EXPERIMENTAL STUDY ON POISSON'S RATIO FOR FRP TENDONS

FRP のポアソン比に関する実験的研究

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Abstract: This experimental research investigates the Poisson's ratio of the Fiber Reinforced Polymers (FRP). The FRP used for this experiment are Aramid and Carbon fiber types. The aim of this current work is to determine the Poisson's ratio experimentally. To determine the transfer bond for the FRP, parameters that are not clearly defined are friction factor and Poisson's ratio. The authors have conducted and reported the experimental study on the friction factor. Unlike the steel for construction, the FRPs have various surface texture and patterns. The conventional method of using micro-strain gauges to determine the Poisson's ratio cannot be applied to the FRP tendons. Therefore, the authors carried out the experiments by tension test of FRP tendon placed inside the acrylic tube, filled with colored water and using the universal testing machine (UTM). Under the cyclic tension test, the gradual changes of water level inside the tube gives the equivalent volume of the slandering of the FRP, and with the axial change in length, the Poisson's ratio is determined respectively.

INTRODUCTION

In Japan, for the past twenty years, many fundamental research projects have been conducted regarding the application of Fiber Reinforced Polymer (FRP) in the field of construction. In order to use the material with reliability and safety, some basic characteristics of FRP tendons must be cleared. At present, the price of FRP tendons are still quite expensive, so the application in prestressed concrete structures becomes significant, compared to the ordinary reinforced concrete applications.

In pretensioned type prestressed concrete structures, the bonding between the tendons and concrete is a key requirement for transfer bond. A theoretical approach on transfer length made for steel tendons are used in lieu of the one for the FRP1,2). Among the factors affecting the transfer length of FRP, Poisson's ration of FRP tendons and the friction factor between FRP and the ambient concrete are still not clearly established.

Experimental studies on the friction coefficient of FRP tendons in concrete have been started a few years ago and reported previously. This present paper will focus on the Poisson's ratio of FRP.

Also in the analytical approach, the transfer lengths of FRP tendons are determined using the established existing relationships for the prestressing steel tendons.

Unlike the steel for construction, the FRPs have various surface texture and patterns. The conventional method of fixing micro-strain gauges on the surface of steel tendon to measure the Poisson's ratio cannot be applied directly to the FRP tendons.

Therefore, the authors carried out the experiments by tension test of FRP inside the acrylic tube filled with colored water, on the universal testing machine(UTM). Under the cyclic tension test, the gradual changes of water levels inside the tube for the corresponding pull-out loads give the equivalent volume of the slandering of the FRP, and with the axial change in length, the Poisson's ratio is determined respectively.

The experimental results are reported and complimented with the previous results.

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PREVIOUS RELATED RESEARCH

In the past, the analytical approach for transfer length of FRP tendons was made using the relationship for the prestressing steel tendon. The Watanabe,s equation [1] for initial transfer length of steel tendon in pretension type prestressed concrete is as follows:

$$\lambda_0=\frac{\gamma_1}{2\mu\psi}\ln\frac{1}{1-0.95\,\mu\psi\,\sigma_{se}/(\tau_0+\mu\phi)} \qquad (1)$$

$$\phi=\frac{\nu_s\,\sigma_{sc}}{nr_1^2[(1-\nu_c)+(1+\nu_c)r_2^2/r_1^2]/(r_2^2-r_1^2)+(1-\nu_s)} \qquad (2)$$

$$\psi=\frac{\nu_s+n\nu_c\kappa}{nr_1^2[(1-\nu_c)+(1+\nu_c)r_2^2/r_1^2]/(r_2^2-r_1^2)+(1-\nu_s)} \qquad (3)$$

λ_0 :initial transfer length
r_2 :radius of concrete
σ_{se} :initial tensile stress of tendon
μ :friction coefficient
ν_c :Poisson's ratio of concrete
r_1 :radius of steel tendon
κ $=r_1^2/(r_2^2-r_1^2)$
τ_0 :initial bond stress
ν_s :Poisson's ratio of steel
n :modular ratio

When equation 1 for initial transfer length λ_0 was calculated using the six sets of Poisson's ratio and friction factor and compared with the experimental data it was found that the calculated results agreed well with the experiment data2). The Poisson's ratio ranged from 0.1 to 0.32 for carbon FRP and 0.06 to 0.23 for aramid FRP.

