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ADVANTAGE OF DOUBLY REINFORCED SECTIONS AND CONSIDERATION OF HANGER BARS IN RIBBED SLAB DESIGN

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Abstract- *Design of structures may be uneconomical during efforts to meet requirements in practice. One of such cases is the provision of hanger reinforcements in the design of beams and ribbed slabs. In beams and ribbed slabs, theoretically, no reinforcement is required at top of span section and at bottom of support section as there is none moment to be resisted. Although this truth reduces reinforcement consumption, it is not appropriate to practically remove top reinforcements on span and bottom reinforcements on support as at-least they are required to form beam-shape. A rectangular beam requires at least four reinforcements, one at each corner. What practically to the maximum can be done is reducing number of bottom reinforcements on span running to support with allowed reinforcement curtailment ratio. This practice, which is widely observed in Ethiopia, leaves hanger reinforcements (at least two in number with eight millimeter diameter) to always be provided even not having any direct contribution in the moment resistance of given cross section. But there is means to simultaneously make use of the reinforcements provided on unwanted segments as described above for both hanging and design purposes. When sections are designed in doubly reinforced condition, this truth is achieved. This work assessed the cost spent as sections become singly reinforced, leaving hanger reinforcements out of design and cost saved when they are considered.*

Key Words: **Singly Reinforced, Doubly Reinforced, Hanger-bars, Span and support reinforcement, Ribbed slabs.**

1. INTRODUCTION

Most construction of structures, focusing buildings, is carried out using the reinforced concrete material especially in Ethiopia. Frames, which consist of beams as structural, are the most important components of building structures. Although size limitation of beams because of the architectural engineer is one of the sources for sections to be doubly reinforced, It is pretty important to look for the economic advantage too.

Different efforts were handled to search for the economic aspect and comparison of singly reinforced and doubly reinforced beam sections. One is that studied by M.H.F.M Barros et, al who have made optimization in terms of economic moment, optimal area of steel and optimal steel ratio between the top and bottom reinforcements. They concluded that for smaller moments singly reinforced sections are economical whereas for large moments doubly reinforced sections. [1]

Another work entitled as “Cost optimization of doubly reinforced rectangular beam section” focused on searching for optimal section using different optimization techniques. Besides to this, they considered only rectangular beam section and concluded that Genetic Algorism showed less cost of section as compared to generalized reduced gradient technique and interior point optimization technique. [2] Both works by Gebrail Bekdas, et al and Yousif, et al both focused on the optimization techniques. [3], [4]

Throughout the above works, those reinforcements, usually named as hanger bars, which are provided for shape formation and stirrup holding on beam cross sections, are not considered. [5] These hanger bars, especially on ribbed slabs, may be taken at least two in number and eight millimeters in diameter as per the Ethiopian design and construction practice.

In this paper, three different lengths of beams are used with limited minimum width of 0.08m as is practical in Ethiopia. Fixed single span, two span and three span ribs are selected. The depths are parts of design and are expected to be varying. Design template for the analysis and design of ribbed slabs based on EBCS (2) 1995 is developed using Microsoft Excel 2010. Practical concrete and reinforcement grades are considered. Although design for shear was part of the work, it is removed from this document as more or less having negligible effect for the comparison of singly reinforced and doubly reinforced sections. Form work is also out of comparison as the cases studied, one with slab blocks and another without, have equal form work consumption for each respective case. The design method used is Limit state which considers both safety and serviceability issues. The two cases of ribbed slab floors are completely analyzed and designed preceding cost estimation. This work has a general objective on design consideration of ribbed slab reinforcements provided as hangers and compare cost associated to.

Considering rib reinforcements for moment resistance other than their use as hangers on singly reinforced sections is done. Economic comparison of ribbed slabs with and without slab blocks when hangers are considered and not considered is also analyzed.

2. METHODOLOGY

Firstly, based on the concept of limit state design method, an excel sheet template for the calculation of design loads, analysis and design of rib sections is developed. In this study a one-way ribbed slab is considered. Although their respective span and support moments are same, fixed one span, two span and three span ribs of three different lengths with five, six and seven meters are chosen. The design materials selected are C-25, S-300 with class-I works. Longitudinal reinforcements of diameters eight, ten and twelve millimeters and stirrups of diameter six millimeters with single row arrangement are used. Material, deflection and related approaches are followed based on EBCS1 and 2, 1995 code. [6], [7]

Using the developed template, rib sizes are decided, sections are identified as singly reinforced or doubly reinforced preceding identifying as rectangular or Tee. Here, ribs are firstly designed as singly reinforced sections which leave hanger beams not used for moment. Then use of two diameter eight millimeters bars (minimum hanger bar number and size) at bottom of support section is made. And then sections at supports are designed considering span reinforcements running towards support only.

