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Optimizing Reinforcing Re-Bar for Multi-Story Buildings Using Automated Bending Lists

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Abstract

Controlling amounts of reinforcing re-bar during construction project phases enables contractors to reduce total direct cost of R.C. leading to final competitive prices. In this study a computer software **RCD-2**, using Auto-Lisp Language as a support to Auto-Cad software, is designed to help both designers and contractors to automatically produce design and fabrication drawings and bending lists for reinforced concrete sub-systems. The economic implications of using such system is to reduce engineering hours since fabrication drawings are executed automatically leading to savings in both time and cost. An optimization strategy has been developed to help engineers to improve the over all steel bars utilization using the previously produced drawings and bending lists. The optimization process is executed through using several optimization cycles until a minimum amount of used steel bars is reached. A case study of a typical seven stories R.C building with raft foundation is presented. Design and fabrication drawings and reinforcing re-bar bending lists of foundation, columns and slabs (flat slabs) sub-systems were automatically produced. Original re-bars utilization ratio was found to be 88.25%. Optimization cycles were performed for several design alternatives. For each alternative, same types of drawings and bending lists were produced. The optimization procedure suggested in the study was applied and utilization ratio was improved to 95.75% resulting a reduction of total steel amount by 8.5%. It is concluded that the proposed technique is an effective and efficient tool for practicing engineers and contractors to reduce R.C. subsystems cost.

Keywords

cad, auto – cad, auto – lisp, foundation, raft, columns, flat slab, re-bar, reinforcement, reinforced concrete, bending list, fabrication drawings, design drawings, construction projects.

1. Introduction

In this study a computer software **RCD-2**, using Auto-Lisp Language as a support to Auto-Cad software, is developed to help both designers and contractors to automatically convert design drawings into fabrication drawings consequently generates re-bar bending lists for reinforced concrete sub-systems. Current version of the system has the ability to produce:

1. Fabrication drawings of columns (Sections, Re-bar marking and bending lists) depending on available table of columns concrete dimensions and steel bar reinforcement (in form of .dxf file) and columns lay-out.
2. Fabrication drawings of raft foundation (Re-bar marking and bending lists), depending on available foundation lay-out (Auto-CAD drawings) and Req. mesh reinforcement.
3. Fabrication drawing of flat slabs (Re-bar marking and bending lists), depending on available slab lay-out (Auto-CAD drawings) and Req. mesh reinforcement.

In practice, engineers prepare re-bar bending lists for the available design data and solve the
re-bar cutting problem depending on even their experience or using optimization software. This approach doesn't guarantee the most economical use of steel bars. To reach the optimum use of re-bar, several alternatives of detailed drawings and re-bar bending lists must be prepared and an optimization problem for each alternative should be solved. This procedure was made available due to high speed of automated generation of fabrication drawings using **RCD-2**.

2. SYSTEM DESCRIPTION

RCD-2 Is linked directly to Auto-CAD using Auto-LISP language. As shown in Fig. [1], **RCD-2** has a central database for re-bar detailing knowledge, it contains the information required to produce re-bar bending lists for R.C sub systems based on the latest Egyptian code for design and construction of reinforced concrete structures ECCS 203-2001, (Any other code requirements such as ACI and/or BSI code can be easily add to the basic knowledge of the system).

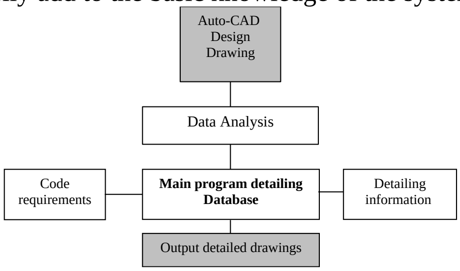

Fig. [1], shows data analysis and output procedure for RCD-2.

Converting design drawings into fabrication drawings using **RCD-2** is accomplished in two steps **<u>Step1</u>**: Identifying design parameters such as locations, dimensions and Req. reinforcement …etc of columns, lay-out, mesh reinforcement and allowable locations of splice…etc for both raft foundation and flat slabs using Auto-Cad entity's definition data. **<u>Step2</u>**: Interrogate Auto-CAD commands to convert these parameters into fabrication drawings consequently producing re-bar bending lists. The main program is designed to drive and control 50 subroutines divided into 10 successive stages, every stage competent to complete its task (s).

Rcd-2 Advantages

The principle advantage of **RCD-2** system is the speed in developing several alternatives of fabrication drawings. The program structure contains several typical details inside its information database, which are applied to produce several solutions of fabrication drawings and re-bar bending lists, consequently these lists can be used as input data for another optimization software to reach the minimum steel bar waste in site .The project elements and design information are identified directly through Auto-Cad entity's definition allowing frequent changes in project parameters according to the user requirements.

RE-BAR Cutting Groups

According to the project execution progress, engineer has to assemble the project elements in groups. The required re-bars for these groups are considered to be the project re-bars cutting groups. In practice the re-bar cutting groups may be as follows:

1. Separate element cutting groups (i.e. foundation elements group, column elements group and slabs elements group…..etc).
2. All elements cutting group, (i.e. generate cutting lists from all project elements re-bars together in one group).
3. Elements combination cutting group, (i.e. generate separate cutting lists from cutting combinations of project elements .

