Load –Deflection Relationship for Clamped-Horizontally Restrained R.C. Polygonal Slabs

Dr. Ali Flayeh Hassan- Asst Prof.
Department of Civil Engineering, College of Engineering, University of Duhok

Received : 25/01/2017
Accepted : 24/05/2017
DOI Link: https://doi.org/10.17656/sjes.10055

Abstract

A theoretical model is presented in the analysis and prediction of the complete load-deflection behavior of fixed-horizontally restrained reinforced concrete polygonal slabs under uniform loading. The limiting cases of fixed reinforced concrete square and circular slabs are also deduced. The proposed model considers three stages, elastic, elasto-plastic and plastic. In the elastic and -elasto-plastic stages, the results of classical plate theory are used. The cracking of concrete and yielding of steel reinforcement are accounted for by suitably modifying flexural rigidity. Changes that occur in support conditions due to possible yielding are also considered. In the plastic stage a rigid plastic membrane analysis is presented. A method is proposed to predict the real ultimate load (including membrane action) and the deflection at the ultimate load.

Key Words : Circular slabs, polygonal slab, square slabs, flexural rigidity, membrane action, yield criterion, yield-line theory.

1. Introduction

Extensive experimental work on restrained slabs [1-5] have shown the load-deflection relationship is in the form of ABCD shown in Fig (1). The ultimate load is considerably higher than that suggested by Johansen yield line theory [6]. This enhancement in ultimate load has been attributed to the effect of induced compressive membrane action. The conventional yield line theory of Johansen based upon rigid-plastic approximation has been proven successful in predicting the initial collapse loads of reinforced concrete slabs with negligible membrane forces. Several researchers for example, wood [1], park [7] and Al-Hassani [8] have used similar methods to obtain initial collapse load with membrane forces and give a load –deflection relationship of the form HCD shown in Fig (1).

In this paper, an attempt is made to predict the complete load-deflection behavior of restrained reinforced concrete polygonal slabs under uniform loading.

2. Theoretical Analysis

A clamped (horizontally restrained) polygonal slab having q number of sides each of length L_1 carrying a uniformly distributed load, is considered, isotropically at center and with the same amount of reinforcement in the top face only at supports, as shown in Fig (2) is analyzed theoretically under the action of uniform load of intensity P. The analysis is carried out in three stages:

1. First stage (elastic).
2. Second stage (elasto-plastic).
3. Third stage (plastic).

The stages of analysis are shown in Fig (3).

a. First stage (elastic stage)

The line OA in Fig (3) represents elastic behavior. The maximum bending moment and maximum deflection occurring at the slab center are calculated from classical plate theory [9, 10] as

$$M_{max} = k_1 PL^2 \quad (1)$$

$$\omega = K_2 \frac{PL^4}{E_C I_g} \quad (2)$$

Where L: is the side length of an equivalent square slab having the same area as that of the polygonal slab,
Thus:

$$L = \sqrt{\frac{q}{4\tan\frac{180}{q}}} L_1 \quad (3)$$

For the extremity q=∞ (i.e the case of a circular slab of radius say R) L is simply evaluated as

$$L = \sqrt{\pi}\, R \qquad (4)$$

This stage is terminated when first cracking appears at the slab center at an intensity of load equals p_{cr}. This represented by point A in figure which can be estimated by equating M_{max} to the cracking moment M_{cr} such that

$$M_{max} = M_{cr} = \frac{f_r J_g}{y_t} \qquad (5)$$

A combination of Eq. (1) and (5) gives

$$p_{cr} = \frac{f_r J_g}{k_1 y_t\, L^2} \qquad (6)$$

And when this load is substituted into Eq. (2), the cracking deflection w_{cr} corresponding to point A will be

$$\omega_{cr} = \frac{k_2}{k_1}\ \frac{f_r L^2}{y_t\, E_C} \qquad (7)$$

By using f_r =0.7 $\sqrt{f_c`}$ and $E_c$ =4700 $\sqrt{f_c`}$ (as recommended by ACI code [11] and knowing that I_g = h^3 /12 and y_t=h/2, Eqs. (6) and (7) may be reduced to

$$P_{cr} = 0.1167\ \frac{\sqrt{f_c'}}{k_1} (\frac{h}{L})^2 \qquad (8)$$

$$\omega_{cr} = 3 \times 10^{-4} \left(\frac{k_2}{k_1}\right) (\frac{L}{h})^2\ h \qquad (9)$$

The constants k_1 and k_2 (the moment and deflection coefficients corresponding to fixed edge conditions) are listed in Table (1) [9, 10]:

b. Second stage (Elasto- plastic)

