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Concrete-Filled High Tensile Steel Tubular Structures

Structures en tubes d'acier à haute résistance remplis de béton

Konstruktionen aus betongefüllten, hochfesten Stahlrohren

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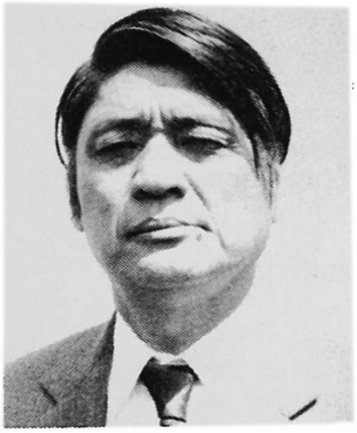

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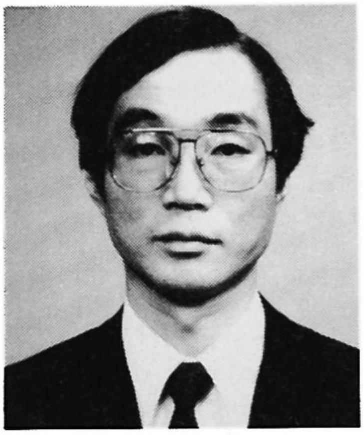

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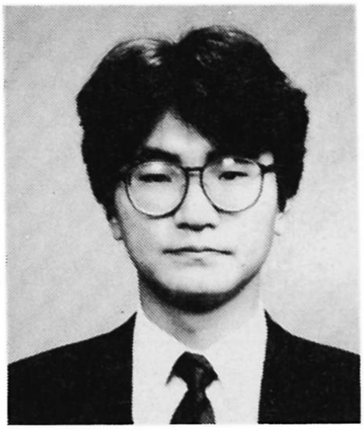

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SUMMARY
This paper describes the analytical method for examining the mechanical properties of concrete-filled high tensile steel tubes with emphasis on their buckling and post-buckling behaviors. Special attention is paid to the role and the modeling of the filled concrete which prevents the growth of the buckling waves in steel walls. The general features of this material are discussed from the obtained results.

RÉSUMÉ
Cette contribution décrit une méthode analytique pour l'examen des caractéristiques mécaniques de tubes d'acier à haute résistance remplis de béton, en considérant leur comportement de flambage et de post-flambage. Une attention particulière est portée sur le rôle et la modélisation du béton de remplissage qui empêche l'apparition des ondes de flambage des parois d'acier. Les caractéristiques générales de ce matériau sont discutées sur la base des résultats obtenus.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt ein analytisches Verfahren zur Untersuchung der mechanischen Eigenschaften von betongefüllten, hochfesten Stahlrohren, unter Berücksichtigung des Beul- und Nachbeulstadiums. Besondere Aufmerksamkeit gilt dabei dem Verhalten und der Modellisierung des Füllbetons, der die Entstehung von Beulwellen der Stahlwände verhindert. Aus den gewonnenen Erkenntnissen werden allgemein gültige Materialeigenschaften erörtert.

1. INTRODUCTION

For the last decades, high strength structural steel tubes are frequently used for structural members in large structures such as tall buildings. In these structures, members can be thinner than ordinary mild steel members by the use of high tensile steel. As a result, high tensile steel tubes are designed efficiently and the radius (diameter) to thickness ratio of steel tubes is larger. Therefore, the mechanical properties of high tensile steel tubes, particularly the local buckling strength of tubes must be fully investigated. The study has been carried out also in our laboratory[2,3].
However, there is not enough of the necessary basic data on the local buckling behavior of high tensile steel tubes, especially on the buckling behavior of concrete-filled high tensile steel tubes. It is generally thought that the local buckling behavior of composite members (concrete encased steel members) is controlled with the concrete. It is not clear whether the similar constraint effect of concrete for concrete-filled high tensile steel tubes can be expected or not. The reason is that the outward deflection of the steel wall may grow under pure compression by the effect of hoop tension.
In this paper, the nonlinear analysis is carried out to study the constraint effect of the concrete on the local buckling behavior of high tensile steel tubular structures under axial compression. The buckling strength and deformation capacity are discussed.

2. MODELING OF CONCRETE-FILLED HIGH TENSILE STEEL TUBULAR STRUCTURES

2.1 Main assumptions

In this section, we describe the modeling of concrete-filled high tensile steel tubular structures under axial compression (see Fig.1). At first we make the following assumptions for the local buckling problem of concrete-filled high tensile steel tubes.

