A Study on the Cover Failure in Concrete Structure Following Concrete Deterioration - 8155

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ABSTRACT

The RC (Reinforced Concrete) structures in the spent fuel dry storage is required structural integrity for a long period of the service life time. A study on the concrete cracking behavior by stress on concrete is necessary for life time estimation of structures because concrete cracking can reduce the radiation shielding performance and deteriorate the durability of spent fuel dry storage. The purpose of this study is to analyze the relationship between the range of the steel expansion and the crack creation and propagation using the ABAQUS tool. Parameters used in this study were concrete strength, concrete cover depth and the steel diameter. The value of steel radius to volume expansion was applied to suppose the expansion of reinforcing bar under the load condition. As a result of this case study, it is confirmed that the critical steel expansion which can initiate cracking is proportional to tensile strength. And primary factors which effect crack creation of concrete cover are in order of concrete strength, cover thickness and steel diameter. If concrete strength is lowered about its 30%, the rate of surface crack occurrence accelerates 15 times maximally. The critical expansion value of steel increased as the increment of concrete cover depth. The surface cracking of concrete cover was created at the value of steel expansion, ranging from 0.019 to 0.051mm under the cover depth 50mm.

INTRODUCTION

In Korea, the spent fuel generated from NPPs (Nuclear Power Plants) has been stored within each plant. With the consideration of the sufficiency of spent fuel storage capacity beyond 2016, the national policy for spent fuel management including the construction of the interim storage for spent fuel shall be decided in a timely manner through national consensus. The dry storage type for interim storage can be considered as one of the candidate options.

RC (Reinforced Concrete) structure in spent fuel dry storage requires long term integrity. However, the concrete cracking of spent fuel dry storage can cause weakening of radiation shielding and durability. In RC structure, the expansive corrosion products create tensile stresses on the concrete surrounding the corroding steel reinforcing bar. This can lead to cracking and spalling of concrete cover as a usual consequence of steel in concrete. Therefore, the cracking estimation by stress calculation based on corrosion rate to the concrete is very important to determine the design life time of spent fuel dry storage. The purpose of this study is to analyze the relationship between the range of the steel expansion and the crack creation and propagation using the ABAQUS tool.

NUMERICAL ANALYSIS

Mechanism of concrete cracking

Concrete can be defined as an inorganic material consisting of cement, water and aggregates. By mixing of water and cement, hydration reactions take place which bind the different materials together. Thus concrete is a composite material that aggregate particles bound together with hydrate cement [1]. The crack occurred in the concrete structure is one of the critical problems for concrete integrity. Crack in concrete structure can cause the serious structural problems, deterioration, and reinforcement corrosion. The reasons that create the crack are very various, but crack is due to tensile stress by load to concrete structure and volumetric change. Crack can be created due to load to structure or tensile stress by volume change of concrete, and in case that the compressing stress or tensile stress to structure exceeds the tensile or compressive strength of concrete [2].

Concrete model

In this study, corrosion failure analysis was carried out using a commercial nonlinear program package ABAQUS 6.5[3]. Material nonlinearity and non uniform pressure was applied in order to consider the real state of corrosion failure. To model concrete, 4 node quadrilaterals method was used. For linear material properties, Young's Modulus was calculated as follows, and Poisson's ratio was assumed as v=0.167

$$Ec = 4.73\sqrt{fc}\ \text{GPa} \qquad \text{(Eq.1)}$$

Corrosion failure analysis is performed using strength of concrete 44MPa which is concrete strength in concrete silo in Wolsung site and Young's modulus Ec=31.37GPa. For the concrete compressive regime Mohr-Coulomb model was applied, and cohesion c was calculated as following formula.

$$c = \frac{1-\sin\phi}{2\cos\phi}\, fc \qquad \text{(Eq.2)}$$

If Druck-Prager Model plasticity is used to model the failure surface in plane stress, the friction angle is approximately 30. For the tensile regime, the smeared crack concept was used to model cracking of continuum element. Cracking occurs in the integration points. Hereby the stress-strain relation is modified in order to account for the stiffness and strength degradation that accompanying cracks. The smeared crack approach was specified by tension cut off, tension softening and shear retention. Especially linear tension cutoff was used in this study. A crack arises of the major principal tensile stress exceeds the minimum of ft and ft(1+σlateral/fc), with σlateral the lateral principal stress. Herein, direct strength ft of concrete can be obtained from split tensile strength fs, ft and fsp was calculated from following (Eq. 3) and (Eq. 4)

$$\text{fsp} = 0.2\, fc^{0.7} \text{ MPa} \quad \text{(by Oluokun)} \qquad \text{(Eq.3)}$$

$$\text{ft} = 0.9\, fsp \text{ Mpa} \qquad \text{(Eq.4)}$$

Modeling

Numerical approach two dimensional models using plane stress elements were applied as shown in Fig. I.

