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A robust multi-objective localized outrigger layout assessment model under variable connecting control node and space deposition

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Abstract. In this article, a simple and robust multi-objective assessment method to control design angles and node positions connected among steel outrigger truss members is proposed to approve both structural safety and economical cost. For given outrigger member layouts, the present method utilizes general-purpose prototypes of outrigger members, having resistance to withstand lateral load effects directly applied to tall buildings, which conform to variable connecting node and design space deposition. Outrigger layouts are set into several initial design conditions of height to width of an arbitrary given design space, i.e., variable design space. And then they are assessed in terms of a proposed multi-objective function optimizing both minimal total displacement and material quantity subjected to design impact factor indicating the importance of objectives. To evaluate the proposed multi-objective function, an analysis model uses a modified Maxwell-Mohr method, and an optimization model is defined by a ground structure assuming arbitrary discrete straight members. It provides a new robust assessment model from a local design point of view, as it may produce specific optimal prototypes of outrigger layouts corresponding to arbitrary height and width ratio of design space. Numerical examples verify the validity and robustness of the present assessment method for controlling prototypes of outrigger truss members considering a multi-objective optimization achieving structural safety and material cost.

Keywords: localized outrigger layout; multi-objective optimization; variable geometric connecting node; space deposition; robustness

1. Introduction

An outrigger is a stiff girder as a brace system that connects an interior core such as shear walls to exterior columns in tall buildings (Moon 2014, Piekarz 2006, Ali and Moon 2007, Kowal 2011). Opposite to low-rise buildings mainly governed by gravity loads such as dead and live loads, horizontal or lateral loads involved by wind and earthquake forces are a critical design condition to especially tall buildings. In order to make effective resistance against the critical lateral loads, a specific one of structural systems, i.e., the outrigger (Fatima *et al*. 2011, Choi *et al*. 2012, Lee and Tovar 2014, Lee *et al*. 2015, Lee 2016) presented in this study may be usually utilized to tall buildings. The outrigger system may consist of several steel truss members or reinforced concrete members, which is similar to typical triangular diagrid or Vierendeel truss structures (Lee and Shin 2014). In general, it is partially installed as a connection member between a mega column and a core structure into specific floors of a tall building. The decision of the several specific floors' installation absolutely depends on design limitation of maximal horizontal displacement at the top of the building in terms of national building design codes and standards (Korean Ministry of Land, Infrastructure and Transportation 2016). Therefore, the estimated maximal displacement becomes within the design limitation.

In order to satisfy the design limitation, a member layout or arrangement design of outrigger is another alternative, which is essential in case outrigger floors are decided or not in tall buildings. The choose of appropriate truss members layout consisting of the outrigger is one of significant issues, since it is directly linked to three key design points of building designs, i.e., construction cost, safety, and function. Especially, a design process of the outrigger layout decision would be a so-called optimized multi-objective which may simultaneously accomplish three key points, while subjected to several given design conditions such as the number of floors occupied by trusses, span length, and input materials of steel or concrete. In general, the outrigger layout as like other member designs has been achieved by qualitative methods (Hong 2014), which are based on mainly experience and intuition of engineers and designers subjected to design limitation of building codes and standards. The member design method produces case by case depending on types of tall buildings, and then time consumption and many efforts of workmanship are naturally required (Wagter 1990). For existing reinforced steel bracing designs similar to the outrigger, Lee *et al*. (2016) proposed the generalized drift curve formulations to provide better positional and connective bracing information in case sudden construction position adjustments. Although shape and connectivity

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among outrigger members absolutely affect building stiffness, the input of material, construction or product ability, definite quantitative grounds, for example such as scientific proofs and reliable optimal design tools for the decision of some outrigger system are too deficient. In recent, optimal outrigger installation problems for tall buildings were dealt with respect to service stage of structural safety and construction stage of structural stability (Zhou *et al*. 2018), however it did not consider economics of material usage.

This study presents a simple and robust assessment method with respect to both structural safety and material economics to determine angles and positions of the outrigger truss for evaluating a general-purpose prototype of non-scaled steel outrigger geometry. The present assessment method is as follows: As an initialization to make the general-purpose prototype of outrigger geometry, arbitrary ratios of height to width of a given outrigger space are defined, and then examples of outrigger layouts recommended by engineers and designers are assigned in terms of the arbitrary height and width scales of the rectangular design space. Members of the examples of outrigger are connected, and positions of the connection node are considered at 1/4, 2/4 and 3/4 of total width of design space. Second, according to a unit-load method known as the Maxwell-Mohr method (Gere and Timoshenko 1991, Kowal 2011), vertical and horizontal displacements on each cases of example outrigger layouts are calculated. Third, the present quantitative challenge for multi-objective optimization (Richardson *et al*. 2013, Deb 2013) to determine the trade-off between two objective functions of cost and displacement is introduced and examined. Finally, optimal outrigger truss layouts are chosen by minimal discrete multi-objective function (Wang 2015) of displacement and material quantity.

