2012 4th International Conference on Computer Modeling and Simulation (ICCMS 2012)
IPCSIT vol.22 (2012) © (2012) IACSIT Press, Singapore

Computer Modeling of Post-Tensioned Structures

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Abstract. Computer modeling of post-tensioned structures was conducted using the finite element software package ABAQUS. This study adopted both unbonded and bonded post-tensioning techniques. Three modeling approaches, all of which incorporate unique techniques not used by other previous researchers, were used to simulate unbonded and/or bonded tendon conditions. The first approach was based on contact techniques which reflect the true physical condition of the tendon in concrete. The second approach used a multiple-spring system that provides more flexibility in modeling and robustness in convergence issues. The third approach was the simulation using a contact formulation (surface-to-surface contact in ABAQUS/Explicit formulations). This paper compares the results from these approaches and verifies the effectiveness of the approaches by comparing analytical and experimental results.

Keywords: Post-tensioned structures, Computer modeling, Finite element method, Concrete, Unbonded tendons, Bonded tendons

1. Introduction

Use of a post-tensioned (PT) structure is increasingly popular; however, interestingly there is a substantial lack of theoretical research. Also, due to the complexity of its stress states, an extensive research on the PT structure is needed. In this paper, research results from unique finite element modeling of such structures are presented. Both unbonded and bonded PT structures are simulated by means of the methods not used by other previous researchers.

Bonding influences the behavior of post-tensioned structures. This study provides modeling results for different tendon systems and discusses the simulatied behavior of previously tested PT structures with bonded and unbonded tendons. Post-tensioning (PT) and grouting processes were accurately considered in the nonlinear modeling. The modeling results can eventually be used for better understanding the behavior of the PT structures.

2. Bonding Condition Modeling

The unbonded conditions (i.e., tendons that slip freely within the plastic tube embedded in the concrete) physically require boundary nonlinearity, which indicates that contact techniques can be employed for exact modeling in the finite element analysis. The first approach utilizes tube-to-tube contact elements (ITT31 in ABAQUS element library) (Fig. 1). The friction between the tendon and the tube is always assumed to be zero as the curvature of the tendon is small. Theoretically, this approach depicts real geometry and may give the most reliable result (Huang et al., 2009).

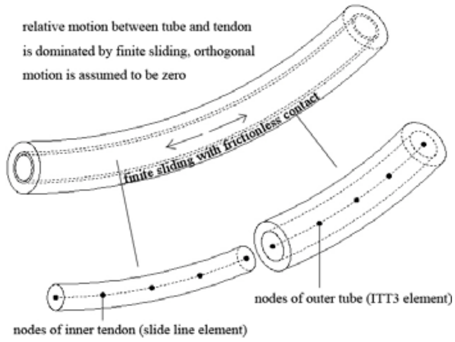

Fig.1 Modeling of unbonded PT tendons using the contact element model

The second approach of using a multiple-spring system is also possible (Fig. 2) (Huang et al., 2009). In this approach, boundary nonlinearity vanishes, which leads to reduction of modeling and computational efforts in ABAQUS. Real and virtual tendons (with negligible stiffness) were modeled as depicted, respectively, and they were connected to each other with a spring attached at each node. The springs were assumed to be rigid enough to rotate with no axial and bending deformations.

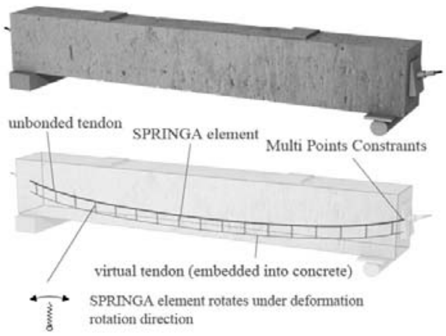

Fig.2 Modeling of unbonded PT tendons using the spring system model

Lastly, the third approach is to model the duct and tendon which contact each other (Surface-to-surface contact in ABAQUS/Explicit contact formulations) (Fig. 3). The tangential behavior of the contact surfaces is frictionless, allowing the tendon to slip freely at the post-tensioning stage. A simple change of the bonding condition from frictionless to infinite friction ensures perfect bonding due to grouting between the tendon and duct after post-tensioning. More details are provided in the paper by Kang and Huang (2011).

