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# Seismic Vulnerability Assessment of Steel Storage Tanks in Iranian Oil Refineries

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Typical storage tanks have been studied in this research

(*Unanchored Cylindrical Steel Liquid Tanks* )

# 1. INTRODUCTION:

Liquid storage tanks are important components of lifeline and industrial facilities.

Modern oil and liquid fuel storage tanks included in lifeline systems vary from 12 to 76 m in diameter with height that are nearly always less than the diameter.

Ground supported , circular cylindrical tanks are more frequent than any other types because they are simply in design, efficient in resisting primary hydrostatic pressure, and can be easily constructed.

The vulnerability and seismic risk level of above ground liquid tanks are very high. Examples of tank collapses and extensive uncontrolled fires have been observed during the following earthquakes:

1933 Long Beach,
1964 Niigata,
1964 Alaska,
1971 San Fernando, and
1999 Kocaeli.

The large-scale damage to unanchored tanks in recent earthquakes highlighted the need for a careful analysis of such tanks.

The objective of this paper is to evaluate the seismic vulnerability of cylindrical liquid storage tanks of an Iranian oil refinery complex according to International documented standards and guidelines such as:

**API650,1998&2005, and ASCE, 1994.**

Also, refined finite element analyses (FEM) is used in order to vulnerability evaluation and retrofit design of studied tanks.

# General information of studied tanks

| Tank | Height(H) | Diameter(D) | Density | Yield stress | Height to diameter Ratio |
|---|---|---|---|---|---|
| No. | mm | mm | $t/m^3$ | $Kg/cm^2$ | (H/D) |
| 1 | 14640 | 37190 | 0.75 | 2400 | 0.39 |
| 2 | 14640 | 31100 | 0.75 | 2400 | 0.47 |
| 3 | 12810 | 24380 | 0.75 | 2400 | 0.53 |
| 4 | 11920 | 18980 | 0.75 | 2400 | 0.63 |
| 5 | 14640 | 14640 | 0.75 | 2400 | 1.00 |

# 2. TANKS FAILURE MODES

The main failure modes of cylindrical above ground tanks includes:

1. Overturning
2. Elastic buckling
3. Sliding
4. Elasto-Plastic buckling (Elephant foot buckling)
5. Roof damage
6. Uplift
7. Different settlement