Consequently, the outrigger geometry prototypes of Lotte World Tower (Cho and Chung 2011, Kim *et al*. 2015), i.e., the representative high-rise building in Korea, are evaluated to use the new design method assessing optimal layouts of the example outriggers in comparison with an original plan of the outrigger. It provides pre-design information of the outrigger to designers and engineers. This leads to general-purpose prototype (Sergio *et al*. 2003), not on a case-by-case basis. The approach may reduce trial-and-error to existing building design processes (Gündel *et al*. 2012) such as full 3D structural analysis methods (Zeng and Wiberg 1989) and finite discretization methods (Akhaveissy 2012, Li *et al*. 2008) simplifying 3D building models using a 3D model for overall analysis of tall buildings.

The outline of this study is as follows. The overview of a target outrigger is presented in Section 2, including applied structural systems. In Section 3, analytical modeling and typologies of outrigger layout alternative are described. Section 4 presents formulations to generate maximal displacement through a modified Maxwell-Mohr method. Section 5 describes the proposed design criteria methods and design algorithm dealing with two types design variable of non-dimensional scaled design space and control node connected by members, associated with multi-objective functions of the displacement and cost, which can produce general-purpose prototypes of outrigger layout. Conclusions and remarks of this study are finally shown in Section 6.

Table 1 Overview of Lotte World Tower

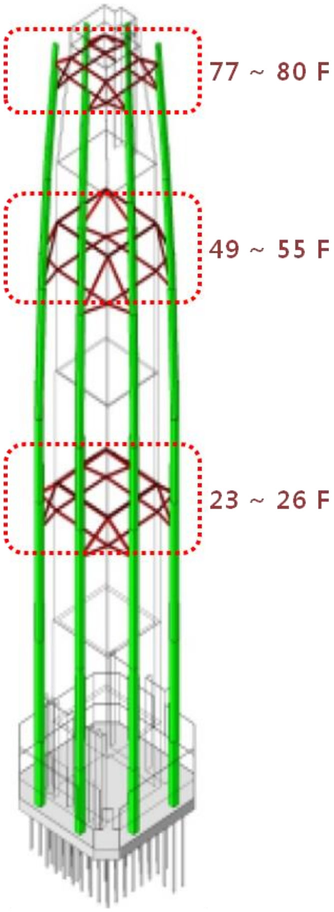
Items	Description
Location	Sincheon-dong, Songpa-gu, Seoul, Republic of Korea
Height	555 m
Number of Stories	123 stories above ground and 6 stories underground
Purpose	Hotel, office, residence, retail, etc.
Structure system	Core wall + Mega Column + Outrigger Belt Truss

2. Description and overview of a target outrigger of tall building

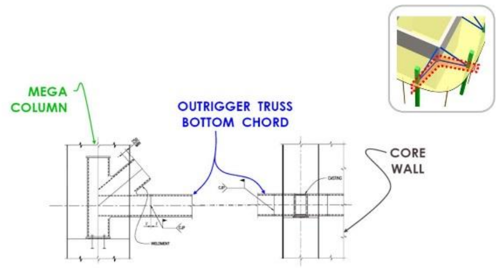
The building to which this study aims to apply the study result is Lotte World Tower (Table 1) located in Jamsil, Seoul, Korea. The final design of this building that used to be called Jamsil 2nd Lotte World Tower was determined after multiple design changes as shown in Fig. 1.

Lotte World Tower, the structure evaluated in this study, has a hybrid system where core walls, mega columns and outriggers & belt trusses are combined as shown in Fig. 2. The core walls and mega columns are RC structures, and outrigger & belt truss are steel structures (Lee and Shin 2015). As a representative lateral load resisting system, the core system is used widely in general buildings. In high-rise buildings, however, a core system alone is insufficient to resist lateral loads. Therefore, a core connected to external mega columns is used to resist, and outriggers and belt trusses are additionally installed in 3 zones including detail descriptions of outrigger members, as shown in Fig. 2.

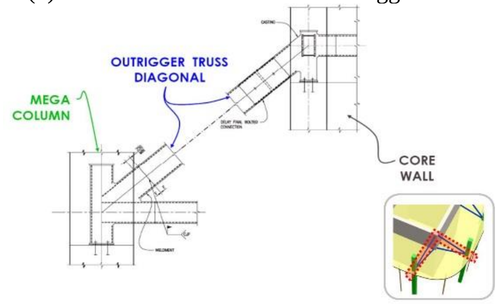
Fig. 1 Bird’s eye view of Lotte world tower project



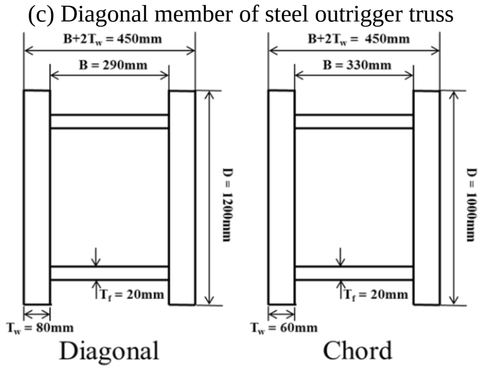
(a) Outriggers in an analysis modeling



(b) Horizontal member of steel outrigger truss



(c) Diagonal member of steel outrigger truss



(d) Cross-section of an outrigger member

Fig. 2 Details of outrigger truss system in Lotte World Tower (Lee *et al*. 2018)

