The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Numerical approach to estimate liquid tightness of outer concrete tank in emergency LNG spillage

*Seung Hee Kwon[1)], Jeong Su Lee[2)], Yun Lee[3)],
Ji-Hoon Kim[4)] and Chan Kyu Park[5)]

[1), 2)] *Department of Civil and Environmental Engineering,*
Myongji University, Yongin, 449-728, Korea
[3)] *Department of Civil Engineering, Daejeon University, Daejeon, 300-716, Korea*
[4)] *Energy System Team, Samsung C&T Corporation,*
Seocho-Gu, Seoul, 137-956, Korea
[5)] *Construction Technology Research Institute, Samsung C&T Corporation,*
Seocho-Gu, Seoul, 137-857, Korea
[1)] *kwon08@mju.ac.kr*

ABSTRACT

When the spillage of LNG happens, the inner face of the concrete wall is directly exposed to the -168˚C liquid. In designing the concrete tank, the liquid tightness was required to be examined by predicting the behavior of the tank due to the thermal load. In the previous analysis for the LNG spillage, the temperature insider the concrete wall was usually assumed to be a steady state, that is, differently from the actual situation, the process of temperature variation insider the wall over time was not considered.

In this study, the liquid tightness of outer concrete tank in emergency LNG spillage was estimated through a numerical simulation. The two dimensional axisymmetric modeling was adopted for the tank. The variation of the temperature insider the concrete wall over time right after LNG spillage was first calculated. Based on the transient states of the temperature profiles over the cross section of the wall, the structural analysis was performed considering the nonlinear constitutive laws of the concrete and the reinforcement. The analysis result was compared to the result obtained based on the steady state of the temperature. Both results for the transient and the steady states of the temperature satisfied the provisions for the liquid tightness: the compression zone size, the crack width near the corner protection, and the stress of the reinforcements. However, more distributed cracks with smaller spacing were found in the result based on the transient states of the temperature.

1. INTRODUCTION

In the process of designing outer concrete tank of LNG storage facilities, liquid

[1)] Associate Professor
[2)] Graduate Student
[3)] Assistant Professor
[4)] General Manager
[5)] Principal Research Engineer

tightness for emergency LNG spillage should be examined. In the existing studies on the LNG spillage, thermal analysis was first performed under the assumption that LNG of cryogenic temperature -168˚C is directly contact to the inner wall of the concrete tank, and the temperature profile inside the wall is in the equilibrium state, that is, the steady state. Then, based on the steady state temperature, the stress and strain were calculated by using a non-linear concrete material model capable of considering tensile cracking and compressive plastic damage. However, it would take a long-time for the temperature to reach to the steady state in reality, and the analysis based on the steady state might not give an accurate estimation of the liquid tightness.

In this study, the liquid tightness of outer concrete tank in emergency LNG spillage was estimated through a numerical simulation. The two dimensional axisymmetric modeling was adopted for the tank. The variation of the temperature insider the concrete wall over time right after LNG spillage was first calculated. Based on the transient states of the temperature profiles over the cross section of the wall, the structural analysis was performed considering the nonlinear constitutive laws of the concrete and the reinforcement. The analysis result was compared to the result obtained based on the steady state of the temperature. The difference between the two analysis results was analyzed, and a discussion on an accurate estimation method of the liquid tightness was made.

2. Numerical Analysis

2.1 Modeling and Analysis Conditions

The concrete tank was modeled as shown in Fig. 1. The two dimensional axisymmetric model was adopted. The vertical and horizontal reinforcements were modeled as embedded elements. The reinforcements oriented in the circumferential direction were modeled as point elements which were provided by the commercial software used in this analysis. The eight-node plane element was used in modeling the concrete. The dimension of the tank was also displayed in Fig. 1. The thickness of the wall exposed to the liquid was 650 mm.

