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University of Technology.
Building and Construction
Engineering Department

Yield Line Analysis Of R.C Rectangulare Slabs With One free edge (SlabCase3)

By

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4th Stage

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الثانية
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شـــــــــكر وأمتنـــان

بسم الله وعلى بركته اتقدم بخالص الشكر
وعظيم الامتنان الى آستاذي الفاضل

الاستاذ الدكتور هشام الحسني

لما خصني من جهد كبير وفضل عظيم في
الاشراف على مشروعي هذا ....
فجزاه الله عني كل الخير ....
كما واتقدم بجزيل الشكر لكل من قدم لي اي عون
ولو بكلمة...............
واخص بالذكر جميع استاذتي الكرام والسيد رئيس القسم
وكل الكادر الاداري لما بذلوه من جهد كبير

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CHAPTER ONE

INTRODUCTION

Introduction

1.1. Yield Line theory

The inelastic behavior of reinforced concrete structures has been the subject of intensified studies for many decades. A major contribution of these studies was focused on the prediction of collapse load of such structures. Accordingly methods have been developed which take into account the conditions applied to the structure prior to failure. One of these methods is the Yield line Theory which considers the limit state of collapse for reinforced concrete slabs.

This theory was first initiated by Ingerslev[1] in 1923, but later developed and greatly extended by Johansen [2] (Denmark) in 1943. The early literature on yield line theory was mainly in Danish and in 1953 Hognestad [3] produced the first summary of this work in English.

In this theory (that forms part of the general theory of limit analysis), the structural elements are assumed to behave in a rigid – perfectly plastic manner, and elastic deformations, strain – hardening effects, shear stresses as well as membrane stresses are ignored.

The method is an upper bound approach and the ultimate load of the slab system is estimated by postulating a collapse mechanism which is compatible with the boundary conditions. The moment at the plastic hinge lines (yield lines) is the ultimate moment of resistance of sections, and the ultimate load (collapse load) is determined either by principle of virtual work or by the equations of equilibrium. Because it is an upper bound approach, it gives an ultimate load which is either correct or too high. Thus, all the possible collapse mechanism (yield line pattern) of the slab must be examined to ensure that the load carrying capacity of the slab is

not overestimated. Furthermore, yield line theory permits the analysis of irregular as well as regular slab shapes with different kinds of supports and load conditions. This has led to an extensive use of the theory and it has been recommended in different codes of Practice[4&5].

1.2. Aim Of The Project

Reinforced concrete rectangular slabs supported on three edges only with the fourth edge free can be categorized into six cases as shown in fig (1). Coefficient for determining the bending moments in these slabs are not available similar to that of methods (2) and (3) of the 1963 ACI code concerning slabs resting on all supports. Therefore, the yield line theory is an alternative approach for analyzing and/or designing such slabs. It is decided in this project to analyze slab case (3) under the action of uniformity distributed load covering the slab full area, by the yield line theory. Based on the results of such analysis an example of a typical slabs of case (3) is also to be given which shows a full detailed design of such slab by the "Ultimate Strength Design Method"