1. The effect of concrete on the local buckling will be estimated at unilateral boundary conditions. Figure 2 shows the method how we determine such a unilateral boundary surface when analyzing the buckling behavior by the step-by-step method.
2. The relationship between stresses and strains follows the Hooke's law to the elastic region and the Prandtl-Ruess stress-strain relation to the plastic region; the stress-strain relation is assumed to be the round-house type for the purpose of considering the influence of residual stresses in steel tubes because of the plastic forming and welding[1].
3. Buckling modes of steel tubes are axi-symmetric. In this paper, we do not consider asymmetric buckling modes.

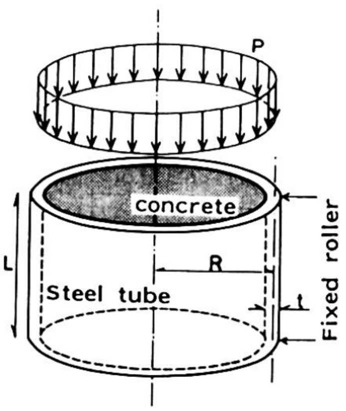

Fig. 1 Geometry

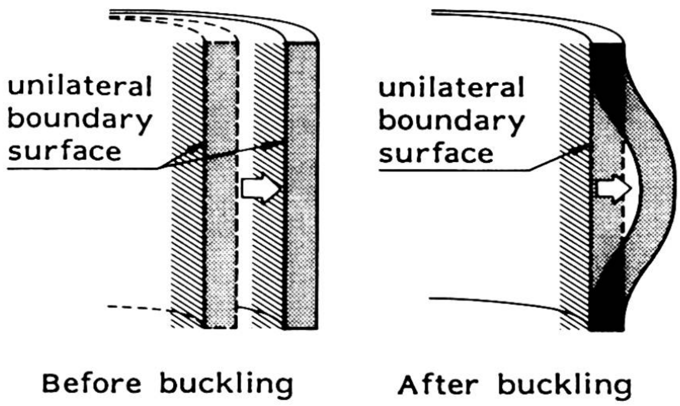

Fig. 2 Determination of concrete surface

4. Friction on the surface between the steel tube and the concrete in tubes (boundary surface) is ignored.

The above assumptions enable us to consider that the concrete in tubes will simply control the local plastic buckling behavior of high tensile steel tubes.

2.2 Analytical method

Here, we briefly describe the analytical method. The characteristics of the analytical method used in this paper are the followings[2,3].

- The present analytical method considers both the geometrical and material nonlinearity.
- The mode superposition method is implemented as numerical techniques.
- The effect of concrete in tubes on contact constraints or unilateral boundary conditions is estimated by the penalty formulation.
- The arc-length-control procedure is adopted to overcome such numerical difficulty that the tangent stiffness becomes indefinite near the buckling load.
- The tube wall is divided into some layers through the thickness, and whether the layer is elastic or plastic state is decided according to the von Mises yield criterion.

3. LOCAL BUCKLING OF HIGH TENSILE STEEL TUBES

3.1 Geometrical and material properties of analytical models

In this section, we actually discuss the local buckling behavior of high tensile steel tubes with unilateral boundary condition.

As to the material parameter, the two types of HT55 series and HT80 series are examined where HT55 series and HT80 series represent steel tubes with the minimum tensile strength of 540 MPa (55kgf/mm^2) and 785 MPa (80kgf/cm^2), respectively. The material properties are the followings[3].

- The value of proportional limit stress: σp is 231 MPa for HT55 series and 476 MPa for HT80 series.
- The value of yield stress: σy (0.2% offset yield stress) is 518 MPa for HT55 series and 760 MPa for HT80 series.

As to the geometric parameter, the radius to wall thickness ratio (R/t) of steel tubes is adopted. As the value of the ratio, we examined the four types for HT55 series and the two types for HT80 series. The behaviors of high tensile steel tubes without concrete were also examined in comparison with that of the concrete-filled tubes

Table 1. Geometrical and material properties of high tensile steel tubes

	HT55 series								HT80 series			
R/t, αc	50, 4.0		35, 5.6		22, 9.0		20,10.0		22, 6.2		15, 9.0	
filled or empty	f.	e.	f.	e.	f.	e.	f.	e.	f.	e.	f.	e.
yield stress(σy)	518 MPa								760 MPa			
Length to radius(L/R)	2.0											

where αc is the nondimensional parameter[2].

