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Reducing Waste from Cutting Reinforcing Steel in Construction Projects

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ABSTRACT

For concrete construction, one problem that a constructor often encounters is that there is a large amount of fraction of reinforcing steel caused by cutting. This study shows a method of reducing waste from the cutting. The study is divided into two steps. The first step is collecting bar bending lists and percentage of wastes caused by cutting steels. The second step is finding a method to minimize waste due to the cutting. The research implements the combination theory in order to generate all possible cutting patterns of reinforcing steels and mathematical programming theory to solve for the patterns that yield minimum waste. A software program is developed in order to generate cutting patterns, formulate mathematical model, and solve the model. The result shows that the wastes of reinforcing steels from the analysis are much less than the wastes of reinforcing steels from the collected data.

Key words: reinforcing steel, waste minimization, cutting stock problem, mathematical programming

INTRODUCTION

For building construction, the structure that is most often built is reinforced concrete because it costs less than other types of structures. The major cost of the structure consists of concrete, reinforcing steel, and formwork. Concrete and reinforcing steel are permanent materials that exist along with the life of the structure while formwork is considered to be a temporary work that will be removed after the structure can support itself.

One problem that a constructor often encounters is that there are a large number of lengths of reinforcing steels used in construction but there are only two standard lengths of reinforcing steels produced in Thailand. The standard lengths are 10 and 12 meters. In construction, therefore, it is necessary to cut the steels from the standard lengths, causing a large amount of wastes of reinforcing steels remain at the job site.

Mirza (1984) has found that the normal percentage of waste of reinforcing steel in general reinforced concrete building is approximately 8.9. However, for a construction project that has a very good controlling system, the percentage of waste of reinforcing steel can be reduced to 6 (Fooster, 1972).

The amount of reinforcing steel needs in Thailand is approximately 2.3 million tons (average from year 1990- 1997, IFCT 1998). If there is a waste of 5 % from using reinforcing steel, it will be 115,000 tons of steel per year. If the unit cost of reinforcing steel is 11,000 Bahts/ton, then this will cost the whole industry 1,265 million Bahts per

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year. If the number of the waste can be reduced, Thailand will reduce the amount of importing steel of over 100,000 tons per year. This will reduce the number of deficit budget from importing of Thailand. Therefore, there should be a study on this problem.

The objective of this study is to find a method for reducing waste of reinforcing steel from cutting.

Scope of this study:

1. Two standard lengths (10m. and 12 m.) of reinforcing steels are used in the analysis.

2. Only bar bending lists of reinforcing steel from building construction projects are used in the analysis.

MATERIALS AND METHODS

Materials and tools

1. A set of PC
   - CPU: Pentium III, with minimum 32 Mb RAM
   - Other accessories: a monitor, key board, mouse, printer, disk drives, floppy disks
2. Software:
   - Operating system: Windows 95
   - Programming language: Basic
   - Other software package: Microsoft Excel Solver (Office 7)

Methods

1. Collecting data

The data that are needed for the analysis are bar bending lists that show types, sizes, lengths, and number of each reinforcing steel used in construction. This data are used to generate possible cutting patterns. The data were collected from construction projects that have preparation of bar bending lists. For construction projects that have no bar bending lists, the data were prepared from the detailed drawings of those projects.

2. Cutting patterns of reinforcing steels

To generate all possible cutting patterns, the combination theory is implemented. The total number of all possible cutting patterns can be computed from the following formula.

$$C_r^n = \frac{(N+r-1)!}{(N-1)!\,r!}$$

In construction, the number of lengths of reinforcing steel is quite varies. It may range from 1 to 100. The number of possible cutting patterns depends on the number of required lengths (N) and the number of reinforcing steel in one group (r).

For instance, if the number of required lengths in a bar bending list is 30 and the maximum number of reinforcing steel in one group is 5, then the total number of possible combination of cutting patterns will be;

$$C_r^n = \frac{(30+5-1)!}{(30-1)!\,5!} = 278{,}256$$

This number is too large and difficult to change to mathematical equations and solve for the solution. Therefore, some assumptions are needed in order to reduce the number of variables to the extent that can be solved for the solution.

Assumptions:

1. From the list of reinforcing steels that the lengths are sorted in an ascending order, if the summation of the length of any steel and the length of the shortest steel in the list is more than 12 m., then remove that steel and the steels that have greater lengths from the group.

