Environmental Impact Assessment Review 31 (2011) 253–260

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

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

Life cycle CO_2 evaluation on reinforced concrete structures with high-strength concrete

Sungho Tae, Cheonghoon Baek *, Sungwoo Shin

Hanyang University School of Architecture & Architectural Engineering 1271, Sa 3-dong, Sangrok-gu, Ansan, Gyeonggi-do, 426-791 Korea

ARTICLE INFO

Article history:
Received 17 September 2009
Received in revised form 12 July 2010
Accepted 13 July 2010
Available online 30 August 2010

Keywords:
Life cycle CO_2
High-strength concrete
Reinforced concrete structure

ABSTRACT

The purpose of this study is to evaluate the environment performance of high-strength concrete used in super tall buildings as material of environmental load reduction.
To this end, this study proposed a plan for the evaluation of energy consumption and CO_2 emission throughout the life cycle of the building, and calculated the energy consumption and CO_2 emission throughout the life cycle of tall apartment building that was actually constructed using this plan.
Then, we evaluated the energy consumption and CO_2 emission reduction performance for the life cycle of the building by the decrease of concrete and reinforced rebar quantities and the increase of building lifespan obtained through conversion of existing building's concrete compressive strength to 40 MPa high-strength concrete.
As a result, the life cycle energy consumption in case 3, a high-strength concrete building, decreased 15.53% and 2.95% respectively compared with cases 1 and 2. The evaluation of the general strength concrete buildings and the life cycle CO_2 emission also decreased 16.70% and 3.37% respectively, compared with cases 1 and 2.

1. Introduction

Global warming, resource depletion and pollution are causing many countries to adopt environmentally-friendly policies. According to the report of the Environmental Protection Agency (EPA), energy consumption and CO_2 emissions of buildings in the United States are responsible for 70% of the entire energy consumption and 38% of the entire CO_2 emissions of the country (Damtoft et al., 2008; Sjostrom, 2001). Construction is an environmentally demanding industry requiring mass consumption and disposal. Architectural production activities should focus on sustainable development to reduce the environmental load of design, construction work, maintenance and disposal (Zhang et al., 1990; Kim, 1995; Li, 2006). Under The World Trade Organization (WTO) system, international organizations such as the United Nations (UN), Organisation for Economic Co-operation and Development (OECD), and International Organization for Standardization (ISO) have considered techniques to reduce global warming, create environmentally sound and sustainable practices and set up compulsory regulations for environmental load reduction (Ardente et al., 2008; Forsberg and Malmborg, 2004).

Skyscrapers have been constructed more frequently since the early 2000s due to their increased land efficiency and recent progress in modern construction techniques, and recently, a considerable amount of attention has been paid to environmentally sound and sustainable "green" buildings. Skyscrapers are advantageous for supporting broad greens and open space, and reducing the building-to-land ratio. Their weak points include lack of social contact and ground connections, and difficulty with natural ventilation. Research and development under the principle of Environmentally Sound and Sustainable Development (ESSD), is now firmly established as an international paradigm (Gao et al., 2009; Lai and Yik, 2009; Giridharan et al., 2007).

Hence, the purpose of this study is to evaluate environment performance of building by the application of high-strength concrete mainly used in super tall buildings as material of environmental stress reduction (hereinafter "high-strength concrete building").

To that end, this study proposed a plan for the evaluation of energy consumption amount and CO_2 emission amount throughout the life cycle of building, and calculated energy consumption amount and CO_2 emission amount throughout the life cycle of tall apartment building actually constructed (hereinafter "existing building") by using this plan.

Thereafter, this study evaluated energy consumption and CO_2 emission reduction performance for the life cycle of building by the decrease of concrete and reinforcing bar quality obtained through conversion from existing building's concrete compressive strength to 40 MPa high-strength concrete.

2. Method of evaluating environmental load for the life cycle of building

2.1. Overview

This study assessed the environmental load of a structure through its life cycle with stages classified into construction, use/maintenance and

* Corresponding author.
E-mail address: baek76@hanyang.ac.kr (C. Baek).

0195-9255/$ – see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.eiar.2010.07.002

removal/disposal. Construction included material production, transportation and construction work on the site. Inter-industry relation analyses were carried out to measure the CO_2 released during material production. Use/maintenance was divided into use of a building and its maintenance steps, and it was analyzed by considering the assessment period and the life of the building, based on the annual energy consumption. Removal/disposal was divided into removal of a structure and disposal of the removed wastes.