OUTLINE OF EXPERIMENTS

Materials

Table 1 shows some of the physical properties of the FRP tendons used for this experiment. Aramid and carbon types FRP tendons having epoxy resin matrix are used. The surface texture of aramid is cross-wound and the carbon is strand.

The diameters for the FRP tendons are determined from volumetric measurement using cylinder filled with water and then diameters are calculated from the predetermined length of FRP samples. The tensile strength and the modulus of elasticity are also determined in the laboratory. The fiber contents are taken from the makers, data.

Table 1. Types of FRP tendon

Symbol	Dia. ϕ (mm)	Fiber Type	Matrix Matl.	Fiber (%)	Ten.Str. (kN)	El.Mod (GPa)	Surface Texture
AFRP	9.70	Aramid	Epoxy	65	152	60	Cross-Wound
AFRP	7.52	Carbon	"	64	208	129	Strand

Test Specimen

As shown in Fig.1 the FRP tendon is placed at the center of a steel sleeve and held vertically with a bracket against the wall. The lower parts of the steel sleeves are sealed with silicon.

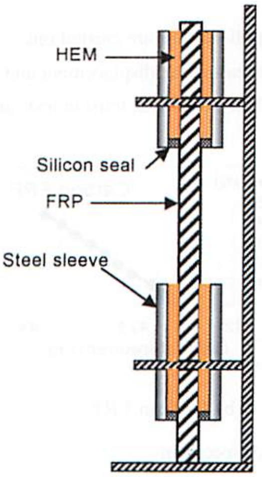


Fig.1. Specimen preparation

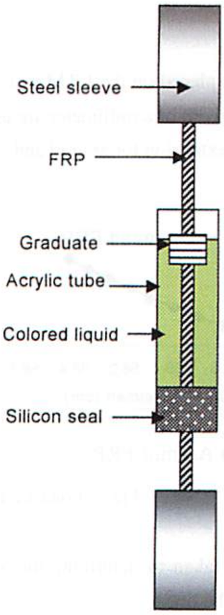


Fig.2. Specimen assembly

The highly expansive material (HEM) slurry is poured into the small opening between the FRP tendon and the steel sleeve. When the expansive pressure took place the FRP tendon is firmly gripped inside the steel sleeve, hence forming the HEM anchorage system. The micro-strain gages fixed on the surface of the steel sleeve are used to monitor the pressure development inside the sleeve. The application of this kind of anchor system is to protect the tendon from the grip of the jaw-chuck of the UTM. Unlike steel, the FRPs are strong in the axial direction only. These HEM anchorscan also be used for tensile test of FRP tendons.

Fig.2 shows the test specimen for the experiment. The transparent acrylics tube having a diameter larger than the FRP tendon is used and the bottom of the tube is sealed with silicon. Colored water is introduced and small markings are made near the surface level.

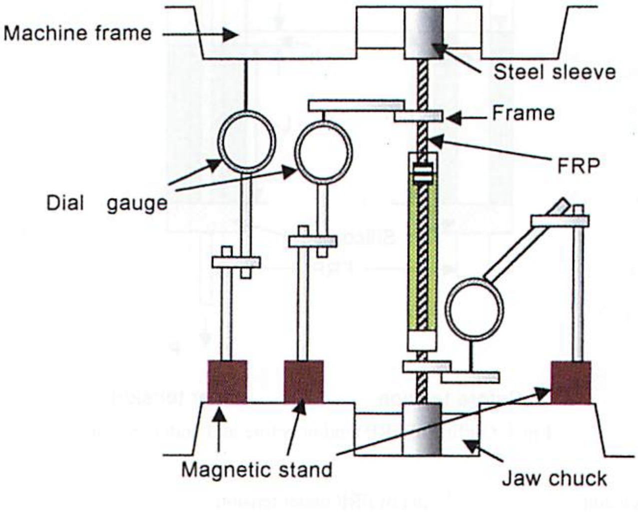
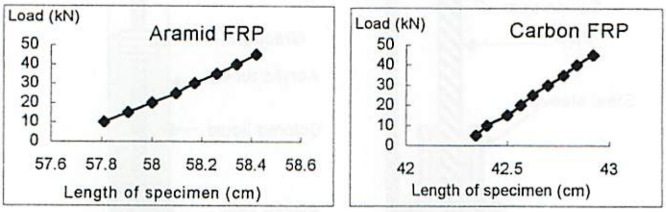


Fig.3. Assemblage for pull-out test

Test Procedure

As shown in fig.3, the specimen is placed on the UTM and cyclic pull-out test are carried out. Dial gauges as well as digital slide caliper having precision of hundredth of a millimeter are used to measure the displacement and change in water levels.

