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# STRUCTURAL ANALYSIS OF RIBBED SLAB

***H. M. Soghair *, A. G. Aly *, M. H. Ahmed * and M. A. Farouk *****

*Civil Engineering Department, Faculty of Engineering, Assiut University*
** Professor at Civil Eng. Dept., Faculty of Eng., Assiut University,*
*** Engineer Expert in Ministry of Justice.*

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*The traditional analysis methods recommended by design codes such as* ***ACI 318-95 (Building 1995), BS 8110 (structural 1997) and ECP 203 'Egyptian code (2007)'*** *allow the ribbed slab to be analyzed in accordance with the rules for solid slab or as the plain flat slab.*
*The traditional method doesn't take into consideration a lot of factors in the analysis such as thickness of slab and depth of the ribs.*
*The ribbed slabs were analyzed in this study using the finite element method through SAP 2000 program. The structure was analyzed as one-unit in two dimensions x and y. This study included one way and two way slabs.*
*This study illustrated the difference in the produced internal forces in the ribs between traditional method and the finite element method. Moreover, this study included the investigation of the factors which aren't taken into account in the traditional method. These factors were the connection between the rib and the supported beam, the effect of solid part on the behavior of rib, the effect of the edge beams on the distribution loads on ribs, the effect of cross ribs, the effect of slab thickness, the effect of the depth of rib, the effect of slab width and the effect of the location of rib.*

## 1- INTRODUCTION

Ribbed slabs are common types of slabs. The main advantages of using ribbed slabs are permitting a given minimum clear height to be maintained with a reduced overall story height, covering a big horizontal area, simple formwork and reduced own weight. The system exhibits higher stiffness and smaller defections.

Traditional methods of analysis are specified in the current structural codes of most countries for the treatment of regular slab systems. The analysis methods recommended by design codes such as **ACI 318-95 (Building 1995), BS 8110 (structural 1997) and ECP 203 'Egyptian code (2007)'** allow the ribbed slab to be analyzed in accordance with the rules for solid slab or as the plain flat slab.

In the analysis of ribbed slab as solid slab "traditional', the structural system of the ribs is considered as beams supported on main cross beams which are considered as rigid supports. The supporting beams are assumed to be simple if there is one bay slab and continues supporting beams if there are more then one bay. On this principle which is mentioned previously the internal forces "S.F and B.M" are determined.

As recommended in this method, solid parts have to be used at the connection of the ribs with the supported beam. These solid parts resist the internal forces which are higher than the loading capacity of the ribs without any effect on the internal forces.

Also, in this method The Egyptian code recommends in addition to the solid part, cross ribs "one to three ribs " in one way ribbed slab when the length of these slabs are greater than 5 m to decrease the deflection of slab.

The ribbed slab was analyzed exactly by finite element theory through SAP 2000 program. The model provides the actual behavior for ribbed slab by analyzing the structure as one-unite in two dimensions. In this method the structure is divided to frame elements and shell elements. Stiffens matrix for these elements are determined. This method takes into consideration the deformations happened for all elements such as vertical displacements and rotations in the two directions ***x, y*** ,and finding the internal forces produced in these elements exactly. This study is concerned specifically with the analysis of ribbed slab in elastic stage.

# 2-NUMERICAL STUDY

## 2.1 Comparison between the Two Methods 'Traditional and Exact'

One way ribbed slab as a model is analyzed by the two methods "traditional and the finite element method ". The Slab was 6*10m simply supported on four sides and subjected to uniform load 1t/m$^2$ and as shown in Fig. (1).

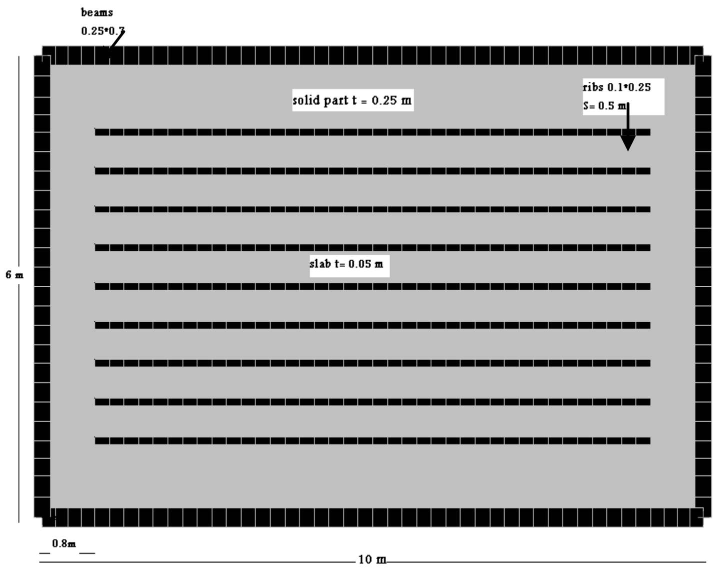



Fig. (1) geometry for one way ribbed slab

The load on each rib equals 0.5 t/m`

The shear force and the bending moment are

$$S.F = \frac{wl}{2} = \frac{0.5 * 8.4}{2} = 2.1t \cdots\cdots \quad (1\ a)$$

$$B.M_1 = Rx - \frac{wx^2}{2} = 2.5 * 0.8 - \frac{0.5*(0.8)^2}{2} = 1.84\,m.t \;..... \quad (1\ b)$$

$$B.M_2 = \frac{wl^2}{8} = \frac{0.5}{8} * (10)^2 = 6.25\,m.t \;..... \quad (1\ c)$$

Where; - $l$ = the length of rib, $x$ = width of solid part

R = the reaction at the end of the rib.

$B.M_1$ : B.M at the contact between rib and solid part

$B.M_2$ : B.M in the middle of rib

S.F.D and B.M.D for the middle rib by the traditional method are as shown in Fig. (2)

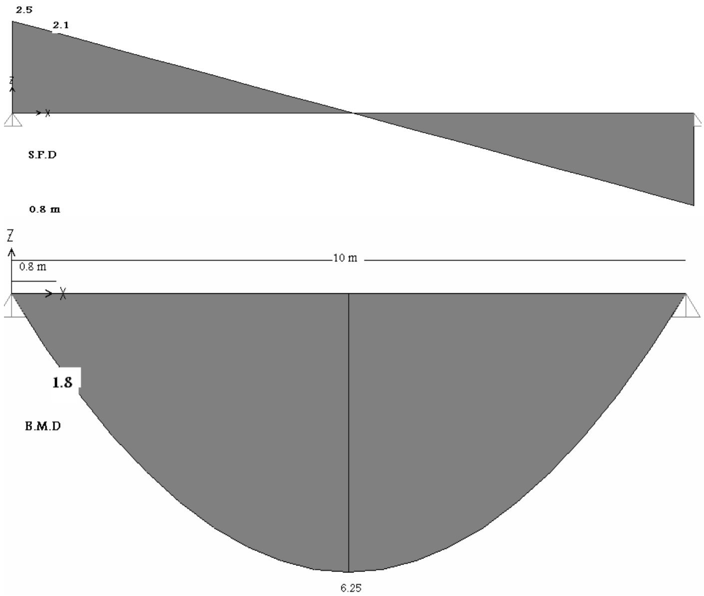



Fig. (2) S.F.D and B.M.D for the rib

S.F.D and B.M.D for the middle rib by the finite element method are as shown in Fig. (3).

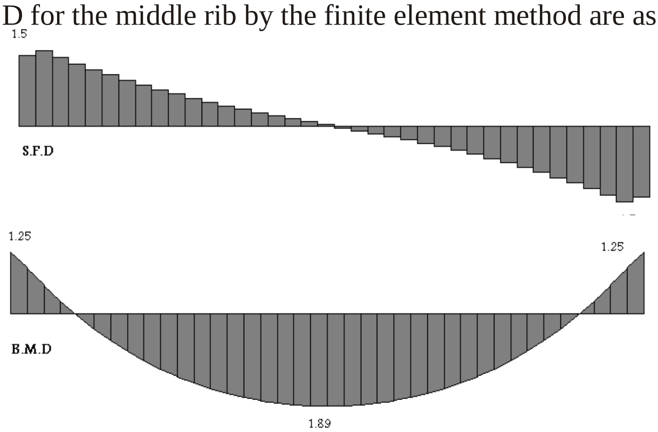



Fig. (3) S.F.D and B.M.D for the rib

The S.F and B.M for the middle rib in Figs. (2) and (3) show a great difference in the internal forces which are produced by the two methods "traditional method" and "exact method".

The value of S.F produced in the rib in exact method is 71% the value of S.F in the traditional method. Also the B.M in the middle of the rib in exact method is 30% the B.M in the traditional method.

Also, in the exact method, the effective load on the rib which causes the moments ( $B.M_1, B.M_2$ ),is

$$w_{eq} = 8(\frac{M_1 + M_2}{l^2}) \ldots\ldots. \qquad (2)$$

In the previous example, it was found that the equivalent load equals 0.35 t/m, this means 70% of the total load "0.5 t/m`" is transferred by the rib and 30 % is transferred by slab. But in the traditional method a 100 % of the load transfers by the rib. As well as B.M at the connecting zone of the rib with the solid part is positive in the traditional method. The B.M is negative at this connecting zone in the exact method. This moment is very important to be taken in design.

## 2.2 Parameters Analysis

The ribbed slab is analyzed exactly by finite element theory through SAP 2000 program, taking into consideration the following factors;-.

- The connection between the rib and the supported beam.
- The effect of solid part on the behavior of rib.
- The effect of the edge beams on the distribution loads on ribs.
- The effect of cross ribs.
- The effect of slab thickness
- The effect of the depth of rib.
- The effect of slab width.
- The effect of the location of the rib.

Ninety nine slabs were analyzed to study these factors. The slabs were simply supported from each side on beams with section 0.25*0.7m. The slabs had constant length equals to 10m and variable width and subjected to uniform load equals to 1 $t/m^2$ . These slabs were one way and two ways and the distance between ribs was constant and equals to 0.5 m.

