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Limitations of Flexural Crack Width in Simply Supported One-Way Ribbed Slab

Bilal Ismaeel Abd Al-Zahra [1], Muhammad Jawad Kadhim [1], Khalid K. Shadhan [1], Ali A. Shubbar [2]

Abstract *–The important consideration in design of multistory concrete buildings is reducing self-weight of the slabs. The system of one-way ribbed slab is one of many systems chooses to reduce self-weight, but this reducing occurs in concrete only what causes high tensile stress in bottom fiber of concrete lead to cracking although the section is reinforced according to design specifications. Limitations of ACI 224R-01 2008 of maximum allowable crack width is 0.3 mm for members exposure to humidity, moist air or soil. The experimental work in this research include five simply supported reinforced concrete one-way ribbed slab with same dimensions and different in ratio of bottom steel reinforcement. The five specimens have reinforcement ratio are 0.0009, 0.0013, 0.0023, 0.0037 and 0.0059 respectively. The aim of this research is checking experimental crack width at design load with permissible limitations according to ACI 224R-01 2008. The experimental work and theoretical calculations, for all the specimens are cracked sections where the first crack appear at load less than design load. At design load the specimens with low and moderate reinforcement ratio 0.0009, 0.0013 and 0.0023 shows crack width less than permissible value of 0.3 mm, while the specimens with high reinforcement ratio 0.0037 and 0.0059 shows crack width more than permissible value of 0.3 mm, where the increases in width of crack causes reducing in the durability of members. At linear stage, the mid span deflection is decreasing as reinforcement ratio increase at same step of loading for all specimens. Finally in design of one-way ribbed slab we emphasize to checking width of cracks according to codes permissible limitation and recommended that using low or moderate reinforcement ratio in this system of slabs.* ***Copyright © 2010 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Ribbed Slab, Crack Width, Reinforced Concrete, Concrete Stresses, Cracked Section And Reinforcement Ratio.*

Nomenclature

f_{ct}	Stress in tension
f_{cc}	Stress in compression

I. Introduction

One-way ribbed slab system is also called one-way joist systems. It consists of a top floor slab usually ranged from 80 to 100 mm, supported by ribs, the ribs width is usually between 120 and 150 mm with spacing of 750 mm center to center. The bottom concrete fiber of ribs exposed to high tensile stress causing cracking of section therefore in design calculations, it is recommended that checking cracks width according to equations of codes and compared it with permissible limitations.

Al-Ansari [1] developed good method in the analysis and design of two-way ribbed using MathCAD software program. This software program shows good results which used functions having classic techniques in educations.

Ahmed et. al [2] conducted a comparison between results of mathematical analysis of one-way ribbed slabs and SAP program. The theoretical analysis gives good results in comparison with these result adopted from method of finite element.

Al-Azzawi and Al-Asdia [3] tested eleven slab specimens. The weight of first group was reducing by voids in concrete section and the other group using materials with low density. From these results, the reduction in weight of specimens is very important because of dead load value in the design of buildings.

Sulaibia and Al-Amieryb [4] studied in thier research the results of finite element analysis using ANSYS program on two experimental works of two-way ribbed slab from other papers. The purpose of their research was to conduct a comparison between experimental work and finite element method. In addition, some parametric studies where selected.

Sacramento et. al [5] conducted an experimental and theoretical analysis of ribbed slabs with wide-beam. Results from experimental and theoretical analysis showed that the main factor effect in the design of two-way ribbed slabs type is dimensions of the wide-beam.

Galeb and Saeed [6] investigated the optimum design of reinforced concrete simply supported one-way ribbed slab. The cost of construction including steel reinforcement, concrete, and formwork for the slab was main factor. The optimum design was worked on ribs spacing, lower ribs width, upper ribs width, rib depth, slab thickness, shear reinforcement and bar diameter.

Imran et. al. [7] studied the optimum design of reinforced concrete ribbed slab, the important function was the combined cost of the materials including steel reinforcement, concrete and formwork. Using MATHEMATICA program the mathematical model was solved.

According to the available literature very limited studies investigated the effect of crack width of one-way ribbed slab. Therefore, the novelty of the current research is to investigate the limitations of flexural crack width in simply supported one-way ribbed slab.

