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A comparative study of environmental performance between CFST and RC columns under combinations of compression and bending

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ABSTRACT

To better understand the environmental performance of columns and assist construction designers in achieving a balance between structural requirements and environmental protection, this paper assessed and compared the EI of columns constructed with two concrete types (CFST and RC) and three cross-sections (circular, rectangular and square) under different combinations of compression and bending. The BEPAS model categorized the columns' EI into two safeguard areas—ecosystem and natural resources, and then expressed the impacts using the EIV index in unit of "yuan". Based on the assessment results and M-N interactive curves, M-N-EI interactive curves were developed to present the EI of columns under various combinations of axial force (N value) and bending moment (M value). Thus, structural performance and environmental performance can be shown in a single figure to conveniently contribute decision-making. The M-N-EI interactive curves were also compared to optimize choices of environmentally friendly concrete types and cross-sections to satisfy structural bearing capacity requirements. Moreover, the influences of various parameters, the H/B of rectangular columns, steel ratio of RC columns, steel strength, steel recycling rate and solid waste recycling rate, were analyzed. An engineering scenario was served as a case study to test the application and operation of the assessment methodology and M-N-EI interactive curves. The results indicate that the new curves can effectively express the EI of columns under different combinations of compression and bending and can potentially be used by the construction industry to achieve environmental goals and provide clear implications for practice.

1. Introduction

RC and CFST columns are widely used building components in China's construction industry. RC columns consist of a mixture of concrete and steel to overcome concrete's relatively low tensile strength and ductility by including reinforcement. In contrast, CFST columns are composite material systems and are constructed of steel tubes filled with concrete (Choi and Xiao, 2009) and this type of column is often described as "1 + 1>2" (Han, 2007). CFST columns have a number of distinct advantages over RC columns regarding structural performance (Nethercot, 2003; Wardenier and Met Staal, 2002). The concrete infill is confined by the steel tube, resulting in a triaxle state of compression that increases the strength and strain capacity of the concrete and delays local buckling of the steel tube by preventing inward buckling. Besides, CFST columns can be constructed easily and rapidly without formwork, which also reduces construction costs (Nie et al., 2008; Wang et al., 2013). Because of their better mechanical performance and lower cost, CFST columns have been increasingly employed in a variety of buildings, bridges, tower structures, and large-span structures over the past several decades (Han, 2007; Yu et al., 2010).

Research on CFST and RC columns is currently focused on their mechanical behaviors and includes experimental studies, theoretical models, finite element models, fiber beam-column models and other analyses (Gourley et al., 2001; Wang et al., 2013; Yu et al., 2010). Roeder et al. (2010) addressed combined axial and flexural loading and predicted the stiffness and resistance of circular CFST columns based on 122 specimens. An and Han (2014) developed a finite element analysis model to analyze the performance of concrete-encased CFST columns under combination of compression

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Nomenclature

CFST	Concrete-filled steel tube
CFSTc	Concrete-filled steel tube with a circular cross-section
CFSTr	Concrete-filled steel tube with a rectangular cross-section
CFSTs	Concrete-filled steel tube with a square cross-section
RC	Reinforced concrete
RCc	Reinforced concrete with a circular cross-section
RCr	Reinforced concrete with a rectangular cross-section
RCs	Reinforced concrete with a square cross-section
D	Outer diameter
B	Outer width
M	Moment
N	Axial load
f_y	Yield strength of the steel
ρ	Steel ratio
t	Thickness of the steel tube
LCA	Life cycle assessment
EI	Environmental impact
EIV	Environmental impact value

and bending. Yang et al. (2014) investigated the experimental behavior of 12 CFST members, 4 reference hollow structural section members and 4 reference plain concrete members under local bearing forces. These works explored the mechanical performance and constructional properties of columns using many methods, and their results lay a foundation for our study.