### 2.2.1 The Connection between Ribs and the Supported Beam.

Ribbed slabs of dimensions (6*10, 8*10 and 10*10) were analyzed to indicate the effect of connection between ribs and supported beams on B.M in the middle rib. These slabs were one way and the ribs were supported directly on the beams without solid part. Each rib had section 0.1*0.25 m and slab thickness was equal to 0.05m. The model is as shown in (Fig. 4).

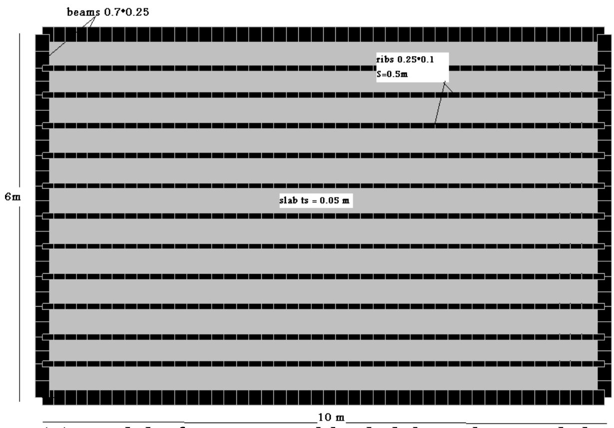



Fig. (4) model of one way ribbed slab without solid part

The B.M.D for the middle rib of slabs by traditional method is as shown in Fig. (5).

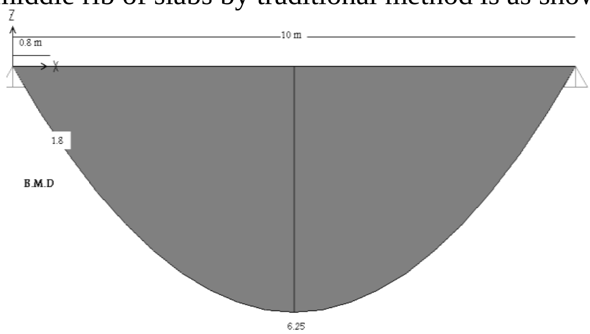
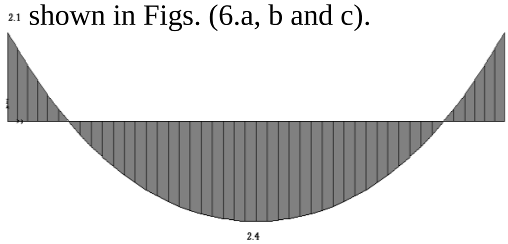
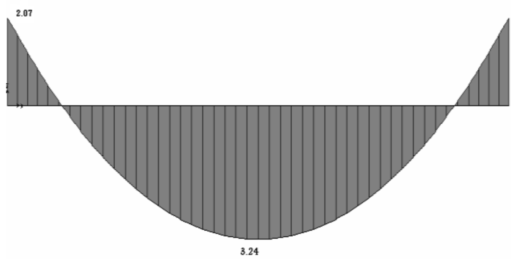



Fig. (5) B.M.D of middle rib by traditional method for all slabs

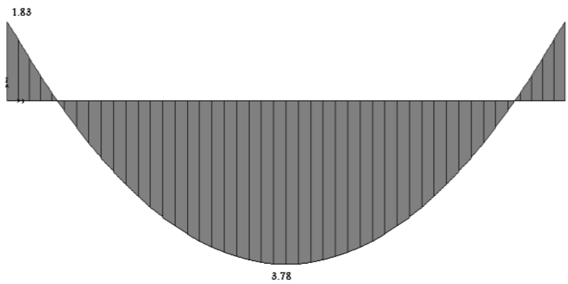
The B.M.Ds for the middle rib of slabs (6*10, 8*10 and 10*10) by exact method are as shown in Figs. (6.a, b and c).




**(a) B.M.D for slab 6*10**




**(b) B.M.D for slab 8*10**




***(c) B.M.D for slab 10*10***

Fig. (6) B.M.D for the middle rib

Comparison between Figs. (5) and (6) shows a great difference in the moments for the middle rib between the two methods ‘traditional and exact’. The moment produced at the end of the rib by traditional method equals to zero for all slabs. The connection between rib and supported beam is rigid and produces negative moments at the ends of the rib. These moments decrease the positive moment in middle of the rib and transfer to the beam as torsion moments.

Also, the negative moments produced at the ends of the rib decrease when the width of slab increases from 6 m to 10 m. When the width of slab increases, the span of supported beam increases and its rigidity and the producing negative moments are decreased.

## 2.2.2 Effect of Solid Part

The same ribbed slabs of (6*10, 8*10 and 10*10) with and without solid part were analyzed by the exact method. These slabs had ribs in one direction. Each rib had section 0.25*0.1 m and thickness of slab 0.05m. This analysis was divided into two parts:-

The first part: - the effect of solid part on the perpendicular direction of rib. In this part, three cases were analyzed as follows:-

Case I: - width of solid part = zero 'without solid part"

Case II: - width of solid part = 0.04 L= 40 cm where *"L" length of slab =10m*

Case III: - width of solid part = 0.08 L= 80 cm

The model is as shown in Fig. (7).

The second part: - the effect of solid part in both directions, on parallel direction of ribs and the perpendicular one. In this part, two cases were analyzed. Case I: - width of solid part in the parallel direction of the ribs = zero 'without solid part". Case II: -width of solid part in the parallel direction of the ribs = 50 cm. in the two cases width of solid part in the perpendicular direction of ribs = 80 cm and the thickness of solid part is the same depth as the ribs. The model is as shown in Fig. (8).

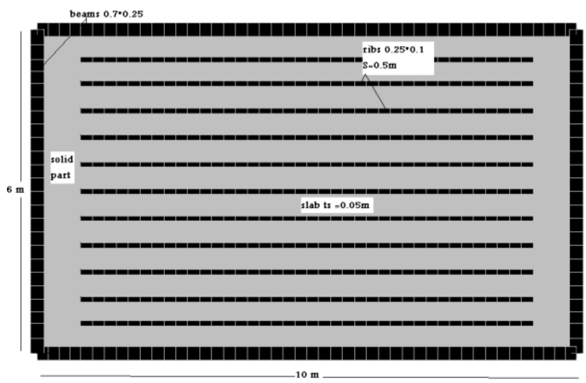



Fig. (7) Solid part on the perpendicular direction of ribs.

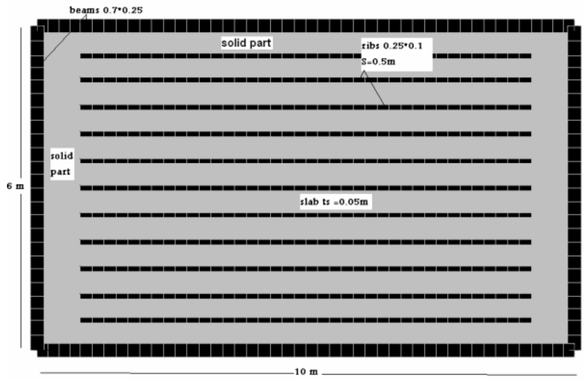



Fig. (8) solid part on the parallel direction of the ribs and the perpendicular direction

### *A) Solid part on perpendicular direction to rib*

B.M.s of rib for slabs of 6*10, 8*10 and 10*10 are shown in Table (1).

Table (1)

| slab | case I | | case II | | case III | |
|---|---|---|---|---|---|---|
| | $B.M_1$ | $B.M_2$ | $B.M_1$ | $B.M_2$ | $B.M_1$ | $B.M_2$ |
| 6*10 | -2.1 | 2.4 | -1.78 | 2.28 | -1.4 | 2.2 |
| 8*10 | -2.11 | 3.24 | -1.7 | 2.97 | -1.24 | 2.77 |
| 10*10 | -1.83 | 3.78 | -1.4 | 3.4 | -0.91 | 3.15 |

Where:-

B.M8 :- the bending moment at the ends of the rib
$B.M_2$ :- the bending moment at the middle of the rib
Case I:- without solid part
Case II:- with solid part of width of 40 cm
Case III:- with solid part of width of 80 cm

The existence of solid part on the perpendicular direction of the ribs decreases the values of negative and positive B.M produced in the rib.

The percentage of the positive and negative B.M in case of slabs without solid part to their values of slabs with solid part of widths 0.4m and 0.8m for studied slabs (6*10, 8*10 and 10*10) are tabled as follows :-

Table (2)

| slab | positive B.M with S.P 0.4m / positive B.M without S.P | negative B.M with S.P 0.4m / negative B.M without S.P | positive B.M with S.P 0.8m / positive B.M without S.P | negative B.M with S.P 0.8m / negative B.M without S.P |
|---|---|---|---|---|
| 6 * 10 | 95% | 84% | 91% | 66% |
| 8 * 10 | 91% | 80% | 85% | 58% |
| 10 * 10 | 90% | 76% | 83% | 50% |

Also, The percentage of the values of negative and positive B.M in cases of slabs without solid part to those of with width of solid part 40cm and width of solid part 80cm for slabs 6*10 and 8*10 to their values for slab 10*10 are as shown in Table (3) ;-

Table (3)

| solid part | positive B.M for slab 6*10 / positive B.M for slab 10*10 | negative B.M for slab 6*10 / negative B.M for slab 10*10 | positive B.M for slab 8*10 / positive B.M for slab 10*10 | negative B.M for slab 8*10 / negative B.M for slab 10*10 |
|---|---|---|---|---|
| without S.P | 63% | 114% | 85% | 114% |
| with S.P 40cm | 67% | 127% | 87% | 121% |
| with S.p 80cm | 70% | 154% | 88% | 136% |

### B) Solid parts on parallel direction of rib and the perpendicular one.

The B.Ms of rib for slabs of 6*10, 8*10 and 10*10 are shown in Table 4.

