Kurdistan Engineers Union

یــەکێتی ئــەنــدازیــارانی کــوردســتان

Term Engineering Paper:

Effect of compressive strength and tensile reinforcement ratio on flexural behavior of high-strength concrete beams

Prepared By

Aras Ahmad Esmael

Sulaymaniyah / Qaladiza

February 2024

Submitted to the

Kurdistan Engineers Union

Abstract

Compressive strength is a load placed to the top and bottom of the sample to be tested until it cracks or becomes altered. It is an essential characteristic for all structural elements, including beams, slabs, columns, and shear walls. Also, in the study, reinforcements in the area of tension zone are crucial for resisting internal tensile stress caused by loads being placed on them. The main objective of this research project recognizing how the compressive strength and tension reinforcement ratio of concrete govern the displacement, ductility, and deflection of concrete-reinforced beams.in the test six beams used, the beams are divided into two groups, group one (B1, B2, B3) & group two (B4, B5, B6). Beams in the same group have the same compressive strength, elasticity modulus; rebar yielding strength, and other parameters. The study's conclusions of comparing the two findings revealed that for initial cracking occurrence in the second study needed more load and thus, causes more moment of cracking and displacement with regard to the first. However, for yielding moment and deflection at yield load, the overall trend is the reverse, with the findings in study one being bigger than, those in study two, with the exception of B5, where the deflection in the second study is greater. The findings vary depending on the ductility index and cracking stiffness. The cracking stiffness in the second research is larger than in the first study, although not for all beams. The same is true for the ductility index, with the exception of beam 4, where the result of ductility index for the first is larger.

Keywords: Cracking moment; High-Strength Concrete; Flexural Resistance; Flexural strength; Comparisons of the critical load.

Term Usage

Table: terms that used in this report

Term	Detail	Reference
I	Moment of inertia of concrete	[2]
Ig	Moment of inertia of gross concrete section.	[2]
Icr	Moment of inertia of cracked transformed section	[2]
ρ	Tension reinforcement ratio = As/bd	[2]
Fr	modulus of rupture of concrete	[7]
Yt	distance of the extreme tension fiber from the neutral axis	[7]
Fc'	Compressive strength of concrete	[2]
Ec	Concrete modulus of elasticity	[7]
δ	deflection	[7]
δs	Service deflection	[7]
δy	Yield deflection	[7]
L	Length of the beam	[7]
Kcr	crack stiffness	[7]
μ	ductility index	[7]
M	Moment	[7]
My	Yield moment	[7]
Mcr	cracking moment	[7]
P	Applied load	[7]

Table of Contents

1. Introduction

Reinforced Concrete (RC) is being used In-depth in the construction industry around the world. The acceptance of High Strength Concrete (HSC) has grown as a result of its clear advantages: heightened elasticity modulus, chemical resistance, resistance to freeze-thaw cycles, decreased creep, decreased drying shrinkage, and decreased permeability, to mention a few. With a low water-to-cementitious material ratio and a high compressive strength of between 50 and 100 MPa, HSC is typically proportioned [1].

High strength concrete (HSC) Reduced sizes and weights of concrete structural parts, especially for long-span beams. because of the decrease in cross sectional components, which affects the members' moment of inertia, I, it is necessary to look at the corresponding deflection under service load [2].

The degree of cracking in a reinforced concrete beam affects its moment of inertia. The concrete section's gross moment of inertia, or Ig, can be used to calculate deflection for loads below the cracking load without taken the reinforcement into account. Still, the member splits at various intervals through the span when the load rises over the cracking load. The variation in curvature throughout the member length caused by the neutral axis fluctuating between fractures lowers the section's flexural stiffness. The value of I changes along the beam span from the highest possible Ig value for the uncracked (gross) portion to a minimum of Icr for the part that has been entirely cracked (transformed).

