Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 73/1/73/2 (1995)

Artikel: Improved ductility of loaded concrete-filled members
Autor: Kvedaras, Audronis K. / Sapalas, Antanas
DOI: https://doi.org/10.5169/seals-55361

Improved Ductility of Loaded Concrete-Filled Members

Ductilité accrue de tubes en acier remplis de béton

Verbesserte Duktilität belasteter, mit Beton ausgefüllter Stahlquerschnitte

Audronis K. KVEDARAS
Professor
Vilnius Technical University
Vilnius, Lithuania

Audronis Kvedaras, born in 1937, received his engineering degrees at Kaunas Polytechnical Institute. At Vilnius Technical University he is responsible for research and lecturing on steel and composite structures.

Antanas SAPALAS
Professor
Vilnius Technical University
Vilnius, Lithuania

Antanas Sapalas, born in 1959, received his engineering degrees at Vilnius Technical University. Now in the Department of Steel Structures, he is responsible for research and lecturing of steel and composite structures, including their fire resistance.

SUMMARY

A relatively recent development in steel structures is the use of concrete-filled structural hollow sections. Researchers are trying to find more accurate and uniform ultimate strength calculation methods for various composite tubular elements under different loadings. Concrete filled steel tubular linear members are discussed. Because of the interaction between circular steel shell and solid or hollow concrete core, they achieve great ductility, which allows them to provide higher values of ultimate strength.

RÉSUMÉ

L'idée d'utiliser des tubes en acier remplis de béton est assez nouvelle. Les auteurs proposent des méthodes de calcul plus simples et plus précises pour différents éléments composites et différents cas de charge. Ils démontrent que grâce à l'interaction entre les tubes en acier et le béton, ce dernier subit de grandes déformations plastiques et la capacité portante des éléments augmente.

ZUSAMMENFASSUNG

Ein verhältnismässig neues Entwicklungsgebiet ist die Füllung hohler Stahlquerschnitte mit Beton. Die Verfasser versuchen, die Grenztragfähigkeit der sehr verschieden belasteten rohrförmigen Elemente einfacher und genauer zu berechnen. Durch die Interaktion zwischen der kreisförmigen Stahlschale und dem kompakten Beton wird eine grosse Duktilität erreicht, und somit eine höhere Bruchfestigkeit.

1.PRELIMINARY REMARKS

1.1.The Peculiarities of Structural Composite Framework

Structural framework of concrete filled steel tubes finds every time wider application because permits to gain a lot of technical and economic advantages [1,2,3]. There are already many favourable examples of the successful application of concrete filled structural steel hollow sections to both - building and bridge structures. Advantages which can be gained by filling hollow circular or rectangular steel tubes with concrete are stimulating researches in the field. The enhancement of concrete strength associated with circular concrete filled tubes can be accounted for. It is assumed the increase in concrete strength due to triaxial effects and time offsets any possible weakening effects due to creep and shrinkage.

Although a lot of speculations are done by various researchers in the field of expression of the influence of interaction between the external steel shell and the internal concrete core on the increase or decrease of their strength due to triaxial or triaxial-diaxial effects, but it must be admitted there the paramount importance of improved ductility of such loaded concrete filled members. Concrete filled steel tubular linear members because of interaction between the steel shell and concrete core during loading obtain great ductility which, we are sure, allows them to enhance the ultimate strength and to create a possibility for partial self repairing even after the rupture. Interaction occurring because of the difference between the values of Poisson's ratios of steel shell and concrete core allows to look for steels with more favourable distribution of their cross-section or strength and strain properties. There the big importance is playing very high reliability or safety of structural systems collected of such concrete filled steel tubular linear members under various abnormal loadings.

So below the attention is paid on the fundamentals of influence creating the state of such improved ductility in the most simple model - in loaded concrete filled steel tubular member. The usual concrete cores of steel tubes are most suitable only for the first stage of development of structural composite framework, because brittle concrete core and elastic plastic steel shell being loaded in composite linear member and interacting together make a favourable improved ductility in quite simple way. It is likely to be used more effective ductile materials in cores of composite linear members instead of concrete such as some kinds of new composites with more deeply expressed properties of self-repairing though the self-regulation of stress strain state by improved ductility, especially under abnormal loading, for instance, occurring during erthquake or different explosive actions.

So the interest in concrete filled steel tubular structures as well as in all other effective types of steel-concrete composite systems which under loading usually the favourable improved ductility in different members and especially in joints are producing by interactions, is now world-wide.

1.2.Situation with design rules and methods.