3. Initialized analytical modeling and typologies of outrigger layout alternative

In order to evaluate general-purpose prototypes of the outrigger layout, a rectangular design space between mega column and core wall is assumed to take some ratios of height and width, within which the outrigger layout is assigned as shown in Fig. 3, arbitrarily chosen by engineers and designers. Outrigger layouts of 6 types in Fig. 3 are considered. Straight lines and gray-filled black circles, respectively, describe each member shape and fixed nodes for positioning outrigger layouts. White-filled black circles denote variable connecting control nodes. Type 1 presents a nominal plan of the outrigger layout to compare each other. All structural steel members are made by SM570 steel with tensile strength 570 MPa (Lee and Shin 2015), whose the yielding stress is 420 MPa, as described in Table 1. The outrigger joints are rather of a complex arrangement, therefore the assumption of pinned joints and axial force acting in the outrigger members is needed. However, it may be rather to be questionable then to be treated as an axiom. Here each outrigger end joint assumed as pinned (Wald *et al*. 2014) is buried within concrete mega column and core wall, and the outrigger at the building is successfully limiting the differential deflections between the exposed mega columns and the adjacent interior core wall.

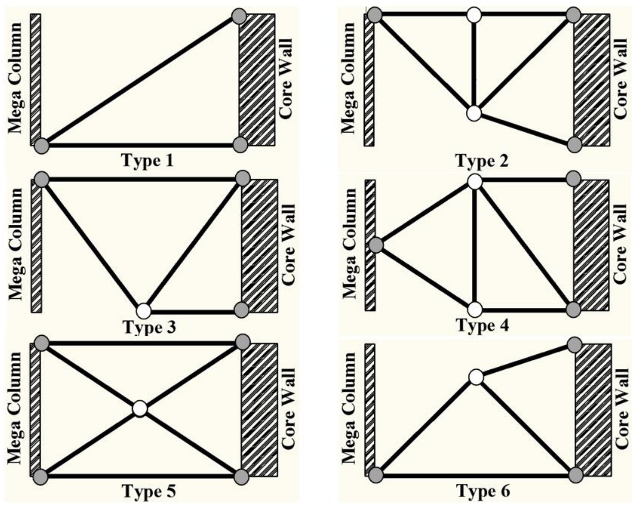


Fig. 3 Representative conceptual general-purpose prototypes of outrigger layouts recommended with connecting control nodes and fixed nodes

Table 2 Steel material properties for outrigger

Steel name	SM570
Yielding strength	420 MPa
Tensile strength	570 MPa
Young's Modulus	2×10^5 MPa
Cross-sectional area	0.5 m^2

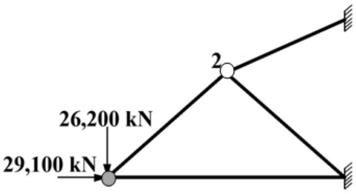


Fig. 4 Loads and boundary conditions of the typical outrigger in all types, here in case Type 6

In this study, positions of the control connecting nodes of white-filled black line circles are design variables. In terms of linear interpolation, they are assumed for the position to be divided by 1/4 interval of width. All representative general connecting nodes of white-filled black line circles as positioned in Fig. 3 are fixed vertically. Types 2 and 6 are fixed at the point of 1/4 and 3/4 of height, vertically. Note that in case Type 6, variation of vertical position of the control node is also considered as an exemplar test in Section 5.3.

The assumption for displacement response assessment criterion is as follows: The evaluation of structural performance of the outrigger alternative is conducted by applying vertical and horizontal loads on mega columns upwards and downwards, as shown in Fig. 4, and by analyzing the magnitude of displacement. The applied vertical and horizontal load criteria are assumed to be 26,200 kN (= 39,156 × sin42°) and 29,100 kN (= 39,156 × cos42°), respectively. The vertical and horizontal component of 39,156 kN at 77~80 floors as shown in in Fig. 2 that work on diagonal members are applied to the outrigger alternative. There is certainly an influence of differential displacements of the core wall and mega column, therefore the reflection of wind load and gravities is considered for analytical assessment simplicity in this study including the assumption of force currency transferred by core wall and mega column. Here, loading locations of each layout are shown as gray-filled black color circles at mega column in Fig. 3. In case Type 5, positions of variable control node and applied loading are all the same. Boundary conditions of outrigger truss members are fixed to core wall as shown in Fig. 4. Loading conditions are 26,200 and 29,100 kN of vertical and horizontal internal forces, respectively.

Because of considering the outrigger as structural truss system, all members are connected each other and the core wall as well as the mega columns by pin joints. Herein, the connection of the mega-columns to the outrigger are modeled as two spring connections (Nanduri *et al*. 2013) as illustrated in Fig. 5.