Engineer has to go through all feasible re-bar cutting groups in successive optimization process and generate the minimum amount of steel bars for each group, so that he can reach the optimum re-bar quantities for the project.

RE-BAR Utilization Factor

A specific re-bar size contribution to the overall re-bar utilization ratio is represented by a factor (U*). U* is defined as:

$$U^* = (C - Ue) \times We \div \sum_{i=1}^{n} We \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

in which:

C is the maximum possible overall utilization ratio. In this study "C" was set to 0.95.
Ue, is the cutting bar size utilization ratio. (≤ 1.0)
We, is the cutting bar size weight.
$\sum We$, is the sum weight of all cutting bar sizes.

n, is the total number of cutting bar sizes.

Only re-bar sizes that contribute to the overall utilization ratio by more than 1% are changed to improve the solution. Optimization process is stoped if all re-bar sizes posses U*< 1, or ten design alternatives (iteration cycles) are performed. Certainly, it is up to the designer to select different values for "C" and (U*) limits.

RE-BAR Optimization Process

To execute optimization process for each re-bar cutting group the following procedure is suggested:

1. Prepare detailed drawings and re-bar cutting lists based on the basic design information.
2. For sizes of U* >1.0, change sizes – usually to smaller sizes – to improve solution. Replace # of bars such that area steel (As) is constant.
3. RCD-2 will generate new design drawings, fabrication drawings and bending lists and total amount of steel reinforcement in tons for different sizes.
4. Applying optimization process to the new reinforcing schedules, calculate new Ue, U*, and Wt for all sizes and overall reinforcement.
5. Repeat previous process until all U* <1.0 or a previously selected number of cycles is reached.

Final solution is based on selecting the cutting group that produces the lowest amount of used reinforcement.

CASE STUDY

This case study was for structural sub-system of a residential building comprising seven typical stories with raft foundation. The basic design information for this building contains eleven types of rectangular columns. The suggested optimization process was applied to reach the minimum amount of used steel bars for both raft foundation and columns pedestals

Out-Put Data

The out-put of this case study comprises the following drawings sets:

1. Fabrication drawings set for the reinforcing tables and re-bar arrangement producing the optimum used re-bars, which includes the following drawings:
   - Detailed drawing of raft foundation, Bottom and Top layers of reinforcement. Fig (2), (3).

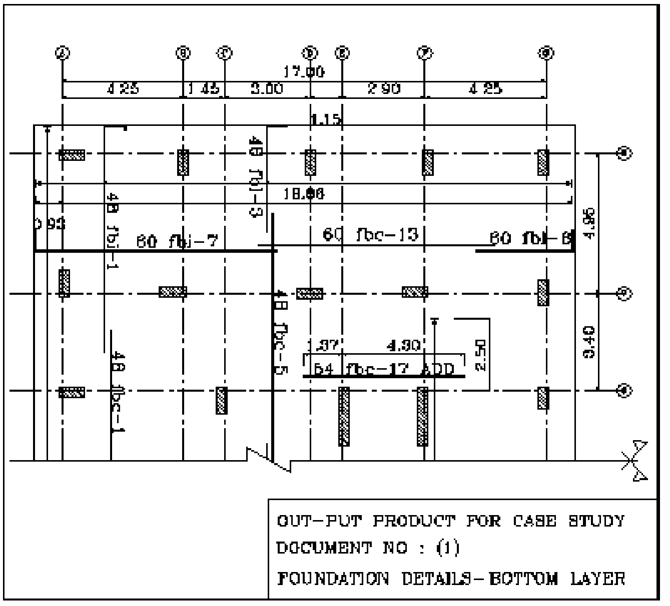

Fig. [2], shows out-put document No(1), reinforcement Bottom layer

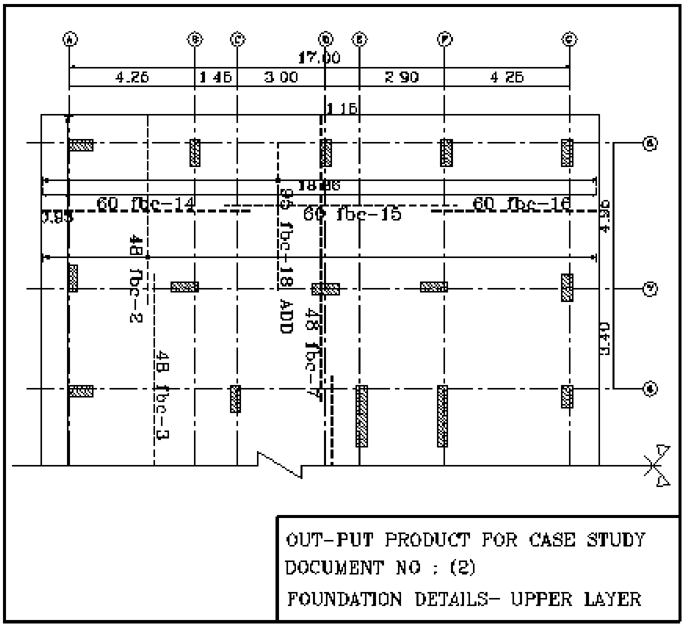

Fig. [3], shows out-put document No(2), reinforcement Top layer

   - Sample of the Foundation bars bending list. Table [4]
   - Columns bars bending list.