# Results of the past earthquakes:

Uncontrolled fire in oil tanks after earthquake

Situation of tanks  after fire

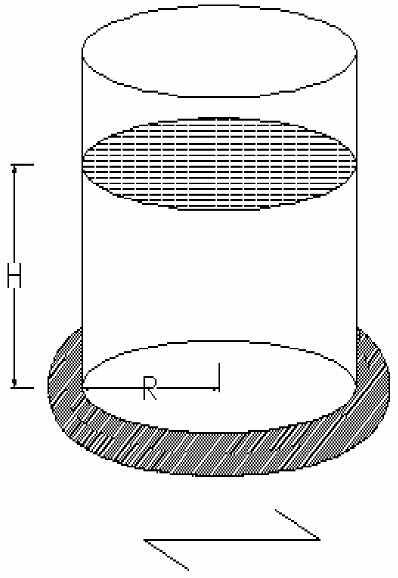

Elephant foot buckling in tanks

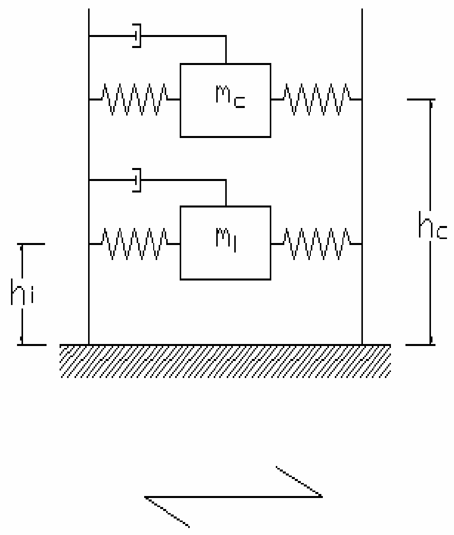

Roof damage in tanks due to liquid slashing

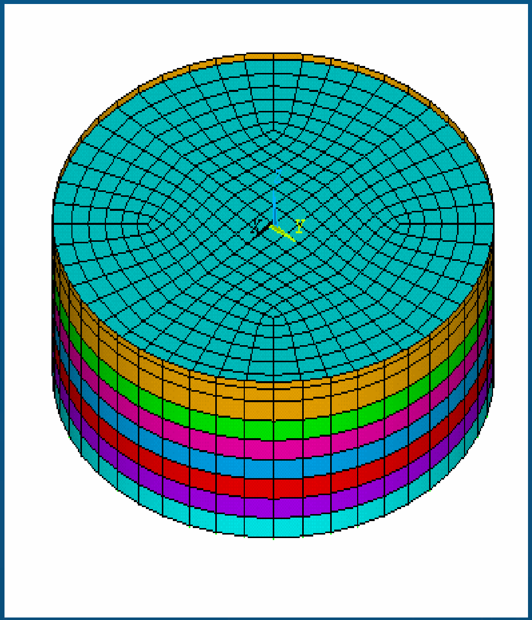
# 3. ANALYTICAL APPROACH

Main assumptions considered in analytical models are as follows:

- refined analytical models is considered for seismic vulnerability evaluation of tanks based on FEM method.
- fluid elements and fluid-structure interaction is considered in analyses.
- shell and beam elements are used for tank shell and structure.
- Linear elastic small deformation analysis is performed for modal analysis.
- The number of modes considered in spectral analysis is based on achievement of 90% seismic structural mass.
- Nonlinear analyses is considered in dynamic analyses.



**General tank view** **Simple model** **Refined model**

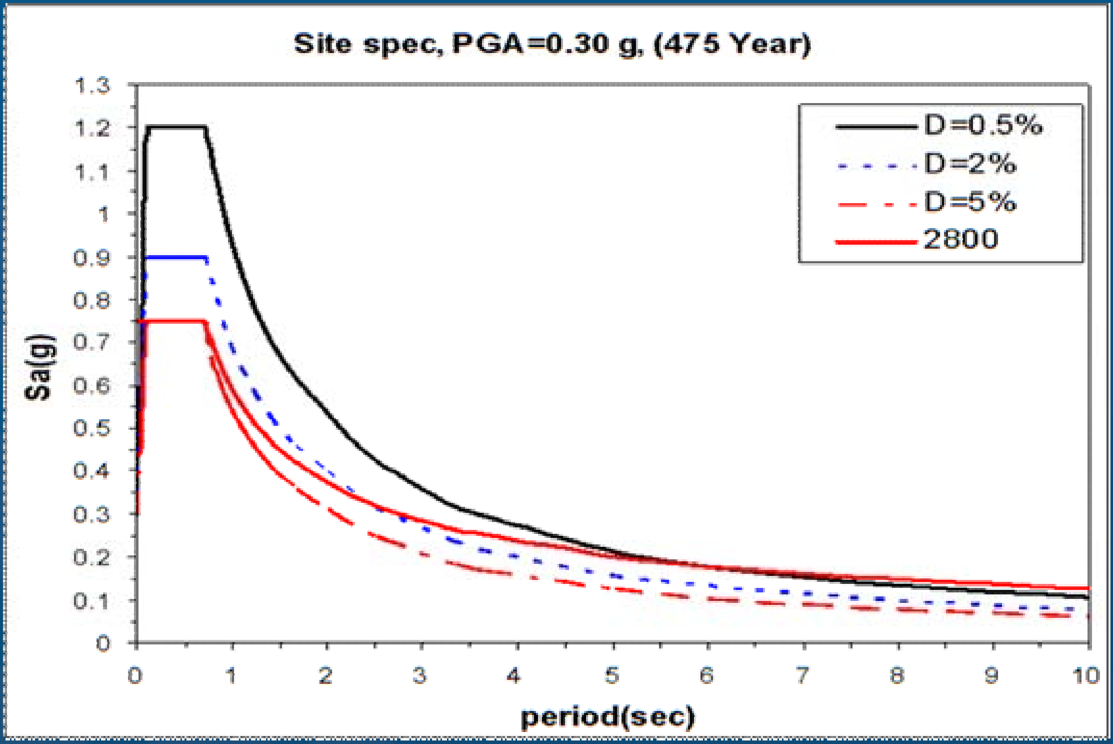
## Simple and refined models of liquid-filled tanks