Our goal in this study is to look at how the tension reinforcement ratio and compressive strength of concrete affect the displacement ductility and deflection of reinforced concrete beams. Changes to a previously published formula for the effective moment of inertia are provided, taking these factors into account [2].

2. Literature review

A solid knowledge of HSC properties, bonding, and anchoring is necessary to assess how a structure will respond and function under both cycle and linear stresses. When shear is included, a beam's flexural strength can be significantly lower than in a pure flexure scenario, and failure could come quickly and brittlely [3]. Due to the phenomenon's complexity, a lot of research has been done to determine the resisting mechanisms of just longitudinally reinforced beams—a process known as the "concrete mechanism [4].

A group of researchers just released an effective equation for calculating the shear strength of just longitudinally reinforced HSC beams [1]. Here is a formula for the shear strength of HSC beams that have stirrups. The design processes that are suggested for regulatory requirements need to be simple, safe, and correct in principle. They also must not to inevitably increase the cost of building or design [1]. The Flexural strength While yet are many researches analyzing the size effects on compressive strength, there is relatively little information available in the literature on studies investigating the size effect on the flexural tensile strength of concrete.

The fluctuation of the employed testing techniques exacerbates the situation.

Sample dimensions are flexible, three- or four-point bending arrangements are employed, and specimens with and without notches are utilized [5].

3. Theoretical analysis

3.1. properties of element and required equation

The HSC beam design used in this work is based on [6]. There are no stirrups in the center of the HSC beam, and they are spaced 150 mm apart throughout the beam span. The beam rests on a support that is 150 mm from the beam edge to the left and right ends' center of support. Based on the ratio of reinforcement to compressive strength, the selected model is marked in Table 2. Six beams are impact loaded in this test [7].

Table 2: Models details [7].

beams	Compressive strength (MPa)	modulus of elasticity (MPa)	Number of rebar’s	% Rebar’s ratio ρ	Yielding strength of rebar’s (MPa)
B1	96.9	37511	2	0.98	607.9
B2	96.9	37511	3	1.47	607.9
B3	96.9	37511	4	1.97	607.9
B4	118.3	38623	2	0.98	595.8
B5	118.3	38623	3	1.47	595.8
B6	118.3	38623	4	1.97	595.8

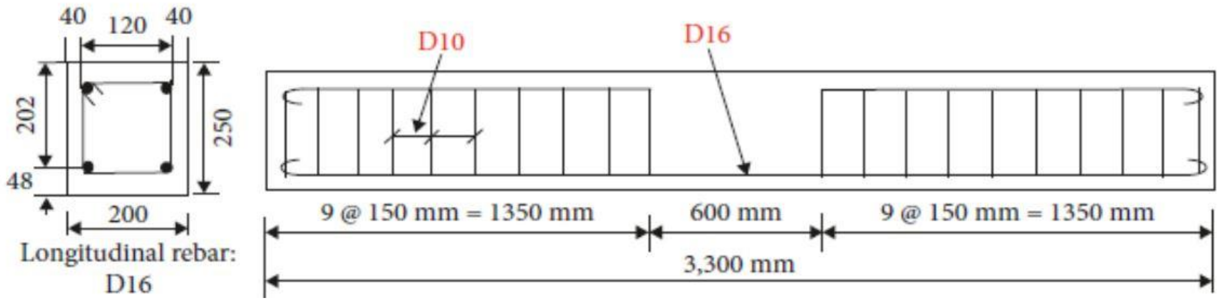

Fig 1: HSC beam details and dimensions [6].