There is a lack of awareness regarding the EI of columns and its relationship with the bearing capacity, although the importance of the environmental performance of structural members in building design has been highlighted (Nadoushani and Akbarnezhad, 2015). The existing building EI assessment studies have compared different building types, construction technology methods and some important construction materials. Dodoo et al. (2012) analyzed the life cycle primary energy balances of a concrete-frame building and a wood-frame building. Nadoushani and Akbarnezhad (2015) assessed the life cycle carbon footprint of concrete-frame and steel-frame buildings. Mao et al. (2013) calculated and compared the characteristics of the greenhouse gas emissions of prefabrication and conventional construction methods. Rodríguez-Alloza et al. (2015) assessed the EI of warm mix asphalt mixtures. Li et al. (2011) evaluated the environmental performances of commonly used commercial concretes with 6 different strength grades. The EIs of CFST and RC columns have not yet been studied or elucidated, let alone an integration assessment of structure and environment performances. This paper attempts to fill this gap to help easily know about the EI of columns as well as its relationship with the bearing capacity, further help structure design and selection.

Therefore, the present study aimed to quantify and compare the EIs of CFST and RC columns satisfying structural bearing capacity requirements. Previous research addressing columns' structural performance (M-N interactive curves) and building environmental assessment model (BEPAS) provides a basis for our study. The EIV index was calculated to express the quantified EI values of columns from an economic perspective. M-N-EI interactive curves were first developed to explore the relationship between the structural performance and the environmental performance of columns, and the influences of certain parameters were discussed. Finally, an engineering scenario served as a case study to illustrate the function of the M-N-EI interactive curves and test their application. The newly developed M-N-EI interactive curves enable designers to consider environmental sustainability in addition to cost and quality when designing columns.

2. Methodology

2.1. M-N interactive curve

The M-N interactive curve is often used in construction design to express the bearing capacity of the axial force (N value) and bending moment (M value) of a column. Fig. 1 shows a typical M-N interactive curve. Generally, balance failure occurs when the column bears the maximal M value, and it divides the M-N interactive curve into two stages: First, a decrease in N leads to an increase in M, the point at which the compression-controlled failure occurs. During this stage, the initial yielding of the extreme tensile fiber of the steel does not occur when the compressive concrete is crushed. In the other stage, tension-controlled failure takes place, in which a decrease in N leads to a decrease in M. During this stage, the initial yielding of the extreme tensile fiber of the steel tube occurs before the compressive outer concrete is crushed.

M-N interactive curves consist of the combinations of N and M a column can bear and are often employed to analyze columns' structural performance. An and Han (2014) applied this method to determine the behavior of a concrete-encased CFST column under different combinations of compression and bending and further explored how the M-N interactive curves change when some parameters, such as concrete strength, steel strength and diameter of the cross-section, vary. In addition, some investigators developed a set of curves to assist in structure design. Nie and Tao (2009) compared the M-N interactive curves of CFST columns with different cross-sectional types and areas and then offered a practical optimization method to aid the cross-section choice. The "Concrete Structure Calculation Manual" (Wu, 2002) summarizes the M-N interactive curves of many structural members (beams, columns and slabs) with different cross-sectional dimensions to make design rapid and simple. These two studies yielded results are especially applicable to Chinese construction projects because they comply with the major Chinese design codes and construction standards for structural members, such as "Code for design of concrete structures" (Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) and

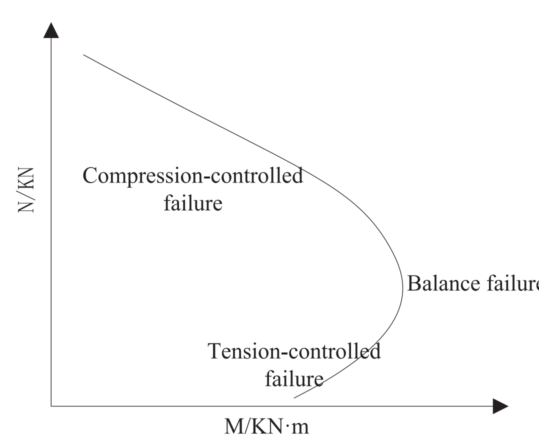

Fig. 1. M–N interactive curve.