2. The summation of lengths of reinforcing steels in any pattern cannot be greater than 12 m. or 10 m. (Standard length).

3. Limit the maximum number of required lengths of reinforcing steel in one group to 5.

4. Limit the number of cutting patterns that will form variables of each reinforcing steel. This can be done by arranging the fractions of

cutting patterns in an ascending order, then select the variables that have smaller fractions. For this research, the number is limited to 10 (this number is obtained from the experiment, showing that the number that is larger than this number has no impact on the solution from the analysis).

3. Creating mathematical model

This step creates mathematical equations in order to change a qualitative problem to a quantitative problem that can be solved. The problem can be analyzed in the class of cutting stock problem (Sohail, 1983). The following is the standard equations (Jensen, 1996) for the integer programming model for this type of problem.

Objective function:

$$\text{Min } Z = C_1 * X_1 + C_2 * X_2 + \ldots\ldots\ldots\ldots + C_n * X_n$$

Constraints:

$$L_1: a_{11} * X_1 + a_{12} * X_2 + \ldots\ldots\ldots\ldots + a_{1n} * X_n = b_1$$
$$L_2: a_{21} * X_1 + a_{22} * X_2 + \ldots\ldots\ldots\ldots + a_{2n} * X_n = b_2$$
$$\vdots \quad \vdots \quad \vdots \quad \vdots$$
$$L_m: a_{m1} * X_1 + am_2 * X_2 + \ldots\ldots\ldots + a_{mn} * X_n = b_m$$
$$X_j \geq 0 \text{ and integer for } j = 1 \text{ to } n$$

Where:

Min Z = the objective function. For this model, it is to minimize waste from cutting steel

C_j = fraction of reinforcing steel in group j; j = 1 to n. For example, group 1 consists of two L_1 (1.60m.), one L_5 (2.40 m.) and one L_8 (6.0 m.), if the standard length is 12 m., then, c_1 = (12 - 1.60*2 + 2.40*1 + 6.0*1) = 0.40 m.

X_j = a variable represents the number of cutting pattern no. j; j = 1 to n

L_i = length of each steel, i =1 to m

a_{ij} = number of reinforcing steel that has the same length in one group for length no. i and group no. j. For example, group 1 consists of two L_1, one L_5 and one L_8, then $a_{11} = 2$, $a_{51} = 1$, and $a_{81} = 1$.

b_i = the number of reinforcing steel for length no. i.

m = the number of lengths in a set of bar bending lists, this number will be the number of constraints in the formula.

n = the number of possible cutting patterns.

4. Finding the solution

In the case that the number of lengths of reinforcing steels is not high, manual calculation can be done in order to generate cutting patterns, variables, equations, and solve the equations. However, the collected data shows that the number of lengths of reinforcing steels is high, therefore, manual calculation is not suitable. As the result, a computer program is needed to be developed. Following are main procedures of developing the software program:

1. Develop a subprogram for inputting data

A subprogram for inputting data is needed in order to keep the data as a file that can be used later. The data include the lengths of reinforcing steels and the amount of reinforcing steel for each length.

2. Develop subprograms for calculation process

The calculation process can be divided into 3 steps.

2.1 Generating all possible cutting patterns

This subprogram generates all possible cutting patterns using data from the previous step. Each pattern will be checked with the assumptions 1, 2, and 3, if it passes the assumptions, then the pattern will be used as a variable. The variable will be saved as a string variable in a data file.

2.2 Developing mathematical model

This subprogram uses the string variables from the data files in the previous steps to generate the mathematical model in a matrix form (m x n). This step uses assumption 4 in order to limit the number of variables in order that they can be solved. The mathematical model includes variables (X_j), coefficients (a_{ij}), waste (C_j), and amount of steel for each length (b_i). The mathematical model will be saved in a data file.

2.3 Solving the model

The model from step 2.2 can be solved using any mathematical programming software, for instance, Microsoft Excel Solver. However, to eliminate interfacing between different software programs, this research uses a subprogram that has been developed by the author in order to solve the model. The subprogram is verified by comparing the solution from the subprogram with the solution from using standard software (Excel Solver). The solution from the subprogram will be saved in a data file for the next step.

3. Develop a subprogram for output

This subprogram generates output using the solution in the previous steps. The output shows the number of cutting patterns needed, standard length(s) used, and the fractions from the cutting patterns.