This paper was structured to consist of the following: the specimens' dimensions, reinforcement design and the details of the methodology of testing were presented in section II. The results of the investigated parameters along with discussion of the findings are presented in section III. Eventually, the conclusion of this research are obtainable in section IV.

II. Experimental Program

II.1. Specimens dimensions.

In this work five simply supported one-way ribbed slabs are designed and tested to ultimate failure load with same geometry and different in flexural positive steel reinforcement ratio.

Firstly, the length of the specimen equal to 3 m was selected, this length relatively large in comparison with length chooses from researchers in laboratories to give more similarity to actual site. Additionally, the dimension of one-way ribbed slabs as shown in Fig. 1 which are calculated according to (ACI 318-19) [8]

$$h = l_n/16 \qquad (1)$$

`=2700/16=168 mm (use h=180mm)

(ACI Table 9.3.1.1)

B = 100mm ≤ 100 mm (ACI 9.8.1.2)

H ≤ 3.5b; h=180mm ≤ 350 mm (ACI 9.8.1.3)

b_f = 600mm ≤ 750 mm (ACI 9.8.1.4)

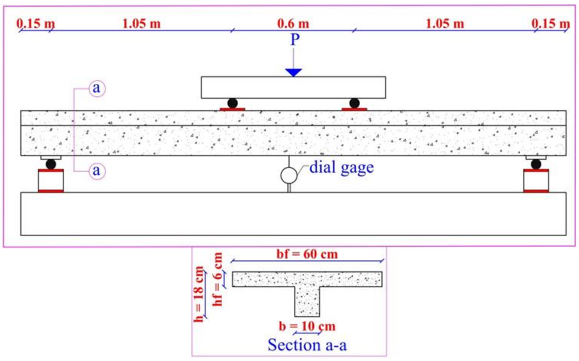

Fig. 1. Typical dimensions of one-way ribbed slabs.

II.2. Reinforcement design.

The five specimens OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 are reinforced with reinforcement ratio 0.0009, 0.0013, 0.0023, 0.0037 and 0.0059 respectively as shown in Fig. 2. Also from this figure the flange is reinforced for shrinkage and temperature with Ø 6 @ 150 mm in two direction, for shear requirement. All specimens are designed and reinforced according to code equations with one leg of Ø 10 @ 70 mm to increase shear capacity and emphasis flexural failure. The cylinders concrete compressive strength is 33MPa [9,10] and yield strength of steel is 420 MPa.

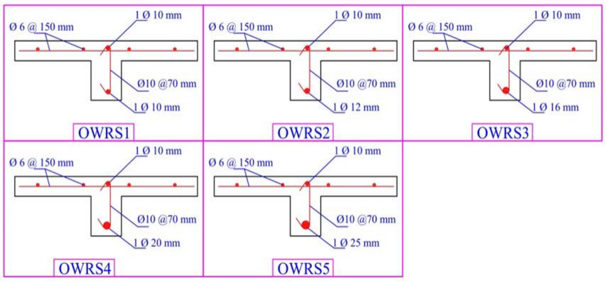

Fig. 2. Details and reinforcement for all the specimens.

The maximum moment (M) from point total point load (P) shown in Fig.1 equal to 0.525P.

$$a = (A_s fy)/(0.85 f_C b_f) \le h_f \text{ (Rectangular section)} \qquad (2)$$

From the theoretical calculations, ultimate moment capacities [11] and maximum point load (P=design load) of all specimens are listed in Table I.

TABLE I
THEORETICAL ULTIMATE MOMENT CAPACITIES AND MAXIMUM POINT LOAD (P=DESIGN LOAD).

Sample ID	As mm^2	a mm	d mm	ρ=As/bd	M kN.m	P kN
OWRS1	78	1.9	145	0.0009	4.2	8.01
OWRS2	113	2.8	144	0.0013	6.0	11.5
OWRS3	201	5.0	142	0.0023	8.8	16.8
OWRS4	314	7.8	140	0.0037	16.1	30.6
OWRS5	490	12.2	137	0.0059	24.2	46.1

II.3. Concrete stresses

In this analysis, the calculation of concrete stress in tension (f_{ct}) to specify uncracked or cracked section and concrete stress in compression (f_{cc}) to specify elastic or unelastic section.

