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Near-Zero Rebar Cutting Waste Management by Adjusting Lap Splice Position

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Abstract **-** In general, rebar cutting waste is estimated to be 3-5% in the construction planning stage. However, technology to reduce RCW was not developed at the construction field, so more than 5% is generated in the actual construction. To solve this problem, many studies was conducted to minimize RCW. Most studies proposed methods to minimize RCW by using stock lengths or market lengths, referred to as standard. In other words, the rebar shown in the structural drawings is combined using the rebar mill or the stock length held to minimize cutting waste. RCW can be reduced if rebars ordered in special lengths are used in rebar combinations. Reducing rebar cutting wastes to near-zero rebar are necessary in terms of cost reduction and sustainable construction. Therefore, the purpose of this study is a basic study of near-zero rebar cutting waste management by adjusting lap splice position. As a result, the optimal amount of rebars in the case site was 17.74 tons, with the rebar cutting waste ratio reduced to less than 1%. In addition, the amount of rebar was reduced by 0.53 tons, which is 2.93% of the actual quantity. About 284 USD was saved, and 1,872 kg-CO2 was reduced.

Keywords**:** rebar cutting waste; minimization; optimization; sustainable construction; CO 2 emission; construction management

1. Introduction

Rebar cutting waste (RCW) is generally estimated to be 3-5% in the construction planning stage [1-4]. However, technology to reduce RCW was not developed at the construction field, so more than 5% is generated in the actual construction [5-9]. To solve this problem, many studies was conducted to minimize RCW [10-14]. Most studies proposed methods to minimize RCW by using stock lengths or market lengths, referred to as standard [15]. In other words, the rebar shown in the structural drawings is combined using the rebar mill or the stock length held to minimize cutting waste. RCW can be reduced if rebars ordered in special lengths are used in rebar combinations [1,3,12,16].

In the case of a reinforced concrete structure, rebars of various lengths are installed, and they have different diameters, numbers, and positions. In South Korea, market lengths, commercially available lengths, are generally divided into units of 0.5m, such as 8.0m, 8.5m, 9.0m, 9.5m, and 10m. In the cut and manufactured process, if the rebars are ordered without careful plan, significant cutting wastes are generated. In other words, in consideration of cutting wastes, an additional quantity of 3-5% is calculated in the rebar order stage.

Kwon, K. et al., (2021) stated that the rebars amount used in the world was 947 million tons in 2019, and assuming RCW ratio of 3 to 5%, global RCW of 2841~47.35 million tons are generated annually[17-19]. And the study stated that if 0.3416 ton·CO2/ton [20] of CO2 emission from rebar is applied, about 971~16.18 million ton of CO2 emission is calculated.

To complement this study, the current CO2 emission was investigated. The amount of rebar used in the world is estimated about 1.16 billion tons in 2022, and assuming an RCW ratio of 3~5%, about 30.47~50.79 million tons of global RCW will be generated annually. In addition, it is estimated that about 30.47~50.79 million tons of global RCW and about 10.40~17.35 million tons of CO2 emission will be generated in 2022. If this result is applied to 1,198 USD/ton based on SD400 as of July 2022 [21], the global cost loss of RCW is calculated to be 365-608 billion USD.

To reduce RCW to near-zero is necessary in terms of cost reduction and sustainable construction. In order to reduce rebar cutting wastes, many studies were conducted about rebar optimization, but near-zero cutting wastes was not defined, and there have been very few studies. Therefore, the objective of this study is a basic study of near-zero rebar cutting waste management by adjusting lap splice position. For reference, near-zero is defined as generating less than 1% of RCW in this study, and the ratio should be reduced according to the research result. This study is conducted on the rebar of girder.

