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Slenderness Limits for Thin-Walled Steel Concrete Filled Box Columns

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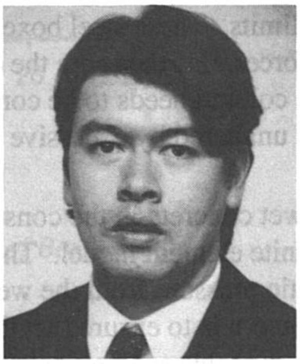

Brian Uy, born in 1970 received his Bachelors and Doctorate in Civil Engineering from the University of NSW. Since graduation he has worked on the design of multistorey buildings with Ove Arup and Partners, Sydney and he is currently lecturing in structural engineering. His main research interests include the application of composite construction in multistorey buildings.

Summary

This paper is concerned with slenderness limits of the thin steel plate used in the construction of concrete filled steel box columns. Requirements for limits on plate slenderness are outlined for construction, service and ultimate loads. Construction loading with regard to axial forces and hydrostatic pressure of wet concrete is considered and the time effects of concrete on the steel plate is studied for service loads. Finally inelastic and post-local buckling under ultimate loads is addressed and a set of experiments is used to calibrate a series of numerical models.

1. Introduction

The initial development of concrete filled steel columns saw the use of hot rolled steel sections for these members, (Bridge[1],Shakir-Khalil and Zegiche[2]). Hot rolled steel sections such as rectangular, square or circular sections used in the past were typically of plate thickness suitable to avoid local buckling when the columns were unfilled and hollow. The prevention of local buckling is important as it allows the columns to be designed to take full account of the steel strength. The relatively thick steel plate of hot rolled steel sections subsequently meant that for building construction, concrete filled steel columns were not widely used because of the exorbitant cost of using a steel section essentially as reinforcement. Their major use has been in highly seismic environments such as Japan where the thick steel sections prolonged local buckling and provided confinement to the concrete core. Furthermore the limitations of hot rolled steel section sizes manufactured as hollow steel columns has limited the geometric size of columns used which meant that for very tall buildings the sizes were unsuitable.

In Australia, a reassessment of concrete filled steel columns has been recently undertaken and consultants and contractors have developed techniques which allow these columns to be extremely competitive in terms of construction. Consulting Engineers, Ove Arup and Partners and Connell Wagner have utilised very thin walled fabricated steel box or tubular columns respectively to act as erection columns, (Watson and O'Brien[3] and Bridge and Webb[4]). These columns typically resist construction loads for several levels prior to the concrete being pumped inside. The use of these columns in Australia has been mainly in tall buildings where thin steel plate is utilised. This paper highlights the importance of each of the construction, service and ultimate loading stages for the choice of the slenderness limit of the steel plate used in these columns.

2. Construction Loading Stage

During construction, a concrete filled steel column is subjected to both axial force from the constructed levels in addition to the hydrostatic pressure from the wet concrete which is pumped inside. The economy of concrete filled steel box columns is influenced by the amount of steel and therefore the steel plate thickness used. Generally box columns are designed with very thin steel plate thus generating large slenderness limits. These steel boxes must be designed against yielding and buckling under the imposed axial forces. Furthermore the effects of wet concrete inducing hydrostatic pressure on the walls of the column needs to be considered so that the final constructed geometry of the columns is unaltered by excessive lateral deflections.

Uy and Das[5] studied the effects of the wet concrete in the construction stage of a concrete filled steel box column using a folded plate finite element model. The presence of the axial load from the constructed floors and the hydrostatic pressure from the wet concrete was incorporated in the analysis. During this stage the main concern is to ensure that the deformations caused by the imposed loads are minimised. The results of this analysis are summarised in the curves of Fig. 1 which shows the effects of the slenderness limit (b/t) and the number of levels being pumped, N_s on the maximum deflection of the column centreline.