The pre-stressing forces are introduced to the wall of the tank in the vertical and the circumferential directions. To consider the pre-stressing force, the external forces were applied to the wall in the vertical and the lateral directions. The lateral force can induce the compressive stress over the wall similarly to the pre-stressing force of the circumferential direction. The magnitudes of the external forces were depicted in Fig. 2. The height of the spillage was 22.0m from the bottom. The inner face of the wall was exposed to the -168˚C LNG liquid. The hydrostatic pressure of the liquid was also applied to the wall and the other loading conditions were displayed in Fig. 2

The initial temperature of the concrete tank was 26.3˚C. The outer faces of the roof and the wall were assumed to be 50.2˚C and 45.1˚C considering the hot summer weather, respectively.

The thermal analysis was first performed to obtain the temperature profile in the wall of the tank considering the two situations: the steady state and the transient state. The structural analysis was followed based on the temperature profile.

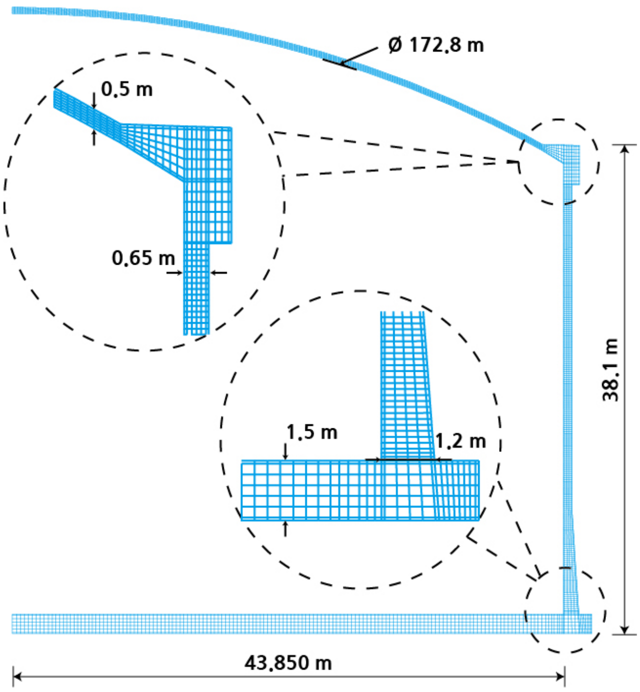


Fig. 1 Axisymmetric Modeling

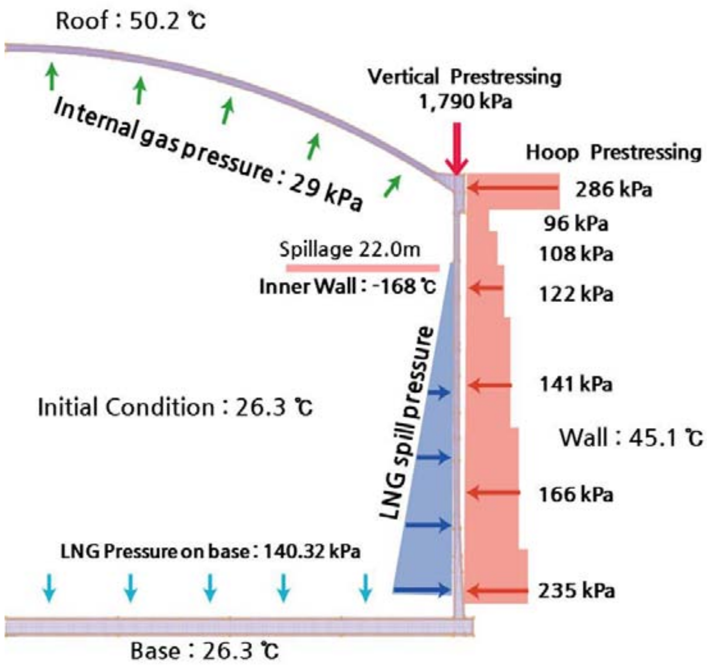


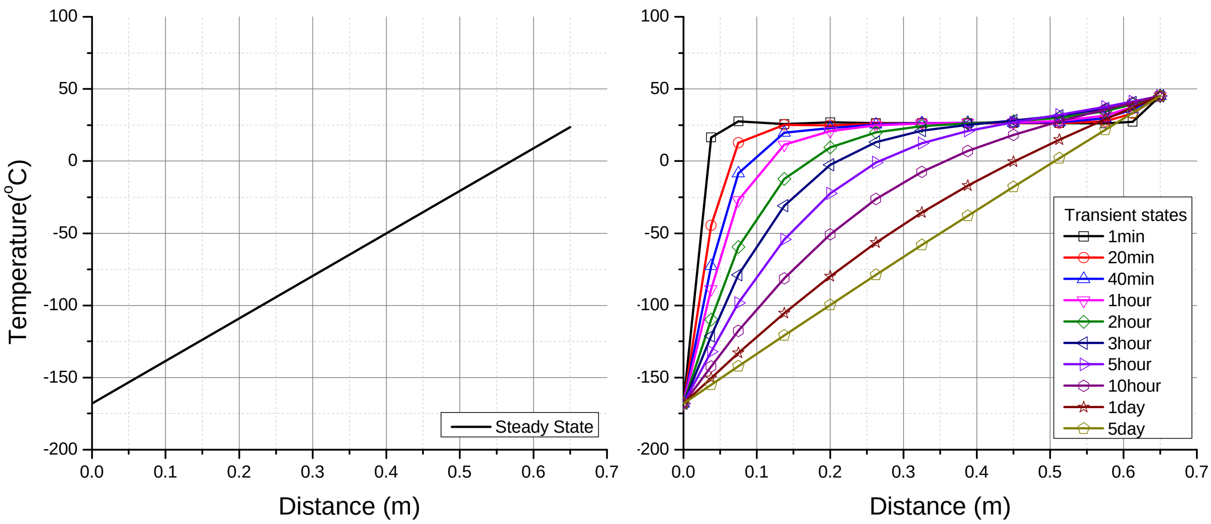
Fig. 2 Initial Conditions(Temperatures and Loads)

2.2 Material Model

The thermal expansion coefficients of the concrete and the steel rebar were 10 × 10^{-6}/°C. The steel was assumed to be a perfect plastic material. The elastic modulus and the yield stress were 200 GPa and 400 MPa, respectively. The concrete model provided by the analysis software (ADINA Ver. 8.8) was used. In the model, the plastic damage in the multi-axial compression and the cracking in the tensile region can be considered. The compressive strength and the Poisson's ratio of the concrete were 38.2 MPa and 0.2, respectively. The other parameters such as elastic modulus, tensile strength, fracture energy were calculated based on the compressive strength.

3. Results and Discussions

Figure 3 shows the results of the thermal analysis. In the steady state, the temperature was linearly distributed over the cross section of the wall. In the transient state, the temperature profile was varying over time as shown in Fig. 3(b). The transient state almost reaches to the steady state 5 days after the spillage. Based on these two situations, the structural analyses were performed.



(a) steady state (b) transient state

Fig. 3 Temperature Profiles over the cross section of the wall

Figure 4 is the deformed shape of the tank which was 250 times magnified. The black line is for the steady state, and the other colors are for the transient states. The deformed shape obtained from the analysis considering the temperature variation in the transient states is larger at the last stage than that of the steady state temperature.

The crack of which the width was larger than 0.3 mm are plotted in Fig. 5. The crack spacing and width were larger in the steady state than those in the transient state. However, there was no crack near the corner protection, which is one of the provisions that should be fulfilled to ensure the liquid tightness.