2. Methods

According to the many studies, the cutting waste management method of rebar is largely divided into stock length [15,22-26]and special length [1,3,12,16]. In these two methods, the target cutting wastes rate and minimum quantity can be added as constraints [1,12,16]. Special length means the length determined by the customer's order, not the length of rebar sold in the market [17]. The special length is not the standardized and sold rebar length in the market, but the length determined by the site's order and specially manufactured at the factory. For example, stock or market lengths refer to producer-determined lengths with regularly spaced values such as 9, 10, 11, and 12m, while special lengths include irregular values such as 8.4, 9.7, and 10.1m. Although there are differences by country, it is common in many countries where stock lengths of 7, 8, and up to 12m are common. In South Korea, it is ordered at least 50 tons at intervals of 0.1m, and delivery time takes more than two months. For example, rebar with a diameter of 25 mm and a length of 8.4 m can be obtained by special order in a quantity of 60 tons and a delivery time of 2 months.

Figure 1 is an example of stock length and special length combinations. In the case of cutting pattern 1 in Figure 1a, two rebars were combined using a stock length of 12 m, and 0.6 m of RCW occurred, corresponding to a cutting waste rate of 5%. Using the special length of 11.4 m as shown in Figure 1b, RCW will be 0 m, and the cutting wastes will be zero. As the example shows, when using special lengths, RCW typically reduced by more than stock lengths.

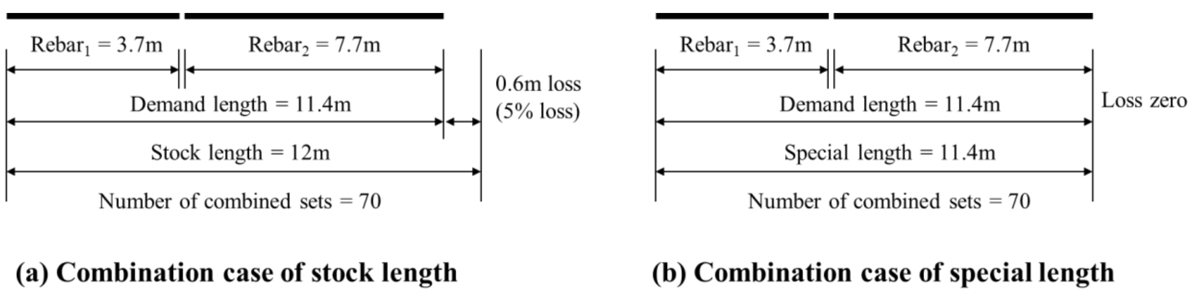


Fig. 1: Example of a combination of stock length and special length

Figure 2 is an example of reinforcement of a beam. In general, in the case of reinforcing bars, the reinforcing bars are anchored at both ends of the building as shown in Figure 2a, and lapping takes place near the columns. In this case, the length of the reinforcing bars given by the shop drawings can be different. And it is predicted that significant cutting wastes will occur even if processed according to the market length or the order length. However, in the case of reinforcement with the same length, it can be controlled with cutting wastes of almost zero level by processing as order length. However, in construction site, cutting wastes cannot be zero. The reason is that the rebar length is not calculated in units of 10cm. For example, when rebar of 8.25 m is required, when actually ordering from the factory on-site, rebar of 8.3m must be ordered. To reduce rebar cutting wastes to near-zero is needed in terms of cost and co2 emission reduction.

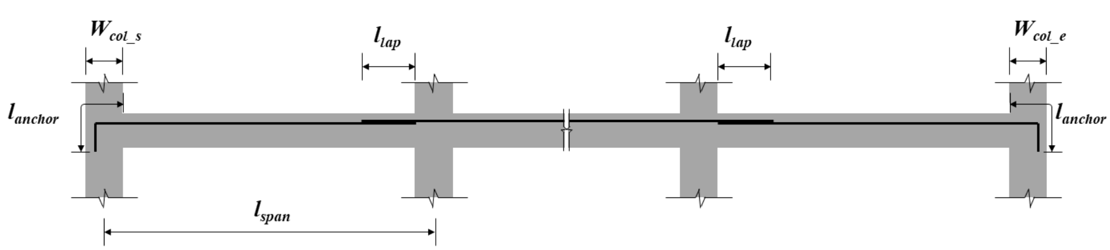


Fig. 2: Top bar example of girder

Equation (1) is for estimating the length of the girder rebar. The total length is calculated by adding up the both ends length of the span, the length of anchorage at both ends, and the total length of the joint rebars, and deducting 1/2 of the columns width at both ends and the bending margin of the rebars at both ends. Equation (2) is for calculating bending margin and can be calculated using the diameter of girder main rebar.

