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EHAVIOR OF HIGH STRENGTH R.C ONE WAY SLABS UNDER THE EFFECT OF CONCENTRATED AND LINE LOADS.

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Abstract

The use of high strength concrete with a compressive strength greater than 42 KN/mm ^{2} is recently increased and accepted by either the designers or the contractors. Most of the current designs building codes are based on the experimental works for normal concrete with a compressive concrete strength less than 40 KN/mm ^{2}. Developing a satisfactory procedure for the design of structures using high strength concrete needs an additional consideration, validation or modification of the existing design building codes.

This research deals with studying the behavior of high strength reinforced concrete slabs under the effect of either concentrated or line loads. Seven simply supported one way slabs were cast and tested as a part of compressive experimental program[1] The slabs had variable rectangularity ratio, slab thickness, load eccentricity, percentage of steel reinforcement, and with different arrangement of main reinforcement. The slabs crack pattern and crack propagation, slab deflections, and both the strains on either concrete extreme fiber and steel strains were also measured and discussed.

Analytical study for the slabs was conducted using a nonlinear finite element computer program (Assembly) to numerically prediction the nominal strength of such slabs under the effect of different situations of concentrated loads. In addition, a comparison between results from some available design building codes with the experimental results was done.

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INTRODUCTION:

Most of the current design procedures of building codes are based on experimental information obtained from normal strength concrete with compressive strength in the range of 20 to 40 KN/mm^2. For developing a satisfactory procedure for the design of structures using high strength concrete, additional consideration, validation or modification of the existing design codes are necessary.

The variations of membrane action and its effect on load capacity were of partially restrained slabs with isotropic reinforcements subjected to concentrated load [2] were investigated. The primary variables included concrete strength, reinforcement content, grade of steel, thickness of slab, and the degree of fixity at support. Test results indicated that the failure modes of partially restrained thick slabs were in flexural punching shear. The load capacity was primarily dominated by the concrete strength and slab thickness. The ductility of slabs decreased with the increasing of reinforcement ratio and slab thickness. In addition, the flexural reinforcement has a pronounced effect on the load capacity. Slabs with a lower reinforcement ratio exhibited greater intensity and longer duration of the state of compressive membrane action if they had the same span- depth ratio and thickness.

Three one –way strips were constructed and tested to provide basic information on the behavior of slabs under the action of concentrated loads [4]. Different boundary conditions were provided for each slabs. Test results indicated that the response of reinforced concrete slabs to concentrated loading measured in terms of the deflection or material strains was found to be dependent on the uniformity of cracking. Moreover, the punching shear strength increases and ductility decreases as the in plane boundary restraint was increased and the tensile stresses in the flexural reinforcement were decreased.

That the use of the two types of code expressions for a design method was studied[5] . Twenty – three reinforced concrete slabs subjected to two equal loads applied centrally within the width and symmetrically in the span were tested. The principal variables were the breadth of the slabs , the dimensions of the loading plates, and lengths of the shear spans. The breadth of slab across which the load could be assumed to spread is uncertain. An estimation could be made on the basis of the loaded width of support calculated by elastic plate theory. The present test data suggested that a full spread could be assumed across a width b of up to 3.5 times the shear span.

The behavior of simply supported hollow block slabs under the effect of line loads at different position was studied by [3]. The studied parameter were, slab aspect ratio, top slab thickness, line load position, direction of the loads, and the number of cross ribs. The studied were carried out used finite element method. The structural model selected in this study is a simply supported hollow blocks slabs analyzed as a linear plane grid model. Results indicated that the total static parallel or crossing moments. For the case of loaded short span the total parallel static moment was distributed between main ribs and parallel edge beams with distribution factor ranges between 50% to 108 % for main ribs and 50 % to 8 % for parallel edge beams. The case of loaded long span and the slab without cross rib nearly all the total static moments was carried by parallel edge beams. For the case of using cross ribs no large difference had occurred.

EXPERIMENTAL PROGRAM:

A seven simply supported one way slabs with span 1.0 m. The parameters studied for slabs were, main reinforcement percentage, varied from 0.62% to 0.76% (S17, S20,S21 &S22 have a reinforcement of 0.62%),(S16&S19 have a reinforcement of 0.71%) &(S18 have a reinforcement of 0.76%), arrangement of steel bars in slab S22. In additional, the type of load (concentrated & line load) is also studied for all slabs tested under concentrated load except S21 tested under line load,

Eccentric load position in x- direction for slabs (S19 & S20). The typical reinforcement details for the slabs are shown in Figure (1), and Table (1) lists the details of slab specimens.

Instrumentation

Before casting, electrical strain gauges (wire strain gauge) with resistance of 120 Ohms and active gauge length of 5 mm were fitted on the steel reinforcement of some slabs. These strain gauges were attached hardly to the steel bars by super glue , and were covered by silicone rubber sealant to protect them during casting and handling .

After casting, mechanical demec points were mounted on the slabs bottom surface as shown in Figure (2) The concrete strains were measured by a mechanical strain gauge of 150 mm , 50 mm gauge lengths and 0.01 mm/mm accuracy. Dial gauges of 0.01

mm accuracy were placed at different positions along the span of the tested slabs to record the deflection at different increment of loadings.

Test Setup and Test Procedure

The slabs were prepared and tested at Reinforced Concrete Laboratory, Cairo University. All the slabs were loaded using hydraulic jacks of 30 ton capacity manually operated by pump. The applied load was measured by using electrical digital load cell . The general setup of tested slabs is shown in Figure (3). Control specimens were tested at the time of the slab testing. The cubes and cylinders were tested by AMSLER compression testing machine (500 ton capacity). All slabs were tested up to failure load level under incremental static loadings. An incremental load of 0.25 ton till cracking and 0.5 ton till failure were used. During each increment, the load was held constant for about 10 minutes to allow observation of cracks and measurements of strains. Load, deflection, concrete strains, steel strains, detection of new cracks and tip of existing cracks were recorded, simultaneously for each load increment.

Table (1) Details of Slab Specimens .