3.2 Results and discussions

At first, we discuss the characteristics of each compressive stress (σ) - compressive strain (ε) relation curves for concrete-filled high tensile steel tubes. Here, the compressive stress is given by the axial load divided by the cross sectional area, and the compressive strain by the axial displacement

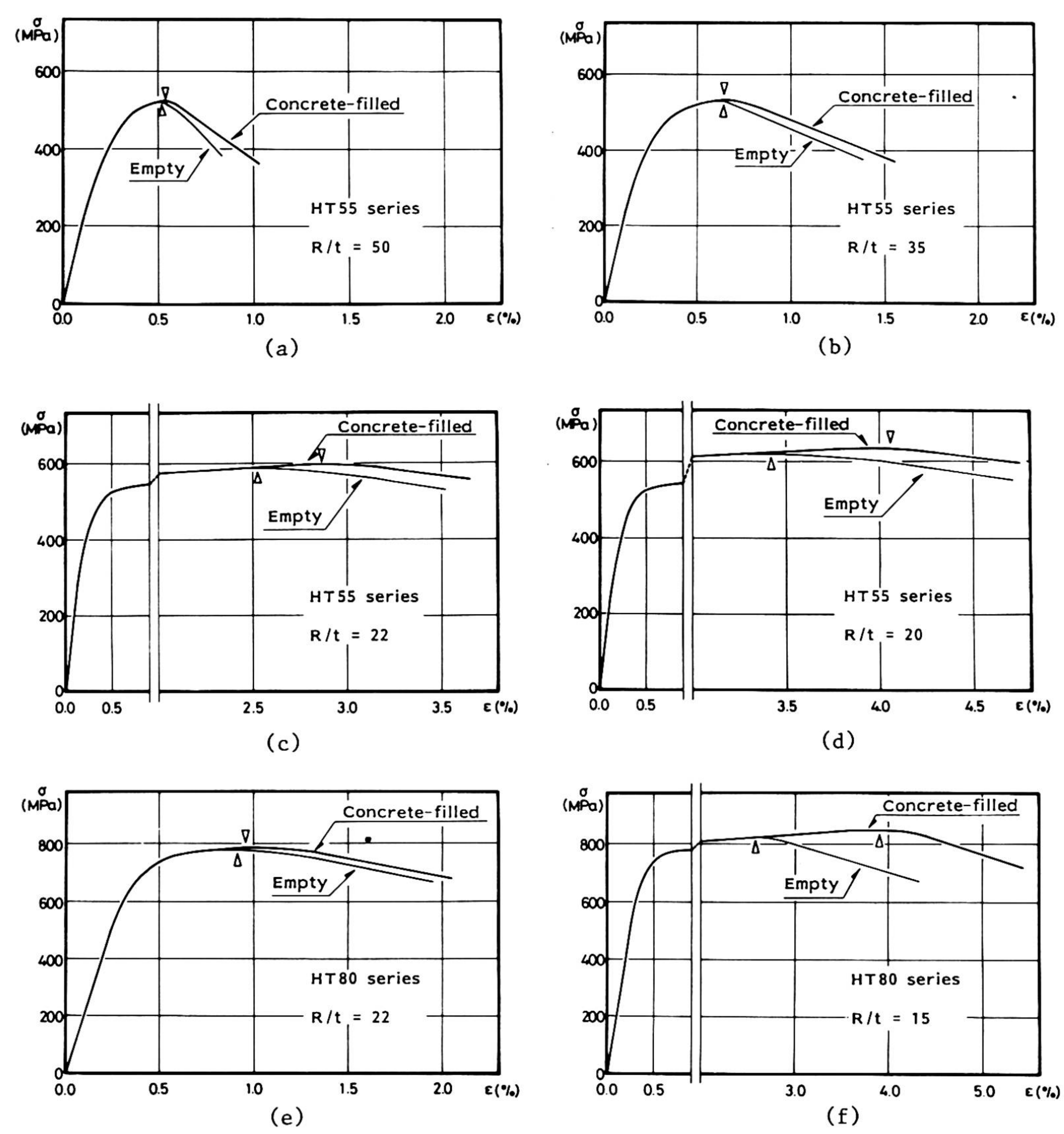

Fig. 3 Compressive stress-strain relation curves

divided by the tube length. Figures 3(a)-3(f) show compressive stress-compressive strain relation curves for high tensile concrete-filled or empty steel tubes with the radius to thickness ratio R/t=50, 35, 22 and 20 for the HT55 series and R/t=22 and 15 for the HT80 series.