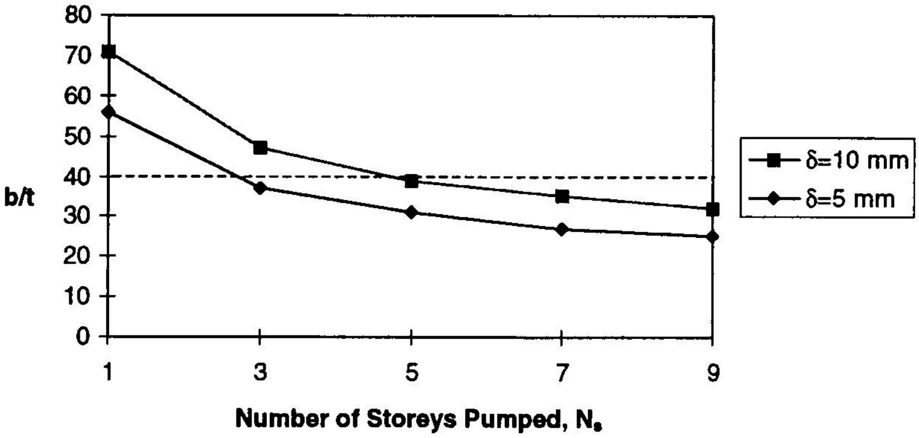

Fig. 1. Allowable Slenderness Limits for Wet Concrete Pumping (L=4,000 mm; b=1,000 mm)

A further study was carried out by Uy and Das[6] on the effects of intermediate bracing of concrete filled thin walled steel box columns. This study was undertaken to determine a strategy during construction to minimise lateral deflections without having to increase the steel plate thickness to excessive values which would render the method uneconomical. The study considered various bracing strategies while adopting slenderness limits which would be appropriate for ultimate strength and service loading. The results of a typical analysis with a column of 1,000 mm width and 4,000 mm height is shown in Fig. 2. The figure shows a deflection profile for a particular pumping strategy for a braced and unbraced column, where H is the height above the base of the column and δ is the lateral deflection of the steel plate. It is worth comparing the results of Fig. 1 with those presented in Fig. 2 for a column with a plate slenderness of 40. It is shown that in order to satisfy a maximum deflection of 5 mm, only two levels can be pumped without the presence of bracing. However the concrete can be pumped to five levels when three intermediate braces are used. This strategy is desirable for the construction of tall buildings as it greatly speeds the rate of construction and minimises the amount of steel plate necessary.

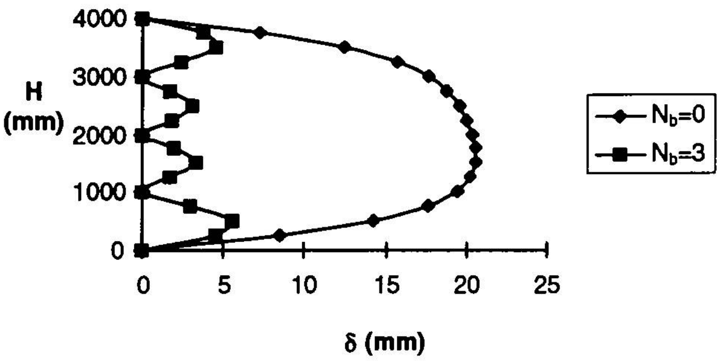

Fig. 2 Maximum Lateral Deflections of Box Column (b/t=40; b=1000 mm, N_s=5)

3. Service Loading Stage

Uy and Das[7] have developed an age adjusted effective modulus method which allows for incremental loading and creep and shrinkage of the concrete for columns in a tall building. The effects of creep and shrinkage determined from experimental research by Terrey et. al[8] and Morino et. al[9] have been used in the determination of the stress redistribution and the total axial shortening of these columns. The analysis was carried out to consider a typical concrete filled steel column for a 60 storey building using a fairly large section.

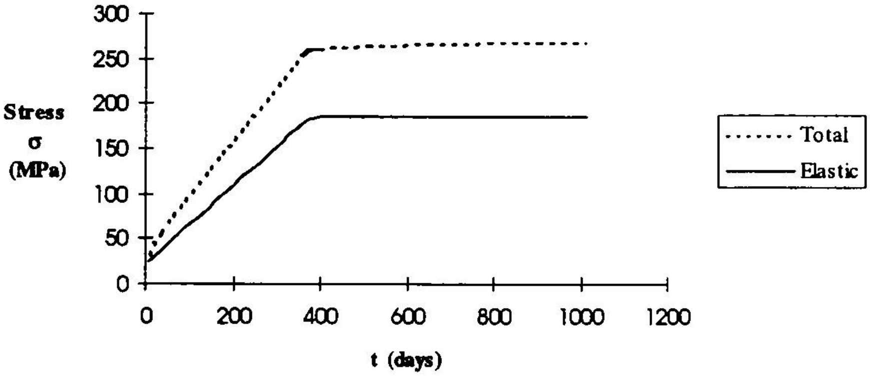

Fig. 3 Steel stress versus time

The results of the stresses and strains on a lower storey column were calculated as these would be the most heavily loaded columns in a building. The effects of creep and shrinkage of concrete in a concrete filled steel column will cause a redistribution of stress to the steel plate. This results in the steel stress increasing by 45 % from 180 MPa to 260 MPa as illustrated in Fig. 3. The effects of creep and shrinkage of the concrete on the slenderness limits are therefore significant and this illustrates that the onset of local buckling may occur prior to ultimate loads being reached.