The cracking moment calculated by applied equation [7].

$$Mcr = \frac{Fr * Ig}{Yt} \dots\dots\dots\dots\dots\dots\dots.\dots\dots.\dots (equ.\ 1)$$

The modulus of rupture in the instance of the HSC offered by [8].is used to determine the Fras values as follows:

$$Fr = 0.42(fc')^{0.68} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (equ. 2)$$

The maximum service deflection by applied equation at the mid-span [7].

$$\delta\, s\ = \frac{M}{24\, Ec\, I}(3L^2 - 4a^2) \dots\dots\dots\dots\dots... (equ. 3)$$

The stiffness of concrete beam reduces immediately as the first fracture appears because the damaged section's concrete's impact to the beam's stiffness is lessened. The crack stiffness of the determined beam models is as follows [9].

$$Kcr \ = \frac{Py - Pcr}{\delta y - \delta cr}(3L^2 - 4a^2) \ldots \ldots ... (equ. 4)$$

The calculation of the beam models' ductility index was recommended by [10].as follow:

$$\mu \ = \frac{\delta p}{\delta y} \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots ..... (equ. 5)$$

3.2. Analysis result

The static analysis HSC models described in Tables 3, 4, and 5 include their findings. The applied load with deflection variations for models B1 through B6 are shown in Figures 2 and 3, which also give the analysis findings as deflection, longitudinal strain at concrete, and crack propagations at yielding load stage. For models B1 through B6, Figures 4 to 9 show the deflection, strain at the concrete, and fracture propagations at the yielding stage. The comparison list found in Tables 3, 4, and 5 demonstrates how the variance is minimal, the mean value is rounded to unity, and the standard deviation is so tiny that all findings are rounded to the mean value. These factors combine to make the points from the numerical and experimental testing so close.

The performance of the HSC beam under static loading is shown in Figures 2 to 3, together with the connected deflections. The models exhibit linear behavior at initial crack loading and then nonlinear behavior beyond the inflection point. An increase in load causes an increase in deflection, which reduces the beam's stiffness and causes the curve to shift toward the horsetail axis.

When compressive strength and the rebar ratio rise, the load capacity increases in the model comparisons. The deflections, concrete stresses, and fracture propagations in three dimensions of an HSC beam during the yielding stage are depicted in Figures 2 through 7 [7].

Table 3: Comparisons of the critical load, crack moment, and deflection at the first fracture load obtained from computational and experimental analysis [7]

beams	Initial cracking state [6].			Initial cracking state [7].			Ratio [7]/ Experimental [6].		
	Pcr (KN)	Mcr (KN.M)	δcr (mm)	Pcr (KN)	Mcr (KN.M)	δcr (mm)	Pcr	Mcr	δcr
B1	16.1	9.6	0.9	17.94	10.28	0.97	1.11	1.07	1.08
B2	16.4	9.8	1	18.1	10.68	1.02	1.10	1.09	1.02
B3	12.7	7.6	0.9	12.96	7.65	0.95	1.02	1.01	1.06
B4	23.3	14	1.2	24.12	14.23	1.31	1.04	1.02	1.09
B5	17.4	10.4	0.9	17.85	10.53	0.94	1.03	1.01	1.04
B6	17.4	10.4	1	20.92	12.34	1.15	1.2	1.19	1.5
Means							1.08	1.06	1.13

Table 4: Results of numerical and experimental analysis are compared in terms of yielding load, yielding moment, and deflection at yield load [7].

beams	Yielding state [6].			Yielding state [7].			Ratio [7]/ Experimental [6].		
	Py (KN)	My (KN.M)	δy (mm)	Py (KN)	My (KN.M)	δy (mm)	Py	My	δy
B1	78	46.8	27.3	78	10.28	22.11	1.00	1.00	0.81
B2	129	30.5	30.5	129	10.68	24.56	1.00	1.00	0.81
B3	162	32.6	32.6	162	7.65	25.11	1.00	1.00	0.77
B4	86.4	51.8	22.2	86.4	14.23	23.95	1.00	1.00	1.07
B5	120.4	72.2	26	120.4	10.53	22.95	1.00	1.00	0.88
B6	157.2	94.3	28.5	157.2	12.34	24.14	1.00	1.00	0.85
Means							1.00	1.00	0.87

Table 5: Comparisons of the findings of computational and experimental research, such as the ductility index and crack stiffness load [7].