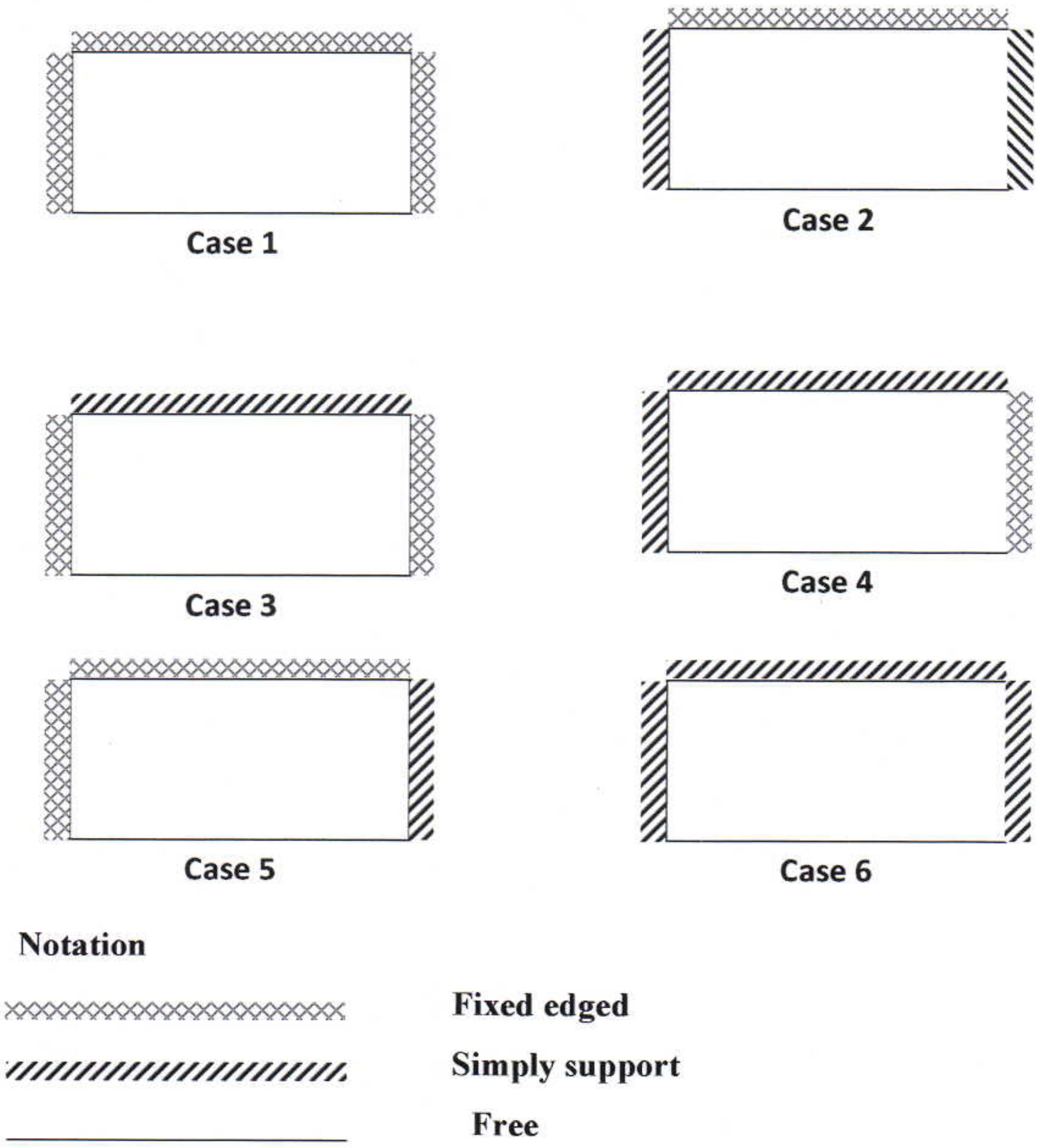


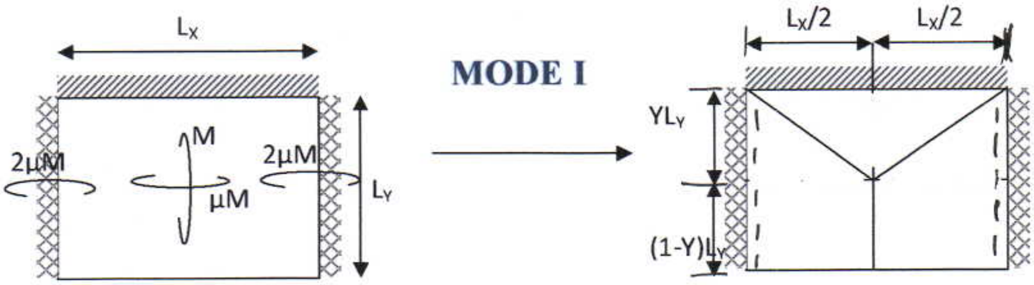
Figure. 1. The Six Cases Of R.C Rectangular Slabs With One Free Edge

CHAPTER

TWO

ANALYSIS & DERIVATIONS

Analysis & Derivations



$$EW = W_U\left[\frac{L_X}{2}\ \frac{YL_Y}{2} * \frac{1}{3} * 4 + L_X\,(1-Y)L_Y * \frac{1}{2}\right]$$

$$= W_U\left[\tfrac{1}{3}\ L_X Y L_Y\ + \tfrac{1}{2} L_X\, L_Y - \tfrac{1}{2} L_X Y L_Y\right]$$

$$= W_U\left[\tfrac{1}{2} L_X L_Y - \tfrac{1}{6}\ L_X Y L_Y\right]$$

$$= W_U\left[L_X L_Y\ \left(\tfrac{1}{2} - \tfrac{1}{6} Y\right)\right]$$

$$EW = W_U\,\tfrac{L_X L_Y}{6}\ (3 - Y)$$

$$IW = 3\mu L_Y\left(\frac{1}{\frac{L_X}{2}}\right) * 2 + M L_X \frac{1}{YL_Y}\ \ 12\ \mu M\frac{L_Y}{L_X} + M\,\frac{L_X}{YL_Y}$$

$$IW = \mu\left(\frac{L_X}{YL_Y} + 12\mu\frac{L_Y}{L_X}\right)$$

EW=IW

$$W_U\,\frac{L_X L_Y}{6}\ (3 - Y) = \mu\left(\frac{L_X}{YL_Y} + 12\mu\frac{L_Y}{L_X}\right)$$

$$W_U = \frac{6M}{L_X L_Y} * \frac{1}{(3 - Y)} * \frac{L^2{}_X + 12\mu Y L^2{}_Y}{YL_Y L_X}$$

