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Cost improvement of 2D FRAME plastic analysis with CFT columns

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ABSTRACT

This paper confirms the difference in structure manufacturing cost and behavior due to the change of the column when the frame structure is designed based on the plastic design. It is important to select an appropriate column member for a structure that is subjected to both axial and lateral loads. If the plastic design method is adopted to design the structure as efficiently as possible, the role of the column becomes more prominent because it not only serves as the beam but also the column through the connection part to transfer the surplus moment to other members when the beam is subjected to an extreme load or more. In particular, the lateral load requires the ductility of the column, and the CFT-type column member secures the ductility through a higher steel ratio than the RC member. By designing the structure by applying the plastic design to the structure subjected to lateral load, this paper will show that the CFT column member has better performance than the RC column member.

1. INTRODUCTION

The increase in vertical loads applied to columns due to the rise of buildings and close studies on irregular horizontal loads such as earthquakes and wind loads have led to interest in the columns themselves. The various shapes of the structure drew attention to the weak resistance to lateral load and the increase in the difficulty of initial concrete pouring and formwork according to the complexity of the structure rather than the strength of the RC member. To overcome this shortcoming, various members are being studied. Among them, studies on CFT show improvement of the shortcomings of RC [1]. The steel tube surrounding the concrete delays local buckling and increases the ductility of the member. As the strength of concrete becomes stronger and the outer steel tube becomes thicker, the resistance to axial force increases due to the confinement effect. Taken together, CFT has advantages over RC in column shape where axial force and bending force act at the same time, so CFT is being used in various studies.

In order to make the most of the appropriate members constituting the structure, appropriate design standards are required. The strength method officially defined according to the ACI design code is a universal design method and is based on elastic analysis. In the early elastic design, only the limit of member strength was considered, but now, based on the limit state design, the redistribution of the moment that occurs in the design of the structure rather than the member is considered. This is an improved design method as, when the members are connected, the overload applied to one member can be transferred to the other member, and at the same time, the moment is redistributed to enable efficient utilization of the member. It is essential to consider the correct behavior of structures in response to inelastic loads such as wind loads or seismic loads. According to Shakir's paper [2], redistribution of 15-30% of different values depending on the condition of the member for each design criterion is allowing Through this, the behavior of the structure is rationally explained rather than the design method considering only the characteristics of the member. However, since the redistribution method is limited to beam members and different redistribution ratios are suggested for each design criterion, it is a method that needs improvement to find the correct value.

From Yuge [3] to Palizi [4], many researchers are working on reducing the cost of the structure by leading the optimal design of the structure through the plastic design method. As such, the plastic design method has an advantage in understanding the precise behavior of the structure by adding the role of the column to the distribution of the moment limited to the beam in the structure. At the same time, it leads to optimization of member and structure design, which leads to reduction of actual construction cost.

In this paper, in the design of the frame structure, the degree of cost reduction due to the change of the column member will be investigated. In this process, plastic design was adopted as a design method to optimize the cost of the structure itself compared to the elastic design and at the same time increase the role of the column in the design than the elastic design. In the case of pillars, in order to determine what role differences in column shape and internal components play in the plastic design process, the most widely used RC member and CFT member, which is expected to have excellent plasticity, were compared. In the case of load, horizontal load as well as vertical load were additionally considered, and in order to minimize the effect of the beam, the same cross section of the beam was used for both RC and CFT column members in the elastic and plastic design process. This paper will show the difference between RC and CFT column members through the p-m correlation shape of the column obtained through numerical analysis and the cost of the column constituting the frame. It can be considered that adopting a plastic analysis in parallel with CFT column will provide cost reduction and safety for frame structures.

2. METHOD

(1) Solution procedure

If the members to compose the structure and the criteria for designing the structure have been selected, the structure can be analyzed through an appropriate numerical analysis model. In the case of beams, the members were constructed in the form of a universal RC reinforcing bar in a rectangle. In the case of columns, the RC member has the same configuration as the beam, but differs in the amount and spacing of reinforcing bars, and the CFT member has a shape in which the concrete is surrounded by a round steel pipe. With the corresponding members, the cross-sections of beams and columns were first established based on the elastic design. In the case of plastic design, since the shape of the member cross-section may vary depending on the location of the plastic hinge in the structure, it was established through the Trial and Error method based on the member cross-section information of the elastic design. Unlike elastic design, which is designed by considering only member information, plastic design considers the moment redistribution relationship between members, resulting in a rather complicated numerical analysis process.

When analyzing a structure based on elastic design, the shape of the structure and the applied load should be set first. Then, an initial cross-section large enough to withstand the load is set, and the members having the corresponding cross-section are divided equally into elements. The stiffness matrix of the entire structural system is constructed by summing the stiffness matrix of each element, and then the displacement and forces of the members are obtained through the initial load and the stiffness matrix of the entire structural system. In the case of a beam, an appropriate cross section can be set based on the relationship between the member's ultimate moment and the member's moment and axial force in the case of a column, and these cross sections are the results of elastic design.

