UPGRADING MECHANISM OF THIN-WALLED CIRCULAR STEEL BRIDGE PIERS WITH IN-FILLED CONCRETE UNDER CYCLIC LOAD

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1. Introduction: Concrete-filled thin-walled steel tubular columns referred hereinafter as CFT columns are used as elevated highway bridge piers in Japan due to high earthquake resistance. In CFT columns for bridge piers, the concrete filled at the lower part of the hollow columns is confined by diaphragms to increase its strength. From the experimental observations, the strength and ductility of steel piers are considerably upgraded due to the composite action and the local buckling restraint, respectively. However, up to the present, no sufficient and precise research has been conducted on the upgrading mechanism of thin-walled steel bridge piers with in-filled concrete. Herein, based on an accurate numerical analysis[1)], recently proposed by authors, mechanical properties that include local buckling of steel tube, axial force distribution in steel tube and in-filled concrete as well as ductile fracture at steel tube are extensively investigated to clarify the upgrading mechanism of CFT columns.

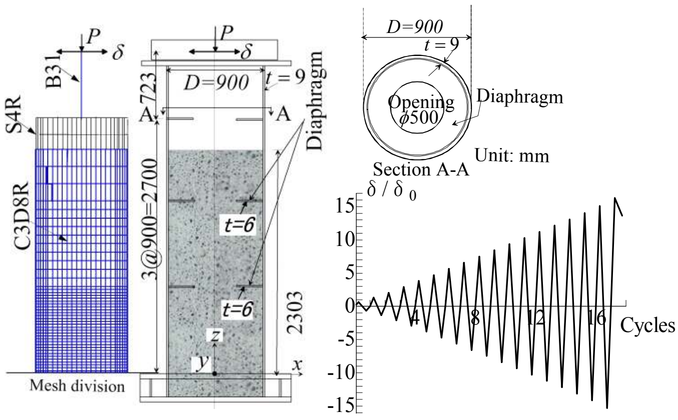

Fig.1 Specimen and analytical model　　Cyclic loading program

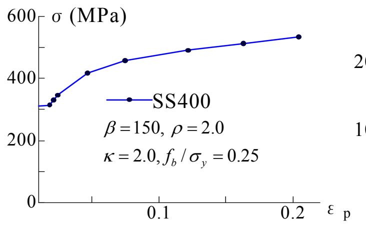

Fig.2 Uniaxial stress-strain relation of steel

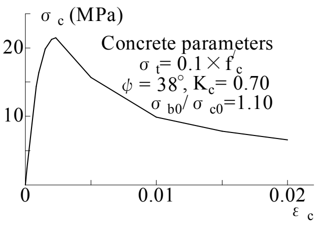

Fig.3 Concrete uniaxial test results

2. Material and interface modeling: To compute the hysteretic behavior of CFT columns, the modified 3-surface cyclic plasticity model[2)] is used as a constitutive model for steel and is implemented in shell element by user subroutine. Regarding the in-filled concrete, material nonlinear behavior is expressed by the concrete damaged plasticity model implemented in ABAQUS[3)]. For steel-concrete cyclic interaction, contact model with friction effect in tangential direction is considered. In this model, $\mu = 0.2$ is used as interface friction parameter. The uniaxial stress-strain relations together with material parameters for steel and concrete are briefly explained in **Fig.2 &3**.

Table 1 Geometric properties of the specimens

Specimens	Height h (m)	Concrete Height (m)	Thicknees, t (mm)	Radius, R(mm)	$\bar{\lambda}$	R_t	δ_0 (mm)	H_0 (kN)	$\frac{P}{\sigma_y A}$
Hollow (No.29)	3.423	--------	9.0	450	0.267	0.123	10.5	400.82	0.199
CFT (No.30)		2.303							

3. Numerical example: A FE model for CFT column shown in **Fig.1** is determined based on the CFT column specimen used in the unidirectional cyclic loading experiment[4)]. The geometric parameters for the specimens are summarized in **Table 1**. No.30 and No.29 are CFT and corresponding hollow columns, respectively. The interaction between in-filled concrete and steel tube including diaphragms as well as base plate is expressed by contact with friction model explained in section **2**.