RESULTS AND DISCUSSION

Five sets of data from five construction projects are used in this research. The data are shown in Table 1 and Table 2. Followings are description of the data.

Data set 1 and set 2 were collected from two construction projects that have bar bending lists. Data set 3 to set 5 were from construction projects that have no bar bending lists, so the lists were prepared from the detailed drawings of the projects.

Table 1 shows the number of required lengths and percentage of wastes from bar bending lists of the five construction projects. The Table shows that the construction projects that have bar bending lists have lower percentage of waste than of those without bar bending lists. The percentages of wastes are used to compare with the percentages of wastes from the analysis.

Table 2 shows the lengths and the numbers of reinforcing steels for the five construction projects. These data are used in the analysis in order to find the cutting patterns that yield minimum wastes from cutting.

Tables 3 to Table 7 show cutting patterns of reinforcing steels from analyzing data of bar bending lists from the five construction projects. Columns 1, 2, and 3 show the group number, the amount of group for each group number, and the standard lengths required respectively. Column 4 shows the cutting patterns. Each pattern shows the number(s) and the length(s) of reinforcing steel(s) in the group. The last column shows the fraction of the cutting patterns.

For instance, group no. 1 in project no. 1 has the number of group equal to 266. This number represents that the group requires 266 pieces of 12 m. (standard length) of reinforcing steel. Each standard length will be cut to two pieces of 2.70 m. and two pieces of 3.30 m. The fraction remains from the cutting is zero.

Table 8 shows the number of possible cutting patterns, the number of cutting patterns that are variables, the number of cutting patterns that are the solution, the number of standard reinforcing steels used, the total length of standard steels used, the waste remains from cutting, and the waste that can be reduced for each project.

Figure 1 shows the comparison between wastes of reinforcing steel from the analysis and wastes of reinforcing steel from collected data. The graph also shows the percentage of reinforcing steel that can be saved. The result shows that the amount of waste from cutting reinforcing steels in each project can be reduced more than 5 %.

CONCLUSION

The study shows that the construction projects that have bar bending list during construction has less waste than the projects that have no bar bending list during construction. However, arrangement of cutting patterns can directly reduce waste from cutting steels. The analysis implements combination theory in order to find all possible cutting patterns. Then, the cutting patterns are changed to the mathematical

Table 1 Number of lengths and % waste of reinforcing steel for each project.

Project no.	Number of length	Waste (%)
1	9	6.8
2	18	8.6
3	10	12.6
4	12	10.8
5	15	11.4

Table 2 Lengths and numbers of reinforcing steels collected from five construction projects.

Length	Project no. 1		Project no. 2		Project no. 3		Project no. 4		Project no. 5	
no.	Length (m)	Number	Length (m)	Number	Length (m)	Number	Length (m)	Number	Length (m)	Number
1	1.80	990	2.82	72	1.24	720	1.4	32	1.60	620
2	2.25	597	2.98	2	2.99	602.	1.8	272	2.20	380
3	2.70	884	3.02	72	3.00	64	2.2	462	2.60	472
4	3.30	768	3.50	228	3.25	560	2.6	560	3.00	510
5	4.35	687	3.56	9	3.30	220	2.8	320	3.40	420
6	5.80	109	3.88	24	3.35	268	3.2	986	4.50	312
7	6.50	77	3.91	12	3.36	320	3.3	420	5.20	216
8	6.75	136	4.00	72	3.43	156	4.0	1160	6.60	220
9	7.60	250	6.06	6	4.05	220	4.8	870	7.50	275
10	-	-	6.24	12	4.30	776	6.65	410	8.20	260
11	-	-	6.32	15	-	-	7.20	410	9.60	120
12	-	-	6.56	15	-	-	7.50	576	9.80	240
13	-	-	8.41	27	-	-	-	-	10.20	60
14	-	-	9.11	9	-	-	-	-	11.50	48
15	-	-	9.26	9	-	-	-	-	11.80	28
16	-	-	11.70	6	-	-	-	-	-	-
17	-	-	11.76	6	-	-	-	-	-	-
18	-	-	11.87	9	-	-	-	-	-	-

Table 3 Cutting patterns from analyzing data of project no.1.