**$m_i$: impulsive mass**
**$m_c$: convective mass**

Dynamic analyses:

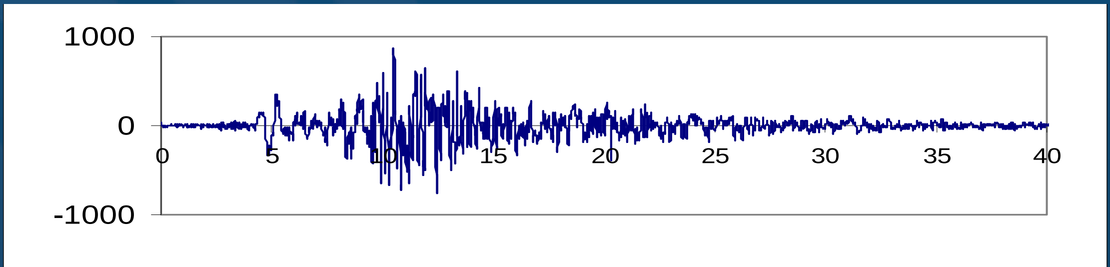
3.1 Spectral analyses
( linear )

Site specific spectra




3.1 Time history analyses
( nonlinear )

Tabas



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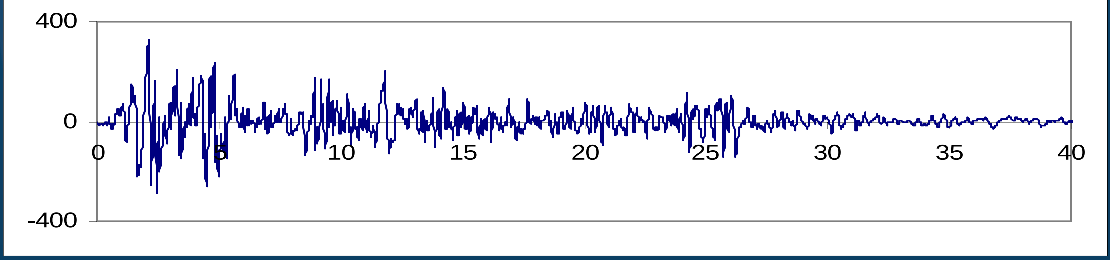
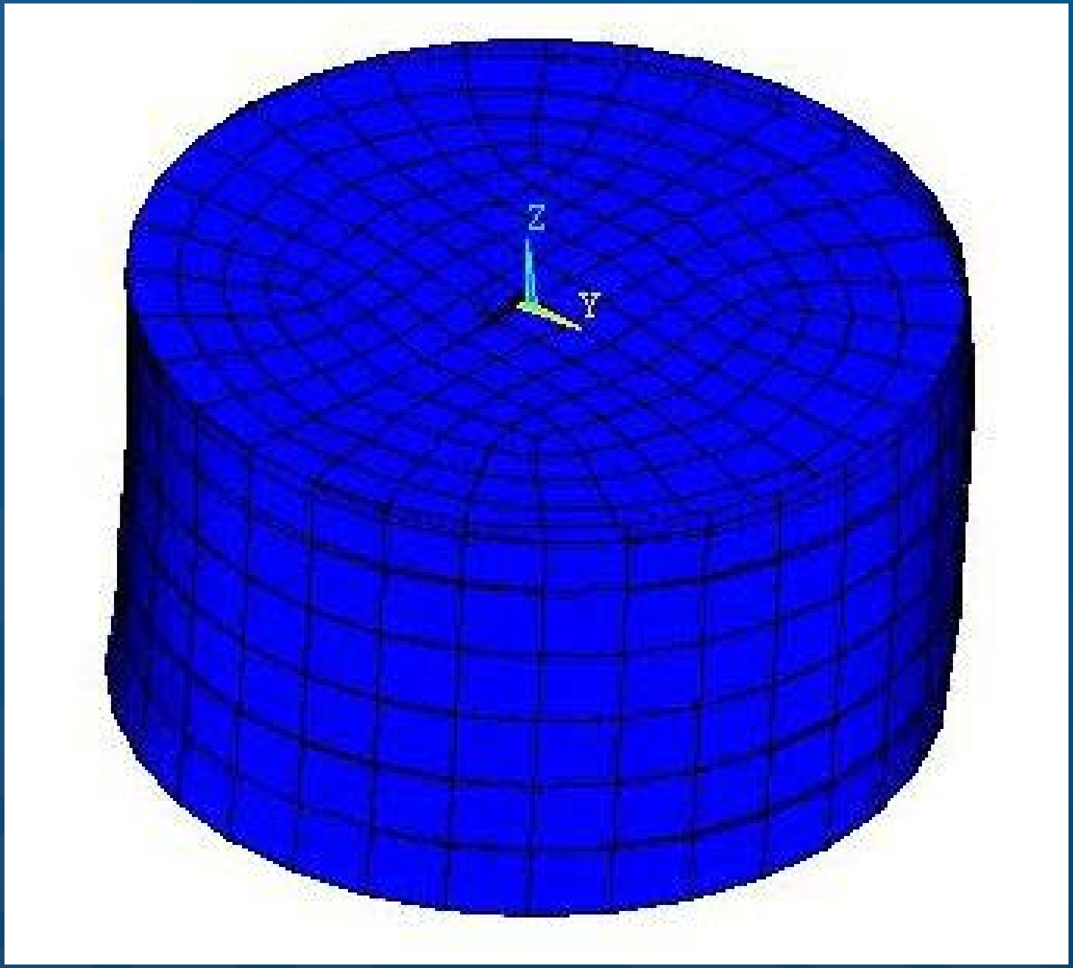


