

Improvements on Life Cycle Assessment: Proposal of Consideration on the Optimum design of High rise steel structure

Yuri Kim¹, Seong Uk Hong², and Young Sang Cho³

¹Hanyang University, Ansan, Korea

²Hanyang University, Ansan, Korea

³Hanyang University, Ansan, Korea

ABSTRACT: There has been agenda in Kyoto protocol that one nation has to reduce certain amount of CO₂ emission and green house gas emissions, as interests and concerns on the environment get higher. Life cycle assessment were developed to evaluate the environmental function of one building and estimate CO₂ and green house gas emissions. Besides, as the number of high rise buildings is increasing over the globe, there have been great developments in construction technologies and structural systems. In high rise buildings, the structural system affects to the entire life cycle cost and gas emissions due to the change of the amount of materials used. This study is for suggesting Life Cycle Assessment to consider the optimum design of the structure. This study will be the fundamental study for developments of LCA methods in near future.

Keywords: life cycle assessment, structural system, high rise steel buildings, LCCO₂

INTRODUCTION

1. BACKGROUND AND PURPOSE

1.1 Background

According to Kyoto protocol, it became mandatory to reduce GHG (Green House Gas) emission to average 5.2% in 38 countries comparing to the emission of 1990. So, it is significant to consider environmental function of buildings. LCA (Life cycle assessment) is a methodology to calculate environmental loading of buildings, including LCCO₂ and GHG emissions.

LCA tools have been developing in many countries and SBTool, LEED, BREEAM,

and CASBEE are tools which evaluate environmental function of buildings through the whole life cycle. Evaluation of these tools can be one parameter of environmental function, so tools have to cover through whole part of environmental function. It has been studied that optimum structural design can decrease LCCO₂ emission due to the reduction in material use. Adapting structural system can be significant in high rise buildings in the respect of the material use, life cycle cost, and GHG emissions.

2.2 Method and purpose of the study

In this study, it is investigated the effect of structural systems to the emission of

LCCO₂, GHG emissions, and Life Cycle cost of buildings.

As a result, the purpose of this study is to suggest the consideration of optimum structural design in LCA. Adapting three cases of structural systems, structural design is performed then LCCO₂ emission is calculated; structural cases are as followed.

- A. Basic model
- B. Braced system (X type and Chevron)
- C. Out-rigger system

Using structural analysis and design software (MIDAS-Gen), structural design of three different cases are performed limiting the lateral deformation less than $H/400$ (H is the total height of structure). Based on the structural design result, LCCO₂ is calculated. As a further study, LCA considering optimum design is performed and the results are compared with LCA tool.

2. STRUCTURAL SYSTEMS OF HIGH RISE BUILDINGS

Control of lateral deformation is the main interest in high rise buildings due to the affect of the earthquake or wind load which is critical to the height of the buildings. Adapting structural systems which resist lateral force raise the strength of structural members to control the lateral deformation. In this study, braced system of X type and Chevron and outrigger system is under investigation.

2.1 Braced system

Braced system is a horizontal cantilever truss which supports structural elements with axial stiffness. Generally, adapted to over 30 story-buildings, it has relatively large stiffness comparing to its material use.

One of the structural characteristics is that it has low ductility but has high rigidity so this system is used in the regions where earthquake is not frequent. Also, it is

mainly used as a sub system in high rise buildings to ensure the safety of structures.

2.2 Outrigger system

Outrigger performs as a cantilever wall or a truss which connects exterior columns. Inner columns are consists of shear walls or braced horizontal trusses.

Boundary condition is rigid connection with inner core and pin connections with exterior columns.

According to previous studies, Taranath [1] suggests the location of outrigger is $0.455H$ for adopting one outrigger and in the case of adopting two outriggers, $0.312H$ and $0.685H$.

3. OUTLINE OF THE STUDY

3.1 Outline of the object building

The basic model of the study is J building in B-Project. Floor load is calculated and applied by the procedure of general steel structures. Wind load is applied to the Sungnam.

LCA methods can be divided by two categories of LCA for the Building Material and Component Combinations (BMCC) and the Whole Process of the Construction (WPC) [2]. LCA for BMCC is regarding the environmental loading and impacts of materials and energy used in whole life cycle of the building. WPC includes to the range of resident's quality of life and cultural and social impacts of the building. WPC is making decision and supporting tool to make a green building.