Group no.	Number of group	Standard length (m)	Cutting pattern (Number – required length (m))	Fraction (m)
1	266	12	2-2.7, 2-3.3	0.00
2	93	12	1-1.8, 3-2.25, 1-3.3	0.15
3	175	12	1-2.25, 2-2.7, 1-4.35	0.00
4	6	12	1-3.3, 2-4.35	0.00
5	140	12	3-1.8, 1-2.25, 1-4.35	0.00
6	109	12	1-1.8, 1-4.35, 1-5.8	0.05
7	77	12	3-1.8, 1-6.5	0.10
8	136	12	1-1.8, 1-3.3, 1-6.75	0.15
9	250	12	1-4.35, 1-7.6	0.05
10	1	12	1-4.35, 1-3.3, 1-2.7	1.65
11	1	12	1-2.7, 3-2.25, 1-1.8	0.75

Note: For the integer programming model, the number of solutions may not be equal to the number of constraints that is normally found in the linear programming model.

Table 4 Cutting patterns from analyzing data of project no.2.

Group no.	Number of group	Standard length (m)	Cutting pattern (Number – required length (m))	Fraction (m)
1	58	10	1-2.82, 2-3.5	0.18
2	2	10	1-2.98, 2-3.5	0.02
3	16	12	2-3.02, 1-3.88	0.08
4	17	10	3-3.5	1.50
5	4	12	1-2.82, 2-3.56	0.06
6	0	12	3-3.88	0.36
7	12	10	2-3.02, 1-3.91	0.05
8	24	12	3-4.0	0.00
9	6	10	1-3.88, 1-6.06	0.05
10	12	10	1-3.5, 1-6.24	0.26
11	15	10	1-3.5, 1-6.32	0.18
12	15	10	1-3.02, 1-6.56	0.42
13	27	12	1-3.5, 1-8.41	0.09
14	9	12	1-2.82, 1-9.11	0.07
15	9	10	1-9.26	0.74
16	6	12	1-11.7	0.30
17	6	12	1-11.76	0.24
18	9	12	1-11.87	0.13
19	1	12	2-3.88, 1-3.56	0.68
20	1	12	3-3.5	1.50
21	1	10	1-3.02, 1-2.82	4.16

Table 5 Cutting patterns from analyzing data of project no.3.

Group no.	Number of group	Standard length (m)	Cutting pattern (Number – required length (m))	Fraction (m)
1	11	10	8-1.24	0.08
2	116	12	4-2.99	0.04
3	64	12	2-1.24, 1-3.0, 2-3.25	0.02
4	138	12	2-1.24, 1-2.99, 2-3.25	0.03
5	12	12	1-1.24, 2-3.3, 1-4.05	0.11
6	51	12	1-1.24, 2-3.35, 1-4.05	0.01
7	222	12	1-3.36, 2-4.3	0.04
8	97	10	2-3.3, 1-3.36	0.04
9	156	12	1-1.24, 1-3.25, 1-3.43, 1-4.05	0.03
10	165	12	1-3.35, 2-4.3	0.05
11	1	12	2-4.3, 1-3.36	0.04
12	1	12	1-4.05, 1-3.35, 1-3.3, 1-1.24	0.0
13	1	12	1-3.3, 7-1.24	0.02
14	1	10	1.24	8.76

Table 6 Cutting patterns from analyzing data of project no.4.

Group no.	Number of group	Standard length (m)	Cutting pattern (Number – required length (m))	Fraction (m)
1	16	12	2-1.4, 2-2.6, 1-4.0	0.00
2	272	12	1-1.8, 1-2.6, 1-7.5	0.10
3	410	12	1-4.8, 1-7.2	0.00
4	22	12	2-2.6, 1-2.8, 1-4.0	0.00
5	43	12	2-2.8, 2-3.2	0.00
6	460	12	1-3.2, 1-4.0, 1-4.8	0.00
7	9	10	3-3.2	0.40
8	220	12	3-4.0	0.00
9	210	12	1-2.6, 1-2.8, 2-3.3	0.00
10	158	12	2-2.2, 1-7.5	0.10
11	410	10	1-3.2, 1-6.65	0.15
12	146	10	1-2.2, 1-7.5	0.30
13	1	12	2-4.0, 1-3.2	0.80
14	1	12	2-3.2, 2-2.8	0.00
15	1	10	2-2.6	4.8

Table 7 Cutting patterns from analyzing data of project no.5.

