비부착 FRP 프리스트레스트 콘크리트보의 휨내력 이론 산정

Theoretical Assessment of Flexural Strength of Unbonded FRP Prestressed Concrete Beams

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ABSTRACT

Fiber reinforced polymer (FRP) usually exhibits inherent brittleness under tensile stress. Application of FRP tendons to concrete beam leads to undesirable flexural behavior due to limited ductility compared to prestressed concrete beam with steel tendons. It has been experimentally observed that partial improvement of flexural behavior can be achieved by releasing FRP tendons' strain by unbonding FRP tendons. In order to estimate and apply the degree of improvement to the design, reasonable yet practical model predicting flexural strength as well as overall flexural behavior of unbonded FRP prestressed concrete beam is needed. In this study, an elaborated model in describing curvature distributions and flexural strength at ultimate stage of unbonded FRP tendons is described. There have been close agreements on the flexural strength of the FRP prestressed concrete beam between the predictions by nonlinear computer program and by the model.

요 약

일반적으로 FRP는 인장응력 하에서 취성적 경향을 나타낸다. FRP 긴장재가 적용된 콘크리트 보는 강재긴장재를 사용한 프리스트레스트 콘크리트보에 견주어 제한된 연성을 지님으로써 바람직하지 않은 휨거동을 나타낸다. FRP 긴장재를 비부착시켜 부재 내에서 발생되는 FRP 긴장재의 변형률을 완화시킴으로써 부분적으로 휨 거동의 향상을 달성할 수 있음이 실험을 통하여 관찰되었다. 비부착된 FRP 프리스트레스트 콘크리트보의 전반적인 휨 거동뿐만 아니라 구조설계 시 휨 거동의 향상 정도를 평가하고 적용하기 위한 휨내력을 예측하기 위한 적당한 실용적 모델이 요구된다. 이 연구에서는 비부착된 FRP 긴장재를 사용한 프리스트레스트 콘크리트보의 극한시 휨 내력 및 곡률 분포를 나타낼 수 있는 이론 모델을 기술하였다. 비선형컴퓨터해석과 이론모델에 의한 비부착된 프리스트레스트 콘크리트보의 휨 강도예측은 잘 일치하였다.

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1. INTRODUCTION

Fiber reinforced polymers (FPR) are new construction materials which have superior material properties compared to steels. FRP is light, non-corrosive, non-magnetic, and strong in tension. In reinforcing or strengthening reinforcement structures, FRPs are extensively used in place of steels which tend to corrode if exposed severe environmental atmosphere. Reduction of the steel area due to corrosion can drastically reduce the nominal moment strength of the prestressed section, which can lead to premature failure of the structural system.

Main application field of FRPs includes rehabilitation of existing concrete structures, ordinary reinforced concrete or prestressed concrete structures. Although FRPs possess beneficial advantages as structural materials, they inherently show brittle failure under tensile stresses, which may lead to an undesirable structural performance. In addition, they exhibit complete elastic stress-strain relations under tensile stresses up to tensile fracture.

When a concrete beam is prestressed by FRP tendons, different load-deflection curves than those of prestressed concrete beam with steel tendons are observed. Prestressed concrete beam reinforced with steel tendons exhibits overall yielding behavior of the beam. Since FRPs are elastic, the prestressed concrete beam with FRP tendons shows basically linear load-deflection curves before and after cracking without clear yielding behavior.

Due to the lack of yielding behavior, there have been extensive concerns on improving ductility of flexural behavior of the beams reinforced with FRP bars or tendons. Since at the ultimate stage, fracture of FRP reinforcements leads to an abrupt brittle failure for under-reinforced concrete beam, it is a common practice to reinforce concrete beam with relatively larger amount of FRP bars than that of balanced ratio. The over-reinforced FRP beam, thus, shows post ultimate behavior by gradual crushing of concretes starting from extreme compressive fiber in a critical section before fracture of FRP reinforcements.

Attempts have been made to improve ductility of FRP prestressed concrete beams by using steel fiber reinforced concretes(Zhoa Guofan(1991, SP128-53), Antoine E. Naaman and Fadi M. Al-Khairi(1996, SP159-24), B. Massicotte(1999, SP182-10)) or confining compressive region(H. Taniguchi(1993, SP138-39), Mohamed M. Ziara(1995, ACI)) or unbonding FRP tendons along their length(Nabil F. Grace(2006, ACI)). Experimental observations on the improvement on ductility or deformability to some extent has been reported by different researchers.

Although methods applied to improve ductility of FRP reinforced concrete beam has been experimentally proved to be effective, there are still in need of analytical approach which can explain their effects.

In this study, theoretical modeling of unbonded FRP prestressed concrete beam is presented. The developed model predicts magnitudes of first crack strength, ultimate strength, and overall load-deflection curves.