As the width of the rib web is small, number of bottom reinforcements provided for doubly reinforced sections at supports is made practical considering enough rib width for appropriate reinforcement placement. Output for design of shear is knowingly not included in this documentation as the effect is likely balanced for both as stirrup length for singly reinforced section is long being spacing wider and for doubly reinforced section is relatively short being spacing is made closer.

In this study, rib width, topping and center to center distance are fixed to 0.08m, 0.05m and 0.4m respectively. Depth for a given rib of selected length is determined based on the minimum deflection requirement. Rib section is then loaded by maximum possible live load (LL) and dead load (DL) keeping the section singly reinforced and designed for both span and support moments. The same section is then exposed to more external load till it is changed to doubly reinforced section requiring maximum of two diameter eight millimeters hanger bars as compression reinforcements. This same section is further loaded for maximum capacity by considering all span reinforcements running to supports as compression stress resistant.

Design load P_d=1.3*DL+1.6*LL

Minimum depth for deflection d_{min}= $(0.4+0.6*f_{yk}/400)L_e/B_a$

Where, f_{yk} characteristics tensile strength of reinforcement

L_e rib effective length

B_a support condition

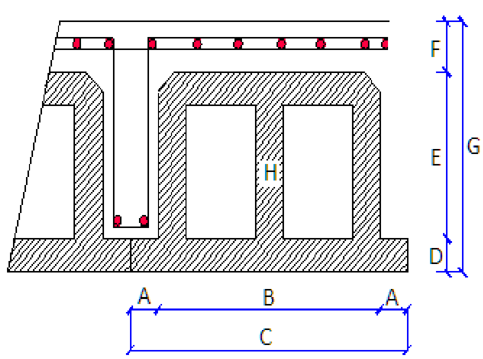

Fig-1: Typical rib section

Where,

2A rib width, C rib center to center length, E web depth, F topping, G slab depth

3. RESULTS AND DISCUSSION

For all the three models, support moment is twice to span moment in amount. Although there are top hanger reinforcements on rib spans which can be considered as compression reinforcements, the analysis output shows that the span moment is small enough such that span section remains singly reinforced.

As shown on tables 1 and 2, the calculated span moments whose sections at supports are singly reinforced and doubly reinforced required nearly same area of reinforcements which remain same in number of reinforcements. I.e, to mean, it is possible to increase support moment capacity by changing the section at support to doubly reinforced without varying its span moment developed from singly reinforced case.

Table-1: Moment and reinforcement area for slabs without blocks

L (m)	P_d (kN/m)	Section, Rectangular	M_f (kNm)	M_s (kNm)	A_f (mm^2)	Field Rien			A_s (mm^2)	Sup Rein, top				$A_{s'}$ (mm^2)	Sup Rein, bot (span-running)		
						8 mm	**10 mm**	**12 mm**		**8mm, hanger**	**8 mm**	**10 mm**	**12 mm**		**8 mm**	**10 mm**	**12 mm**
5	3.67	Singly Rien	3.8	7.6	148	2	1		184.8	2			1		2	1	
	6.23	Doubly Rien	6.5	13	148	2	1		328.6	2			2	98.2	2	1	
	6.8	Doubly Rien	7.1	14.2	150.3	2	1		359.3	2	1		2	128.8	2	1	
6	3.74	Singly Rien	5.6	11.2	172	2	1		237.9	2		2			2	1	
	5.66	Doubly Rien	8.5	17	172	2	1		366.9	2	1		2	99.1	2	1	
	6.94	Doubly Rien	10.4	20.8	190.4	2		1	448.6	2	1		3	180.8	2		1
7	3.84	Singly Rien	7.8	15.7	204	2		1	279.9	2	1	2			2		1
	5.63	Doubly Rien	11.5	23	204	2		1	416.1	2			3	98.5	2		1
	6.46	Doubly Rien	13.2	26.4	204	2		1	475.3	2	1		3	157.7	2		1