Group no.	Number of group	Standard length (m)	Cutting pattern (Number – required length (m))	Fraction (m)
1	49	10	2-1.6, 2-3.4	0.00
2	120	12	1-2.2, 1-9.8	0.00
3	118	12	1-1.6, 4-2.6	0.00
4	122	12	4-3.0	0.00
5	40	12	2-3.4, 1-5.2	0.00
6	18	12	1-3.0, 2-4.5	0.00
7	82	12	1-1.6, 2-5.2	0.00
8	220	10	1-3.4, 1-6.6	0.00
9	275	12	1-4.5, 1-7.5	0.00
10	260	12	1-1.6, 1-2.2, 1-8.2	0.00
11	120	10	1-9.6	0.40
12	120	10	1-9.8	0.20
13	60	12	1-1.6, 1-10.2	0.20
14	48	12	1-11.5	0.50
15	28	12	1-11.8	0.20
16	1	12	2-5.2, 1-1.6	0.00
17	1	12	1-4.5, 2-3.4	0.70
18	1	12	4-3.0	0.00
19	1	10	1-1.6	8.40

Table 8 Comparisons between wastes of reinforcing steels from collecting data with wastes of reinforcing steels from analyzing the data.

Description	Project no. 1	Project no. 2	Project no. 3	Project no. 4	Project no. 5
Number of all possible cutting patterns	77	112	238	425	152
Number of cutting patterns to be variables	56	90	50	79	78
Number of patterns for solution	11	21	14	15	19
Total required length (m.)	14985.6	2634.95	12166.66	27258.5	19185.3
Number of 10 m. reinforcing steel used	0	147	109	566	510
Number of 12 m. reinforcing steel used	1254	103	927	1813	1184
Total length of standard reinforcing steel (m.)	15048	2706	12214	27416	19308
Fraction from analysis (m.)	62.40	71.05	47.34	157.5	122.70
Fraction from analysis (%)	0.41	2.70	0.38	0.57	0.63
Fraction from collected data (%)	6.80	8.60	12.60	10.80	11.40
Reinforcing steel saved (%)	6.39	5.90	12.22	10.23	10.77

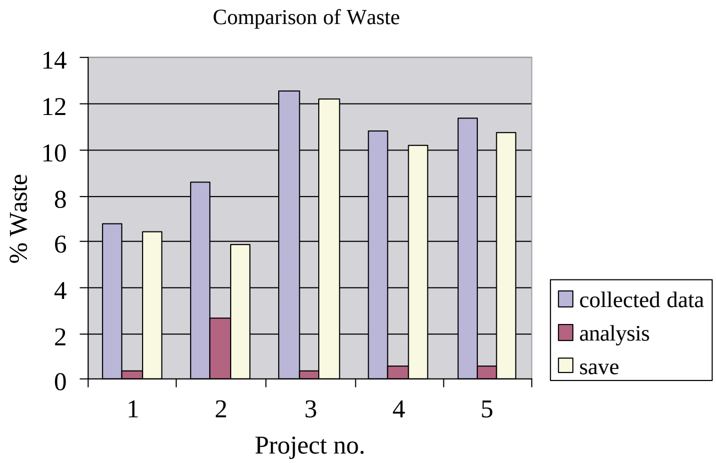

Figure 1 Comparisons between waste of reinforcing steel from the analysis and collected data.

model . The model is solved by the subprogram developed by the author

The comparison between wastes of reinforcing steels from collected data and from the analysis shows that the wastes from the analysis is much less than those of collected data. Therefore, the method showed in this study should be implemented in real construction projects that have a problem with cutting steels. The method may be applied to other cutting problem, for example, cutting timbers or cutting structural steels that have limited numbers of standard lengths.

Abbreviations

a_{ij}	the number of steel that has equal length in steel no. i and cutting pattern no. j; i =1 to m and j = 1 to n
b_i	the quantity of reinforcing steel for steel no. i ; i = 1 to m
c_j	the fraction of cutting pattern no. j ; j = 1 to n
C^N_r	the number of possible combination
L_i	length of reinforcing steel for steel no. i; i = 1 to m
Min Z	Objective function in the form of minimizing total waste of reinforcing steel
X_j	the variable that represent number of cutting pattern no. j ; j = 1 to n
N	the number of length of reinforcing steel in a bar bending list
r	the number of reinforcing steels in one group
m	the number of reinforcing steel having different lengths (the number of constraint in the mathematical model)
n	the number of variables in the mathematical model

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