In this study, the object LCA tools are LCA for WPC. SBTool, LEED, CASBEE, and BREEAM are representative LCA for WPC tools. Especially, SBTool will be investigated because of its well-organized evaluation system and quantitative parameters. Also, SBTool for tall building is under development. This study is for suggesting structural issues in LCA for high rise buildings so it can be the fundamental

study in development of SBTool for high rise buildings.

2.3 Parameter analysis of SBTool

Table I: Parameters and indicators under issues on energy use and environmental loading

Issues	Parameters	Indicator [unit]
Energy and Resource consumption	Non/Renewable energy	Embodied energy per unit area for unit year [GJ/m ² *yr]
	Electrical peak demand for facility operation	The peak monthly electric demand [MJ/m ²]
	Minimal use of materials (finishing/virgin)	The percentage of above-grade interior floor, wall, ceiling surface areas [%]
	Potable water	Site area not/requiring watering [m ²]
Environmental loading	Greenhouse gas emission	CO ₂ equivalent emissions per Kg. per m ² of gross area [GJ/m ² *yr]
	Other atmospheric emission	Emission of GHG equivalent per year in kg. per unit area
	Solid waste	Volume of solid waste [m ³]
	Water use	Estimated total water use [L/day]

SBTool has seven issues which are the largest divisions;

- A. Site selection, project planning and development
- B. Energy and resource consumption
- C. Environmental loadings
- D. Indoor environmental quality
- E. Service quality
- F. Social and economic aspects
- G. Cultural and perceptual aspects

Here, two issues, B. Energy and resource consumption and C. Environmental loading, have relations with the structural systems.

Following table shows the parameters under the issues. Parameters are calculated or derived based on the indicators. In embodied energy, electrical peak demand, GHG emission and so on, it is figured out that these parameters are based on the unit area, or gross area of the building. For that reason, there is no consideration on the total volume or weight of the structure itself in parameters except solid waste parameter. Also, it is assumed that there are parameters are connected to the total volume or weight of the building, or to the construction phase. When there is reduction of material use due to adapting optimum structural system.

4. CASE STUDY

4.1 Outline and limitations

Object building is J building of B-project in Korea. Using this building design which has no lateral force resisting system, adapting lateral resisting structural systems, the total usage of materials is calculated and compared based on the structural design result of each case. Load condition is shown in Table II and Table III. Also allowable maximum lateral displacement is 263mm which is H/400 (here, H means the height of the building.)

Table IV: Floor load

Load type		Load(kg/m ³)
Dead load	Concrete	250
	Metal deck	15
	Interior/Partition	75
	Steel self-weight	50
	Total	390
Live load	Residential	200
	Total	200

Table V: Wind load condition

Region	Wind velocity	Class	Note
Kyeonggi-do (Korea)	25	A	Inland(I)

4.2 Model cases

Actual building of this object model is concrete structure. In this study, it is changed to steel structure from concrete structure. Based on the basic model which has no lateral force resisting system, these are structural systems to be adapted to the basic model as followed and modelling results are shown in Figure 1, Figure 2, and Figure3.

- i. Case 1: Basic model
- ii. Case 2: Braced system (X type)
- iii. Case 3: Braced system (Chevron)
- iv. Case 4: Outrigger system

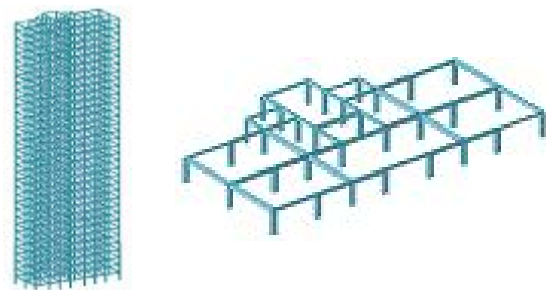


Figure 1: The basic model without any structural system and the typical story structure

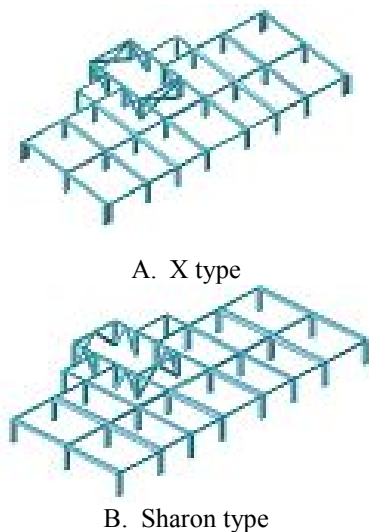


Figure I: The model of braced system (Chevron type) in the typical story

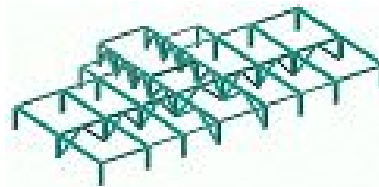


Figure 3: The model of outrigger system in the typical story

4.3 Optimum structural system and material use

Table VI: the total weight of steel and the reduction rate by cases for I building

