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HCLPF Capacity against Sliding Failure of Flat-Bottom Vertical Fluid Storage Tank

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1. Introduction

Flat-bottom vertical fluid storage tanks (Flat-bottom tank) are widely used in Nuclear Power Plants (NPPs) and especially used for Condensate Storage Tanks (CST), Aux. Feed Water Storage Tanks (AFWST) and Refueling Water Storage Tanks (RWST) which are designed by Seismic Category I in the existing NPPs and their failures result in one of the most significant contributors in Seismic Probabilistic Safety Assessment (Seismic PSA) or Seismic Margin Assessment (SMA). Seismic failures of flat-bottom tank are usually caused by sliding of tanks and shell buckling/anchorage due to overturning of tank. Fragility analysis is performed for the failure modes and HCLPF (High confidence and Low Probability of Failure) capacity is determined as well.

NP-6041 [Ref.1] describes a detailed methodology for fragility of flat-bottom tank and Generic Implementation Procedure (GIP) [Ref.2] also shows a methodology for seismic evaluation of the tank. Besides, API-650 [Ref.3] is a design code for flat-bottom tank and seismic capacity assessment can be performed using the code.

In this study, seismic fragilities for flat-bottom tank using methodologies of NP-6041, GIP and API-650 are compared and differences of each methodology are identified. A sliding failure of tank is considered only for the study.

2. Methods and Results

NP-6041 App. H shows a fragility analysis for an example tank which is illustrated in Figure 1. For the tank, the dimensions, component weights, and material properties are as below.

- Tank radius : R = 20 ft
- Tank height : H_T = 43.4 ft
- Water height : H_W = 37 ft
- Head weight : W_H = 17.2 kips
- Shell weight : W_S = 44.9 kips
- Bottom weight : W_B = 12.8 kips
- Water weight : W_W = 2,900 kips
- Shell average thickness : t_S = 0.22 in
- Material & Density : SA240-Type 304 stainless steel $E_S = 28\text{x}10^6$ psi, p_S = 490 pcf

NUREG/CR-0098 [Ref.4] median spectrum anchored 0.27g PGA illustrated in Figure 2 is considered as a reference earthquake. Vertical PGA is considered by 2/3 times horizontal PGA (0.18g PGA). Fragility analyses are performed by methodologies of GIP and API-650 and compared with that of the example tank of NP-6041. A procedure to develop fragilities for each methodology is as below.

Step 1) Horizontal impulsive mode frequency (F_I) / convective mode frequency (F_C) are determined and effective impulsive weight of fluid (W_I) / effective convective weight of fluid (W_C) are calculated.
Step 2) Horizontal impulsive spectral acceleration (S_{AI}) / convective spectral acceleration (S_{AC}) for the frequencies are developed. 5% damped reference spectrum for impulsive mode and 0.5% damped reference spectrum for convective mode are considered respectively in NP-6041 and API-650. 4% damped reference spectrum is recommended in GIP, however, the same 5% damped spectrum is considered for the fragilities because it's reasonable to use 5% damping for the tank. Vertical spectral acceleration is determined by 5% damping as well.
Step 3) Horizontal seismic response for base shear (V_{SH}) is developed by horizontal impulsive and convective responses determined using the corresponding spectral accelerations and weights for each mode.
Step 4) Sliding shear capacity (V_{SC}) is developed. A coefficient of friction (COF) between tank base and its foundation and tank weight are determined for the shear capacity. COFs of 0.70 and 0.55 are recommended in NP-6041 and GIP respectively, however, the same COF of 0.55 is applied for both for the study. COF of 0.4 is applied in API-650. It is noted that anchor bolt tension due to overturning ($\sum T_B$) is added to effective weight for sliding capacity in NP-6041.

Table 1 shows results of frequencies / weights (F_I, $F_{C,}$ W_I, W_C) and spectral accelerations ($S_{AI,}$ S_{AC}) for developing seismic base shear of each methodology. Table 2 shows results of seismic base shear (V_I, V_C, V_{SH}), shear capacity (V_{SC}), factor of safety (V_{SC}/V_{SH}) and HCLPF capacity of each methodology. Based on the results, the followings are recognized.