Table (4)

| slab | case I | | case II | |
|---|---|---|---|---|
| | B.M1 | B.M2 | B.M1 | B.M2 |
| 6*10 | -1.4 | 2.2 | -1.25 | 1.89 |
| 8*10 | -1.24 | 2.77 | -1.31 | 2.55 |
| 10*10 | -0.91 | 3.15 | -1.05 | 3 |

Where:-

B.M1 :- the bending moment at the ends of the rib
B.M2 :- the bending moment at the middle of the rib
Case I:- without solid part
Case II:- with solid part of width of 50 cm

The existence of solid parts on the parallel direction of the ribs decreases the positive B.M for all studied slabs. The positive B.M produced in the rib with solid part were 86%, 92% and 95% the positive B.M of case of without solid part for slabs 6*10, 8*10 and 10*10 respectively. But the values of negative B.M of case with solid part were 89%, 106% and 115% the negative B.M of case without solid part for slabs 6*10, 8*10 and 10*10 respectively.

Also, The percentage of the values of negative and positive B.M in cases of slabs with and without solid part for slabs 6*10 and 8*10 to their values for slab 10*10 are tabled as follows :-

Table (5)

| solid part | positive B.M for slab 6*10 / positive B.M for slab 10*10 | negative B.M for slab 6*10 / negative B.M for slab 10*10 | positive B.M for slab 8*10 / positive B.M for slab 10*10 | negative B.M for slab 8*10 / negative B.M for slab 10*10 |
|---|---|---|---|---|
| with S.P | 63% | 119% | 85% | 124% |
| without S.p | 70% | 154% | 88% | 136% |

## 2.2.3 The effect of edge beam

Slabs of dimensions of (6*10, 8*10 and 10*10) with and without edge beam were analyzed to indicate the effect of the edge beams on the behavior of the ribs "middle rib and edge rib'. These slabs had ribs in one direction and supported directly on the beams and the beams were parallel to the ribs. Each rib had section 0.1*0.25 m and the thickness of slab 0.05m. This section was studied as two cases: - the first case was with edge beams and the second was without edge beam and replaced by rib with the same section of 0.1*0.25m. The model is shown in Fig. (9)

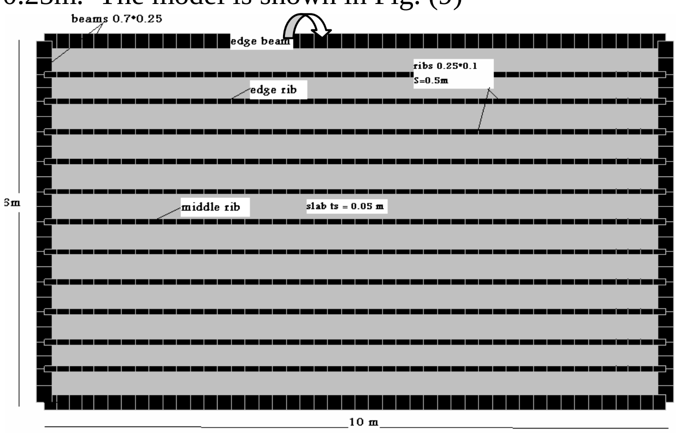



Fig. (9): The effect of edge beam

The B.Ms of middle rib for slabs (6*10, 8*10 and 10*10) are shown in Table (6).

Table (6)

| slab | case I | | case II | |
|---|---|---|---|---|
| | B.M1 | B.M2 | B.M1 | B.M2 |
| 6*10 | -2.1 | 2.4 | -0.09 | 5.6 |
| 8*10 | -2.11 | 3.24 | -0.11 | 5.73 |
| 10*10 | -1.83 | 3.78 | 0.1 | 5.8 |

Where:-

B.M1 :- the bending moment at the ends of the rib
B.M2 :- the bending moment at the middle of the rib
Case I:- with edge beam
Case II:- without edge beam

The positive B.M in case I is lower than the positive B.M in case II for all studied slabs. The values of positive B.M of slabs 6*10, 8*10 and 10*10 in case I with edge beam are 0.43, 0.57and 0.65 the values of positive B.M in case II without edge beam respectively . This difference may be because two reasons:-

The first one; in case I, the edge beam parallel to ribs increases the rigidity of slab especially in the perpendicular direction of the ribs and the loads are distributed in two directions. Part of this load is transferred through ribs and the other part is transferred through slab in the perpendicular direction on the rib, and the slabs are as two way. In this case the transferred load through the ribs which is equal to, $w_{eq} = 8(\frac{M_1 + M_2}{l^2})$ is equal to 0.36, 0.42, 0.44 t/m` for slabs 6*10, 8*10 and 10*10 respectively. But in case II ‘without edge beam’ the rigidity of slab becomes smaller. This leads to transfer most of the load through the ribs and the load is transferred through ribs in all slabs equally. $w_{eq} = 8(\frac{M_1 + M_2}{l^2})$ =0.45 t/m`, and the role of slab in this case in transferring the loads is negligible. This case is completely similar to the solution using the traditional method where the loads are transferred through ribs only.

The second reason is negative moment which is produced at end of the rib at the connection of the rib with supported beam. This moment decreases positive B.M. While in case of slabs without edge beam, the loads transfer completely from slab and ribs to the supported beams which are in the perpendicular direction on the ribs, which leads to increase the displacements of these beams. This causes that the produced negative B.M at the end of rib reaches zero.

The B.M.D of edge ribs in case I with edge beam was different than the produced B.M in the middle rib. While it was in case of without edge beam almost constant compared with the produced B.M in the middle rib for all slabs. The B.Ms of the edge rib for slabs in the two cases for slabs (6*10, 8*10 and 10*10) are shown in Table (7).

Table (7)

| slab | case I | | case II | |
|---|---|---|---|---|
| | B.M1 | B.M2 | B.M1 | B.M2 |
| 6*10 | -0.6 | 1.3 | 0 | 5.5 |
| 8*10 | -0.37 | 1.54 | 0.09 | 5.6 |
| 10*10 | -0.85 | 2.22 | 0 | 5.67 |

Where:-

B.M1 :- the bending moment at the ends of the rib
B.M2 :- the bending moment at the middle of the rib
Case I:- with edge beam
Case II:- without edge beam

### 2.2.4 The effect of cross ribs

Slabs of dimensions (6*10 and 8*10) with and without cross ribs were analyzed to study the effect of cross ribs on the internal forces. These slabs had ribs in one direction. Each rib had section 0.1*0.2 m and slab thickness equals to 5 cm. The slabs had solid parts in two directions with width 0.5m and 0.8m in direction parallel to ribs and perpendicular to ribs respectively. The thickness of solid parts was the same depth of the ribs. Three cases were studied:-

Case I: - slab without cross rib

Case II: - slab with one cross rib

Case III: - slab with three cross ribs

The models of cases II and III are shown in Figs (10 and 11)

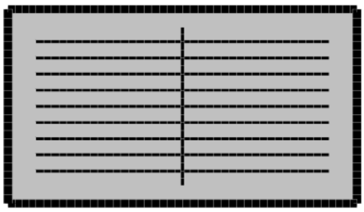


Fig (10) Case II one cross rib

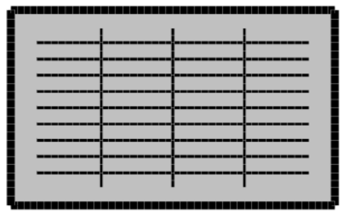


Fig (11) case III three cross ribs

The B.Ms of the different cases for slabs (6*10 and 8*10) are shown in Tables (8) and (9).

Table (8) B.Ms of the main ribs

| slab | case I | | case II | | case III | |
|---|---|---|---|---|---|---|
| | B.M1 | B.M2 | B.M1 | B.M2 | B.M1 | B.M2 |
| 6*10 | -1.25 | 1.89 | -0.78 | 1.4 | -0.56 | 1.36 |
| 8*10 | -1.31 | 2.55 | -1 | 2.18 | -0.83 | 2 |

Table (9) B.Ms of the cross ribs

| slab | case II | | case III | |
|---|---|---|---|---|
| | B.M1 | B.M2 | B.M1 | B.M2 |
| 6*10 | -1.94 | 2.6 | -1.35 | 2.16 |
| 8*10 | -2.63 | 2.84 | -1.95 | 2.5 |

Where:-

B.M1 :- the bending moment at the ends of the rib
B.M2 :- the bending moment at the middle of the rib
Case I:- without cross ribs
Case I:- with one cross rib
Case II:- with three cross ribs

The produced B.M in the main ribs for slabs using cross ribs was decreased compared with those without cross ribs. The values of negative and positive B.M in cases of slabs with one cross rib and three cross ribs to their values in case of slabs without cross ribs are as in Table (10) :-

Table (10)

| slab | positive B.M with one cross rib / positive B.M without cross rib | negative B.M with one cross rib / negative B.M without cross rib | positive B.M with three cross rib / positive B.M without cross rib | negative B.M with three cross rib / negative B.M without cross rib |
|---|---|---|---|---|
| 6 * 10 | 74% | 62% | 72% | 45% |
| 8 * 10 | 85% | 76% | 78% | 63% |

The produced B.M in the cross ribs were great compared with the main ribs and must be taken into consideration. The values of negative and positive B.M in cases of with one cross rib and three cross ribs for cross rib to their values of the main rib are as in Table (11) :-

Table (11)

| slab | case of one cross rib | | case of three cross ribs | |
|---|---|---|---|---|
| | positive B.M for cross rib / positive B.M for main rib | negative B.M for cross rib / negative B.M for main rib | positive B.M for cross rib / positive B.M for main rib | negative B.M for cross rib / negative B.M for main rib |
| 6 * 10 | 185% | 250% | 158% | 240% |
| 8 * 10 | 130% | 263% | 125% | 235% |

Also, the B.M of cross rib decreases with increasing the number of cross ribs. The values of negative and positive B.M for cross rib of case III for slab 6*10 are 70% and 83% the values of negative and positive B.M for cross rib of case II. The values of negative and positive B.M for cross rib of case III for slab 8*10 are 74% and 88% the values of negative and positive B.M for cross rib of case II.

