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SHEAR STRENGTH OF CONCRETE BEAM USING ALTERNATIVE STEEL REINFORCEMENT

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Master's Thesis

Supervisor

Prof. Dr. Tuncer ÇELİK

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The thesis titled SHEAR STRENGTH OF CONCRETE BEAM USING ALTERNATIVE STEEL REINFORCEMENT prepared by BASMA MAHMOUD SOBHI and submitted on 07/12/2022 has been **accepted unanimously** for the degree of Master of Science in Civil Engineering.

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Basma Mahmoud SOBHI

Signature

DEDICATION

To the one who honored me by bearing his name, my father, may God Almighty have mercy on him...

To the light of my eyes, the light of my path, and the joy of my life, my mother, then my mother, then my mother. whose prayers and words were the companion of brilliance and excellence...

To my brothers, I offer you to dedicate this gift with love, honor and dignity.

To everyone who literally taught me.

To everyone who supported me, even with a smile.

ABSTRACT

SHEAR STRENGTH OF CONCRETE BEAM USING ALTERNATIVE STEEL REINFORCEMENT

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The design shear strength must be sufficient to prevent a shear failure which is characterized by small defects that are difficult to observe as well as a lack of ductility where it suddenly occurs without warning other than flexure failure. Many researchers investigated the structural behavior of concrete beams under the shear effect experimentally, and they focus on the improvement of concrete properties by enhancing the concrete compressive strength of added steel fibers, some of these work's study using new types of reinforcement instead of ordinary steel stirrup. Experiments on concrete beams subjected to a concentrated point load at mid-span for different parameters of concrete compressive strength (30, and 50 MPa), shear reinforcement types (steel tube, and steel stirrup), and arrangement of shear reinforcement (angle of reinforcement 45º, and 90º). Ten specimens were tested to study the behavior of concrete beams under the shear effect. The dimensions of the beam are 160*300* 1150 mm for width, height, and length respectively. The clear span of the test specimen is 1000 mm. the longitudinal reinforcements are 3 Φ 16 mm in the bottom layer and 2 Φ 8 mm in the top layer. Also, the material properties (concrete and steel) are measured in this work. The steel tubes used instead of the steel reinforcement bar were filled with concrete materials, except for two specimens in which hollow tubes were used.

The results of experimental work show that the tested specimens produced cracks resulting from bending and shearing stress, but the shear cracks appear before flexure cracks. The minimum cracking load that appears in the specimen has 29.35 MPa as concrete compressive strength,

while the maximum cracking load that appears in the specimen has 48.77 MPa as concrete compressive strength. The tested specimens have failed under the influence of shear stresses, and the type of failure can be classified as a brittle failure (shear failure modes). As a result of the increase in the compressive strength of concrete, the ultimate load is higher for the tested specimens. specimens containing 45° shearing steel reinforcement had higher resistance than specimens containing 90° shearing steel reinforcement. Finally, the alternative shear reinforcement (steel tube) used instead of ordinary steel stirrup is considered acceptable to resist shear stresses.

Keywords: Concrete Beam, Shear Failure, Steel Tube, Shear Crack, Load Deflection

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ABBREVIATIONS

RC	:	Reinforced concrete
ASCE	:	American Society of Civil Engineers
ACI	:	American Concrete Institutes
OPC	:	Ordinary Portland Cement
C3A	:	Tri-Calcium Aluminates
SO3	:	Sulfate Content
Mgo	:	Magnesium Oxide
IQS	:	Iraqi Standard Specification
ASTM	:	American Society for Testing and Materials
BSI	:	British Standards Institute
SCC	:	Self-Compacting Concrete
GFRP	:	Glass Fiber Reinforced plastic
W/C	:	Water/Cement
WIB	:	Welded Inclined Bars
HPC	:	High-Performance Concrete

SYMBOLS

M1 : Normal Concert mix number (1) give compressive strength of (30)Mpa

M2 : Normal concert mix number (2) give compressive strength of (50)Mpa

$\sqrt{fc}$: The square root term of compressive strength

V : Shear resistance

Dm : Change in the moment

Dx : Change in the distance

Vcu : Ultimate shear resistance

Vcz : Shear resistance by compression zone

Vag : Shear resistance by aggregate interlocking

Vd : Shear resistance by dowel action of the longitudinal tension steel

a/d : Shear span to effective depth ratio

Vu : Factored applied shear at section considered

Ø : Factor of strength reduction

Vc : Shear resistance by concrete section

Vs : Shear resistance by steel reinforcement

Av : Area of steel shear reinforcement

Fy : Yield stress of steel reinforcement

F'c : The shear concrete strength

Fcu : Compressive strength

Fu : Ultimate stress

D : Effective depth of the concrete section

B : Width of the concrete beam

S : Spacing of stirrup

A : Inclination angle of stirrup

ג : Lightweight reduction factor

Mu : factored moment at section considered

P : Is the ratio of longitudinal steel reinforcement

S : Steel tube

B : Steel bar

H : Empty steel tubes

F : Coefficient to calculate the effect of the shearing steel when it is inclined at a certain angle

ID^1 : Specimens have shear reinforcement of 90 arrangement

ID^2 : Specimens have shear reinforcement of 45 arrangement

Pu : Ultimate load

As : Area of shear steel reinforcement

L/4 : The distance from both sides of the supports

L/3 : The distance in the middle area as transverse reinforcement

1. INTRODUCTION

1.1 GENERAL

In reinforced concrete beams, it is well known and accepted that flexural and shear forces will arise and grow along the length of the beam, for the safe loading, the first thing to be considered in the design is these two forces. Flexure moment is used to determine the cross-section dimensions for the beam and the longitudinal reinforcement needed for them. The design shear strength must be sufficient to prevent a shear failure which is characterized by small defects that are difficult to observe as well as a lack of ductility where it suddenly occurs without warning other than flexure failure, which happens gradually, giving warnings before the failure occurs, so the designer must ensure no occurrence of shear failure (unwanted failure) before a flexure failure occurs[1][2] [3][4]. Figure (1-1) shows the shear stresses in the concrete beam [5].

1.2 SHEAR STRENGTH OF CONCRETE

While bending is most often the critical failure mechanism for Reinforced Concrete (RC) sections shear should always be considered. Shear forces are present wherever the bending moment in a member varies along its length, since

$$V = \frac{dM}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1\text{-}1)$$

Let's consider the behavior of an RC beam without shear reinforcement. The key to understanding the behavior of such a beam lies in remembering

a. concrete is very weak in tension

b. within the beam there are principal planes along which the tensile and compressive forces are a maximum

If cracks are to occur in a concrete section they are most likely to develop along the most heavily stressed tensile isoclines. Thus the development of a tensile crack follows the following sequence.