2. EXISTING MODELS - Review

L.Lee et al.(1999) suggested computational method of the unbonded tendon stress at the flexural failure of a member prestressed with steel tendons. Their equations were based on global compatibility requirement and the plastic hinge length. Their model depends on the assumption of curvature distributions made at the ultimate state (Fig. 1) and contains parameters obtained from regression analysis of test data. The model's validity was made by comparing the flexural tendon stress and its additional increase at ultimate stage.

Similar approach was made by C.D.Lee et al.(2007) in predicting flexural stress of unbonded FRP prestressed concrete beam at ultimate stage. Using the linear elastic properties of FRP tendons, they developed the model theoretically without involvement of experimentally determined parameters. Their model found to reasonably predict the ultimate flexural strength of unbonded FRP prestressed concrete beams.

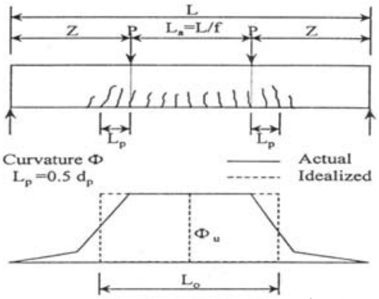

Fig. 1 Assumed curvature distribution (L.Lee et al.(1999))

Since steel and FRP material properties are different under tensile stress, there are different curvature distributions between prestressed concrete beams containing steel tendons and FRP tendons. For more precise modeling on the flexural strength for the unbonded FRP prestressed concrete beams, their distributions must be taken into account.

3. MODEL DESCRIPTION

The model has been developed based on the curvature distributions at ultimate stage: curvature by end eccentricities, at cracking, and at maximum moment. Different curvature distributions were obtained for different loading conditions (3-point or 4-point loading) by calculating curvatures at those locations. At each section where the value of curvature is sought, the condition of sectional equilibrium is used for the assumed unbonded FRP strains. From the obtained curvature distributions with the assumed FRP strain, the elongation of concrete at the level of unbonded FRP tendons are evaluated. Using this concrete strain at the level of unbonded FRP tendons, the unbonded FRP tendon strains are updated. The process is repeated until the predicted nominal flexural strength of the beam converge. Fig. 2 shows details of the unbonded FRP prestressed concrete beam used for simulation using the nonlinear computer program. Predictions by computer simulation and by the suggested model coincide with reasonable accuracy with relative error in the range between 0.016~0.053.

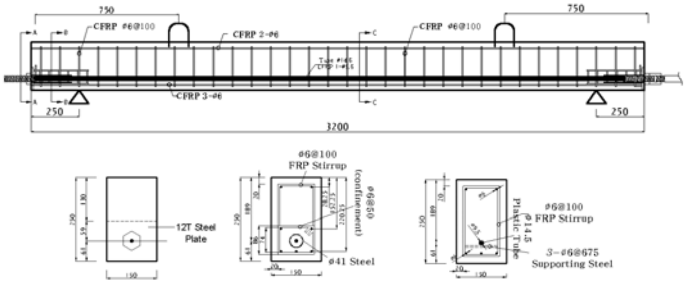

Fig. 2 Details of tested unbonded FRP prestressed concrete beam.

4. CONCLUSIONS

FRPs are brittle under tensile stress in nature. The beams prestressed with FRP tendons fail in undesirable brittle manner. Various experimental attempts have been made in order to improve structural behavior of FRP prestressed concrete beams. It was found that by unbonding FRP tendons, strains of FRP tendons were released, which in turn increased the ductility and deformability of beam. Although the effect of unbonding FRP tendons on the improvement of ductility has been observed, limited number of theoretical approach has been reported.

In this study, more detailed approach has been introduced, which could be used to find not only ultimate flexural strength of unbodned FRP prestressed concrete beams but also overall curvature distributions and, thus, consequently deflections at cracking and ultimate stage. The model was able to predict the ultimate strength of unbonded FRP tendons with the accuracy in relative error of 0.93%.

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REFERENCES

1. Edward G. Nawy., Prestressed Concrete : a fundamental approach, 5th Ed., Chapter 2, Person Prentice-Hall, 2006, pp.58

2. L.Lee, J.Moon and J.Lim., "Proposed Methodology for Computing of Unbonded Tendon Stress at Flexural Failure," ACI Structural Journal, V. 96, No. 6, Nov-Dec. 1999, pp.1040-1048

3. C. J. Burgoyne., "Rational use of advanced composites in concrete," Structures & Buildings, V. 146, No. 3, Aug. 2001, pp.253-262

4. Nabil F. Grace., Tsuyoshi Enomoto., Saju Sachidanandan., and Sreejith Puravankara., "Use of CFRP/CFCC Reinforcement in Prestressed Concrete Box-Beam Eridges," ACI Structural Journal, V. 103, No. 1, Jan-Feb. 2006, pp.123-132