beams	Experimental [6].		[7]		Ratio [7]/ Experimental [6].	
	Crack stiffness Kcr (KN/mm)	μ Ductility index	Crack stiffness Kcr (KN/mm)	μ Ductility index	Crack stiffness Kcr	μ Ductility index
B1	2.35	3.38	2.84	4.17	1.21	1.23
B2	3.82	1.47	4.71	1.83	1.23	1.25
B3	4.71	1.47	6.17	1.90	1.31	1.29
B4	3.00	4.34	2.75	4.01	0.92	0.92
B5	4.11	2.35	4.66	2.65	1.13	1.13
B6	5.09	2.26	5.93	2.67	1.16	1.18
Means					1.16	1.16

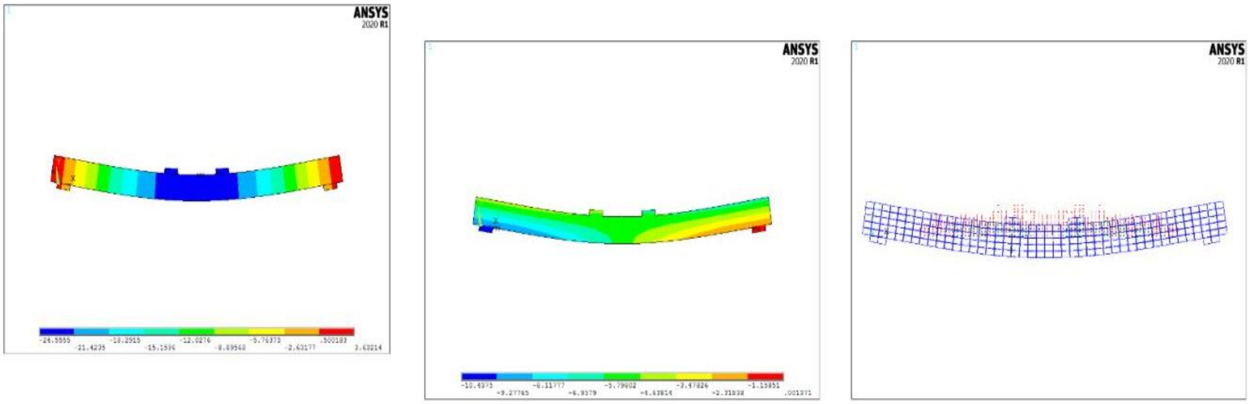

Fig 2: Deformation, Displacement along the beam, and the development of cracks-B1[7].

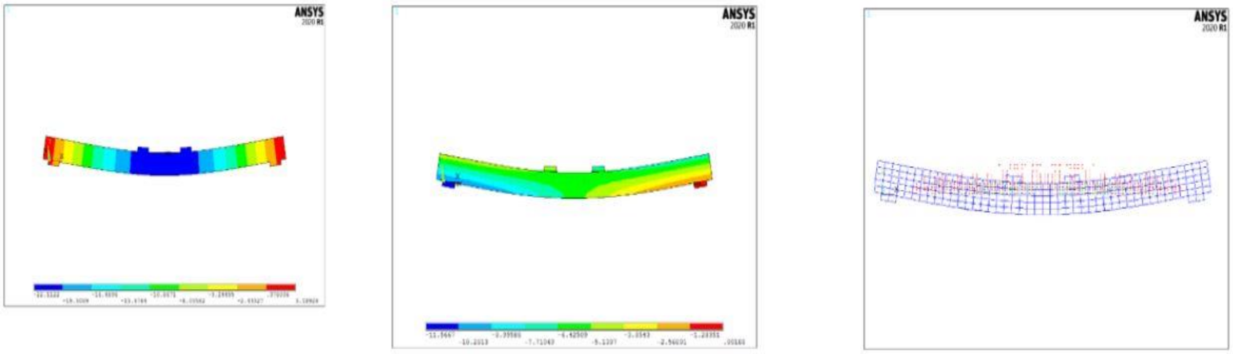

Fig 3: Deformation, Displacement along the beam, and the development of cracks-B2 [7].