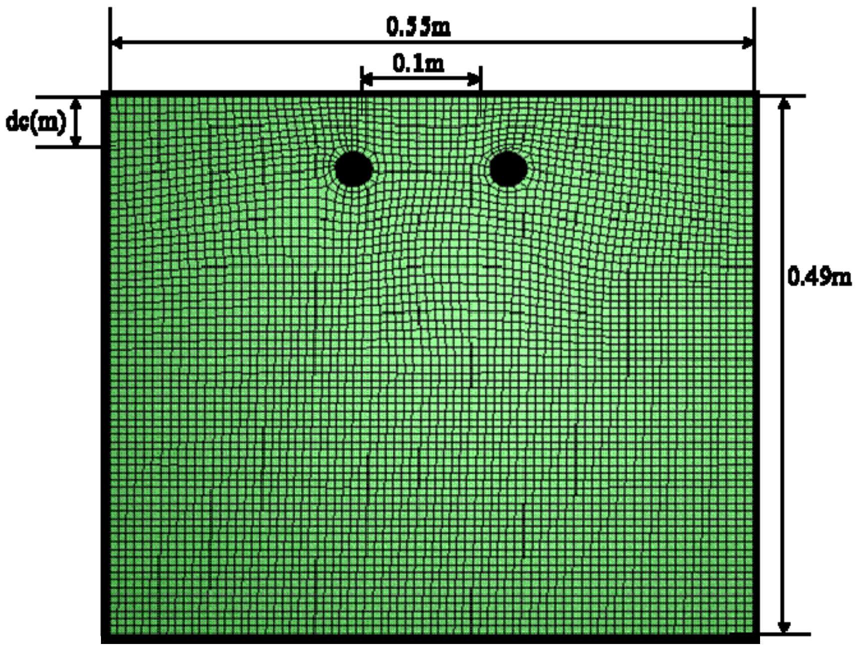


Fig. I FEM mesh used in analysis

Because detailed design for MACSTOR-400 is not decided yet, this study, basically, used the data from concrete silo in Wolsung site for simulation.

It is assumed diameter of reinforcement 25mm, 32mm, space between reinforcements 100mm, thickness of concrete over 50mm. This study carried out the simulation with the case of 100mm and 150mm of cover thickness, conservatively.

Also, long-term exposure to high temperature can cause deterioration of compressive strength and creep resistance in concrete. As temperature rises up, compression strength and tensile strength is decreased. A temperature increase from 20℃ to 100℃ may cause a reduction of the tensile strength of concrete by as much as 50%. Therefore, three different cases were used in this investigation, and tensile strength (ft) varied from 1.308MPa to 2.545MPa.

Table. I Physical properties of materials

	Case 1	Case 2	Case 3
fc (MPa) (Compressive strength)	44	32	17
ft (MPa) (Tensile strength)	2.545	2.036	1.308
E (GPa) (Elastic modulus)	31.37	26.76	19.50
dc (mm) (concrete cover depth)	50	50	50
	70	70	70
	100	100	100
	150	150	150
ds (mm) (steel diameter)	25	25	25
	32	32	32
ν (Poisson's ratio)	0.167	0.167	0.167
Ey (MPa) (Yield strength of bar)	400	400	400

Load condition

Corrosion of reinforcing steel and other embedded metals is one of the leading causes of deterioration of concrete. When steel corrodes due to carbonation by carbon dioxide and salt attack by chloride ion diffusion, the resulting rust occupies a greater 2~6 times volume steel[4]. The expansion creates tensile stresses in the concrete, which can cause cracking and spalling eventually. In this study, it was assumed that the corrosion products are formed uniformly around the steel reinforcing bar which results in a uniform expansive stresses around steel bar. This assumption is typically used and widely accepted while modeling the volume expansion caused by corrosion. A uniform layer of corrosion products would create uniform expansive stresses at the interface surface between steel and concrete that results in a uniform radial displacement at the surface of the rust layer[5]. The applied value of volume expansion is steel radius which means rust occupies 4 times volume steel.

