Energy and Buildings 118 (2016) 301–315

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Design model for analysis of relationships among CO_2 emissions, cost, and structural parameters in green building construction with composite columns

Byung Kwan Oh[a], Jun Su Park[a], Se Woon Choi[b], Hyo Seon Park[a,*]

[a] Department of Architectural Engineering, Yonsei University, Seoul 120-749, Republic of Korea
[b] Department of Architecture, Catholic University of Daegu, Gyeongsan-si 712-702 Republic of Korea

ARTICLE INFO

Article history:
Received 16 February 2016
Received in revised form 2 March 2016
Accepted 5 March 2016
Available online 8 March 2016

Keywords:
Embodied CO_2
Sustainable design model
Green building construction
Greenhouse gas
Optimal design model

ABSTRACT

Although a concrete-filled steel tube (CFT) column, which is one of the composite columns frequently used in building construction because of its structural performance, economic feasibility, and good space utilization, has a high potential to reduce CO_2 emissions because of combining two heterogeneous materials, the relationship among CO_2 emissions, cost, and structural parameters in green construction of buildings with CFT columns was not yet carried out. In this study, an optimum design model was proposed to analyze the relationship. Based on the analysis, it was founded that CFT with circular sections were more effective than square type in terms of CO_2 emissions and cost by 57.03% and 11.18%, respectively, while square type was advantageous in aspect of space utilization than the circular section by 9.73%. Also, with the consideration of various strengths of materials, CO_2 emissions, cost, and space utilization for the columns can be reduced by 24.38%, 29.66%, and 21.08%, respectively. In addition, the proposed model was applied to construction of a 35-story real building. From the analysis of optimum designs for the building, the circular section was more advantageous than square section regarding the CO_2 emission and material cost by 2.47% and 8.57%, respectively, while square section occupied smaller space than circular section by 17.95%. It is concluded that CO_2 emission, cost, and space utilization of the column in the real building can be reduced by 21.05%, 14.97%, and 20.18%, respectively, with the optimum section type and material strength.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

The production of greenhouse gases (GHGs) around the world has caused global environmental problems such as climate change, global warming, and sea-level rise. In 2004, it was estimated that CO_2 accounted for approximately 77% of the total GHG emissions, and annual CO_2 emissions have increased by 80% since 1970 [1]. Buildings are important energy consumers and account for 40% of the total global energy consumption. This building energy consumption has increased CO_2 emissions, which are the main cause of GHGs. Therefore, there are ongoing efforts to reduce and manage the CO_2 emissions produced by buildings.

The life cycle of a building is generally divided into the design and material production phase, transport and construction phase, and operation and maintenance phase. A case study [2] on the CO_2 emissions of a mid-rise (35-story) apartment building's life cycle, which had a 50-year life span, reported that the CO_2 emissions during the building's life cycle were divided into 28.6% in the design and material production phase, 3.2% in the transport and construction phase, and 67.9% in the operation and maintenance phase. Thus, the largest CO_2 emission phase in buildings is the operation and maintenance phase. In the operation phase, energy is consumed for cooling and heating, as well as ventilation, to provide a comfortable indoor living space for building residents, which produces CO_2. Much effort has gone into reducing the CO_2 emissions produced during the operation phase of a building [3–5]. However, buildings consume CO_2 not only in the operation and maintenance phase, but also prior to this, such as in the design and material production phase, and the material transport and construction phase, which are also generally considered in attempts to reduce CO_2 emissions [6–9]. According to one study [2], the CO_2 produced in the design and material production phase and the material transport and construction phase accounts for approximately 32% of the CO_2 produced during the entire life cycle of the building. In the

* Corresponding author. Fax: +82 2 365 4668.
E-mail addresses: hspark@yonsei.ac.kr, hspark462@gmail.com (H.S. Park).

http://dx.doi.org/10.1016/j.enbuild.2016.03.015
0378-7788/© 2016 Elsevier B.V. All rights reserved.

design phase, the sizes of the building's structural members are determined, along with the amounts of building materials. CO_2 is emitted when these structural materials are produced. For example, the CO_2 emissions produced during the manufacture of cement (which is mainly used in building construction) amounts to approximately 307 million metric tons annually [10], and therefore cannot be ignored.

In the design phase of a building, the amounts and layout of the structural materials are determined to satisfy the safety and serviceability requirements of the building. Accordingly, much effort has gone into minimizing the CO_2 emissions produced during the manufacture and construction of structural materials, and such methods are called sustainable structural design (SSD). This design method aims to satisfy all of the structural constraints while minimizing the production of CO_2 by calculating the CO_2 emissions in accordance with a life-cycle assessment (LCA) database and the strength of the structural material. Studies on minimizing the CO_2 emissions of building structures have mainly focused on reinforced concrete (RC) structures. RC is composed of concrete and steel rebar. Therefore, there is room for design optimization because of the differences in the material costs and CO_2 emissions of these two components. Purnell [11] compared the designs of basic structural member components in RC building structures and discussed the relationships between the CO_2 emission and the strength, length, and load resistance capability of the structural members. In another study [12], the CO_2 emissions were considered when designing the optimum RC columns. In this process, the effects of various design factors were analyzed, and the designs were assessed using environmental indices. In addition to studies on members, studies on RC frame structure design have been conducted using optimization techniques to find the optimum designs while considering the CO_2 emissions [13–16]. These optimum design studies considered not only the existing safety, but also the environmental friendliness. However, most of these studies on environmental friendliness have been limited to RC structures, with only a few studies conducted on composite structures, which are often applied to the column designs for building structures.