Advantages which can be gained by filling steel tubes with concrete are stimulating the preparation of design rules and methods. Usually any combination of axial loads and end moments about the principal axes may be considered, including cases where unequal moments are applied to both ends of the columns. The enhancement of concrete strength associated with circular concrete filled tubes can be accounted for by the procedure. Then design procedures differ in very large scale. At [6] is clearly shown that the confining effect of the tube enhances the strength as the unconfined strength is 34% greater, on average, than the test results. The Eurocode 4 [7] equation gave an average estimation of strength 2% below the average test strength with the failure load underestimated in 26 cases from 44; this is unacceptable for application to design (even after material factors are applied).

There authors are trying to find the way for more accurate and uniform method of calculation of ultimate strength of various composite tubular elements under very different loadings and actions with an easy possibility to avoid too large scatter between the calculated values and the test data, taking advantage of the mathematical theory of elasticity [4] and the theory of plasticity [5] to simplify the solutions.

2.THE FIELD AND RESULTS OF THEORETICAL INVESTIGATIONS

2.1.Behaviour of short compressed members

Our theoretical investigations at first dealt the strength, stress - strain behaviour and limit states of short axially compressed members with solid concrete cores enhanced with circular steel hollow sections. The stability of composite members of the same cross - sections have been investigated too, especially because it was based on the strength results of short elements. For description of stress - strain behaviour the presumptions of elasticity or plasticity theories usually are used. Application of the theory of plasticity as a rule leads to analysis of hollow and solid cylinders, loaded separately with coaxial forces and internal pressure [5]. The Prandtley's diagram is usual there to describe the relation-ships between the stresses and strains (Fig.1).The yield relationships in such case are ordinary expressed as

$$\sigma_r^2+\sigma_r\sigma_\Theta+\sigma_\Theta^2=k^2, \qquad (1)$$

or $0{,}5(\sigma_1-\sigma_2)=k$, (2)

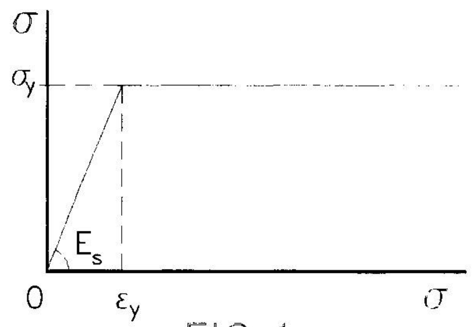

FIG.1

in dependence of criterion of beginning of plastification taken in analysis; where $k=(1/3^{0.5})\sigma_y$ for the Eq.1 (if the HubberMises-Hanley criterion is used) or $k=0{,}5\sigma_y$ for the Eq.2 (if the Sen-Venanh-Tresca criterion is used). These and some other fundamental relationships of the theory of plasticity are useful in analysis of stress-strain behaviour and limit state of concrete filled steel tubular members, but the assumption of independent action of coaxial forces and internal pressure is in contradiction with the reality, because in short compressed circular composite members the only external coaxial pressure is acting on them. In such cases the internal radial and tangential stresses may occur only if the different values of Puasson's ratio for different materials of components of composite cross- section exist. Then the necessity to compensate the breaks occurring on the circles of contacts between the different media arises [4]. But it is impossible by the means of methods of the theory of elasticity [4] to evaluate the increased stiffness even on the beginning of plastification (i.e. when the Puasson's ratios as of concrete core so the circular steel shell get equal each other ($\nu_b=\nu_s=0{,}5$) neither by requesting the reasoning of complex variable functions for more comfortable description nor auxiliary problems about the plain strains following to [4]. The above mentioned evaluation is possible only if to request the law about the equality of axial strains of both media - concrete core and circular steel shell:

$$\varepsilon_{zb}=\varepsilon_{zs}. \qquad (3)$$

In the solid concrete core the triaxial stress behaviour of all-round compression exist and in the circular thin-walled steel hollow section only diaxial stress behaviour may be accounted. Then during the plastification of both izotropic media (concrete core and steel shell) when above mentioned different stress behaviours exist, the Eq.3 should exist too. That is being after analogy of the auxiliary problem about the plains strains of elastic coaxial media with different Puasson's ratios [4]. So on the contact circle (between internal surface of steel tube and external surface of solid concrete core) the radial stress σ_r of interaction between the both media should occur

$$\sigma_r=(\overline{R}_b E_s-R_{yn}E_b)/(E_s-0{,}5E_b), \qquad (4)$$

where R_b and R_{yn} - the characteristic strength of composite and yield strength of steel; E_b and E_s - the modulus of elasticity of the both materials respectively. There are taken assumptions about relationships between the stresses and strains of concrete and steel at limit state of plastification according to those given in Fig.1. The occurring interaction between the both materials of short composite member in compression allows not only now to look on diaxial stress strain behaviour in both materials, but also to fix a limit state at quite improved ductility usually impossible to carry in each separated single medium. Then according to [5] if action on circular tube consist of coaxial and radial pressure the longitudinal yielding begins from the internal fibres and comes to an end with the external one. So for concrete filled circular steel tubular member it is permissible to assume the plastification firstly covers the internal concrete core and only after that it arises in steel tube. On the ductility of concrete core it is possible to look as on the pseudoplasticity because of process of microcracking of concrete.