$$= 6M.\frac{L^2{}_X + 12\mu Y L^2{}_Y}{Y(3-Y)L^2{}_X L^2{}_Y}$$

$$= 6M\left[\frac{\frac{1}{L^2{}_Y}+\frac{12\mu Y}{L^2{}_X}}{Y(3-Y)}\right] * \frac{L^2{}_X}{L^2{}_X}$$

$$W_U = \frac{6M}{L^2{}_X}.\frac{\left(\frac{L_X}{L_Y}\right)^2 + 12\mu Y}{3Y - Y^2}$$

$$\frac{\partial W}{\partial Y} = 0 \Rightarrow = \frac{6M}{L^2{}_X}\frac{(3Y-Y^2)(12\mu) - \left[\left(\frac{L_X}{L_Y}\right)^2 + 12\mu Y\right](3-2Y)}{(3Y-Y^2)^2}$$

$$12\mu(3Y - Y^2) - (3-2Y)\left[\left(\frac{L_X}{L_Y}\right)^2 + 12\mu Y\right] = 0$$

$$36\mu Y^2 - 12\mu Y^2 - 3\left(\frac{L_X}{L_Y}\right)^2 - 36\mu Y + 2Y\left(\frac{L_X}{L_Y}\right)^2 + 24\mu Y^2 = 0$$

$$12\mu Y^2 + 2\left(\frac{L_X}{L_Y}\right)^2 Y - 3\left(\frac{L_X}{L_Y}\right)^2 = 0 \quad \div\ 12\mu$$

$$Y^2 + \frac{1}{6\mu}\left(\frac{L_X}{L_Y}\right)^2 Y^2 - \frac{1}{4}\left(\frac{L_X}{L_Y}\right)^2 = 0$$

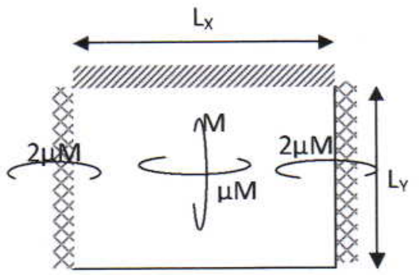
$$Y = \frac{-\frac{1}{6\mu}\left(\frac{L_X}{L_Y}\right)^2 + \sqrt{\left[\left(\frac{1}{6\mu}\right)\left(\frac{L_X}{L_Y}\right)^2 + 4*\frac{1}{4}\left(\frac{L_X}{L_Y}\right)^2\right]*\left(\left(\frac{1}{6\mu}\right)\left(\frac{L_X}{L_Y}\right)^2\right)^2 * \left(\frac{6\mu}{\left(\frac{L_X}{L_Y}\right)^2}\right)^2}}{2}$$

$$= \frac{-\frac{1}{6\mu}\left(\frac{L_X}{L_Y}\right)^2 + \frac{1}{6\mu}\left(\frac{L_X}{L_Y}\right)^2\sqrt{1+36\mu^2\left(\frac{L_X}{L_Y}\right)^2}}{2}$$

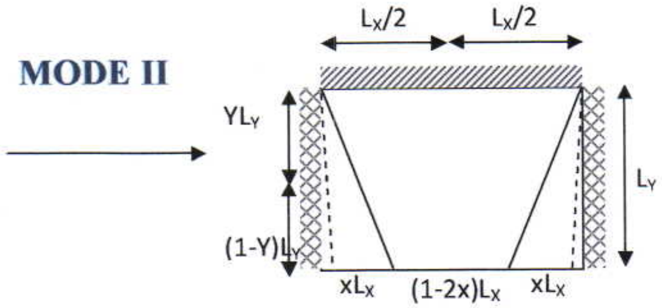
$$= \frac{1}{12\mu}\left(\frac{L_X}{L_Y}\right)^2 \left[\sqrt{1 + 36\mu^2 \left(\frac{L_X}{L_Y}\right)^2} \;\; - 1\right]$$

$$Y = \frac{1}{12\mu} \cdot \frac{1}{K^2}\left[\sqrt{1 + 36\mu^2\, K^2} \;\; - 1\right] \quad , where\ K = \frac{L_y}{L_x}$$

$$\frac{WL^2{}_X}{M} = 6\,\frac{\left[\frac{1}{K^2} + \ 12\mu Y\right]}{3Y - Y^2}$$



