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Original Article

Analysis of Waste Material on Reinforced Concrete Work in Wetlands by Linear Programming Method

Candra Yuliana[1], Gawit Hidayat[2], Jihan Safitri[3]

[1]*Department of Engineering Professional Education, Lambung Mangkurat University, Banjarbaru, Indonesia*
[2,3]*Department of Civil Engineering, Lambung Mangkurat University, Banjarbaru, Indonesia*

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Abstract *- Iron concrete is a material that has the highest percentage of costs, which is around 20% - 30%. The rest of the construction material is something that exceeds what is required, both in the results of work and construction materials that are left/scattered/damaged so that they cannot be used again according to their function. The dominant pieces of material that occur in a project include the remnants of pieces of reinforcing iron in reinforced concrete. The rest of the material wasted due to iron cutting errors is about 5% - 10% of the proportion of iron material costs. The optimization of the Linear Programming method with the help of the Add-In Solver in Microsoft Excel shows a material saving or reduction of 23.90% for the construction of stirrup reinforcement for reinforced concrete columns and beams.*

Keywords *- Column and beam work, Linear programming, Stirrup, Waste of material.*

1. Introduction

Construction is India's second largest industry after agriculture. It has a significant impact on the economy of the country and employs a large number of people [3]. Construction materials are an important component in project implementation and determine the cost of a project. During project implementation in the field, it is unavoidable to avoid the appearance of residual construction materials [4]. Residual material is one of the problems that must be faced in building construction. Minimizing material waste can reduce costs and environmental impact [5, 6].

Iron concrete is a material that has the highest proportion of costs, which is around 20% - 30% [1]. The remaining pieces of reinforced concrete are the dominant component of the remaining material in a project. The rest of the material wasted due to iron-cutting errors is around 5% - 10%. Factors causing material waste are design, material procurement, material handling, execution, residue, and theft [27]. The percentage of remaining iron in a project wasted due to iron-cutting errors is around 11% - 15%. The material waste savings for multi-story building reinforcement work is 3.6% - 4.51% [8].

The dominant factor causing the occurrence of residual material during the implementation of building construction projects in Aceh Province is the residual factor with the indicator error when cutting the material [9]. According to similar research that has been carried out, it has resulted in savings on the waste of material of 21.56%, and the total iron that has been saved is 23.46% [10]. According to Kork, M., and Sabry [11, 12], using Excel Solver can optimize waste in cutting reinforcement. Efforts that can be made to reduce the emergence of construction waste are to minimize design changes and material control [13].

From observations in the field, there is material waste, as shown in Figure 1. The research was carried out specifically on the stirrup reinforcing steel material because the stirrup reinforcement requires a cutting process following the planned dimensions, so it often results in scrap pieces of reinforcing steel.

Fig. 1 Remaining Pieces of Steel Reinforcing

The goal is to compare the percentage of waste of iron material savings for stirrup reinforcement based on the field and the linear programming method.

2.Materials and Methods

2.1. Waste of Material

Waste is typically generated over the life cycle of a building, from the design stage to construction, renovation, and demolition [28]. Reinforcing is part of the structural work. This work plays an important role in the quality aspect of implementation because reinforcing steel has an important function in the strength of the building structure [15]. Reinforcement is carried out by craftsmen or workers who are experts and skilled in building structural steel. In addition, this work requires tools such as bar cutters, bar benders, tape measures, and gloves.

Waste material is generally defined as a substance or an object that the owner desires to dispose of, while construction material waste is defined as material that is not used, resulting from the construction, repair, or alteration process [16–20]. Material waste is defined as loss, such as material, time, and productivity, which impacts direct and indirect costs but does not add value from a consumer point of view [1]. Bossink and Browers (1996) researched measuring and preventing residual construction materials in the Netherlands. The research was conducted on 7 types of building materials in 5 buildings house from April 1993 to June 1994. Obtained total residual weight of construction materials between 1% to 10% of the weight of the construction material [21].