4. Resisting mechanism of CFT column: The hysteretic behavior of CFT column (No.30) obtained from cyclic loading experiment and the results computed from proposed FE model are shown in **Fig.4** for comparison. It can be seen that the accuracy of the FE model is generally acceptable. It is mentionable that the post-peak behavior of PCFT column is followed with ductile fracture at steel tube. The details of this ductile failure mechanism are discussed later with considering the criterion for metal facture initiation followed by local buckling of steel tube.

The computed deformed shapes of steel tube at $\delta = +6.0\delta_0$ are compared in **Fig.5** for CFT (No.30) and corresponding hollow column (No.29). The comparison represents that the local deformation at steel tube of CFT column is very small and the local buckling of steel tube is delayed. To describe the causes of delayed local buckling of steel tube, the upgrading resisting mechanism of CFT column is schematically shown in **Fig.6** in terms of axial force distribution in steel tube and in-filled concrete. Herein, the total axial force N is divided into two parts: axial force in in-filled concrete N_c and axial force in steel tube N_s . When compressive dead load is applied at the top of the column (**Fig.6 (a)**), total axial force is distributed in steel tube and in-filled concrete simultaneously. If the horizontal load is increased gradually and no local buckling occurs (**Fig.6 (b)**), steel tube carries major part of compressive load. After occurrence of the local buckling (**Fig.6(c) & (d)**), compressive rigidity of steel tube decreases gradually and compressive load is mainly carried by the in-filled concrete. On the other hand, the tensile force developed due to the bending moment cannot be resisted by in-filled concrete. This is because crack occurs in the horizontal direction and the in-filled concrete losses its tensile strength. Therefore, the tensile force is

Key words: Hysteretic behavior, Local buckling, FEM analysis, Metal fracture, CFT column, Resisting mechanism
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mostly resisted by steel tube, which in turn, restrains the progress of the local buckling of steel tube.

The upgrading resisting mechanism of CFT column mentioned above is confirmed by the numerical results. In this respect, the axial load distribution is computed at base of CFT column (No.30), and obtained results are shown in **Fig.7**. From **Fig.7**, it is observed that under the compressive load P at the initial stage, the steel tube carries 20% of compressive load P, while concrete core takes remaining 80%. Then, the axial force of steel tube N_s gradually enters into the tensile zone under cyclic loading and it maximum value attains 170% of $|P|$ at $\delta = \delta_{\max}$ or $\delta_{\min}$ for each cycle. On the other hand, the compressive magnitude of the axial force acting on the in-filled concrete N_c increases under cyclic loading and reaches the maximum value of 270% of $|P|$. The total axial force $N = N_s + N_c$ is also shown in **Fig.7** to verify the accuracy of the computed results. The total axial force is almost equal to P, irrespective of loading cycles. Rather, there is a little variation in constant value of N due to numerical error. However, this error remains with in a tolerable limit.

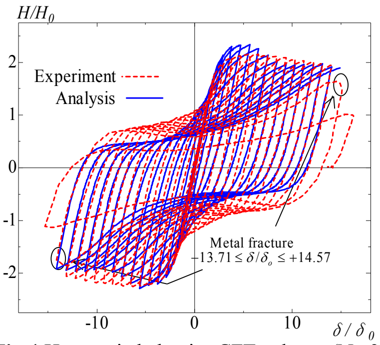
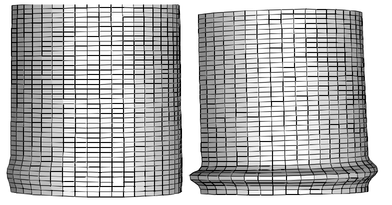


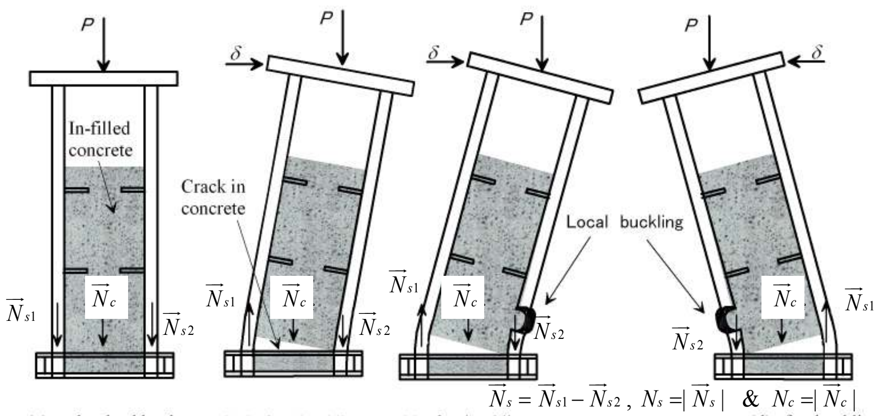
Fig.4 Hysteretic behavior CFT column (No.30)


at $\delta = +6.0\delta_0$

(a) CFT (No. 30) (b) Hollow (No.29)