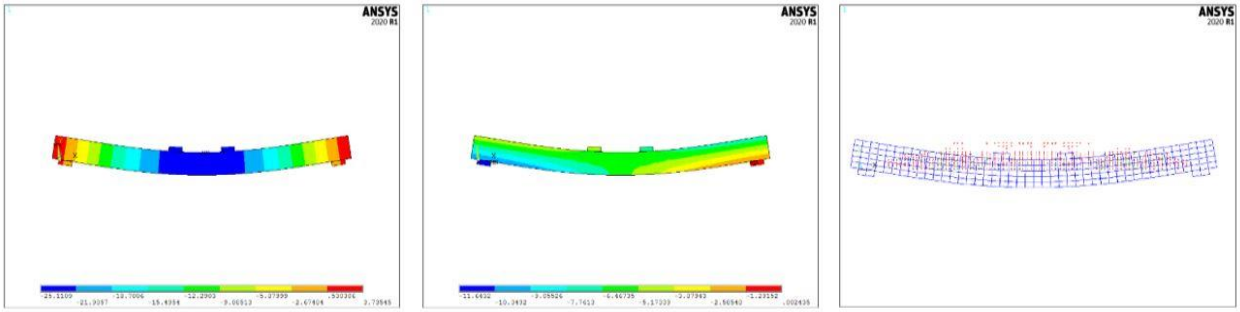

Fig 4: Deformation, Displacement along the beam, and the development of cracks-B3 [7].

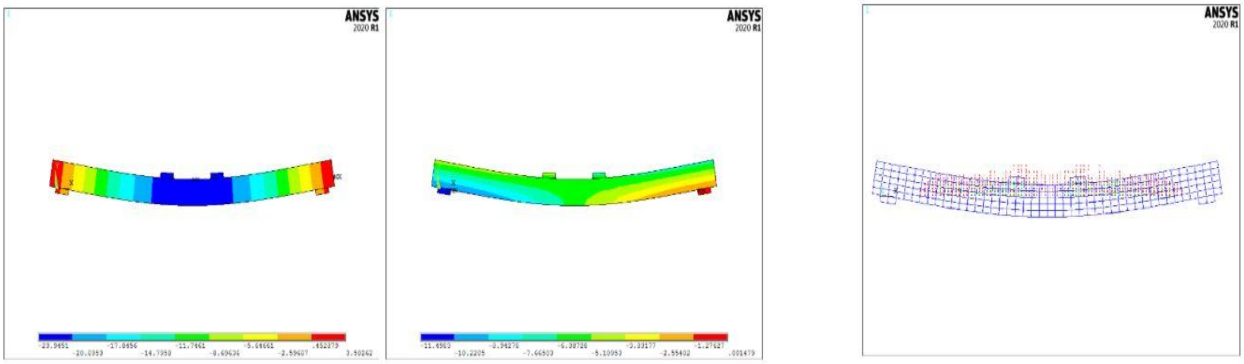

Fig 5: Deformation, Displacement along the beam, and the development of cracks-B4 [7].