2.2. Linear Programming

Linear Programming is a mathematical technique to achieve the optimum objective function of the constraint function specified in decision-making [22–25]. Linear programming is often used to minimize or maximize a problem. This program must meet the requirements of the objective function to be achieved, expressed in the form of a linear function. There must be alternative solutions to choose the best one that makes the value of the objective function optimum, and resources are available in limited quantities. The constraint is expressed in the form of a linear inequality.

The stages in linear programming modeling are determining decision variables, formulating goals, and constraining constraints. Linear programming is formulated mathematically as follows:

- Purpose function (minimum or maximum):

$$Z = C_1x_1 + C_2x_2 + \cdots + C_nx_n \quad (1)$$

- Boundaries:

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq = \geq b_1 \quad (2)$$

$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq = \geq b_2 \quad (3)$$

$$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq = \geq b_m \quad (4)$$

- non-negative terms:

  $x_i \geq 0$, with $i = 1, 2, \ldots, n$

  $a_{ij} \geq 0$, with $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$

  where:

- Z is the total remaining pieces of concrete iron.
- $x_1, x_2, \ldots, x_n$ are the value sought (decision variable) in this case is the required iron bar.
- $C_1, C_2, \ldots, C_n$ are the remaining piece of reinforcing iron for each alternative.
- $a_{11}, \ldots, a_{1n} \ldots, a_{mn}$ are the coefficients of the mathematical model constraint function.
- $b_1, b_2, \ldots, b_m$ are the amount of each resource.

2.3. Method

The data required consists of primary data and secondary data. Primary data were obtained from interviews and observations in the field, namely the cutting process, the number of steel bars procured, and the length and diameter of the reinforcing bars used in the field. Secondary data in the form of shop drawings detail the reinforcement of columns and beams.

The data is processed using the linear programming method with the help of the Add-In Solver in Microsoft Excel. The steps for making linear programming are, determining which decision variable, in this case, is the number of iron bars needed that affect the rest of the pieces. Then make a goal formulation, namely optimization of the smallest total waste of material from each alternative. Next, formulate the constraints that become obstacles. The limitations are the length of reinforcing steel on the market as long as 12 m with a diameter of 10 mm, the number of pieces produced must be greater than or equal to the number of pieces required, and also the resulting decision variable must be an integer greater than or equal to zero.

3.Results and Discussion

3.1. Volume Requirement

Calculating the volume requirement for steel stirrups for beams and columns used in the field, as shown in Table 1, with a diameter of 10 mm, is 7473.4 kg.

The calculation of the need for steel stirrups based on the plan drawing is used for the analysis process in Linear Programming. The results of calculations and grouping based on iron length can be seen in Table 2.

Table 1. Volume of Steel Bars from Field Data

Type	Total volume Requirement		
	m	bar	kg
K1-1 (40x40 cm)	1148.40	95.70	708.18
B1-1 (30x50 cm)	2915.00	242.92	1797.58
B2-1 (30x40 cm)	1664.83	138.74	1026.65
B3-1 (15x30 cm)	95.40	7.95	58.83
K1-2 (40x40 cm)	1148.40	95.70	708.18
B1-2 (30x50 cm)	3070.38	255.87	1893.40
B2-2 (30x40 cm)	2057.42	171.45	1268.74
B3-2 (15x30 cm)	19.20	1.60	11.84
	Total	1010	7473.40

Table 2. Reinforcement Needs of Stirrups Based on Shop Drawings

Type	Dimension (cm)			Number of Pieces	Total (kg)
	h	b	L		
K1-1	40	40	140	720	621.936
B1-1	50	30	140	1,558	1,345.800
K1-2	40	40	140	720	621.936
B1-2	50	30	140	1,558	1,345.800
Total				4,556	
B2-1	40	30	120	1,029	761.872
B2-2	40	30	120	1,235	914.394
Total				2,264	
B3-1	30	15	70	142	61.330
B3-2	30	15	70	22	9.502
Total				164	