Slab No.	Slab dimensions $L_x \times L_y$ (m)	f_{cu} (KN/mm ^{2})		Span to depth ratio L/d	Slab thickness (cm)	reinforcement ratio(%)	
		28 days	56 days			long	short
S16	1×0.5	81.5	102.0	12.5	4	0.71	0.71
S17	1×0.5	81.5	102.0	6.25	8	0.62	0.62
S18	1×0.5	85.0	100.0	6.25	8	0.76	0.76
S19	1×0.5	82.0	102.0	12.5	4	0.71	0.71
S20	1×0.5	82.0	102.0	6.25	8	0.62	0.62
S21	1×0.5	85.0	100.0	6.25	8	0.62	0.62
S22	1×0.5	88.5	92.0	6.25	8	0.62	0.62

TEST RESULTS AND DISCUSSION:

The effect of studied parameter on the overall behavior of test slabs is presented herein after.

1-Load deflection relationship

The load – deflection curves were obtained using LVDT measurements at three points under the slab surface.

The applied load versus the deflection at the center of the slab for all test are shown in Figure (4). The first yielding of the bottom reinforcement, while the first crack occurs in flexural zone. The load deflection curves can be used in classifying failure type failure modes can be explained into one categories, is pure flexural failure. Pure flexural failure takes place in slabs in which most of the reinforcement yields before reach ultimate capacity of slabs, and consequently the slab exhibits large deflection prior to failure.

The load deflection curves indicated that they failed in flexural. Nevertheless, none of these slabs reached, the state of steadily increasing deflections at constant load.

It is obvious that the variation of studied parameters had a great effect on slab load deflection. The slab stiffness up to initial cracking increased by about 9 %, with the variation of steel reinforcement arrangement. On the other hand, slab S_{22}, the maximum deflection decreased by nearly 6 %, that for slab $S_{17.}$ Table (2) shows the variation of the parameters and the stiffness. Generally, as the slab depth, and reinforcement ratio increase the stiffness of the slab increased.

The deflection profile for slabs $S_{17,}$ and S_{22} up to 70 % of the failure load is as shown in Figure (5). The deflection profile showed nearly a symmetric profiles especially for early stage of loading in made span, and unsymmetrical profiles for slab with eccentricity load. Test results revealed that as the depth of the slab increased ductility was decreased. It is evident that as the depth increased the slab stiffness increased. However, in spite of the increase in stiffness, a decrease in ductility is evident.

2- Cracking and failure characteristics.

For the slabs failing in flexural, the crack pattern for slabs, as shown in Figure (6). The first crack load for all slabs was distribution at the bottom surface under the load point. As the load increases, these cracks propagated along slab span and towards the free sides of the one way slabs. In addition, the slab cracking load, ultimate load and mode of failure for the test slabs, are listed in Table (2).

Test results revealed that as slab thickness increased, the slightly effect of the cracks number, but the cracks width decreased. Also the increase of steel reinforcement percentage generally had more and closer cracks radiating from the load point toward the periphery.

3-Concrete Strains.

For all the tested slabs, measurements were made to determine the distribution of the concrete strains along span. Figure (7) shows the compressive strain distribution for typical test slabs. The strains were high at the load point, but they decreased rapidly as the distance increases from the point load.

The strain profile showed nearly asymmetric profiles especially for early stage of load. Also the strain profile for slabs with eccentricity point load are unsymmetrical profiles. The strain measured values are listed in Table (3).

4- Steel strains.

Longitudinal steel strains in some of the tested slabs are measured by using electrical foil strain gauges, which were attached to the reinforcement bars before concrete casting. Figure (8) shows the relation between the load (P) and steel strain up the failure load. The observed steel strains are as given in Table (4) for slabs. It is evident that strain of the flexural reinforcement was inversely proportional to the radius measured from slab center of the loading point, where strain is determined. Strain for a small tension specimen of the steel bars showed a maximum strains of 2000 micro strains. The highest strain and consequently the initial yielding occurred below the loading point. The degree to which yielding spread in the tension steel varied with the reinforcement ratio. At higher reinforcement levels, the yielding at tension reinforcement occurred at higher applied loads, and was localized at the load point. For lightly reinforced slabs, yielding initiated at the load point and gradually progressed throughout the whole tension reinforcement.

Comparison of shear provisions in various codes.

The design provisions for the shear strength incorporated in the various codes are direct result of the empirical procedures derived from tests on slabs specimens of normal strength concrete of compressive strength less than 40 MPa. It is important to examine the existing formula for predicting the shear strength of high strength concrete slabs.

The common shear resistance of normal strength concrete slabs and relevant procedures of six Codes; American Building Code (ACI-95), British Standard Code (BS-8110), Europe model Code (CEB-FIP-90),Australia Code (A3600), and Egyptian Code (ECCS-2001) will be compared with experimental results of seven one way high strength concrete slabs.

Generally the design of reinforced concrete one way slabs is governed by punching. There are many theories about the slab column connection and many tests have been conducted, but the design rules differ considerably.

Table (5) lists values of shear strength and the ratios ($P_{exp.}$ / $P_{predict}$) for each code. For the slabs with aspect ratio equal 2.0 (one way slabs), $P_{calculated}$ is over estimated for all codes expected BS-8110 is under estimated by about 49 %.

Comparison of test and analytical results.

Computer program [Assembly] coded in Fortran language by Dr. M. Basil Emara[6] , the application of an analytical finite element in studying the behavior of reinforced concrete high strength slabs. The analysis trace the slab load-deformation and determine the internal strain for concrete and steel. The nonlinear stress-strain relationships for concrete and steel reinforcement is considered. The bond-slip between the reinforcement and concrete is also considered. The time dependent effects, the thermal effects and, the effect of the inelastic load reversals and large deformations are not included and considered to be outside the scope of this studied.

A 3-D nonlinear finite element analysis is used to predict the ultimate load capacity of flat slabs at an either concentrated or line loads. Twenty two slabs without shear reinforcement tested and tested by different investigators were analyzed.

