

A Study of Optimum Design of High Rise Steel Structure by Braced Frame Systems and LCCO₂ Analysis

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ABSTRACT: Today there is a great interest and research on the huge structure and high rise buildings due to the development in structural technology and materials. Also, the interest in environmental issues are heightened that there is an active researches in reduction of CO₂ in every industrial fields. As a part of these researches, there is also significant increase in interests for optimized architecture. In this study, I have made a basic model of steel structure to yield the optimization system by using the lateral force resistances currently used in high rise buildings today. I have identified the minimum weight system while maintaining the iso-lateral position of the structure for each system and I was able to confirm the significant reduction in weight when compared against the basic design. As a result of this study, I estimated that through the optimized design of a structure to reduce the construction material and cost with which I would be able to offer a possibility to reduce the CO₂ emission.

Keywords: Optimum design, Steel structure, CO₂ reduction, Lateral resistance system

1. INTRODUCTION

1.1 Background and purpose of the study

Interests and research on huge structures and high rise buildings are increasing due to the developments on structural technologies and materials. Also, environmental issues are considered as important problems over the globe so as to the optimization of structural design.

Selection of a structural system is significant in high rise building, because it is almost impossible to change and it depends on the whole life cycle cost of the building. Research has been performed on minimum use of materials through adapting of the structural system and minimizing the effect

of lateral load. The important factor in structural design for high rise buildings is to have minimum size of structural members while ensuring the maximum strength. From this procedure, economical structural design can be performed.

In this study, the optimized braced system is investigated which resist against lateral load effectively. From this result, total material magnitude and LCCO₂ emission is calculated quantitatively.

1.2 Methods and process

Step 1: Calculation of structural volume on the basic model of I apartment in B-project

- Calculation of element size while basic load case is applied
- Step 2: Modelling of basic model
 - Modelling based on the calculated structural element size by structural design program
- Step 3: Adaptation of the lateral force resistant system
 - 3 types of lateral force resistant systems are adapted to the basic model and the results are compared
- Step 4: LCCO₂ analysis and derivation of the optimum design
 - Calculation of LCCO₂ by SUSB-LCA ver. 1.0
 - Derive optimum design of I building of B-project

Process of this study is shown as above, and lateral force resistance systems will be studied and based on this study, adapt these lateral force resistant systems to derive the optimum design. After all, for those cases of models, LCCO₂ is analyzed.

1.3 Range and limitations of this study

Aim of this study is to calculate the total volume of structural materials for cases of lateral force resistant systems and to analyze the affection of CO₂ reduction by systems.

The standard of lateral control is under H/400 and material use is compared among systems while the maximum lateral deformation is fixed to a certain value among systems.

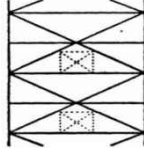
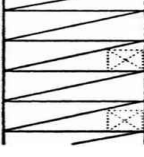
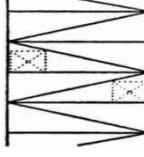
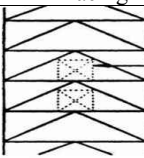
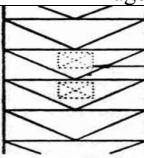
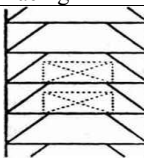
2. GENERAL INFORMATION OF BRACED SYSTEM AND OUTRIGGER SYSTEM

2.1 Braced system

Braced system is a horizontal cantilever truss which fastens corners of the structure consists of two columns and beams. The characteristic of this system is having relatively large strength by material use for over 30 story-buildings.

Table I is the types of braced systems and it is divided in two categories of centric braced frame and eccentric braced frame. In centric braced frame, axis of all elements intersects at one point in the form of X, diagonal, chevron, V, and knee so the member force is easily transformed to the axial force. Also, it is used as lateral force resistant system in the region where earthquake is frequent due to the low ductility and high strength. Usually, it is used as a sub-system which ensures the structural stability.