3.2. Determining Linear Program Functions

Reinforcement iron is grouped by diameter and then grouped again by length. The same size number of stems are put together while those that are not the same are grouped with the same length (see Table 3). The iron-cutting model uses a cutting technique that produces minimal waste. There are five alternatives based on the standard 12 m iron length. In the alternative I, there are 6 pieces of reinforcing iron with a length of 140 cm and 3 pieces of iron with a length of 120 cm so that it does not produce waste of material, etc. Then the objective function of the several alternative cuts are:

$$Z = 0.0\ X_1 + 0.1X_2 + 0.0X_3 + 0.3X_4 + 0.0X_5$$

With boundaries:

$X_1 + X_2 + X_3 + X_4 \geq 4556$
$X_1 + X_3 + X_4 + X_5 \geq 2264$
$X_2 + X_3 + X_4 \geq 164$

Table 3. Alternative Cutting

No	Type (cm)			waste (cm)	Number of Pieces	Remaining amount (cm)
	140	120	70			
I	6	3	0	0	0	0
II	8	0	1	10	0	0
III	3	3	6	0	0	0
IV	7	1	1	30	0	0
V	0	10	0	0	0	0
Needs	4556	2264	164	Tota l	0	0
Cutting	0	0	0			

Data tables must be predefined for all functions required in a linear program. For example, the alternative data for cross-section reinforcement can be seen in Fig. 2.

a) Determine the objective function
The objective function in this optimization is the total remaining pieces of concrete (cell J8)
b) Determine the decision variables
The decision variable is the number of iron bars required, affecting the remaining pieces. Each row in a cell I can be left blank or filled with the number 0 (zero) then the solver program will fill in the numbers in that row.
c) The functions of the constraints in this analysis are:
- The number of pieces desired must be equal to (=) or greater (≥) than the number of pieces required (formula "=SUM(E3:E7)")
- The decision variable must be an integer or ≥ 0

	A	B	C	D	E	F	G	H	I	J
1	Alternative	Cut Needs (Pieces)			Number of Pieces			Waste (cm)	Amount of concrete iron (rod)	Amount Remaining iron concrete (rod)
2		140	120	70	140	120	70			
3		(cm)	(cm)	(cm)	(cm)	(cm)	(cm)			
4	1	6	3	0	0	0	0	0	0	0
5	2	8	0	1	0	0	0	10	0	0
6	3	3	3	6	0	0	0	0	0	0
7	4	7	1	1	0	0	0	30	0	0
8	5	0	10	0	0	0	0	0	0	0
9	Needs	4556	2264	164				Total	0	0
10	Cutting				0	0	0			

Fig. 2 Excel View

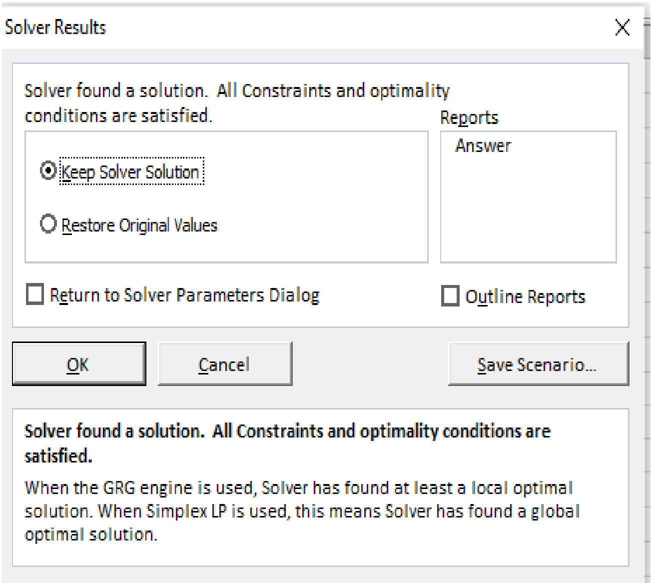

Fig. 3 Solver Result Display

3.3. Process Data Input in Solver

After the functions and variables are determined, the next step is to run the solver. Several things must be understood in running the solver, namely:

1. Set Objective: enter data which is the objective function (cell J8).
2. By Changing cell: enter decision variable data (cell I3 - I7.
3. Subject to the Constraints: enter the delimiter function data that is $E$9 = $B$8; $F$9 = $C$8; $G$9 = $D$8 and $I$3:$I$7 = integer.
4. If the data has been successfully analyzed, it will appear as in Figure 3. If it doesn't work, it will look like in Fig. 4, so the entered variables must be corrected.