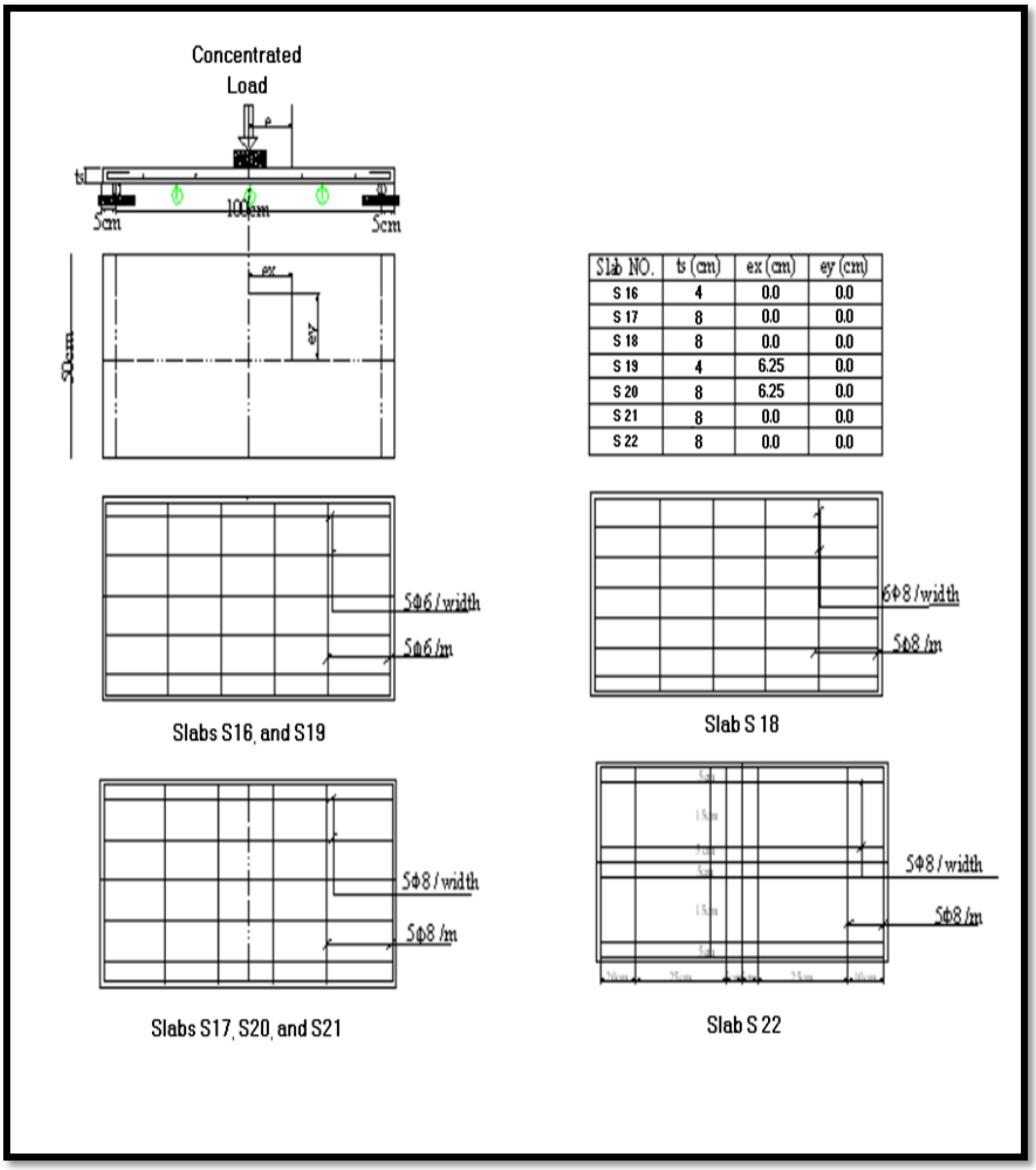
Particular attention was paid to ensure that the predicted mode of failure judged by strain in steel and concrete corresponded closely to that observed in the experiments. Good agreement was observed between predicted ultimate load capacity and the experimentally measured load. It is concluded that the present program can confidently be used to predict the ultimate load in practice.

The results of analytical analysis are discussed for reinforced concrete high strength slab and compared to those obtained experimentally.

The comparison includes; the initial cracking load, the slab ultimate load, slab maximum deflections, area calculated under the load- deflection curve, and initial slope for load deflection curve. The effect of these parameter on the load – deflection relationships as shown in Figures (9-a) comparison between four one way slabs S16,S17,S18, and S22 subjected to concentrated and line loads. The initial slope for load deflection relationship proceeds from the numerical analysis represent the same in 60 % for the ultimate load capacity, also the maximum deflection near the maximum deflection that the experiment results. Figure (9-b) shows comparison between three one way slabs S19,S20,and S21 subjected to eccentricity concentrated load. The initial slope, and the value of maximum deflection proceeds from the numerical analysis increased by about 10 %, and the ultimate load capacity increased by about 20% from that experimental results.

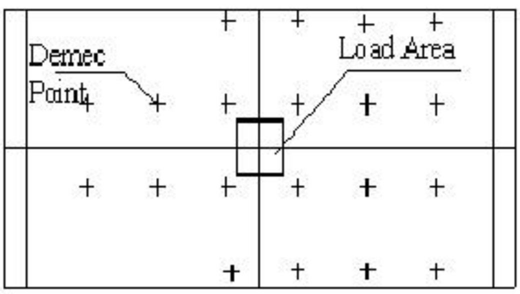
Figure (9-c) shows comparison between seven one way slabs subjected to both line load, and eccentricity concentrated load, also the comparison between experimental ,and numerical results of ultimate load capacities is represented in Figure (10).

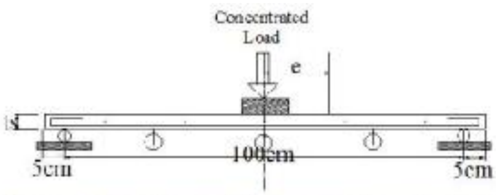
In final the analytical results for test slabs, it is clear that there is good agreement, between both analytical and experimental results.



Slab NO.	ts (cm)	ex (cm)	ey (cm)
S 16	4	0.0	0.0
S 17	8	0.0	0.0
S 18	8	0.0	0.0
S 19	4	6.25	0.0
S 20	8	6.25	0.0
S 21	8	0.0	0.0
S 22	8	0.0	0.0

Fig. (1) Reinforcement and Details of Slab Specimens.





