Transactions of the Korean Nuclear Society Spring Meeting
Taebaek, Korea, May 26-27, 2011

The Seismic Fragility Analysis of a Condensate Storage Tank with Age-Related Degradation

Young-Sun Choun [a*], Min Kyu Kim [a], In-Kil Choi [a], Jinsuo Nie [b], Joseph I. Braverman [b], Charles H. Hofmayer [b]
[a] *Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Daejeon, 305-353, Republic of Korea*
[b] *Energy Science & Technology Department, Brookhaven National Laboratory, Upton, NY 11973-5000, USA*
[*] *Corresponding author: sunchun@kaeri.re.kr*

1. Introduction

The rate of age-related degradation in nuclear power plants (NPPs) is not significantly large but increasing as the plants get older. The slow but increasing rate of degradation of structures and passive components (SPCs) can potentially affect the safety of the older plants and become an important factor in decision making in the current trend of extending the operating license period of the plants.

This paper investigates the seismic fragility capacity of the condensate storage tank (CST) for five cases: (1) a baseline analysis where the design condition (undegraded) is assumed, (2) a scenario with degraded stainless steel tank shell, (3) a scenario with degraded anchor bolts, (4) a scenario with anchorage concrete cracking, and (5) a perfect correlation of the above three degradation scenarios.

2. Fragility Analysis Method for Liquid Tanks

The conservative deterministic failure margin (CDFM) method is used in the fragility analysis of the undegraded and degraded CST. The CDFM method was developed for simplicity based on the Fragility Analysis (FA) method, in such a way that the high confidence low probability of failure (HCLPF) capacity can be calculated deterministically without specifying many subjective parameters.

A sophisticated procedure to calculate the HCLPF capacity of flat bottom tanks using the CDFM method is introduced in Appendix A of NUREG/CR-5270 [1].

3. Fragility Analysis of the Undegraded Tank

3.1 Condensate Storage Tank

The CST was shown to have a significant impact on the seismic core damage frequency (CDF) of a NPP, contributing 17.7% for a Korean NPP [2].

The CST is a flat-bottomed cylindrical tank filled with water under atmospheric pressure. The inner diameter of the tank is 50’ (15.24 m) and the height of the tank (up to the design water level) is 37’-6” (11.43 m). The thickness of the tank shell is 5/8” (16 mm). The thickness of the bottom plate is about 7 mm. The shell plate, bottom plate, and the roof plate of the tank are made of SA240-304 stainless steel.

The CST is heavily anchored to the reinforced concrete foundation through 78 anchor bolts. The anchor bolts have a diameter of 2-1/2” (63.5 mm) and are A36 steel. The length of the anchor bolts is 3’-6” (1.07 m), with an embedment of about 2’-1” (0.64 m). The anchor bolts were post-installed in pre-formed holes in the concrete foundation with non-shrinking grout. The compressive strength of the concrete foundation of the CSTs was specified as 4,500 psi. The actual compressive strength of the non-shrinking grout was reported to be 7,550 psi and 111,000 psi, respectively, at 7 days and 21 days [3].

3.2 Fragility Analysis

The design basis earthquake (DBE) used for the design of the subject CST was based on NRC Regulatory Guide 1.60 [4] design spectrum anchored to a PGA level of 0.20 g. The initial estimate of the seismic margin earthquake (SME) is set to 1.67×0.2 g = 0.334 g, in which the factor 1.67 comes from the SRM/SECY 93-087 [5] requirement. For developing the fragility curve, the aleatory uncertainty β_R = 0.20 and the epistemic uncertainty β_U =0.27 were used [1].

Based on the HCLPF capacity and the uncertainties, the median fragility capacity can be estimated to be 0.923 g. Fig. 1 shows the mean fragility curve and the median, 5% percentile, and 95% percentile fragility curves.

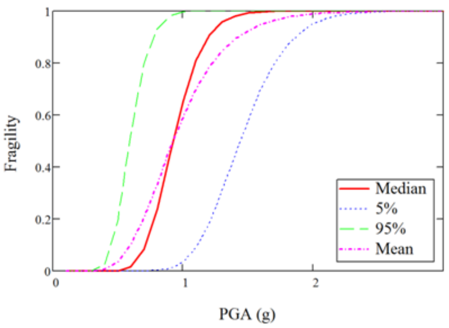


Fig. 1. Fragility curves of the undegraded condensate storage tank

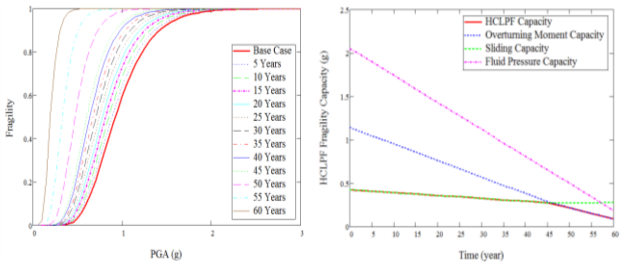
4. Fragility Analysis of Degraded Tank

Three separate degradation scenarios and one combined degradation scenario were considered: (A) degraded stainless tank shell, (B) degraded anchor bolts, (C) anchorage concrete cracking, and (D) a perfect correlation of the three degradation scenarios.

