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:

$F_i = A_i (W_s + W_r + W_f + W_i)$

$F_c = A_c W_c$
Seismic design process for ASTs

Underlying concepts

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

Design at this level for performance at this level

Just a step in between

Seismic design process for ASTs

**API 650 Appendix E**

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

AST design conditions

- Shell compression; uplift
- Lateral stability
- Hydrodynamic hoop stress
How do $S_s$ and $S_1$ accelerations affect the seismic response of ASTs in Cushing? (NSHM 2014 $S_s=0.2\,\text{g}$, $S_1=0.065\,\text{g}$)

<table>
<thead>
<tr>
<th>Tank Diameter</th>
<th>Contribution of $S_1$</th>
<th>Contribution of $S_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>13%</td>
<td>87%</td>
</tr>
<tr>
<td>150</td>
<td>15%</td>
<td>85%</td>
</tr>
<tr>
<td>194</td>
<td>18%</td>
<td>82%</td>
</tr>
<tr>
<td>200</td>
<td>19%</td>
<td>81%</td>
</tr>
<tr>
<td>229</td>
<td>20%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Response is primarily $S_s$
CUSHING STORAGE TANK EVALUATION
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:
  - \(S_s = 2.5 \text{ EPGA} \); \(S_1 = 1.25 \text{ EPGA}\)

Shake maps are found at:
http://earthquake.usgs.gov/earthquakes/shakemap/
Cushing tanks/stations USGS/NEIC

October 10, 2015
Cushing map showing recorded PGAs

http://www.strongmotioncenter.org/cgi-bin/CESMD/iqrStationMap.pl?ID=CushingOK_10Oct2015_us10003mqq
Shake map and peak acceleration map

Earthquake October 10, 2015
Monitored values from shake map
Earthquake October 10, 2015

Highest Recorded PGA Around Cushing

Closest Monitoring Device to Tank Farms
Historical PGAs at the nearest station

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

*Note: Cushing is located at 35.9825 N & 96.7642 W.*
**S_s and S_1 computation based on PGAs**

\[ S_s = 2.5 \, EPGA \; ; \; S_1 = 1.25 \, EPGA \]

<table>
<thead>
<tr>
<th></th>
<th>PGA %g</th>
<th>EPGA %g</th>
<th>Computed</th>
<th>Values Used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2/3) PGA</td>
<td>S_s (g)</td>
<td>S_1 (g)</td>
<td>S_s (g)</td>
</tr>
<tr>
<td><strong>Current Design</strong></td>
<td>N/A</td>
<td>N/A</td>
<td>0.200</td>
<td>0.0625</td>
</tr>
<tr>
<td><strong>Highest PGA</strong></td>
<td>59.85</td>
<td>39.9</td>
<td>0.998</td>
<td>0.4988</td>
</tr>
<tr>
<td><strong>Closest PGA</strong></td>
<td>12.96</td>
<td>8.64</td>
<td>0.216</td>
<td>0.108</td>
</tr>
</tbody>
</table>

**Parameters derived from PGAs**

**Values Used in Analysis**
Are these PGAs in the ballpark?

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
Selected tank dimensions for evaluation (48’)

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Height</th>
<th>Maximum Capacity (bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120’</td>
<td>48’</td>
<td>87,792</td>
</tr>
<tr>
<td>150’</td>
<td>48’</td>
<td>137,044</td>
</tr>
<tr>
<td>194’</td>
<td>48’</td>
<td>228,913</td>
</tr>
<tr>
<td>200’</td>
<td>48’</td>
<td>242,779</td>
</tr>
<tr>
<td>229</td>
<td>48’</td>
<td>317,994</td>
</tr>
</tbody>
</table>
Seismic parameters for increased seismicity

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


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.
Draft hazard maps for increased seismicity ($S_1$) (2016 USGS Report)

Factor of almost 3
Draft hazard maps for increased seismicity ($S_s$)  
(2016 USGS Report)
1.0 Second Spectral Acceleration

