# Un-bonded Tendon Model for Nonlinear Analysis of PSC Structures

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## 1. Introduction

A prestressed concrete structure has many advantages, such as delaying cracks, saving materials, reducing deflection, and has been widely or increasingly used in long span structures, shells, and nuclear containment vessels.

In this paper, a numerical model for un-bonded tendon is proposed based on the finite element method, which con represent straight or curved un-bonded tendon behavior.

By using the model, a numerical procedure for material nonlinear analysis of PSC structure with un-bonded tendon is presented. This procedure can predict the response of PSC structures throughout their service load history, such as elastic and plastic deformation, cracking and damage patterns. Finally, two numerical examples are presented to verify the validity and the applicability of this model and the numerical procedure.

## 2. The Un-bonded Tendon Model

### *2.1 Description of the Un-bonded Tendon Model*

When tendons are bonded to the concrete, applied loads on the structure produce equal changes in strain in the tendon and the adjacent concrete, but the strain change in an un-bonded tendon is not compatible with the adjacent concrete, only the displacements of the tendons at the anchors are the same as the adjacent concrete.

The un-bonded tendon element has several nodes and is allowed to move along a curved duct in concrete (Fig 1).

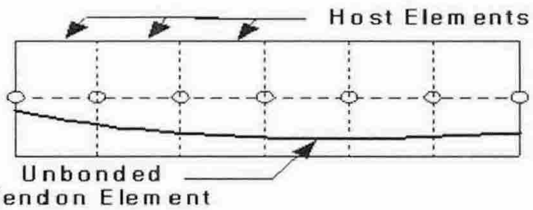


Figure 1. Un-bonded Tendon Embedded in Concrete Element

Relative movements between the host elements and the tendon element are caused by the differences of strains of the host elements and the tendon element. The strain of the un-bonded tendon element may be calculated by dividing the sum of elongations at each node of host element into the total length of the tendon element.

The Gauss-Lobatto integration is used to define the element forces and stiffness.

### *2.2 Material Model for Tendon*

A tri-linear stress-strain model is adopted to simulate the stress-strain behavior of prestressing tendon as defined in Fig. 2. The unloading and reloading modulus for tendon is taken as equal to the initial elastic modulus.

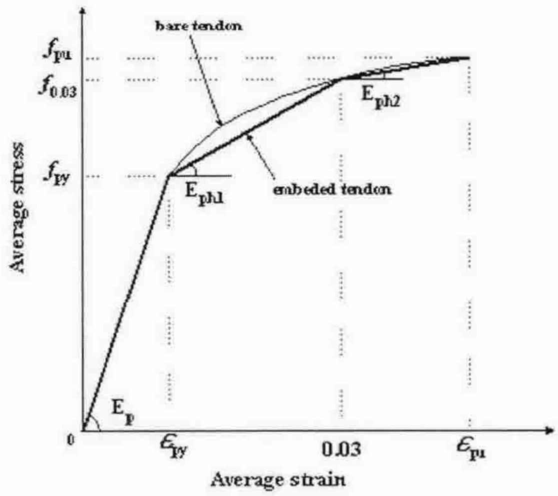


Figure 2. Tendon Material Model.

### *2.3 Construction of the Un-bonded Tendon Element*

The Un-bonded Tendon element was implemented a general-purposed finite element analysis program. The program named RCAHEST(**R**einforced **C**oncrete **A**nalysis in **H**igher **E**valuation **S**ystem **T**echnology) [3], that based on FEAP that developed by Taylor[5]. Custom elements and nonlinear routines are easily adaptable in RCAHEST. By combining of the developed the un-bonded tendon element and the host element (reinforced concrete shell element [2]), prestressed concrete structures may be analyzed.

## 3. Numerical Examples

A simple PSC beam tested by Tau and Du (1985) and a two-span continuous PSC beam tested by Burns et al. (1991) are used to verify the validity of the un-bonded tendon model.