MODE II



$$EW = W_U\left[\frac{1}{2}\ L_X X L_Y * 4 * \frac{1}{3} + L_Y(1-2X)L_X * \frac{1}{2}\right]$$

$$= W_U\left[\frac{2}{3}\ L_Y\, XL_X + \frac{1}{2}\ L_Y\, L_X - L_Y\, XL_X\right]$$

$$= W_U\left[\frac{1}{2} L_Y\, L_X - \frac{1}{3} L_Y\, XL_X\right]$$

$$EW = \frac{W_U L_Y\, XL_X}{6}\ [3-2X]$$

$$IW = M2XL_X\frac{1}{L_Y} + \left(3\mu M L_Y\frac{1}{XL_X}\right) * 2$$

$$= 2MX\frac{L_X}{L_Y} + 6\mu M\frac{L_Y}{XL_X}$$

$$= 2M\left[X\frac{L_X}{L_Y} + 3\mu\frac{L_Y}{XL_X}\right]$$

$$EW = IW$$

$$\frac{W_U L_Y\, XL_X}{6}\ [3-2X] = 2M\left[X\frac{L_X}{L_Y} + 3\mu\frac{L_Y}{XL_X}\right]$$

$$W_U = \frac{12M}{L_X L_Y(3-2X)}\left[\frac{XL^2{}_X + 3\mu L^2{}_Y}{XL_X L_Y}\right]$$

$$= 12M.\frac{XL^2{}_X + 3\mu L^2{}_Y}{X(3-2X)L^2{}_X L^2{}_Y}$$

$$= 12M.\frac{\frac{X^2}{L^2{}_Y} + \frac{3\mu}{L^2{}_X}}{X(3-2X)} * \frac{L^2{}_X}{L^2{}_X}$$

$$W_U = \frac{12M}{L^2{}_X}.\frac{X^2\left(\frac{L_X}{L_Y}\right)^2 + 3\mu}{3X-2X^2}$$

$$\frac{\partial W}{\partial X} = 0 \Rightarrow = \frac{(3X-2X^2) * 2X\left(\frac{L_X}{L_Y}\right)^2 - \left[(X^2\left(\frac{L_X}{L_Y}\right)^2 + 3\mu) * (3-4X)\right]}{(3X-2X^2)^2}$$

$$6X^2\left(\frac{L_X}{L_Y}\right)^2 - 4X^3\left(\frac{L_X}{L_Y}\right)^2 - 3X^2\left(\frac{L_X}{L_Y}\right)^2 + 4X^3\left(\frac{L_X}{L_Y}\right)^2 - 9\mu + 12\mu X$$

$$\left[3X^2\left(\frac{L_X}{L_Y}\right)^2 + 12\mu X - 9\mu = 0\right] \div 3\left(\frac{L_X}{L_Y}\right)^2$$

$$X^2 + 4\mu\left(\frac{L_Y}{L_X}\right)^2 X - 3\mu\left(\frac{L_Y}{L_X}\right)^2 = 0$$

$$X = \frac{-4\mu\left(\frac{L_Y}{L_X}\right)^2 + \sqrt{\left(4\mu\left(\frac{L_Y}{L_X}\right)^2\right)^2\left[1 + \frac{3}{4\mu}\left(\frac{L_X}{L_Y}\right)^2\right]}}{2}$$

$$X = \frac{-4\mu\left(\frac{L_Y}{L_X}\right)^2 + 4\mu\left(\frac{L_Y}{L_X}\right)^2 \sqrt{\left[1 + \frac{3}{4\mu}\left(\frac{L_X}{L_Y}\right)^2\right]}}{2}$$

$$X = 2\mu\left(\frac{L_Y}{L_X}\right)^2 \left[\sqrt{\left[1 + \frac{3}{4\mu}\left(\frac{L_X}{L_Y}\right)^2\right]} - 1\right]$$

$$X = 2\mu K^2 \left[\sqrt{\left[1 + \frac{3}{4\mu}\frac{1}{K^2}\right]} - 1\right] \qquad \textit{, where } K = \frac{L_y}{L_x}$$

$$\frac{W{L^2}_X}{M} = 12\,\frac{X^2.\frac{1}{K^2} + 3\mu}{3X - 2X^2}$$

CHAPTER THREE

RESULTS

Results

		$Y = \frac{1}{12\mu}\cdot\frac{1}{K^2}\left[\sqrt{1+36\mu^2 K^2} - 1\right]$ $\frac{WL^2_X}{M} = 6\,\frac{\left[\frac{1}{K^2} + 12\mu Y\right]}{3Y - Y^2}$		$X = 2\mu K^2\left[\sqrt{\left[1+\frac{3}{4\mu}\frac{1}{K^2}\right]} - 1\right]$ $\frac{WL^2_X}{M} = 12\,\frac{X^2\cdot\frac{1}{K^2} + 3\mu}{3X - 2X^2}$			
		MODE I		MODE II		TRUE VALUE	
μ	$k = \frac{L_Y}{L_X}$	Y	$\frac{WL^2_X}{M}$	X	$\frac{WL^2_X}{M}$	TRUE MODE	TRUE $\frac{WL^2_X}{M}$
0.2	0.2	0.3	25.91	0.14	34.35	I	25.91
	0.6	0.27	27.91	0.34	14.013	II	14.013
	0.75	0.25	20.75	0.4	12.06	II	12.06
	1	0.23	14.62	0.47	10.17	II	10.17
	1.5	0.2	9.905	0.57	8.43	II	8.43
	2	0.17	8.21	0.63	7.65	II	7.65
	3	0.13	6.8	0.68	7.01	I	6.8
	4	0.1	6.26	0.71	6.76	I	6.26
	5	0.08	5.96	0.72	6.63	I	5.96