The relationship between load and extension for aramid and carbon FRP tendons at tension tests are shown in fig.4 (a) and (b).



(a) Aramid FRP (b) Carbon FRP

Fig.4. Load vs. length of specimen

Linear portion for load-extension is taken to determine the average Poisson's ratios. Throughout the experiment the load-extension relationships were found to be linear.

RESULTS AND CONCLUDING REMARKS

Small metal frames are attached to the FRP portions to monitor and the actual elongation of the FRP only. The pull-out loads ranged from 5kN to 45kN with 5kN intervals.

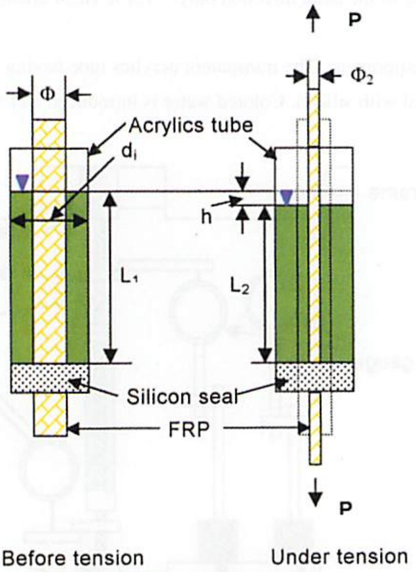


Fig.4. Outline of FRP tendon before and under tension

Φ_1 dia. of FRP before tension

L_1:water level difference

Φ_2 dia.of FRP under tension

L_2:water level under tension

h:water level difference
d_i:inner dia. of acrylics tube
P:tensioning load
⊿L:elongation of FRP at tensioning
L:length of FRP before tensioning

For each specimen, ten sets of loading cycles for every step of load and the respective readings from gauges are recorded simultaneously. The maximum load is taken as the 60% of the ultimate tensile capacity of the FRP tendon.

Figure 4, shows the enlarged portion of the water level difference and the state of FRP tendon, before and under tension. A simple relation can be obtain from the volumetric equivalency of the water before and during the tensioning, inside the acrylics tube for both cases will gibe the diameter of the FRP under tension Φ_2 as:

$$\Phi_2=\sqrt{\frac{(L_1-L_2)d_i^2-L_1\cdot\Phi_1^2}{L_2}} \qquad (4)$$

The radial strain ε_x can be expressed as:

$$\varepsilon_x=\frac{\Phi_1-\Phi_2}{\Phi_1} \qquad (5)$$

The longitudinal strain ε_y can be expressed as:

$$\varepsilon_y=\frac{\varDelta L}{L} \qquad (6)$$

Therefore the Poisson's ratio ν of FRP can be expressed as:

$$\nu=\frac{\varepsilon_x}{\varepsilon_y} \qquad (7)$$

Table 2. Poisson's ratio

Specimen	Poisson's ratio
AFRP	0.38
CFRP	0.45

Table 2 shows the average values of Poisson's ratio obtained from this experiment. Prior to this investigation, the authors have carried out two preliminary experiments on FRP tendons; the one without steel sleeve anchors and the other one without the additional frame for dial gauges at the FRP tendons. The results obtained from these past experiments showed higher Poisson's ratio, ranging from 0.7 to 0.9 This reason is considered to be the larger elongation at higher load levels, due to the HEM protruding from the steel tube. And when jaw-chuck was directly applied to the FRP, the end portions were crushed and causing further elongations in the axial direction. The UTM used for this study have a chuck clearance of only 120cm. Therefore, more refine data can be expected if the UTM have a larger clearance to accommodate longer specimen.