## 2.2.5 The effect of slab thickness

This section is divided into two parts, the first is concerned with one way ribbed slabs and the second is concerned with two way ribbed slabs.

### *A) One way ribbed slabs.*

One way slabs of dimensions (4*10, 6*10, 8*10 10*10and 12*10) were analyzed. These slabs had ribs in one direction. Each rib had section of 0.1*0.2 m and the slab thicknesses were (4, 5, 8, 12, 16) cm for each slab. The slabs had solid parts in two directions, direction parallel to ribs and perpendicular to ribs with width 0.5m and 0.8m respectively. The thickness of solid parts was the same depth of the ribs. The S.Fs and B.Ms for the middle rib of slabs (4*10, 6*10, 8*10, 10*10, and 12*10) are tabled as follows:-

Table (12)

summary for the internal force in the middle rib

| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | |
|---|---|---|---|---|---|---|
| | | ts = 4cm | ts = 5 cm | ts = 8 cm | ts =12 cm | ts =16 cm |
| S.F (t) | 4*10 | 0.96 | 0.74 | 0.42 | 0.19 | 0.11 |
| B.M "1" (m.t) | | -0.7 | -0.46 | -0.136 | 0.03 | 0.07 |
| B.M "2" (m.t) | | 0.64 | 0.53 | 0.41 | 0.35 | 0.3 |
| eq. Load (t/m') | | 0.150 | 0.112 | 0.106 | 0.061 | 0.026 |
| S.F (t) | 6*10 | 1.54 | 1.3 | 0.7 | 0.24 | 0.15 |
| B.M "1" (m.t) | | -1.46 | -1.11 | -0.38 | 0 | 0.09 |
| B.M "2" (m.t) | | 1.5 | 1.28 | 0.84 | 0.59 | 0.45 |
| eq. Load (t/m') | | 0.336 | 0.271 | 0.138 | 0.067 | 0.041 |
| S.F (t) | 8*10 | 1.74 | 1.57 | 0.92 | 0.34 | 0.17 |
| B.M "1" (m.t) | | -1.62 | -1.37 | -0.57 | -0.03 | 0.09 |
| B.M "2" (m.t) | | 2.1 | 1.95 | 1.34 | 0.86 | 0.6 |
| eq. Load (t/m') | | 0.422 | 0.376 | 0.217 | 0.101 | 0.058 |
| S.F (t) | 10*10 | 1.77 | 1.65 | 1.04 | 0.35 | 0.2 |
| B.M "1" (m.t) | | -1.44 | -1.29 | -0.6 | -0.03 | 0.08 |
| B.M "2" (m.t) | | 2.52 | 2.4 | 1.8 | 1.12 | 0.71 |
| eq. Load (t/m') | | 0.449 | 0.418 | 0.272 | 0.130 | 0.071 |
| S.F (t) | 12*10 | 1.78 | 1.66 | 1.1 | 0.42 | 0.21 |
| B.M "1" (m.t) | | -1.17 | -1.07 | -0.52 | 0 | 0.1 |
| B.M "2" (m.t) | | 2.87 | 2.76 | 2.15 | 1.34 | 0.8 |
| eq. Load (t/m') | | 0.458 | 0.434 | 0.303 | 0.152 | 0.079 |

*Notes*

1- ts ;- the thickness os slab
2- S.F :- max . Shear force for the rib
3- B.M "1" :- bending moment for rib at connectting with solid part
4- B.M "2" :- bending moment at mid of the rib
5- eq. load :- equivalent load for moments $= 8(\frac{M_1 + M_2}{l^2})$

The produced shear force and bending moments in the rib decrease as the thickness of slab increases.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 11.5%, 9.7%, 9.8%, 11.3% and 11.8% the values of S.F for slabs with thickness of 4cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 46.9%, 30%, 28.6%, 28.2% and 27.9% the values of B.M for slabs with thickness of 4cm respectively.

Also, the values of the equivalent load for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 17.3%, 12.2%, 13.7%, 15.8% and 17.2% the values of the equivalent load for slabs with thickness of 16cm respectively.

The produced B.M at the connection between rib and solid part changes with the change of slab thickness. The value of this moment is negative for slabs with thickness of 4cm then decreases with increasing the thickness until reaches to zero or positive value for slabs with thickness of 16 cm.

## *B) Two way ribbed slabs.*

Ribbed slabs of dimensions (6*10, 8*10 and 10*10) were analyzed. These slabs had ribs in two directions. Each rib had section 0.1*0.2 m and slab thicknesses were (4, 5, 8, 12, 16) cm. The slabs hade solid parts in two directions, direction parallel to ribs and perpendicular to ribs with width 0.55m. The thickness of solid parts is the same depth of the ribs. The S.Fs, B.Ms in the middle rib in each direction for slabs (6*10), (8*10) and (10*10) are shown in Tables (13) and (14).

Table (13) direction a

summary for the internal force in the middle rib direction a

| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | |
|---|---|---|---|---|---|---|
| | | ts = 4cm | ts = 5 cm | ts = 8 cm | ts =12 cm | ts =16 cm |
| S.F (t) | 6*10 | 0.93 | 0.83 | 0.55 | 0.26 | 0.14 |
| B.M "1" (m.t) | | -0.26 | -0.23 | -0.09 | -0.03 | 0.05 |
| B.M "2" (m.t) | | 0.99 | 0.95 | 0.8 | 0.53 | 0.31 |
| eq. Load (t/m') | | 0.416 | 0.393 | 0.296 | 0.186 | 0.087 |
| S.F (t) | 8*10 | 1.15 | 1.06 | 0.7 | 0.31 | 0.15 |
| B.M "1" (m.t) | | -0.62 | -0.55 | -0.29 | -0.02 | 0.05 |
| B.M "2" (m.t) | | 1.4 | 1.36 | 1.13 | 0.76 | 0.48 |
| eq. Load (t/m') | | 0.339 | 0.321 | 0.239 | 0.131 | 0.072 |
| S.F (t) | 10*10 | 1.29 | 1.19 | 0.8 | 0.35 | 0.17 |
| B.M "1" (m.t) | | -0.88 | -0.79 | -0.43 | -0.06 | 0.06 |
| B.M "2" (m.t) | | 1.72 | 1.67 | 1.41 | 1 | 0.68 |
| eq. Load (t/m') | | 0.262 | 0.248 | 0.186 | 0.107 | 0.063 |

Table (14) direction b

summary for the internal force in the middle rib direction b

| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | |
|---|---|---|---|---|---|---|
| | | ts = 4cm | ts = 5 cm | ts = 8 cm | ts =12 cm | ts =16 cm |
| S.F (t) | 6*10 | 0.81 | 0.74 | 0.5 | 0.24 | 0.14 |
| B.M "1" (m.t) | | -0.41 | -0.37 | -0.2 | 0 | 0.06 |
| B.M "2" (m.t) | | 0.7 | 0.68 | 0.63 | 0.54 | 0.44 |
| eq. Load (t/m') | | 0.112 | 0.106 | 0.084 | 0.055 | 0.038 |
| S.F (t) | 8*10 | 1.05 | 0.98 | 0.67 | 0.3 | 0.16 |
| B.M "1" (m.t) | | -0.68 | -0.61 | -0.34 | -0.05 | 0.06 |
| B.M "2" (m.t) | | 1.18 | 1.15 | 1.01 | 0.77 | 0.57 |
| eq. Load (t/m') | | 0.188 | 0.178 | 0.136 | 0.083 | 0.052 |
| S.F (t) | 10*10 | 1.29 | 1.19 | 0.8 | 0.35 | 0.17 |
| B.M "1" (m.t) | | -0.88 | -0.79 | -0.43 | -0.06 | 0.06 |
| B.M "2" (m.t) | | 1.72 | 1.67 | 1.41 | 1 | 0.68 |
| eq. Load (t/m') | | 0.262 | 0.248 | 0.186 | 0.107 | 0.063 |

The produced internal forces in the ribs in each direction decrease with the increase of the thickness of slab.

The values of S.F and positive B.M in direction \`a\` at thickness 16 cm of slab 6*10 are 15% and 31.3% the values of S.F and B.M at thickness of 4 cm of slab respectively.

Also, the values of S.F and B.M in direction \`b\` at thickness of 16 cm of slab are 17.3 % and 62.9 % the values of S.F and B.M at thickness of 4 cm of slab respectively .

The percentage of the load transfer by the ribs in both directions a and b at thickness of 4 cm of slab equals 100%. But with increasing the thickness of slab, 25% of total load transfer by ribs and 75% transfer by slab at thickness of 16cm.

The coefficients ($\alpha$ ) and ($\beta$ ) at thickness of 4cm of slab equal 0.79 and 0.22 respectively and ($\alpha$ ), ($\beta$ ) at thickness of 16 cm of slab equal 0.17 and 0.08 respectively.

The values of S.F and B.M in direction `a` at thickness of 16 cm of slab 8*10 are 13 % and 34.3% the values of S.F and B.M at thickness of 4 cm of slab respectively .

Also, the values of S.F and B.M in direction `b` at thickness of 16 cm of slab are 15.3% and 48.3% the values of S.F and B.M at thickness of 4cm of slab respectively.

The percentage of the load transfer by the ribs in both directions a and b at thickness of 4 cm of slab equals 100%. With increasing the thickness of slab 24.8 % of total load transfer by ribs and 75.2 % transfer by slab at thickness of 16cm .

The coefficients ($\alpha$ ) and ($\beta$ ) at thickness of 4cm of slab equal to 0.67 and 0.36 respectively. ($\alpha$ ) and ($\beta$ ) at thickness of 16 cm are 0.14 and 0.1 respectively.