- Frequencies slightly differs from each methodology, however spectral accelerations for each methodology are identical because reference earthquake is flat widely between 2~8Hz.
- In NP-6041, anchor bolt tension is added to effective weight and significantly increases shear capacity (about 27%).
- In NP-6041, bottom weight of tank is not considered for the example tank, however, it can be considered for both demand (seismic base shear) and capacity.
- In GIP, impulsive mode and convective mode are not separated and only water weight is considered for developing seismic base shear and shear capacity.

- In API-650, COF shall not exceed 0.4. Response modification factor (R) can be considered (R = 2~4), however the example tank is assumed to be a safety-related component installed in NPP, therefore it's appropriate to apply unity conservatively.

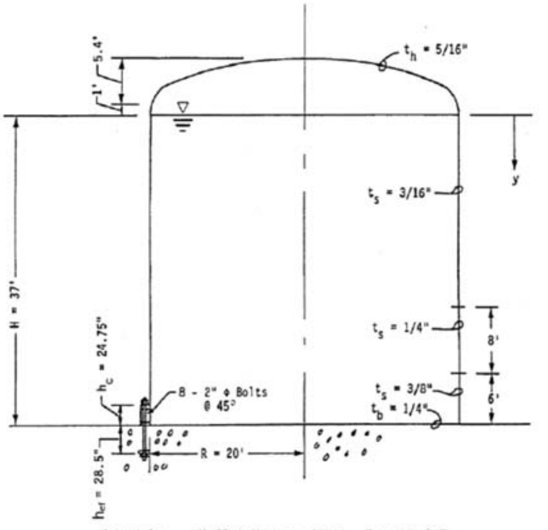

Figure 1. Example Tank [Ref.1]

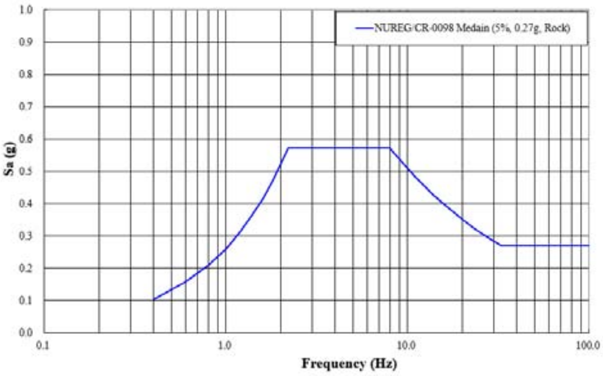

Figure 2. Reference Spectrum (NUREG/CR-0098 Median, Rock, 5%, 0.27g PGA)

3. Conclusions

In this study, HCLPF capacity against sliding failure of tank are compared using methodologies of NP-6041, GIP and API-650. As shown by Table 1&2, HCLPF by API-650 is the lowest and that by NP-6041 is the highest, because API-650 is a design code and should be conservative, whereas NP-6041 is a very realistic procedure and can get a highest HCLPF capacity. Also, more detailed analyses are required ($\sum T_B$ etc.) for NP-6041. Methodology of GIP is the simplest and relatively have a good HCLPF number. Mean fragility curves using HCLPF capacities and generic uncertainty (β_C = 0.4) are developed in Figure 3. For the example tank, HCLPF capacity would be governed by shell buckling/anchorage due to overturning, however it's not considered in the study.

