Lateral Behavior of the Diagrid System with Different Sizes of Module

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Abstract

The purpose of this paper is an additional research about methodology for preliminary design of Diagrid System. Some cases of structure were designed by methodology for preliminary design, and the lateral behavior of all these cases of structures depending on size of module was analyzed. In order to make sure of these results, an additional research was also conducted on optimal S value in expanded range. If effective design is defined that maximum displacement of structure is close to target displacement, as the module became smaller, the structure was designed effectively and required tonnages of steel decreased. When selecting size of Diagrid member by methodology for preliminary design, it tends to have high redundancy compared with desired performance. So this study tried to solve this problem by adopting expended s value and suggested s value table was included the end of the study.

Keywords

Diagonal Frame Structure; Unit; Lateral Deformation; S Value.

1. Preface

The diagonal frame structure, as a high-effective structural system fully exploiting structural spatial potentials, uses various forms of vertical frame structure as the skeleton of the outer envelope wall of the high-rise building, encloses the spatial grid-like simplified structure, and combines the vertical bearing and the anti-side force structure. At the meanwhile, the grid-like fashion of the diagonal frame structure has a strong geometric law, with a special architectural visual effect to be obtained.

In general, such a structure can be regarded as a support frame simplified system, which is different from the general framed-tube structure in that the outer barrel is composed of slanting rods that continuously crosses the outer surface of the building in two directions, replacing the traditional vertical columns or adding the slanting supports. The great stiffness of the outer barrel enables it to withstand the great horizontal loads [1], making it possible to reduce the stiffness of the inner barrel or the inner frame; the strong anti-lateral stiffness can ensure the overall safety of the structural system and the favorable comfort in case of any earthquake or wind load, and brings more flexibility to the interior layout of the architecture.

Moon has made relevant improvements in the initial design of the diagonal frame structure [2]. The previous design calculation is a progressive method of iterative calculation design. He proposed to reach the most effective initial design calculation method with the least effort. By such a method, the components can be selected by the initial calculation results of the shear force and bending moment of the components. The initial design method is conservative with a larger margin of the obtained results of the component design, apart from which it is not easy to directly measure the dimensions of the units or the interval, type, etc. of the components.

Therefore, in the design calculation of structural components using this calculation formula, the purpose of the research is to explore the influences of architectural models with certain unit dimension and component spacing. After the design of the models using the preliminary design method, the model is made by the virtue of Midas and the structural lateral deformation and material dosage are obtained, which are evaluated and compared with the target performances.

2. Preliminary Design Method of the Diagonal Frame Structure

Moon has proposed the initial design method for the selection of diagonal components in relevant documents [2,3]. In this calculation formula, when the optimal angleθ of the oblique member and the transverse shearing deformationχare selected and curvatureγ is determined, the S value can be analyzed.

$$A_{d,w} = \frac{VL_d}{2N_w E_d h\gamma \cos^2\theta} \tag{1}$$

$$A_{d,f} = \frac{2ML_d}{2N_f B^2 E_d h\chi \sin^2\theta} \tag{2}$$

The significant effects of the above formula are as mentioned above. In this study, various assumptions and simplified calculations are adopted to simplify the shear stiffness and lateral stiffness required by the rigid design to determine the cross-sectional area of the oblique structural members, i.e., the initial design of the components is simply transformed into the cross-sectional area design of the component. Besides, the formulas (1) and (2) above serve as the induction formulas based on oblique cross-grid structural units. Therefore, as the height of each unit of the buildings differs, the underlying shear and the overturning moment differ as well. Therefore, high-rise buildings can be simplified into cantilever beams perpendicular to the ground, of which the top displacement can be calculated as per the following formula:

$$u(H) = \gamma^* H + \frac{\chi^* H^2}{2} \tag{3}$$

Where γ※ is the shearing strain required for the structure, χ※ is the curvature, H is the total height of structure, γ※H is the shear deformation and γ※H2/2 is the bending deformation (seen as Diagram 1).

