Torsional Behavior of the R/C Member Subjected to Axial Tension

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Abstract

In this paper, to confirm the effects of the R/C member subjected to torsion and axial tension, the R/C member subjected to torsion, bending and axial tension is investigated experimentally and numerically. The test was done without the axial tensile force or with axial tensile force 2MPa and with torsion-bending (T/M) ratio (1.0) under the pure bending. In numerically, the member without torsion was compared with the R/C member subjected to torsion. From the experimental and numerical results we obtained the relation between the ultimate strength and torsion of the R/C member subjected to axial tensile force.

Key Words : Reinforced concrete, Torsion, Axial tension, Bending moment.

1. Introduction

Recently, structures of large-scale curved beams and box girders have been designed and constructed. In case of members of those structures, a twisting moment is acting dominantly. The fracture mechanism of R/C member subjected to torsion is difficult problem, as well as R/C member subjected to shear force. In generally, it is comparatively rare case that R/C member only subjected to torsion. Almost the case, the R/C member is subjected to combined shear, bending, torsion and axial force. Recently, Fang, et all. (2002) investigated the R/C member combined shear and torsion for high-strength concrete with different torque-shear (T/V) ratios under relatively low bending[1)]. The behavior of R/C members subjected under the combined load is extremely complicate[2),3)].

On the other hand, R/C member is subjected axial tension by the internal stress caused by drying shrinkage and change temperature effects of concrete, and is subjected the horizontal force produced by the earthquake motion[4)]. Generally, when the R/C member is subjected the axial tensile force, the ultimate strength of R/C member decreases remarkably. Also these forces affect the safety and the design of the structure. However, it is difficult to obtain the behavior of the member under such a combined load action.

In this paper, the R/C member subjected to combined torsion and axial tension under pure bending are analyzed experimentally and numerically. In the first, the effect of axial tensile force on the ultimate strength of the R/C member subjected to bending is investigated. The experimental study has done with paying attention to the region of pure bending. Next, Torsion-bending (T/M) ratio was set up 1.0. Also the combined torsion and bending test of the beam was done with the axial tensile stress σ_n=0MPa (TE-1), σ_n=2MPa (TE-2). Also, bending test of the member without torsion was done with the axial tensile stress σ_n=0MPa (SE-1), σ_n=2MPa (SE-2). The experimental results are compared with numerical results using finite element method. Moreover, in order to investigate the relationships of torsion and axial tension under pure bending moment, the beams under combined torsion and axial tensile force are compared with those without torsion.

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2. Experimental program

2.1 Specimens

Fig.1 shows the applied load to the specimen. Also Fig.2 shows the plan of the specimen. Axial tension is introduced at 15cm from both ends. Beams are supported at the same points mentioned above (see Fig.1). The vertical load was applied to both wings via actuator where the loading points are 450mm from the centroidal axis of the main beam in order to set T/M to 1.0. In the Fig.2 the part of the hatching line shows the region under pure bending.

2.2 Details of specimen

Fig.3 shows the cross section and the arrangement of steel reinforcements in the test region of the specimen. The cross section was 200×100(mm). The longitudinal rebar consists of 3×D13 bars, in both tensile and the compression regions, respectively. The transverse rebar consists of closed $\phi 6$ stirrups spaced on 100mm in the test region. The material properties of concrete and rebar are shown in Table.1.

2.3 Test apparatus and experimental procedure

The details of the test apparatus are shown in Fig.4. Axial tension is introduced by the longitudinal actuator as shown in Fig.4 (a), and the load is kept in fixed tension. Then transverse load is applied to the two loading point by the loading beam via the transverse actuator as shown in Fig.4 (b). Transverse load was increased until a beam was failing under displacement control system. Also the diagram of cracking growth is marked within each loading step on the test region.

3. Experimental results

3.1 Failure behavior

Fig.5 shows the crack states in failure stage on the front, top, and back face of test region for specimens TE-1 and TE-2, respectively. From Fig.6, diagonal cracks were observed. Cracks are formed on the front face and then extended to the top and back face.

It was shown that the twisting moment was predominant than bending moment on the test region. The diagonal cracks of TE-2 shows larger angle than that of TE-1.