The values of S.F and B.M at thickness of 16 cm of slab 10*10 where direction a = direction b are 13.17 % and 39.3% the values of S.F and B.M at thickness of 4cm respectively.

The percentage of the load transfer by the ribs in both directions a and b at thickness of 4 cm of slab equals 100%. With increasing the thickness of slab, 25.2% of total load transfer by ribs and 74.8 % transfer by slab at thickness of 16cm.

Also, the coefficients ($\alpha$ ) = ($\beta$ ) at thickness of 4cm of slab equal 0.5 and ($\alpha$ ) = ($\beta$ ) at thickness 16 cm of slab equal to 0.15.

Also, the produced B.M at the connecting between rib and solid part in each direction a and b changes with the change of slab thickness. This moment is negative for slabs with thickness of 4cm and then decreases when the thickness increases until the value of moment reaches to zero or positive values for slabs with thickness of 16 cm.

### 2.2.6 Effect of the depth of rib

The effect of the depth of rib on the internal forces was studied. This analysis is divided into two parts, the first is concerned with one way ribbed slabs and the second is concerned with two way ribbed slabs.

#### *A)* One way ribbed slabs.

Slabs of dimensions (4*10, 6*10, 8*10 10*10and 12*10) were analyzed. These slabs had ribs in one direction. The ribs had depth (0.15, 0.2 and 0.25) m and constant width 0.1m. The slabs had solid parts in two directions, direction parallel to ribs and perpendicular to ribs with width 0.5m and 0.8m respectively. The thickness of solid parts was the same depth of the ribs. The S.Fs and B.Ms of the middle rib for slabs (4*10, 6*10, 8*10, 10*10, and 12*10) are tabled as follows :-

Table (15)

| summary for the internal force in the middle rib | | | | |
|---|---|---|---|---|
| forces | SLAB | rigidity of rib at thickness of slab = 5 cm | | |
| | | tr =15 cm | tr =20 cm | tr =25 cm |
| S.F (t) | 4*10 | 0.46 | 0.74 | 0.99 |
| B.M "1" (m.t) | | -0.29 | -0.46 | -0.6 |
| B.M "2" (m.t) | | 0.24 | 0.53 | 0.92 |
| eq. Load (t/m') | | 0.060 | 0.112 | 0.172 |
| S.F (t) | 6*10 | 0.97 | 1.3 | 1.54 |
| B.M "1" (m.t) | | -0.79 | -1.11 | -1.25 |
| B.M "2" (m.t) | | 0.7 | 1.28 | 1.89 |
| eq. Load (t/m') | | 0.169 | 0.271 | 0.356 |
| S.F (t) | 8*10 | 1.28 | 1.57 | 1.73 |
| B.M "1" (m.t) | | -1.17 | -1.37 | -1.31 |
| B.M "2" (m.t) | | 1.24 | 1.95 | 2.55 |
| eq. Load (t/m') | | 0.273 | 0.376 | 0.438 |
| S.F (t) | 10*10 | 1.43 | 1.65 | 1.75 |
| B.M "1" (m.t) | | -1.3 | -1.29 | -1.05 |
| B.M "2" (m.t) | | 1.67 | 2.4 | 3 |
| eq. Load (t/m') | | 0.337 | 0.418 | 0.459 |
| S.F (t) | 12*10 | 1.48 | 1.66 | 1.76 |
| B.M "1" (m.t) | | -1.25 | -1.07 | -0.73 |
| B.M "2" (m.t) | | 2 | 2.76 | 3.33 |
| eq. Load (t/m') | | 0.368 | 0.434 | 0.460 |

*Notes*

1- tr ;- the depth of rib
2- S.F :- max . Shear force for the rib
3- B.M "1" :- bending moment for rib at connectting with solid part
4- B.M "2" :- bending moment at mid of the rib
5- eq. load :- equivalent load for moments $= 8\left(\frac{M_1 + M_2}{l^2}\right)$

The produced shear force and bending moments in the rib increase as the depth of rib increases.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 2.15, 1.59, 1.35, 1.23, and 1.19 the values of S.F with depth of 15 cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 3.83, 2.7, 2.05, 1.8, and 1.66 the values of B.M with depth of 15 cm respectively.

Also, the values of the equivalent load for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 2.86, 2.1, 1.6, 1.36 and 1.25 the values of the equivalent loads with depth of 15cm respectively.

The value of negative B.M at the connection of the rib with solid part increase as the rib depth increases, when the ratio of width of slab "a" to length of slab "b" <1.0. And by increasing the ratio ***a/b*** over 1.0, the negative B.M decreases as the depth of rib increases. This may be because great decrease happens in the rigidity of solid part which related with the rib and decrease the restriction of the rib's movement.

## *B) Two way ribbed slabs.*

Ribbed slabs of dimensions (6*10, 8*10 and 10*10) were analyzed. These slabs had ribs in two directions. The depth of rib were (15, 20 and 25) cm and the width equals to 10cm. The thickness of slab equals to 5cm. The slabs had solid parts in two directions, direction parallel to ribs and perpendicular to ribs with width 0.5m. The thickness of solid parts was the same depth of the ribs.

The S.Fs and B.Ms produced in the middle rib in each direction for slabs (6*10), (8*10) and (10*10) are shown in Tables (16) and (17).

Table 16 direction a

| summary for the internal force in the middle rib direction a | | | | |
|---|---|---|---|---|
| forces | SLAB | rigidity of rib at thickness of slab = 5 cm | | |
| | | tr = 15cm | tr = 20 cm | tr =25 cm |
| S.F (t) | 6*10 | 0.77 | 0.83 | 0.88 |
| B.M "1" (m.t) | | -0.34 | -0.23 | -0.09 |
| B.M "2" (m.t) | | 0.72 | 0.95 | 1.1 |
| eq. Load (t/m') | | 0.353 | 0.393 | 0.396 |
| S.F (t) | 8*10 | 1 | 1.06 | 1.07 |
| B.M "1" (m.t) | | -0.7 | -0.55 | -0.33 |
| B.M "2" (m.t) | | 1 | 1.36 | 1.62 |
| eq. Load (t/m') | | 0.286 | 0.321 | 0.328 |
| S.F (t) | 10*10 | 1.13 | 1.19 | 1.19 |
| B.M "1" (m.t) | | -0.96 | -0.79 | -0.48 |
| B.M "2" (m.t) | | 1.16 | 1.67 | 2.1 |
| eq. Load (t/m') | | 0.214 | 0.248 | 0.260 |

Table (17) direction b

| summary for the internal force in the middle rib direction b | | | | |
|---|---|---|---|---|
| forces | SLAB | rigidity of rib at thickness of slab = 5 cm | | |
| | | tr = 15cm | tr = 20 cm | tr =25 cm |
| S.F (t) | 6*10 | 0.66 | 0.74 | 0.81 |
| B.M "1" (m.t) | | -0.42 | -0.37 | -0.24 |
| B.M "2" (m.t) | | 0.39 | 0.68 | 1.04 |
| eq. Load (t/m') | | 0.082 | 0.106 | 0.129 |
| S.F (t) | 8*10 | 0.91 | 0.98 | 1.02 |
| B.M "1" (m.t) | | -0.71 | -0.61 | -0.4 |
| B.M "2" (m.t) | | 0.75 | 1.15 | 1.55 |
| eq. Load (t/m') | | 0.147 | 0.178 | 0.198 |
| S.F (t) | 10*10 | 1.13 | 1.19 | 1.19 |
| B.M "1" (m.t) | | -0.96 | -0.79 | -0.48 |
| B.M "2" (m.t) | | 1.16 | 1.67 | 2.1 |
| eq. Load (t/m') | | 0.214 | 0.248 | 0.260 |

The produced internal forces in the ribs in each direction decrease as the depth of rib increases.

The values of S.F and positive B.M in direction `a` for slab 6*10 at depth of 25 cm of rib are 1.14 and 1.52 the values of S.F and B.M at depth of 15 cm of rib respectively.

Also, the values of S.F and positive B.M in direction `b` at depth of 25 cm of rib are 1.22 and 2.66 the values of S.F and positive B.M at depth of 15 cm of rib respectively .

The equivalent load in direction 'a' and 'b' at depth of 15 cm of rib are 0.435 t/m`, this means that 87% of the total load transfer by ribs in each direction 'a' and 'b' and 13% by slab. But with increasing the depth of rib until reaches to 25cm, 100% of total load transfer by ribs.

The coefficients ($\alpha$ ) and ($\beta$ ) at depth of 15cm of rib equal 0.7and 0.16 respectively and ($\alpha$ ), ($\beta$ ) at depth of 25cm of rib equal 0.78 and 0.25 respectively.

The values of S.F and positive B.M in direction `a` for slab 8*10 at depth of 25 cm of slab are 1.07 and 1.62 the values of S.F and positiveB.M at depth of 15 cm of rib respectively .

Also, the values of S.F and positive B.M in direction `b` at depth of 25cm of rib are 1.12 and 2.08 the values of S.F and positive B.M at depth of 15cm of rib respectively.

The equivalent loads in directions 'a' and 'b' at depth of 15 cm of rib are 0.433 t/m`, this means that 86.6 % of the total load transfer by ribs in each direction 'a' and 'b' and 13.4% by slab. But with increasing the depth of rib until reaches to 25cm, 100% of total load transfer by ribs.

The coefficients ($\alpha$ ) and ($\beta$ ) at depth of 15cm of rib equal 0.56, 0.28 respectively. ($\alpha$ ) and ($\beta$ ) at depth of 25 cm are 0.64, 0.39 respectively.

The values of S.F and positive B.M for slab 10*10 where direction a = direction b at depth of 25 cm of rib are 1.05 and 1.8 the values of S.F and positiveB.M at depth of 15cm respectively.

The equivalent load in direction 'a' and 'b' at depth of 15 cm of rib are 0.428 t/m`, this means that 85.6 % of the total load transfer by ribs in each direction 'a' and 'b' and 14.4% by slab. But with increasing the depth of rib until reaches to 25cm, 100% of total load transfer by ribs.