Table I: Types of braced frame systems

		
X Bracing	Diagonal Bracing	
		
Chevron Bracing	V Bracing	Knee Bracing

2.2 Outrigger

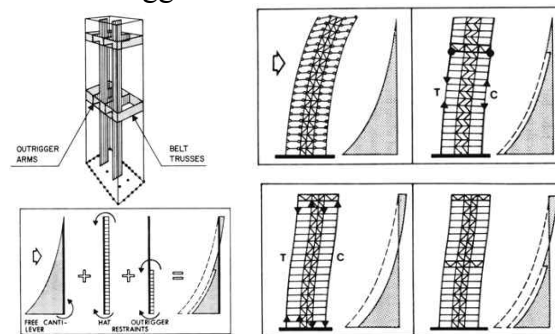


Figure 1: Principle of outrigger system

Outrigger is wall girder of truss girder which connects the inner core to the outer columns. The principle of outrigger is shown in the Figure 1. Its connection to the inner core is rigid and pin to the columns. Also, it acts like a support so create the

point of inflection to the core deformation. In the end, reduce the overall deformation.

In previous studies, Taranath[1] is suggested that $0.455H$ is the optimum position of the single outrigger and $0.312H$ and $0.685H$ of the double outriggers by McNabb[2] et al. S Smith and Salim[3] showed the optimum position of outrigger, the deformation at the top, and efficiency of moment reduction is expressed as a formula of flexural strength ratio by analysis of behaviour of structure which is applied to the distributed lateral load.

3. OUTLINE OF THE PROJECT

3.1 Outline of the object building

The basic model is I building of B-project as shown in Figure 2. The height of the building is 95,000mm with 35 stories. Table II and Table III is specifications of the floor load and wind load applied to, respectively. The calculation of the floor load is typical method for steel structures and the wind load is calculated based on the region of Sung-nam in Kyeonggi-do.

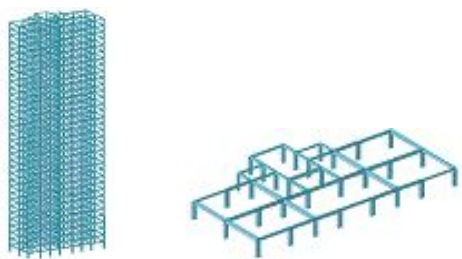


Figure 2: the basic analysis model

Table II: Specifications of static load cases of dead load and live load in the model analysis

Load type		Load (kg/m ²)
Dead load	Con'c	250
	Metal deck	15
	Interior / Partition	75
	Steel self-weight	50
	Total	390
Live load	Residential	200
	Total	200

3.2 Material reduction for lateral force resistant systems

For the object building, analysis on the material reduction is performed by limiting the lateral deformation of 237mm at the top of the building where the maximum deformation occurs. Model cases are as followed.

- Case 1: Basic model
(non-lateral force resistant system)
- Case 2: Braced frame system (X type)
- Case 3: Braced frame system (Chevron)
- Case 4: Outrigger system

Table III: Wind load condition

Region	Standard velocity for design (m/s)	Level of wind exposure	Note
Kyeonggi-do (KOREA)	25	A	Inland(I)

3.3 Grouping of structural elements

Using the structural analysis and design program (MIDAS Gen), the object building on the four cases of structural systems is designed. The group of structural elements are divided by 5 stories and there are seven groups. Table III shows element assignment in the group of the typical story (from story 1 to story 5).

Table IV: Grouping and size of the members in the typical floor

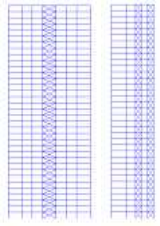
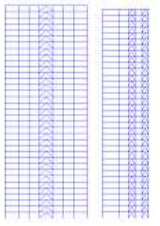
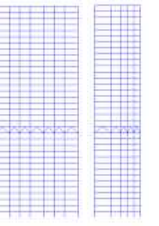
Title of element, location / size	
Column	Girder
C 1 : H458×417×30/50	G 1 : H294×200×8/12
C 2 : H428×407×20/35	G 2 : H340×250×9/14
C 3 : H498×432×45/70	G 3 : H482×300×11/15
C 4 : H498×432×45/70	G 4 : H588×300×12/20
C 5 : H310×305×15/20	G 5 : H396×199×7/11
C 6 : H428×407×20/35	G 6 : H506×201×11/19
C 7 : H498×432×45/70	G 7 : H440×300×11/18
C 8 : H428×407×20/35	G 8 : H396×199×7/11
C 9 : H344×348×10/16	G 9 : H194×150×6/9
C10 : H414×405×18/28	G10 : H294×200×8/12
C11 : H428×407×20/35	G11 : H396×199×7/11
C12 : H458×417×30/50	G12 : H298×201×9/14

Element size of the basic model is calculated based on the Table I and basic elements were chosen from the Manual of steel construction[4] and designed by structural analysis and design program until the limitation on the lateral deformation is satisfied. This is noticeable that structural design was performed increasing the number of the groups to increase the reliability and accuracy which is distinguishable with other studies.