Composite columns have the advantages of steel's high tensile strength and ductility, as well as concrete's high compressive strength and rigidity. The properties of composite columns, such as their high strength, high stiffness, high ductility, and large strain energy absorption, can help to reduce the column cross-sections. Thus, composite columns have been widely employed in the framing systems for high-rise buildings [17]. One study [18] reported that 54% of high-rise buildings taller than 200 m employed composite members, and their use continues to increase. Such composite members include concrete-filled steel tube (CFT) columns, in which steel tubes are filled with concrete. These CFT columns play a load-resistance role in buildings by combining two heterogeneous materials: steel and concrete. The material costs and CO_2 emissions vary considerably during the production of the two materials for composite columns, depending on the strengths of the materials. Therefore, it is possible to derive the optimum design to reduce the CO_2 emissions through the appropriate combination of the two heterogeneous materials. For CFT columns, which have many advantages in terms of structural performance, as well as the constructability and material cost, there is a potential to further reduce CO_2 emissions with the same or lower material costs, depending on how appropriately the material strengths and amounts are combined.

Thus, in this study, an optimum design model that can minimize the CO_2 emissions of the CFT columns in buildings was proposed to analyze the relationship among CO_2 emissions, cost, and structural parameters. In the optimum design process, the cross-section type of CFT column, material size, and strength of each material are set as structural design parameters. The objective function is established as the amount of the CO_2 emissions of the CFT column and minimized using genetic algorithm (GA), which is one of the widely used optimization techniques, while satisfying design code-based structural safety considered as constraint functions. For various load scenarios obtained by combining various required moment and axial loads, the optimum designs were obtained by the proposed design model. For the derived optimum SSD results of the CFT column, (a) the CO_2 emissions, (b) structural material cost, (c) space utilization capability, and d) structural performance were examined in terms of (i) material composition of the section (width or diameter of concrete and thickness of steel tube), (ii) section type used in the CFT columns (e.g., circular and square types), and (iii) material (compressive and yield) strengths. Furthermore, based on the optimum design results for total 2,500 loading scenarios, a CO_2 emission function for SSD of the CFT columns were provided for design guideline and the environmental assessment of the CFT column. Finally, the optimum sustainable design model for CFT column was applied to an actual building design and the obtained design results were analyzed in view of environmental performance, structural weights and composition of design variables in CFT column.

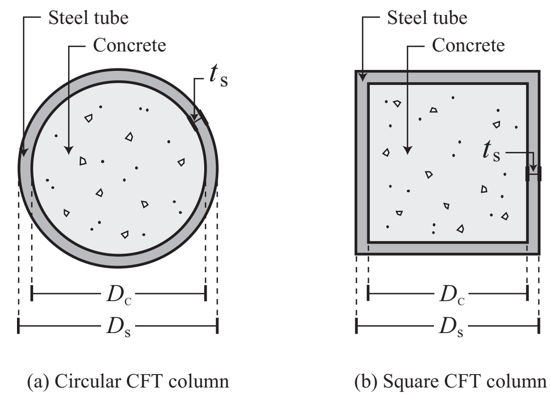

Fig. 1. Cross-sections of CFT columns.

2. CFT columns in building

A CFT column is composed of two materials (concrete and steel). The strength of each complements the weakness of the other, which provides a superior load resistance performance. Thus, CFT columns have been widely used as the main columns of various buildings, including high-rise buildings, for a lateral force resistance system [20]. The steel tube of a CFT column significantly improves the ductility of the concrete core by completely wrapping it in steel. Simultaneously, the concrete effectively prevents the local buckling of the steel tube, which produces a much larger local buckling strength than that of a hollow steel tube [17].

CFT columns are divided into square and circular shapes, as shown in Fig. 1. Because a square CFT column has a high cross-sectional second moment, it has a higher flexural resistance than a circular CFT column with the same amount of structural material. In contrast, a circular CFT column has a large and uniform flexural rigidity in all directions of the column, which is an advantage when it is used as a compressive member, compared to other types of members.

A design method for columns using two materials (concrete and steel) has been developed and applied [21]. The codes of the American Concrete Institute (ACI) [22] and American Institute of Steel Construction (AISC) [23], which are typical design codes for concrete and steel, respectively, provide two different practical design methods for CFT columns because of the combination of the steel and concrete materials. The ACI considers CFT columns as general

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات