Analysis of Waste Levels of Column Reinforcement Work Planning with Cutting Optimization Software

Sulthanul Auliya Jagad[1], I Nyoman Dita Pahang Putra*[2]
[1,2]Department of Civil Engineering, Faculty Teknik and Sains Universitas Pembangunan Nasional Veteran East Java, Indonesia
e-mail: [1]auliyasulthanul@gmail.com, *[2]**putra_indp.ts@upnjatim.ac.id**

Abstract

In the era of globalization, construction development in Indonesia has experienced significant acceleration, accompanied by innovation in its implementation methods. One of the main problems in construction projects is material waste, especially in column work. This study aims to analyze the level of waste in column reinforcement work by applying the cutting optimization method using Cutting Optimization Pro software and analyzing the diameter of the reinforcement that produces the greatest waste. The research method used is quantitative by analyzing secondary data through shop drawings and detailed standards from construction projects. The study was conducted on column work from Ground to Floor 5 by calculating material requirements using the Bar Bending Schedule and optimizing cutting patterns through Cutting Optimization Pro Software. The results show that the lowest percentage of waste D16 is 0%, the highest at Ø8 is 2.653%, and the overall average waste is 0.916%. This study provides new insights into the importance of innovation in material planning and management in the construction industry. By utilizing optimization software, contractors can improve efficiency and reduce the impact of material waste. This study is expected to be a reference for contractors in adopting new technologies in the management of material waste.

Keywords— Waste Level, Bar Bending Schedule, Software Cutting Optimization Pro

1. INTRODUCTION

In the era of globalization, the development of construction in Indonesia is increasingly rapid, and the development of construction implementation methods is also increasingly innovative. New technologies and innovations in every implementation of building structures always aim to increase efficiency in the success of a project. This involves 5 project resources, namely Workers (man), Methods (method), tools (machine), costs (money), and materials (materials). Materials have a significant influence (40% - 60%) on project costs; therefore, indirectly, materials play an important role in supporting the success of a project [1]. Construction project management is a scientific concept that carries out and completes a job on a construction project so that the work is carried out on time, at the right cost, and with the right quality. In the implementation of construction projects, the use of labor, tools, and materials can deviate from planning. Therefore, it is necessary to control so that the planned material and time do not exceed the planning limits [2].

One of the problems that often occurs in construction projects is the excess of leftover material produced during the construction process due to negligence in using and controlling materials in the field. This negligence causes the occurrence of material waste that is difficult to avoid [3]. Material waste refers to unused, inefficient, or excess resources, including labor, equipment, materials, or costs, which must be carefully managed during construction to ensure efficiency and success [4]. There are two types of construction material waste, namely direct waste or waste material that is produced directly in the field due to ongoing construction activities, and indirect waste or waste material that is produced indirectly due to the planning process. The most common construction waste in a project is direct waste [5]. Several studies in Indonesia show that the waste material produced by a project can reach 2.9% - 12.5% of the total weight of the total weight of materials on the project [6].

The types of waste materials most often produced from high-rise building construction projects, sorted from the highest ranking, are reinforcing steel, formwork wood, paint, ceramics, gypsum board and kalsiboard, bricks and cement blocks, cement, coral, sand [7]. Reinforcing steel material is the material that produces the largest waste value compared to other materials, such as ceramics, cement, ready-mix concrete, bricks, sand, piles, and crushed stone, with a value of 34.68% [8]. Reinforcing steel material is a material that has the highest percentage value to cost, which is around 2%-20% [9]. From the research above, it can be concluded that the material that produces the largest residual value is reinforcing steel. This is because reinforcing steel is the main component in structural work, which is a vital work that, on average, has a very large volume in construction projects [10], and because reinforcing steel material has a high purchase value [11].

Material waste can increase construction costs. This can disrupt the smooth running of construction projects and must be minimized by contractors. Prevention and handling of waste materials from the planning stage to implementation in the field of construction projects really needs to be considered by contractors [7]. Many factors cause waste of construction materials, including changes in design drawings, miscoordination between office staff and field workers, errors in cutting materials during the manufacturing process, and many other factors, so that construction material management is needed to minimize waste materials [3].

Reinforcing steel has a fairly high value, so careful calculations are needed to minimize losses from waste materials that cannot be reused [12]. The average waste level value for permitted reinforcing steel material is 5%. It can be categorized as waste if it is more than 5% [13]. Control of the remaining reinforcing steel material on the project is still relatively weak because the control system still uses conventional methods, namely only relying on the performance of workers in the field without any control, so there is a high possibility of cutting errors that have the potential to produce waste [6]. The common way to overcome waste is only through material management to minimize the remaining material that occurs, namely a bar bending schedule to simplify the calculation of the material requirements [14]. The creation of bar bending schedule is based on the the reinforcement pattern of each structural element, which is distinguished based on the shape and type of structural element used. Several requirements need to be considered in designing reinforcement: the quality of steel and concrete reinforcement, the minimum distance between reinforcement, hooks, and bends, requirements for the concrete cover of lap joints, and length of distribution. The size of the reinforcement iron cross-section requirement must be adjusted to the structural calculations made by the planning consultant. Supervisory consultants for reinforcement fabrication are needed to ensure that the length, shape, quantity diameter, and placement of reinforcement are in accordance with the design drawings and those in the field [14].

In real conditions in the field, special tools are needed to cut and bend the reinforcement iron. The tool used is the Bar Bending Machine, which can also be called the Reebar Cutter. Before cutting, usually the iron foreman will provide a note of the length and quantity needed for each job to the blacksmith. However, this is not effective enough to reduce the waste because it is only carried out by the management, not on the work method in the field or the method of cutting the reinforcement steel pattern [6]. In planning using the Bar bending schedule, it takes a long time to plan the cutting pattern for 1 iron bar so that it produces little leftover material. Reinforcing iron material is generally sized from 6 mm to 32 mm. One iron rod is 12 m long.

To maximize the control of waste material in the Graha Cahaya Kusuma Building Construction project, which still uses conventional methods in making cutting patterns for reinforcing steel, it is necessary to apply a new method with the help of Software that can analyze, correct the method of cutting reinforcing steel quickly saving time during the planning process, and create the most optimal reinforcement steel cutting arrangement pattern so that the use of the remaining reinforcing steel material can be reused for subsequent work using the same diameter [15].

This study uses the help of Cutting Optimization Pro software to facilitate the creation of reinforcing steel cutting patterns. The time required to create a cutting pattern for each job is about 1 to 2 seconds. This is very helpful in saving the time required during the planning process. If using manual calculations, it takes a long time to plan an optimal cutting pattern, especially if there is a calculation error; it is necessary to recalculate from the beginning, which takes even longer. The Software Cutting Optimization Pro is very efficient and effective in controlling and managing reinforcing steel, which can reduce waste generated from cutting reinforcing steel in the field. The optimization carried out by Cutting Optimization Pro Software is by reusing reinforcing steel with a length that meets the remaining cutting of reinforcing steel that has been used in other parts [16]. The result of this software is the most optimal cutting pattern of reinforcing steel that can be used in daily fabrication. In addition, this software can display data on reinforcing steel material stock in the field, making it easier to control reinforcing steel material [12]. Utilizing this software can also help determine the minimum length of reinforcing steel, which is stated as waste material. This is based on the length of reinforcing steel, which is considered waste material, must be less than the smallest length of reinforcing steel required, which is obtained from the structural calculation.

2. RESEARCH METHODS

The research method used in this research is quantitative. The quantitative method is a method where the data is expressed in numbers or in the form of numbers [14]. So that it will produce more systematic, specific, and structured research to obtain conclusions [17]. This research was conducted on the column work of the Ground, Upper Ground, Floor 1, Floor 2, Floor 3, Floor 4, and Floor 5 of the Graha Cahaya Kusuma Office Building Construction project, which is located on Jl. Kendangsari no 28 - 30 Surabaya. This study uses secondary data in the form of Shop Drawings and Detail Standards obtained from the Graha Cahaya Kusuma Building Construction Project. The steps in this research are:

2.1. Identification Problems

In this research, the author identified the value of waste-level planning for steel reinforcement materials. This is because steel is one of the materials that cause a lot of waste, which can cause losses to the contractor. Therefore, this research intends to maximize the waste value planning of column reinforcement work on the Ground, Upper Ground, 1st Floor, 2nd Floor, 3rd Floor, 4th floor, and 5th floor on the Graha Cahaya Kusuma project with the help of Cutting Optimization Pro Software.

2.2. Literature Review

A literature review is a critical and systematic analysis of previous studies related to the research topic to be studied. This analysis includes steps to identify what is known or unknown from previous studies, various controversies or debates that arise from a number of existing research results so that in the end it can be formulated what questions need to be followed up through subsequent studies and the process of finding a theoretical basis that is relevant to the research topic. The author collects literature studies in the form of journals, books, and regulations related to the waste level of reinforcing steel materials [18]. The purpose of a literature review is to find out what has been done and what has not been done by previous researchers, to find out the various strategies of previous researchers in studying the same topic, about the data collection techniques used and the details of the instruments, and to evaluate things that may have been inappropriate in previous research in order to prevent subsequent researchers from making similar mistakes. Literature reviews can also provide provisions for making interpretations and discussions in a concise and in-depth manner regarding the results that will be obtained, so that at the end of the research various suggestions and recommendations can be formulated in a more focused manner.

2.3. Data Collection

The data required in this study are secondary data obtained from the consultants and contractors of the Graha Cahaya Kusuma Building Construction Project. The data obtained include:

1. Shop Drawing of Column Work

   Shop Drawing is a detailed technical drawing that has been made by the contractor and is used as a reference / work guide so that the implementation process can be ensured in accordance with the design that the consultant has planned. In addition, the purpose of shop drawing is as a medium of communication and reporting between consultants and field implementers. So, work errors that result in demolition can be minimized with the help of shop drawings. So construction projects can run optimally and on time [19]. In this research, the author uses a shop drawing to calculate the quantity and length of the material used.
2. Column Work Detail Standard

   This detail the researchers use the standard as a reference for the anchorage length, which will affect the length of the material used. The Detail Standard used in this project is a standard set by the structural planning consultant as a reference for contractors in the implementation of work in the field. Detail standards generally refer to SNI, but usually, each construction project has its standards that will be used as a reference in every work.

2.4. Material Requirements Calculation

Calculation of the need for reinforcing steel material is only carried out on column work from the Ground, Upper Ground, Floor 1, Floor 2, Floor 3, Floor 4, and Floor 5 floors, and Calculation of material requirements is carried out by referring to the shop drawings obtained from the contractor and also to the standard details used in the project. Calculate material needs by creating a bar bending schedule (BBS). The Bar bending schedule is a list of reinforcement bending patterns that contain data on the diameter, shape, length, and number of reinforcements used [14]. The Bar bending schedule calculation is made to make it easier for researchers to summarize the length of material needed. The BBS calculation considers the anchorage length and distribution length according to the detailed standards applied in the project. The bar bending schedule can be prepared without using software, but the time required in the work process is relatively long. In addition, if there are changes during the project, it can take even longer. Therefore, a bar bending schedule was developed with a computer program to make calculations easier [17]. The number and type of reinforcement bars resulting from the Bar bending schedule calculation will later be used as a reference for input into the Cutting Optimization Pro, which will then create the most optimum, efficient, and effective cutting pattern [20]. and will later be used as a guide in daily fabrication.

This is an example of a Bar bending schedule calculation for Column Work K1-1 Grid 2 Ground Floor:

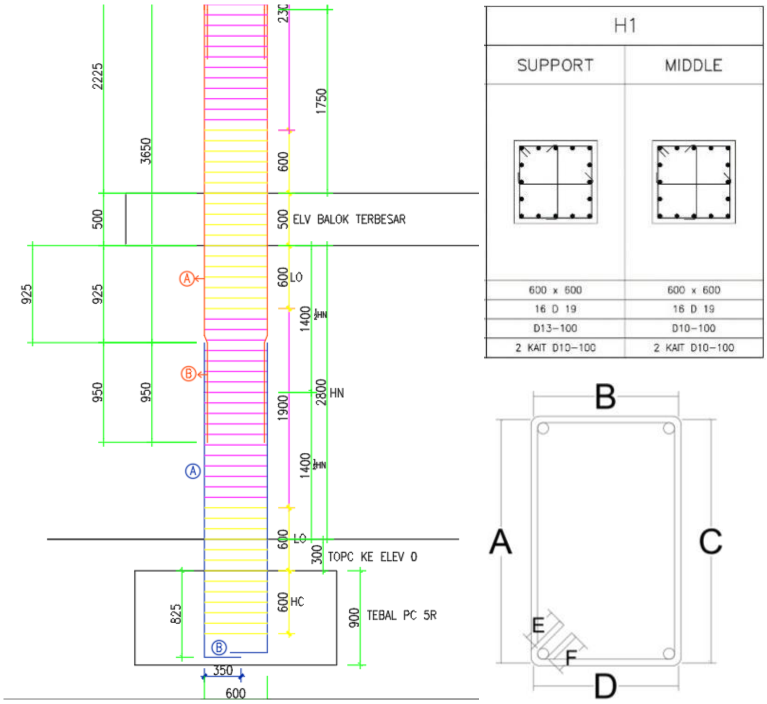


Figure 1. Column Reinforcement Details K1-1

An Example of Column Reinforcement Details of K1-1 can be seen on Figure 1 Above. After determining the detailed drawings and the dimensions of the required reinforcing steel used, a bar bending schedule is then made to facilitate the recapitulation of the amount needed for each material.

The calculation for column K1-1 Grid 2 on the Ground floor:

Column Size	: 600 mm x 600 mm
Floor to floor height	: 33000 mm
Main Reinforcement	: 16 Pieces of D19
Support Stirrup Reinforcement	: D13
Middle Stirrup Reinforcement	: D10
Stirrup Distance	: 100 mm
Overlap Reinforcement	: 9500 mm
Hook D13	: 130 mm
Hook D10	: 115 mm
Anchorage Length	: 350 mm

For Element 1 (Dark Blue) required:

1. = A + B

= [(Pile cap depth – concrete cover – pile cap diameter in x direction – pile cap diameter in y direction) + Top Pile cap Depth to Elv 0 + (elv Floor to Floor – largest beam elv) / 2 + ½ overlap length] + Anchorage Length

= [(900 – 40 – 16 – 19) + 300 + (3300 – 500) / 2 +1/2 * 950] + 350

= A + B = 3000 + 350

= 3350 mm (16 pieces of D19)

For element 1 (dark blue) it required 16 pieces of D19 steel bar with a length of 3350 mm

For Element 2 (Dark Red) required:

2. = A + B

= [½ (Height FtF Lt G – Largest Beam Elev) + Largest Beam Elev + (½ Hn Lt UG + ½ Anchorage Length) + Achornage Length
= [925+500+2225] + 950
= A + B = 3650 + 950
= 4600 mm (16 Pieces of D19)
For element 2 (dark red) it required 16 pieces of D19 steel bar with a length of 4600 mm

For Element 3 [Support Stirrup] (Yellow) required:
3. = A + B + C + D + E + F
= Column length + Column width + Column length + Column width + Hook + Hook
= A + B + C + D + E + F = 600 + 600 + 600 + 600 + 130 + 130
= 2660 mm (25 Pieces of D13)
For element 3 (yellow) it required 25 pieces of D13 steel bar with a length of 2660 mm

For Element 3 [Middle Stirrup] (Purple) required:
4. = A + B + C + D + E + F
= Column length + Column width + Column length + Column width + Hook + Hook
= A + B + C + D + E + F = 600 + 600 + 600 + 600 + 115 + 115
= 2630 mm (18 Pieces of D10)
For element 4 (purple) it required 18 pieces of D10 steel bar with a length of 2630 mm

For Element 4 (Ties direction Y) required:
5. = A + B + C
= Column length + Hook + Hook
= A + B + C = 600 + 115 + 115
= 830 mm (43 pieces of D10)
For element 4 it required 43 pieces of D10 steel bar with a length of 830 mm

For Element 5 (Ties direction X) required:
6. = A + B + C
= Column length + Hook + Hook
= A + B + C = 600 + 115 + 115
= 830 mm (43 pieces of D10)
For element 5 it required 43 pieces of D10 steel bar with a length of 830 mm

Based on bar bending schedule calculation above, can be summarized in Table 1 below. In table 1 below, there is the material diameter, bending length, total length, and amount of material required for each type of column.

Table 1. Recapitulation Bar bending schedule Column K1-1 Grid 2

K1-1 Grid 2									
Element	**Diameter**	**A**	**B**	**C**	**D**	**E**	**F**	**Total Length (mm)**	**Total (pieces)**
1	D19	3000	350					3350	16
2	D19	3650	950					4600	16
3	D13	600	600	600	600	130	130	2660	18
3	D10	600	600	600	600	115	115	2630	25
4	D10	600	115	115				830	43
5	D10	600	115	115				830	43

2.5. Making Cutting Patterns Using Software Cutting Optimization Pro

After the length data and requirements of each material are obtained, the cutting pattern is optimized to get the most effective results and produce the least waste. Here are the steps for using Cutting Optimization Pro Software to get the most optimal cutting pattern.

1. *Determine the minimum length of material cut that can still be used for further cutting.* The first step to set the minimum length that can be entered into the stock that can later be reused in the next cut is to click on the settings, then press the technical button and select Linear (1D). After that, enter the minimum length to "minimum scrap size added to stock," then click ok. The steps above can be seen in Figure 2 below:

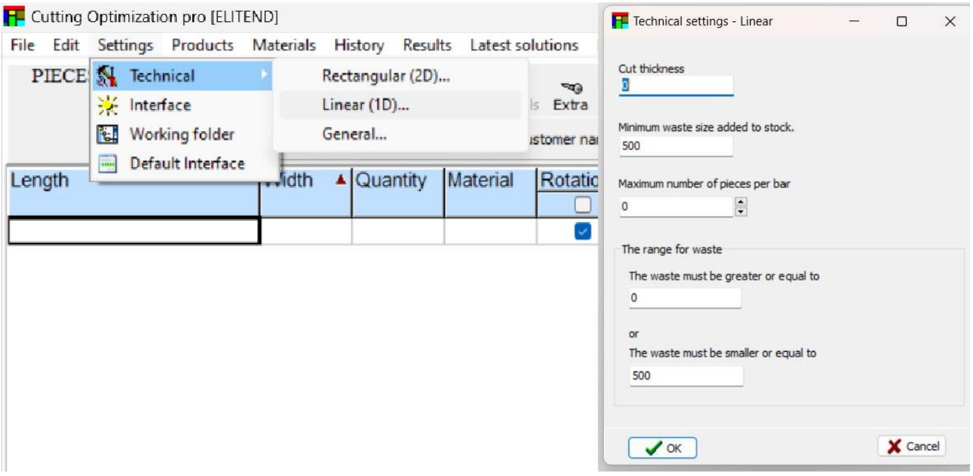
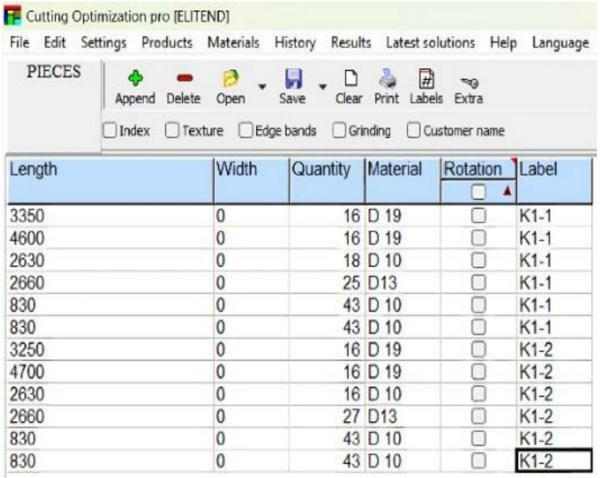


Figure 2. Setting Minimum Length to Add to Stock

Based on research conducted by [9] on 30 contractors, the contractors implemented reuse activities, namely always utilizing the remaining pieces of reinforcing steel measuring more than 50 cm for stirrups. Reinforcing steel material can still be reused if the length is still longer than 1 m [21]. In this study, what is considered waste is actually reinforcing steel that has a length of less than 50 cm because the smallest value of the column work is 83 cm. If a reference is used based on Kim's research, the reinforcing steel that should still be reused must end up as waste. This can cause losses to the contractor.

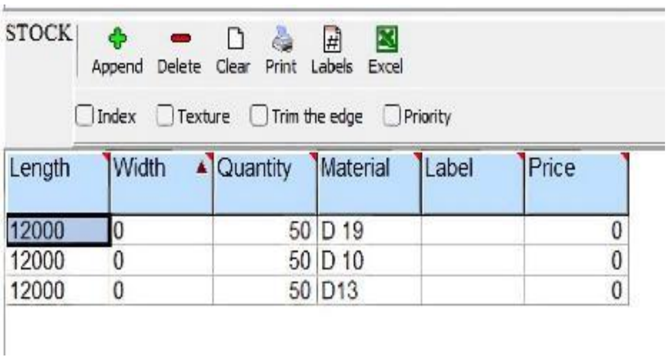
2. *Entered the length of reinforcement, the number of reinforcements, and the type of reinforcement done according to the result from the Bar bending schedule.* From the calculation of the bar bending schedule, the length, number, and diameter of the reinforcement have been obtained and then entered into the SCOP in the cutting menu. In this study, every 2 types of columns were entered to make it easier for the hammersmith during fabrication. Entering all types of columns at once can indeed make the cutting pattern more optimal, but the hammersmith who works on the reinforcement will find it difficult during fabrication and can make the artisans cut incorrectly. The steps above can be seen in Figure 3 below:



Length	Width	Quantity	Material	Rotation	Label
3350	0	16	D 19		K1-1
4600	0	16	D 19		K1-1
2630	0	18	D 10		K1-1
2660	0	25	D13		K1-1
830	0	43	D 10		K1-1
830	0	43	D 10		K1-1
3250	0	16	D 19		K1-2
4700	0	16	D 19		K1-2
2630	0	16	D 10		K1-2
2660	0	27	D13		K1-2
830	0	43	D 10		K1-2
830	0	43	D 10		K1-2

Figure 3. Input data on reinforcement length, Materials, Quantity, and Label.

3. *Entered the amount of material available in the Stock column. Stock material is categorized based on the diameter required.*
   Enter the material purchase plan based on the diameter in the inventory column. If the material available in the inventory column is insufficient, then SCOP cannot produce a cutting pattern. It is necessary to add material stock so that SCOP can produce a cutting pattern.



Length	Width	Quantity	Material	Label	Price
12000	0	50	D 19		0
12000	0	50	D 10		0
12000	0	50	D13		0

Figure 4. Input Stock materials

4. *Then press start so that the Software Cutting Optimization Pro can provide the most effective and efficient cutting pattern.*
   After the start button is clicked, SCOP can generate the most optimal cutting pattern for 1 12m long iron rod. Generating a cutting pattern for each job on this software takes an average of 1 to 2 seconds. This certainly saves much time during planning. In addition, the cutting pattern generated by SCOP is easy for blacksmiths to read, so it can facilitate blacksmiths in the daily fabrication process. In addition to providing cutting patterns, SCOP can also show how much leftover material and material can still be reused for further cutting on each job. The Example Results of the cutting pattern can be seen in Figure 5 below

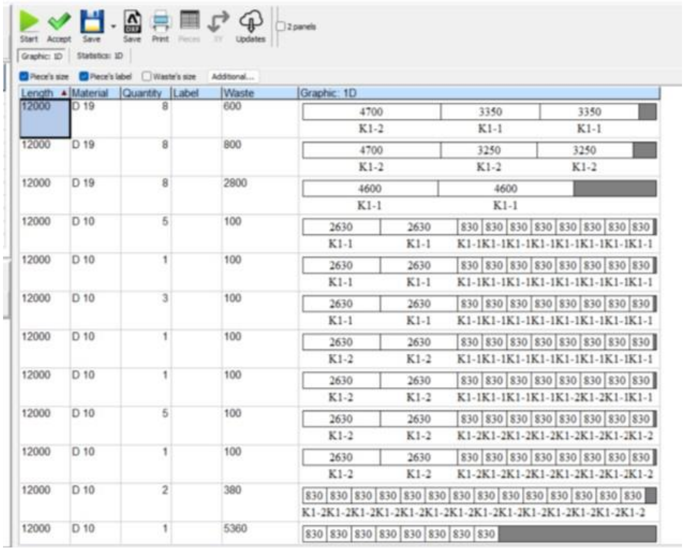


Figure 5. Output Software Cutting Optimization Pro

Based on the cutting example above, there are 17 pieces of D10 with a length of 100 mm and 2 pieces of D10 with a length of 380 mm, which are included in the actual waste. The remaining materials that can still be used again will go into stock, which can later be used in the next cutting pattern. An example of a recapitulation of materials that go into actual waste and an example of a recapitulation of materials that enter stock and can be used for further cutting is presented in Figure 6 below:

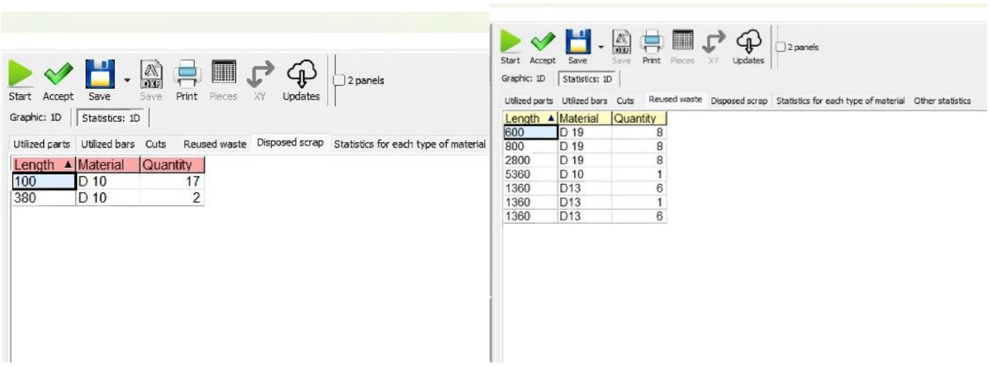


Figure 6. Actual Waste and Remaining Material That is Still Reused

3. RESULT AND DISCUSSION

3.1. Recapitulation of Reinforcing Steel Needs and Purchase Plans

The calculation of the bar bending schedule is carried out for each type of column from the ground floor to the 5th floor. After the calculation is carried out, a recapitulation is carried out for each floor and the diameter required. Table 2 below is the result of the recapitulation of the calculation requirements on each floor and each diameter. The diameters required for each floor are steel sizes D19, D10, D13, D16, and Ɵ8

Table 2. Recapitulation Material Requirements

Rekapitulasi Kebutuhan (mm)					
	D19	**D10**	**D13**	**D16**	**Ɵ8**
Ground	4582860.00	5801119.97	6378768.00	251400.00	3023210.00
Upper Ground	2815010.00	3984550.16	3984550.16	87300.00	469560.00
Lantai 1	2573740.00	4030950.16	4030950.16	87300.00	469560.00
Lantai 2	2532540.00	4050850.16	2287180.00	87300.00	469560.00
Lantai 3	3362460.00	4046970.16	2265740.00	87300.00	469560.00
Lantai 4	2456840.00	4055460.16	2257160.00	87300.00	469560.00
Lantai 5	656124.00	1677640.16	1204192.00	91404.00	469560.00
Total	18979574.00	27647540.94	22408540.32	779304.00	5840570.00

3.2. Recapitulation of the purchase plan for reinforcing steel materials

After calculating the recapitulation of reinforcing steel requirements, the number of purchases of reinforcing steel (stick) is planned. Planning the number of purchases of reinforcing steel (stick) is obtained from the SCOP after inputting all column work. The recapitulation of purchasing planning is presented in Table 3 below: In Table 3 is the plan for purchasing longer for each diameter from the ground floor to the 5th floor, along with the total planned material purchase requirements for each diameter. Purchase plan in units of stick, where 1 stick is 12 m long.

Table 3. Recapitulation of Purchase Plan

Recapitulation of Purchase Plan (Stick[12m])					
	D19	**D10**	**D13**	**D16**	**Ɵ8**
Ground	435	508	565	24	258
Upper Ground	271	344	225	9	40
Floor 1	250	344	219	9	41
Floor 2	246	345	220	9	40
Floor 3	320	334	215	9	41
Floor 4	235	347	214	9	40
Floor 5	70	143	111	9	41
Total	1827	2365	1769	78	501

3.3. *Recapitulation Stock Materials*

In addition to creating an optimal cutting pattern, SCOP can also coordinate the stock of materials from the remaining cutting results that still have a length above 50 cm, for the remaining cutting results below 50 cm will be included in the actual waste value. The recapitulation of the remaining materials that can still be used for other work is presented in Table 4 below:

Table 4. Recapitulation Stock

Recapitulation Stock (mm)					
	D19	**D10**	**D13**	**D16**	**Ɵ8**
Ground	0	0	0	0	0
Upper Ground	617728	249920	325445	36600	6300

Recapitulation Stock (mm)					
	D19	**D10**	**D13**	**D16**	**Ө8**
Floor 1	1054572	324970	687585	57300	930
Floor 2	1480832	353550	1015765	78000	7770
Floor 3	1900320	375360	1362360	98700	2610
Floor 4	2377800	268200	1670364	119400	9450
Floor 5	2731356	315180	1974804	140100	4290
Total	10162608	1887180	7036323	530100	31350

Based on the table above, the calculation on the ground floor does not have a stock recapitulation because there is still no remaining material from the previous work. In the ground floor work, the stock obtained is the remaining material from the upper ground floor work that can still be reused for the upper ground floor work, and so on**.**

3.4. Recapitulation Waste Level

The calculation of the actual remaining material produced by SCOP only takes 1 - 2 seconds, much more effective than using conventional methods. In addition, SCOP can set the minimum length for steel that is categorized as actual waste. In this calculation, the minimum value that goes into waste is reinforcing steel with a length of less than 50 cm, this is because the minimum value for column work is 830 cm The recapitulation of an actual waste is presented in Table 5 below:

Table 5. Actual Waste

Actual Waste (mm)					
	D19	**D10**	**D13**	**D16**	**Ө8**
Ground	19412	44960.03	75787	0	66490
Upper Ground	146	68399.84	7720	0	15810
Floor 1	0	6846984	8040	0	15600
Floor 2	0	67369.84	6240	0	15600
Floor 3	0	68179.84	6240	0	15600
Floor 4	9632	61539.84	6400	0	15600
Floor 5	0	54639.84	3200	0	15600
Total	29190	433559.06	113627	0	160300

Based on the table above, it is found that D16 on all floors has a waste value of 0, this is because the remaining cutting of D16 is still above 50 cm which can later be reused for cutting in subsequent work.

The Waste Percentage is calculated to determine the volume of waste generated from each material analyzed. The waste percentage is calculated using the Formula (1) [22].

$$\text{Percentage Waste (\%)} = \frac{Volume\ Waste\ (mm)}{Volume\ Materials\ Needed\ (mm)}\ x\ 100\ \% \qquad (1)$$

Where: The volume of waste used is iron with a length of less than 50 cm because if the iron is more than 50 cm in size, it can still be reused for stirrups or other work that is in accordance with the available length [9].