This stage starts from the cracking load at point A to Johansen yield line theory load at point D of Fig (3). The effect of cracking of concrete and yielding of steel is included by choosing a decreasing moment of inertia function (I_e) analogous to that specified by section (9.5.3.4) of ACI code [11] , but was modified and related to the load intensities as;

$$I_e = (\frac{p_{cr}}{p_a})^3\, I_g + \left[\, 1 - \left(\frac{p_{cr}}{p_a}\right)^3\right] I_{cr}\ \leq\ I_g \qquad (10)$$

The ACI code equation

$$I_e = (\frac{M_{cr}}{M_a})^3\, I_g + \left[\, 1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \qquad (11)$$

cannot be applied for region CD, since points C and D have the same moment capacity given by Eq. (18)

Where

P_{cr} = cracking load

P_a = The intensity of uniformly distributed load at the stage for which the deflection is calculated

I_g = Gross moment of inertia of section = h3/12

I_{cr} = moment of inertia of cracked transformed section

$$I_{cr} = \frac{b\, d^3}{3}\ [k^3 + 3n\rho\, (1-k)^2] \qquad (12)$$

Where

$$k = \sqrt{(\rho n)^2 + 2\rho n} - \rho n \qquad (13)$$

n = the modular ratio = E_S/E_C

For continuous members, ACI code stipulates that I_e may be taken as the average values obtained from Eq. (11) for the critical positive and negative moment section. Thus, for clamped polygonal slabs, the fallowing expression may be used;

$$I_e = 0.5\ (Ie_{(c)} + Ie_{(e)}) \qquad (14)$$

Where the subscript c and e refer to center and the edges, respectively.

Referring to Fig (3), the elasto-plastic stage is subdivided into three intermediate stages represented by portions AB, BC and CD of the load –deflection curve.

Portion AB

During this portion of the load- deflection curve, the slab has tension cracks penetrating all the way to the neutral axis and spreading outward from slab center, When the terminating point B is reached, the steel bars commence to yield at the slab center and the moment capacity of the slab at this section is simply the yield moment M_y which can be easily calculated on the basis of the stress distribution shown in Fig (4) as

$$M_y = \rho\, f_y\, d^2\, (1 - \frac{k}{3}) \qquad (15)$$

The corresponding load and deflection are

$$p_y = \frac{M_y}{k_1\, L^2} \qquad (16)$$

and

$$\omega_y = \omega_{cr} + k_2 \frac{(p_y - p_{cr})L^4}{E_c (I_e)_y} \quad (17)$$

Portion BC

Along portion BC, the slab continues to yield and a heavy spread of cracks may be witnessed accompanied by inelastic stress distribution of concrete until when point C is reached the section of the slab at center has reached its ultimate moment capacity (M_u) where

$$M_u = \rho f_y d^2 (1 - 0.59 \rho \frac{f_y}{f_{c'}}) \quad (18)$$

The corresponding load and deflection are

$$p_u = \frac{M_u}{k_1 L^2} \quad (19)$$

and

$$\omega_u = \omega_y + k_2 \frac{(p_u - p_y) L^4}{E_C (I_e)_u} \quad (20)$$

Portion CD

Further increments in loading allow a complete yield line pattern to form in slab as shown in Fig. (5) with positive yield lines accompanied by circumferential negative yield lines. The Johansen`s yield line theory load P_J (corresponding to point D) for the q-sided restrained polygonal slab under consideration is determined using the equilibrium method and taking moment about axis of rotation of a typical slab element gives

$$P_J = \frac{24 (M_u^+ + M_u^-)}{L_I^2 \cot^2 \frac{180}{q}} \quad (21)$$

If the slab is square,

$$P_J = \frac{24 (M_u^+ + M_u^-)}{L_I^2} \quad (22)$$

When the slab is circular of radius R,

$$P_J = \frac{6 (M_u^+ + M_u^-)}{R^2} \quad (23)$$

And for the special case of hexagonal slab,

$$P_J = \frac{8 (M_u^+ + M_u^-)}{L_I^2} \quad (24)$$

At point D in Fig (2) it is assumed that the slab has yield along the boundaries, thus resulting in slightly altered edge conditions. Thus, the slab is assumed to be partially restrained and the deflection corresponding to point D is determined from

$$\omega_J = \omega_u + k_3 \frac{(p_J - p_u)}{E_C (I_e)_J} \quad (25)$$

And k_3= the average of the deflection coefficients corresponding to the fixed and simply supported edge condition are listed in table (2) [9, 10] In this way, the load-deflection plot in the second stage is determined.

c. Third stage

As the slab deflects more, the lower part of the slab at the boundary has a tendency to move outward against the boundary element resulting in the development of inplane compressive forces (compressive membrane forces) in the slab. The compressive membrane forces will cause the ultimate load of the slab to be considerably greater than the ultimate load calculated using Johansen`s yield line theory. At larger deflections, the slab edges tend to move inward and tensile membrane forces will be induced which will enable the slab to carry further load by catenary action.