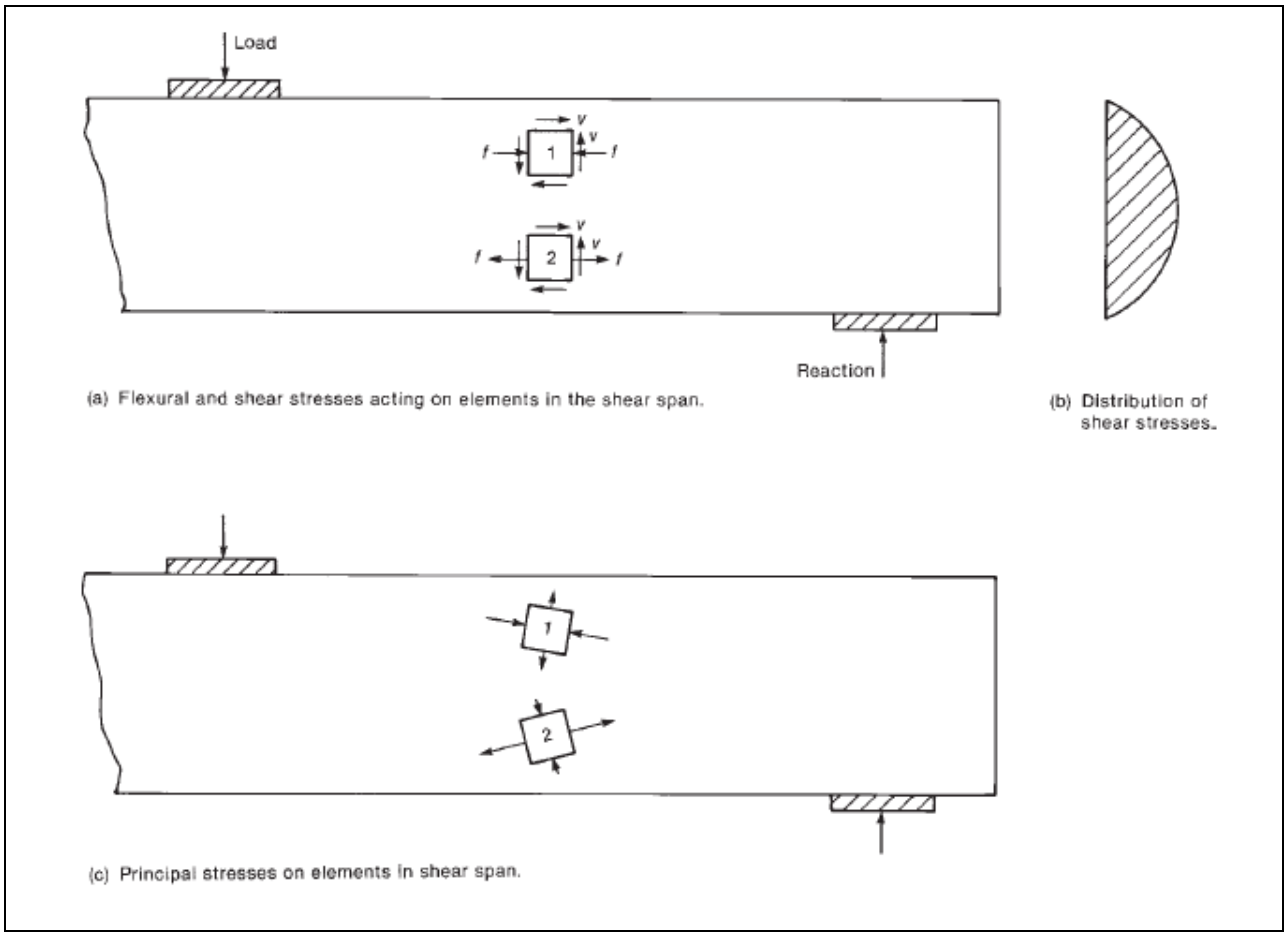


Figure 1.1: Normal, Shear, and Principal Stresses in an Uncracked Concrete Beam.

The crack starts off as a tensile crack which develops at right angles to the tensile face of the beam. As the load increases the tensile crack follows the path of the tensile isoclines and curves. This crack may develop in a number of ways each of which leads to a shear failure. Diagonal tension failure: The diagonal crack extends over the entire depth of the beam, causing the beam to split into two parts. The final failure for this type of crack may be dowel failure. Shear tension or shear bond failure: if the applied load is close to the support then the diagonal crack may stabilize at some point but a secondary crack may develop along the tension steel, causing some loss of bond. As the steel begins to slip, it induces tensile stresses in the concrete adjoining the bars, causing the concrete cover to split. This process continues until failure occurs due to loss of anchorage. Shear compression failure: if the diagonal crack does extend deeply into the compression zone then the concrete above the crack may fail due to crushing[6][7][8] [9].

Consider the beam which has a flexural/shear crack running from the extreme tension fiber to the neutral axis. Shear transferred across this plane by a combination of the following three actions

a. Direct shear transfer by uncracked concrete in the compression zone.

b. Mechanical interlocking of the aggregate along the diagonal crack. This is called aggregate interlock or interface shear transfer.

c. Dowel action of the longitudinal tension steel.

Shear is resisted by a combination of these three actions,

$$Vcu=Vcz+Vag+Vd \quad . \quad . \quad . \quad . \quad . \quad (1\text{-}2)$$

The overall shear resistance of a section without shear reinforcement is a function of many parameters including the concrete properties and the section size properties in addition to the quantity of the flexural reinforcement. Extensive amount of experimental studies in this field had pointed out the main factors that affect the shear strength of beams with web reinforcement are; concrete strength, width and depth of the beam cross section, span to depth ratio a/d and the longitudinal reinforcement ratio.

The ASCE-ACI Committee 426 [10] has classified failure modes of simply supported rectangular beams without web reinforcement based on a/d as follows:

a. Failure mode I ($a/d > 6$):

This is the case of very slender beams where reinforced concrete tends to fail in flexure even before the formation of inclined cracks.

b. Failure mode II ($2.5 < a/d < 6$):

In this case, some of the flexural cracks grow and may become flexural-shear cracks. The diagonal cracks may continue to the top and bottom faces of the beam and cause the yield of the tension steel. The beam may split into two pieces at failure. The crack is called the diagonal tension crack.

c. Failure mode III (a/d < 2.5):

Which is the case in short beams where a diagonal crack may propagate along the tension steel causing splitting between the concrete and the flexural longitudinal reinforcement bars which are called shear-tension failure. The case where the diagonal crack results in the crushing of the compression zone are called the shear-compression failure.

The fourth case is a special case for very short beams where (a/d < 1). In this case, different types of failure can be observed such as anchorage failure of tension steel, bearing failure, flexural failure, tension failure of arch-rib, and compression strut failure.

Figure (1-2) below shows the main three possible types of cracks that may be formed in a simply supported beam subjected to uniformly distributed load[11] [12][13][14][15].