For specimen OWRS1,

Ø=10 mm, As=78 mm^2

$$Ec=4700\sqrt{(f'_c)} = 26999 \text{ MPa} \quad (3)$$

Es=200000 MPa

$$n=E_s/E_c = 7.4 \quad (4)$$

$$(n-1)A_s = 499 \text{ mm}^2 \quad (5)$$

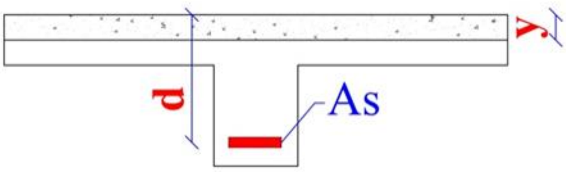

Fig. 3. Location of N.A.

Assume uncracked section and from Fig.3.

$$(600y^2)/2= (600-100) \times (60-y)^2/2+(100 \times (180-y)^2)/2+ 499 (145-y) \quad (6)$$

y=53.4 mm

$$I_{un}= (600 \times 53.4^3)/3 + (500\times6.6^3)/3 + (100 \times 126.6^3)/3+ 499 \times 91.6^2 =102.3 \times10^6 \text{ mm}^2 \quad (7)$$

$$f_{ct}= MC/I \quad (8)$$

$= (4.21 \times 10^6 \times (180-53.4) / (102.3 \times 10^6)$

$=5.6$ MPa > $f_r= 0.62 \sqrt{(f_c')} =3.5$ (then cracked section)

Then for cracked section, nAs= 577 mm^2

$(600y^2)/2=577(145-y)$, y=15.7 mm

$$I_{cr}= (600 \times 15.7^3) /3 + 577 \times 129.3^2 = 10.42 \times10^6 \text{ mm}^2 \quad (9)$$

$f_{ct} = 66$ Mpa > f_r (cracked section)

$f_{cc}= 6.3$ MPa < $(f_c')/2 = 16.5$ MPa (elastic section)

The other calculation results for all specimens are listed in Table II.

TABLE II
THEORETICAL CONCRETE STRESSES IN TENSION AND COMPRESSION

Sample ID	Concrete stress in tension f_{ct} (MPa)		Concrete stress in compression f_{cc} (MPa)	
OWRS1	66	cracked section	6.3	elastic section
OWRS2	67	cracked section	7.7	elastic section
OWRS3	58	cracked section	9.0	elastic section
OWRS4	72	cracked section	14.0	elastic section
OWRS5	75	cracked section	18.3	unelastic section

II.4. Experimental work.

The five one-way ribbed slabs in this research are casted in one stage as shown in Fig. 4 and Fig. 5. The process of casting done in one stage using rotary mixer relatively large to confirmation same concrete compressive strength and properties for all specimens.

The concrete is casting in the wood formwork, after casting electrical vibrator was used to vibrate the fresh concrete.

All the specimens were covered by a polyethylene sheet to prevent evaporation of water during days of curing. After complete time of curing, the specimens are painted with white color after complete cleaning, then the specimens prepared for testing.

Fig. 4. Wood formwork and reinforcement of the specimens

Fig. 5. Concrete casting of the specimens.

II.5. Test of the specimens

Using 1000 kN capacity hydraulic testing machine all specimens tested up to failure. Each beam is loaded with two equal concentrated loads at top face of the slab (P/2) as shown in Fig. 1, Fig. 6 and Fig. 7.