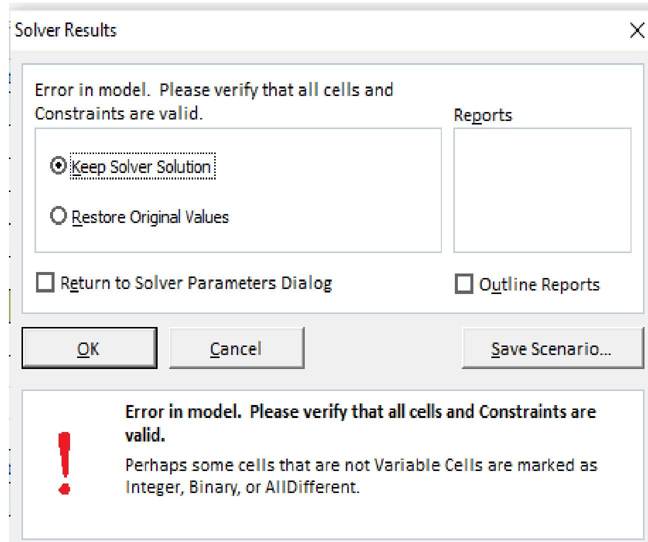

Fig. 4 Error Solver Result Display

In Fig. 5, it can be seen that the cell, which is the decision variable, is filled with integers and the cell, which is the objective function, finds the minimum remaining pieces of 600 cm or 6 m. Solver analysis resulted in the total need for iron and concrete as much as 768 rods; the remaining pieces were 600 cm.

3.4 Comparison of Field Needs and Solver Linear Programming Results

The comparison of the amount of concrete used in the field and the results of the linear programming solver of beam and column stirrups can be seen in Table 4.

The need for stirrup reinforcement for beams and columns in the field is 1010 bars or 7473.4 kg. Meanwhile, using Solver Linear Programming, as many as 768 sticks or 5683.2 kg. Linear Programming can save the use of reinforcing iron material as much as 242 rods or 1790.8 kg to optimize material use and minimize waste by as much as 23.96%.

Alternative	Cut Needs (Pieces)			Number of Pieces			Waste (cm)	Amount of concrete iron (rod)	Amount Remaning iron concrete (cm)
	140 (cm)	120 (cm)	70 (cm)	140 (cm)	120 (cm)	70 (cm)			
1	6	3	0	4248	2124	0	0	708	0
2	8	0	1	144	0	18	10	18	180
3	3	3	6	66	66	132	0	22	0
4	7	1	1	98	14	14	30	14	420
5	0	10	0	0	60	0	0	6	0
Needs	4556	2264	164				Total	768	600
Cutting				4556	2264	164			

Fig. 5 Excel Display After Solver

Table 4. Comparison of the Needs of Steel Reinforcing Stirrups

Method Description		Field Data	Linear Programming
Concrete Iron Needs	Pieces	1010	768
	Weight (Kg)	7473.4	5683.2
Difference	Pieces	242	
	Weight (Kg)	1790.8	
	%	23.96	

4. Conclusion

Based on the results of the analysis for this research with a case study on the BPKB Service Building Project of the South Kalimantan Police, it can be concluded that:

1. The total use of iron for beam and column beam reinforcement with a diameter of 10 mm in the field is 7473.40 kg
2. The need for stirrup reinforcement for columns and beams with Linear Programming is 5683.2 kg.
3. The Linear Programming method can save the use of reinforcing iron material as much as 242 rods or 1790.8 kg to optimize the use of materials and minimize the remaining 23.96%.

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