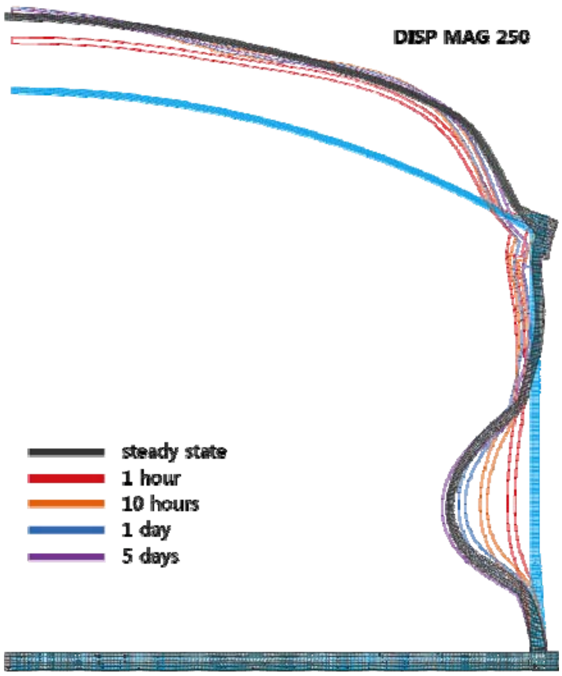
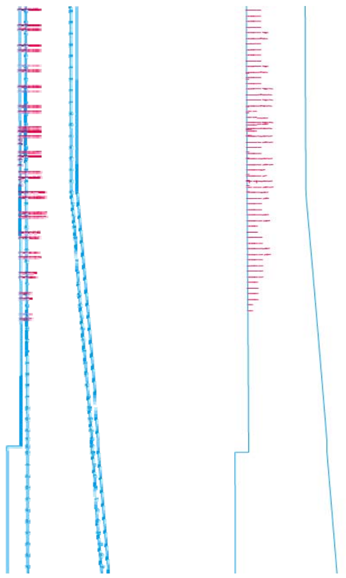


Fig. 4 Deformed Shapes

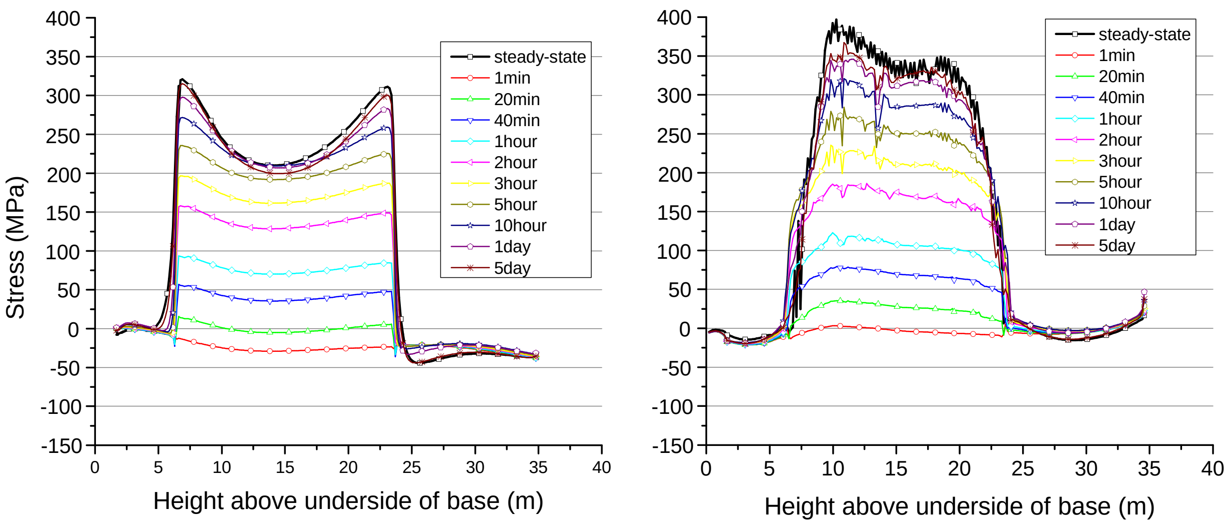


(a) steady state (b) transient (5days)