3.4 Braced system

Table V is the model which is resulted from structural design adapting braced frame system. The type of braced system is X and chevron. Braced system is a horizontal cantilever truss which supports the lateral load with axial strength of structural members. Deformation of the braced structural system is approximately 80 to 90% of the basic system with no lateral force resistance. It is adaptable from low rise buildings to semi high rise buildings for the economical material use.

Table V: Model of braced system of X and Chevron type, and outrigger system

		
X type braced frame system	Chevron braced frame system	Outrigger system

3.5 Outrigger system

As shown in Table V, outrigger system was adapted to the basic model of Figure 2. Generally, the number of outriggers is not over 4. There used 1 outrigger for the object building is 35-story building. According to the preceding studies, it is known that

0.455H is the optimum location of the outrigger and 0.312H and 0.685H when 2 outriggers were applied. In this model, the outrigger was placed in the 15th story which is located 0.445H.

4. Model analysis

4.1 Deformation control

Models were created with the addition of the lateral force resistant systems. Limiting the maximum deformation of the model, size of the members was controlled and the material reduction rate was compared and analyzed among four systems. The reason of limiting the lateral deformation to 190mm is to limit the material reduction by the difference in the lateral deformation as shown in Table VI.

Table VI: Allowable maximum lateral deformation [mm]

Type of structural system	Lateral deformation [mm]	Allowable max. lateral deformation [mm]
Basic model	190	237
Outrigger at the 15 th floor	190	
Braced system (X type)	190	
Braced system (Chevron)	190	

4.2 Comparison on material use by cases of structural systems

Efficiency of each structural system was verified for the calculation of total material use by structural system adaptation. Figure 3 shows the material use by lateral force resistant systems and Table VII shows the reduction rate of material.

Generally, it is known that adaptation of the outrigger system cause the increase on material use for lateral resistance. In this study, it is figured that 3.9% of material increased for the case of outrigger system. However, braced systems of X and chevron

shows decrease by 6.05% and 8.00%, respectively.

According to the type of braced system it shows different rate of reduction and different affection to the lateral deformation control by total material weight.

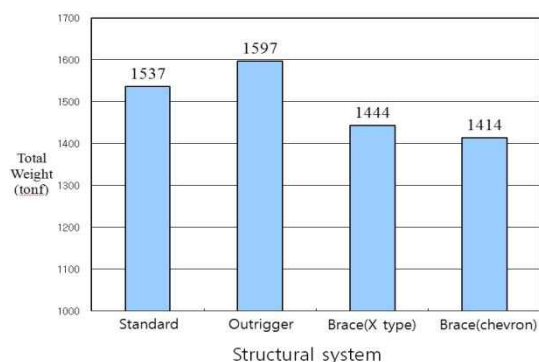


Figure 3: Total weight of structure by structural system

Table VII: Reduction rate by structural system

Type of structural system	Weight[tonf]	Reduction Rate
Basic model	1,537	-
Outrigger system	1,597	3.90%
Braced system (X type)	1,444	-6.05%
Braced system (Chevron)	1,414	-8.00%

5. OPTIMUM STRUCTURAL DESIGN MODEL

Based on the lateral deformation and the total material use performed on the steel structure, the object structure was changed from RC shear wall structure to the steel structure. As a result, it is the chevron type of braced system the optimized structural model which is shown in Figure 4. According to the Table VIII, it shows the material reduction of 8% with 123tonf reduction in material use (from 1537tonf to 1414tonf).

6. ANALYSIS ON LCCO₂

To evaluate the LCCO₂ reduction, environmental assessment program [SUSB-LCA ver. 1.0] which was developed from SUSTainable Building Research Center [SUSB] was used on the basic model of the object building, the model which was changed into steel structure from RC structure, and the model with chevron braced steel system.