Fig. 6. Specimen before loading

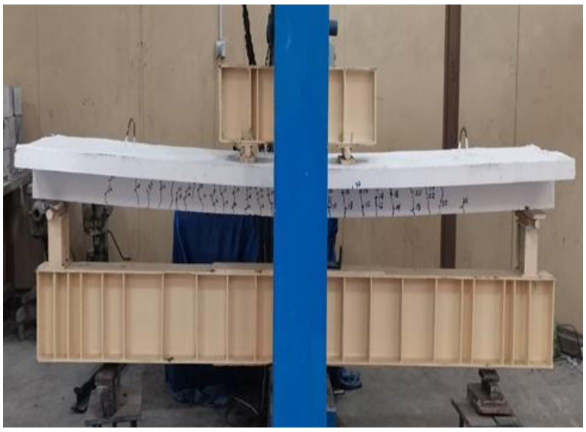

Fig. 7. Specimen after loading

III. Results and Discussions

The load deflection curves for all five reinforced concrete one-way ribbed slabs are shown in Fig. 8. These curves shows the relationship between total load (P) and mid span deflection. From this figure it can be noted that the deflection in first steps of loading is different from specimen to other where the deflection decreasing as reinforcement ratio increase at same step of loading, for example at load 6 kN the deflection of OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 are 8.0, 6.1, 3.7, 3.4 and 2.1 mm respectively.

Also from Fig. 8 the total ultimate load (P) at failure for each specimen OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 are 14.5, 20.1, 32.2, 46.5 and 66.5 kN respectively. The final mid span deflection at failure load for each specimen OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 are 50.8, 47.8, 41.1, 44.2 and 42.9 mm respectively.

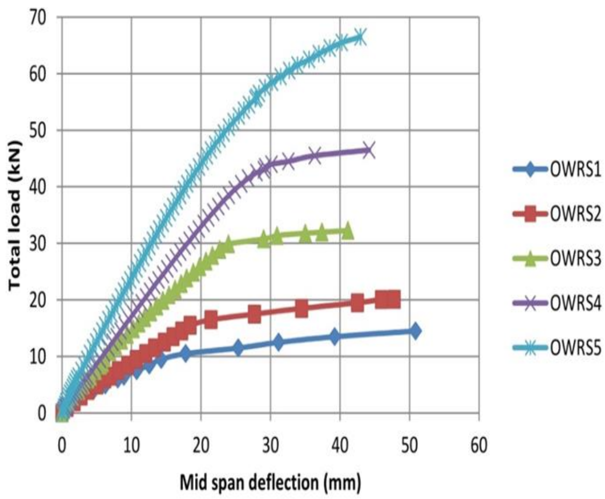

Fig. 8. Total ultimate load (P) against mid span deflection for all the specimens

The total load (P) versus flexural crack width at mid span for all the specimens is shown in Fig. 9. The data recorded from first cracking load to step load near ultimate load due to appearance many crack in region of maximum positive zone at failure load. The first crack appears for specimens OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 at load 2, 1.5, 1.8, 3 and 5 kN respectively as shown in Fig. 10. The final crack width for each specimen OWRS1, OWRS2, OWRS3, OWRS4 and OWRS5 are 0.80, 0.80, 0.76, 0.70 and 0.72 mm at load (near ultimate (P)) 11, 16.5, 29.5, 44.5 and 56 kN respectively.

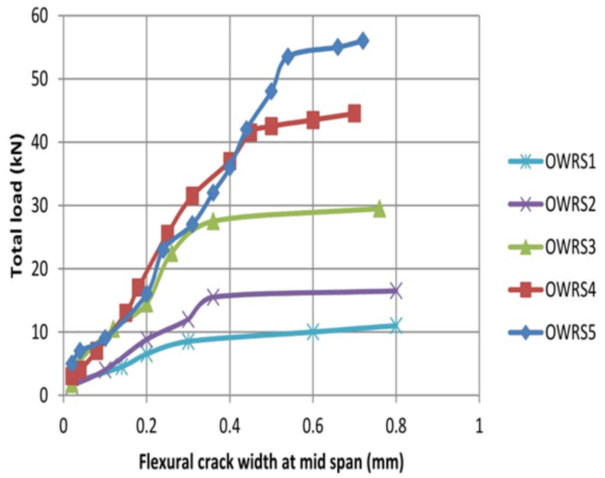

Fig. 9. Load versus flexural crack width at mid span for all the specimens.