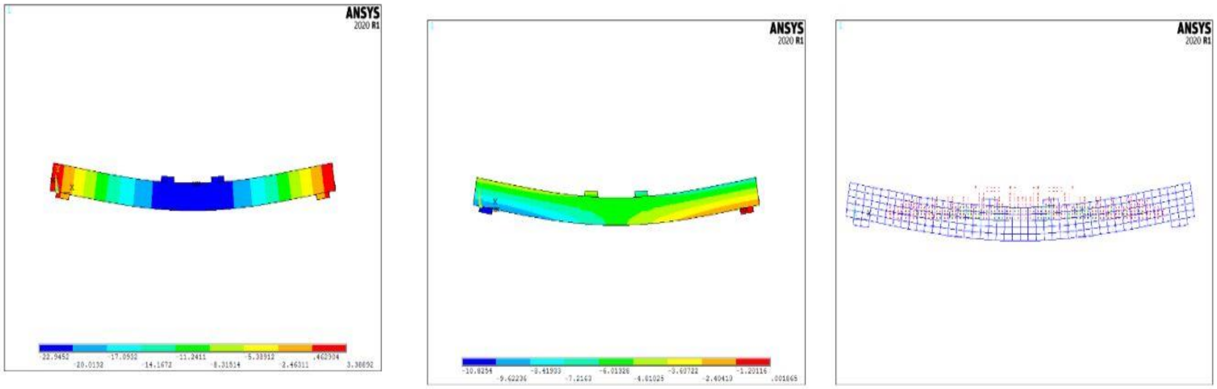

Fig 6: Deformation, Displacement along the beam, and the development of cracks-B5 [7].

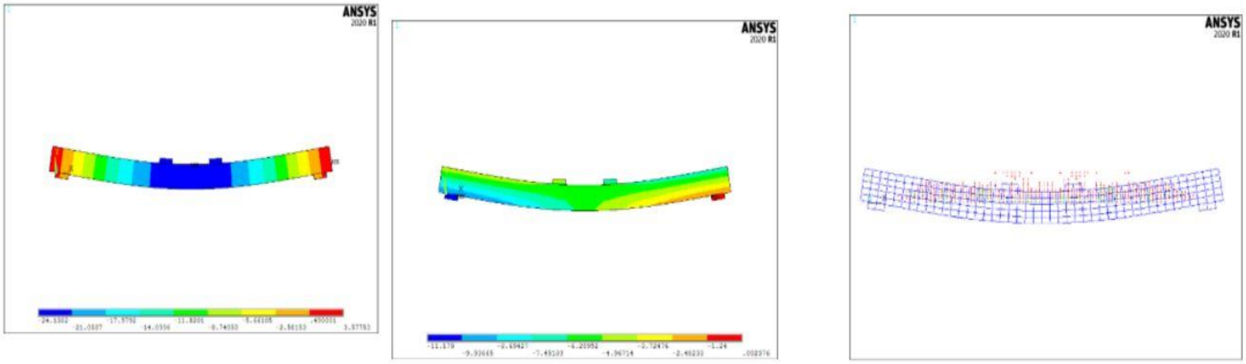

Fig 7: Deformation, Displacement along the beam, and the development of cracks-B6 [7].

4. Discussions

Regarding the outcomes of both investigations, it is vital to clarify which of them received the greatest and lowest results in each test, as well as why we will discuss it below.

For the cracking moment, the results demonstrate that the largest cracking moment is in beam number 4, with a value of 14.23 KN.M in the second study. While for the identical beam in the first investigation, the outcome is relatively close at 14 KN.M .regarding minimum cracking moment, the first study's beam number 3 had the lowest cracking moment of 7.6 KN.M.

Concerning deflection at the first fracture load, in the second investigation, beam number 4 had the greatest deflection at the initial fracture force, measuring 1.31 mm. whereas the minimal value of deflection is 0.9 mm for the three beams 1, 3, and 5, respectively in the first study. for Whatever has relation with both ductility index and crack stiffness, the results achieved from the tests show that the maximum value of ductility index is of beam number 4 in the first study which is 4.34.but, the minimum value of the ductility index is 1.47 for beams 2,3 the same in the first study.

The maximum value of cracking stiffness is of beam number 3 in the first study as specified to 6.17 KN/mm. while, the minimum value of cracking stiffness can be found in beam number one in the first study, which is 2.35 KN/mm.

5. conclusion

The following facts have been proven by this debate**:**

5.1. Effect of compressive strength

Table 6 summarizes the impact of compressive strength on the strength capacity and bending at the yielding stage. Each control model load's deflection value is computed by projecting it onto the load-deflection of the other model. As the compressive strength increased, the deflection decreased because of the model's growing resistance in the tension zone and the rise in the modulus of rupture.