# 4. ANALYSES RESULTS

## Sample Modal Analyses Results:

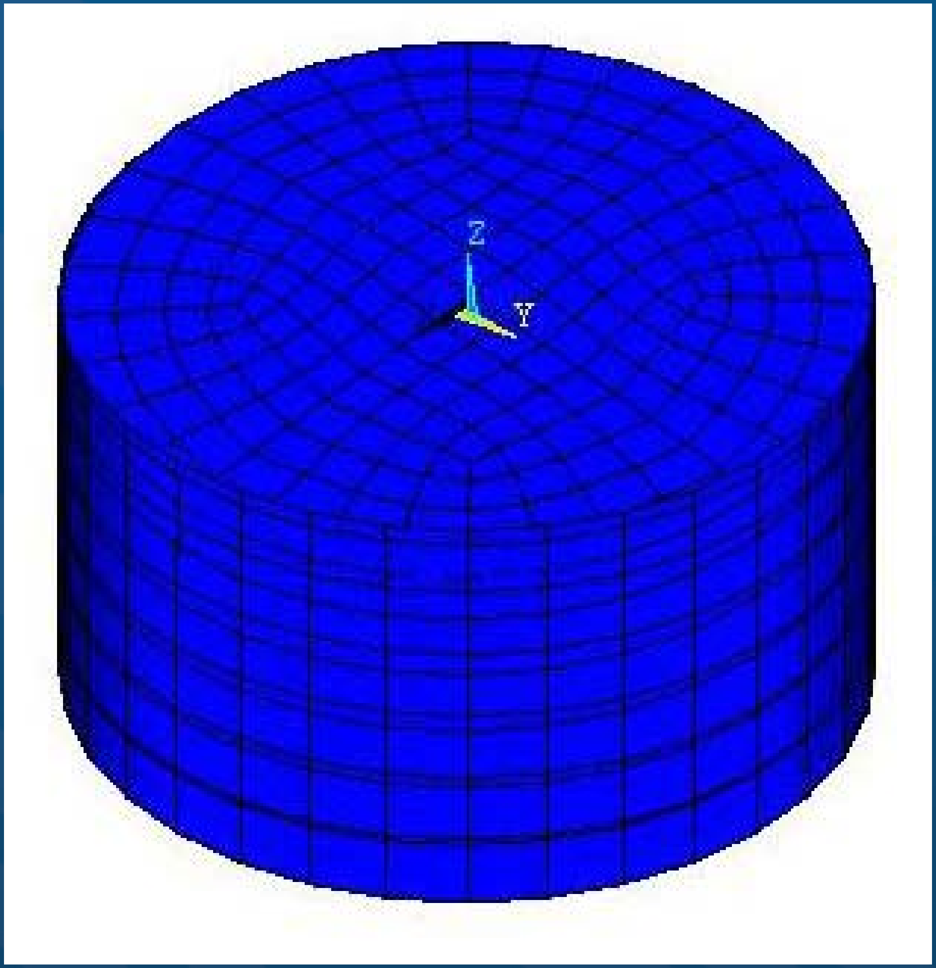
| Mode Shape | Impulsive | Convective | Vertical |
|---|---|---|---|
| Frequency (Hz) | **4.0** | **0.17** | **4.5** |