The analysis of membrane action is carried in two parts using the following assumption:

1- The materials are rigid- perfectly plastic

2- The form of failure is pyramid as determined by yield line theory method

3- The adopted failure mode does not change with deformations.

First part: The behavior of the slab under compressive membrane action. This is represented by portion DE of the load –deflection curve of Fig (3). The analysis is carried out by first establishing a yield criterion similar to that developed by wood [1] for a slab section under simultaneous action of a yield moment M and axial force N, each per-unit width, acting at the mid–depth of the slab (Fig. (4). The stress block parameters are based on ACI code instead of British standard code of practice CP114 (1957) [12] which were adopted by wood.

Referring to the stress distribution at ultimate stage shown in the Figure,

$$N = 0.85 f_c' a - A_s f_y \quad (26)$$

$$M = 0.85 f_c' a \left(\frac{h}{2} - \frac{a}{2}\right) + A_s f_y \left(d - \frac{h}{2}\right) \quad (27)$$

A substitution of (a) obtained from Eq. (26) into Eq. (27) leads to the fallowing non- dimensional yield criterion

$$\frac{M}{M_a} = 1 + \alpha \left(\frac{N}{T}\right) - \beta \left(\frac{N}{T}\right)^2 \qquad (28)$$

Where M_u : is as given by Eq.(18)

$$T = A_s f_y = \rho d f_y \qquad (29)$$

$$\alpha = \frac{\frac{1}{2}\frac{h}{d} - 1.18 \rho \frac{f_y}{f_c'}}{1 - 0.59 \rho \frac{f_y}{f_c'}} \qquad (30)$$

and $$\beta = \frac{0.59 \rho \frac{f_y}{f_c'}}{1 - 0.59 \rho \frac{f_y}{f_c'}} \qquad (31)$$

The maximum moment is reached when

$$\frac{N}{T} = \frac{\alpha}{2\beta} \qquad (32)$$

giving $$\frac{M_{max}}{M_u} = 1 + \frac{\alpha^2}{4\beta} \qquad (33)$$

Which is an enhancement factor for horizontally restrained slab. This implies that the ultimate load which corresponds to zero deflection since it is based on assuming that the slab behaves in a rigid- perfectly plastic manner will be

$$\frac{P_{mi}}{p_J} = 1 + \frac{\alpha^2}{4\beta} \qquad (34)$$

From which $$P_{mi} = \left[1 + \frac{\alpha^2}{4\beta}\right] P_J \qquad (35)$$

Where p_{mi} = initial ultimate load including membrane action

This correspond to point H in the Fig (3)

It is worth re-emphasizing here that the value of the ultimate load according to Eq. (35) is somewhat exaggerated. If elastic strains, for instance had been introduced in the analysis, the value of the ultimate load would have been reduced and will be given as

$$P_{ma} = F \; P_{mi} \qquad (36)$$

where P_{ma} = Actual ultimate load including membrane action

F = Reduction factor

From the results of the extensive series of test, Wood [1] suggested the following reduction factors for the ultimate load.

% reinforcement ρ	reduction factor F
$\rho > 0.8$	0.70
$0.8 > \rho > 0.4$	0.60
$\rho < 0.4$	0.50

Eq. (28) is valid for deflections between ω_J and ω', where ω' represent the limiting deflection at which the slab is cracked throughout its depth at center and is found to be

$$\omega' = \omega_J + \frac{4}{3} h \qquad (37)$$

The second part of this stage belongs to all values of the deflection greater than ω' where the slab will be cracked throughout its depth in the central region. Thus, for the cracked –through slab section, the yield criterion becomes

$$\frac{N}{T} = -1 \qquad (38)$$

$$\frac{M}{M_u} = 1 - \alpha - \beta \qquad (39)$$

Using the plastic potential theory with total strain approach [6], the load –deflection relationship for the first part of this stage is established by determining first the position of the neutral axis along the yield lines through a combination of geometrical consideration and inplane equilibrium. Thereafter, the yield criteria [Eq. (28)] together with Eq. (26) are used to evaluate moments and membrane forces along the yield lines. The yield load is then found from moment equilibrium of one of the (q) triangular elements of the collapsed slab. The corresponding load-deflection relationship is found as follows:

For $\omega_s \le \omega \le \omega'$

$$\frac{P}{P_J} = 1 + \frac{\alpha^2}{4\beta} - \frac{\alpha}{4}\left(\frac{\alpha}{\beta} + 2\right)\frac{\omega}{h} + \frac{5}{64}\beta\left(\frac{\alpha}{\beta} + 2\right)^2\left(\frac{\omega}{h}\right)^2 \qquad (40)$$

Eq. (40) reduced to Eq. (34) with $\omega = 0$

For $\omega > \omega'$

$$\frac{P}{P_J} = 1 + \beta + \frac{\alpha}{2}\left(\frac{\alpha}{\beta} + 2\right) + \beta\left(\frac{\alpha}{\beta} + 2\right)\left(\frac{\alpha}{\beta} + 2.5\right)\left(\frac{\omega}{h}\right) + \frac{1}{3}\beta\left(\frac{\alpha}{\beta} + 2\right)^2\left[\left(\frac{\omega}{h}\right)^2 - \sqrt{\left(\frac{\omega}{h}\right) \times \left(2 + \frac{\omega}{h}\right)^3}\right] \qquad (41)$$

In Eqs. (40) and (41), the effect of the number of sides (q) on the load –deflection behavior of the fixed polygonal slab is included in the load term p_J .

The load - deflection relationship given by Eqs. (40) and (41) will have the shape shown by the dotted curve HEFG shown in Fig (3). Point H of the curve corresponds to the theoretical peak load. The coordinates of point E corresponds to the actual peak load and determined by first calculating p_{ma} using Eq. (36), then the corresponding deflection ω_{ma} may be obtained by the substituting into Eq. (40), thus

$$\frac{\omega_{ma}}{h} = \frac{B - \sqrt{B^2 - 4AC}}{2A} \quad (42)$$

where $A = \frac{5}{64}\beta\left(\frac{\alpha}{\beta} + 2\right)^2 \quad (43)$

$$B = \frac{\alpha}{4}\left(\frac{\alpha}{\beta} + 2\right) \quad (44)$$

$$C = 1 + \frac{\alpha^2}{4\beta} - \frac{P_{ma}}{p_J} \quad (45)$$

3. Summary of theoretical analysis

A complete load –deflection diagram for a horizontally restrained polygonal slab can be obtained with reference to Fig (3) as follows

1- The values of the coordinates of the points A, B, C, D and E are calculated using the appropriate equation as indicated below

Point	No. of Eq. used to evaluate the (deflection)	(load)
A	9	8
B	17	16
C	20	19
D	25	21
E	42	36

2- The referred points O, A, B, C, D and E are connected by straight lines to obtain part OABCD of the load- deflection diagram

3- The remaining part (the rigid- perfectly plastic curve) of the load-deflection diagram represented by EFG is drawn using Eqs. (40) and (41) for $\omega \geq \omega_{ma}$ given by Eq (42)

4. Illustration of the procedure and discussion of results:

To illustrate the theoretical procedure, Fig (6) is constructed which shows the difference in the load- deflection curves between different shapes of model concrete slabs (square, hexagonal and circular) all of which are fixed, uniformly loaded, isotropically reinforced at the bottom face and the same reinforcement percentage is used as negative (top) steel around the edges. They have the following identical properties,

Area of slab =1m^2, h=30mm, d=26 mm, ρ= 0.25% fc'=20 MPa, fy=414 MPa and Es = 200 000 MPa

A complete load-deflection diagram for each shape can be obtained as follows:

1- The values of the coordinates of the points A, B, C, D and E are calculated using the appropriate equation as indicated previously. The results are as shown below.

Point	slab shape					
	square		circle		hexagon	
	Def.	load	Def.	load	Def.	load
A	0.52	20.9	1.78	18.6	1.2	19.25
B	0.96	28.4	3.3	25.3	2.22	26.2
C	1.03	29.4	3.54	26.2	2.4	27.2
D	1.65	32.6	3.54	26.2	2.7	28.3
H	0	110.2	0	88.66	0	96.0
E	29.12	56.4	31.0	45.3	30.17	48.9
F	41.65	48.1	43.54	38.65	42.7	41.71
G	90	60.6	90	48.7	90	52.6

The referred points are connected by straight lines to obtain a complete load-deflection relationship for each shape similar to that of Fig (3). These are shown in Figs (6).