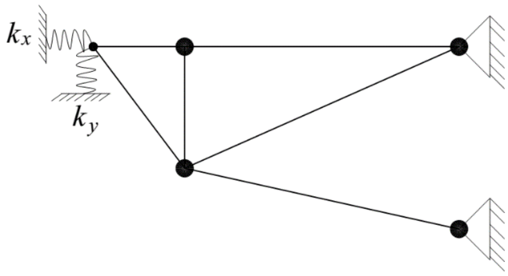


Fig. 5 Analytical model of an outrigger layout with two spring connections in all types, here in case Type 2

The stiffnesses of two springs k_x and k_y are determined by the assumption of the limited displacement of the connection point between the outrigger and the mega column, namely, $\Delta x = \Delta y = 5$ cm. Therefore, the following stiffnesses may be written as

$$k_x = \frac{P_x}{\Delta_x} = \frac{26.2}{0.05} = 524kN/m \tag{1}$$

$$k_y = \frac{P_y}{\Delta_y} = \frac{29.1}{0.05} = 582kN/m \tag{2}$$

4. A robust outrigger layout assessment method for analysis and optimization model

4.1 Modified Maxwell-Mohr equation for analysis model

A specific modified version is applied to verify the vertical and horizontal displacements of outrigger truss according to unit-load method, known also as the Maxwell-Mohr method (Gere and Timoshenko 1991). In case of the present outrigger truss structure with pinned joints which has loads acting only at the joints, a summation for all members yields the following unit-load Eq. (1) for linear elastic truss structure.

$$\Delta = \Sigma \frac{N_U N_L L}{EA} \tag{3}$$

where N_U and N_L denote virtual unit load and real axial force, respectively. E, L, and A are Young's modulus of steel, length of member and cross-sectional area.

Assumed that vertical displacements are not considered due to typical horizontal displacement limitation usually used for tall building design, horizontal displacements are only carried out in this study for analytical simplification. The design horizontal displacement (ΔU) is assumed to be the sum of all horizontal displacements for each member element. Eq. (3) shows that the displacement ΔU at any joint of the outrigger truss can be found by the following procedure : (a) determine the axial vertical and horizontal force P_V and P_U, respectively, in all members due to the actual axial loads; (b) form the expressions of $P_V L/EA$ and $P_U L/EA$ for each member; and (c) add these expressions for all members to obtain the horizontal displacement.

4.2 Multi-objective function for performance and cost-based optimization model

So far, we have investigated the total length considering the degree of deflection and economical efficiency according to each outrigger type. To make these two design criteria of deflection (A) and economical aspect (B), each objective function A and B may be written as Eqs. (4) and (5), respectively. Eqs. (4) and (5) may be combined as multi-objective assessment, i.e., Eq. (6) of both objectives in this study.

$$A = min(\|d_1 + d_2\|) \tag{4}$$

$$B = \text{total length} \tag{5}$$

$$\text{Objective function} = \min(\alpha A + \beta B) \tag{6}$$

where α and β are the impact factor of A and B, respectively, which represent the relative proportions with the sum of 1. They can be determined according to the intention of structural designers, engineers or clients. In A, d_1 and d_2 are a horizontal and vertical displacement, respectively.

The multi-objective function Eq. (8) for each design criterion of A and B, which is independent of the impact factor, can be finally derived through inequality of arithmetic mean and geometric mean of Eq. (7) as follows. Here κ denotes $2\sqrt{\alpha\beta}$.

$$\alpha A + \beta B \geq 2\sqrt{\alpha\beta AB} \tag{7}$$

$$\text{multi - objective function} = \min(\kappa\sqrt{AB}) \tag{8}$$

5. Numerical applications and discussion of the proposed outrigger prototype assessment

In Section 5, several numerical examples for the assessment method of Section 4 to generate general-purpose prototypes in terms of the outrigger layout in Lotte World Tower are executed to find the one possessing of the optimal performance. As can be seen in Section 2, the outrigger is located between mega column and core wall to effectively resist against lateral loads such as wind and seismic load and permanent gravities.

In Sections 5.1 and 5.2, the distance from the mega column to the variable control node of each outrigger is set to w_o. According to the ratio to the total w (width), the results are summarized under the design space condition of 1:1 and 1:1.5 ratio of width and height. In this study, the assessment method is proposed to investigate appropriate outrigger layouts through treating control node's position and dimension of design space in which outrigger is assigned. It is separately measured in terms of displacement for safety and total length of members for economical aspect.

Section 5.3 describes a design criteria assessment method using control nodes with the variable position of both width and height in Type 6. In Section 5.4, the present design criteria method using multi-objective functions with both displacement and cost is executed, which is followed by the present design algorithm in Section 5.5 to robustly and automatically access general-purpose prototypes of outrigger layouts.

5.1 Design criteria method – the ratio of width and height = 1.0

5.1.1 Displacement assessment of outrigger layout alternative

First, we consider that the ratio of width and height is 1.0. The value used in this study is w = h = 12 m, and then the design range of w_o is 3 m, 6 m, and 9 m. Linear interpolation is assumed between the design ranges. The point of action of the load is partly joined with the mega-column and follows the same analytical method as the general truss shape. The displacement values of the outrigger type according to the ratio of w_o and w are shown in Fig. 6. Here, horizontal and vertical displacement resulting from vertical and horizontal applied loads are considered as a representative condition, because its maximal value is usually dealt with as critical design limitation to tall building design.

As can be seen in Fig. 6, Type 2 has the largest displacement increase the rate, as the ratio of w_o and w increases. On the other hand, in case Type 4, the greatest displacement reduction ratio is found, as the ratio of w_o and w increases. Type 6 produces the smallest displacement summation of all the ratio of w_o/w, and therefore it has the best structural performance. The displacement value which varies according to the ratio of w_o / w and outrigger types cannot be generalized, but it can be estimated to some extent according to the position of control nodes considering construction and economy aspects. If so, to find the differences in the types of outriggers that are considered economically is also needed.