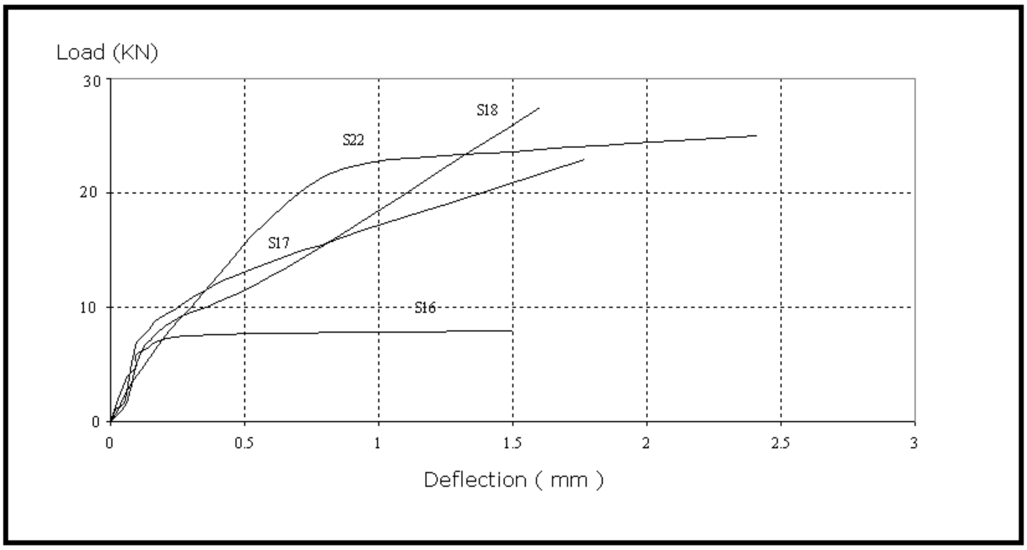


Fig.(2) Point Measurement Location for All Slabs

Fig.(3) General Setup of Test Slabs

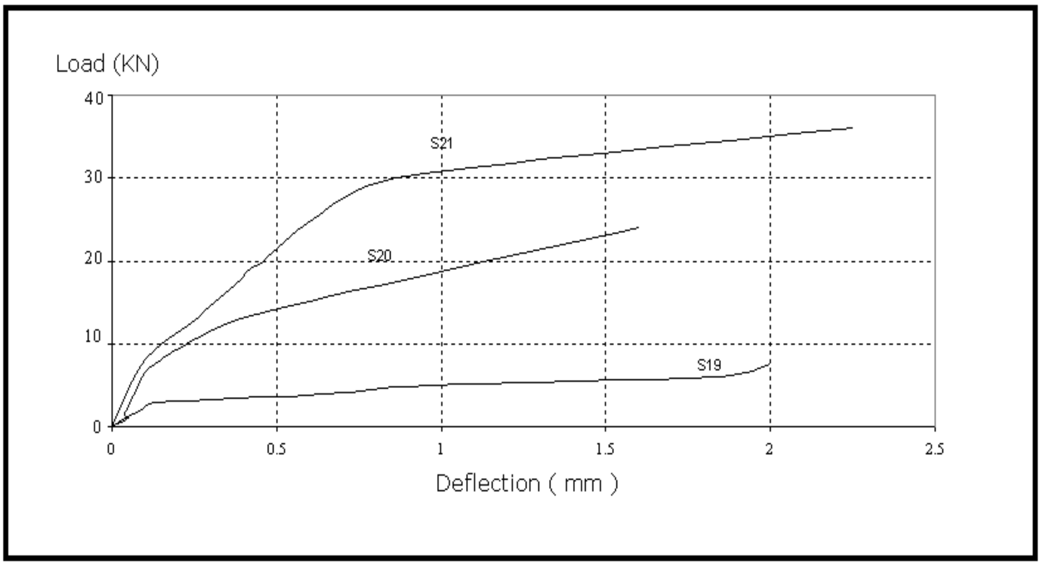


Fig. (4) Load Max. Deflection Curve for Tested Slabs.