		$Y = \frac{1}{12\mu}\cdot\frac{1}{K^2}\left[\sqrt{1+36\mu^2K^2} - 1\right]$ $\frac{WL^2_X}{M} = 6\,\frac{\left[\frac{1}{K^2} + 12\mu Y\right]}{3Y - Y^2}$		$X = 2\mu K^2\left[\sqrt{\left[1+\frac{3}{4\mu}\frac{1}{K^2}\right]} - 1\right]$ $\frac{WL^2_X}{M} = 12\,\frac{X^2\cdot\frac{1}{K^2} + 3\mu}{3X - 2X^2}$			
		MODE I		MODE II		TRUE VALUE	
μ	$k = \frac{L_Y}{L_X}$	Y	$\frac{WL^2_X}{M}$	X	$\frac{WL^2_X}{M}$	TRUE MODE	TRUE $\frac{WL^2_X}{M}$
0.4	0.2	0.57	120.15	0.2	50.77	II	50.77
	0.6	0.44	26.05	0.43	22.35	II	22.35
	0.75	0.39	21.51	0.49	19.72	II	19.72
	1	0.33	17.6	0.56	17.25	II	17.25
	1.5	0.25	14.35	0.64	15.05	I	14.35
	2	0.2	12.96	0.68	14.16	I	12.96
	3	0.15	11.66	0.71	13.44	I	11.66
	4	0.11	11.15	0.73	13.16	I	11.15
	5	0.1	10.76	0.74	13.04	I	10.76

		$Y=\frac{1}{12\mu}\cdot\frac{1}{K^2}\left[\sqrt{1+36\mu^2K^2}-1\right]$ $\frac{WL^2_X}{M}=6\,\frac{\left[\frac{1}{K^2}+12\mu Y\right]}{3Y-Y^2}$		$X=2\mu K^2\left[\sqrt{\left[1+\frac{3}{4\mu}\frac{1}{K^2}\right]}-1\right]$ $\frac{WL^2_X}{M}=12\,\frac{X^2\cdot\frac{1}{K^2}+3\mu}{3X-2X^2}$			
		MODE I		MODE II		TRUE VALUE	
μ	$k=\frac{L_Y}{L_X}$	Y	$\frac{WL^2_X}{M}$	X	$\frac{WL^2_X}{M}$	TRUE MODE	TRUE $\frac{WL^2_X}{M}$
0.6	0.2	0.81	104.3	0.22	64.31	II	64.31
	0.6	0.53	33.81	0.48	29.9	II	29.9
	0.75	0.46	26.14	0.54	26.83	I	26.14
	1	0.38	22.52	0.36	28.21	I	22.52
	1.5	0.28	19.38	0.67	21.57	I	19.38
	2	0.22	18	0.7	20.6	I	18
	3	0.15	16.72	0.73	19.85	I	16.72
	4	0.12	16.09	0.74	19.57	I	16.09
	5	0.1	15.72	0.741	19.44	I	15.72

$$Y = \frac{1}{12\mu} \cdot \frac{1}{K^2}\left[\sqrt{1 + 36\mu^2 K^2} - 1\right]$$