$$L_{total} = \sum_{i=1}^{l} l_{span\_i} + \sum_{j=1}^{m} l_{anchor\_j} + \sum_{k=1}^{n} l_{lap\_k} - (W_{col\_s} + W_{col\_e})/2 - l_{margin} \quad (1)$$

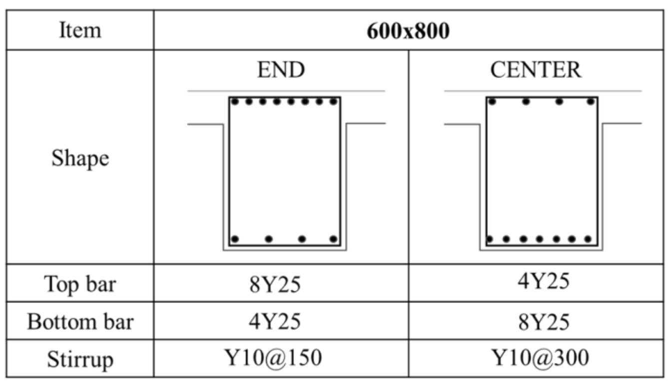
$$l_{margin} = 2.5d \times 2 \quad (2)$$

L_{total} = total beam length, l_{span_i} = span length, l = number of spans, l_{anchor_j} = anchor length, m = number of anchors (normally anchors at both ends), l_{lap_k} = lapping length, n = number of laps, W_{col_s} = width of column at the starting point, W_{col_e} = width of column at the ending point, d = diameter of girder main rebar (m), l_{margin} = bending margin of rebar at both ends

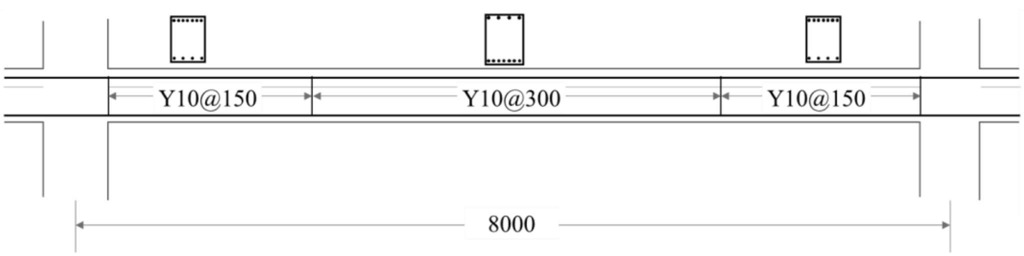
3. Results

3.1. Selection of Case Project

A case project of this study was selected. It is a commercial building project with a total floor area of 66,644 ㎡, 3 stories under the ground and 25 stories above the ground, constructed in Seoul. The site area of the project was not large enough to rebar on site. Figure 3 shows the girder rebar details of the case study.



(b) Section view of girders



(b) Section view of building

Fig. 2: Rebar details of girder

2.2. Cost management

To compare the rebar cost, the required, optimized, and actual input rebar quantity were calculated. Table 1 show that the required rebar quantity was 17.73 tons, and the actual input rebar quantity was 18.28 tons with an RCW ratio of 3.00%. The optimized rebar quantity is 17.74 tons, with the RCW ratio reduced to less than 1%. As a result, the optimized rebar quantity and cost were reduced by 0.53 tons and 284 USD, respectively. This value is 2.93% of the actual input rebar quantity.

As a result of calculating CO_2 emission using this value, 1,872kg-CO_2 was saved. This value is for one girder on all floors. If it is calculated the rebar quantity for columns, slabs, walls, stairs, and foundations including all girders with the quantity of all floors, the cost and CO_2 emission reduction will increase.