4.1 Fragility Analysis for Degraded Tank Shell

The effect of the stress corrosion cracking (SCC) was assumed to be similar to the loss of material for simplicity. The smaller thickness due to loss of material is assumed to occur at local regions at the base of the tank shell, and, therefore, only the capacity calculation but not the frequency and the response calculation will be changed.

Fig. 2(a) shows the mean fragility capacity of the CST with degraded tank shell for a series of years, from 0 up to 60 years. Figure 2(b) shows that the HCLPF capacity is clearly dominated by the sliding mode until slightly after 45 years, and then by the overturning mode.



(a) Mean fragility capacity (b) HCLPF capacity

Fig. 2. Mean fragility capacity and HCLPF capacity curves for degraded tank shell

4.2 Fragility Analysis for Degraded Anchor Bolts

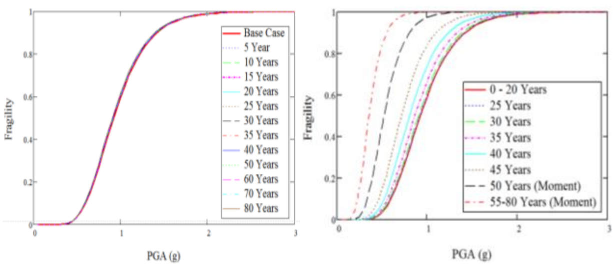
The direct impact of the degraded anchor bolts is simply on the bolt hold down capacity, and consequently on the overturning moment capacity and the sliding capacity.

Fig. 3(a) shows the mean fragility capacity of the CST with corroded anchor bolts for a series of years, from 0 up to 80 years. In a practical sense, it is obvious that the mean fragility is virtually unchanged for a period of 80 years.

4.3 Fragility Analysis for Cracked Anchorage Concrete

The impact of the cracked concrete is directly on the bolt hold-down capacity but not the tank shell buckling capacity and the fluid pressure capacity; the overturning moment capacity and the sliding capacity are affected consequently.

Fig. 3(b) shows that the mean fragility does not change in the first 20 years and in the last 25 years, with an increasing rate of fragility capacity deterioration for the years in the middle.

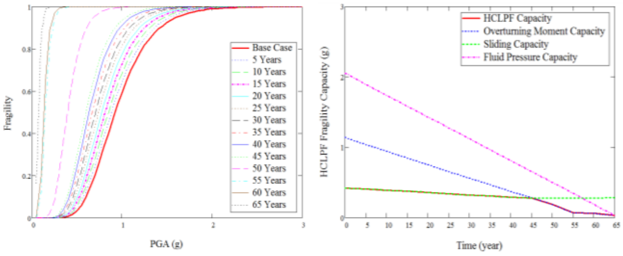


(a) degraded anchor bolts (b) concrete cracking

Fig. 3. Mean fragility capacity curves for degraded anchor bolts and anchorage concrete cracking

4.4 Fragility Analysis for Multiple Degradations

Fig. 4 shows the median fragility and HCLPF capacity curves for the CST with combined degradations up to 65 years. The three degradation cases are assumed to be perfectly correlated.



(a) Mean fragility capacity (b) HCLPF capacity

Fig. 4. Mean fragility capacity and HCLPF capacity curves for multiple degradations

The fragility curves before the end of 45 years show a steady but slow degradation process as shown in Fig. 4(a). Between 45 years and 55 years, a sudden increase of the degradation severity is shown by the large spacing between the corresponding fragility curves. The very small spacing between 55 and 60 years suggest a very small drop in the fragility capacity.

The HCLPF capacity is dominated by the slow deterioration of the sliding capacity before the end of 45 years as shown in Fig. 4(b). Between 45 years and 55 years, the dominating failure mode switches to the overturning moment mode and the resultant deterioration rate in the fragility becomes higher. Between 55 and 60, the HCLPF capacity is still dominated by the overturning moment capacity, which levels to a small constant because the CST effectively is an unanchored tank.

5. Conclusions

It is found that the HCLPF capacity can deteriorate only by the tank shell degradation or the anchorage concrete cracking. The degradation of anchor bolts is not a significant factor. It is recognized that the most critical factor for a high quality time-dependent fragility analysis is the identification of accurate and reliability material degradation models.

REFERENCES

[1] R.P. Kennedy, R.C. Murray, M.K. Ravindra, J.W. Reed, J.D. Stevenson, "Assessment of Seismic Margin Calculation Methods," and Supplement 1, NUREG/CR-5270, U.S. Nuclear Regulatory Commission, Washington, D.C., 1989.

[2] Y.S. Choun, I.K. Choi, J.M. Seo, Improvement of the Seismic Safety of Existing Nuclear Power Plants by an Increase of the Component Seismic Capacity: A Case Study, Nuclear Engineering and Design, Vol.238, pp.1410-1420, 2008.

[3] N.H. Lee, I.H. Moon, I.S. Ju, Failure Mechanism for Large-sized Grouted Anchor Bolt under Tensile Load, Proceedings of SMiRT-16, 2001, Washington, D.C.

[4] Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C., 1973.

[5] SRM on SECY 93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," U.S. Nuclear Regulatory Commission, Washington, D.C., 1993.