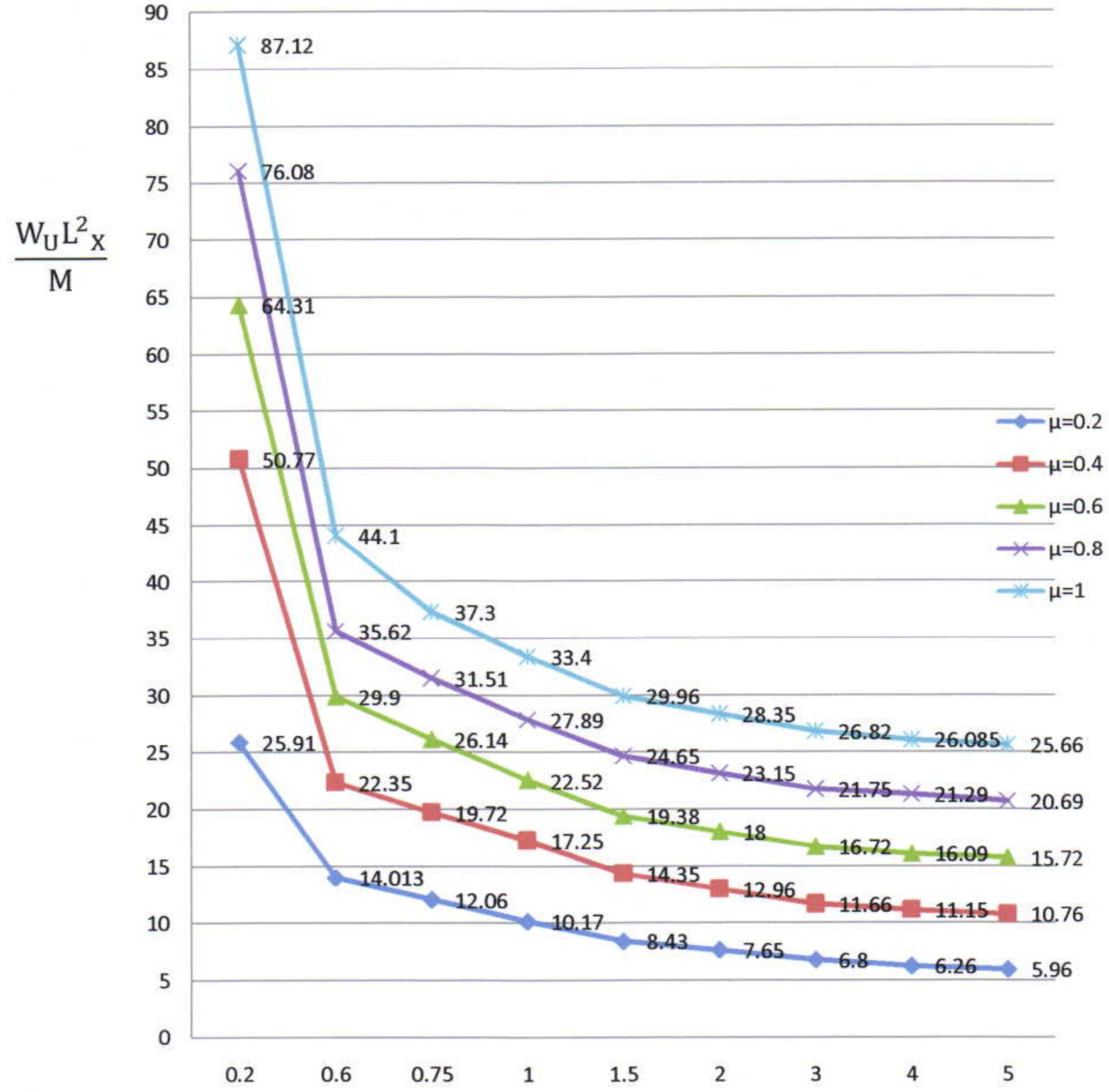
$$\frac{WL^2{}_X}{M} = 6\,\frac{\left[\frac{1}{K^2} + 12\mu Y\right]}{3Y - Y^2}$$

$$X = 2\mu K^2\left[\sqrt{\left[1 + \frac{3}{4\mu}\frac{1}{K^2}\right]} - 1\right]$$

$$\frac{WL^2{}_X}{M} = 12\,\frac{X^2 \cdot \frac{1}{K^2} + 3\mu}{3X - 2X^2}$$

		MODE I		MODE II		TRUE VALUE	
μ	$k = \frac{L_Y}{L_X}$	Y	$\frac{WL^2{}_X}{M}$	X	$\frac{WL^2{}_X}{M}$	TRUE MODE	TRUE $\frac{WL^2{}_X}{M}$
0.8	0.2	1	103.8	0.25	76.08	II	76.08
	0.6	0.59	35.62	0.52	37.1	I	35.62
	0.75	0.51	31.53	0.6	33.781	I	31.51
	1	0.41	27.89	0.36	30.62	I	27.89
	1.5	0.29	24.65	0.68	28.04	I	24.65
	2	0.23	23.15	0.71	27.02	I	23.15
	3	0.16	21.75	0.73	26.25	I	21.75
	4	0.21	21.29	0.74	25.97	I	21.29
	5	0.1	20.69	0.743	25.84	I	20.69

		$Y=\frac{1}{12\mu}\cdot\frac{1}{K^2}\left[\sqrt{1+36\mu^2K^2}-1\right]$ $\frac{WL^2_X}{M}=6\,\frac{\left[\frac{1}{K^2}+12\mu Y\right]}{3Y-Y^2}$		$X=2\mu K^2\left[\sqrt{\left[1+\frac{3}{4\mu}\frac{1}{K^2}\right]}-1\right]$ $\frac{WL^2_X}{M}=12\,\frac{X^2\cdot\frac{1}{K^2}+3\mu}{3X-2X^2}$			
		MODE I		MODE II		TRUE VALUE	
μ	$k=\frac{L_Y}{L_X}$	Y	$\frac{WL^2_X}{M}$	X	$\frac{WL^2_X}{M}$	TRUE MODE	TRUE $\frac{WL^2_X}{M}$
1	0.2	1.17	109.4	0.28	87.12	II	87.12
	0.6	1.76	65.70	0.54	44.1	II	44.1
	0.75	0.53	37.3	0.59	40.14	I	37.3
	1	0.42	33.44	0.65	37.17	I	33.4
	1.5	0.3	29.96	0.7	34.48	I	29.96
	2	0.23	28.35	0.72	33.48	I	28.35
	3	0.16	26.82	0.735	32.65	I	26.82
	4	0.12	21.085	0.74	32.37	I	26.085
	5	0.1	25.66	0.744	32.27	I	25.66