2- It is seen that the predicted load –deflection relationships are fairly comparable with typical load –deflection relationships of restrained slabs as indicated in Fig (1). They have one common characteristic feature. Unfortunately, there is no experimental data available in hand to show the discrepancies.

3- The proposed method enables the determination of the deflections at the ultimate load [Eq. (36)]. It is seen from the above table that the computed deflection at ultimate load for the square, circular and polygonal slabs was almost equal to the slab thickness. This prediction agrees with that obtained by Hopkins and Park [2] through testing a ¼ scale nine panel (three by three) reinforced concrete slab and beam floor.

4- Comparing the predicted actual ultimate load (peak load) with that of Johansen's yield line theory, there is 73% increase in the ultimate load for this particular case.

5. Conclusions:

A method is presented for prediction of the complete load-deflection behavior of regular q-sided reinforced concrete polygonal slabs that are fully restrained on all sides and subjected to uniform loading.

The main conclusions to be drawn from the present study are:

1- The predicted load-deflection curves are very comparable in shape with the typical experimental load –deflection curves of restrained slabs. Unfortunately, there is no experimental data available in hand to show the discrepancies.
2- The method of analysis is applicable to any restrained regular q-sided polygonal slabs including the limiting cases of square slabs (q=4) and circular slabs (q=∞)
3- The actual ultimate load including the compressive membrane action is much higher than predicted by Johansen's yield line theory and ACI code.
4- The proposed method enables the prediction of the deflection at ultimate (peak) load. According to this method, the predicted deflection at ultimate load is almost equal to the slab thickness. This result confirms with that obtained from tests.

Notation

A_s = Area of tensile reinforcement per unit width of slab
a = Depth of the equivalent rectangular compression block of concrete
d = Effective depth of slab
E_c = Modulus of elasticity of concrete
E_s = Modulus of elasticity of steel
F = Load reduction factor
f_c' = Concrete cylinder strength
f_y = Yield stress of steel reinforcement
h = Overall depth of slab
I_g = Moment of inertia of the slab gross section per unit width
I_{cr} = Moment of inertia of the slab cracked transformed section per unit width
I_e = Effective moment of inertia per unit width for computation of deflection
$I_{e(c)}$ = I_e at slab center
$I_{e(e)}$ = I_e at slab edges
k = Ratio of neutral axis depth to effective pth, defined by Eq. (13).
k_1 = Constant in equation for load for given fixed slab
k_2 = Constant in equation for deflection for given fixed slab
k_3 = Constant in equation for deflection for given partially fixed edge
L_1 = Side length of polygonal slab
L = Side length of an equivalent square slab having the same area as that of the polygonal slab
M = Bending moment per unit width of slab
M_a = Bending moment per unit width of slab at stage deflection is calculated
M_{cr} = Bending moment at first cracking
M_y = Bending moment at yielding at slab center
M_u = Ultimate bending moment without membrane action
N = Axial force at mid-depth per unit width of slab
n = Modular ratio = E_s / E_c
P = Intensity of uniform load
P_a = Intensity of uniform load at stage deflection is calculated
P_{cr} = Intensity of uniform load at first cracking
P_J = Johanse`s yield line theory load
P_{ma} = Actual ultimate load including membrane action
P_{mi} = Initial ultimate load including membrane action
P_u = ultimate load without membrane action
P_y = Intensity of load at yielding at slab center
q = Number of sides of polygon slab
R = Radius of circular slab
y_t = Distance from centroidal axis of gross section
$\propto, \beta$ = Constants in equation for yield criterion
ρ = Ratio of steel area to effective area of a slab section of unit width = A_s/d
ω = Vertical deflection at center of slab
ω_{cr} = Vertical deflection at cracking at center of slab
ω_J = Vertical deflection at Johanse`s load at center of slab
ω_{max} = Vertical deflection at actual ultimate load (P_{ma}) at center of slab
ω_u = Vertical deflection at ultimate load (P_u) at center of slab
ω_y = Vertical deflection at first yielding of steel at center of slab

References

1- Wood, R.H., "Plastic and Elastic Design of Slabs and Plates" Thomas and Hudson, London, England, 1961.

2- Hopkins,D.C, and Park ,R. ″ Test on a Reinforced Concrete Slab and Beam Floor Designed with Allowance for Membrane Action ″ . Cracking, Deflection and Ultimate Load of Concrete Slab Systems. ACI Special Publication 30, American Concrete Institute, Detroit, 1971, PP. 223-250

3- Datta,T.K., and Ramesh ,C.K.,″Some Experimental Studies on a Reinforced Concrete Slab- Beam System″. Magazine of Concrete Research, London, England, Vol.27, 1975, PP.111-120

4- Foster, S., J, Bailey, C, G, Burgess, I. W. and Plank, R. J., "Experimental Behavior of Concrete Floor Slabs at Large Displacement ", Engineering Structures, April, 2004. Pp. 1231 – 1247.