Case	Total Weight of Steel [tonf]	Reduction rate[%]
Case 1	2,822	-
Case 4	2,414	-14.5%
Case 2	2,137	-24.3%
Case 3	2,023	-28.3%

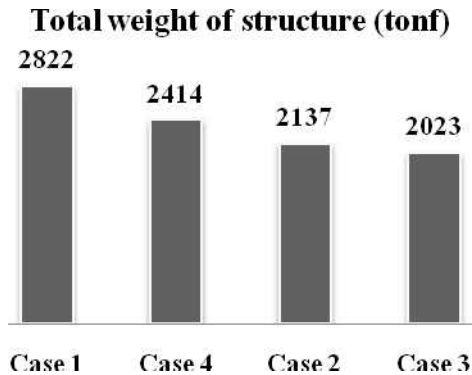


Figure 4: Comparison of the total steel weight by structural systems

Limiting the maximum lateral displacement to 263mm, by structural systems, total weight of steel is calculated based on the design result. The total weight of steel by structural design is shown in Table VII and Figure 4.

Maximum steel use occurs in basic model (Case 1) and chevron type of braced system (Case 3) shows the minimum weight in both buildings. From this result, adapting structural systems in high rise buildings can reduce the total weight of structure and total material use.

Also it is investigated by Y. S. Cho. [3]

that the reduction rate increases as the building is critical to the lateral load. In case of high rise buildings, lateral load increases significantly as building height. That means consideration on structural system in LCA is important in the evaluations on high rise buildings.

4.4 Calculation of LCCO₂ emissions based on the material use

Based on the weight of steel use in construction phase which was calculated previously, LCCO₂ emission (Life Cycle CO₂) is calculated using SUSB-LCA. SUSB-LCA ver. 1.0 is LCA program for LCCO₂ calculation and the result is shown in Figure 5. There is an assumption that CO₂ emissions during facility operation phase and demolition phase do not change in four cases. During construction phase, CO₂ emission ranges from 0.896 x10⁷kg-CO₂ to 0.986 x10⁷kg-CO₂.

Also, it is noticeable that the construction phase takes approximately 30% of all life cycle CO₂ emission in this object building. Existing parameters of estimating LCCO₂ emission only reflects the operation phase so it is required to consider the construction phase and demolition phase for more accuracy. LCCO₂ during construction phase comes from the structural material including emission during manufacturing, delivering, and construction phase.

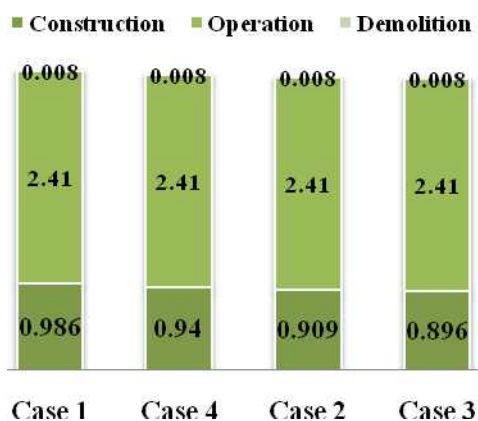


Figure 5: LCCO₂ (x10⁷kg-CO₂) emission by structural systems

5. LIFE CYCLE ASSESSMENT

Table VIII: Categories and parameters under issues with assessment score by SBTool (Case 1: Basic model)