The coefficients ($\alpha$) and ($\beta$) at depth of 15cm of rib equal 0.42 and ($\alpha$) and ($\beta$) at depth of 25 cm of rib equal 0.52.

The previous results show that the rate of increase of load when the rib depth increase from 15 cm to 25 cm is lower than the rate of increase of load in one way slab.

The increase of load of the ribs in each direction when the depth of rib increases from 15 cm to 25 cm is small, but there are large difference in positive B.M of ribs in each direction 'a' and 'b'. This may be because the produced negative B.M at the connection between ribs and solid part is large at depth 15 cm of rib which causes decrease positive B.M, while at depth 25 cm of rib, the negative B.M is very small , this causes increase in positive B.M.

## 2.2.7 Effect of the width of slab:-

The effect of change of the width of slab on the internal forces with fixing both the depth of rib and slab thickness were studied in one way and two way ribbed slabs.

### *A) one way ribbed slab*

The same slabs of dimensions (4*10, 6*10, 8*10, 10*10 and 12*10) were analyzed with fixing the depth of rib and slab thickness at 20cm and 4cm respectively. The S.F and B.M of slabs (4*10, 6*10, 8*10, 10*10 and 12*10) are shown in Table (18).

Table (18)

| forces | slabs | | | | |
|---|---|---|---|---|---|
| | 4*10 | 6*10 | 8*10 | 10*10 | 12*10 |
| S.F (t) | 0.96 | 1.54 | 1.74 | 1.77 | 1.78 |
| B.M1 (m.t) | -0.7 | -1.45 | -1.62 | -1.44 | -1.17 |
| B.M2 (m.t) | 0.64 | 1.5 | 2.1 | 2.52 | 2.87 |
| eq. load t/m` | 0.150 | 0.336 | 0.421 | 0.449 | 0.458 |

The produced shear force and bending moments in the rib increase as the width of slab increases.

The values of S.F and positive B.M for slab 12*10 are 1.85 and 4.48 the values of S.F and positive B.M for slab 4*10 respectively.

The value of equivalent load for slab 12*10 is 3.05 the value of equivalent load for slab 4*10.

The previous behavior was similar for all different cases of slab thickness and depth of rib

### *B) Two way ribbed slab*

The same slabs of dimensions (6*10, 8*10 and 10*10) were analyzed with fixing the depth of rib and slab thickness at 20cm and 4cm respectively. The S.F and B.M of slabs (6*10, 8*10 and 10*10) in direction 'a' and 'b' are shown in Tables (19 and 20).

Table (19) Direction a

| forces | slabs | | |
|---|---|---|---|
| | 6*10 | 8*10 | 10*10 |
| S.F (t) | 0.93 | 1.15 | 1.29 |
| B.M "1" (m.t) | -0.26 | -0.62 | -0.88 |
| B.M "2" (m.t) | 0.93 | 1.4 | 1.72 |
| eq. Load (t/m') | 0.396 | 0.339 | 0.262 |

The produced shear force and bending moments in the rib in direction "a" increase as the width of slab increases. While the maximum value of equivalent load was at width 6m and the minimum value was at width of slab of 10m.

The values of S.F and positive B.M of the ribs in direction ‘a’ for slab 10*10 are 1.38, and 1.85 the values of S.F and positive B.M for slab 6*10 respectively.

The value of equivalent load of the ribs in direction ‘a’ for slab 10*10 is 0.66 the value of equivalent load for slab 6*10.

Table (20) Direction b

| forces | slabs | | |
|---|---|---|---|
| | 6*10 | 8*10 | 10*10 |
| S.F (t) | 0.81 | 1.05 | 1.29 |
| B.M "1" (m.t) | -0.41 | -0.68 | -0.88 |
| B.M "2" (m.t) | 0.7 | 1.18 | 1.72 |
| eq. Load (t/m') | 0.112 | 0.188 | 0.262 |

The produced shear force and bending moments in the rib in direction "b" increase as the width of slab increases. Also the minimum value of equivalent load was at width of slab of 6m and the maximum value of equivalent load was at width of slab of 10m

The values of S.F and positive B.M for slab 10*10 of the ribs in direction ‘b’ are 1.6 and 2.46 the values of S.F for slab 6*10 respectively.

The value of equivalent load of the ribs in direction ‘b’ for slab 10*10 is 2.34 the value of equivalent load for slab 6*10.

The previous behavior was similar for all different cases of slab thickness and depth of rib.

## 2.2.8 The Location of rib

The effect of slab thickness and the depth of rib on the internal forces were studied for the ribs which are located in quarter of slab and another rib located at the slab edge for different slab thickness and depth of the middle rib.

The S.Fs and B.Ms of the quarter rib for one way slabs (4*10, 6*10, 8*10, 10*10, and 12*10) are shown in Table (21)

Table (21)

| summary for the internal force in the qurter of slab | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | | rigidity of rib at thickness of slab = 5 cm | | |
| | | ts = 4cm | ts = 5 cm | ts = 8 cm | ts =12 cm | ts =16 cm | tr =15 cm | tr =20 cm | tr =25 cm |
| S.F (t) | 4*10 | 0.83 | 0.66 | 0.37 | 0.19 | 0.11 | 0.45 | 0.66 | 0.87 |
| B.M "1" (m.t) | | -0.54 | -0.36 | -0.1 | 0 | 0.08 | -0.24 | -0.36 | -0.45 |
| B.M "2" (m.t) | | 0.58 | 0.5 | 0.4 | 0.35 | 0.3 | 0.22 | 0.5 | 0.85 |
| S.F (t) | 6*10 | 1.25 | 1.04 | 0.58 | 0.24 | 0.14 | 0.76 | 1.04 | 1.27 |
| B.M "1" (m.t) | | -1.05 | -0.77 | -0.25 | 0.02 | 0.09 | -0.56 | -0.77 | -0.85 |
| B.M "2" (m.t) | | 1.25 | 1.07 | 0.75 | 0.56 | 0.45 | 0.57 | 1.07 | 1.6 |
| S.F (t) | 8*10 | 1.48 | 1.29 | 0.74 | 0.29 | 0.17 | 1 | 1.29 | 1.5 |
| B.M "1" (m.t) | | -1.23 | -0.96 | -0.34 | 0 | 0.11 | -0.82 | -0.96 | -0.94 |
| B.M "2" (m.t) | | 1.76 | 1.57 | 1.14 | 0.79 | 0.57 | 0.96 | 1.57 | 2.17 |
| S.F (t) | 10*10 | 1.62 | 1.44 | 0.85 | 0.34 | 0.2 | 1.16 | 1.44 | 1.62 |
| B.M "1" (m.t) | | -1.24 | -1 | -0.36 | 0 | 0.12 | -0.94 | -1 | -0.9 |
| B.M "2" (m.t) | | 2.19 | 2 | 1.49 | 1 | 0.67 | 1.3 | 2 | 2.64 |
| S.F (t) | 12*10 | 1.7 | 1.54 | 0.94 | 0.38 | 0.21 | 1.13 | 1.54 | 1.7 |
| B.M "1" (m.t) | | -1.15 | -0.94 | -0.33 | 0.05 | 0.12 | -0.97 | -0.94 | -0.76 |
| B.M "2" (m.t) | | 2.55 | 2.37 | 1.8 | 1.17 | 0.75 | 1.6 | 2.37 | 3 |

The S.F and B.M of the ribs are maximum values at thickness of 4cm of slab, and then decrease until reach to the minimum values at thickness of 16cm of slab.

Also, with increasing the depth of rib, the S.F and B.M.D increase until reach to maximum values at depth of 25cm.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 13.3%, 11.2%, 11.5%, 12.4% and 12.35% the values of S.F with thickness of 4cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 51,7%, 36.8%, 32.4%, 30.6% and 29.4% the values of B.M with thickness of 4cm respectively.

The values of the equivalent loads for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 19.8%, 15.3%, 15.3%, 15.9% and 16.9% the values of the equivalent loads at thickness of 4cm respectively.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 1.89, 1.67, 1.5, 1.4 and 1.5 the values of S.F with depth of 15cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 3.86, 2.8, 2.28, 2, and 1.88 the values of B.M at depth of 15 cm respectively.

Also, the values of the equivalent loads for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 2.88, 2.13, 1.75, 1.6 and 1.46 the values of the equivalent loads with depth of 15cm respectively.

The S.F.s and B.M.s of the edge rib for slabs (4*10, 6*10, 8*10, 10*10, and 12*10) are shown in table (22)

Table 22

summary for the internal force at the slab edge

| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | | rigidity of rib at thickness of slab = 5 cm | | |
|---|---|---|---|---|---|---|---|---|---|
| | | ts = 4cm | ts = 5 cm | ts = 8 cm | ts =12 cm | ts =16 cm | tr =15 cm | tr =20 cm | tr =25 cm |
| S.F (t) | 4*10 | 0.43 | 0.39 | 0.28 | 0.17 | 0.1 | 0.26 | 0.39 | 0.5 |
| B.M "1" (m.t) | | -0.12 | -0.06 | 0 | 0.07 | 0.09 | -0.07 | -0.06 | 0 |
| B.M "2" (m.t) | | 0.44 | 0.41 | 0.37 | 0.33 | 0.3 | 0.2 | 0.41 | 0.71 |
| S.F (t) | 6*10 | 0.85 | 0.7 | 0.43 | 0.23 | 0.14 | 0.5 | 0.7 | 0.9 |
| B.M "1" (m.t) | | -0.54 | -0.37 | -0.09 | 0.06 | 0.11 | -0.3 | -0.37 | -0.35 |
| B.M "2" (m.t) | | 0.95 | 0.84 | 0.66 | 0.53 | 0.44 | 0.44 | 0.84 | 1.3 |
| S.F (t) | 8*10 | 0.78 | 0.62 | 0.41 | 0.26 | 0.16 | 0.41 | 0.62 | 0.85 |
| B.M "1" (m.t) | | -0.28 | -0.13 | 0 | 0.12 | 0.13 | -0.19 | -0.13 | 0 |
| B.M "2" (m.t) | | 1.09 | 1 | 0.84 | 0.67 | 0.53 | 0.57 | 1 | 1.48 |
| S.F (t) | 10*10 | 0.73 | 0.58 | 0.43 | 0.31 | 0.18 | 0.33 | 0.58 | 0.82 |
| B.M "1" (m.t) | | -0.05 | 0.1 | 0.2 | 0.18 | 0.15 | 0 | 0.1 | 0.23 |
| B.M "2" (m.t) | | 1.19 | 1.1 | 0.96 | 0.79 | 0.6 | 0.64 | 1.1 | 1.62 |
| S.F (t) | 12*10 | 0.68 | 0.55 | 0.45 | 0.34 | 0.2 | 0.3 | 0.55 | 0.8 |
| B.M "1" (m.t) | | 0.13 | 0.29 | 0.34 | 0.24 | 0.16 | 0.11 | 0.29 | 0.42 |
| B.M "2" (m.t) | | 1.28 | 1.2 | 1.04 | 0.85 | 0.65 | 0.69 | 1.2 | 1.74 |