5- Kumar. V. and Harish, V., "Experimental Study on Deformation Behavior of Partially Restrained Steel Fiber Reinforced High Strength SCC Two Way Rectangular Slabs", International Research Journal of Engineering and Technology, Vol.2, Juley (2015), pp. 830 -835.

6- Johansen, K.W., ″ Yield-line Theory ″, Cement and Concrete Association, London,1962, PP.181

7- Park,R, ″ The Ultimate Strength of Rectangular Concrete Slabs under Short- Term Uniform Loading with Edges Restrained Against Lateral Movement″, Proceedings of the Institution of Civil Engineers, London, England, Vol.28,June ,1964,PP.125-150

8- Al-Hassaini, H.M, ″ Ultimate Strength of Clamped R.C. Rectangular Slab, ″ Journal of Engineering and Technology,Vol. 12 , No.4 ,1993,PP.71-103

9- Timoshenko,S.P.and Woinowsky-krieger,s.,″Theory of Plates and Shells″, 2nd Edition,McGraw-Hill, New York,1959

10- Young,W.C. and Budyans,R.Q. ″ Roark's Formulas for Stress and Strains, ″7th Edition,MCGraw- Hill, New York,2002

11- Building Code Requirements for Reinforced Concrete (ACI 318-11), American Concrete Institute, Detroit,2011

12- British Standard Code of Practice C.P.114 (1957), ″ The Structural Use of Concrete″.

العلاقة بين الحمل والاود للبلاطات الخرسانية المسلحة المضلعة الشكل ذات الحافات المثبتة والمقيدة جانبيا

أ . م .د . علي فليح حسن

قسم الهندسة المدنية –كلية الهندسة – جامعة دهوك

المستخلص :

يقدم البحث نموذجا نظريا لايجاد العلاقة المتكاملة بين الحمل المنتظم والاود للبلاطات الخرسانية المضلعة الشكل ذات الحافات المثبتة والمقيدة جانبيا . يشكل البحث ايضا استنباط الحالات الخاصة المتمثلة بالبلاطات الخرسانية المسلحة المربعة والدائرية الشكل . يغطي النموذج المراحل الثلاثة الرئيسية والمتمثلة بمراحل المرونة ، اللامرونة واللدونة وفي مرحلة اللدونة الاخيرة يتم الاخذ بنظر الاعتبار التاثير المهم للفعل الغشائي في البلاطة . وتم تقديم طريقة لاحتساب الحمل الاقصى الحقيقي مع الاود عند هذا الحمل .

الكلمات المفتاحية : البلاطات الدائرية ، البلاطات المضلعة ، جساءة الانثناء ، الفعل الغشائي ، معايير الخضوع ، نظرية خط الخضوع .

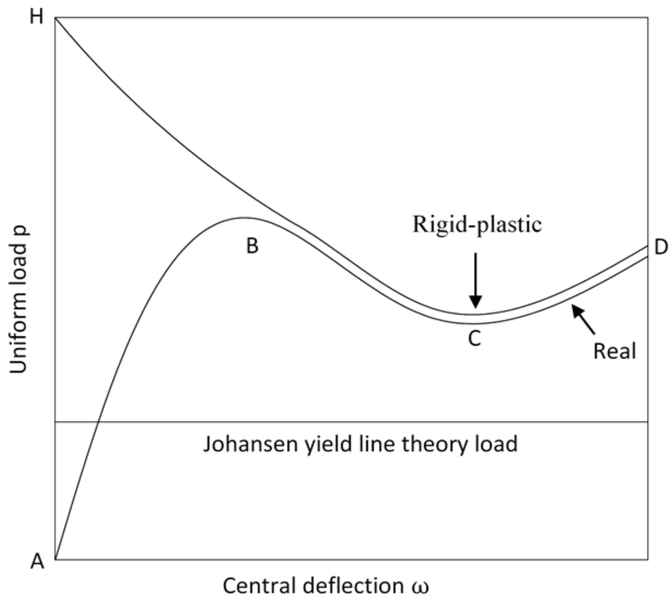


Fig.1: Load – deflection relationship for horizontally restrained R.C. slab.