These values are consistent with the theoretical analyses (Haroun) .

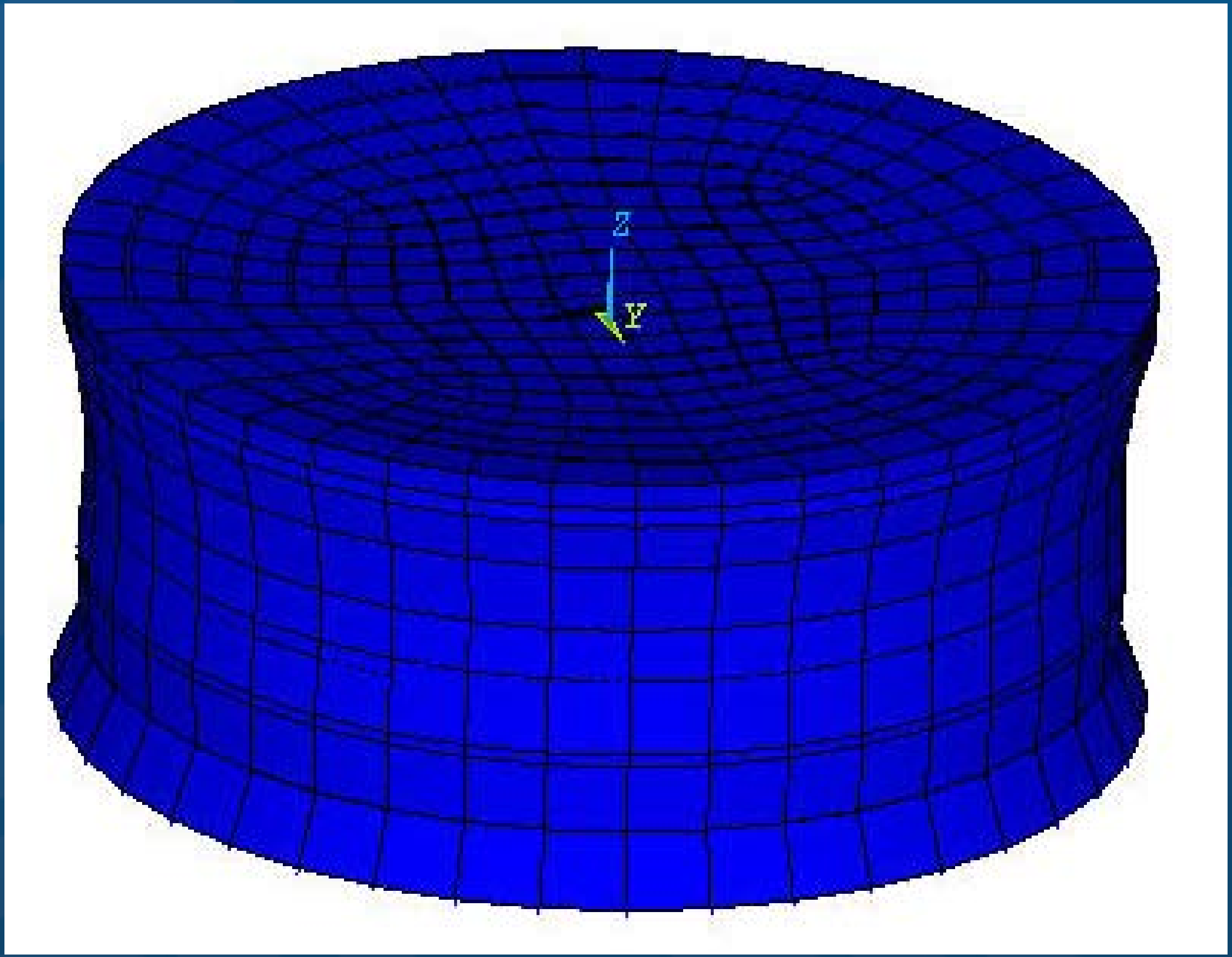



**a) Impulsive mode (4.0 Hz)**

(reason for uplift )