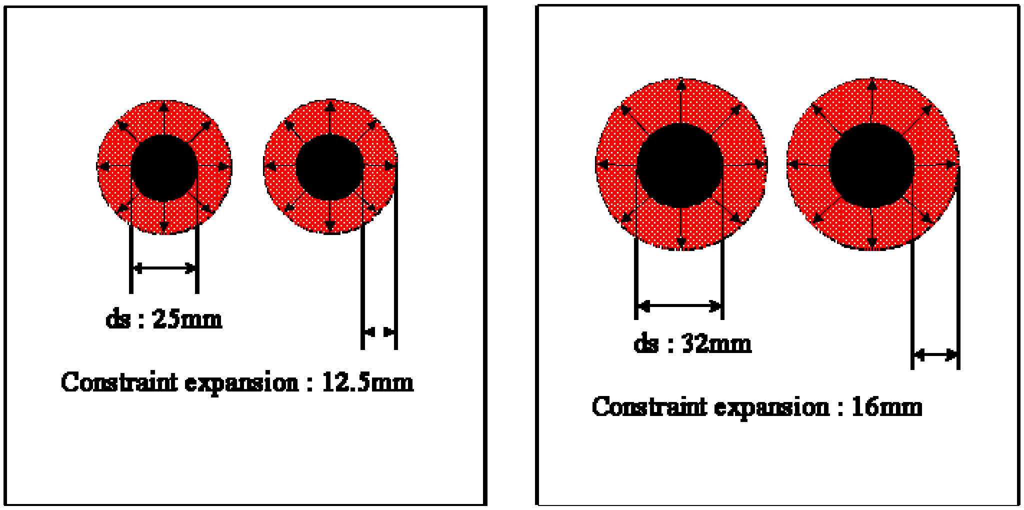


Fig. II Load condition was applied to analysis

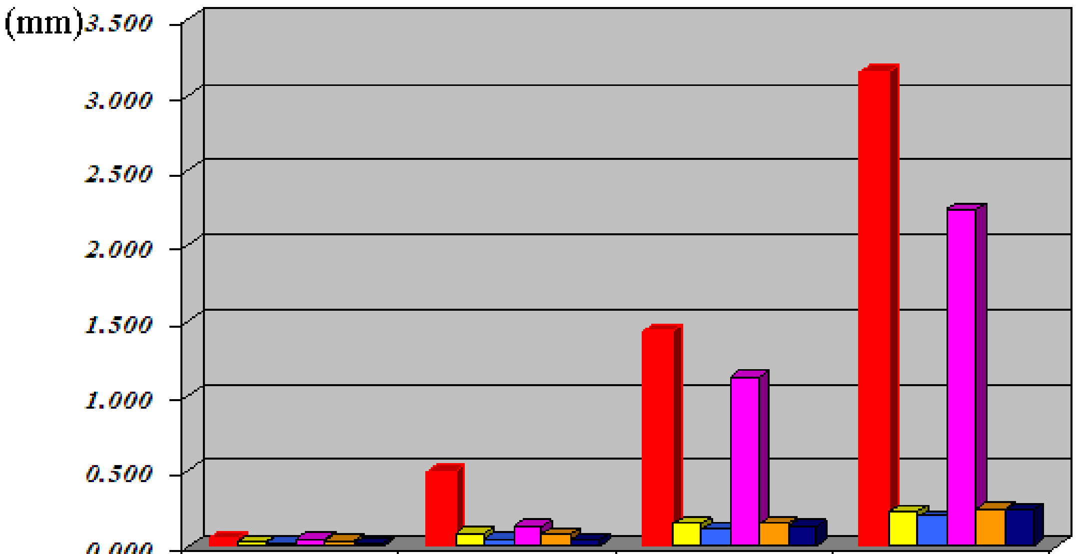
RESULTS

Constraint expansion induced concrete surface crack

Generally, the higher concrete strength and the thicker concrete cover depth, steel constraint expansion (quantity of corrosion product) is increased. It means that possibility of concrete surface cracking is little. The steel constraint expansion is in proportion to steel diameter under the same condition and is a similar value under the condition of cover depth 50mm regardless of concrete strength and steel diameter. It means that decreasing steel diameter is benefit for structure’s safety under consideration of the concrete surface cracking. And it would ensure the safety of structure to set up more than 40MPa for concrete compressive strength under the cover depth more than 100mm because surface cracking is initiated and has a similar constraint expansion value in case of fc32 and fc17. In Fig. 3 constraint expansion value induced concrete surface crack case by case are presented.