Figure (1-3) shows the shear and moment at inclined cracking and failure of beams without reinforcement as function of shear span to effective depth "d" ratio.[11]

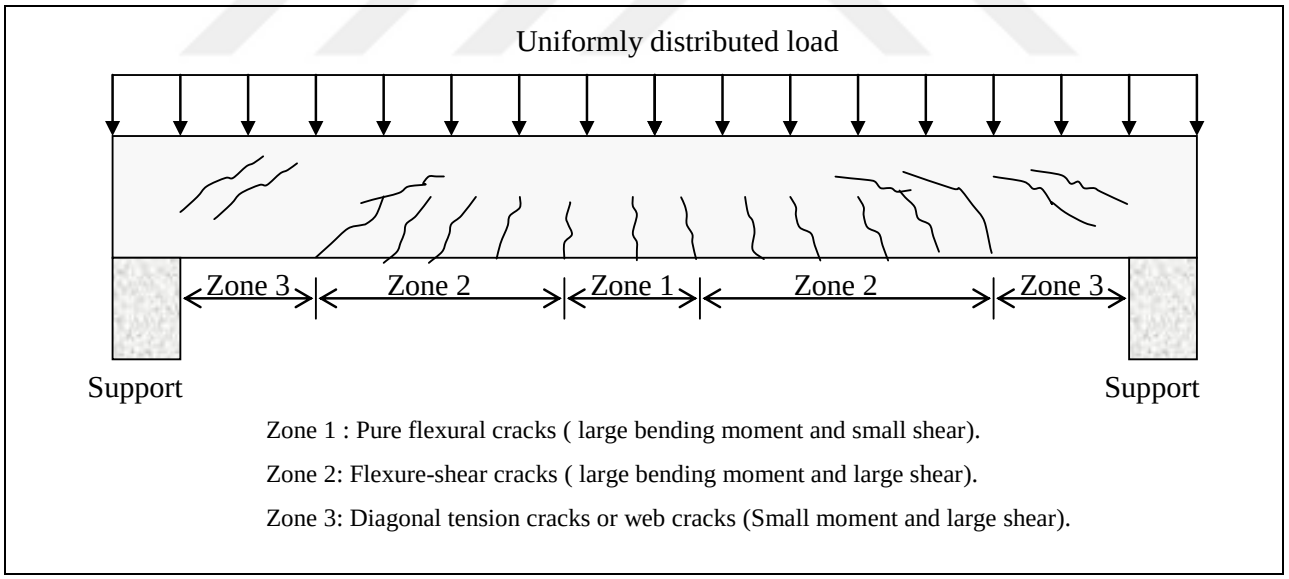


Figure 1.2: Possible Crack Types in a simply supported concrete beam.

1.3 SHEAR DESIGN BASED ON ACI CODE

Based on the ACI 318-14 Code [7] the applied shear force must be less than the internal resistance of the concrete beam, the internal shear strength can be defined by the following equations..

$$Vu \leq \emptyset(Vc + Vs) \quad \text{... . . . (1-3)}$$

Where Vu is the factored applied shear, Vc & Vs are the shear resistance by concrete section and steel reinforcement, and $\emptyset$ is the factor of strength reduction.

There are many types of steel stirrups that are used to reinforce concrete beams against shear stresses, Figure (1-4) [7] shows some kinds of shear reinforcement steel stirrups. If the stirrup with 90º, the shear resistance by steel reinforcement can be calculated according to the following equation

$$Vs = \frac{Av.fy.d}{S} \quad \text{. . . . . (1-4)}$$

Where Av is the area of steel shear reinforcement, fy is the yield stress of steel reinforcement, d is the effective depth of the concrete section, and S is the spacing of stirrups, while if the stirrup is included with any angle "α" as shown in Figure (1-5) [7], the Vs is calculated by Eq. (1-5).

$$Vs = \frac{Av.fy.d.(\sin\alpha + \cos\alpha)}{S} \quad \text{. . . . (1-5)}$$

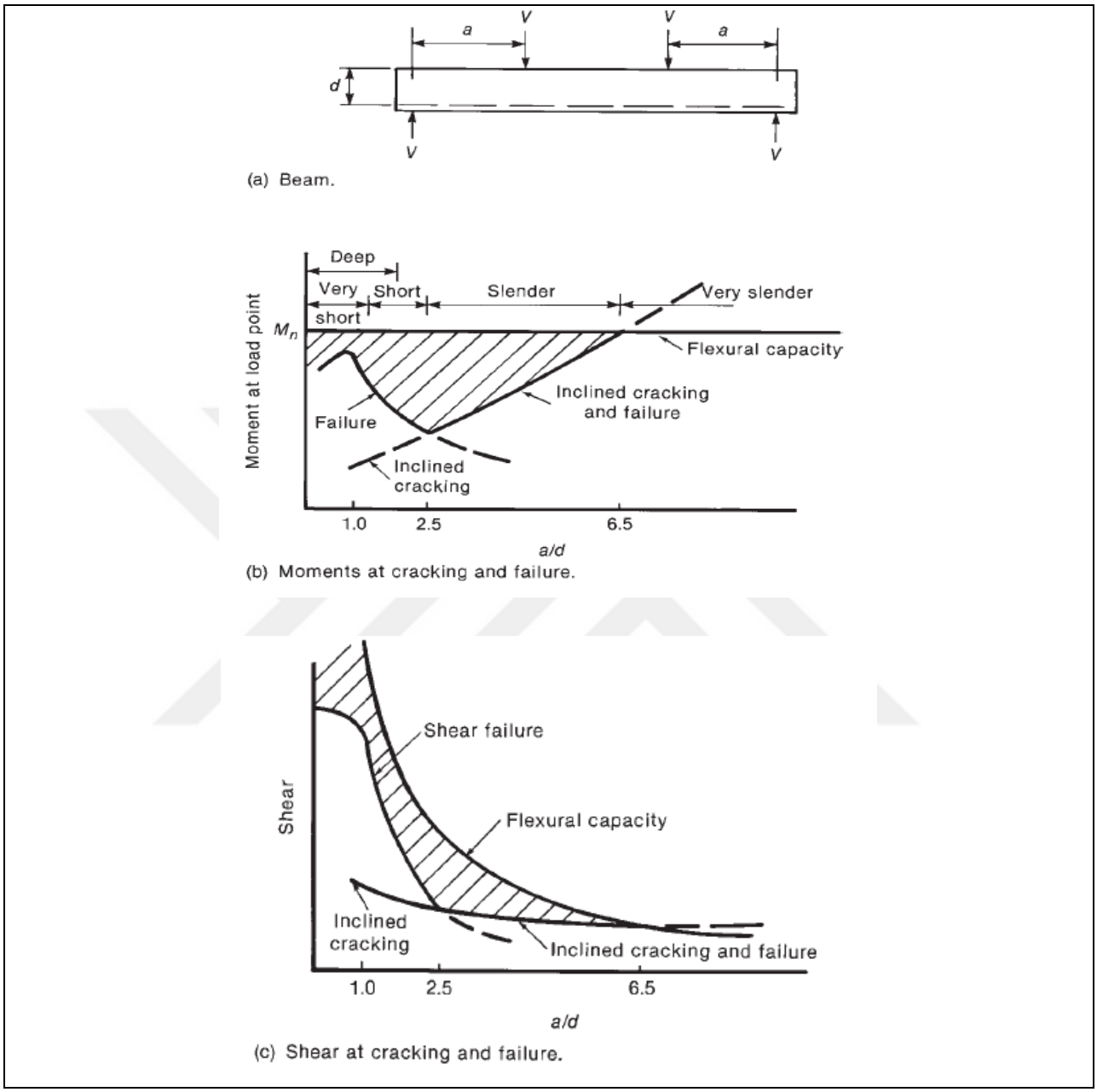


Figure 1.3: Effect of (a/d) Ratio on Shear Strength of beams without shear reinforcement.