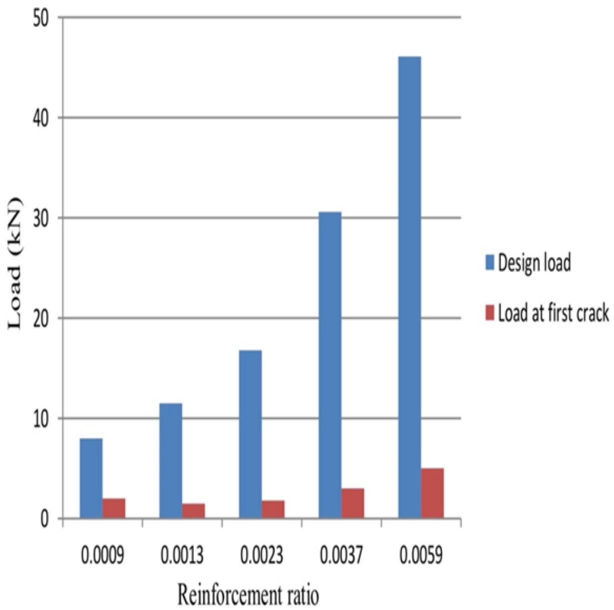

Fig. 10. Load at first crack and design load with reinforcement ratio for all the specimens.

Figs. 11 to 15 show the crack pattern and failure modes of all tested specimens.

For specimens OWRS1 and OWRS2 as shown in Fig. 11 and Fig. 12, first the flexural crack start at mid span at bottom fiber of section then other cracks appears and tending form bottom to top flange up to failure load.

For specimens OWRS3 and OWRS4 as shown in Fig. 13 and Fig. 14, first the flexural crack start at mid span at bottom fiber of section then other cracks appears and tending form bottom to top flange, also at final load steps appear another small inclined shear cracks near supports with increasing applied load gradually up to failures.

For specimens OWRS5 as shown in Fig. 15, first the flexural crack start at mid span at bottom fiber of section then other cracks appears and tending form bottom to top flange, also at final load steps appear another inclined shear cracks near supports with increasing applied load gradually up to failures

Fig. 11. Crack pattern of OWRS1

Fig. 12. Crack pattern of OWRS2

Fig. 13. Crack pattern of OWRS3

Fig. 14. Crack pattern of OWRS4

Fig. 15. Crack pattern of OWRS5

From ACI 224R-01 2008 [12] the maximum permissible width of crack are listed in Table III, also maximum design width of crack value of 0.3 mm is recommended in BS 8110 for reinforced concrete members.

The comparison between theoretical analysis and experimental results are shown in Table IV and Fig. 16.

TABLE III
MAXIMUM ALLOWABLE CRACK WIDTHS (ACI 224R-01, 2008).

Exposure Condition	Width of crack (mm)
Dry air	0.41 mm
Humidity, moist air and soil	0.30 mm
Deicing chemicals	0.18 mm
Sea water	0.15 mm
Water retaining structures	0.10 mm

For all the specimens the first crack load is lower than design load where member are cracked section.

The specimens are not appropriate when exposed to deicing chemicals because of the crack width at design load more than permissible crack of 0.18mm according to ACI 224R-01, 2008 [12] limitations.

When the specimens exposed to humidity, moist air or soil, the specimens OWRS1, OWRS2 and OWRS3 having low and moderate reinforcement ratio 0.0009, 0.0013 and 0.0023 are appropriate where the crack width at design load less than maximum permissible crack of 0.3 mm, while the specimens OWRS4 and OWRS3 having high reinforcement ratio 0.0037 and 0.0059 are not appropriate where the crack width at design load more than maximum permissible crack of 0.3 mm.

When the specimens exposed to dry air all the specimens are appropriate except specimen with high reinforcement ratio 0.0059, where the crack width lower than maximum permissible crack of 0.41 mm.

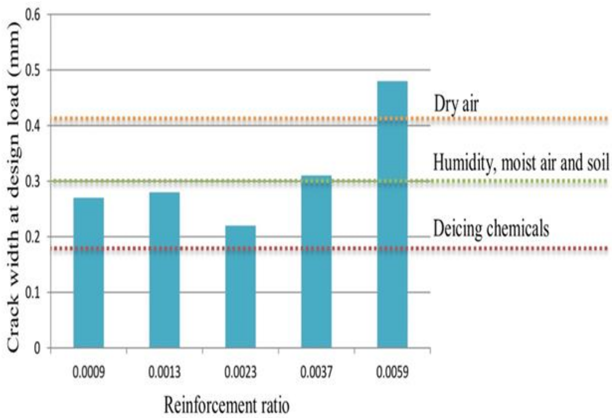

Fig. 16. Crack width at design load with reinforcement ratio for all the specimens

TABLE IV
COMPARISON THEORETICAL ANALYSIS LOADS AND EXPERIMENTAL RESULTS.