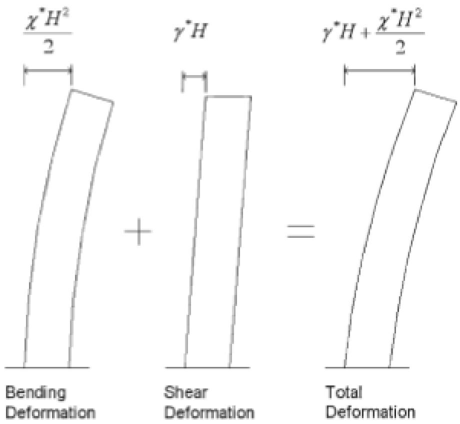

Diagram 1: Shearing and Bending Deformation of High-rise Building

The structural design begins with determining the shear and bending deformation required for the structure. To understand the relationship between the shear and deformation required for the structure, a dimensionless parameter S value is proposed, i.e., the ratio of the deformation caused by bending and shear at the top of the structure. S value is calculated as per the following formula:

$$s = (\frac{\chi^* H^2}{2})/(\gamma^* H) = \frac{H\chi^*}{2\gamma^*} \tag{4}$$

As the height of the building increases, its aspect ratio gradually increases, and the building structure increasingly exhibits the characteristics of the cantilever structure, at which the S value (ratio between bending and shearing) turns to be the need for structural optimization design.

3. Evaluation on the Impact of Dimensions of the Unit

3.1 Model Design and Parameters

In order to evaluate the impact of the size of the dimensions of the diagonal frame units on the structure, the model applied is the one used in the paper by Moon who proposes the initial design method. The external diagonal component is designed as per the design method proposed by Moon.

The diagonal frame angle and horizontal load of each model remain unchanged. The dimensions of the model unit, that is, the number of floors forming a unit, serves as a variable. As shown in Fig. 1, the floor of a unit is 8, 6, 4 and 2 respectively. In addition, in order to investigate the influence of aspect ratio on the diagonal frame structure, control models of three aspect ratio are set for each unit model in this paper, with a total of 12 models. The parameters of each model are as shown in Table 1.

In this paper, the rigid floor assumption is adopted, assuming all grid nodes of the façade of the tubular structure as rigid connection. As per Moon's relevant study on the optimal oblique angle, the oblique angle in this paper is as θ=66.8°. Besides, with reference to the main parameters S value in the initial design method, it is found that the optimal value S=5 when the aspect ratio is 7.

Table 1. Parameters of All Models

Item	Value
Total height	252m, 168m, 84m
Width	36m
Aspect ratio	7, 4.67, 2.33
Height of level	3.5m
Dimensions of unit	8 levels, 6 levels, 4 levels, 2 levels
Oblique angle	66.8°
Floor load	4.5kN/m2
Dead load	2.5kN/m2

3.2 Analysis Results

As per the initial design method, the component dimensions of each structural model are designed by the interfloor displacement and the overturning moment of the building.

The structural model is modeled by the virtue of the structural analysis software Midas-Gen, as seen in Figure 1. The same horizontal load is applied to each structural model. After the linear analysis is run, the maximum lateral displacement of the top floor and the dosage of the oblique members of each structural model are shown in Table 2. It can be seen from the structure that the smaller the difference between the maximum lateral displacement of the top floor and the target displacement, the smaller the dosage of the member under the same target displacement, that is, the structural design is optimal.

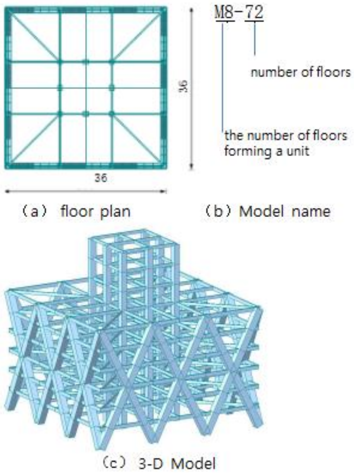

Figure 1. Basic Structural Model

Table 2. Analysis Results of Each Structural Model (aspect ratio: 7)

Name of model	Target displacement (m)	actual displacement (m)	ratio actual/target	dosage of oblique member (kN)
M8-72	0.504	0.446	0.88	146586.096
M6-72	0.504	0.454	0.90	141653.388
M4-72	0.504	0.460	0.91	138437.388
M2-72	0.504	0.4653	0.92	133691.628

Table 3. Analysis Results of Each Structural Model (aspect ratio: 4.67)