Volume materials needed are obtained from purchasing planning and stock from previous work. Based on the waste volume recapitulation table in Table 6, the percentage of the Waste Level value can be calculated as follows:

Table 6. Percentage Volume Waste

Volume Waste (%)					
	D19	**D10**	**D13**	**D16**	**ϴ8**
Ground	0.372	0.738	1.118	0	2.148
Upper Ground	0.004	1.657	0.286	0	3.294
Floor 1	0	1.659	0.306	0	3.171
Floor 2	0	1.627	0.236	0	3.25
Floor 3	0	1.701	0.242	0	3.171
Floor 4	0.342	1.478	0.249	0	3.25
Floor 5	0	3.184	0.240	0	3.171
Total	0.091	1.432	0.402	0	2.653

In this calculation, the diameter of 16 has a result of 0 because it does not have any actual waste (the remaining cutting is less than 50cm). In this calculation, the largest waste value is obtained, which is 2.653% at ϴ8 (ϴ8 is the symbol of diameter 8 plain rebar). This is far below the minimum standard, which is 5%.

4. CONCLUSION

The research conducted on column reinforcement work on the Graha Cahaya Kusuma Building Construction Project was motivated by problems that often occur in construction projects, namely the high waste of reinforcing steel material, which can reduce contractor profits. The lowest waste percentage value was obtained at diameter D16, which was 0%; the highest waste percentage at diameter ϴ8 was 2.653%, and the average waste percentage in reinforcing steel planning on column work on the Graha Cahaya Kusuma Building Construction Project was 0.916%. Based on previous research, the waste produced in this study is relatively low. According to [13], the maximum planning waste value is 5%, and if it is more than that, it can be said that there is waste. This proves that the use of Cutting Optimization Pro Software is effective in optimizing reinforcing steel cutting patterns, so it is expected to reduce waste material. This provides a new perspective that there is a new method that contractors can use to identify waste material in reinforcement work. The application of Cutting Optimization Pro can be a practical solution for contractors to streamline the use of reinforcing steel bar and become an alternative method of controlling construction material waste that is easier and faster than doing conventional calculations. Utilizing this software can also help determine the minimum length of reinforcing steel, which is stated as waste material. This is based on the length of reinforcing steel, which is considered waste material, must be less than the smallest length of reinforcing steel required, which is obtained from the structural calculation.

5. ACKNOWLEDGMENTS

This research was conducted on an office building construction project owned by a private corporation and was conducted with the help and support of Universitas Pembangunan Nasional Veteran East Java where the authors are part of the institution as a lecturer and student.

REFERENCES

[1] S. F. Korompot, J. Tjakra, and J. B. Mangare, "Analisis Perbandingan Waste Pada Penulangan Balok Dengan Menggunakan Metode Konvensional Dan Software Cutting Optimization Pro," *TEKNO*, vol. 22, no. 87, 2024, doi: 10.35793/jts.v22i87.54737.

[2] Mahyuddin *et al.*, A. Karim, Ed. *Manajemen Proyek Konstruksi* Yayasan Kita Menulis, 2023.

[3] E. Q. Chaise, K. S. Lians, and R. S. Alifen, "Analisa Sisa Material pada Pekerjaan Struktur Konstruksi Beton Bertulang " *Jurnal Dimensi Pratama Teknik Sipil*, vol. 9, no. 2, 2020. [Online]. Available: https://publication.petra.ac.id/index.php/teknik-sipil/article/view/10664.

[4] M. E. Silaban and A. H. Pamungkas, "Analisis Waste Material menggunakan Fault Tree Analys pada Pekerjaan Concrete Barrier," *TECHNOLOGIC*, vol. 14, no. 2, 2023, doi: 10.52453/t.v14i2.363.

[5] A. Asnudin, "Pengendalian Sisa Material Konstruksi pada Pembangunan Rumah Tinggal " *Majalah Ilmiah Mektek*, vol. 12, no. 3, 2010. [Online]. Available: https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Pengendalian+Sisa+Material+Konstruksi+pada+Pembangunan+Rumah+Tinggal+&btnG=.

[6] I. W. Muka, M. A. Widyatmika, and I. M. N. Antara, "Analisis Perbandingan Waste Besi Tulangan etode Konvensional dengan Software Cutting Optimization Pro " *TEKNIKA*, vol. 15, no. 2, 2020, doi: 10.26623/teknika.v15i2.2852.

[7] I. G. P. A. S. Putra, G. A. P. C. Dharmayanti, and A. A. D. P. Dewi, "Penanganan Waste Material pada Proyek Konstruksi Gedung Bertingkat " *Jurnal Spektran*, vol. 6, no. 2, 2018, doi: 10.24843/SPEKTRAN.2018.v06.i02.

[8] S. Intan, R. S. Alifen, and L. S. Arijanto, "Analisa dan Evaluasi Sisa Material Konstruksi Sumber Penyebab Kuantitas dan Biaya " *Civil Engineering Dimension*, vol. 7, no. 1, 2005, doi: 10.9744/ced.7.1.pp.%2036-45.