2.2. Ductility and stress strain analysis

In the steel shell just before the longitudinal yielding is the elastic plastic stress strain behaviour which may be analysed according to the fundamentals of the version of small elastic plastic strains of the theory of plasticity. It is known that for steel tubes of complicated stress behaviour (tension compression) quite suitable is the law of generalised curves, which is being expressed as

$$\sigma_i = E_i \varepsilon_i . \tag{5}$$

where E_i - secant modulus determined on generalised curve according to generalised strain; σ_i - generalised stress for diaxial stress strain behaviour is being expressed as

$$\sigma_i = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}; \tag{6}$$

ε_i - generalised strain, expression of which for diaxial stress strain behaviour is

$$\varepsilon_i = \frac{2}{3}\sqrt{\frac{1-\nu+\nu^2}{(1-\nu)^2}\left[\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_1 \varepsilon_2 \left(\frac{3\nu}{1-\nu+\nu^2} - 1\right)\right]}; \tag{7}$$

σ_1, σ_2, ε_1, ε_2 -longitudinal and radial stresses and strains of steel shell respectively, ν - Poisson's ratio of material.

Usually it is assumed that generalised curve is universal for any stress state. So it may be determined according to the curve of uniaxial stress strain behaviour described by the data of standard steel tension test (Fig.2.).that the beginning of the full longitudinal yield of steel shell corresponds to the constant value of secant modulus of steel

$$E_{ui} = 0{,}67 \cdot E_s . \tag{8}$$

That means that exactly fixed ultimate value of generalised strain of steel shell (as elastic plastic deformation criterion of ultimate strength) is known

$$\varepsilon_{iy} = 1{,}5 \cdot R_{yn} / E_s . \tag{9}$$

Then the value of radial strain is

$$\varepsilon_2 = (1/E_s) \cdot (\sigma_2 + 0{,}5 R_{yn}) \tag{10}$$

and the longitudinal one

$$\varepsilon_{1y} = -0{,}5 \cdot \left(\varepsilon_2 + \sqrt{3 \cdot (\varepsilon_{iy}^2 - \varepsilon_r^2)}\right), \tag{11}$$

where σ_r is the radial stress of interaction, above marked as σ_r.

There is found very important thing The secant modulus of concrete at fixed value of generalised strain is

$$E_{ui,b} = E_b / \varepsilon_{iy} , \tag{12}$$

where R_b - the characteristic strength of concrete cylinders.

2.3. Ultimate strength expressions

After the values of ε_{1y}, ε_r, E_{ui}, $E_{ui,b}$ are known, the ultimate values of longitudinal stresses in steel shell and in concrete core have to be determined by

$$\sigma_1 = (4/3)\cdot E_{ui}\cdot(\varepsilon_1 + 0{,}5\varepsilon_r). \tag{13}$$

Then the ultimate strength of composite member have to be expressed by

$$N_u = \sigma_{1s}A_s + \sigma_{1b}A_b \geq N\ . \tag{14}$$

Approximately $\sigma_{1s} \approx 1{,}074R_{yn}$ for circular steel hollow section, $\sigma_{1b} \approx 1{,}64R_b$ for solid concrete core and $\sigma_{1b} \approx 1{,}32R_b$ for hollow concrete core. So improved ductility of steel shell enhances ultimate strength. In some cases the ultimate strength of composite member may be expressed at the moment when the radial stresses of steel shell reach the yield point. Usually that depends on the stock of elasticity of concrete filled circular steel tubular member. Then the value of σ_{1s} and σ_{1b} may be a little higher ($R_{yn} \leq \sigma_{1s} < R_{un}$; $\sigma_{1b} \approx 1{,}74R_b$), depending on the generalised elastic plastic deformation. If walls of steel tubes are superthin, the local stability of such shells have to be checked because might be $\sigma_{1s} < R_{yn}$. and criterion of ultimate strength $\varepsilon_{1u} > \varepsilon_{1y}$. The design values of ultimate strength of materials of composite members are a little less as a rule.