4. Ultimate Loading Stage

Whilst it has been shown that the construction and service loading stages are very important and have an effect on the choice of the slenderness limit, it is the ultimate loading stage which usually governs the plate slenderness limit of a column. An optimum design requires that the steel box is able to develop it's full yield stress. One of the major advantages in allowing such a column to develop it's full yield stress is to ensure that the full amount of steel is being utilised prior to buckling. In order to identify appropriate values of the slenderness limit, two studies have been undertaken. Box column experiments were used to determine the local and post-local buckling behaviour of the columns. Furthermore an inelastic finite strip local buckling analysis was carried out and calibrated with the experiments.

4.1 Box Column Experiments

As part of a series of ultimate strength experiments on concrete filled steel box columns, several columns were tested purely to determine the local and post-local buckling behaviour of the steel plate by applying load to the steel box only. Table 1 outlines the dimensions and properties of these experiments. These experiments were useful in the determination of the local buckling stress in addition to the extension of a post-local buckling model originally developed by Uy and Bradford[10] for profiled steel sheeting. Table 1 also illustrates the yield stress σ_y and residual stress σ_r determined from tensile coupon tests and strain gauge measurements. The maximum load achieved N_{us} was recorded and the load at which buckling first occurred N_{ol} is given. The maximum load given by gross yielding is calculated as N_y. From these results the ratio of the local buckling stress to yield stress is determined and the effective width of the steel plates is also calculated. These will be used in comparison with the numerical models in the next section. A typical failure of these specimens is illustrated in Fig. 4 for specimen NS5 after inelastic local buckling has occurred showing the local buckle at mid height.

Test No.	b (mm)	b/t	σ_y (MPa)	σ_r (MPa)	N_{us} (kN)	N_y (kN)	N_{ol} (kN)	σ_{ol} (MPa)	σ_{ol}/σ_y	b_e/b
NS5	180	60	300	55	517	659	450	205	0.68	0.78
NS11	240	80	300	57	563	875	500	171	0.57	0.64
HS5	120	40	300	45	450	443	430	291	0.97	1.02
HS11	150	50	300	47	488	551	465	253	0.84	0.89

Table 1. Local Buckling Tests

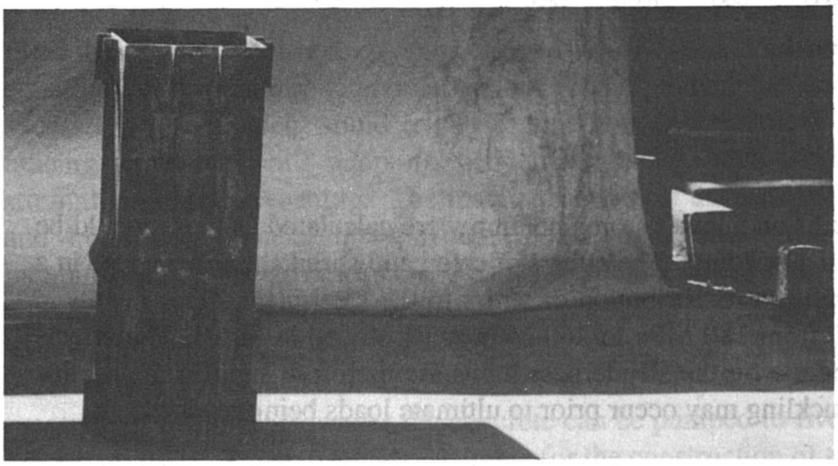

Fig. 4. Local Buckling Specimen NS5

4.2 Finite Strip Local Buckling Analysis

A finite strip method developed previously by Uy and Bradford[10] has been recently augmented by Uy[11] to consider the local buckling of welded steel box columns incorporating residual stresses. Results of this analysis are included in Fig. 5 which highlights the importance of the residual stresses in the elastic range. The box column experiments are also compared with the finite strip analysis in Fig. 5 and these suggest that the residual stresses of these columns are quite substantial. It should be noted that the local buckling stress is difficult to determine from tests and requires further investigation. The effective widths of the box columns are compared with the semi-empirical model of Uy and Bradford[10] and AS 4100[12] using a rational local buckling coefficient. The results illustrate the influence of residual stresses as the box column experiments allow less redistribution than profiled steel sheets. It is suggested that the AS4100[12] approach should be used as it is shown to be conservative.

