Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Analysis of Prestressed Concrete Containment Vessel(PCCV) under Severe Accident Loading

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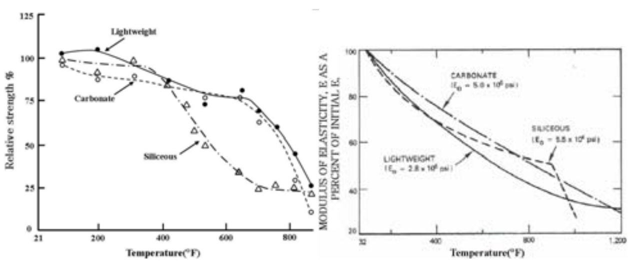
1. Introduction

The design specifications based on LOCA(Loss of Coolant Acident) which have been applied to Reactor Building Design from 1960s had revealed the limitation of safety through Three Mile Island(TMI) accident. Accordingly, the evaluation criteria on safety of nuclear structures due to severe accidents were established on 10 CFR 50.34(f) based on 'TMI Action Plan'. To complement design basis specifications, a lot of criterion concerning various severe accidents have been made, which need to be considered to insure safety in operation and construction of Nuclear Structures.

This paper is focused on the analysis of behavior of the NUPEC/NRC 1:4 scale prestressed concrete containment vessel under pressure and temperature loading beyond design basis accident. The analyses are mainly performed in two kinds of loading cases; one for Saturated Steam Condition which is a loading condition within the range of temperature that is not effective for changes of material properties and the other for Station Blackout (SBO) loading condition which is a representative severe accident scenario including pressure with temperature.

2. Changes of material properties due to Temperature

Material properties of concrete, rebar, tendon and liner steel have tendency to lose resistant capability due to various chemical and mechanical phenomena as temperature increases. The results of previous empirical researches on the effects of temperature increase on material properties are shown in Fig. 1 [1,2].



(a) Compression Strength Ratio[1] (b) Young's Modulus Ratio[2]

Fig. 1 Material Properties vs. Temp.

A smooth curve for strength degradation versus temperature as estimated below (provided as a reference with temperature variation) is introduced into the finite element analysis model.

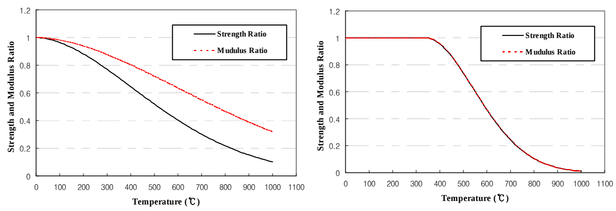
$$S_{temp\_rc} = e^{-(T/632)^{1.8}} \quad (1)$$

where T = Temperature in degree ^{o}C

Further, based on the literature, elastic modulus reduction is calculated by equation (2).

$$E_{temp\_rc} = \sqrt{S_{temp\_rc}} \quad (2)$$

S_{temp_rc} and E_{temp_rc} vs. Temperature are shown in Fig. 2 (a). The thermal expansion coefficient is assumed to be constant at 1.18E-5 cm/cm/^{o}C up to 260^{o}C of temperature rise and then gradually increases to 2.18E-5 cm/cm/^{o}C at 430^{o}C .



(a) Concrete (b) Steel

Fig. 2 Material Properties Reduction vs. Temp

In addition, strength reduction of steel is considered in the analysis model as idealized below based on previous research results [3,4] and shown in Fig. 2(b)

$$S_{temp\_rs} = e^{-[(T-340)/300]^{1.9}} \quad for \quad T > \text{C}340^{\circ}C \quad (3)$$
$$S_{temp\_rs} = 1.0 \quad for \quad T \le 340^{\circ}C$$

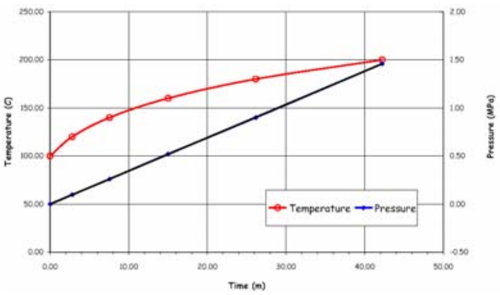
The thermal expansion coefficient of steel is assumed to be constant at 1.18E-5 cm/cm/^{o}C up to 614^{o}C of temperature rise.

3. Finite Element (FE) Analysis

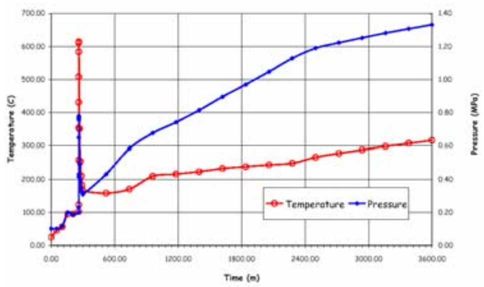
Table 1 Load Cases

Load Case	Loading Combination
CASE 1	Dead Load+ Effective Tendon Force + Saturated Steam Condition
CASE2	Dead Load+ Effective Tendon Force + Station Blackout Scenario(SBO)

Two applied Load Cases are summarized as in Table 1 and shown in Fig. 3.



(a) CASE 1



(b) CASE 2

Fig. 3 Temperature and Pressure Loading Histories

The axi-symmetric finite element model which is utilized to predict the overall response of the 1:4 scale PCCV under internal pressurization and/or thermal loading is shown in Fig. 4. This model consists of axi-symmetric solid elements for concrete portions, nonlinear soil spring elements between basemat and foundation, and three-node shell elements connected to the axi-symmetric solid elements for concrete portions using rigid link elements as shown in Fig. 4. The pressure levels corresponding to loading cases are summarized in Table 2. In case 1, the pressure levels to reach initial con'c crack, rebar yielding and liner rupture are slightly lower than those in case of pressure only to be negligible in view of security of safety. On the other hand, in case 2, the pressure levels to reach initial concrete crack, yielding of liner steel and rebar, and liner rupture are considerably lower than when subjected to pressure only. Accordingly, the effects of temperature should be considered for safety evaluation of Prestressed Concrete Containment Vessel(PCCV) under Severe Accident Loading Histories.

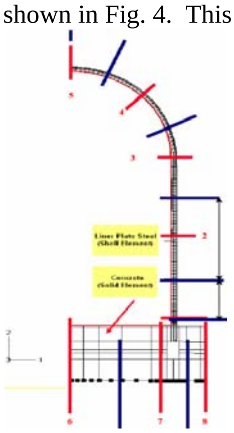


Fig. 4 FE Model

Table 2 Comparisons of Pressure Levels (Mpa)

Item	Pre. Only	Case 1	Case 2
Initial con'c crack	0.60	0.60	0.60
First yield of hoop rebar	1.16	0.88	0.78
Yielding of liner steel	0.75	1.03	0.46
Liner rupture (1.0% strain)	1.03	1.20	0.46
Tendon yielding (1% strain)	1.43	1.41	-
Tendon yielding (3% strain)	1.51	1.47	-

4. Conclusions

The analyses of PCCV under severe accident loading, especially containing high temperature histories were performed in this paper. In case of design basis accident which contain temperature histories under 200°C, the effects of temperature on ultimate capacity of PCCV could be negligible. On the other hand, in case of severe accident which contain temperature histories over 300°C, the effects of temperature should be considered for safety evaluation of PCCV.

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