Fig. 5 Cracking patterns

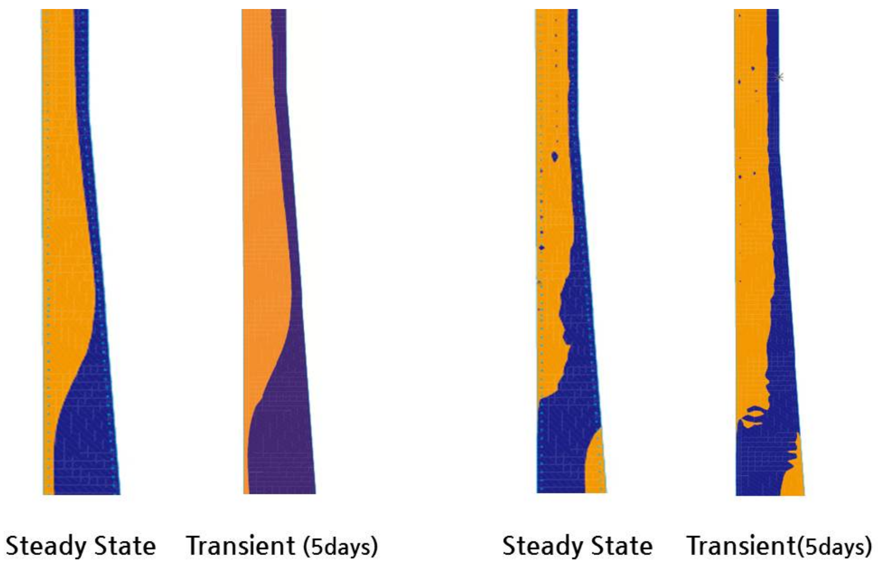
The stresses of the reinforcements located in the circumferential and the vertical directions were shown in Fig. 6. In the spillage region, the stresses of the reinforcements were highly increased. The stress in the stead state is slightly higher than the maximum stress level in the transient state. However, the stress of the reinforcement is less than the yield stress in both cases.

Figure 7 shows the stress contours in the hoop and the vertical directions. The blue region is the compressive zone in which the compressive stress is more than 1 MPa. The stress contours in both cases were very similar to each other. In the steady state and the transient state, the regions were more than 80 mm which is the limit for the liquid tightness.



(a) Hoop reinforcement (b) Vertical Reinforcement

Fig. 6 Stresses of Reinforcements located in the inner part of the wall



(a) Hoop Direction (b) Vertical Direction

Fig. 7 Compression Zone more than -1.0 MPa

4. CONCLUSIONS

The liquid tightness of outer concrete tank in emergency LNG spillage was estimated through a numerical simulation. The variation of the temperature insider the concrete wall over time after LNG spillage was first calculated. Based on the transient and the steady states of the temperature profiles over the cross section of the wall, the structural analysis was performed. The analysis result was compared to the result obtained based on the steady state of the temperature. Both results for the transient and the steady states of the temperature satisfied the provisions for the liquid tightness: the compression zone size, the crack width near the corner protection, and the stress of the reinforcements. However, more distributed cracks with smaller spacing were found in the result based on the transient states of the temperature.

REFERENCES

Bazant, Z.P., and Oh, B.H. (1983), “Crack band theory for fracture of concrete,” Mat. and Str., 16(93), 155-177.

Kwon, S.H., Kim, Y.Y., and Kim, J.K. (2005), “Long-term behaviour under axial service loads of circular columns made from concrete filled steel tubes,” Mag. of Con. Res. 57(2), 87-99.

Kwon, S.H., Zhao, Z., and Shah, S.P. (2008), “Effect of specimen size on fracture energy and softening curves of concrete: Part II. Inverse analysis and softening curve,” Cem. Con. Res. 38(8), 1061-1069.

Kwon, S.H., Kim, T.H., Kim, Y.Y., and Kim, J.K. (2007), “Long-term behaviour of square concrete-filled steel tubular columns under axial service loads,” Mag. Conc. Res. 59(1), 53-68.

Kwon, S.H., and Shah, S.P. (2008), “Prediction of early-age cracking of fiber-reinforced concrete due to restrained shrinkage,” ACI Mat. J., 105(4), 381-389.

Zhao, Z., Kwon, S.H., and Shah, S.P. (2008), “Effect of specimen size on fracture energy and softening curves of concrete: Part I. experiments and fracture energy,” Cem. Conc. Res. 38(8), 1049-1060.