Table-2: Moment and reinforcement area for slabs with blocks

L (m)	P_d (kN/m)	Section, Rectangular	M_f (kNm)	M_s (kNm)	A_f (mm²)	Field Rien			A_s (mm²)	Sup Rein, top				$A_{s'}$ (mm²)	Sup Rein, bot (span-running)		
						8 mm	10 mm	12 mm		8mm, hanger	8 mm	10 mm	12 mm		8 mm	10 mm	12 mm
	4.35	Singly Rien	4.53	9.1	148	2	1		228	2			1		2	1	
5	6.27	Doubly Rien	6.52	13.1	148	2	1		330.7	2			2	98.2	2	1	
	6.65	Doubly Rien	6.93	13.9	148	2	1		351.2	2	1		2	128.8	2	1	
	4.1	Singly Rien	6.15	12.3	172	2	1		267.1	2		2			2	1	
6	5.64	Doubly Rien	8.46	16.9	172	2	1		365.4	2	1		2	99.1	2	1	
	6.98	Doubly Rien	10.47	21	191.6	2		1	451.3	2	1		3	180.8	2		1
	4.22	Singly Rien	8.63	17.3	204	2		1	315.4	2	1	2			2		1
7	5.63	Doubly Rien	11.5	23	204	2		1	416.2	2			3	98.5	2		1
	6.46	Doubly Rien	13.2	26.4	204	2		1	475.4	2	1		3	157.7	2		1

It is also observable that in the same tables compression reinforcements required in supports as a result of doubly reinforced sections are completely those running from span. This means, no single additional reinforcement is provided in supports as compression reinforcements other than those running from span.

But for support moments, additional tensile reinforcements are required other than the two diameter eight millimeter hanger bars running from span for both singly reinforced and doubly reinforced sections. The task is thus, increasing the section capacity without increasing its size and without changing material but by changing singly reinforced section in to doubly reinforced and making use of already provided hanger bars. It also does not increase considerable self weight on the floor system with the insertion of few support tensile reinforcements. This requires more support reinforcements than the singly reinforced ones as shown on the stated tables.

Table-3: Equal capacity ribs analysis no slab block

L (m)	P_d (kN/m)	Depth (mm)	Section, Rectangular	M_f (kNm)	M_s (kNm)	Field Rien.			Sup Rein, top			Sup Rein, bot (span-running)		
						8 mm	**10 mm**	**12 mm**	**8 mm,** **hanger**	**8 mm**	**12 mm**	**8 mm**	**10 mm**	**12 mm**
5	6.23	260	Singly Rien	6.6	13.2	2	1		2		2			
		220	Doubly Rien	6.5	13	2	1		2		2	2	1	
	6.8	270	Singly Rien	7.2	14.4	2		1	2		2			
		220	Doubly Rien	7.1	14.2	2	1		2	1	2	2	1	
6	5.66	300	Singly Rien	8.7	17.4	2		1	2		2			
		250	Doubly Rien	8.5	17	2	1		2	1	2	2	1	
	6.94	320	Singly Rien	10.7	21.3	2	2		2	1	2			
		250	Doubly Rien	10.4	20.8	2		1	2	1	3	2		1
7	5.63	340	Singly Rien	11.8	23.5	2	2		2	1	2			
		290	Doubly Rien	11.5	23	2		1	2		3	2		1
	6.46	360	Singly Rien	13.6	27.1	2	2		2	2	2			
		290	Doubly Rien	13.2	26.4	2		1	2	1	3	2		1

Table-4: Equal capacity ribs analysis with slab block

L (m)	P_d (kN/m)	Depth (mm)	Section, Rectangular	M_f (kNm)	M_s (kNm)	Field Rien.			Sup Rein, top			Sup Rein, bot (span-running)		
						8 mm	**10 mm**	**12 mm**	**8 mm,** **hanger**	**8 mm**	**12 mm**	**8 mm**	**10 mm**	**12 mm**
5	6.27	250	Singly Rien	6.7	13.4	2		1	2		2			
		220	Doubly Rien	6.5	13.1	2	1		2		2	2	1	
	6.65	270	Singly Rien	7.2	14.3	2		1	2		2			
		220	Doubly Rien	6.9	13.9	2	1		2	1	2	2	1	
	5.64	300	Singly Rien	8.8	17.6	2		1	2		2			
		250	Doubly Rien	8.5	16.9	2	1		2	1	2	2	1	

6		330	Singly Rien	11.0	22.1	2	2		2	1	2			
	6.98	250	Doubly Rien	10.5	21	2		1	2	1	3	2		1
		340	Singly Rien	12	24	2	2		2	1	2			
	5.63	290	Doubly Rien	11.5	23	2		1	2		3	2		1
7		360	Singly Rien	13.9	27.7	2	2		2	2	2			
	6.46	290	Doubly Rien	13.2	26.4	2		1	2	1	3	2		1

For ribbed slabs without slab blocks, only one diameter twelve millimeters support reinforcement per rib running one-third of total rib length) is required to modify the five meters long rib capacity from 3.67kN/m² to 6.23kN/m². The capacity can further be increased to 6.8kN/m² by adding at support one diameter twelve millimeters and one diameter eight millimeters reinforcements.