The behavior of the edge rib has the same trend as the rib in the quarter of the slab. So the S.F and B.M of the rib are maximum values at thickness of 4cm of slab, and then decrease until reach to the minimum values at thickness of 16cm of slab. Also, with increasing the depth of rib, the S.F and B.M.D increase until reach to maximum values at depth of 25cm.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 23.3%, 16.5%, 20.5%, 24.7% and 29.4% the values of S.F with thickness of 4cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 68.2%, 46.30%, 48.60%, 50.4% and 50.8% the values of B.M with thickness of 4cm respectively.

The values of the equivalent loads for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 38%, 22%, 29%, 36% and 42.3% the values of the equivalent load with thickness of 4cm respectively.

The values of S.F for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 1.92, 1.8, 2.07, 2.48 and 2.66 the values of S.F with depth of 15cm respectively.

The values of positive B.M for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25 cm of rib are 3.55, 2.95, 2.6, 2.53 and 2.52 the values of B.M with depth of 15 cm respectively.

The values of the equivalent loads for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 2.66, 2.23, 1.94, 2.15 and 2.3 the values of the equivalent loads with depth of 15cm respectively.

The produced B.M at the connection between rib and solid part in the rib in the quarter of slab and the edge is negative at thickness 4cm of slabs then decreases with increasing the thickness until reaches zero or positive value at thickness of 16 cm of slabs.

The produced S.F and B.M in the middle rib are bigger than S.F and B.M in other ribs at thickness 4cm. The difference in the internal forces between the ribs decrease as the slab thickness increases. This difference reaches to the minimum values at thickness of 16 cm of slab.

Also, the difference in the internal forces between the ribs decrease with increasing the depth of the rib for all slabs except in slab 4*10 where the difference in the internal forces between the ribs increases with increasing the depth of the rib.

Comparison of the internal forces between the middle rib, the quarter rib and the edge rib with change the slab thickness is shown in tables 23.

Table 23

comparing the internal force with changing thickness of slab

| forces | SLAB | rigidity of slab at depth of ribs = 20 cm | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ts = 4cm | | | ts = 5 cm | | | ts = 8 cm | | | ts = 12 cm | | | ts = 16 cm | | |
| | | at the edge | in qurter | in middle | at the edge | in qurter | in middle | at the edge | in qurter | in middle | at the edge | in qurter | in middle | at the edge | in qurter | in middle |
| S.F | 4*10 | 0.43 | 0.83 | 0.96 | 0.39 | 0.66 | 0.74 | 0.28 | 0.37 | 0.42 | 0.17 | 0.19 | 0.19 | 0.1 | 0.11 | 0.11 |
| B.M "1" | | -0.12 | -0.54 | -0.7 | -0.06 | -0.36 | -0.46 | 0 | -0.1 | -0.14 | 0.07 | 0 | 0.03 | 0.09 | 0.08 | 0.07 |
| B.M "2" | | 0.44 | 0.58 | 0.64 | 0.41 | 0.5 | 0.53 | 0.37 | 0.4 | 0.41 | 0.33 | 0.35 | 0.35 | 0.3 | 0.3 | 0.3 |
| S.F | 6*10 | 0.85 | 1.25 | 1.54 | 0.7 | 1.04 | 1.3 | 0.43 | 0.58 | 0.7 | 0.23 | 0.24 | 0.24 | 0.14 | 0.14 | 0.15 |
| B.M "1" | | -0.54 | -1.05 | -1.46 | -0.37 | -0.77 | -1.11 | -0.09 | -0.25 | -0.38 | 0.06 | 0.02 | 0 | 0.11 | 0.09 | 0.09 |
| B.M "2" | | 0.95 | 1.25 | 1.5 | 0.84 | 1.07 | 1.28 | 0.66 | 0.75 | 0.84 | 0.53 | 0.56 | 0.59 | 0.44 | 0.45 | 0.45 |
| S.F | 8*10 | 0.78 | 1.48 | 1.74 | 0.62 | 1.29 | 1.57 | 0.41 | 0.74 | 0.92 | 0.26 | 0.29 | 0.34 | 0.16 | 0.17 | 0.17 |
| B.M "1" | | -0.28 | -1.23 | -1.62 | -0.13 | -0.96 | -1.37 | 0 | -0.34 | -0.57 | 0.12 | 0 | -0.03 | 0.13 | 0.11 | 0.09 |
| B.M "2" | | 1.09 | 1.76 | 2.1 | 1 | 1.57 | 1.95 | 0.84 | 1.14 | 1.34 | 0.67 | 0.79 | 0.86 | 0.53 | 0.57 | 0.6 |
| S.F | 10*10 | 0.73 | 1.62 | 1.77 | 0.58 | 1.44 | 1.65 | 0.43 | 0.85 | 1.04 | 0.31 | 0.34 | 0.35 | 0.18 | 0.2 | 0.2 |
| B.M "1" | | -0.05 | -1.24 | -1.44 | 0.1 | -1 | -1.29 | 0.2 | -0.36 | -0.6 | 0.18 | 0 | -0.03 | 0.15 | 0.12 | 0.08 |
| B.M "2" | | 1.19 | 2.19 | 2.52 | 1.1 | 2 | 2.4 | 0.96 | 1.49 | 1.8 | 0.79 | 1 | 1.12 | 0.6 | 0.67 | 0.71 |
| S.F | 12*10 | 0.68 | 1.7 | 1.78 | 0.55 | 1.54 | 1.66 | 0.45 | 0.94 | 1.1 | 0.34 | 0.38 | 0.42 | 0.2 | 0.21 | 0.21 |
| B.M "1" | | 0.13 | -1.15 | -1.17 | 0.29 | -0.94 | -1.07 | 0.34 | -0.33 | -0.52 | 0.24 | 0.05 | 0 | 0.16 | 0.12 | 0.1 |
| B.M "2" | | 1.28 | 2.55 | 2.87 | 1.2 | 2.37 | 2.76 | 1.04 | 1.8 | 2.15 | 0.85 | 1.17 | 1.34 | 0.65 | 0.75 | 0.8 |

The comparison between the middle rib and quarter rib at (thickness of slab of 4and 16 cm with constant rib depth) is as follows:-

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 1.15, 1.23, 1.17, 1.09 and 1.05 the values of S.F of the quarter rib respectively.

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 1.0, 1.07, 1.0, 1.0 and 1.0 the values of S.F of the quarter rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 1.1, 1.2, 1.19, 1.15and 1.12 the values of B.M of the quarter rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 1, 1, 1.05, 1.06 and 1.06 the values of B.M of the quarter rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 1.19, 1.29, 1.24, 1.15 and 1.09 the values of equivalent load of the quarter rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 1.04, 1.02, 1.11, 1.14 and 1.11 the values of equivalent load of the quarter rib respectively.

The comparison between the middle rib and edge rib at (thickness of slab of 4and 16 cm with constant rib depth) is as follows:-

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 2.25, 1.81, 1.92, 2.11 and 2.24 the values of S.F of the edge rib respectively

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 1.1, 1.07, 1.06, 1.11 and 1.05 the values of S.F of the edge rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 1.45, 1.58, 1. 93, 2.11and 2.24 the values of B.M of the edge rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 16cm are 1, 1.02, 1.13, 1.18 and 1.23 the values of B.M of the edge rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with thickness of 4cm are 2.4, 1.97, 2.72, 3.2 and 3.5 the values of equivalent load of the edge rib respectively.

The values of equivalent load of the middle rib with thickness of 16cm for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) are 1.08, 1.1, 1.28, 1.39 and 1.43 the values of equivalent load of the edge rib respectively.

Comparison of the internal forces between the middle rib, the quarter rib and the edge rib with change the depth of rib is shown in Table 24.