In case of HT55 series, the maximum compressive stress (σm) and the strain (εm) at the maximum load level of the concrete-filled steel tubes with R/t=50 and R/t=35 is nearly equal to that of the empty steel tubes, though the results for each condition in tubes somewhat differ in the behavior after the buckling (see Fig.3(a) and (b)). In the results of steel tubes with R/t=22 and R/t=20, the effect of concrete in tubes on the plastic local buckling behavior appears contrastively (see Fig.3(c) and (d)). Particularly the strain at the maximum stress of the concrete-filled steel tube with R/t=20 is quite large compared

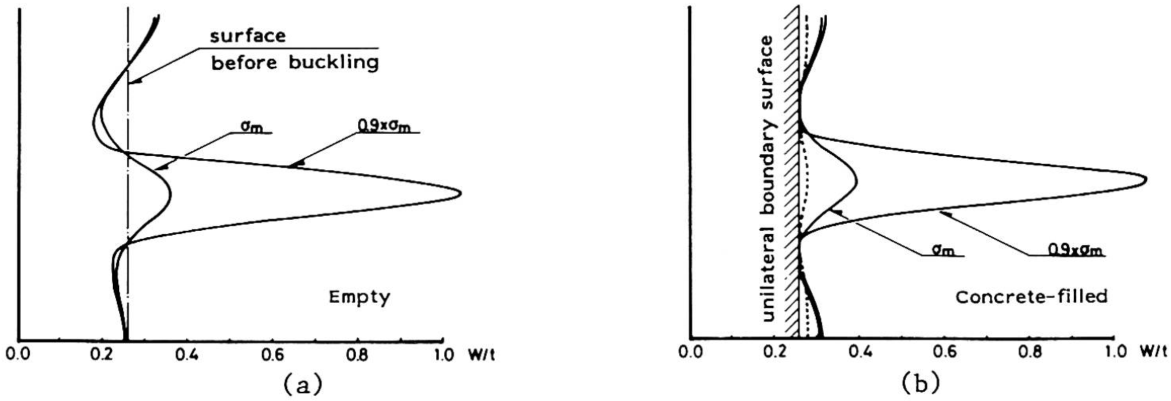

Fig. 4 Distribution of lateral displacement of tubes

with that of the empty steel tube.

In case of HT80 series, the results of concrete-filled steel tubes with R/t=22 is nearly equal to the results of empty ones, and this tendency is similar to ones with R/t=35 for HT55 series (see Fig.3(e)). The results of concrete-filled and empty steel tubes with R/t=15 is considerably different on the strain at the maximum compressive stress in the same manner as the results of steel tubes with R/t=20 for HT55 series (see Fig.3(f)).

Thus, the constraint effect of the concrete on the control with the plastic local buckling behavior becomes even stronger when the radius to thickness ratio of steel tubes is smaller.

Figure 4 shows the distribution of lateral displacement of concrete-filled and empty tubes with R/t=22 for HT55 series at the point of the maximum stress and at the point of 0.9 x σm after buckling. In the empty tube, the deflection of clear cosine wave grows near the point of the maximum stress(see Fig.4(a)). As to the tube with concrete, the constraint effect of the concrete controls the sudden growth of inward lateral displacement of the steel tube. The dotted line in Fig.4(b) shows the deflection line of the concrete-filled steel tube at the buckling load of the empty tube. As shown in this figure, the concrete-filled tube does not buckle at the buckling load of the empty tube. The maximum stress of the concrete-filled tube, therefore, rises more than the maximum stress of the empty tube.