Fig. 1 and Table 1 show the classification of buildings by the method of environmental load evaluation and evaluation items for the life cycle of building proposed in this study respectively. In addition, expressions (1) and (2) show the calculations of energy consumption and CO_2 emission for the life cycle of building (Shin, 2007).

$$LCE = \sum E_{ij} \tag{1}$$

$$LCCO_2 = \sum CO_{2ij} \tag{2}$$

where, LCE is life cycle energy consumption (MJ/m^2), $LCCO_2$ is life cycle CO_2 emission (kg-CO_2/m^2), E_{ij} is life cycle energy consumption (MJ/m^2) for each stage (i) and material (j), CO_{2ij} is life cycle CO_2 emission for each stage (i) and material (j), and E = 1: construction stage (1–1 = material production step, 1–2 = transportation step, 1–3 = construction work step), 2: use/maintenance stage (2–1 = use step, 2–2 = maintenance step), 3: removal/disposal stage (3–1 = removal step, 3–2 = disposal step).

2.2. Construction stage

The construction stage was divided into three steps: material production, transportation and construction work. The material production step ranged from gathering raw materials to producing building materials to be used in the construction work stage. The transportation step refers to transporting building materials to the construction sites. The construction work step ranges from starting construction to construction completion. The construction stage was also divided into three kinds of work: construction work, public work and facility work. The energy consumption and CO_2 emissions were determined for each kind of work. The construction work included 17 types of sub-work, including temporary, pile, reinforced concrete, masonry, waterproofing, tile, stone and steel works. The public work was composed of three types of sub-work: a retaining wall and waterproofing, pile, and appurtenant public works. The facility work included 17 types of sub-works including facility, piping of machine rooms and gas piping works.

The energy consumption and CO_2 emissions during construction material production were calculated by applying a unit of a construction material, which was drawn by inter-industry relation analyses, to the material volume to be used for buildings (Lee et al., 2009).

Table 1
Classification of environmental load assessment.

Stage	Classification	Sub-classification
1. Construction stage	1) Material production step	① Construction work. ② Public work. ③ Facility work
	2) Transportation step	① Transportation
	3) Construction work step	① Construction work. ② Public work. ③ Landscaping work. ④ Power consumption
2. Use/maintenance stage	1) Use step	① Power consumption. ② Heating energy. ③ City gas consumption
	2) Maintenance step	① Improvement and repair
3. Removal/disposal stage	1) Removal step	① Removal
	2) Disposal step	① Loading. ② Returning

2.2.1. Material production step

Energy consumption and CO_2 emission for the production of each construction material are computed, as described above, based on the inter-industry relation analysis.

Material production step is the stage of calculating the CO_2 emission and energy amount consumed to produce the construction materials used in building construction. At this time, the energy consumption and CO_2 emission to produce each construction material are based on inter-industry relation analysis as mentioned above. Therefore, through identification of the material quantity put into the construction of buildings, the energy consumption and CO_2 emission in the production of the construction materials used in the building intended for evaluation can be calculated.

$$E_{C\text{-}M} = \sum M_{ij} \cdot COST_m \cdot U_{M,E} \tag{3}$$

$$CO_{2C}\text{-}M = \sum M_{ij} \cdot COST_m \cdot U_{M,CO_2} \tag{4}$$

where $E_{C\text{-}M}$ (MJ/m^2) is energy consumption of material production step, M_{ij} (Unit/m^2) is the amount of construction material (j) used for the construction type (i), $COST_m$ (Won/Unit) is the cost of construction material (m), $U_{M,E}$ (Mj/Won) is the basic unit of energy consumption for construction material (m), $CO_{2C\text{-}M}$ (kg-CO_2/m^2) is CO_2 emission of material production step, and $U_{M,CO2}$ (kg-CO_2/Won) is the basic unit of CO_2 emission for construction material (m).

2.2.2. Transportation step

Energy consumption and CO_2 emission of transportation step can be computed based on transportation method, transportation distance, load on the transportation vehicle, and expenditure of oil and power used for transportation. However, records on equipment use

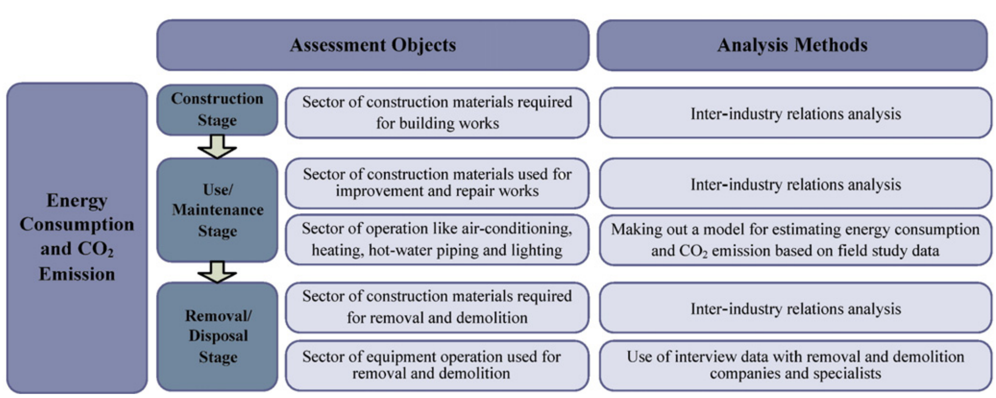

Fig. 1. Method of environmental load assessment.