5.1.2 Total length assessment of outrigger layout alternative

To investigate the economical efficiency according to each type, the total length of outrigger truss member is considered in this study. The length of the truss also

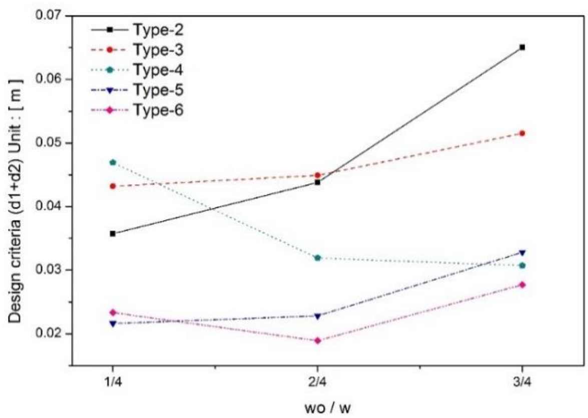


Fig. 6 Combined horizontal and vertical displacements of outrigger layouts according to positions of control node

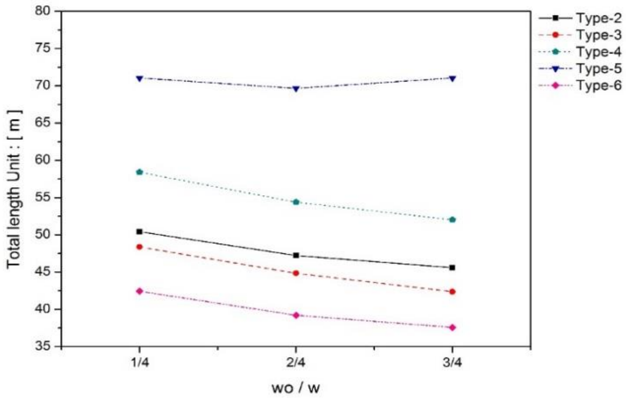


Fig. 7 Total length of outrigger layouts according to positions of control node

depends on the ratio of w_o and w. The result is illustrated in Fig. 7.

As can be seen in Fig. 7, the total steel requirement of the Type 6 outrigger system is the smallest. Since it is determined by the shape, the comparison would be easy. As the ratio of w_o and w increases, the total length of all outrigger type decreases. To examine the economics, usability, and safety of the structures, Figs. 6 and 7 should be considered simultaneously.

5.2 Design criteria method – the ratio of width and height = 1.5

5.2.1 Displacement assessment of outrigger layout alternative

In this example, the ratio of width and height is 1.5 (w = 12 m, h = 8 m). The assessment is performed in the same manner as first example, and the displacement values according to the ratio of w_o and w are described in Fig. 8. As can be seen in Fig. 8, the displacement of outrigger types according to the ratio of w_o and w tends to be similar to that of first example.

However, in comparisons with first example, when the ratio of width and height is 1.5, the value of the displacement is larger than that of width and height = 1.0. It indicates that the absolute value of the amount of displacement becomes larger, while design space is widened in the longitudinal direction.

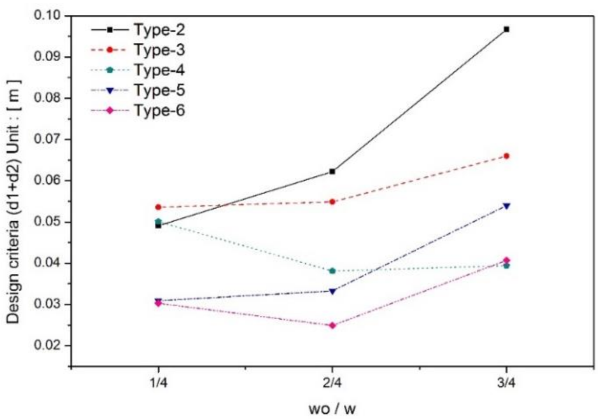


Fig. 8 Horizontal displacements of outrigger layouts according to positions of control node

5.2.2 Total length assessment of outrigger layout alternative

Such as in first case, the total length according to each outrigger type is assessed based on the ratio of w_o and w to consider economical efficiency. As can be seen in Fig. 9, the Type 6 steel requirement is the lowest such as in first case.

Also in Fig. 8, since Type 6 has the smallest amount of displacement, Type 6 is the most optimized shape as in first example.

5.3 Design criteria method: control nodes with variable position of both width and height in Type 6

In this example, ABAQUS 6.5-1 software (Khennane 2013, SIMULIA 2008) is used to simulate the outrigger system. In each type of outrigger, the variation of horizontal and vertical locations of the connecting points is considered. 6 locations of the connecting control node are dealt with and shown in Fig. 10, especially, in case Type 6.

Summed horizontal and vertical displacements of the loading point of each cases are obtained from ABAQUS 6.5-1 results. Fig. 11 presents the results of 6 control nodes cases of outrigger Type 6. In Type 6, the ratio between the width and height of the outrigger domain W:H is 4:3 (in reality, width is 20 m and height is 15 m).