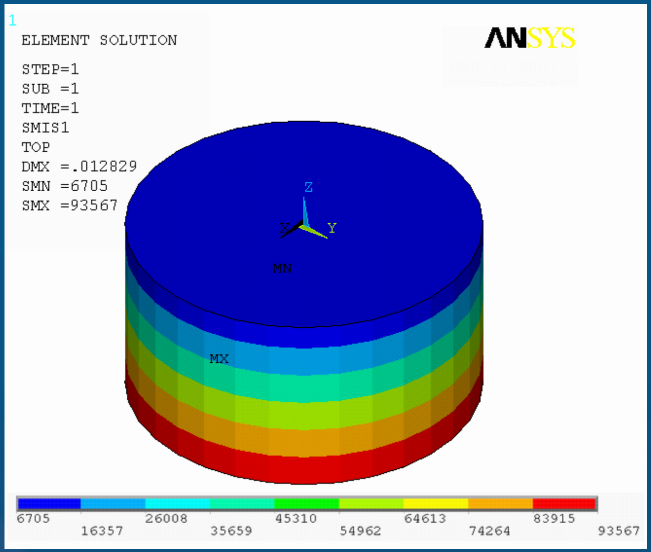



**b) Convective mode (0.17 Hz)**
(reason for roof damage)

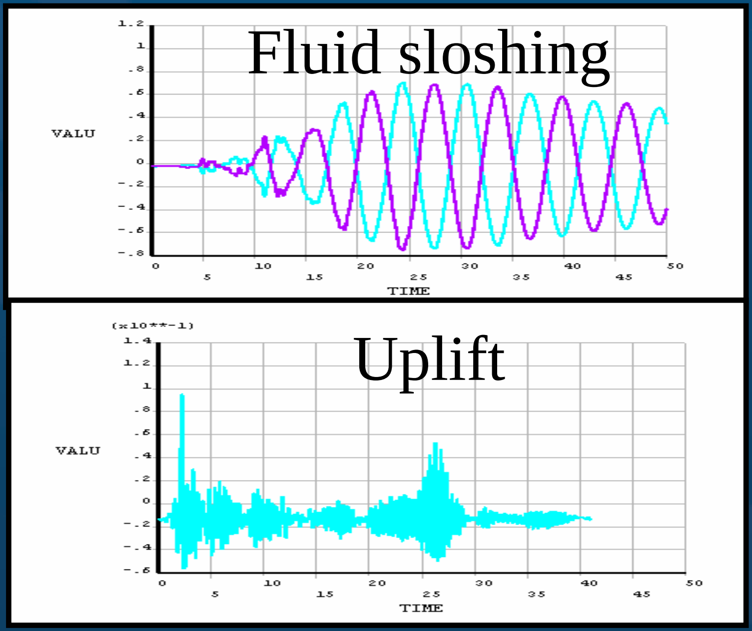



**c) Vertical  mode (4.5 Hz)**
(reason for annular stresses)

# Hydrostatic pressure:
# (Shell stresses)




# Dynamic analyses:

## 1. Overturning Mode

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 0.961 | 1.57 | Safe |
| 2 | 1.12 | 1.57 | Safe |
| 3 | 0.55 | 1.57 | Safe |
| 4 | 1.17 | 1.57 | Safe |
| 5 | 1.96 | 1.57 | Vulnerable |

## 2. Elastic Buckling Mode

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 3.69 | 24.86 | Safe |
| 2 | 5.73 | 37.36 | Safe |
| 3 | 12.16 | 32.34 | Safe |
| 4 | 7.69 | 39.39 | Safe |
| 5 | - | - | - |

## 3. Elephant foot buckling Mode

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 172 | 226 | Safe |
| 2 | 165 | 226 | Safe |
| 3 | 159 | 226 | Safe |
| 4 | 160 | 226 | Safe |
| 5 | 118 | 226 | Safe |

## 4. Sliding Mode

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 23.14 | 45.78 | Safe |
| 2 | 15.63 | 31.97 | Safe |
| 3 | 8.45 | 18.53 | Safe |
| 4 | 7.41 | 9.69 | Safe |
| 5 | 4.89 | 7.15 | Safe |

## 5. Sloshing Mode (Roof damage)

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 2.32 | 0.64 | Vulnerable |
| 2 | 2.31 | 0.64 | Vulnerable |
| 3 | 2.78 | 0.55 | Vulnerable |
| 4 | 1.72 | 0.55 | Vulnerable |
| 5 | 1.58 | 0.64 | Vulnerable |

## 6. Uplift Mode

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 1.4 | 30 | Safe |
| 2 | 2.4 | 30 | Safe |
| 3 | 19.0 | 30 | Safe |
| 4 | 6.5 | 30 | Safe |
| 5 | 24.0 | 30 | Safe |

# 7. Different Settlement

| Tank No. | Calculated Value | Allowable Value | Result |
|---|---|---|---|
| 1 | 0.0 | 5.0 | Safe |
| 2 | 0.0 | 5.0 | Safe |
| 3 | 1.0 | 5.0 | Safe |
| 4 | 0.3 | 5.0 | Safe |