Name of model	Target displacement (m)	Actual displacement (m)	ratio actual/target	dosage of oblique member (kN)
M8-48	0.336	0.2028	0.60	51725.004
M6-48	0.336	0.2184	0.65	50351.868
M4-48	0.336	0.222	0.66	48653.136
M2-48	0.336	0.2268	0.67	46343.328

Table 4. Analysis Results of Each Structural Model (aspect ratio: 2.33)

Name of model	Target displacement (m)	Actual displacement (m)	ratio actual/target	dosage of oblique member (kN)
M8-24	0.168	0.0468	0.28	9581.112
M6-24	0.168	0.0468	0.28	9125.388
M4-24	0.168	0.0492	0.30	8491.872
M2-24	0.168	0.0504	0.30	8022.672

Based on the analysis results above, the smaller the oblique unit is, the closer the maximum horizontal displacement value is to the target value, and the smaller the material dosage is. The difference between the analysis results and the target displacement is expressed by the ratio of the two (analysis results/target displacement). The calculation suggests when the horizontal displacement increases by 2 to 6%, taking the 8-floor unit as an example, the dosage of material is reduced by about 9-16%. From the relationship between the horizontal displacement and the dosage of material, it can be seen that in the case where the aspect ratio of the structural model is 7, when the lateral displacement increases by 1%, the dosage of material of the oblique member is reduced by 1 to 2%; in the case where the aspect ratio of the structural model is 2.33, when the lateral displacement is increased by 2%, the dosage of material of the oblique member is reduced by about 16%. In addition, under the influence of aspect ratio, when the dimensions of the oblique unit are reduced, the structure with larger aspect ratio can control the development of lateral displacement more effectively. On the contrary, as the dimensions of the oblique unit decreases, the structure of smaller aspect ratio can save more materials.

In summary, the larger the diagonal frame unit is, the more unreasonable the structural design is, and the overall dosage of material is increased correspondingly. In addition, as the aspect ratio increases, the goal of limiting the development of lateral displacement with less dosage of material can be achieved. However, when the structure aspect ratio is relatively larger, the variation of the lateral displacement and the increase of the material dosage are not too much as the diagonal frame unit changes. In order to give play to the advantages of the diagonal frame structure and considering the convenience of construction and design of the building, the dimensions of the diagonal frame unit can be freely selected as per the actual needs.

In addition, it can be seen that the cross-sectional area of the oblique structure determined as per the initial design method has a large degree of freedom. The analysis results above suggest that the smaller the aspect ratio is, the greater the degree of freedom of structural design is. The choice of the optimal S value and the optimal oblique angle affects the results of the structural design. Based on the analysis above, the same oblique angle is adopted to eliminate the influence of the angle of the oblique member. To study and analyze the influence of the dimensions of diagonal frame structure unit and optimal S value on the overall structure, a further research and analysis is made in this paper. Based on the analysis results above, it is necessary to research the influence of S value on the overall structure.

4. Optimal S Value under Different Aspect Ratios

4.1 Models and Variables

In the researches by Moon, the main reference index S value of the initial design method is analyzed, with the recommendation that the diagonal frame structure with an aspect ratio of 5 or more and the oblique angle within 60-70° should in in line with the formula (Formulas 5 and 6) as follows:

$$s=\left(\frac{H}{B}-3\right) for\ \frac{H}{B}\geq 5 and\ 60^{\circ}\leq\theta\leq 70^{\circ} \tag{5}$$

$$s=\left(\frac{H}{B}-2\right) for\ \frac{H}{B}\geq 6 and\ 60^{\circ}\leq\theta\leq 70^{\circ} \tag{6}$$

Based on this, further researches and analysis on S value are carried out in this paper. In this paper, the aspect ratio of the structural model is designed to be 1-10 for the purpose of analyzing the optimal S value under various aspect ratios.

In order to study the influence of aspect ratio on structure, based on the research results above, another 10 new structural models are designed, of which the parameters are as shown in Table 5. The aspect ratio and S value of each model are different, with other parameters the same. The aspect ratio of the structure ranges from 1 to 10, and the S value ranges from 1 to 10.