Table 24

| comparing the internal force with changing depth of rib | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| forces | SLAB | rigidity of rib at thickness of slab = 5 cm | | | | | | | | |
| | | tr =15 cm | | | tr =20 cm | | | tr =25 cm | | |
| | | at the edge | in qurter | in middle | at the edge | in qurter | in middle | at the edge | in qurter | in middle |
| S.F | 4*10 | 0.26 | 0.45 | 0.46 | 0.39 | 0.66 | 0.74 | 0.5 | 0.87 | 0.99 |
| B.M "1" | | -0.07 | -0.24 | 0.29 | -0.06 | -0.36 | -0.46 | 0 | -0.45 | 0.6 |
| B.M "2" | | 0.2 | 0.22 | 0.24 | 0.41 | 0.5 | 0.53 | 0.71 | 0.85 | 0.92 |
| S.F | 6*10 | 0.5 | 0.76 | 0.97 | 0.7 | 1.04 | 1.3 | 0.9 | 1.27 | 1.54 |
| B.M "1" | | -0.3 | -0.56 | -0.79 | -0.37 | -0.77 | -1.11 | -0.35 | -0.85 | -1.25 |
| B.M "2" | | 0.44 | 0.57 | 0.7 | 0.84 | 1.07 | 1.28 | 1.3 | 1.6 | 1.89 |
| S.F | 8*10 | 0.41 | 1 | 1.28 | 0.62 | 1.29 | 1.57 | 0.85 | 1.5 | 1.73 |
| B.M "1" | | -0.19 | -0.82 | -1.17 | -0.13 | -0.96 | -1.37 | 0 | -0.94 | -1.31 |
| B.M "2" | | 0.57 | 0.96 | 1.24 | 1 | 1.57 | 1.95 | 1.48 | 2.17 | 2.55 |
| S.F | 10*10 | 0.33 | 1.16 | 1.43 | 0.58 | 1.44 | 1.65 | 0.82 | 1.62 | 1.75 |
| B.M "1" | | 0 | -0.94 | -1.3 | 0.1 | -1 | -1.29 | 0.23 | -0.9 | -1.05 |
| B.M "2" | | 0.64 | 1.3 | 1.67 | 1.1 | 2 | 2.4 | 1.62 | 2.64 | 3 |
| S.F | 12*10 | 0.3 | 1.13 | 1.48 | 0.55 | 1.54 | 1.66 | 0.8 | 1.7 | 1.76 |
| B.M "1" | | 0.11 | -0.97 | -1.25 | 0.29 | -0.94 | -1.07 | 0.42 | -0.76 | -0.73 |
| B.M "2" | | 0.69 | 1.6 | 2 | 1.2 | 2.37 | 2.76 | 1.74 | 3 | 3.33 |

The comparison between the middle rib and quarter rib at (depth of rib 15 and 25 cm with constant slab thickness) is as follows:-

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 1.02, 1.27, 1.28, 1.23, and 1.3 the values of S.F of the quarter rib respectively

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 1.14, 1.21, 1.15, 1.08 and 1.03 the values of S.F of the quarter rib respectively

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 1.09, 1.23, 1.29, 1.28 and 1.25 the values of positive B.M of the quarter rib respectively

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 1.08, 1.18, 1.17, 1.14 and 1.11 the values of positive B.M of the quarter rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 1.15, 1.3, 1.36, 1.34 and 1.26 the values of equivalent load of the quarter rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 1.14, 1.29, 1.25, 1.14 and 1.08 the values of equivalent load of the quarter rib respectively

The comparison between the middle rib and edge rib at (depth of rib 15 and 25 cm with constant slab thickness) is as follows:-

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 1.76, 1.94, 3.12, 4.33, and 4.93 the values of S.F of the edge rib respectively

The values of S.F of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 1.98, 1.71, 2.03, 2.13 and 2.2 the values of S.F of the edge rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 1.2, 1.6, 2.17, 2.6 and 2.9 the values of positive B.M of the edge rib respectively.

The values of positive B.M of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 1.29, 1.45, 1.72, 1.85 and 1.91 the values of positive B.M of the edge rib respectively

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 15cm of rib are 2, 2.01, 3.17, 4.6 and 5.6 the values of equivalent load of the edge rib respectively.

The values of equivalent load of the middle rib for slabs (4*10, 6*10, 8*10, 10*10 and 12*10) with depth of 25cm of rib are 2.15, 1.95, 2.62, 2.92 and 3.06 the values of equivalent load of the edge rib respectively

The difference in the internal forces between the ribs may be due to: - each of rib rigidity and slab rigidity shared in resisting and transferring the loads. Most of transferred load by slab is distributed in the perpendicular direction on the ribs. Near to the edge, the rigidity of slab in the perpendicular direction on ribs is increasing due to its influencing to the solid part and edge beams. So near to the edge, the load portion on slab is increasing but decreasing on the ribs, and due to that, the internal forces in the middle rib are bigger than other ribs.

## CONCLUSIONS

From this study, the following conclusions can be deduced:

1. There was a great difference in the internal forces 'S.F and B.M' which are produced in the ribs by the two methods "traditional method" and "exact method".
2. A) The produced moment at the end of the rib by traditional method equals to zero for all slabs, while in fact, the real behavior is completely different concerning the internal forces on the rib. The connection between rib and supported beam is rigid and produces negative moments at the ends of the rib. These moments decrease the positive moment in middle of the rib and transfer to the beam as torsion moments. The negative moments must be considered in design.

   B) With increasing the width of slab, the produced negative moments at the ends of the rib decrease.
3. The edge beams which are parallel to the ribs in the traditional method have no effect on the distribution of the loads or the internal forces produced in the rib. Where the traditional method assumed that the loads are transferred completely through the ribs to supported beams. The effect of edge beams was investigated in this study , where it was found :-

   A) The existence of edge beams decreases the negative and positive B.M for all studied slabs.

   B) The case of slab without edge beam was completely similar using the traditional method or exact method where the role of slab in this case in transferring the loads is negligible and the loads are transferred through ribs only.

   C) The edge beams causes the difference of the B.M.D for the edge ribs than the produced B.M in the middle rib. While it was in case of slab without edge beam almost constant compared with the produced B.M in the middle rib for all studied slabs.
4. The effect of the existence of solid parts on decreasing the bending moments produced in the ribs
5. A) The Egyptian code recommends using cross ribs "one to three ribs " in one way ribbed slab when the length of these slabs are greater than 5 m to decrease the deflection of slab. The code doesn't take into account the effect of cross ribs on the structural behavior of the ribs and the internal forces which produced in the cross ribs. This study showed that using cross ribs, the B.M produced in the main ribs for slabs was decreased compared with those without cross ribs.

   B) The produced B.M in the cross ribs was great compared with the main ribs and must be taken into consideration.
6. A) In the traditional method, the load completely transfers from the slab surface to the ribs regardless the change in slab thickness. This study showed the effect of slab thickness on the internal forces in the ribs where different slabs were studied with thicknesses of (4, 5, 8, 12 and 16)cm and it was found :-With increasing the thickness of slab, the produced shear force and bending moments in the rib decrease. So the maximum values of S.F and B.M were at thickness of 4cm of slab, then decrease until reach to the minimum values at thickness of 16cm of slab.

   B) The produced B.M at the connection between rib and solid part changes with the change of slab thickness. The value of this moment was negative for slabs with thickness of 4cm then decreased with increasing the thickness until reached to zero or positive value for slabs with thickness of 16 cm.

7. Increasing the depth of the rib (15, 20 and 25) cm increase the produced shear force and bending moment in the rib.
8. The produced shear force and bending moments in the rib increase with increasing the width of one way slabs.
9. A) The produced shear force and bending moments in the rib in short direction "a" increase with increasing the width of two way slabs. While the maximum value of equivalent load was at width 6m and the minimum value was at width of slab of 10m.

   B) The produced shear force and bending moments in the rib for two way slabs in long direction "b" increase as the width of slab increases. Also the minimum value of equivalent load was at width of 6m of slab and the maximum value of equivalent load was at width of slab of 10m.
10. In two way slabs, the coefficients ($\alpha$) and ($\beta$) don't depend only on the dimensions of slab, but also depend on the thickness of slab and the depth of rib.
11. A) The internal forces decrease as the location of rib is near to the edge of slab. So the produced S.F and B.M in the middle rib were bigger than S.F and B.M in other ribs. The difference in the internal forces between the ribs decreases as the slab thickness increases. Also, with increasing the depth of rib, the S.F and B.M increase until reach to maximum values at depth of 25cm. While in the traditional method, loads transfer uniformly through the ribs.

    B) The behavior of the quarter rib and edge rib had the same trend as the rib in the mid of the slab. So the S.F and B.M of the rib were maximum values at thickness of 4cm of slab, and then decrease until reach to the minimum values at thickness of 16cm of slab. Also, with increasing the depth of rib, the S.F and B.M increase until reach to maximum values at depth of 25cm.

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# التحليل الإنشائي للبلاطات ذات الأعصاب

يتم التحليل التقليدي للبلاطات ذات الأعصاب في كثير من كودات التصميم مثل الكود المصري والكود الامريكى والكود البريطاني طبقا لقواعد التصميم للبلاطات المصمتة أو البلاطات المسطحة. هذه الطرق "التقليدية" لا تأخذ في الاعتبار الكثير من العوامل التي تؤثر على قيم القوي الداخلية المتولدة في الأعصاب مثل سمك البلاطة أو عمق العصب. لذا كانت الحاجة إلى طريقه أخرى تأخذ في الاعتبار العوامل المهملة في الطريقة التقليدية. فقد تم تحليل البلاطات ذات الأعصاب في هذه الدراسة كوحدة واحده عن طريق نظرية العناصر الدقيقة باستخدام برنامجٍ SAP2000 في البعدين x,y والتي أوضحت وجود فروق كبيره في القوى الداخلية المتولدة من عزوم انحناء وقوى قاصه بينها وبين الطريقة التقليدية . أيضا شملت هذه الدراسة العوامل التي لم تؤخذ في الاعتبار في الطريقة التقليدية وهى الاتصال بين العصب والكمرات الساندة، تأثير وجود الأجزاء الصلبة العمودية على الأعصاب والموازية له،الكمرات الطرفية الموازية للأعصاب وتأثيرها على القوى الداخلية،الأعصاب الداعمة للبلاطات ذات الاتجاه الواحد في حالة زيادة بحورها وتأثيرها على سلوك الأعصاب الرئيسية ، تأثير تغير سمك البلاطة، تغير عمق العصب ، تغير عرض البلاطات، تأثير تغير موقع العصب واقترابه من حافة البلاطة. وقد بينت الدراسة مدى تأثير هذه العوامل على قيم القوى الداخلية المتولدة في الأعصاب وضرورة أخذها في الاعتبار عند التحليل.هذه الدراسة اشتملت على تحليل البلاطات ذات الأعصاب في الاتجاه الواحد وفى الاتجاهين في السلوك المرن للمادة.