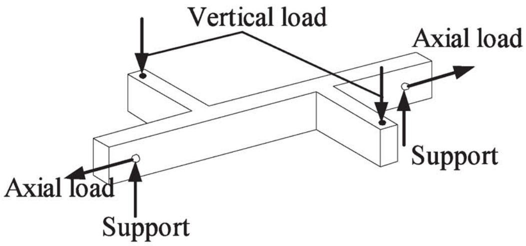


Fig.1 Form of typical specimen

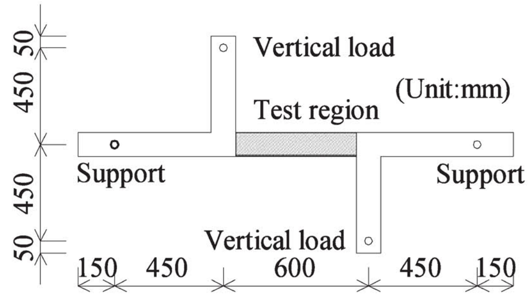


Fig.2 Plan of specimen

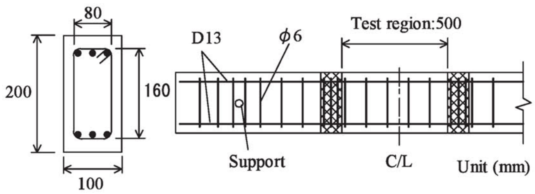
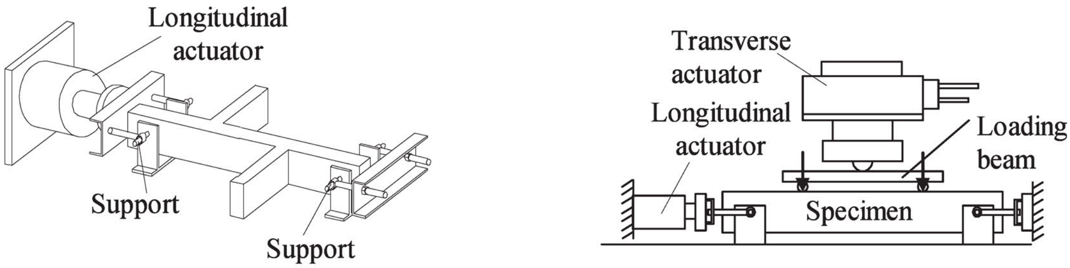


Fig.3 Details of specimen

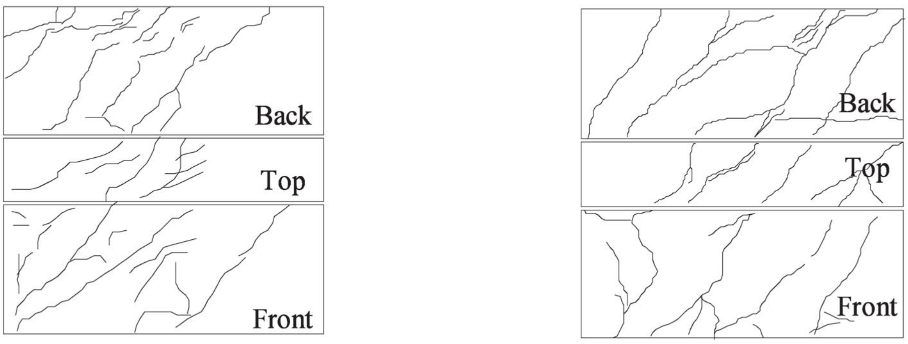
Table 1 Material properties

Concrete		
Elastic modulus E_c (GPa)	29.70	
Compressive strength σ_c (MPa)	27.29	
Tensile strength σ_t (MPa)	2.08	
Rebar		
Rebar type	D13	ϕ6
Elastic modulus E_c (GPa)	204.41	193.19
Tensile strength f_u (MPa)	450.94	315.12
Yield stress σ_c (MPa)	334.14	254.52



(a) Schematic of apparatus with axial tension (b) Schematic of apparatus with loading

Fig.4 Details of apparatus



(a) Specimen without the axial tension TE-1 (b) Specimen with the axial tension TE-2