Table 5. Model Design of Various Ratio

Item	Value
S value	10,9,8,7,6,5,4,3,2,1
Height	360m~36m
Width	36m
Aspect ratio	10,9,8,7,6,5,4,3,2,1
Height of floor	3.6m
Dimensions of unit	2 floors

Angle of oblique member	67.4°
Spacing of oblique member	3m

4.2 Analysis Results

The relationship between the aspect ratio and the S value of the structural model is as shown in Figures 2 and 3. The data in the figures serve as the ratio of the actual displacement and target displacement of each model (actual displacement/target displacement). Each curve in the figures corresponds to an aspect ratio. The larger the value on the same curve, the closer the actual displacement is to the target displacement, suggesting that the point is the optimal design solution for this aspect ratio. It can be seen from the figure that the optimal S value is 6~4 when the aspect ratio is larger, while the range of the optimal S value is reduced to 3~1 when the aspect ratio is relatively decreased. To further study the range of the optimal S value when the aspect ratio is below 5, the models with an aspect ratio of 1~4 are added and analyzed, of which the results are as seen in Figure X. The comprehensive analysis suggests that the optimal S value range of the diagonal frame structure under different aspect ratios are as shown in Table 6.

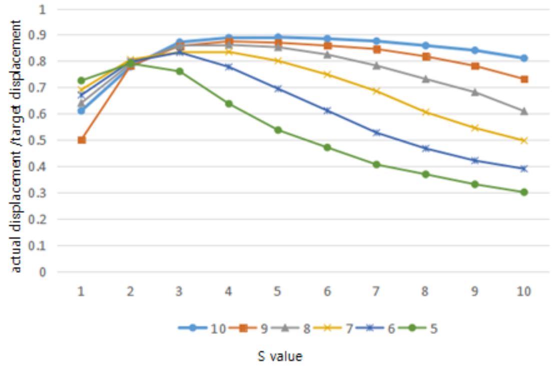

Figure 2. Relationship of Aspect Ratio-S Value (Aspect ratio: 5-10)

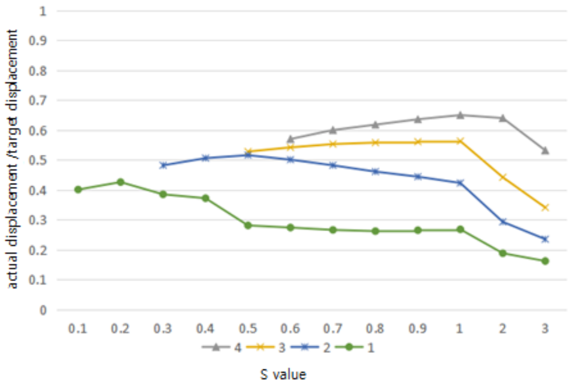

Figure 3. Relationship of Aspect Ratio-S Value (Aspect ratio:1-4)

Table 6. Range of S Value under Different Aspect Ratios

Aspect ratio	S value
1	0.09-0.3
2	0.3-0.7
3	0.8-1.0
4	0.9-2.0
5	1.0-3.0
6	2.0-4.0
7	2.0-5.0
8	3.0-5.0

9	4.0-6.0
10	4.0-7.0

5. Conclusion

Based on the research results by Moon, further researches are carried out. The influences of the dimensions of diagonal frame structure units on the structure are analyzed via the lateral displacement and dosage of materials, and the conclusions are as follows:

(1) When the initial design method is applied to design the building structure, the smaller the structural unit is, the closer the lateral deformation is to the target value, and the dosage of the oblique structural members is reduced correspondingly.

(2) As the dimensions of units decrease, the larger the aspect ratio of the model, the greater the ability of the model to constrain lateral deformation, and the smaller the aspect ratio. As dimensions of units decrease, the aspect ratio is smaller, the less the dosage of the model is.

(3) The internal force and maximum lateral displacement of the component of all structural models designed as per the initial design method enjoy larger degree of prosperity.

(4) Based on the existing initial design method, the new S value proposed in this paper can to some degree reflect the influence of aspect ratio.

Based on the existing initial design method, multiple sets of reference models are made in this paper, with further analysis and researches on the super high-rise diagonal frame structure. The angle, cross-sectional area, dimensions of unit and aspect ratio of the oblique members have a greater influence on the diagonal frame structure. On the one hand, the influence of all factors shall be researched further in the future, on the other hand, it is necessary to further optimize the initial design method.

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