2. Re-bar cutting tables for the optimum solution of re-bar used.

Optimization cycles were performed for each one of the suggested re-bar cutting groups namely:

1. Separate elements, based on basic design information.
2. Combination (A), Modified basic design information.
3. Combination (B), Raft bars as1st group + Columns bars as 2nd group.
4. Combination (C), All project elements.

For each cutting group, same types of drawings and bending lists were produced. The optimization procedure suggested in the study was applied. Basic re-bar utilization was 88.25%, final re-bar utilization ratio was improved to 95.75% resulting a reduction of total steel amount by 8.5%. The optimization cycles out-put for basic design, the optimum solution, and optimal solutions for different cutting groups process are shown in tables [1, 2, 3].

Table [1], Re-bars Optimization, Comb. (A) Basic Design Information

	Foundations				Columns				G.beams			
Ø	No.	Wt	U	U*	No.	Wt	U	U*	No.	Wt	U	U*
12	___	___	___	___	54	0.575	85.06	0.08	___	___	___	___
16	1372	26.01	81.89	4.60	425	8.06	89.52	0.58	182	3.45	84.47	0.48
19	9	0.24	82.80	0.03	549	14.69	93.51	0.29	___	___	___	___
20	73	2.16	87.67	0.21	280	8.30	97.13	0.0	___	___	___	___
22	44	1.57	90.97	0.08	264	9.44	88.45	0.82	___	___	___	___

Reinforcement re-bars information:

Raft Foundation:	24.91	tons
Columns:	37.91	tons
G.Beams:	2.92	tons
Total Req.:	65.74	tons
Total Cut:	74.50	tons

%Uavr: 88.25 %

Table [2] Re-bars Optimization, Comb (C).

	Foundations + Columns + G. beams			
Ø	No.	Wt	U	U*
12	54	0.575	85.06	0.08
16	1550	29.40	96.00	0.0
19	1436	38.42	93.94	0.60

Reinforcement re-bars information:

Raft Foundation:	24.91	tons
Columns:	37.66	tons
G.Beams:	2.92	tons
Total Req.:	65.50	tons
Total Cut:	68.40	tons

%Uavr: 95.75%

Table [3] Optimal solution for different cutting groups.

Comb.	Req. re-bar	Used re-bar	%U	Gain in re-bar
Basic (A)	65.74	74.50	88.25	----
B	64.12	69.05	92.90	5.45
C	65.50	68.40	95.75	6.10

Table [4], Sample of the Foundation bars bending list.

FOOTING BAR BENDING LIST

BAR NO.	BAR SHAPE	ø	NO.	BAR DIM.				L(Mm)	W/M(Kg)	T.W(Kg)
				A(Mm)	B(Mm)	C(Mm)	R(Cm)			
fbb-1		16	446	300	1530	---	6	1830	1.580	1289
fbb-2		19	254	300	1680	---	6	1980	2.230	1121
fbc-1		19	48	9534	---	---	6	9534	2.230	1020
fbc-2		19	48	6374	---	---	6	6374	2.230	682
fbc-3		19	48	8788	---	---	6	8788	2.230	940
fbc-4		19	48	10674	---	---	6	10674	2.230	1142
fbc-5		16	48	8715	---	---	6	8715	1.580	660
fbi-1		19	48	144	710	7980	6	8816	2.230	943
fbi-2		19	48	145	710	7885	6	8740	2.230	935
fbi-3		16	48	10	710	3724	6	4446	1.580	337
fbi-4		16	48	9	710	3200	6	3920	1.580	297
fbi-5		19	60	144	710	3434	6	4290	2.230	574

OUT-PUT PRODUCT FOR CASE STUDY
DOCUMENT NO : (3)
FOUNDATION RE-BAR BEDING LIST.TABLE. No. (4)

From table [4], it is concluded that:

1. The total required re-bars vary from 64.12 tons to 64.74 tons for all cutting groups.
2. The value of the total used re-bars varies from 74.50 tons to 68.40 tons.
3. The utilization factor improved from 88.25 % to 95.75 resulting a saving in the total re-bar weight by 6.10 tons which represents 8.5 %.

CONCLUSIONS:

RCD-2 is a very useful tool to reduce the cost of R.C. Using the system results in:

1. Reducing the human errors since it produces drawings automatically.
2. Reducing the cost of man-hour spent in drafting process.
3. Producing proper bending lists which leads to minimizing the site fabrication waste of re-bar
4. Reducing engineering hours necessary in cases of design changes or construction changes.
5. Permitting examination of several design alternatives and cutting groups to reach the best possible utilization of steel reinforcement.
6. Reducing the total amount of used reinforcement results the following:
   - Decreasing the total material budget.
   - Decreasing the total transportation cost.
   - Decreasing the total labor cost.

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