The total displacements and initial angles of each cases

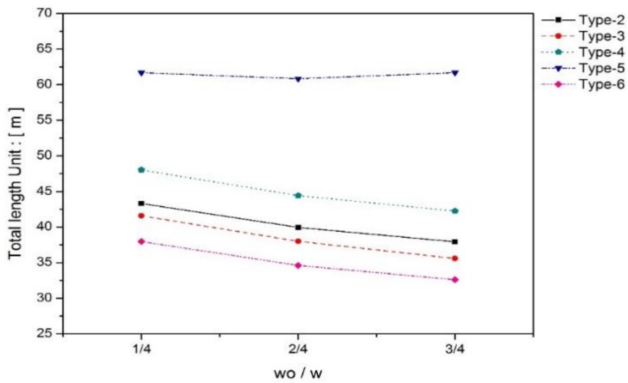


Fig. 9 Total length of outrigger layouts according to positions of control node

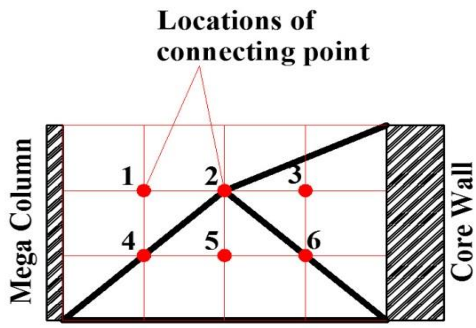


Fig. 10 Locations of the connecting point in the outrigger

Table 3 Summed horiz. & vert. displacements at loading points and corresponding angles in Type 6 and W:H = 4:3

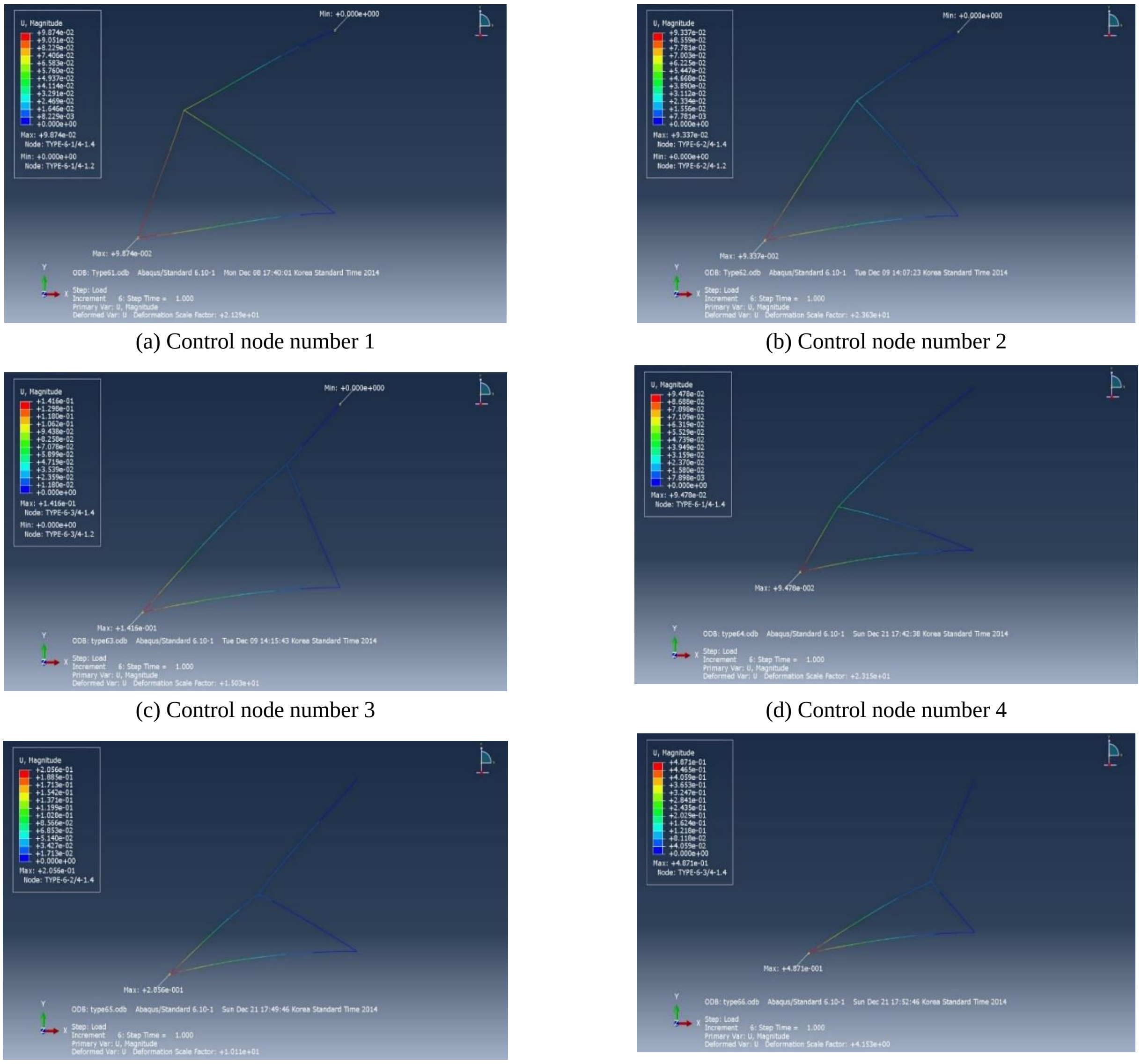
Position	1	2	3	4	5	6
Displ. (m)	9.87e-02	9.34e-02	1.42e-01	9.48e-02	2.06e-01	4.87e-01
Angle (°)	63	45	34	45	27	18