(2016, 2017 USGS Comparison)

1.0-second spectral response acceleration with a 1% probability of exceedance in 1 year
### $S_s$ and $S_1$ computation based on PGAs

$S_s = 2.5 \text{ EPGA} ; S_1 = 1.25 \text{ EPGA}$

<table>
<thead>
<tr>
<th>Parameters Derived From PGAs</th>
<th>PGA %g</th>
<th>EPGA %g</th>
<th>(2/3) PGA</th>
<th>$S_s$ (g)</th>
<th>$S_1$ (g)</th>
<th>$S_s$ (g)</th>
<th>$S_1$ (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Design</td>
<td>N/A</td>
<td>N/A</td>
<td>0.200</td>
<td>0.0625</td>
<td>0.20</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Highest PGA</td>
<td>59.85</td>
<td>39.9</td>
<td>0.998</td>
<td>0.4988</td>
<td>1.07</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Closest PGA</td>
<td>12.96</td>
<td>8.64</td>
<td>0.216</td>
<td>0.108</td>
<td>0.27</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Updated USGS 2016</td>
<td>44.16</td>
<td>29.44</td>
<td>0.736</td>
<td>0.368</td>
<td>0.6557</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>Updated USGS 2017</td>
<td>59.93</td>
<td>39.95</td>
<td>0.998</td>
<td>0.499</td>
<td>0.8576</td>
<td>0.1105</td>
<td></td>
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</tbody>
</table>

Parameters From USGS 2016/2017 Map
1% probability of exceedance in 1 Year
Evaluation 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.
HIGH SEISMIC EFFECTS ON STORAGE TANKS
High seismic effects on tanks

Fig. 5 Rocking motion due to high frequency earthquake

Seismic effects on tanks

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

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

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

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
High seismic secondary effects on tanks

Sloshing of liquid

$M_w \ 7.4$  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

High seismic secondary effects on tanks

Naphtha Tank Fire

$M_w$ 8.3 HOKKAIDO, JAPAN
Areas susceptible – open top tanks
Cone roof tank with internal floating roof
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
INFRASTRUCTURE
CONSIDERATIONS
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

- 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

Flexible connections prevented piping damage in 2001 Peru Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers)  $M_w$ 8.4 PERU

Infrastructure considerations

- 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)

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

Mw 8.8 CHILE

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

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)
SEISMIC PREPAREDNESS
What measures can we take?

Reference: http://lamngyeung.blogspot.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 and 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
Seismic hazard classification

1. Seismic event occurrence PGA Recorded
   - PGA < z
     - No Inspection Required
   - PGA ≥ z
     - PGA < Y
       - Yes: Inspect All equipment Classified “C”
       - No: PGA ≥ X
         - Yes: Inspect all equipment classified “A”, “B”, and “C”
         - No: Inspect all equipment classified “C” and “B”
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
Phillips 66 Seismic Response Protocol

Warren Cole
Phillips 66 Pipeline Integrity Manager
Phillips 66 Seismic Response Protocol

- Detailed protocol to provide quick response to seismic activity near pipelines and facilities
- Internally developed software application for quick notification
- Integrates with Phillips 66 pipeline database
- Analyzes USGS seismic events per P66 policy
- Predefined response zones & restart criteria
Protocol Overview

Step 1: Identification

- USGS Earthquake Notification System
- Sensor Detection
- Field Identified Earthquake

Step 2: Notification

- Quake 66 Notification

Step 3: Response

- Response Process
  - Shutdown Zone
  - Visual Assessment Zone
  - Precautionary Inspection Zone
Notification Process

Control Center Notification
Quake 66 Automated alert sent to Controller to initiate response based on predefined criteria

Field Notification
Receives automated alert and response instructions from Control Center for response zones
Response Process

- Predefined response zones based on magnitude and distance to pipeline centerline
- 3 different response zones
- Field and Control Center procedures defined for each zone
- Restart criteria defined for each zone as applicable