The simple PSC beam tested by Tau and Du (1985) is 160 x 280 mm in cross section, 4400 mm in length, and were tested with third point loading over a 4200 mm span. The two-span continuous PSC beam tested by Burns et al. (1991) is 304.8 x 355.6 mm in cross section, 7620 mm in span. Material properties of the beams are shown in table 1.

Table 1. Material Properties.

| Beam Type | Con. | Prestressed reinforcement | | | | | Reinforcing bar | | |
|---|---|---|---|---|---|---|---|---|---|
| | $f_{ck}$ MPa | $E_{ps}$ **Gpa** | $f_{pe}$ MPa | $f_{py}$ MPa | $f_{pu}$ Mpa | $A_p$ **mm²** | $E_s$ **GPa** | $F_y$ MPa | $A_s$ **mm²** |
| Tau and Du | 30.6 | 205 | 960 | 1465 | 1790 | 58.8 | 200 | 267 | 157 |
| Burn et al. | 34.4 | 200 | 1395 | 1688 | 1860 | 296 | 200 | 413 | 296 |

Since the two beams were symmetric about its center, only one-half of the structure is analyzed. Two PSC beam was modeled by 2 un-bonded tendon element and 7 RC shell elements.
The resulting load-displacement responses for the beams are presented in fig. 3.

## 4. Conclusion

This paper proposed an un-bonded tendon model, based on the finite-element method, for the nonlinear analysis of PSC structures with un-bonded tendon. Since the tendon model can describe the uniform stress of un-bonded tendon element at any load step.

By using proposed tendon element and host element (RC shell or RC frame element), the analysis of the PSC structures with un-bonded tendon becomes efficient and succinct. The numerical procedure composed of the proposed tendon model and reinforced concrete models, can predict the responses of PSC structures including externally strengthened concrete structures throughout their service–load history, such as elastic and plastic deformation, cracking, and damage patterns. The accuracy and efficiency of this model were verified by the way of comparison with experiment results.

## Acknowledgments

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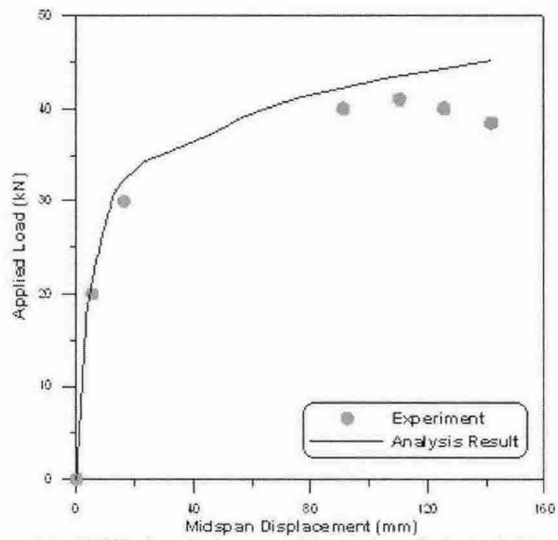
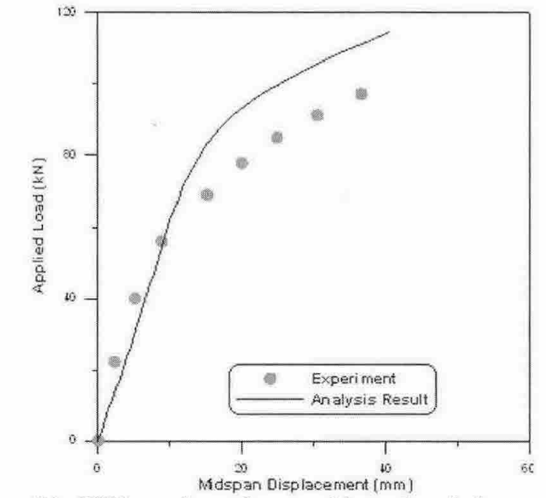



(a) PSC simple beam with un-bonded straight tendon.




(b) PSC continues beam with un-bonded curved tendon.

Figure 3. Load-Displacement of Analysis Result.

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