Table 1. Important factors for developing seismic base shear of each methodology

	NP-6041	GIP	API-650
F_I	$\frac{C_{LI}}{2\pi H}\sqrt{\frac{E_S}{\rho_S}}$ $= 5.941$ Hz $(C_{LI} = C_{wI}\sqrt{\frac{0.127\rho_S}{\rho_L}})$	$F_f\sqrt{\frac{0.0361}{\rho_L}}\sqrt{\frac{E_S}{30\times 10^6}}$ $= 6.288$ Hz $(F_f = F_f`\frac{1200}{R})$	$\frac{1}{\frac{1}{27.8}\frac{C_i H}{\sqrt{\frac{t_S}{D}}}\sqrt{\frac{\rho_S}{E_S}}}$ $= 7.564$ Hz
F_C	$\sqrt{\frac{1.50\frac{ft}{sec^2}}{R} * \tanh(1.835(\frac{H}{R})}$ $= 0.274$ Hz		$\frac{1}{\frac{0.578}{\sqrt{\tanh\frac{3.68H}{D}}}\sqrt{D}}$ $= 0.273$ Hz
$\frac{W_I}{W_W}$	$H/R \geq 1.5$ $1.0 - 0.436\left(\frac{R}{H}\right)$ $= 0.764$	Q` = 0.718 (Figure 7-3)	$D/H < 1.333$ $1.0 - 0.218\left(\frac{D}{H}\right)$ $= 0.764$
$\frac{W_C}{W_W}$	$0.46\left(\frac{R}{H}\right) * \tanh(1.835\left(\frac{H}{R}\right))$ $= 0.248$		$0.23\left(\frac{D}{H}\right) * \tanh(3.67\left(\frac{H}{D}\right))$ $= 0.248$
S_{AI}	0.572 (5%)	$S_{af} = 0.572(5\%)$	0.572 (5%)
S_{AC}	0.084 (0.5%)		0.572 (5%)

Table 2. Seismic base shear and shear capacity of each methodology

	NP-6041	GIP	API-650
V_I	$S_{AI}(W_H + W_S + W_I) = 1{,}304$ kips	$Q`\, W_W\, S_{af}$ $= 1{,}192$ kips	$S_{AI}(W_H + W_S + W_B + W_I) = 1{,}312$ kips
V_C	$S_{AC}\, W_C = 60$ kips		$S_{AC}\, W_C$ $= 60$ kips
V_{SH}	$\sqrt{{V_I}^2 + {V_C}^2}$ $= 1{,}306$ kips		$\sqrt{{V_I}^2 + {V_C}^2}$ $= 1{,}313$ kips
COF	0.55	0.55	0.40
V_{SC}	COF $(W_{VE} + \sum T_B) = 1{,}814$ kips $(W_{VE} = (W_{TE} + P_a(\pi R^2))$	COF $(1 - 0.21 S_{af})\, W_W$ $= 1{,}403$ kips	COF $(W_H + W_S + W_B + W_W) + (1 - 0.4 S_{av})$ $= 1{,}008$ kips
$\sum T_B$	693.6 kips	N/A	N/A
$\frac{V_{SC}}{V_{SH}}$	1.389	1.177	0.768
HCLPF	0.375g	0.318g	0.207g

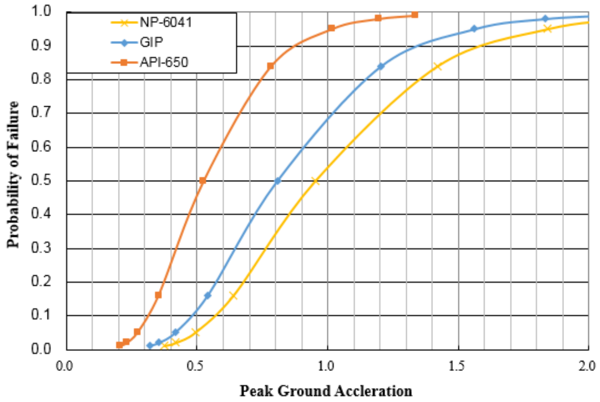

Figure 3. Mean Fragility Curve

REFERENCES

[1] Electric Power Research Institute, NP-6041-SL1, A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1), Palo Alto, CA, August 1991.

[2] SQUG, Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment, Revision 3A, December. 2001.

[3] American Petroleum Institute, Welded Tanks for Oil Storage, API Standard 650 Twelfth Edition, March 2013.

[4] Nathan M Newmark and Associates, Development of Criteria for Seismic Review of Selected Nuclear Power Plants, NUREG/CR-0098, Urbana, IL, May 1978.