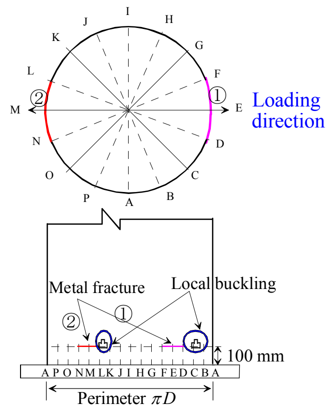
Fig. 5 Deformed shapes at the lower part of steel pipe ($\times$ 1.5)

From above discussions, it is clear that the steel tube of CFT column sustain relatively large inelastic deformation and tensile force. As a result, ductile metal fracture is likely to occur at steel tube. As a matter of fact, this metal fracture is observed at outside of steel tube during cyclic loading experiment on CFT column[4], which is schematically shown in **Fig.8 (a)**. This metal fracture initiation is investigated numerically by considering the localized equivalent plastic strain of the CFT column and corresponding hollow column. The computed results are shown in **Fig.8 (b)** for comparison. From **Fig.8 (b)**, the fracture of the CFT column initiates when equivalent plastic strain $\bar{\varepsilon}^p$ attains 121%. In contrast, the hollow column is so far from the fracture.



(a) under dead load (at $\delta = 0$) (b) before buckling (at $\delta = +\delta_0$) (c) after buckling (at $\delta = \delta_{\max}$) (d) after buckling (at $\delta = \delta_{\min}$)

Fig.6 Resisting mechanism of CFT column



(a)

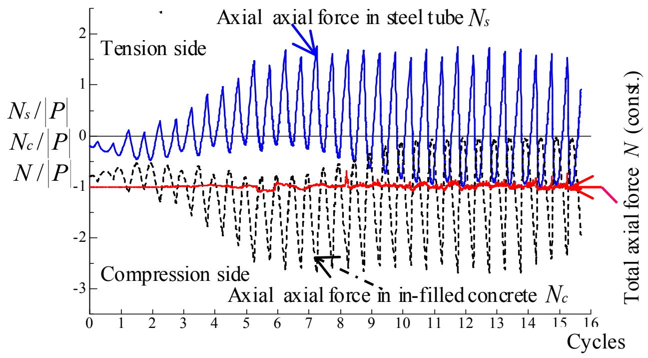
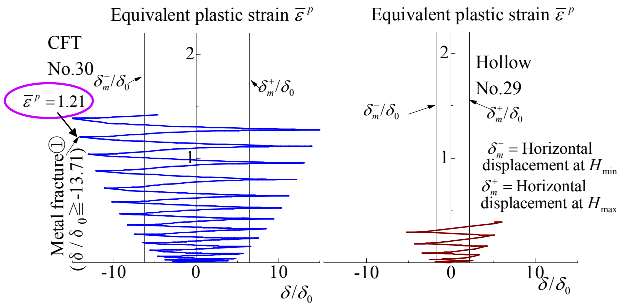


Fig.7 Axial load distribution in steel tube and in-filled concrete (No.30)



(b)

Fig.8 (a) Location of metal fracture (No.30), (b) Fracture initiation criterion

5. Summary and concluding remarks: An upgrading resisting mechanism of thin-walled CFT columns is investigated by an accurate and numerically stable FE model, proposed by authors. Under cyclic loading, the tensile axial force develops in steel tube after the occurrence of local buckling and this tensile force restrains the progress of the local buckling. On the other hand, compressive force is mostly resisted by the in-filled concrete after occurrence of local buckling. Due to the tensile force that occurs in steel tube, ductile metal fracture may occur and this fracture has an unfavorable effect on upgrading the strength and ductility of CFT columns.

References

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