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Assessment of Effective Prestressed Force of Nuclear Containment Building using SI Technique

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1. Introduction

Bonded tendons have been used in reactor buildings of heavy water reactors and the light water reactors of some nuclear power plants operating in Korea. The assessment of prestressed forces on those bonded tendons is becoming an important issue in assuring their continuous operation beyond their design life. In order to assess the effective prestressed force on the bonded tendon, indirect assessment techniques have been applying to the test beams which were manufactured on construction time.

Therefore, this research mainly forced to establish the assessment methodology to measure directly the effective prestressed force on the bonded tendon of containment buildings using System Identification (SI) technique. To accomplish this purpose, simple SI method was proposed and adapted three dimensional finite element analysis of the 1:4 scale prestressed concrete containment vessel (PCCV) tested by Sandia National Laboratory in 2000.

2. FE Models and Constitutive Models

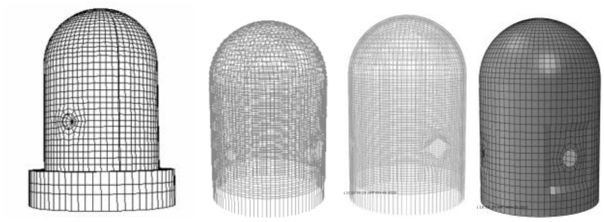
2.1 FE Models

Figure 1 shows the Finite Element (FE) mesh of concrete, tendon, steel liner plate and reinforcement. The mesh for concrete wall and dome are used lower order solid elements (ABAQUS elements C3D8, Lagranginan formulation). The reinforcement and tendon is modeled with truss element as displayed in Figure 1 (T3D2). The truss element are coupled with the solid element of the concrete with the *EMBEDDED ELEMENTS function of ABAQUS. In this function, the nodes of a truss element are kinematically constrained to the nodes of the solid element in which it is located. It means that the displacement of the node of the truss element is average value of the displacement of the neighboring nodes of the solid element in which the truss element is embedded. The mesh for steel liner plate are used 4-node membrane element (M3D4).

2.2 Constitutive Models

The Concrete Damaged Plasticity Model uses the concept of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete.

The stress-strain relationship of reinforcement is usually assumed to be elasto-plastic with a distinct yield stress of bare bar's yield stress. However, when the reinforcing bars are surrounded by concrete, the average stress-strain relationship exhibits very different behavior than that exhibited by a bare bar without concrete. To consider this phenomenon, we generally underestimate the yield stress, this is the apparent yield stress of an embedded bar in concrete. In the program, the apparent yield stress for this situation is represented by Hsu's model.



(a) concrete (b) tendon (c) reinforcement (d) liner

Fig. 1. FE models for PCCV

3. SI Technique

SI technique is defined as a type of inverse problems to estimate stiffness parameters of structure from the results such as displacement, stress et al., between measured responses and calculated responses with FE method. To find a optimized solution, iterative works may be performed several times. Figure 2 shows the SI technique with Abaqus FE program.

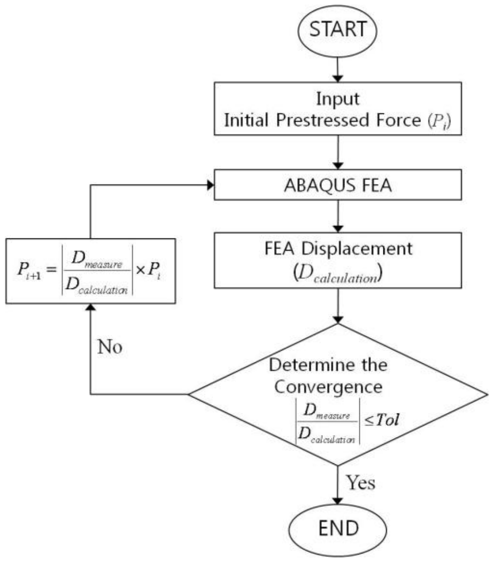


Fig. 2. SI technique

4. FEA and SI Results

To verify the three dimension FE models and constitutive models, nonlinear analysis was employed. Figure 3 shows the result of FE analysis for 1:4 prestressed concrete containment vessel. Displacement sampling point is the mid-height of the wall, that is elevation 10.73m. The FE analysis and experiment result curves are very well matched. Accordingly, FE mesh is well-formed.