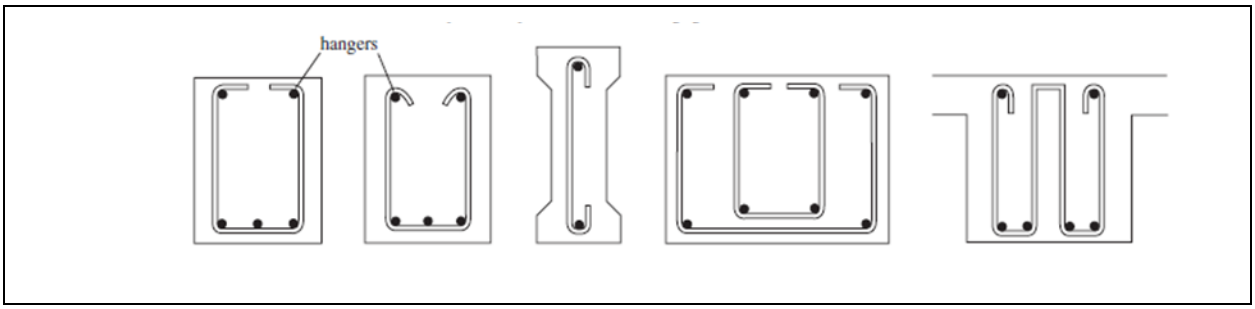


Figure 1.4: Open Stirrups for Beams with Negligible Torsion

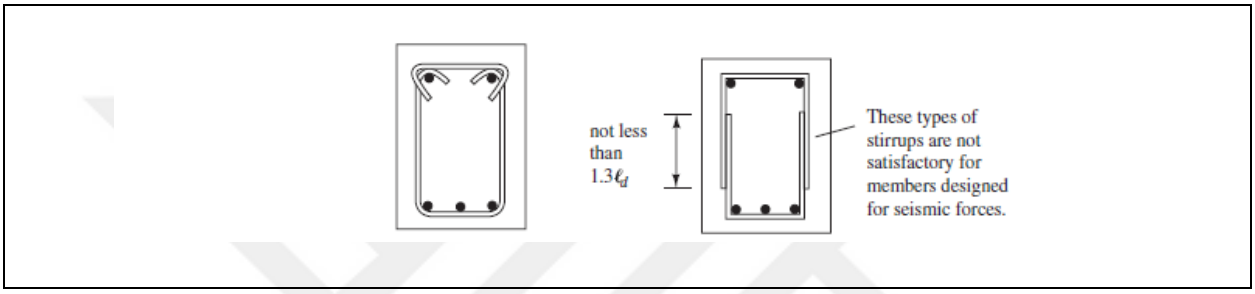


Figure 1.5: Closed Stirrups for Beams with Significant Torsion

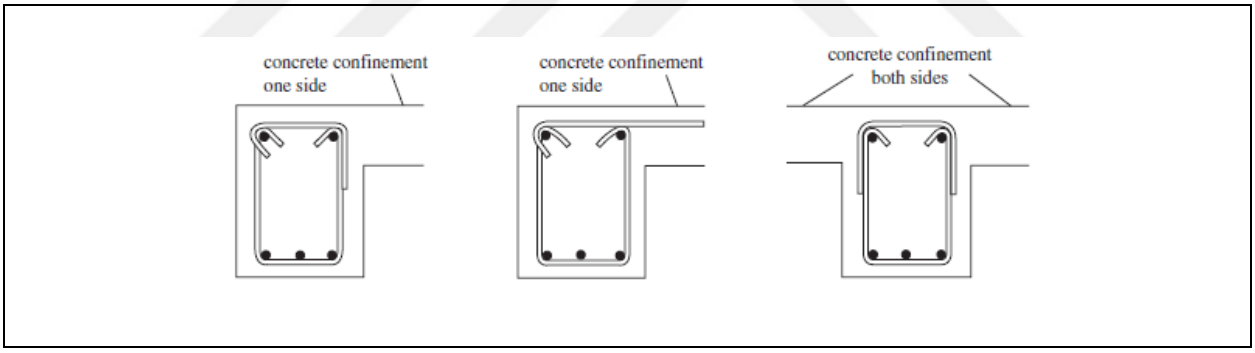


Figure 1.6: Type of Shear Reinforcement Steel Stirrups [16].

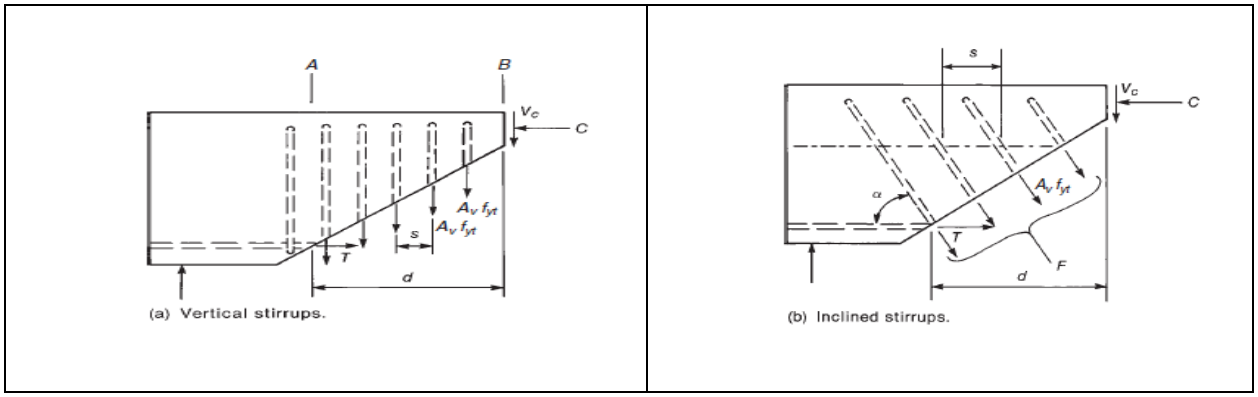


Figure 1.7: Arrangement of Steel Stirrups[7].

The ACI 318-14 Code gives two methods to estimate the shear concrete strength for concrete beams without axial force effect, the first method is simpler, Equation (1-6) displays shear concrete strength Vc which calculated by this method.

$$Vc = 0.17\lambda\sqrt{f'c}\, b.d \qquad . \qquad .. \qquad . \qquad . \qquad (1\text{-}6)$$

Where *f'c* is concrete compressive strength, λ is the lightweight reduction factor, b, and d are the effective dimensions of the concrete beam.