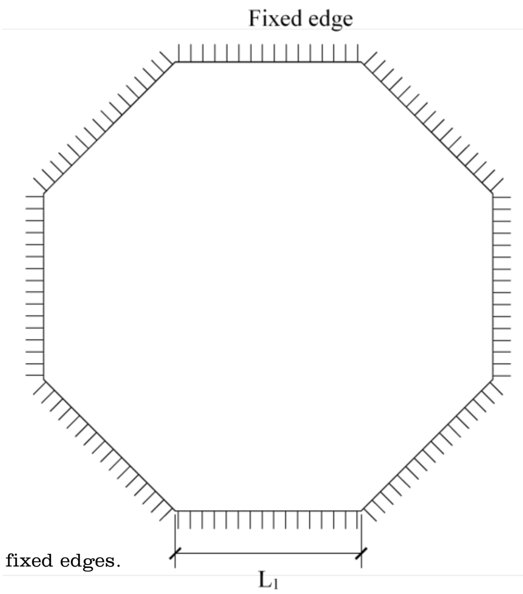


Fig.2: Polygonal slab with fixed edges.

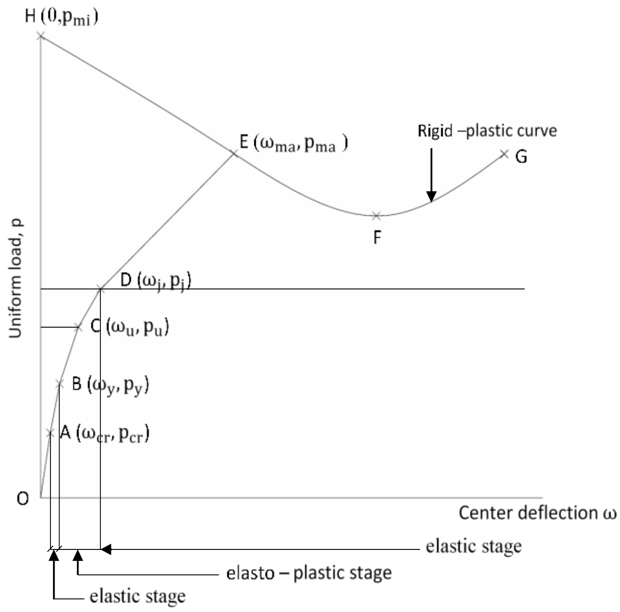


Fig.3: Idealized load –deflection curve for a horizontally restrained polygonal slab.

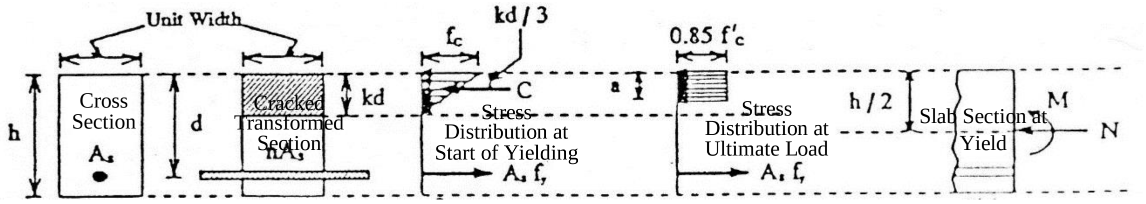
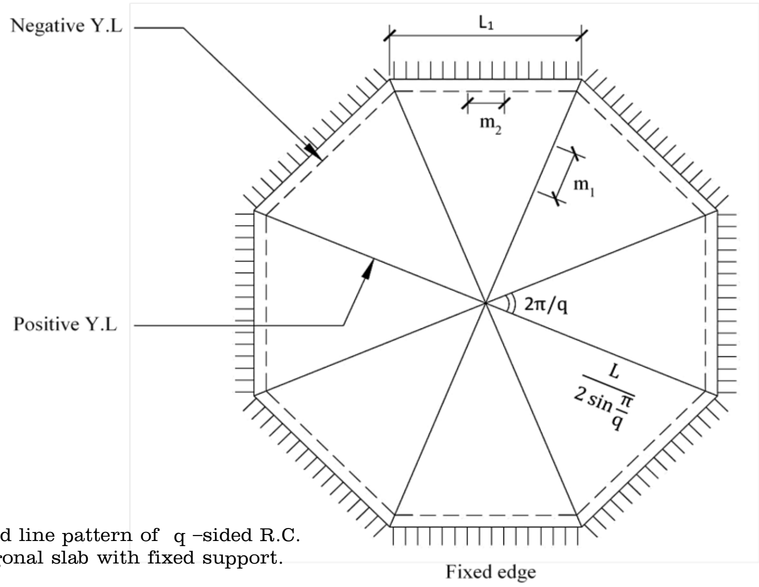
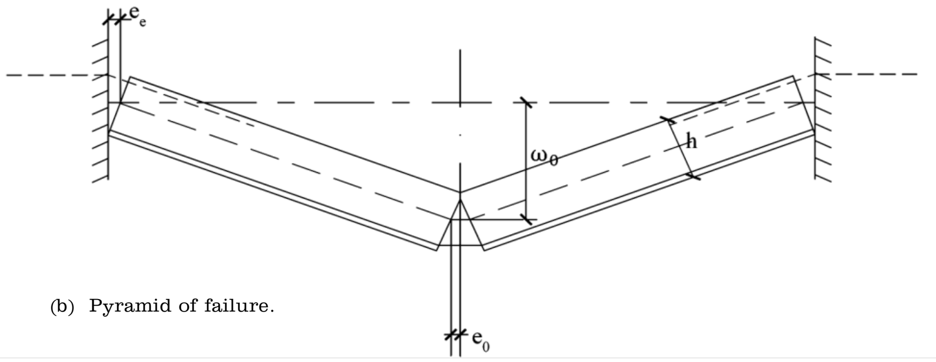