| 5 | 1.0 | 5.0 | Safe |

# 5. VULNERABILITY ANALYSES

Average results of studied tanks

| No. | Mode of failure | No. of Vulnerable tanks (%) |
|---|---|---|
| 1 | Overturning | 20 |
| 2 | Elastic buckling | - |
| 3 | Sliding | - |
| 4 | Elephant foot buckling | - |
| 5 | Roof damage | 100 |
| 6 | Uplift | - |
| 7 | Different settlement | - |

This means that Roof damage and Overturning are dominant in the studied tanks

# 6. CONCLUDING REMARKS:

Seismic vulnerability evaluation of unanchored liquid storage tanks in an oil refinery complex were presented in this paper. Refined finite element analyses method has been used for static and dynamic analyses of 5 different types of tanks in the complex. The following observations can be explained from analytical results:

1. It was observed that the response of tanks was dominated by the uplift mechanism that varied with the intensity and frequency of the input ground motion
2. By increasing the diameter/height ratio, the first sloshing mode period increases and the vulnerability level of tank decreases
3. Tanks with height to diameter ratio greater than 0.7 are unstable with the problem of overturning.

4. Minimum freeboard of tanks should be 10 percent of the tank height to avoid of roof damage during an earthquake.
5. Other failure mechanisms are not dominant in the case studied tanks.
6. Generally, about 50 percent of the existing tanks in the complex are very vulnerable and require retrofitting and strengthening.

However, future research will also permit a greater understanding of the response of other types of tanks under various seismic loadings.

# Thanks for Your Attention

For any comments please contact:

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