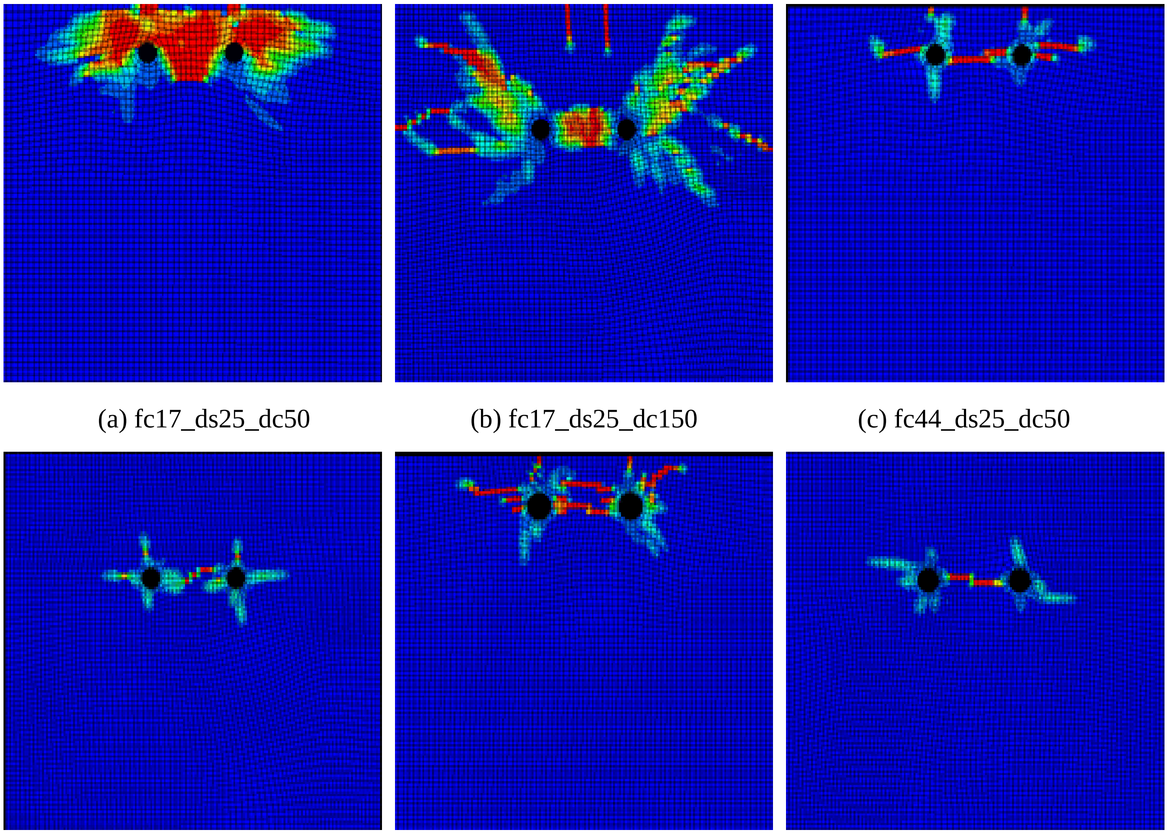
Crack formation in concrete due to reinforcement corrosion

The result of simulation by ABAQUS is shown in Fig. IV. Fig. IV shows the crack formation in concrete due to reinforcement corrosion at constraint expansion 10% of origin shape.



	50	70	100	150
case1_25	0.051	0.500	1.430	3.154
case2_25	0.030	0.086	0.146	0.233
case3_25	0.024	0.047	0.112	0.195
case1_32	0.048	0.128	1.120	2.240
case2_32	0.034	0.078	0.148	0.248
case3_32	0.019	0.040	0.131	0.240

Fig. III Constraint expansion value induced concrete surface crack case by case



(a) fc17_ds25_dc50 (b) fc17_ds25_dc150 (c) fc44_ds25_dc50

(d) fc44_ds25_dc150 (e) fc44_ds32_dc50 (f) fc44_ds32_dc150

Fig. IV. Crack contour around steel at constraint expansion 10% of initial shape

According to the simulation results, in case that concrete strength is 17MPa, it is estimated the crack initiation around reinforcing bar and crack propagation to surface of concrete regardless of cover depth while crack is arrested in near reinforcement regardless of diameter of reinforcement bar in a model with 150mm of cover thickness with concrete strength 44MPa. Also, it was found that there is a delicate difference in variation with steel diameter from Fig 4 (c) and (e). If the models of the same concrete strength but steel diameter, it is clear that the diameter of the smaller is delayed crack propagation around steel than that of the larger steel diameter.

