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Effect of Neutron Irradiation on Beam-Column Interaction of Reinforced Concrete

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1. Introduction

Reinforced Concrete (RC) is widely used to build a containment, biological shield, foundation, and support structures in nuclear power plants (NPPs). Age-related effects on such RC structures have been extensively studied in detail. However, the effect of neutron irradiation requires further studies from its limited database. Most of RC structures have been regarded as sound as the neutron fluence below 1.0x10^{19} n/cm^2. The reduction of strength is not considered in a periodic inspection program at aging NPPs. However, RC structures, such as biological shields and supports for a reactor vessel, could be exposed to see the critical level of neutron fluence at years of operation [1 ~ 4]. In this regard, beam-column interaction of a typical RC member is numerically investigated as a result of neutron irradiation.

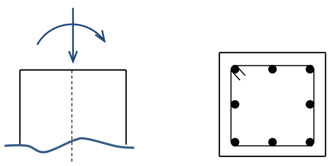


Fig. 1. A typical RC member subjected to combined axial load and bending moments.

2. Methods and Results

Total neutron exposure of a RC member was inferred from the safety analysis report (SAR) of Shin-Kori NPP [5]. The first interval for the periodic safety review is 10 years and it is estimated to be exposed to a neutron fluence of up to 1.95 x 10^{17}n/cm^2. For 40 year of the design life of NPPs, it is expected to see 7.8 x 10^{17} n/cm^2. Also, maximum neutron fluence, 1.95 x 10^{18} n/cm^2, is selected in relation to the experimental data (Fig. 3)

2.1 Material Behavior of Reinforce Concrete Member

It is suggested that the expected fluence level before the significant reduction of the concrete strength is 1.0 x 10^{19}n/cm^2 from the work by Hilsdorf et al. [6]. Therefore, strain-stress relationship for concrete is fixed with an incremental neutron irradiation and assumed to be parabolic, where the compressive strength (f_c') and its corresponding strain (ε_c') are 40MPa and 0.002, respectively.

The effect of irradiation also occurs in the reinforcement embedded in concrete. Material of reinforcement in RC is mild steel and it is expected to be exposed to environment due to long-term micro cracks around a concrete cover (Fig. 2).

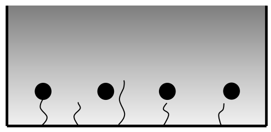
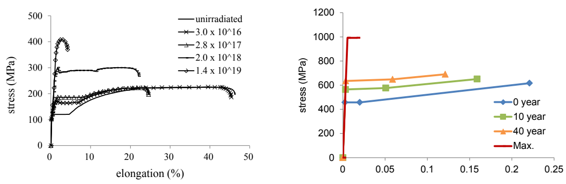


Fig. 2. Conceptual figure for micro cracks around a concrete cover.

The irradiated behavior of mild steel is reported by Murty et al. [7] as shown in Fig. 3(a). But, the experimental results are obtained from a wire specimen atypical with a rebar specimen for RC. Then, they are consistently scaled such that the yield strength becomes 450MPa and the young modulus 183,000MPa with linear segmentation (Fig. 3(b)). The strain-stress relationships for reinforcement are simplified as such for numerical simulations using the program Response-2000 [8].



(a) (b)

Fig. 3. (a) Strain-stress relationships with a wire specimen (b) Modified strain-stress relationships for reinforcement with years of NPP operation.

2.2 Numerical Simulation of Beam-Column Interaction

Fig. 4 shows a typical RC column section and then, the behavior of beam-column interaction is numerically simulated using the program Response-2000. Response-2000 is based on fiber section model where an RC element is refined as a bundle of fibers represented by a uniaxial material model.

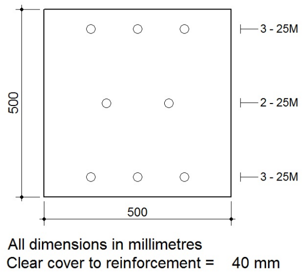
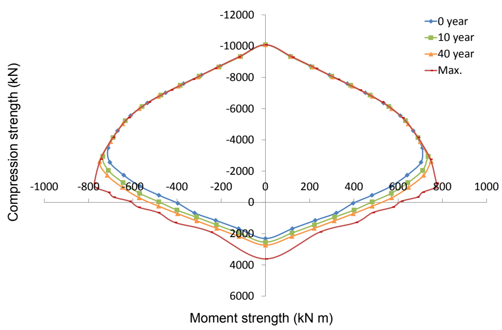
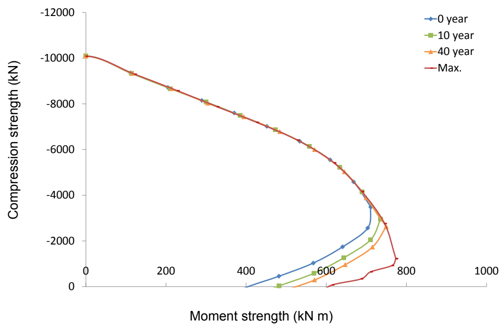


Fig. 4. RC section for beam-column interaction.

The beam-column interaction can be characterized by a diagram called a P-M diagram (axial compression and bending moment strength interaction diagram). The numerical results with years of NPP operation are shown in Fig. 5.



(a)



(b)

Fig. 5. (a) P-M diagram results from software Response-2000 (b) change of balanced compressive strength.

Where, x-axis is the bending moment strength (kN·m) and y-axis is the axial compression strength (kN). In the first quadrant (the upper right part), the balanced compressive strength, P_b, moves lower as the irradiation progresses and, as a result, the compression controlled area becomes more dominant. This suggests that the member characteristic migrates to a more brittle region as the yield stress of the longitudinal steel increases.

3. Discussion

The effect of neutron irradiation on beam-column interaction is evaluated. ACI318 [9] requires the strength reduction factor, ϕ=0.70, for the compression controlled area and the higher up to 0.9 as the tensile strain in steel reinforcement goes higher. This concept works well with this example. However, this does not take into account the energy dissipation capacity of the member but it only expresses the ultimate strength. Therefore, the current strength evaluation concept may be misleading when the material behavior of steel reinforcement becomes brittle due to the neutron irradiation. In such case, even for the transient and tension controlled area, the strength reduction factor needs to be modified to account for the potential ductility loss. Further research is crucial from the perspective of long-term operation of NPPs.

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