Fig.5 Crack state on the test region

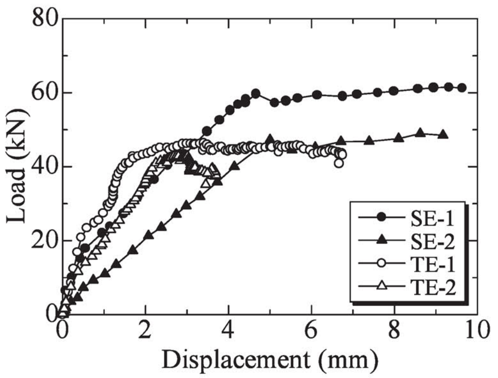


Fig.6 Load-Displacement Curves

3.2 Ultimate strength

The load-displacement relationships at the center of specimen are shows in Fig.7. As shown in this figure, in the member without torsion, the ultimate load is decreased when the axial tensile force is introduced. From Fig.7, for both TE-1 and TE-2, the load-displacement relationships are almost liner up to initial cracking load. The initial crack appeared TE-2 earlier rather than TE-1. Hence, it was observed that the tensile force decreases the rigidity of the R/C member. Generally, the R/C member decreases the strength when the R/C member is subjected to axial tensile force. However in this experimental result, the ultimate strengths for TE-1 and TE-2 show almost the same value. This means that, an axial tensile force does not influence into the flexural ultimate strength of R/C members.

4. Finite element method

In this paper, the behavior of R/C members subjected to combined torsion, bending and axial tension is analyzed by finite element method based on three-dimensional solid element[5]. Twenty nodes isoparametric three-dimensional solid element is adopted.

In this analysis, in order to investigate the relationship between axial tensile force and torsion, the numerical analysis is done to the specimen subjected to torsion and the beam without torsion. Material properties

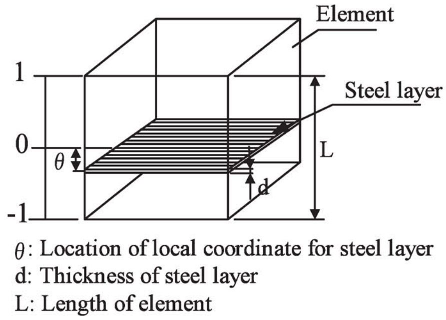
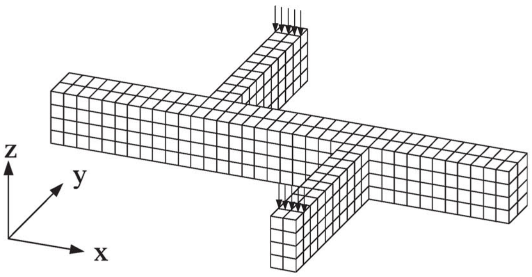


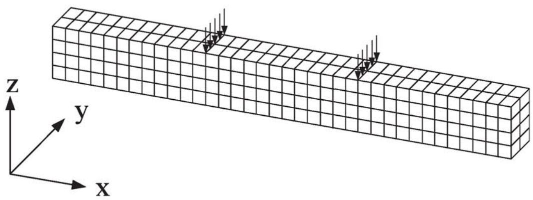
Fig.7 Local coordinate and location of steel layer

Table 2 Material properties

Concrete	
Poisson's ratio ν	0.311
Density ρ (g/cm^3)	2.45
Rebar	
Tangential modulus E_2 (GPa)	20.6



(a) Numerical model for torsion



(b) Numerical model for straight beam

Fig.8 Numerical models

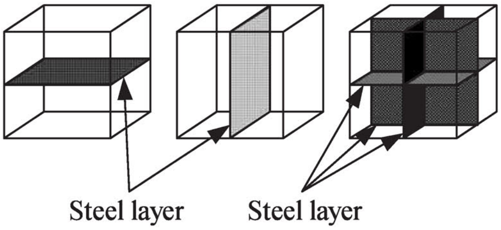


Fig.9 Solid element containing steel layer

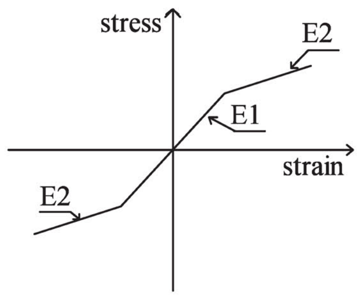


Fig.10 Elastic-plastic stress strain relation of rebar

are the same as Table.1. Addition properties are shown in Table.2. The applied distributed load is idealized by the concentrated load, and also the rebar is modeled as the steel sheets defined in the local coordinates, as shown in Fig.7. The numerical models of subjected to torsion and beam without torsion are shown in Fig.8 (a), (b). The numerical model of the beam subjected to torsion was divided into 416 elements and 2741 nodes; on the other hand, the numerical model of the beam without torsion was divided into 288 elements and 1909 nodes. Moreover, loading point for the straight beam was set to 45cm apart from the supports. The model subjected to torsion and axial tension (0MPa) is TA-1, another one (2MPa) is TA-2. The numerical model subjected to only axial tension (0MPa) is SA-1, another one (2MPa) is SA-2.