The same output is observed for ribbed slabs with slab blocks. A five meters singly reinforced rib section with a capacity of 4.35kN/m² can be made resist 6.27kN/m² design load providing additional one diameter twelve support reinforcement only. It is also true to have 6.65kN/m² capacity by adding one diameter twelve and one diameter eight support reinforcements on the singly reinforced section.

This trend extends similarly to six meters and seven meters long ribs for both ribbed slabs with and without slab blocks.

Beyond that, if we intend to resist those design loads resisted by doubly reinforced sections by singly reinforced ones, we have to provide larger cross sections being the reinforcement requirements kept nearly same.

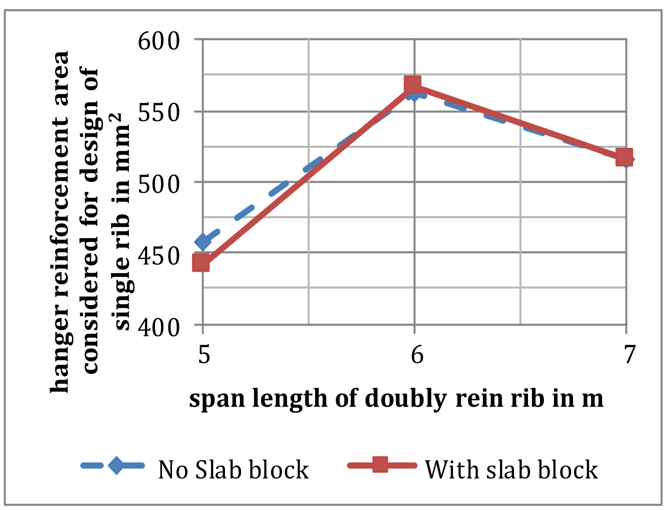

Fig-2: Area of reinforcement saved per rib because of hanger bars consideration

A 6.23kN/m² design load excluding slab block for five meters long rib is resisted by 220mm doubly reinforced section depth or by 260mm singly reinforced section depth with almost no difference in total reinforcement area requirement. Here, even the hanger reinforcements are considered for the singly reinforced sections also so as to account for all possible constraints for doubly reinforced hanger reinforcement consideration approach. The hanger reinforcements on top of rib span are used as support reinforcements as they extend to both ends and the span (bottom) reinforcements serve as compression reinforcements when reached to supports for support sections designed as doubly reinforced.