[9] J. B. Negara and M. Suryanto, "Analisis Sisa Material Besi Tulangan pada Proyek Konstruksi Bangunan Gedung " *Jurnal Rekats* vol. 7, no. 4, 2019. [Online]. Available: https://ejournal.unesa.ac.id/index.php/rekayasa-teknik-sipil/article/view/31440.

[10] S. O. Putri and Firmansyah, "The Efficiency of Steel Material as Buildings Construction," in *International Conference on Informatics Engineering, Science & Technology*, Bandung, 2020, vol. 879, no. 1: IOP Conference Series Materials Science and Engineering, doi: 10.1088/1757-899X/879/1/012148.

[11] I. G. N. E. Partama, I. G. M. Sudika, and E. L. B. Saputra, "Analisis Sisa Besi Tulangan Menggunakan Software Cutting Optimization Pro pad Konstruksi Gedung (Studi Kasus: Proyek Pembangunan Villa Stilo, Tibubeneng, Kec. Kuta Utara, Kab. Badung-Bali)," *Jurnal Teknik Gradien*, vol. 15, no. 2, pp. 30-38, 2023, doi: 10.47329/teknik_gradien.v15i02.1075.

[12] D. Kurniawan and M. Ujianto, "Optimasi Perhitungan Kebutuhan Tulangan dan Tulangan sisa (Waste Shear Wall menggunakan Software Cutting Optimization Pro pada Proyek Pembangunan Gedung MRT Jakarta " *Prosiding Seminar Nasional Teknik Sipil 2023 Fakultas Teknik Universitas Muhammadiyah Surakarta* 2023. [Online]. Available: https://proceedings.ums.ac.id/index.php/sipil/article/view/2770.

[13] N. K. S. E. Yuni, N. P. I. Yuliana, and I. K. Sudiarta, "Analisis Waste Material Besi dalam Upaya Pengendalian Sisa Material Konstruksi," *Jurnal Teknik Sipil Terapan*, vol. 5, no. 1, 2023, doi: 10.47600/jtst.v5i1.561.

[14] S. S. Nasautama and M. Sitompul, "Analisis Kebutuhan Tulangan dan Tulangan Sisa (Waste) Pekerjaan Struktur Kolom, Balok dan Pelat Lantai Proyek Pembangunan Pasar Baru Kabupaten Mandailing Natal " *PORTAL: Jurnal Teknik Sipil,* vol. 14, 2, 2022, doi: 10.30811/portal.v14i2.

[15] I. A. P. S. Mahapatni and I. K. I. Juliana, "Analisis Waste Level dan Waste Cost Bekisting dan Pembesian pada Pekerjaan Struktur Proyek Konstruksi (Studi Kasus: Pembangunan Gedung SMPN 4 Sukawati)," *Widya Teknik,* vol. 17, no. 1, 2022, doi: 10.33508/wt.v17i1.

[16] Ghaisani'Abidah and I. P. A. Wiguna, "Perbandingan Kombinasi Pemotongan Pembesian dengan Metode Manual Bar Bending Schedule dan Tekla Structures " *Jurnak Teknik ITS* vol. 12, 2, 2023, doi: 10.12962/j23373539.v12i2.112943.

[17] M. W. Jayantari, P. S. T. Dewi, and P. G. A. Yoga, "Analisa Perbandingan Volume Dan BiayaBar Bending Schedule Dengan Metode SNI-2847:2013 DanBS 8666:2005 Pada Proyek Pembangunan Kantor Pacto, Denpasar," *Reinforcement Review in Civil Engineering Studies and Management,* vol. 1, no. 2, 2022, doi: 10.38043/reinforscement.v1i2.4102.

[18] S. Z. Mauliddiana, Anisah, and A. Maulana, "Studi Literatur Penggunaan Perangkat Implementasi Building Information Modeling (BIM) dalam Penyelenggaraan Konstruksi di Indonesia," *Prosiding Seminar Pendidikan Kejuruan dan Teknik Sipil (E-Journal),* vol. 1, 2023. [Online]. Available: https://journal.unj.ac.id/unj/index.php/spkts/article/view/35965/15633.

[19] R. Immanuel and B. E. Yuwono, "Kematangan Shop DrawingSebagai Penentu Pekerjaan Ulang (Rework) Proyek Konstruksi," *Construction Engineering and Susainable Development,* vol. 3, no. 1, 2020, doi: 10.25105/cesd.v3i1.8023.

[20] M. S. D. Riyanto and M. Solikin, "Analisis Perbandingan Waste Metode Distribusi dengan Software Cutting Optimization Pro pada Pekerjaan Penulangan Pilecap (Studi Kasus: Proyek XYZ Semarang)" *Prosiding Seminar Nasional Teknik Sipil 2023 Teknik Sipil Fakultas Teknik Universitas Muhammadiyah Surakarta,* 2023. [Online]. Available: https://proceedings.ums.ac.id/index.php/sipil/article/view/2694.

[21] S.-K. K. W.-K. Hong and J.-K. Joo, " Algorithms for Reducing the Waste Rate of Reinforcement Bars," *Journal of Asian Architecture and Building Engineering,* vol. 3, no. 1, 2004, doi: 10.3130/jaabe.3.17.

[22] C. S. Poon, A. T. W. Yu, and L. H. Ng, "On-site Sorting of Construction and Demolition Waste in Hong Kong," *Resources, Conservation and Recycling,* vol. 32, pp. 157-172, 2001, doi: 10.1016/S0921-3449(01)00052-0.