Issue (score)	
Categories (score)	Parameters (score)
B. Energy and resource consumption (0.9)	
B1 Total life cycle non-renewable energy (0.26)	B1.1 Annualized non-renewable primary energy embodied in construction material (0.09)
	B1.2 Annual non-renewable primary energy used for facility operation (0.11)
B2 Electrical peak demand for facility operation (0.11)	
B3 Renewable energy (-0.11)	B3.1 Use of off-site energy (-0.5)
	B3.2 Provision of on-site energy(-0.5)
B4 Materials (0.57)	B4.1 Minimal use of finishing materials (-0.11)
	B4.2 Minimal use of virgin materials (0.18)
	B4.3 Use of durable materials (0.29)
	B4.4 Use of bio-based product obtained from sustainable sources (-0.17)
	B4.5 Use of cement supplementing materials in concrete (0.26)
	B4.6 Use of materials that are locally produced (-0.11)
	B4.7 Design for disassembly, re-use or recycling (0.34)
B5 Potable water (0.36)	
C. Environmental loading (1.59)	
C1 Greenhouse gas emissions (-0.03)	C1.1 Annualized GHG emissions embodied in construction materials (-0.25)
	C1.2 Annual GHG emissions from all energy used for facility operations (0.02)
C2 Other atmospheric emissions (0.43)	C2.1 Emissions of ozone-depleting substances during facility operations (2.44)
	C2.2 Emissions of acidifying (0.3)
	C2.3 Emissions leading to photo-oxidants (0.42)
C3 Solid waste (0.23)	
C4 Rainwater, stormwater and wastewater (0.12)	
C5 Impacts on site (0.66)	
C6 Other local and regional impacts (0.18)	
Total score (2.49)	

Previously, it is verified that adaptation of structural system cause reduction in entire structural weight and LCCO₂. With the result of LCCO₂ calculation, life cycle assessment is performed using existing LCA tool, SBTool in four cases of structural systems.

5.1 Life Cycle Assessment by existing SBTool [4]

Assessment was performed by existing SBTool. In this study, object two issues are considered out of seven issues which are related to material use and environmental loading which are affected by adaptation of structural systems. The issues are energy and resource consumption and environmental loading.

Figure II shows the result sheet of assessment. In energy and resource consumption, the score is 1.2 in energy and resource consumption and 1.6 in environmental loading issue when full score is 5.0. Detailed categories and parameters under issues are shown with score in Table VIII. Bolded characters are connected to the volume of structure which is reductive by structural systems.

5.2 Parameters which are affected by structural systems

Assessments were performed by structural systems on Case 2, Case 3, and Case 4. Following parameters are connected to the energy embodied in materials which are changed by structural systems and Table IX shows the variable of each parameter. For those parameters,

- B1.1 Annualized non-renewable primary energy embodied in construction material
- B4.1 Minimal use of finishing materials
- B4.2 Minimal use of virgin materials
- C1.1 Annualized GHG emissions embodied in construction materials

Parameter B1.1 shows the highest difference between Case 1 and Case 3. In Case 1, it got 1.8% while 19.2% in Case 3.

Parameters of B4.1 and C1.1 gains the same score for all cases. It is due to the influence of the structural system is not enough to change the range of benchmark causing change in the score.

Table IX: Parameters which varies by structural systems

Parameter ID	Variable [Unit]
B1.1	Embodied energy [GJ/m ²]
B4.1	The percentage of areas consists of exposed structural elements [%]
B4.2	The percentage of areas consists of non-virgin materials [%]
C1.1	The annual amount of CO ₂ -equivalent emissions [kg/m ² -yr]

Table X: Variables (weighted scores, when full score is 5.0) of parameters in Table IX

	B1.1	B4.1	B4.2	C1.1
Case 1	225 (0.09)	8 (-0.11)	30 (0.18)	40.9 (-0.25)
Case 4	201.67 (0.52)	7 (-0.11)	27 (0.14)	36.4 (-0.25)
Case 2	184 (0.83)	7 (-0.11)	25 (0.12)	33.5 (-0.25)
Case 3	178 (0.96)	6 (-0.11)	24 (0.11)	32.3 (-0.25)

5.3 Total life cycle assessment on categories of energy and resource consumption and environmental loadings by cases of structural systems

On the category B1, total life cycle non-renewable energy shows the score ranges from 0.26 to 0.42 by structural systems. As structural material use increases, the score tends to decrease significantly. That is, one of the parameters under this category, embodied energy is depend upon the total structural volume which varies by structural systems.

Category B4 is concerned with materials and it scores from 0.57 to 0.54. Area of virgin material and finishing material of the total material use is decreasing. It is assumed that decreasing rate of virgin or finishing material area is relatively less than decreasing rate of total material use.