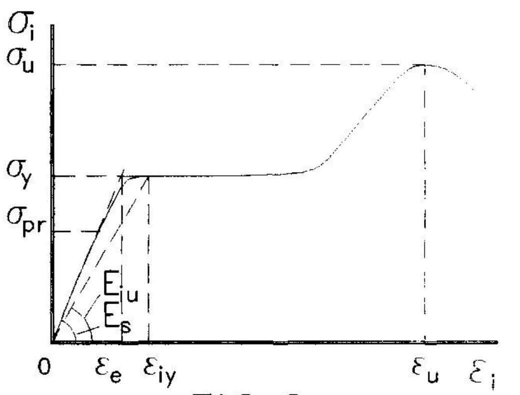

FIG.2

3. The efficiency of composite members

Increase in design strength of stub composite column depends on the yield point of steel R_{yn}, characteristic cylinder strength of concrete R_b and reinforcing factor $\mu_r = A_s/A_b$. The casual relationship of those three quantities

$$\eta = \mu_r \cdot R_{yn}/R_b\ . \tag{15}$$

The magnitude of increase in ultimate strength of composite member can be expressed as

$$K_E = N_{exp}/N_{de}, \tag{16}$$

where N_{exp} - experimental value of ultimate strength of member in compression at the beginning of longitudinal yield of steel shell; N_{de} - superposition of ultimate strengths of steel shell and concrete core determined separately as for pure reinforced concrete element:

$$N_{de} = R_{yn}A_s + R_bA_b\ . \tag{17}$$

The relationship between the parameter η and the steel contribution factor δ from [7] can be expressed as

$$\eta = \delta/(1-\delta). \tag{18}$$

Fig.3. deals with the illustration of casual relationship between K_E and η for short spun concrete filled steel tubular element in compression for only one value of the relative thickness of hollow concrete core

$\beta_i = 2{,}0$. If look on any other values of β_i the family of such curves should be plotted. The factors K_E values have been calculated for the group of spun concrete filled steel tubular buckle members: $K_E = 1{,}21$ - in uniaxial compression; $K_E = 1{,}27$ - in eccentric compression; $K_E = 1{,}32$ - in bending. The short stubby column of the same cross - section has $K_E = 1{,}17$. That means more high efficiency of buckle differently loaded members than short one and is in contradiction to requirement of [7] not allow confinement effects when slenderness ratio is $\lambda > 0{,}5$. On the ground of similar diversities erroneous conclusions about the efficiency of only short coaxially compressed concrete filled steel tubular members sometimes are being done.

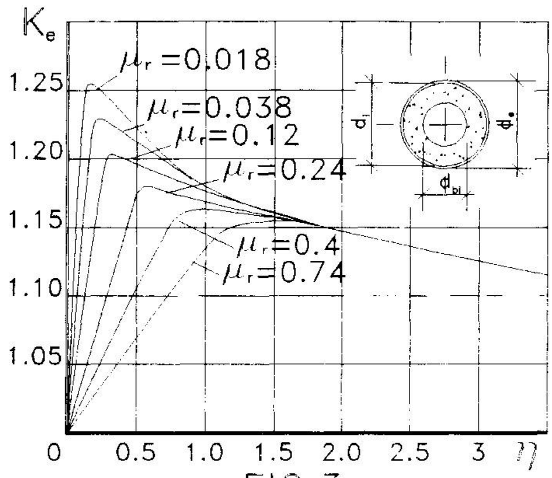

FIG.3

4.Conclusions

1. An improved ductility of concrete core and steel shell allows enhance the strength of concrete filled steel tubular members with great efficiency and safety.
2. The improved ductility of loaded concrete cores and circular steel shells allows to prepare the quite accurate way for analysis of ultimate strength of short composite elements on the base of principles of the theory of plasticity.
3. Design procedure of various composite members is most efficient and reliable if based on the results of design of short concrete filled circular steel tubular columns.

REFERENCES

1. Proceedings of the Second International Speciality Conference on Concrete Filled Steel Tubular Structures. Harbin, China, 1988.- 322p.
2. Proceedings of the Third International Conference on Steel - Concrete Composite Structures. Association for International Cooperation and Research in Steel - Concrete Composite Structures. Fukuoka, Japan, 1991.- 739p.
3. STEEL CONCRETE COMPOSITE STRUCTURES. Proceedings of the 4th International Conference held by ASCCS. Košice, Slovakia, June 20th - 23th 1994. - Bratislava, Expertcentrum, 1994. - 604p.
4. MUSKHELISHVILI I., Some of Fundamental Problems of Mathematical Theory of Elasticity. Moscow: Science, 1966.- 708p. (in Russian).
5. SOKOLOVSKI B., Theory of Plasticity. Moscow: Higher School, 1969.- 606p.(in Russian).
6. GOODE C.D., Composite Columns - State of the Art. - Steel - Concrete Composite Structures. Proceedings of the 4th International Conference held by ASCCS. Košice, Slovakia, 1994.- pp 63-69.
7. ENV 1994-1-1: 1992 Eurocode 4. Design of Composite Steel and Concrete Structures. Part 1.1. - General rules and rules for buildings. British Standard Institution, London.