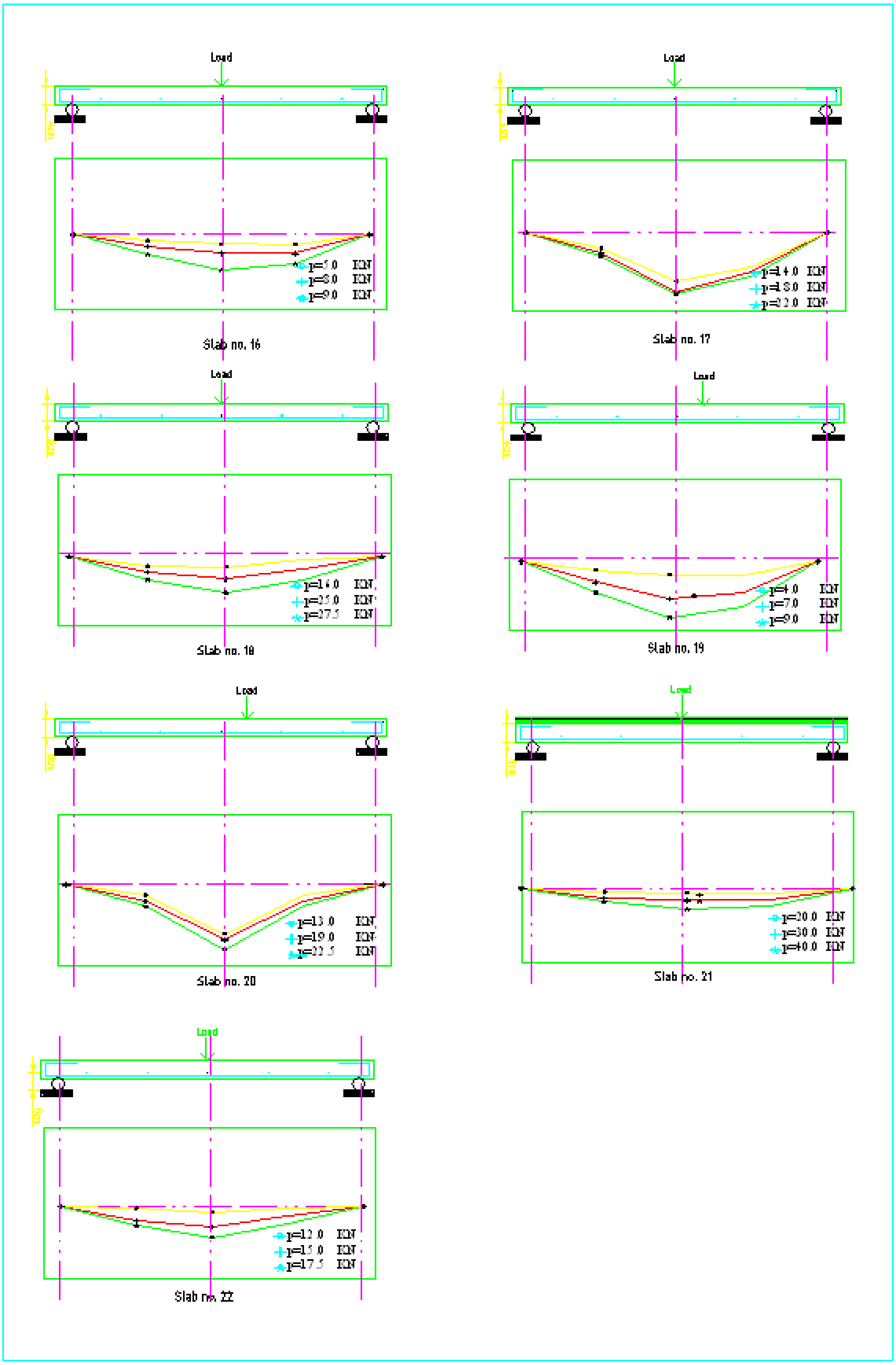


Fig. (5) Load – Max. Deflection Profile for Tested Slabs.

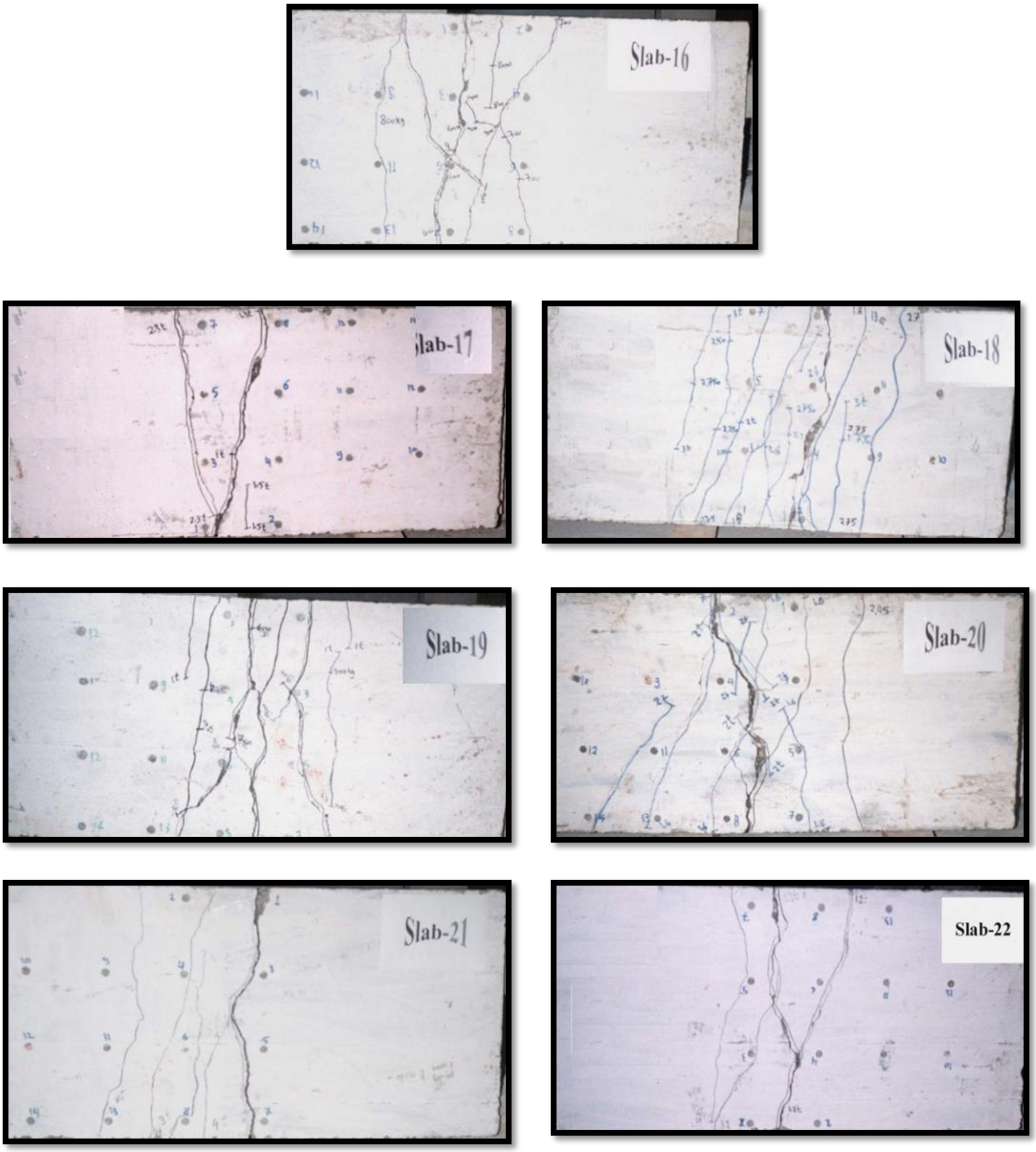


Fig. (6) Crack Pattren for Tested Slabs.

Table (2) Summery of Test Result.