The second method used to estimate the shear concrete strength of concrete beams is shown by Eq. (1-7), this method is more accurate compared to the first method.

$$Vc = less\ of \begin{cases} \left(0.16\lambda\sqrt{f'c} + 17\rho\frac{Vu.d}{Mu}\right) b.d \\ \left(0.16\lambda\sqrt{f'c} + 17\rho\right) b.d \\ 0.17\lambda\sqrt{f'c}\, b.d \end{cases} \qquad .. \qquad (1\text{-}7)$$

Where ρ is the ratio of longitudinal steel reinforcement to the effective dimension of the concrete section, Vu, and Mu factored shear force and moment at section considered[17][18][19].

1.4 SCOPE OF THE WORK AND OBJECTIVES

This research study aims to find an alternative to shear reinforcement to improve the shear resistance of reinforced concrete beams, the specimens were designed to fail by shear and stay stable with bending. The parameters below were adopted in this study.

a. Concrete compressive strength, where two types of concrete mixes were used to give a compressive strength of 30 and 50 MPa.

b. arrangement of shear reinforcement (stirrup), to study the arrangement of reinforcement two angles are used (45, and 90) of the stirrup.

c. used alternative shear reinforcement (steel tube) instead of steel bar in the stirrup. Two cases of steel tubes that are used as a shear reinforcement hollow and filled with concrete materials.

1.5 THESIS ORGANIZATION

This thesis consists of five chapters as shown below:-

a. Chapter One:- presents a brief overview of the importance and danger of shear failure on structures and its types and also presents the resistance mechanisms and types of shear reinforcement.

b. Chapter Two: - Presents a literature review of many of the works that have been researched on improving the shear strength of reinforced concrete beams either in terms of physical properties, the most important of which is tensile or improving transverse reinforcement.

c. Chapter Three:- deals with an overview of the experimental work program. Also, it shows the details presented of the reinforced concrete specimens, material properties, installation procedures, and test setup.

d. Chapter Four :- included the experimental work results, the graphical representation, and the results associated discussion.

e. Chapter Five :- presents the conclusions and suggestions for future research of the entire work.

2. LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will review the available literature to acquire a perspective on the performance of concrete beams under the shear force effect. This chapter involves many significant reviews: the first review concerns shear failure. The second review focuses on using alternative shear reinforcement. The third review focuses on how to improve shear strength and convert failure from brittle failure to ductile failure either by improving concrete tensile specifications or increasing the strength of reinforcement. Finally, the summary of all these studies was prepared at the chapter's end.

2.2 PREVISE STUDIES

Presented a statistical study on the ultimate shear strength of Self-Compacting Concrete (SCC) containing steel fiber. The study included a review of many equations proposed by previous researchers with some equations adopted by international codes for shear strength in concrete containing steel fiber. The specimens taken for the study (113 specimens) included many variables such as cross-sectional dimensions, specimen length, compressive strength, longitudinal steel ratio, steel fiber percent, and (a/d) ratio. The authors concluded that the bigger size of the aggregate led to decreased shear strength in concrete having steel fibers because the aggregate will reduce the uniformity of concrete and difficult connection of steel fiber in the concrete mix[20].

Tested ten concrete beams with five different fiber volume fractions 0.0%, 0.3%, 0.6%, 0.9%, and 1.2%. Steel fibers are a modern technology that contributes to increasing the shear resistance by bridging shear cracks. The steel fiber is used in shear-critical structures in which the use of stirrups is undesirable. This study is based on an evaluation of the effect of the different ratios of these fibers in the concrete mixture on the shear strength of reinforced concrete beams with light tensile strength. The results show that the percentage of fibers of 1.2% can be a substitute for the minimum stirrups according to ACI 318-14 and that it is able to change the failure pattern from shear failure to shear-flexure failure. while the ratio of fibers of 0.6% can be a substitute for the minimum for the stirrups according to Eurocode. The specimens containing the highest

percentage of added fibers 1.2% resulted in the highest inclined cracking load with an increase in shear strength up to 24 times more than the samples with a ratio of 0.0%[21].

investigated Thirteen concrete beams with dimensions (0.15, 0.42, and 2.9 m). The reinforced concrete beams content of three steel bars (14 mm) in the tensile area and two (10 mm) in the compression area, in addition to the transverse reinforcement, (double-legged stirrups 6 mm with a spacing of 160 mm). The authors study the effect of using recycled aggregates instead of natural coarse aggregates on shear strength, also to know the ability of the square root term of compressive strength ($\sqrt{fc}$)[22].

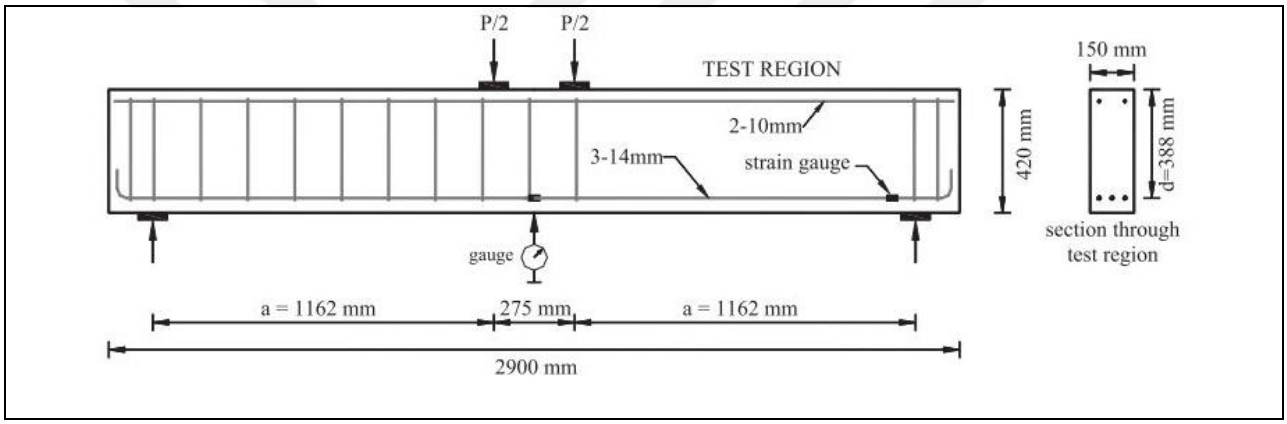


Figure 2.1: Details Tested Specimen [22].

The test results show that the replacement of aggregates caused a decrease in shear strength.

Tested six reinforced concrete beams. The specimens are reinforced with 10 mm in the top layer and 13 mm in the bottom layer. The variables that were adopted in this study, are the tensile strength of the steel fibers and the ratio of the shear extension to depth a/d with values (1.5, 2.5, 3.5). Table (2-1) show the details of the specimens test. shear reinforcement (stirrups) was added only at the ends of the beam near the supports in order to install the longitudinal bars and prevent premature failure. Figure (2-2) shows the details of specemens test[23].