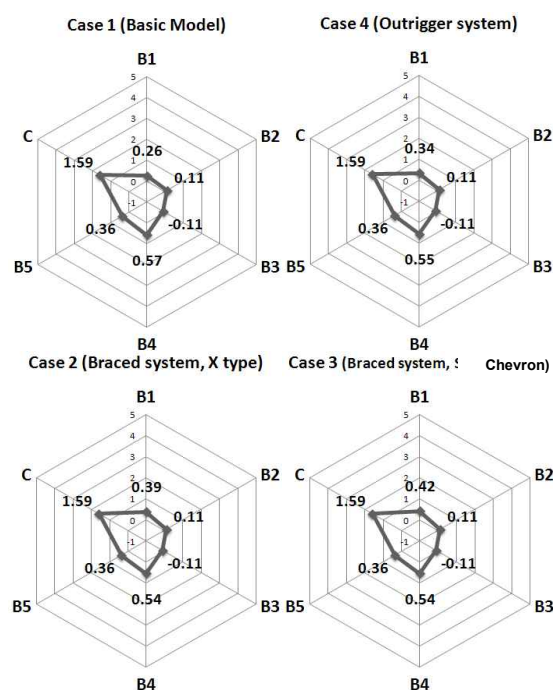


Figure 6: Assessment result on categories of B. Energy and resource consumption and C. Environmental loading

*B1: Total life cycle non-renewable energy
 B2: Electrical peak demand for facility operation
 B3: Renewable energy
 B4: Materials
 B5: Portable water
 C: Environmental loading

5.4 Proposal: Addition of the parameters on the structural system in SBTool

It is figured out that structural system is concerned with reduce the total amount of material use, LCCO₂ and other GHG emissions. Thus, the assessment result showed significant in some parameters regarding material use in SBTool.

As a result, it can be proposed that a parameter on the adaptation of structural system is added to existing SBTool to derive the optimum structural system in the pre-design phase in the building project planning which causes the minimum LCCO₂ and GHG emissions and material use for high rise buildings.

Following Table XI is the specifications of the parameter on the optimum structural system proposed.

Table XI: Proposed parameter on the optimum structural system for high rise building in design phase in SBTool

Intent	To suggest the optimum structural design, in order to minimize the direct and indirect material use and LCCO ₂ or GHG emissions.	
Indicator	The percentage of reduction by adaptation of a structural system	
Information sources	Use structural analysis and design software to derive the total structural weight by structural systems	
Benchmarks	Reduction rate is under 5%	-1
	Reduction rate is more than 5% less than 10%	0
	Reduction rate is more than 10% less than 20%	3
	Reduction rate is over 20%	5

This parameter will be effective during pre-design or design phase possible options are shown as score to help in decision making of the structural system for high rise buildings.

It has a limitation that there is only consideration on the structural issue with no consideration on the addition of the cooling and heating load results from the decrease in the volume of structure as wall or slab thick, which can be significant LCCO₂ and GHG emission factor in the operation phase of the building. In further study, this problem should be considered to derive accurate evaluation parameter through the whole life cycle.

Also, in the present evaluation parameter proposed, it is required to use the structural analysis and design program to calculate the reduction rate of structural weight. It is required to set up the library of reduction rate in the evaluation tool for convenience and independence. For this reason, it should be figured out the quantitative correlation between the reduction rate and the scale of the structure, type of structure (RC, Steel, composite, and etc.), and the structural system to establish the reasonable benchmarks for parameters.

6. CONCLUSION

In this study, models were designed by cases of the structural systems controlling the lateral deformation to 263mm, by using structural analysis and design program. From this procedure, the total weight of structure was calculated, and computed to the LCCO2 calculation program, SUSB-LCA ver. 1.0. From that result, optimum design was figure out so the fact was proved that the total weight of the structure depends on the lateral force resisting systems. Finally, each case is evaluated by LCA tool, SBTool and followings are concluded in this study.

- 1) Optimum design in this case study for the object building was the chevron type braced frame system by reducing 799tonf which corresponds to 28.3% reduction from the basic model without lateral force resisting system.
- 2) In SBTool, there are parameters are connected to the optimum design of the structural system. These parameters are under energy and resource consumption and environmental loading issues.
- 3) Evaluations by SBTool in four cases were conducted and the results shows that it got highest score by 2.91 in Chevron type of brace frame system which is adapted to the optimum structural system and minimum score in basic model by 2.78, which is the maximum weight of the structure among cases.
- 4) In SBTool, it is proposed to addition of parameters on the optimum structural system to encourage the minimum material use in the process of decision making during pre-design and design phase of the building construction.

- 5) In further study, it should be studied that quantitative benchmarks of reduction rate according to the scale of the structure, the shape of the structure, and effect of heating and cooling load.

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