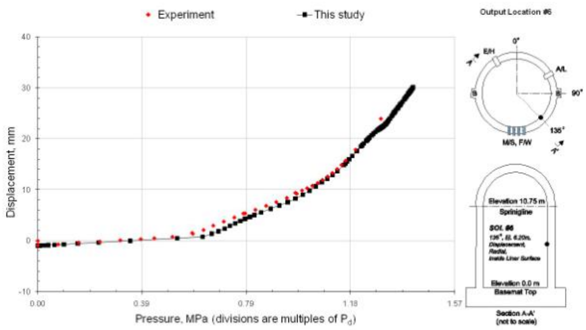


Fig. 3. FE analysis result

Using the proposed SI technique (see Figure 2), iterative analysis was performed to find out the experimental measured displacement value at mid-height of the PCCV. In this case, because the true prestressed force of the tendon was known, initial prestressed force (P_i) was inputted the 0.1 times value of the real prestressed force at the first step. And then second prestressed force (P_{i+1}) was calculated with respect to the SI procedures in Figure 2.

Figure 4~Figure 6 show the results for displacement, effective prestressed force and error rate derived by proposed SI technique in this paper. Convergence rate is very fast as shown in these figures.

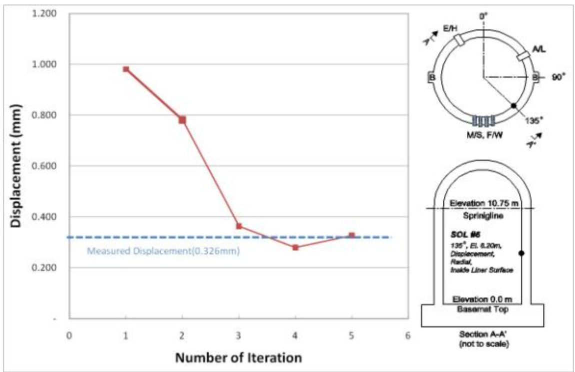


Fig. 4. Displacement and number of iteration relationship

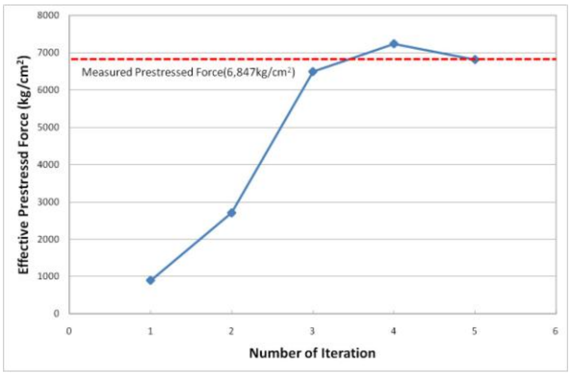


Fig. 5. Assessment result of tendon force

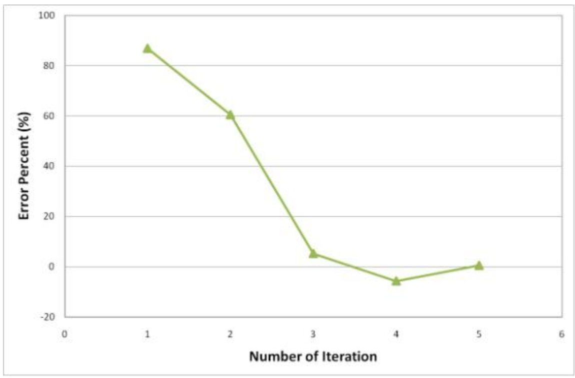


Fig. 6. Convergence process of SI technique

5. Conclusion

This paper describes SI technique to predict the effective prestressed force of nuclear containment building. And simple SI technique was proposed. To verify the proposed SI technique with FE method, three dimensional FE analysis was employed at the 1:4 scale prestressed concrete containment vessel tested by SNL. From the analysis results, the proposed SI technique is useful to estimate effective prestressed force of containment building.

Acknowledgement

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