Slab No.	f_{cu} (KN/mm ^{2})	P_{cr} (KN)	Δcr (mm)	$P_{failure}$ (KN)	P_{cr} /$P_{failure}$	Stiffness**
S_{16}	102.0	4	0.49	8	0.50	1.03
S_{17}	102.0	13	0.71	22.5	0.58	1.96
S_{18}	100.0	16	0.59	27.5	0.58	2.73
S_{19}	102.0	5	0.66	9	0.55	0.61
S_{20}	102.0	14	0.87	22	0.64	1.50
S_{21}	100.0	20	0.45	40	0.5	4.44
S_{22}	92.0	12	0.67	17.5	0.68	1.79

** Stiffness corresponding to load deflection curve.
P_{cr} corresponding to first measured cracking load.
$P_{failure}$ corresponding to measured failure load.

Table (3) Summery Concrete Strain.

Slab No.	f_{cu} (KN/mm ^{2})	Mid span concrete ultimate strain (micro strain) bottom	Load(P)* (KN)
S_{16}	102.0	+1250	7
S_{17}	102.0	+1170	12
S_{18}	100.0	+2310	22.5
S_{19}	102.0	+1380	6
S_{20}	102.0	+1930	13
S_{21}	100.0	+1310	30
S_{22}	92.0	+1910	12

(P)* corresponding to 66 % $P_{failure}$

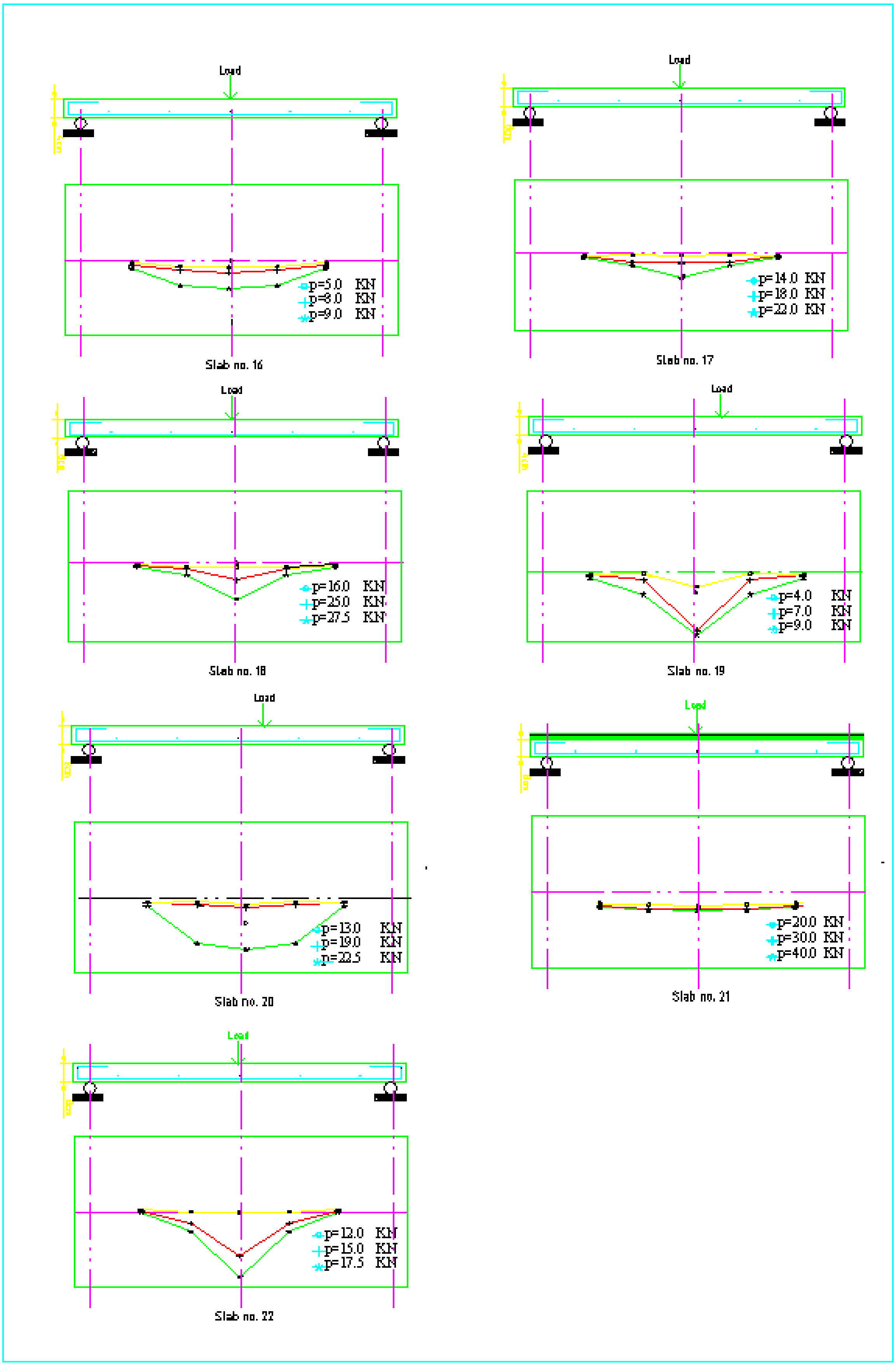


Fig. (7) Load Concrete Strain Profile for Tested Slabs.

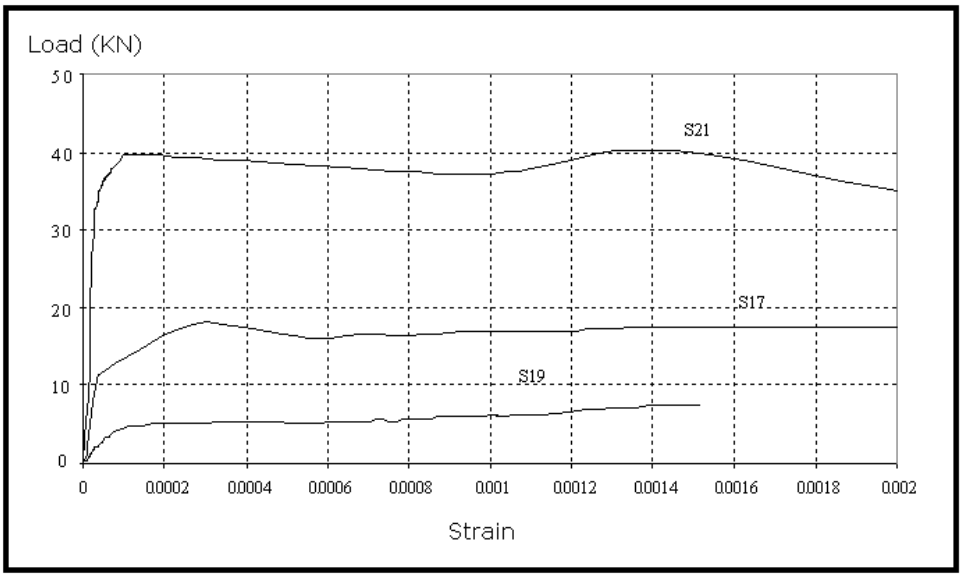


Fig. (8) Load Steel Strain for Tested Slabs.