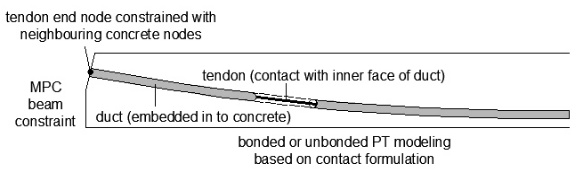

Fig.3 Modeling of unbonded PT tendons using the contact formulation

3. Concrete Modeling

The concrete constitutive model used is a built-in "damaged plasticity model" in ABAQUS. No considerations were given to the concrete damage during unloading. The damage and stiffness degradation descriptions during cyclic loading conditions were not used in the concrete constitutive model.

Two tensile stress-strain relations were applied: 1) the cracking strain was set to a very small value without tension stiffening to avoid convergence, and 2) tension stiffening increased with a gradual descending slope after reaching the tensile strength of concrete. More detailed information is available elsewhere (Huang et al., 2009).

4. Tendon, Bonded Steel & Anchorage Modeling

An elasto-perfect plastic model was assumed for modeling of mild reinforcing steel, while a nonlinear model consisting of multiple isotropic elasto-plastic segments was used for modeling post-tensioning tendons. For the anchorage, Multi-Points Constraints (MPCs) were imposed to constrain nodes with different coordinates. The Beam MPC provides a rigid beam between nodes that can be utilized to simulate the compatibility of deformations between the unbonded PT tendon and anchorage.

5. Elements

The 8-node first-order element with one reduced integration rule (C3D8R in ABAQUS element library) was used for both implicit and explicit analyses (see Fig. 4). This first-order reduced integration element greatly saves computational cost and also avoids shear locking that would be a problem in the first-order full integration element. Bonded reinforcing steel bars were modeled using 2-node truss elements (T3D2 in ABAQUS element library) embedded within the concrete elements.

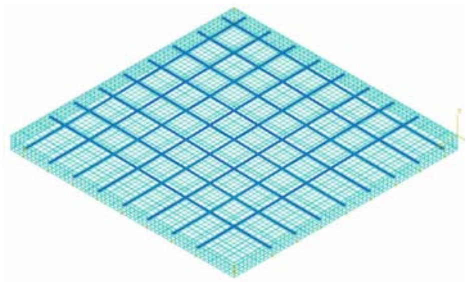

Fig.4 Elements used for unbonded PT slab analysis

6. Comparison Among Different Tendon Modeling Techniques

Comparison among different tendon modeling techniques was made in this section. As shown in Fig. 5, which shows the modeling results for previously tested, unbonded PT slab-column connections, there is little discrepany between the first and second methods. Also, as described earlier in this paper, two different tension stiffening models were considered.

The results for previously tested, unbonded PT beams are shown in Fig. 6. A negligible difference exists between the results based on the two approaches. Additionally, the two numerical analyses have a good agreement with the experimental data. This verifies that all three approaches are effective; however, the first and second approaches are time-consuming and computationally costly. Therefore, the more robust third approach would be recommended.