For aramid tendons, Poisson's ratio between 0.32 and 0.62 have been reported by Gerritse and Schurhoff [4)]

Mikami [5)] made an experimental study for Poisson's ratio of aramid FRP by fixing the 1-mm straight micro-strain gauges on the axial and tangential directions on the FRP surface. The approximate values for aramid FRP according to Mikami was found to be higher than 0.6. The method of using strain gauges is likely to be localized and the average value of Poisson's ratio may differ for the overall tendon.

Sano et al [6)] studied the Poisson's ratio of FRP tendons in the long slender concrete specimen at prestressing and measuring the strains from the surface of the concrete. Using the thick wall cylinder theory, the Poisson's ratio ranged between 0.08 to 0.27 for aramid and 0.5 to 0.23 for carbon FRP.

The experiments are still on going for the Poisson's ratio of FRP tendons and started with under-tension state and gradually decreasing the load to measure the Poisson's ratio. The results of this experiment will be published in the future conference.

ACKNOWLEDGEMENTS

The authors would like to thanks Professor A.E. Naaman of Michigan University who kindly suggested this idea of pulling the FRP tendon in a fluid to determine the Poisson's ratio.

REFERENCES

1. Akira Watanabe: Studies in Transmission Length of Pretensioned Prestressed Concrete., Memoirs of Faculty of Engineering, Kyushu University, Japan. 1965.
2. Myo Khin, Takashi Idemitsu, Kohji Takewaka and Susumu Matsumoto: Fundamental Study on Bond Behavior of Various FRP Rods in Pretensioned PC Members.. JSCE Journal, No.526/V-29 1995
3. Myo Khin, Kohji Takewaka, Susumu Matsumoto and Takashi Idemitsu: Experimental Study on Friction Factor for FRP Tendons in Pretensioned Prestressed ConcreteMembers.. Third International Symposium on Non-Metallic (FRP) Reinforcements for Concrete Structures. Sapporo, Oct. 1997.
4. A. Gerritse. and H.J. Schurhoff: Prestressing with Aramid Tendons, 10th FIP Congress, New Delhi, 1986
5. H. Mikami: Study on Application of Braided FRP Rods for Reinforcement of Concrete Members. Special Report of Technical Research Institute of Mitsui Construction Co. Ltd. No.3, 1992
6. S. Sano, Takashi Idemitsu, Takehiro Yamasaki and Myo Khin: A Study on End Anchorage of CFRP Reinforcements on Pretensioned PC Thin Slabs. Proceedings of Japan Concrete Institute, June 1994.

EXPERIMENTAL STUDY ON POISSON'S RATIO FOR FRP TENDONS

ＦＲＰのポアソン比に関する実験的研究

〔研究要旨〕

近年，高弾性，高強度を持ちまた変形に対する抵抗力性，耐疲労性の大きな繊維が登場し，さまざまな用途に使用されるようになった。なかでも炭素繊維，ガラス繊維，アラミド繊維，ボロン繊維，アルミナ繊維，スチール繊維などの高機能を有する繊維はロッドや連続メッシュ状に加工し使用することで軽量で高強度，非磁性で錆びない特性を持たせることが出来る。建設分野では，鉄筋やプレストレストコンクリート鋼材の代替材として将来大いに期待できる材料である。

本研究は，シリーズ１に続きＡＦＲＰ（アラミド繊維）ＣＦＲＰ（カーボン繊維）をロッド化し，ＰＣ緊張材の代替材として利用する場合に必要なポアソン比の算出を実験的に試みたものである。ＦＲＰは普通鉄鋼と異なり表面性状が複雑で一般のマイクロ歪ゲージを用いたポアソン比測定が出来ない。ＦＲＰロッドの伝達長は，実験値より求められているが，この値を数値解析により導くためには，ロッドのポアソン比と摩擦係数値が必要となる。筆者らは摩擦係数に関しての研究成果はすでに報告済みである。シリーズ２ではＣＦＲＰを新たに加え図１，２，３に示す実験装置を用い，引張りにより減少する体積をアクリルパイプに張った液面の挙動を数値化し，別に導入した算定式を用いてひずみを算出した。

その結果，ロッド材のポアソン比としてはかなり正確な実験値を得ることができた。

今後は，ＦＲＰロッドとアクリルパイプ端面固定の問題や液面読取ゲージの工夫等の改善を試み，より高い制度の歪測定法を目指す予定である。