Table 4 Summed horiz. & vert. displacements at loading points and corresponding angles in Type 6 and W:H = 1:1

Position	1	2	3	4	5	6
Displ. (m)	5.78e-02	5.45e-02	7.87e-02	5.39e-02	1.09e-01	2.70e-01
Angle (°)	69	53	42	53	34	24

Table 5 Summed horiz. & vert. displacements at loading points and corresponding angles in Type 6 and W:H = 3:4

Position	1	2	3	4	5	6
Displ. (m)	4.24e-02	5.31e-02	1.21e-01	5.26e-02	1.27e-01	3.36e-01
Angle (°)	74	61	50	61	42	31



(a) Control node number 1

(b) Control node number 2

(c) Control node number 3

(d) Control node number 4

(e) Control node number 5

(f) Control node number 6

Fig. 11 Total displacement contours of ABAQUS with 4:3 domain ratio and 1~6 control nodes in case Type 6

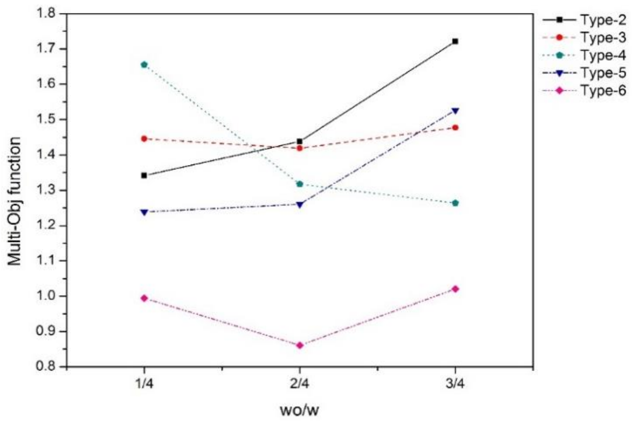


Fig. 12 Optimized multi-objection function values in case the ratio of width and height = 1.0

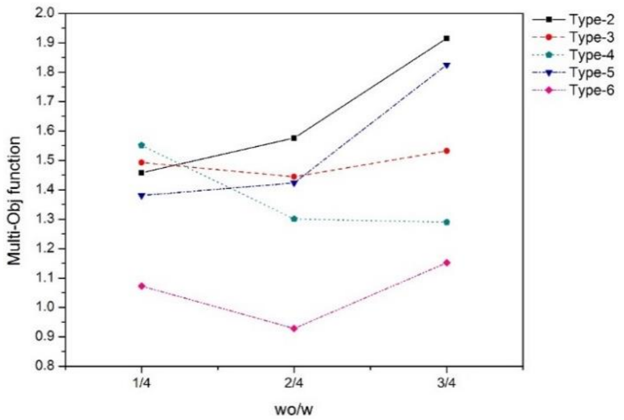


Fig. 13 Optimized multi-objection function values in case the ratio of width and height = 1.5

corresponding to each connecting point of outrigger Type 6 with domain ratio 4:3 are shown in Table 3. Among these cases, the connecting point which is located at position number 2 produces the minimum displacement at the loading point and the corresponding angle of 45°. Tables 4 and 5 present the behavior results in cases of domain ratio of 1:1 (width is 15 m and height is 15 m) and 3:4 (width is 15 m and height is 20 m), respectively.

In case Type 6, Figs. 12 and 13 describe results of Tables 3, 4, and 5. Figs. 12 and 13 show optimized multi-objection function values in case the ratio of width and height = 1.0 and 1.5, respectively.

As can be seen, the displacement value tends to be minimized when the control node is gradually located in the left and top direction of the design space. In other words, the increasing ratio of width and height may produce the increase of the displacement.

Type 1 is originally adopted in a real construction, where all nodes are linked to either core wall or mega column. The present study concludes Type 6 as the most efficient solution, however, it may not be clear how the additional node (middle node in Type 6 - typically termed node 4) is considered to be stable and integral in 2D analysis. In spite of the limitation of the study, it can be concluded that the middle node 4 has a significant influence on the control of displacement, i.e., resistance against internal force path, in any middle point into diagonal member.

This study examined the optimized shape of outrigger system and the required amount of steel according to the design field. In conclusion, it can be found that the layout of Type 6 is the most optimized shape and topology. In other words, it means that Type 6 is the most suitable when designing a general outrigger system, and it is found that it is economical and satisfies the safety and usability of the structure.