Table 1: Comparison of rebar quantity

Description	Rebar quantity (ton)	Cost (USD)	CO2 emission (kg-CO2)
Required (R)	17.73	9,417	62,048
Optimized (O)	17.74	9,424	62,094
Actual (A)	18.28	9,709	63,967
Optimized Reduction rate (O-R)/O			0.08%
Actual Reduction rate (A-R)/A			3.00%

2.3. Schedule management

The market length means rebar length commonly supplied by a steel mill. In South Korea, it is 6-12m and is supplied in units of 1m. The order length is when a customer orders a specific length from a steel mill. And time management is important because an order must be made in units of 10cm in units of a certain amount (e.g. 100 tons) or more and a certain period (e.g. 1 month) in advance.

Figure 4 is the near-zero cutting waste management process. First, the site description, each building, each floor, and each member as basic information are input (a). In this process, the project code, classification code by building, floor, and member are input. In the reinforcement detail information input stage, information generated after structural design is input (b). To precisely perform rebar processing such as columns, beams, and slabs according to the information generated in Figure 4b, the cover thickness for each member, standard hook setting, and information on rebar joint and anchorage must be linked. (c). To create a bar bending schedule (BBS), serial number, shop drawing number, bar mark, shape code, dimensions for each part, cut length, number, and weight are required (d). In the bar cutting list (BCL) preparation stage, rebar number, diameter, rebar length, number, weight, and bar mark calculated from BBS are required. The maximum and minimum lengths of rebars that can be ordered are investigate, and the target cutting waste rate of rebars is set (f). Rebars are assembled using the optimization equation defined above.

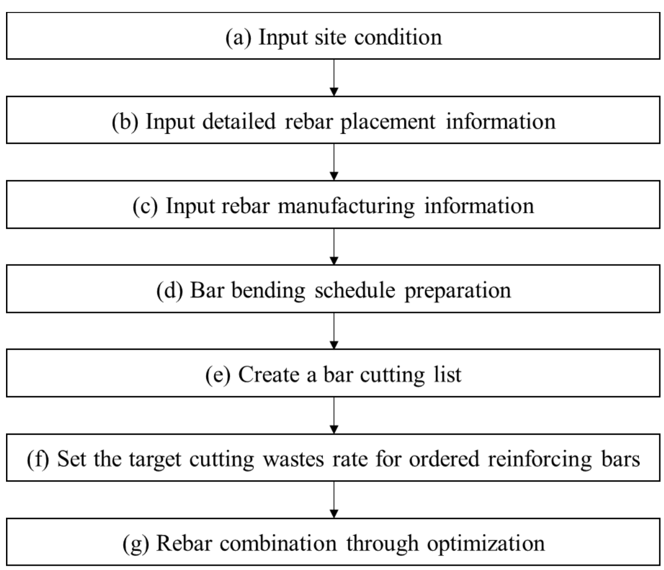


Fig. 3: Near zero cutting waste management process

4. Conclusion

Rebars generate a significant amount of cutting waste during the construction stage and a lot of construction cost is required. To solve this problem, this study proposed a management plan for near-zero cutting waste for sustainable construction. The results verified through the case project are as follows.

First, in the case site, the required rebar quantity was 17.73 tons, and the optimized rebar quantity was 17.74 tons, with the RCW ratio reduced to less than 1%. 2.93% of the actual input rebar quantity was saved, and it means reducing 284 USD and 1,872kg-CO2 in terms of cost and CO2 emission.

Second, it was confirmed that if the rebars in the structural drawing were rearranged to a special length, RCW can be achieved close to zero. In other words, it was confirmed that RCW can be greatly reduced by rearranging rebars of a certain length while satisfying the structural design standards.

Third, schedule management is important because rebar must be ordered in advance of a certain amount or more than a certain amount of the standard unit. In this study, the RCW management process was introduced and the methods were explained.

This study was analyzed in terms of cost, and schedule management for near- zero cutting waste. This study calculated only the rebars amount for one girder. However, if it will be calculated the rebar quantity for columns, slabs, walls, stairs, and foundations including all girders with the values of all floors in the future, it will be possible to further reduce the cost and CO2 emission. In addition, research on minimizing RCW (e.g. stirrup) should be conducted. Optimization will be performed with special length-priority, and stock length will be performed on the remaining reinforcing bars in the next step.

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