Table 2.1: Details of The Specimens Test [23].

Mixture	Section (mm × mm)	d (mm)	Longitudinal Rebar		ρ (%)	V_f (%)	Fiber Tensile Strength (MPa)	a/d
			Bottom	Top				
70-NF-1.5	($b \times h$) 160 × 290	250	4-D13	2-D10	1.27	0.75	1200	1.5
70-NF-2.5								2.5
70-NF-3.5								3.5
70-HF-1.5	160 × 290	250	4-D13	2-D10	1.27	0.75	1600	1.5
70-HF-2.5								2.5
70-HF-3.5								3.5

Note: d = depth; ρ = reinforcement ratio; V_f = fiber volume; a/d = shear span-to-depth ratio.

Based on the test results the authors conclude, that by using high-strength steel fibers, the failure pattern changed from brittle to ductile, with cracks continuing to appear even after yielding and this indicates that the addition of steel fibers does not have a clear effect on the shear resistance as much as its strong effect on the transformation of the failure pattern from brittle to ductile. Also, the test is over before the tensile area is yielded and before the steel bar at the area of compression has already reached the yield stage, and this indicates the role of steel fibers in increasing the resistance of concrete by making it less brittle and increasing its ductility.

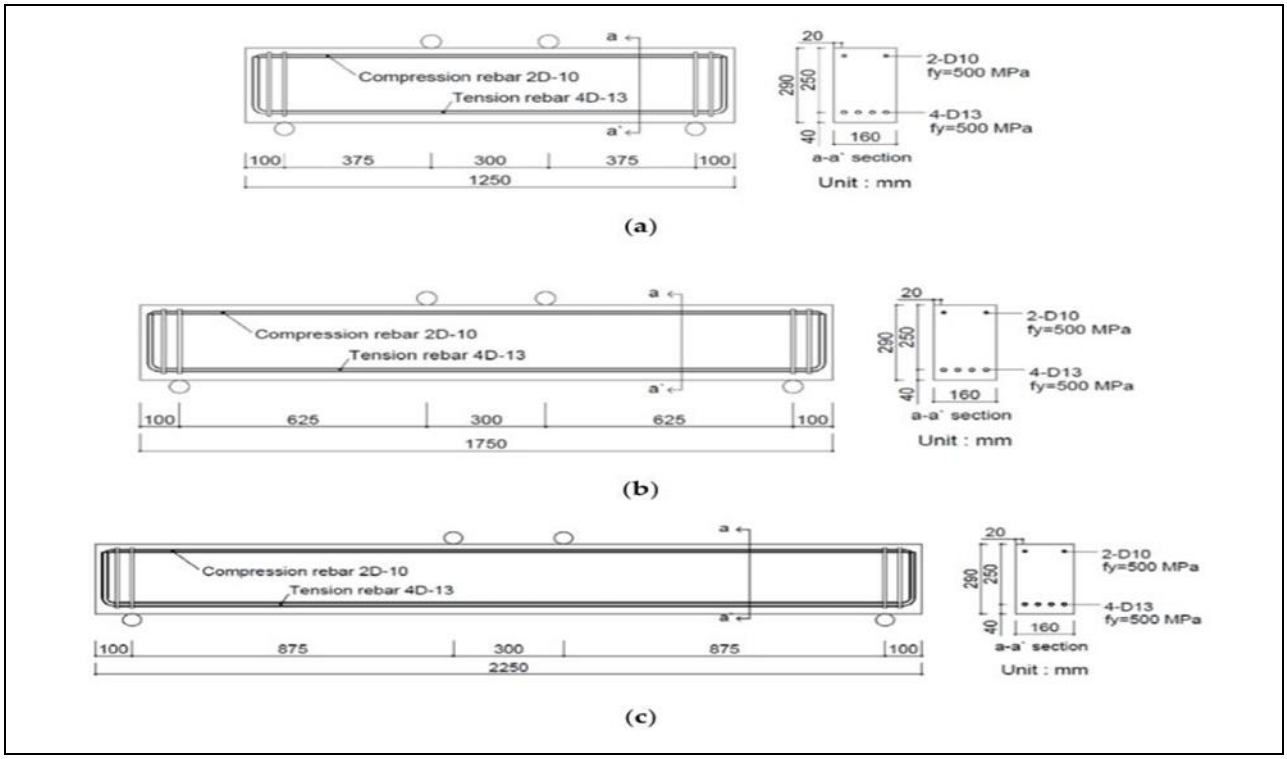


Figure 2.2: Details of Test Specimens [23].

Tested thirty-six concrete beams with dimensions 140, 140, and 1500 mm consisting of a concrete mixture containing 20% fly ash by weight of cement. The specimens were divided into four groups, the first group used normal concrete, the second group contained 1.5% steel fibers of the type Dramix, the third group was prestressed concrete beams, and the last group is prestressed concrete beams containing steel fibers. This study focuses on the improvement of the shear and flexural strength of concrete by adding steel fibers. The results show that the steel fibers increased the load capacity of concrete beams by 30-50% over ordinary non-prestressed beams, also in prestresses concrete the load capacity increased by 30-90%. The steel fibers increased the resistance of concrete beams to cracking, where the crack width did not exceed 6 mm, and 3 mm in the case of reinforced concrete beams non-prestressed and pre-stressed respectively. Based on the results, the reinforced concrete beams with steel fibers improve shear strength and crack resistance and reduce brittle failure behavior[24].

Tested twelve concrete beams reinforced by polymer bars (GFRP) with adding steel fibers, the effect of the latter on the shear strength was studied using the bending strength and concrete compressive strength as specific parameters, Figure (2-3) shows the details of the tested specimens. The authors noted the occurrence of two types of shear failure (flexure shear) and disengagement failure between bars and concrete and indicated that the second type of failure when it occurs increases the shear resistance[25].

Investigated ten full-scale concrete beams with dimensions 150, 200, and 2000 mm. The specimens were divided into three groups, each group with different steel fiber ratios of 0, 0.5, and 1%. Each group contains three specimens that differ in the technique of strengthening using CFRP sheets, Table (2-1) shows the details of the test specimens. Figure (2-4) shows the dimensions and reinforcement details of the tested specimens. The results show that the failure mode depends on the ratio of steel fiber. The load capacity of the specimens can be enhanced when using a GFRP sheet as external shear reinforcement[26].

Study the effect of water/cement (W/C) ratio with the volumetric ratios of the steel fibers on the shear strength, the author tested twenty reinforced concrete beams, a group of them which contained (w/c) = 0.5 with the volume ratios of the fibers (0, 0.3, 0.5, and 0.7%) and another group included (W/C) ratios of (0.35) and fiber volume ratio of (0, 0.2, 0.4, and 0.6%) in the presence of stirrups for both groups. the author concluded that the addition of steel fibers does

not dispense with the presence of stirrups in shear resistance and also noted that the shear resistance decreases with increasing (W/C) ratios, and it increased with increasing fiber volume ratios[27].