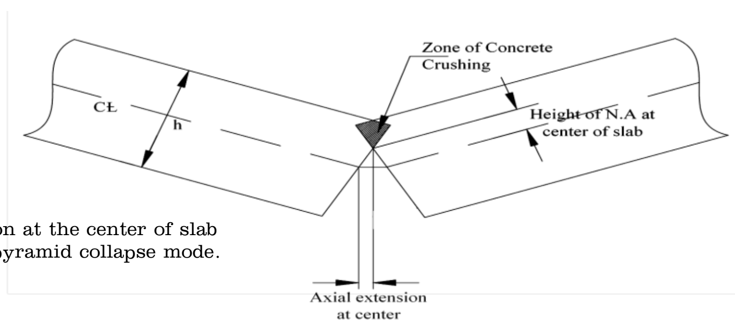
Fig.4: Stress distribution on slab section.



(a) Yield line pattern of q –sided R.C. polygonal slab with fixed support.



(b) Pyramid of failure.



(c) Condition at the center of slab with a pyramid collapse mode.

Fig.5, (a,b,c) : Yield line pattern for q-sided fixed polygonal slab with pyramid collapse mode.

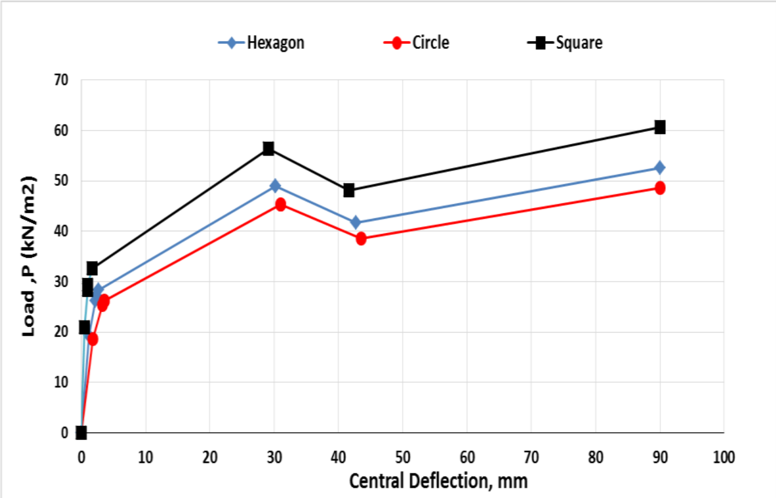


Fig.6: Theoretical prediction for different types of R.C. polygonal slabs.

Table1: Factors k_1 and k_2 for different Shapes of fixed polygonal slabs.

Type of polygonal slab	k_1	k_2
Square slab q=4	0.0231	0.0012
Circular slab q= ∞	0.0259	0.0046
Hexagonal slab q= 6 *	0.025	0.0030

* The values of k_1 and k_2 for hexagonal slabs are suggested, since they are not available in literature.

Table 2: Factors k_1 and k_2 for different Shapes of partially restrained polygonal slabs

Type of polygonal slab	k_1	k_2
Square slab n=4	0.0326	0.0027
Circular slab n= ∞	0.0445	0.0058
Hexagonal slab n= 6	0.0388	0.0045

In this way, the load-deflection plot in the second stage is determined.