Comparison with required time to creation of concrete cover crack

In Fig. V required time to creation of concrete cover crack at each case is presented. Assuming the required time to crack creation of concrete surface cover is 100 in the cover depth 150mm of case1_25 model, it means that the time 7.37 and 6.16 is required in the model of case2_25 and case3_25 respectively.

In the condition of thicker cover depth, the main parameter affected occurrence of crack is concrete strength. Surface crack creation shows delay at smaller steel diameter condition, and shows early at lower concrete strength. If concrete strength is lowered about its 30%, the time of surface crack occurrence accelerates 15 times maximally.

CONCLUSIONS

The critical value of steel constraint expansion caused as the increase of concrete strength. As a result of this case study, it is confirmed that the critical steel expansion which can initiate cracking is proportional to tensile strength. And primary factors which effect crack creation of concrete cover are concrete strength, cover thickness and steel diameter. In the condition of cover depth over 100mm, the constraint expansion value was increased with concrete compressive strength, whereas insignificant difference was shown in below cover depth of 70mm regardless of concrete strength.

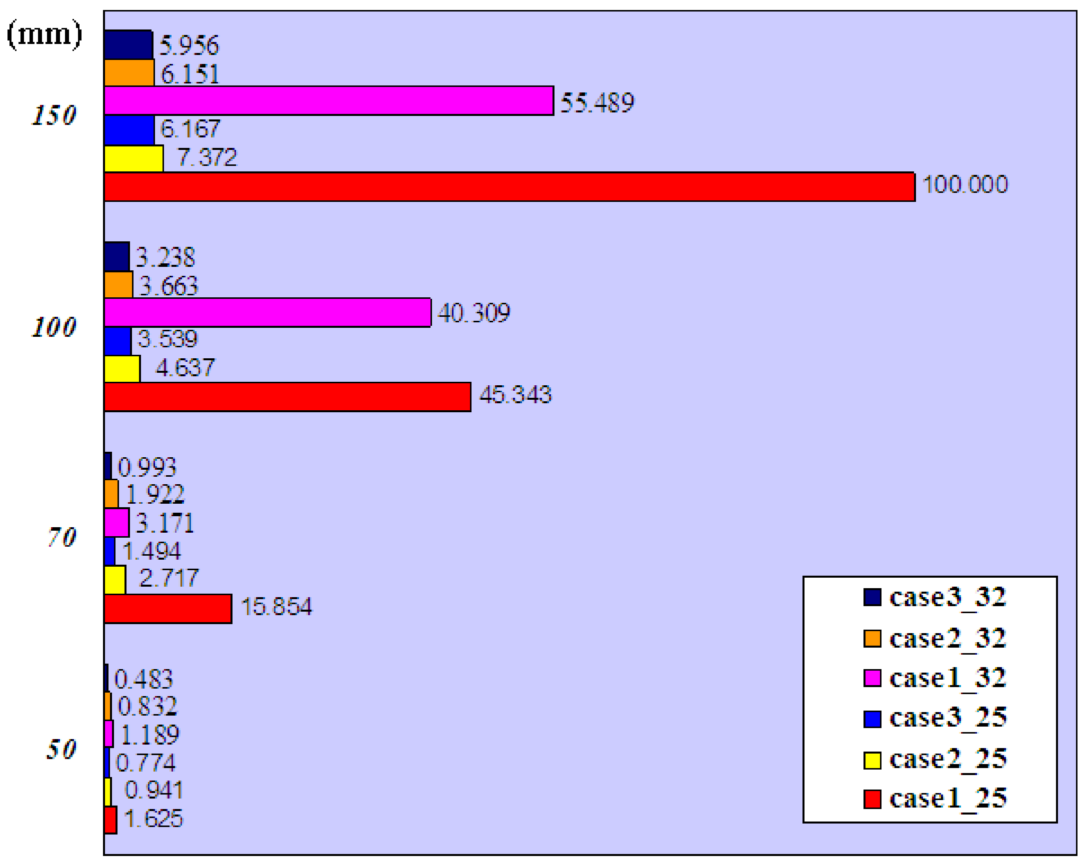


Fig. V Comparison with required time to creation of concrete cover crack

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