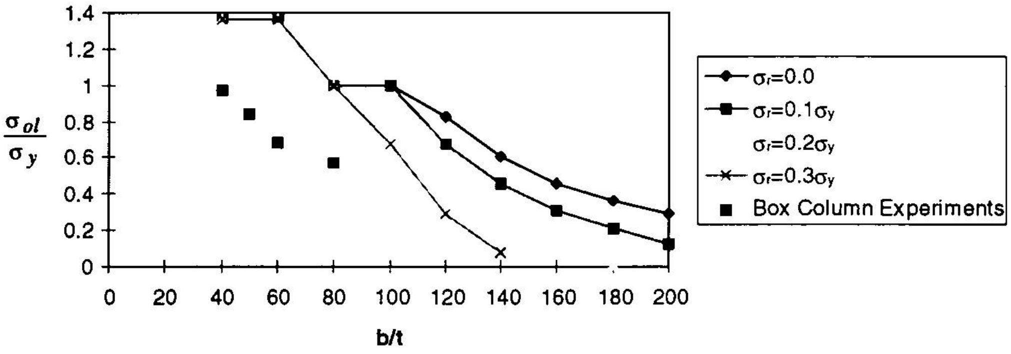

Fig. 5 Effect of Residual Stresses on Local Buckling Stress (σ_y=300 MPa; Pure Compression)

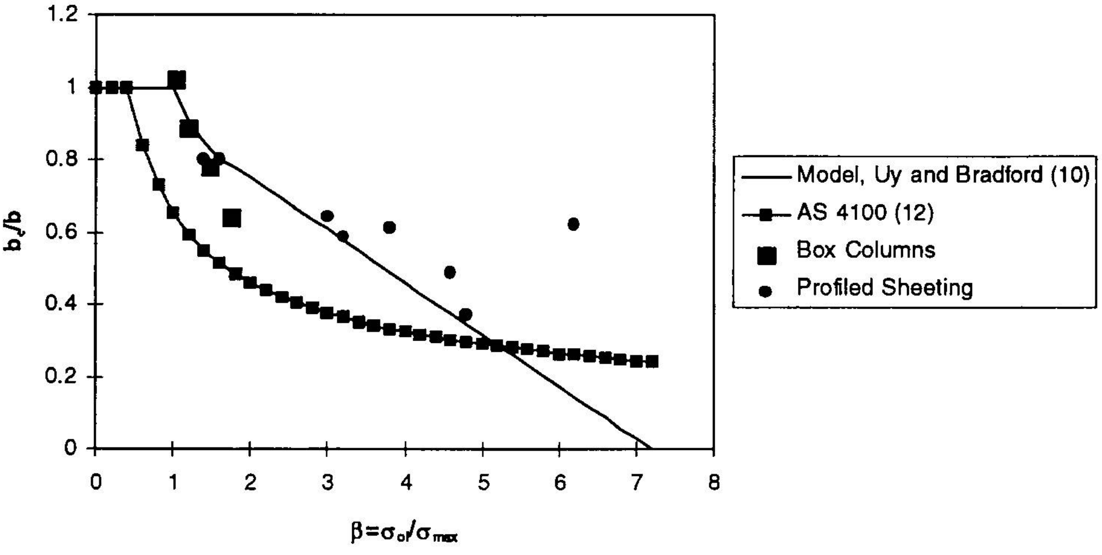

Fig. 6. Effective Width Model

5. Conclusions

This paper has presented research on the construction, service and ultimate load behaviour of the steel box in a concrete filled box column and has shown the importance of considering each of these loading stages for the steel plate slenderness selection. Further research is necessary and experimental work is currently being conducted into the construction, service and ultimate load behaviour of these members which will provide further data on the effects of the concrete on the steel plate.

6. Acknowledgements

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