Arise in compressive strength causes the modulus of elasticity to rise as well, which lowers the deflection. Because Steel fiber connects the concrete particles by acting as a bridge; therefore, it raises the concrete's strength so that it can support imposed loads. Thus, it improves the ductility of the concrete, optimizes its strength capacity, and serves as a suitable support for resisting tensile strength in the tension zone. This lowers cracks and the severity of crack development in the presence of increasing compressive strength.

Table 6: Compressive strength's impact on beams strength and deflection [7].

beams	Yield state		% (+) increase and (-) decrease	
	Py (KN)	δy (mm)	(+) Py	$(-)\delta y$
B1	78.00	22.11	……	…..
B4	86.40	23.95	10.77	4.89

5.2. Influence of the ratio of rebar

The control model loads displayed in Table 7 below demonstrate how the rebar ratio affects strength capacity and deflection at the yielding stage. Ultimately, it is apparent that as the rebar ratio grew, the concrete became more ductile and resistant to the applied load. While for the deflection the effect is the opposite, as the rebar ratio increased led to decrease in deflection. However, the rebar ratio increases strength capacity too. The increase in the rebar ratio has a clear influence on the initial cracking load fracture since it also increased the initial cracking load and made the fracture more ductile, which in turn made the model more ductile.

Table 7: Impact of the rebar ratio on the models' deflection and strength [7].

beams	Yield state		% (+) increase and (-) decrease	
	Py (KN)	δy (mm)	(+) Py	$(-)\delta y$
B1	78	22.11	……	…..
B2	129	14.29	65.38	3537
B3	162	11.5	107.69	47.99
B4	86.40	23.95	……	……….
B5	120.4	15.71	39.35	34.41
B6	157.2	12.65	81.94	47.18

6. Reference

[1]- Campione, G., Cucchiara, C. and Monaco, A., 2014. Flexural and shear resistance of High-strength concrete beams. *J Civil Eng Sci*, *3*(2), pp.129-141.

[2]- Ashour, S.A., 2000. Effect of compressive strength and tensile reinforcement ratio on flexural behavior of high-strength concrete beams. *Engineering structures*, *22*(5), pp.413-423.

[3]- Ahmad, S.H. and Lue, D.M., 1987. Flexure-shear interaction of reinforced high strength concrete beams. *Structural Journal*, *84*(4), pp.330-341.

[4]- Khuntia, M. and Stojadinovic, B., 2001. Shear strength of reinforced concrete beams without transverse reinforcement. *Structural Journal*, *98*(5), pp.648-656.

[5]- Fládr, J. and Bílý, P., 2018. Specimen size effect on compressive and flexural strength of high-strength fibre-reinforced concrete containing coarse aggregate. *Composites Part B: Engineering*, *138*, pp.77-86.

[6]- Al-Kamal, M.K., 2019. Nominal flexural strength of high-strength concrete beams. *Advances in concrete construction*, *7*(1), p.001

[7]- Ali S.A., Mohammad M.A., Yasir W.A., Abdullah M.M., 2021. Effect of Compressive Strength and Tensile Reinforcement Ratio On Flexural Behavior Of High-Strength Concrete Beams-Static And Dynamic Analysis. J. of Xi'an Shiyou University, Natural Sciences Edition. ISSN:1673-064X.

[8]- Rashid, M.A., Mansur, M.A. and Paramasivam, P., 2002. Correlations between mechanical properties of high-strength concrete. *Journal of materials in civil engineering*, *14*(3), pp.230-238.)

[9]- Branson, D.E., 1963. *Instantaneous and time-dependent deflections of simple and continuous reinforced concrete beams* (No. HPR Report No. 7). Alabama. State Highway Department.

[10]- Gergely, P. and Lutz, L.A., 1968. Maximum crack width in reinforced concrete flexural members. *Special Publication*, *20*, pp.87-117.