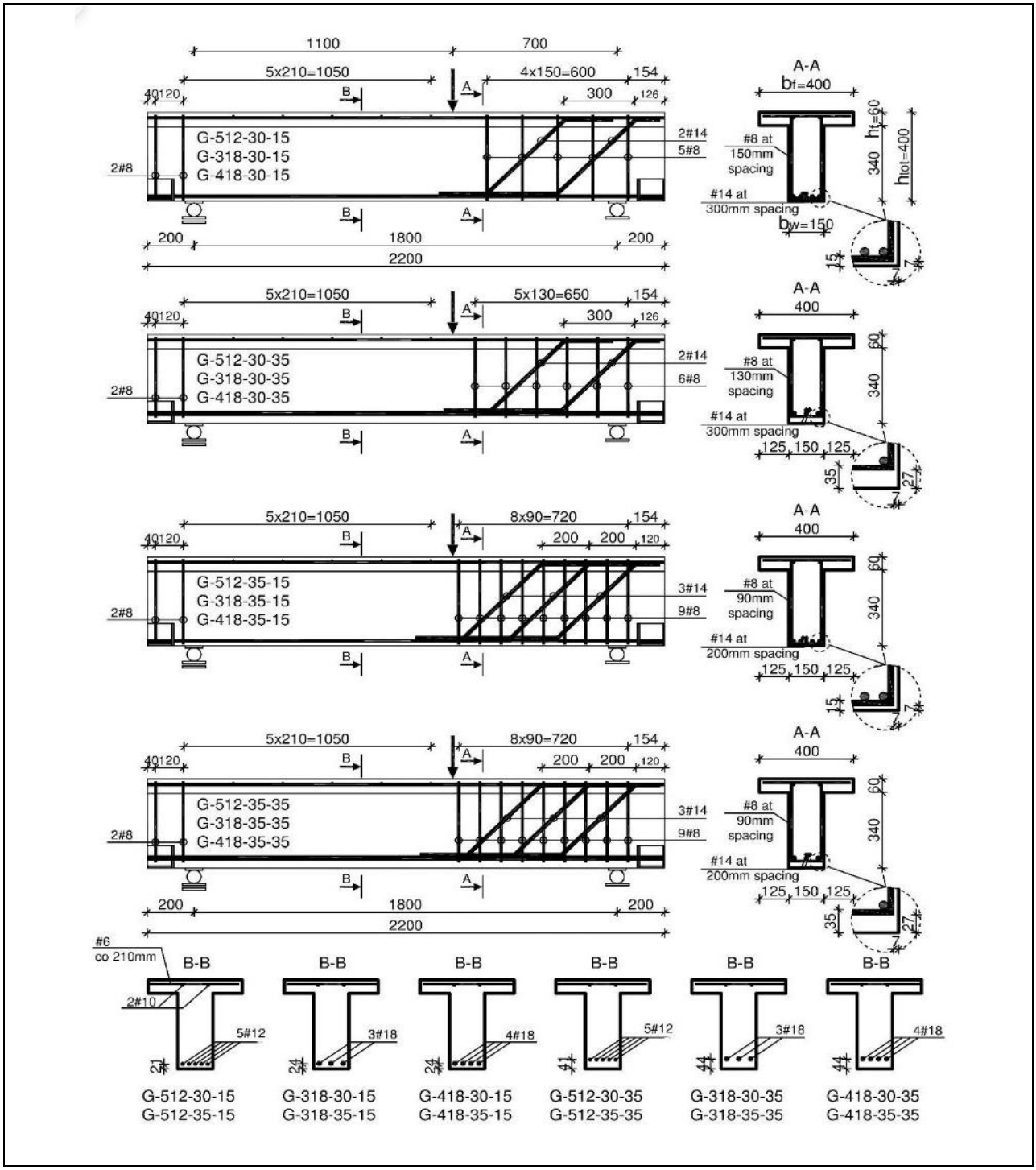


Figure 2.3: Details of The Tested Speciemns [25].

Table 2.2: Details of The Test Specimens [26].

Groups	Beam symbols	Steel fiber %	Strengthening application	Strengthening pattern
GFR0	GFR0-N	0	None / As built	
	GFR0-S1	0	U - Jacketing	
	GFR0-S2	0	Side Bounding - Sheets	
GFR05	GFR05-N	0.50	None / As built	
	GFR05-S1	0.50	U - Jacketing	
	GFR05-S2	0.50	Side Bounding - Sheets	
GFR1	GFR1-N	1.0	None / As built	
	GFR1-S1	1.0	U - Jacketing	
	GFR1-S2	1.0	Side Bounding - Sheets	

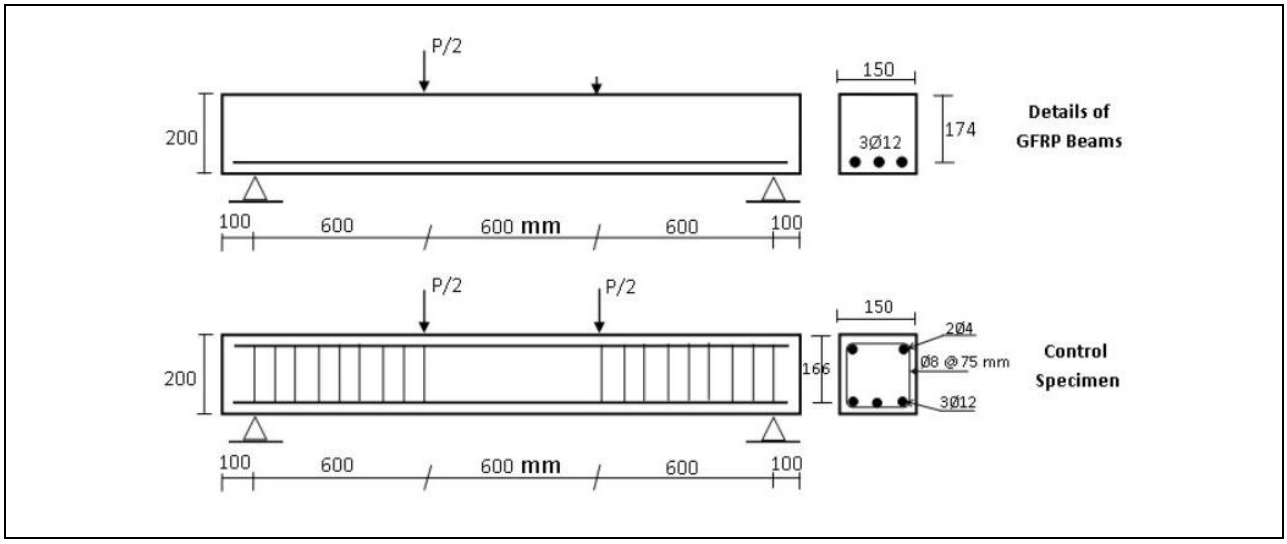


Figure 2.4: Dimensions and Reinforcement details of the tested specimewns [26].

