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State of the art report on steel–concrete composite columns

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Abstract

Steel–concrete composite columns are used extensively in modern buildings. Extensive research on composite columns in which structural steel section are encased in concrete have been carried out. In-filled composite columns, however have received limited attention compared to encased columns. In this paper, a review of the research carried out on composite columns is given with emphasis on experimental and analytical work. Experimental data has been collected and compiled in a comprehensive format listing parameters involved in the study. The review also includes research work that has been carried out to date accounting for the effects of local buckling, bond strength, seismic loading, confinement of concrete and secondary stresses on the behaviour of steel–concrete composite columns.

Introduction

Two types of composite columns, those with steel section encased in concrete and those with steel section in-filled with concrete are commonly used in buildings. Basic forms of cross-sections representative of composite columns are indicated in Fig. 1. Concrete-encased steel composite columns have become the preferred form for many seismic-resistant structures. Under severe flexural overload, concrete encasement cracks resulting in reduction of stiffness but the steel core provides shear capacity and ductile resistance to subsequent cycles of overload.

Concrete-filled steel tubular columns have been used for earthquake-resistant structures, bridge piers subject to impact from traffic, columns to support storage tanks, decks of railways, columns in high-rise buildings and as piles. Concrete-filled steel tubes require additional fire-resistant insulation if fire protection of the structure is necessary. Because of the increased use of composite columns, a great deal of theoretical and experimental work has been carried out.

This paper presents the state of art knowledge on steel–concrete composite columns including experimental and analytical studies. A summary of experiments reported in literature is presented in a tabular form. The discussion includes behaviour of short and slender composite columns. Use of high strength concrete in composite columns is briefly outlined. A detailed discussion on the effect of local buckling, bond strength, confinement of concrete, seismic behaviour and secondary stresses on composite columns are presented.

Section snippets

Short columns

In the early stages of loading, Poisson's ratio for concrete is lower than that for steel, and the steel tube has no restraining effect on the concrete core. As the longitudinal strain increases, Poisson's ratio of concrete which is 0.15–0.2 in the elastic range increases to 0.5 in the inelastic range [1]. Therefore, the lateral expansion of uncontained concrete gradually becomes greater than that of steel. A radial pressure develops at the steel–concrete interface thereby restraining the…

Slender columns

Slender columns are generally subjected to compression and bending. Failure occurs when the conditions of stressing under which stable equilibrium is no longer possible

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between internal and external forces. At this point, for minimal added strain, the increase in external bending moments is more than that the section can take. The elastic critical buckling stress of an ideally straight column is written as: $f_{cr}=N_{cr}A=\pi^2 E(L/r)^2$This expression is non-dimensionalized as$\bar{N}=f_{cr}f_y=1\lambda^2$ where $\lambda=(L/r)\lambda_E$ and λ_E…

Experimental studies

Some of the earlier tests on composite columns were carried out by Burr [4], and were followed over the years by more experimental and theoretical studies by other researchers. Experiments were conducted to obtain basic information to serve as an aid to analyse modeling or to formulate design criteria. The following sections presents summary of experiments on both encased and in-filled composite columns tested by various researchers with a view to establish their behaviour and load-carrying…

Use of high strength concrete in composite columns

High strength steel has several advantages in its applications to tall buildings. Improvement in ductility of high strength steel has enhanced the research activities in this area. High strength and low weight are beneficial in seismic design with seismic response being reduced by the low weight of a structure. The stiffness in concrete increases with its characteristic strength. Higher strength concrete has an effective initial modulus of elasticity that increases roughly in proportion to the…

Analytical studies

Ultimate load of a column can be defined as the highest load for which an equilibrium-deflected shape can be obtained, in other words the load at which the column stiffness becomes zero. Principal factors that make the determination of the ultimate load complicated are the non-linear material characteristics of both concrete and steel, geometrical imperfections and residual stresses in the steel section. It involves sub-division of the cross-section into a number of slices to allow the strain…

Shear resistance and bond strength

The use of mechanical connectors may be necessary in special circumstances in which the limiting bond stress is likely to be exceeded for example in the presence of significant transverse shear on the column, and also in the case of dynamic and seismic loading. For a smooth steel surface, the mechanical resistance is of less importance than for an embossed or irregular steel surface. The influence of an interface pressure on the force transfer is therefore more important for a smooth steel…

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Ductility

It is often necessary to determine the ductility or rotational capacity of a given column. The curvature ductility, defined as the ratio of curvature at ultimate load to the curvature at yield, can be obtained analytically by studying the moment curvature relationship. Kitada [33] described the difference in local buckling modes between cross-sections of steel and composite columns, the difference in cross-sections between composite columns in bridge piers and buildings. It is observed that the …

Seismic behaviour

Partially-encased composite steel–concrete beam-columns under cyclic and pseudo-dynamic loading was presented by Elnashai and Elghazouli [35], [36]. Provision of additional transverse bars intended to inhibit local buckling at large displacements and to increase the interaction between the two materials was considered in the study. The modified section seemed to be showing significant improvement in the ductility and energy absorption capacity under cyclic and transient dynamic loading. After…

Effect of local buckling

Thin-walled circular composite columns used in many constructions have to be designed to account for the confinement effect of concrete restraint against local buckling of steel tube. Design of the steel casing using a rational analysis for local buckling would lead to considerable saving on material cost. A concrete-filled tube has a local buckling capacity of about 50% more than that for unfilled tube since the steel tube is restrained against buckling inwards by the concrete infill [43].…

Long-term effects

The physical properties of concrete are such that it contracts while setting followed by a lengthy period of shrinkage and of creep under load. Increasing lateral strain accompanied by transfer of stress from concrete to steel results in reduction of ultimate load capacity of slender columns subjected to eccentric load. In theory, shrinkage of the concrete is more effectively restrained in steel–concrete columns than

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in ordinary reinforced concrete columns. Because of the humid conditions...

Effect of confinement

Circular hollow sections provide a significant amount of confinement while this effect is negligible in the case of rectangular sections. Additional strength occurs because of the increase in compressive strength of the concrete core that is restrained laterally by the surrounding steel tube. This increase in concrete strength outweighs the reduction in the yield strength of steel in vertical compression due to the confinement tension needed to contain the concrete. The confinement effect is...

Comparison with steel columns

The basic buckling modes of steel and composite columns are illustrated in Fig. 8 [33]. In the case of concrete-filled steel tubular columns, concrete inside the tube prevents inward-buckling modes of the steel tube wall, and the tube-wall in turn provides effective lateral confinement to the concrete inside the tube. Typical examples of load–average strain curves for steel and concrete-filled column are shown in Fig. 9.

The unloading response of the tubes becomes rapid in case of composite...

Design codes

Over the last two decades, researchers have suggested analytical methods and design procedures for composite columns and design codes have been formulated. Each of these codes is written so as to reflect the design philosophies and practices in the respective countries. Over the last two decades, different specific codes for the design of concrete filled steel tubular columns have been used....

Conclusions

Considerable progress has been made during the last two decades in the investigation of steel–concrete composite columns, and information available is summarized in this paper. The details of experimental works available are given in Table 1 for encased composite columns and in Table 2 for in-filled composite columns. The tables provide information such as number of tests, section shape, loading type, variables considered in the study and the origin of work, etc. Fundamental knowledge on...

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