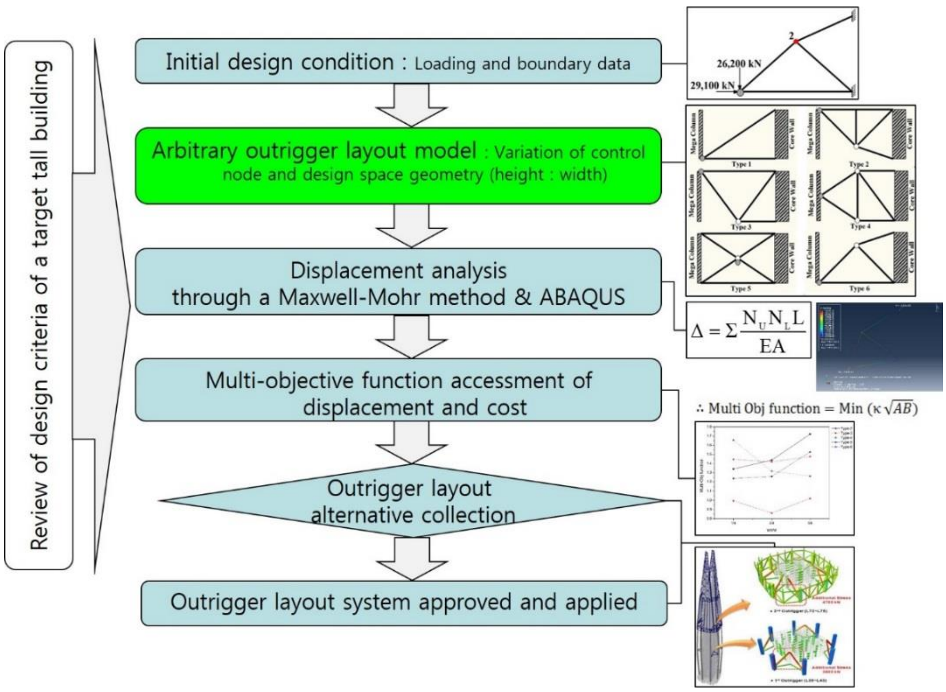


Fig. 14 The present design process to assess general-purpose prototypes of outrigger layout

Also, if we check the result of merging each design criteria by using multi-objective function, Type 6 shape is more suitable. It is expected that the overall context will be the same, even though there may be some difference in the value depending on the type and section of the steel.

As shown in Kim *et al*. (2015), the real outrigger type applied to Lotte World Tower is Type 1. Nevertheless, the present integrated performance assessment provides flexibility or alternative of the outrigger type decision to engineers and designers for other tall building projects.

The shape of Type 6 is found to have similar structural performance, but there is the possibility of a reduction in quantity compared to Type 1, although Type 6 has 4 joints, one more than original plan. Consequently, the constructability will be evaluated according to the connection method or the shape of joints where 3 braces meet in Type 6.

5.5 The present design algorithm to assess general-purpose prototypes of the outrigger layouts

The new robust assessment method to generate the best prototype of structural outrigger layouts is represented in Fig. 14 (Lee *et al*. 2018). The outrigger alternative to satisfy both structural safety and economics is assessed through a specific Maxwell-Mohr method and multi-objective discrete optimization. Design space of height to width and horizontal or vertical position of control node is used for variables for outrigger layout decision.

The present process starts initialization of a given outrigger design such as loading and boundary conditions. As design variables, a variable design space of height and width and a variable control node moving in the design space are defined and applied to outrigger layout candidates recommended by engineers and designers. Summed horizontal or vertical displacements through a modified Maxwell-Mohr method are calculated through ABAQUS 6.5-1 software (SIMULIA 2008), and then material quantities are measured through quantities of member straight lines.

Consequently, multi-objective functions of the displacement and cost are treated to determine appropriate outrigger layouts. The present processes for design leads to make a general-purpose prototype concept. That is, designers and engineers may immediately provide solutions such as product profiles, if similar outrigger layout design initialization condition is given to treat another tall building. It saves time and effort in structural design of tall buildings.

It is a simple and sequential non-optimization method combined with computational calculation of displacements and 2D and 3D commercial software such as ABAQUS (applied in this study), and ETABS (ETABS 2000). By using the software, the optimization of chosen structural outriggers of tall building is verified across the structural analysis of the whole Lotte World Tower in this study.

To design outrigger members with safe and economical structural aspects, the general-purpose prototype information does not allow conventional trial-and-error based on engineer's experience owing to computationally automatic algorithm using conventional and familiar software.

6. Conclusions

This paper presents a robust real-time framework assessing design decision of designers and engineers to determine localized outrigger layouts of general-purpose prototypes under arbitrary non-scaled outrigger design space geometry.

First, outrigger layouts set into several initial design conditions of height to width of an arbitrary given design space, i.e., variable design space. Second, defined outrigger layouts are assessed in terms of the proposed multi-objective function optimizing both minimal total displacement and total material quantity subjected to impact factor indicating the importance of objectives. Finally, the product of the assessment is one outrigger layout of the general-purpose prototypes with connecting node and space deposition of members according to each design space geometry, which is initialized by designers and engineers.

To evaluate the proposed multi-objective function, an analysis model uses the modified Maxwell-Mohr method, and optimization model is defined by the ground method assuming arbitrary discrete straight members. It is a new robust assessment method that can create a prototype of outrigger layout from a local point of view, because it can produce new outrigger layout by defining different height and width ratio of design space in an arbitrary target tall building.

As a numerical example to verify the reliability of the proposed method, we analyze the connectivity between local outrigger members for arbitrary parts of Lotte World Tower. As a limitation of this research, this study is an assessment method to be made simply by many design assumptions of mega structure such as tall buildings. In the near future research, it is necessary to additionally reflect realized design parameters such as core load sharing ratio, consideration of bolt or welded joint, and connection between concrete and steel members.

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