Table (4) Steel Maximum Strain for Some of the Test Slabs.

Slab No.	P_{cr} (KN)	$P_{failure}$ (KN)	Ultimate steel strain at $P_{failure}$ (micro strain)
S17	10	23	2430
S19	3	9	1990
S21	25	36	2600

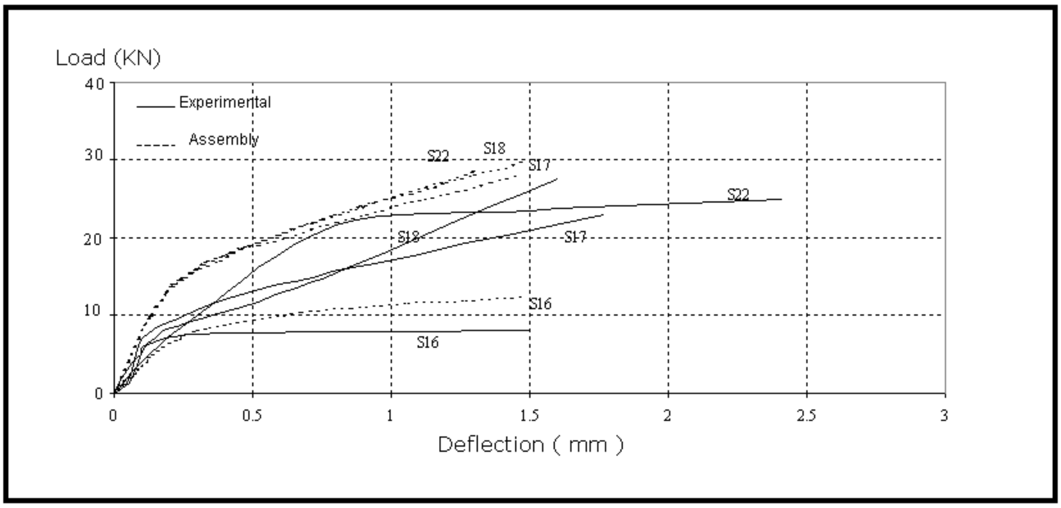
Slab NO.	Exp. Results (KN)	ACI (95) (KN)	BS.8110 (85) (KN)	CEB-FIP (90) (KN)	Egyptian (2001) (KN)	$\frac{(1)}{(2)}$ Ratio	$\frac{(1)}{(3)}$ Ratio	$\frac{(1)}{(4)}$ Ratio	$\frac{(1)}{(5)}$ Ratio

ϵ_y = 1625 micro- strain (Ø6mm)
= 1500 micro- strain (Ø8mm)

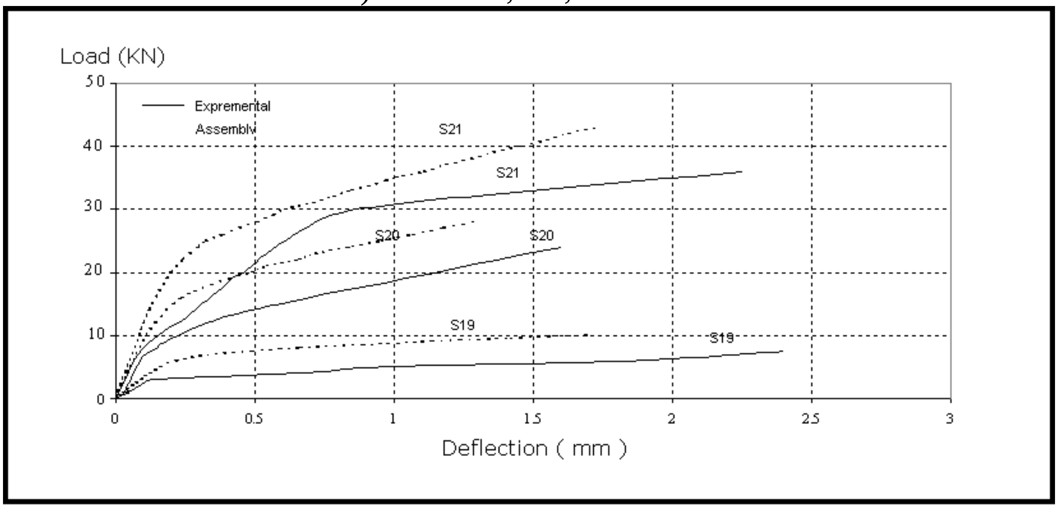
	(1)	(2)	(3)	(4)	(5)				
S_{16}	8	23	7	12	24	0.35	1.15	0.66	0.33
S_{17}	22	33	12	18.5	52	0.67	1.85	1.20	0.45
S_{18}	27.5	43	12.5	19	52	0.65	2.20	1.45	0.55
S_{19}	9	53	7	12	24	0.17	1.30	0.75	0.37
S_{20}	22.5	63	11.2	18.5	52	0.36	1.85	1.20	0.45
S_{22}	17.5	83	12	27.5	52	0.20	1.5	0.95	0.33