90
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0.2
0.6
0.75
1
1.5
2
3
4
5
87.12
76.08
64.31
50.77
44.1
37.3
35.62
33.4
31.51
29.9
29.96
28.35
27.89
26.82
26.085
25.66
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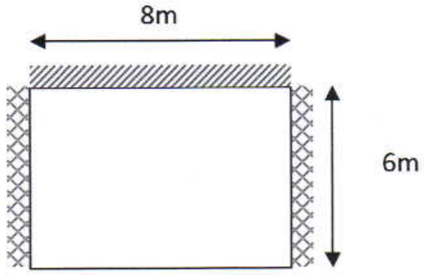
25.91
24.65
23.15
22.52
22.35
21.75
21.29
20.69
19.72
19.38
18
17.25
16.72
16.09
15.72
14.35
14.013
12.96
12.06
11.66
11.15
10.76
10.17
8.43
7.65
6.8
6.26
5.96
μ=0.2
μ=0.4
μ=0.6
μ=0.8
μ=1

$$k = \frac{L_Y}{L_X}$$

CHAPTER FOUR

REINFORCEMENT

Reinforcement



Fy=400MPa

Fć =20MPa

$$k = \frac{L_Y}{L_X} = \frac{6}{8} = 0.75$$

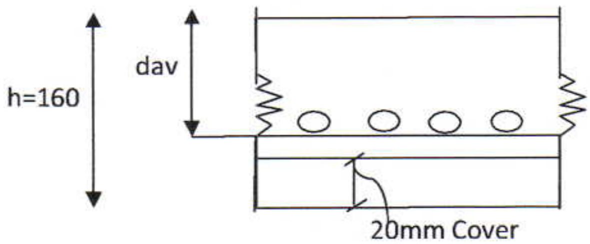
$$Slab\ thickness = \frac{Perimeter\ of\ Slab}{180} = \frac{2(6+8)*10^3}{180} = 155.5 = 160^{mm}$$

Using φ *12^mm in both direction*

d_{av}=h – cover – d_b

=160 – 20 – 12

d_{av}= 128^{mm}



using μ=0.8

loading

(Dead load)

Self wt. of slab= 0.16 * 24 = 3.84 KN/m²

Tiles and mortar = 0.04 * 24= 0.96 KN/m^2

W_d= 4.8 KN/m^2

Assuming W_l = 4 KN/m^2

W_u= 1.2W_d+1.6 W_l

=1.2(4.8)+1.6(4)=12.16 KN/m^2

K=0.75 and μ=0.8

$$\frac{W_U L^2{}_X}{M} = 31.51$$

$$\frac{12.16\,(8)^2}{M} = 31.51$$

$$M_{ux}^{+} = 24.68\ KN.m/m$$

$$M_{uy}^{+} = \mu M_{ux}^{+} = 0.8(24.68) = 19.75\ KN.m/m$$

$$M_{uy}^{-} = 2\mu M_{ux}^{+} = 2(0.8)(24.68) = 39.488\ KN.m/m$$

Reinforcement

$\Phi\ \ M_n \geq M_u \qquad \Phi = 0.9$

$M_{ux}^{+} = 24.68\ KN.m/m$

$M_n \geq 27.42$ KN.m/m

$\bar{\bar{F}}_c = 0.85F\acute{c}$

$$\frac{a}{d} = 1 - \sqrt{1 - \frac{2M_n}{\bar{\bar{F}}_c b d^2}}$$

$$\frac{a}{128} = 1 - \sqrt{1 - \frac{2 * 27.42 * 10^6}{0.85 * 20 * 1000 * 128^2}}$$

$a = 13.3^{mm}$

T=C

AsFy=0.85F$\acute{c}$ba

As*400=0.85*20*1000*13.3

As=565.25mm^2/m

Asmin=0.0018bh

=0.0018*1000*160=288mm^2/m

$$S = \frac{\frac{\pi}{4}(12)^2(1000)}{565.25} = 200mm$$

S_{max}=2h=2*160=320mm

Use φ 12^{mm} @ 200mm c/c

M^+_{uy}=19.75 KN.m/m

φ $M_n \geq M_u$

$M^+_{ny} \geq 21.94$ KN.m/m

$$\frac{a}{d} = 1 - \sqrt{1 - \frac{2M_n}{\bar{\bar{F}}_c bd^2}}$$

$$\frac{a}{128} = 1 - \sqrt{1 - \frac{2 * 21.94 * 10^6}{0.85 * 20 * 1000 * 128^2}}$$