Specimen ID	Theoretical design load kN	Width of crack at design load mm	Load at first cracking	Load at crack 0.18 mm kN	Load at crack 0.30 mm kN	Load at crack 0.41 mm kN	Ultimate load kN
OWRS1	8.0	0.27	2.0	5.8	8.5	9.0	14.5
OWRS2	11.5	0.28	1.5	7.8	12.0	16.0	20.1
OWRS3	16.8	0.22	1.8	13.5	24.5	28.0	32.2
OWRS4	30.6	0.31	3.0	17.0	30.0	37.0	46.5
OWRS5	46.1	0.48	5.0	15.0	27.0	37.0	66.6

IV. Conclusion

This research was carried out with the aim of to investigate the limitations of flexural crack width in simply supported one-way ribbed slab. Depending on the obtained experimental results, the following conclusions were found:

1. All specimens are cracked sections, where the first crack occurs at load less than design load.
2. All the specimens with reinforcement ratio from 0.0009 to 0.0059 are not appropriate when exposed to deicing chemicals, where crack width more than maximum allowable crack of 0.18 mm.
3. For specimens having low and moderate reinforcement ratio from 0.0009 to 0.0037 the flexural crack width at design load less than maximum permissible value of 0.3 mm.
4. For specimens having high reinforcement ratio from 0.0037 to 0.0059, the flexural crack width at design load more than maximum permissible value of 0.3 mm.
5. It is important to calculate width of crack according to equations of codes and comparison these results with permissible limitations of the ACI 224R-01 2008.
6. At linear stage, the mid span deflection decreasing as reinforcement ratio increase at same step of loading for all specimens

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Authors' information

[1] Department of Civil Engineering, College of Engineering, University of Babylon, Iraq.
[2] Department of Civil Engineering, Liverpool John Moores University, Liverpool, L3 2ET, UK.
*Corresponding author email: A.A.Shubbar@ljmu.ac.uk

Dr. Bilal Ismaeel Abd Al-Zahra was born in Babylon, Iraq in 1980. He has BEng and Msc in civil engineering from university of Al-Nahrain, Iraq at 2002 and 2005, respectively. Dr. Abd Al-Zahra obtained a PhD in civil engineering (structures) from university of Baghdad Iraq in 2009. He is currently working as lecture in the Civil Engineering Department at the College of Engineering - University of Babylon.

Dr. Muhammad Jawad Kadhim was born in Al-Inbar , Iraq in 1976. He has BEng and Msc in civil engineering from university of Babylon, Iraq at 1998 and 2002, respectively. Dr. Kadhim obtained a PhD in civil engineering (structures) from university of Babylon, Iraq in 2008. He is currently working as an assistant professor in the Civil Engineering Department at the College of Engineering - University of Babylon

Dr. Khalid K. Shadhan was born in Al-Hilla , Iraq in 1975. He has BEng in civil engineering from University of Babylon, Iraq at 1997, and Msc in structural engineering from University of Technology, Iraq at 2000, respectively Dr. Khalid obtined a PhD in civil engineering (structures) from university of Babylon, Iraq in 2008. He is currently working as an assistant professor in the Civil Engineering Department at the College of Engineering - University of Babylon.

Dr. Ali A. Shubbar was born in Babylon, Iraq in 1993. He has BEng (Hons.) and MSc in civil engineering from Liverpool John Moores University, UK at 2016 and 2017, respectively. Dr. Shubbar obtained has a PhD in low carbon building materials from Liverpool John Moores University, UK in 2020. He is currently working as a Research Assisstant at the Eco-I North West that aims to stimulate economic growth by developing robust business-university collaborations that lead to R&D and innovation with economic potential..