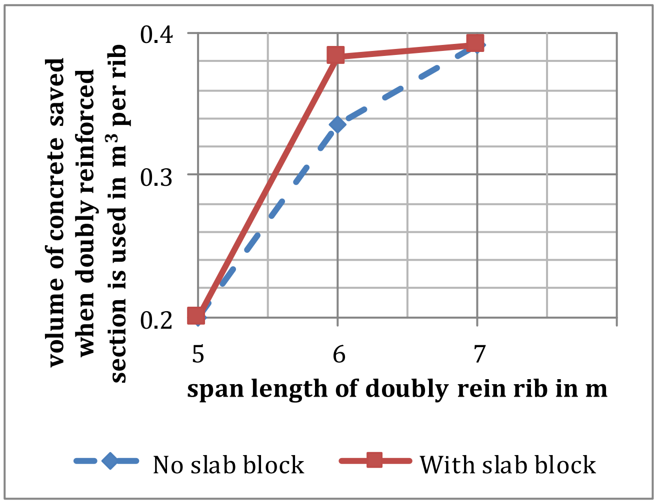

Fig-3: Volume of concrete saved per rib because of doubly reinforced section

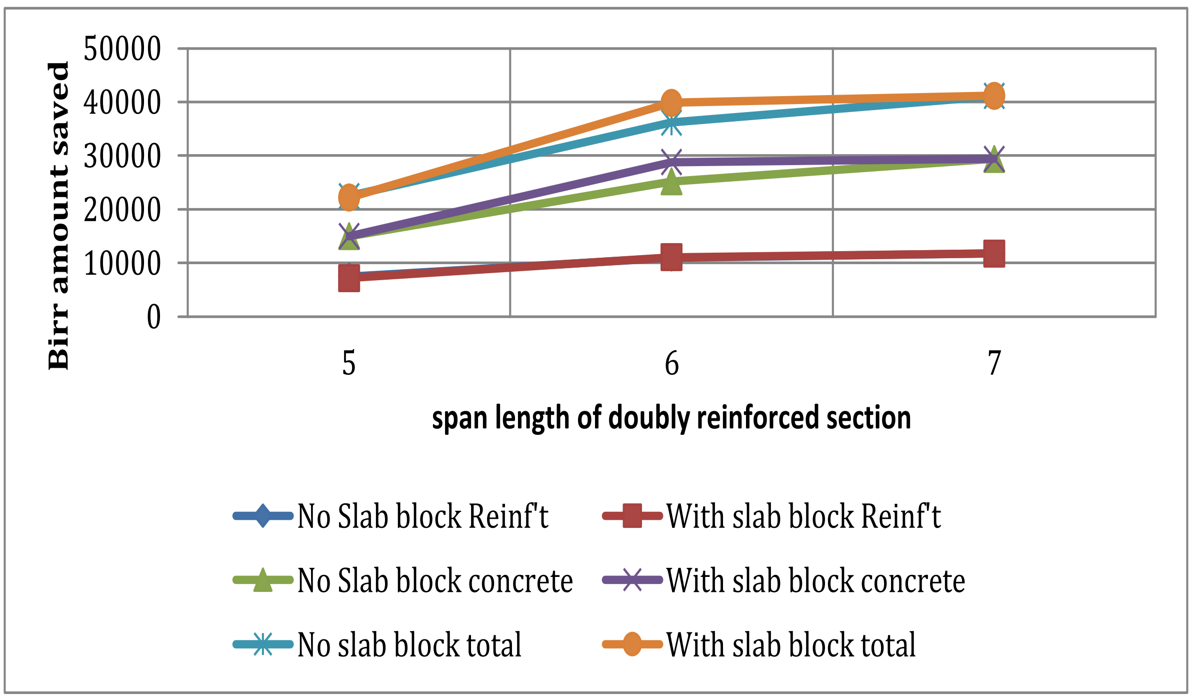

Fig-4: Amount of Birr saved on 10 meters wide panel from reinforcement, concrete and total respectively

Fig-3 shows the amount of reinforcement area (mm^2) replaced by those reinforcements which mainly were serving as hangers. We can observe that for a single rib a minimum of 442 mm^2 and maximum of 567 mm^2 reinforcement area each extending one third distance from both ends is saved. It also shows amount of concrete saved in m^3 as doubly reinforced section is used. Here for a single five meters long rib, there is $0.2m^3$ concrete save. This value increases as span length increases.

Considering 50 birr/kg rate of reinforcement, the amount saved because of use of hanger reinforcements for a single rib can be calculated. For a ten meters wide single floor panel, with rib lengths five meters and seven meters respectively, the amount of money saved is 7451.9 birr and 11747.2 birr respectively. If we consider a single story building with ten such panels, the values become 74,519.2 birr and 117,471.9 birr respectively!

Rate for one meter cube concrete is taken as 3000 birr. The minimum expense saved from saves of concrete volume for a single rib of five meters length is 0.2*3000=600 birr. Considering ten meters wide panel, this value reaches 15,000 birr! It is as large as 29,400 birr for seven meters rib length. This is to mean a one story building with ten such panels will have 150,000 birr and 294,000 birr saves respectively.

Thus, from a single story building with ten such panels a 224,519.2 birr 411,471.9 birr is saved by considering hanger bars and changing singly reinforced ribs in to doubly reinforced for five and seven meters long ribs respectively.

4. CONCLUSION AND RECOMMENDATION

When sections are considered as doubly reinforced, the study limited the number of top hangers to two in number and eight millimeters in diameter which is the least possible consideration so as to assess the economy for the maximum constraint. The numbers of bottom reinforcements at supports, which are span reinforcements, are limited to maximum number of the span reinforcements calculated as the section is immediately made doubly reinforced. This is to mean that there is possibility of increasing the capacity (design load) by further providing compression reinforcements, which of course increases both the span and support reinforcements, without increasing the concrete size.

There is a clear out put in this research such that, consideration of hangers in the design of sections which is possible by having doubly reinforced sections leads to both save in considerable amount of reinforcements and concrete. It is also possible to either increase amount of design load to be resisted by ribbed slabs by changing to doubly reinforced sections without changing their depth considered saving the reinforcement amount or support a given design load by at least smaller rib size saving the concrete amount.

It is thus, valuable to consider design of ribs as doubly reinforced making use of hanger reinforcements and idle reinforcements running from bottom part of span. This research can be extended by varying the rib width, rib center to center length and thickness of topping.

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