$a = 10.5^{mm}$

AsFy=0.85F$\acute{c}$ba

As*400= 0.85*20*1000*10.5

As_{reg}=446.96mm²/m>Asmin=288mm²/m

$$S = \frac{\frac{\pi}{4}(12)^2(1000)}{446.96} = 253.04mm < S_{max}$$

Use φ 12^{mm} @ 250mm c/c

M^-_{uy}=39.488 KN.m/m

M^-_{ny}=43.88 KN.m/m

$$\frac{a}{d} = 1 - \sqrt{1 - \frac{2M_n}{\bar{\bar{F}}_c bd^2}}$$

$$\frac{a}{128} = 1 - \sqrt{1 - \frac{2 * 43.88 * 10^\wedge 6}{0.85 * 20 * 1000 * 128^2}}$$

a=22^{mm}

AsFy=0.85Fćba

As*400= 0.85*20*1000*22

Asreg=937.88mm²/m

$$S = \frac{\frac{\pi}{4}(12)^2(1000)}{937.88} = 120.588\ mm < S_{max}$$

S=120mm

φ 12^{mm} @ 100mm c/c

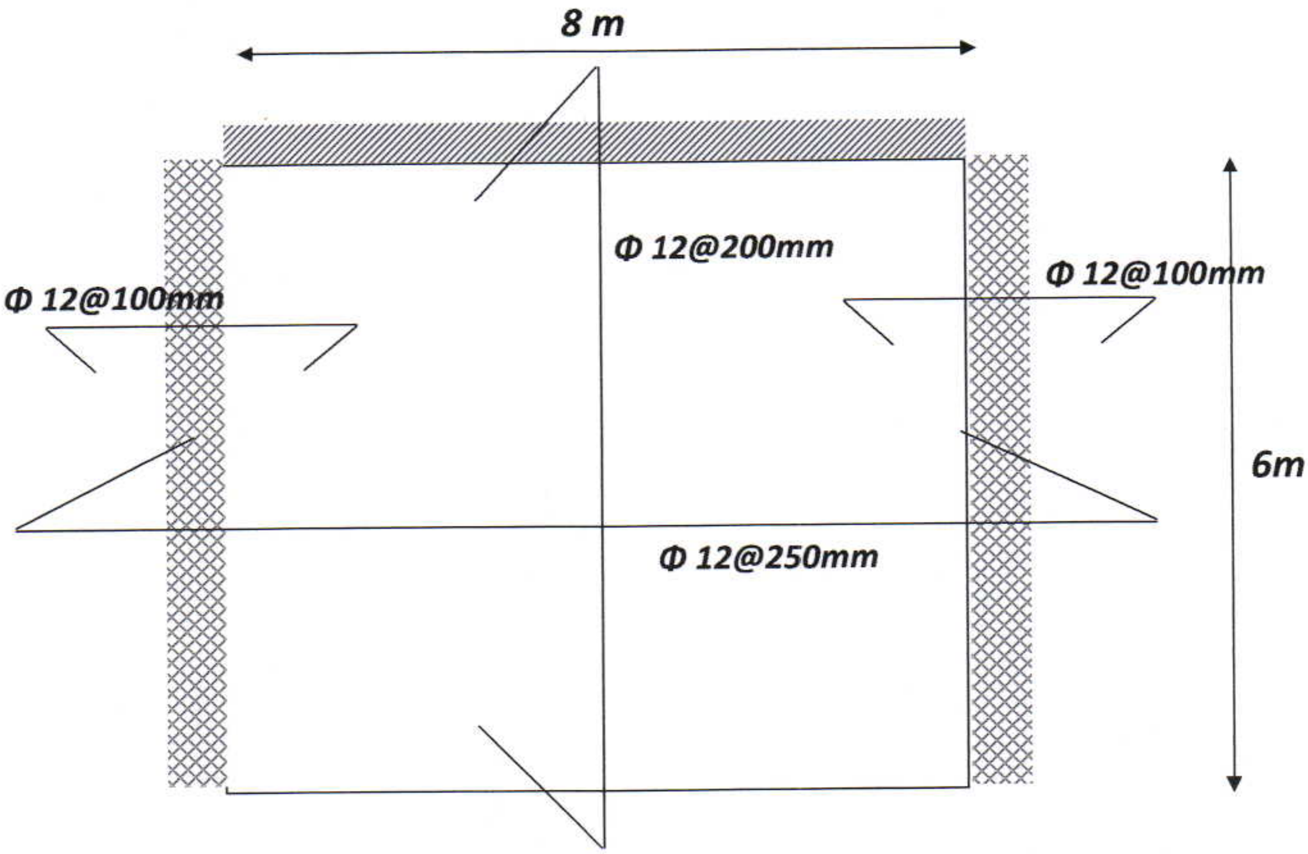


Figure. 2. Reinforcement of Slab

CHAPTER FIVE

CONCLUSIONS

Conclusions

1. For specific slab and for constant values of slab aspect ratio (K) . If the coefficient of orthotropy (μ) increases the loading of the slab (W_U) also increases.

2. For specific coefficient of orthotropy (μ) . If the slab aspect ratio (K) increases the loading of the slab (W_U) decreases.

3. When the value of (μ) increase mode I is control except when K is small mode II controls.

References

References

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