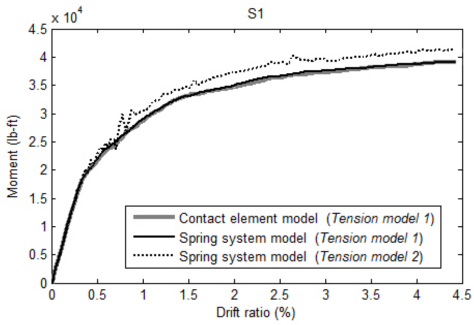

Fig.5 Comparison between the contact element model and spring system model

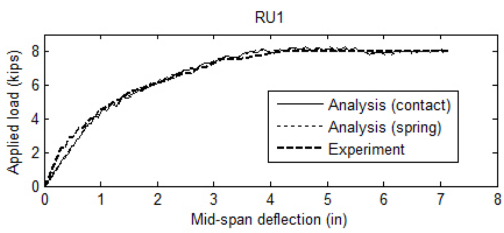

Fig.6 Comparison between the contact formulation and spring system model

7. Comparison Between Experiment and Computer Modeling

In this section, the experimental data and computer modeling results were compared. The two unbonded PT slab-column connections were modeled using the spring system model. The global responses of moment-drift ratio relations were well compared (Fig. 7). Such an accuracy is highly competitive with other modeling results obtained from prestressed and reinforced concrete structures.

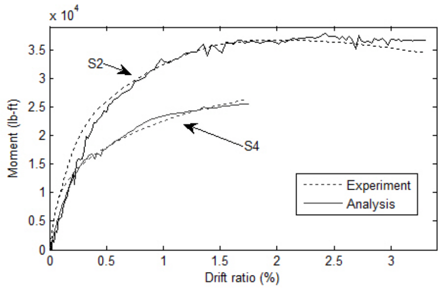

Fig.7 Comparison of moment-drift ratio relations between experimental and analytical results for unbonded PT slab-column connections

As shown in Fig. 8, the unbonded tendon stress increase against the moment increase was well simulated in the nonlinear finite element model. The unbonded tendon increase is related to the crack number and width as well as the total tendon length elongation. This result shows that the combined concrete and unbonded tendon modeling was well conducted, which proves that it is robust.

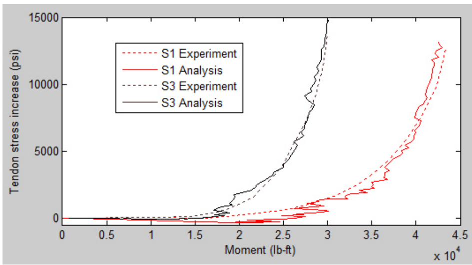

Fig.8 Comparison of moment-tendon stress increase relations from analytical and test results of unbonded PT slab-column connections

The load-deflection relation for the bonded PT beam is shown in Fig. 9, where the deflection against the moment increase was captured reasonably well. In this modeling, the bonded PT tendon-concrete condition was simulated by using the contact formulation, and its modeling capability was quite reliable.

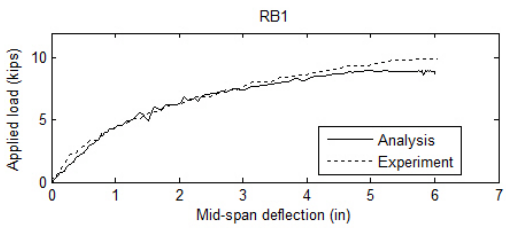

Fig.9 Modeling of unbonded PT tendons using the spring system model

8. Summaries

This paper introduces three approaches of modeling post-tensioned structures either with bonded or unbonded tendons, all of which incorporate unique techniques not used by other previous researchers. The previously tested PT structures were used for model verification. All three tendon modeling approaches were reliable, while the third method of the contact formulation is the most computationally efficient. The developed model was capable of simulating both the unbonded and bonded tendons quite effectively.

9. References

[1] HUANG Yu; KANG Thomas H.-K.; RAMSEYER Chris; RHA Chang-soon. Background to Multi-Scale Modelling of Unbonded Post-Tensioned Concrete Structures. Int. J. Theoretical and Applied Mutiscale Mechanics [J], 2009, PP:219-238

[2] KANG Thomas H.-K.; HUANG Yu. Finite Element Modeling of Nonlinear Behavior of Grout-Bonded Post-Tensioned Members and Connections, The 2011 International Conference on Computational Technologies in Concrete Structures [C], 2011.9.