Table (5) Compression of Calculated Slab Failure under the Effect of

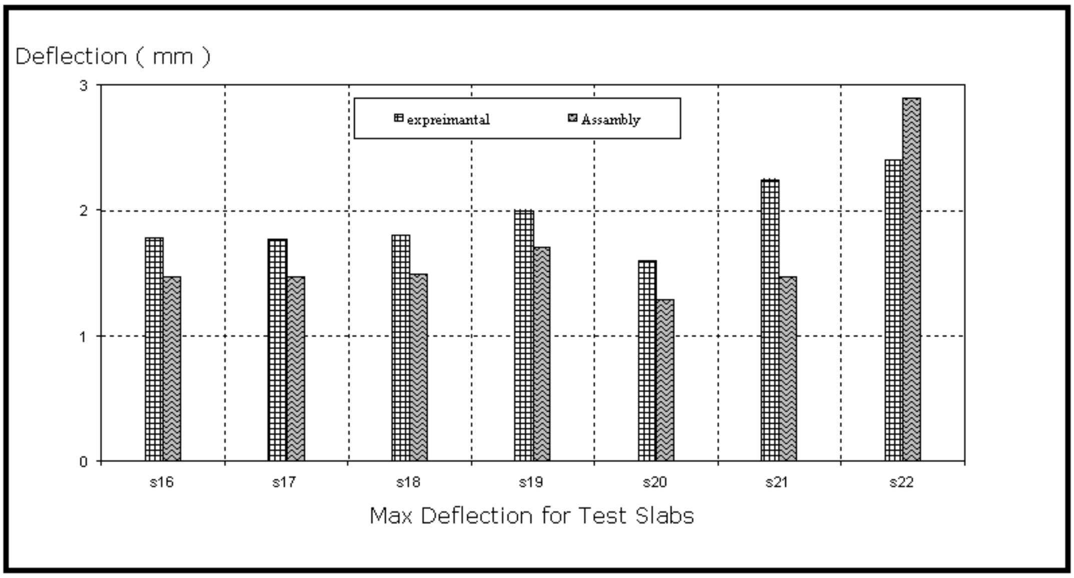
Concentrated Loads according to Different Building Codes.



a) Slabs S16,S17,S18 &S22.



b) Slabs S19,S20 &S21.



c) Max. Deflection for Test Slabs.

Fig.(9) Comparison between the Experimental & Numerical Analysis for Load Deflection Relationship for Tested Slabs.

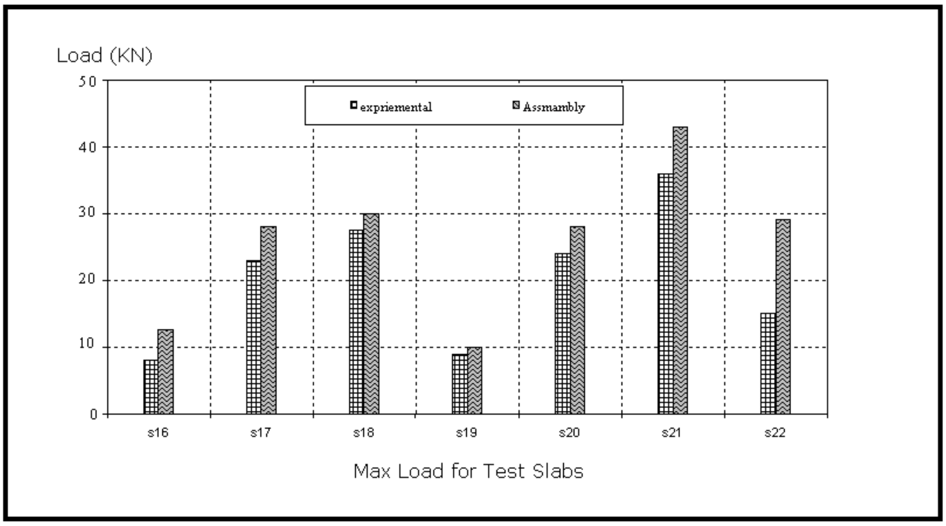


Fig.(10) Comparison between the Experimental & Numerical Results for Tested Slabs.

Conclusions

A seven simply supported one way slabs were tested. The main variables include rectangularity ratio, percentage of reinforcement content, slab thickness, load eccentricity, type of loading, and the arrangement of the slab main reinforcement. The slab cracking pattern and crack propagation, slab deflections, and strains distribution on both concrete extreme fiber stress and for steel strain are discussed. Analytical study was conducted using a nonlinear finite element computer program developed earlier [Assembly] to numerically prediction of the slab nominal strength under the effect of concentric, and eccentric concentrated or line loads.

Within the limits of this investigation, the following conclusions are drawn :-

1- The slab cracking loads for all the tested slabs observed to be at 30 up to 40% of its failure load, except slab with concentrated reinforcement, and slabs subjected to line load, where the initial cracks started at 40 up to 50 % of their respective failure loads.

2- The concentrated reinforcement arrangement delayed the appearance of first cracking, which clearly indicates that reinforcement conferment had a noticeable effect in the slab cracking behavior.

3- Slab has small thickness, with steel reinforcement percentage less than 0.3%, showed a real punching cracks occurred and punching shear failure was the governing failure mode.

4- All the tested slabs failed in a flexural failure.

5- The deflection profile for all slabs with centric load, showed an approximately symmetric profile with respect to mid span at early stage of loading, and unsymmetrical shape profile was shown in the case of eccentric load.

6- The load – deflection profiles for all the tested slabs, showed a linear profiles up to the initial cracking load. Then a steeper slopes in the load – deflection profiles as representing a higher propagation of cracking than that of the initial cracking stage.

7- For lightly reinforced slabs (μ = 0.3%), steel yield initiated at the loading point and gradually propagate through the direction of tension reinforcement. However for a higher reinforcement ratio reinforcement yielding was consider within the load area.

8- The ultimate load capacity calculated by variable building codes is over estimated by about (47 %, and for the A.C.I building cod, which did not take the effect of reactively high compressive strength. The comparison showed a nearly

more an the double of the ultimate load capacity) for all codes except two codes BS-8110, and CEB-FIP, which they are under estimated by about (12.5 % to 53 %), and (17 % to 30 %) respectively.

9- The results obtained by the analytical model showed a satisfactory agreement within 25 % with the experimental results in predicating slab deflections and slab ultimate loads capacity.

10- A 3-D nonlinear finite element computer program (Assembly) is a possible tools to use to obtain a good lower bound to the observed slab ultimate load. It is hoped that this work will enable designer to use a nonlinear analysis with confidence for the design and checking purposes.

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