4.1 Concrete behavior in compression

The inelastic behavior of concrete possesses the recoverable strain components and irrecoverable strain component. In this paper, the elasticity theory is used for recoverable strain components and the strain hardening plasticity approach is used for irrecoverable strain components. To evaluate the stress state of the concrete for given strain state, four conditions that is the yield criterion, the flow rule, the hardening rule and the crushing condition must be defined.

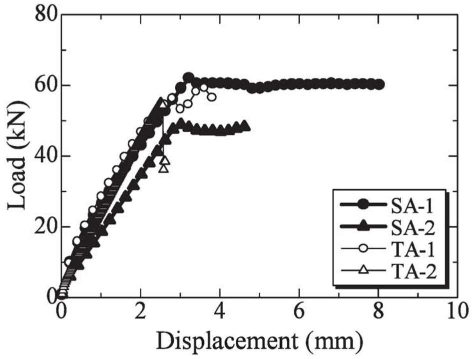


Fig.11 Numerical results with torsion

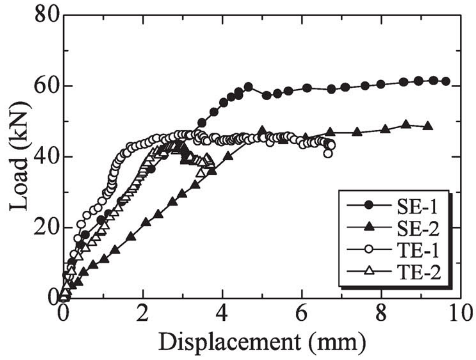


Fig.12 Numerical results without torsion

4.2 Concrete behavior in tension

Cracking is one of the major causes of nonlinearly of the R/C structure because cracking stress in tension shows lower than the failure stress in compression. In this paper, the response of concrete in tension is modeled as a linear-elastic brittle material and maximum tensile stress criteria are employed. The smeared crack approach is adopted to represent the cracked element behavior. The concrete behavior is defined as the isotropic materials before cracking and as the anisotropic materials after cracking. Also two conditions that are tension stiffness and cracking shear modulus are defined.

4.3 Material model for the rebar

The rebar are considered as steel sheets that possess equivalent thickness and has uniaxial behavior resisting only against the axial force in the bar direction. The solid element including the rebar is shown in Fig.9. The bilinear idealization is adopted in order to model the elastic-plastic stress strain relationship, as shown in Fig.10 and both the tensile and the compressive state are governed by the same relationship.

5. Numerical results

The load-displacement relationship of the member which subjected to torsion and the member without torsion are shown in Fig.11 and Fig.12 respectively. From these figures, in the numerical results and the experimental results, the member subjected to torsion and the member without torsion are shown the same behavior. In the numerical results of the member without torsion, the ultimate strength of the beam (SA-2) subjected axial tensile stress (σ_n=2MPa) is smaller than the beam SA-1 (σ_n=0MPa) remarkably. However, in case of the member subjected to torsion, the ultimate strength of TA-1(σ_n=0MPa) and TA-2(σ_n=2MPa) are almost equal. This is the same behavior with the experimental results. From this, it can say that in case of the member without torsion, the axial tension force gives the effect for the R/C member to reduce the rigidity. However, in the member subjected to torsion, the reduction of the ultimate strength by the axial tension force is small. This means that the effect of the axial tensile stress is changed by the level of the twisting moment. Therefore, it is clear that the ultimate strength of the member subjected to torsion is depended on the twisting moment more than the effect of axial tension force.

6. Conclusions

In this paper, the R/C member subjected to torsion, bending and axial tension were investigated experimentally and numerically. Also the beam without torsion was analyzed for comparison. From both experimental and numerical investigations, the following conclusions are obtained.

1) In the region of pure bending that subjected to combined torsion (T/M to 1.0), the influence of torsional cracking is appeared remarkably. Therefore, the twisting moment is more predominate than bending moment in the test region.
2) In the finite element method, the numerical results agree with the experimental results in the inclination of load-displacement relationship.
3) Form both numerical and experimental results, in case of the member subjected to torsion, it is observed that the effect of the axial tensile stress is changed by the level of twisting moment.

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