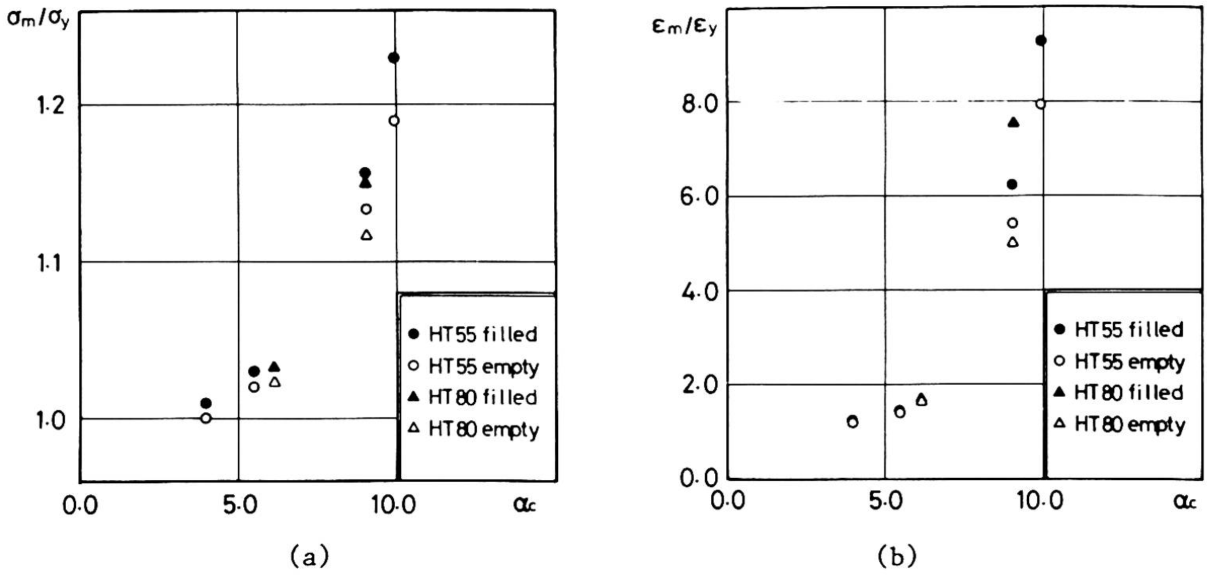

Fig. 5 Relation between αc and $\sigma m/\sigma y$, $\varepsilon m/\varepsilon y$

Next, by the nondimensional parameter (αc), three factors of. the strength increase ratio and the plastic deformation capacity are discussed to clarify the mechanical properties of concrete-filled high tensile steel tubes. The strength increase ratio is the maximum compressive stress (σm) divided by the compressive yield stress (σy). The deformation capacity is the strain (εm) at the maximum compressive stress divided by the strain (εy) at the compressive yield stress. The parameter αc is written as

$$\alpha c = E/\sigma y \times t/D, \quad \text{where } E: \text{Young's modulus, } D: \text{diameter of tubes} \quad (1)$$
$$\sigma y: \text{yield stress}, \quad t: \text{thickness of tubes}$$

Figures 5(a) and (b) show the relationship between αc and $\sigma m/\sigma y$, $\varepsilon m/\varepsilon y$ of concrete-filled and empty tubes respectively. The constraint effect of concrete in tubes on the plastic local buckling of tubes considerably appears when αc becomes greater than 9. This matter means that when the value of the radius to thickness ratio is less than about $11500/\sigma y$, the concrete in tubes is efficient to prevent the plastic local buckling of tubes.
In comparison with the results of tubes with αc=9.0 for HT55 series and HT80 series, the degree of the constraint effect of the concrete on the plastic deformation capacity fairly depends on the material property, thougl. the effect is almost the same on the stress increase ratio.
Thus, the constraint effect of concrete on the buckling of tubes is more efficient when the radius to thickness ratio of steel tubes is smaller, or the yield stress of steel tubes is higher.

4. CONCLUSION

The properties of concrete-filled high tensile steel tubes under pure compression, has discussed by the nonlinear analysis with considering unilateral boundary condition of concrete in tubes. The analytical research seems to be very useful to discuss the mechanical properties in paying attention to the pure constraint effect of the concrete on the buckling behavior of the steel tube. The results obtained may be summarized as follows.
- In thick wall steel tubes, the effect of concrete in tubes on the properties of the strength increase ratio and the plastic deformation capacity is efficient compared with thin wall steel tubes in both HT55 series and HT80 series, where the thick wall steel tubes mean ones with the diameter to thickness ratio less than $23000/\sigma y$(MPa) or $3500/\sigma y$(psi).
- As to the comparison of the HT55 series with the HT80 series, the effect of concrete in tubes for the HT80 series is more remarkable than that for the HT55 series.
- As to the slope of strength inferiority, the values for the two types of concrete-filled and empty high tensile steel tubes make little difference.

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