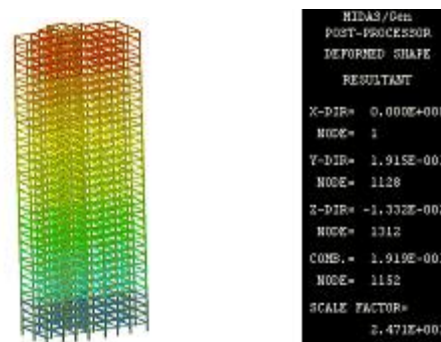


Figure 4: Optimum structural system

Table VIII: Optimum structural system

Basic model	
Maximum lateral deformation	Total weight (Steel)
190mm	1,537tonf
↓(8% reduction)	
Braced frame system (Chevron type)	
Maximum lateral deformation	Total weight (Steel)
190mm	1,414tonf

The entire life of the building was set to 40 years. Assessment was performed by SUSB-LCA ver. 1.0[5] and the CO₂ reduction rate by the material use is shown in Figure 5. 3.96% of material decreased when RC structure changed into steel structure(case 1) and the optimum design is chevron braced frame structure(case 2) with 123tonf. However, it is analyzed that the reduction rate is not significant in the construction phase.

7. CONCLUSION

It is important to guarantee the strength of structural members. Especially in high

rise buildings, lateral deformation due to earthquake or wind load is significant so it is important to control the lateral deformation by lateral force resistant system.

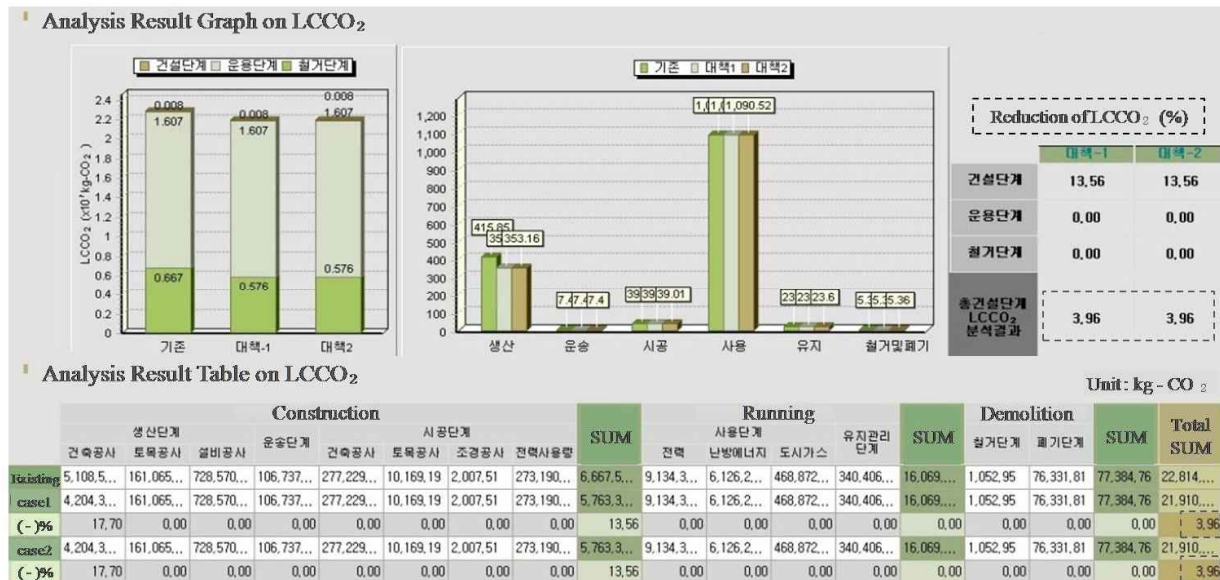


Figure 5: LCCO₂ evaluation

I building of B-project, it was adapted to braced frame system structural design was performed repeatedly to control the maximum lateral deformation by 80% reduction of the lateral deformation in the basic model which has no lateral force resistant system. As a result of this process, reduction weight of material was analyzed quantitatively.

- 1) For models with lateral force resistant systems, reduction rate of material is 6.05% to 8%.
- 2) It was occurred effective reduction of material in chevron type of brace frame system than outrigger system and chevron type of brace frame system in the same static load case and condition of the same deformation.
- 3) When RC structure was changed to steel structure, it reduced 3.96% material reduction by adaptation of optimum structural system.

In order to practice the optimum structural system for high rise buildings, it is

required to be figured the affect of the shape of the buildings and affect of the material property in further studies.

ACKNOWLEDGEMENT

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