For plastic design, cost reduction of beam and column cross-section can be expected compared to elastic design. In the process of numerical analysis, when the member reaches the ultimate strength, the stiffness matrix is adjusted so that the point can perform plastic hinge behavior. Accordingly, it is necessary to find a combination of members that the structure itself can withstand while reducing the cross sections of each beam and column set in the elastic design process. Due to the adjustment of the member cross-section and the adjustment of the stiffness matrix of the connection area, more analysis processes are required than the elastic design method.

(2) Application

It was found that the application of the plastic analysis described above is necessary for the optimal configuration of the frame structure. In addition, the application of CFT columns to frame structures instead of RC columns is highly likely to improve the results of plastic analysis. Therefore, elastic and plastic analysis according to various load types was performed on the frame structure employing RC and CFT columns to determine the degree of cost reduction in beams, columns, and frames.

In order to understand the degree of cost reduction of the structure due to the appearance of the plastic hinge, we first investigated how the cost change occurred as a result of the optimal analysis of elasticity and plasticity in a symmetrical structure composed of 2 bay-6 floors. The vertical load consists of uniformly distributed vertical dead ($w_D = 3.5\text{kN/m}^2$) and live ($w_L = 2.5\text{kN/m}^2$) loading. In general, numerical analysis was performed on the load and structure shape as in fig.1.

Table 1 shows the change in cost according to each application between RC and CFT columns, and between elastic analysis and plastic analysis. And as expected, the CFT column is more economical than the RC column, and the plastic analysis is also more economical than the elastic analysis. It can be seen that when CFT column and plastic analysis are applied at the same time, it can lead to cost savings of close to 20% compared to the case where RC column and elastic analysis are applied.

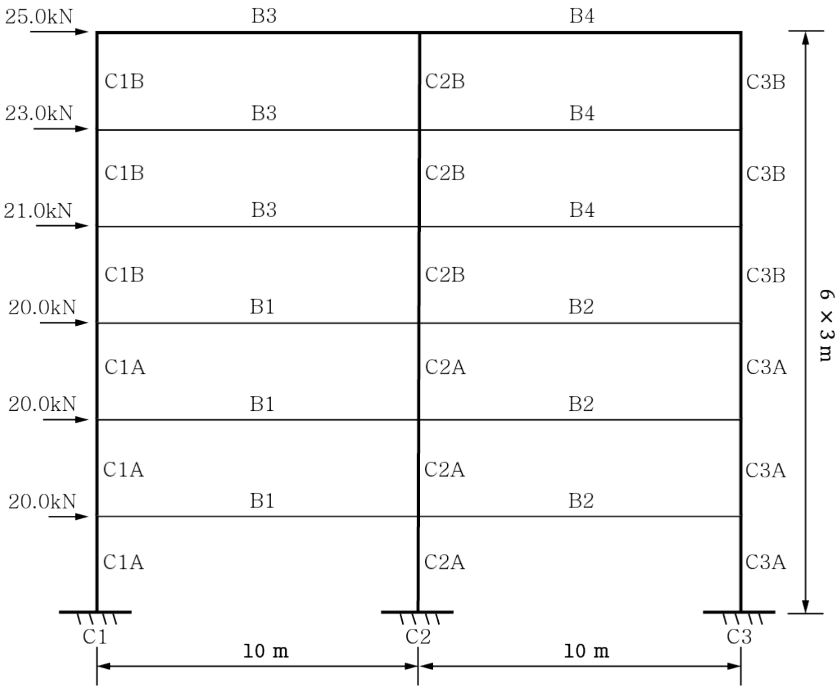

Fig. 1 2 bay 6 floor building

Table 1 Comparison of total cost in frame structure

Design	Frame with CFT columns			Frame with RC columns		
Elastic Design	COLUMN COST	BEAM COST	TOTAL COST	COLUMN COST	BEAM COST	TOTAL COST
	24.01%	68.18%	92.19%	31.82%	68.18%	100.00%
Plastic Design	COLUMN COST	BEAM COST	TOTAL COST	COLUMN COST	BEAM COST	TOTAL COST
	21.87%	58.32%	80.19%	27.63%	58.32%	85.94%

3. CONCLUSIONS

This paper introduces the cost advantages that can be obtained when plastic analysis is performed using CFT column members instead of RC column members when designing a frame structure. By adding a spring element to the connection between the beam and column members, a plastic analysis method was introduced, which controls the distribution of moments after the ultimate state of the member so that the failure of the member becomes one of the processes in which the structure is destroyed, not the destruction of the structure. As a result of numerical analysis, this paper could lead to the following results. (1) Compared to elastic analysis, the difference between the maximum positive moment and maximum negative moment in the plastic analysis of the beam was reduced, enabling the design of a beam with a small cross-sectional force, leading to an economical design of the beam. (2) In the form of structures with lower floors, a phenomenon occurs that, as much as the central lower column with the greatest axial force, the part where the column and beam are connected one-to-one at the top level requires a larger cross-section than the column on the lower floor. This phenomenon should be solved by increasing the moment resistance of the column by increasing the steel ratio of the column cross-section in the elastic analysis, but it was found that a significant reduction in the cross-section can be achieved if the plastic analysis is applied. This was clearly confirmed by the cost trend in Table 1. This is because switching from an elastic design to a plastic design resulted in a cost reduction of more than 12%.

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