Presented a statistical study concrete shear strength for one hundred and seventy-five beams examined by other researchers, all of these specimens not contain shear reinforcement. This study included many variables such as cross-sectional dimensions, compressive strength, longitudinal steel ratio, and (a/d) ratio. The study presented four equations that predict the shear

strength of the concrete beam. These equations were compared with the equations presented by the ACI 318. The author found a good convergence of some of the equations with the practical results of the tested specimens[28].

Studied the results of four wide reinforced concrete beams under shear performances. The influence of the support widths (100% of the beam width), the arrangement of flexural reinforcement, across the beam width, and the presence of shear reinforcement. The third specimen consists of concrete with a steel plate. The results showed that a wide beam with a steel plate has no effect on the shear strength of concrete and the effect focused on the flexural strength, also the support width has no significant effect on the shear strength of concrete. Increasing the tension of the steel reinforcement area of the wide beam increases the ultimate load capacity by about (30% to 40%)[29].

Discussed the shear behavior of four wide beams that had dimensions of (560×215×1800) mm under one point load. The shear span to effective depth (a/d) ratio is equal (4.52), using vertical shear reinforcement, concrete compressive (45) MPa strength, and a steel plate of 4 mm. The main parameter of the study was the effect of the existing solid and hollow vertical steel plates on the shear capacity of the tested wide beams. Details of test specimens and results are shown in Figure (2-5). The results explained that the presence of longitudinal vertical steel plates and vertical solid steel plates instead of web reinforcement had an influence on the shear strength of concrete by increasing shear capacity from (9.52% to 12.14%) respectively. Although shear capacity contains transverse vertical hollow steel plates instead of web reinforcement had increased by about (47.62%)[30].

Figure 2.5: Using Steel Plate in The Tested Specimens [30].

Studied the behavior of shear steel plates on the lateral side of four wide reinforced concrete beams which had dimensions of (215x560x1800)mm. The parameters of the study were replaced 10mm stirrups with (125mm) spacing by different spacing shear steel plates with a thickness of 3mm spacing of (125, 166, and 250 mm) instead of reinforcing with normal stirrups. The compressive strength of concrete is equal to (33MPa), the specimens are shown in Figure (2-6). The results showed that the using of steel plates instead of stirrups is a good alternative; it gets good agreement for yield and ultimate load and deflection with increasing (5%) yield load. The use of shear steel plates leads to low weight (2.7%)[31].

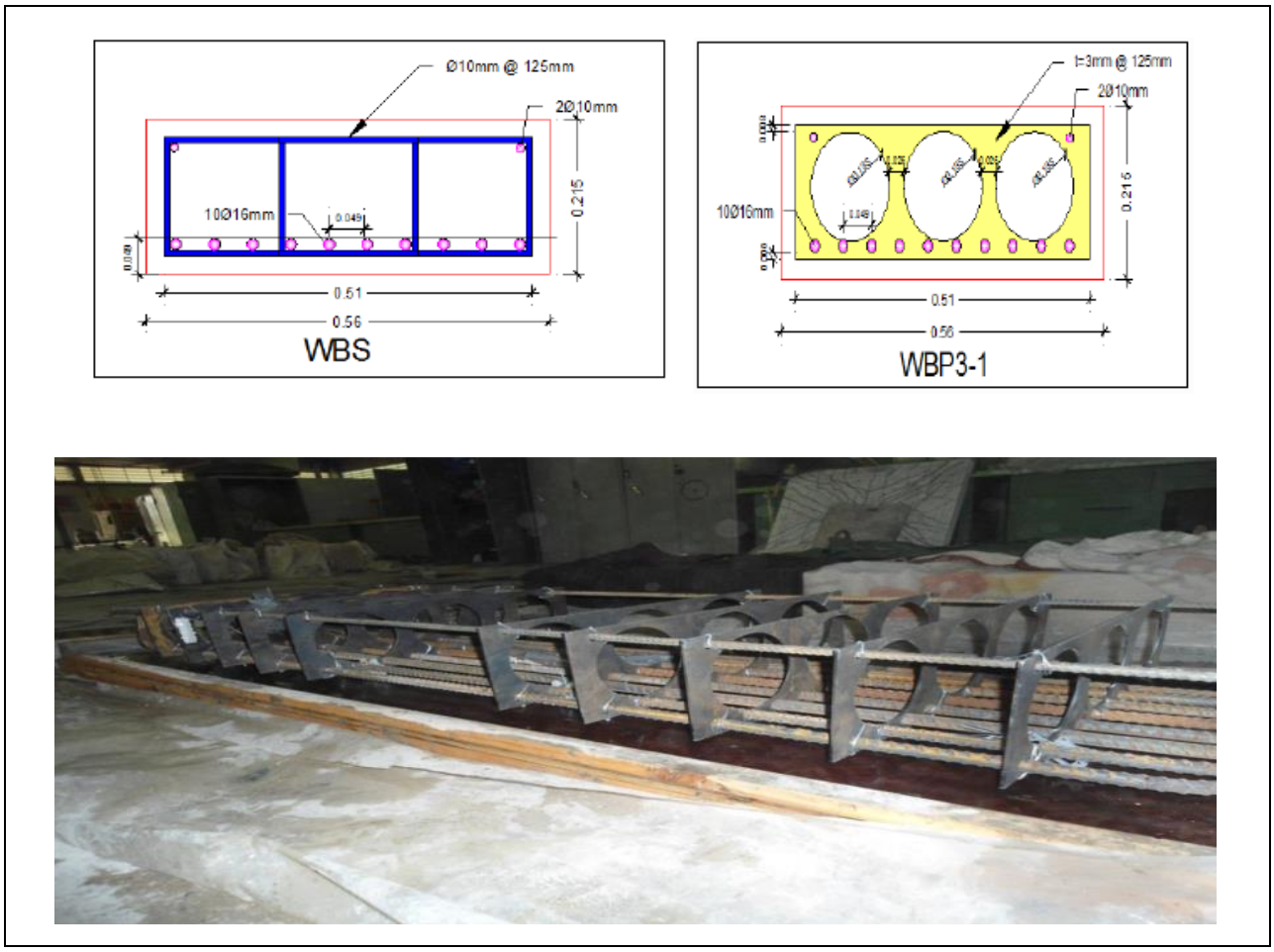


Figure 2.6: Section WBS with Stirrups, Section WBP3-1 with Steel Plate [31].

Exanimated of five reinforced concrete beams using welded inclined bars (WIB) as a transverse reinforcement, concluded that the shear reinforcement is fully capable of resisting shear [32].

Examined four reinforced concrete beams using ordinary steel bars as longitudinal reinforcement and transversely reinforcement using fiber-reinforced polymer compounds this type of reinforcement caused an increase in the maximum loading capacity and also that these compounds have a direct effect on the failure patterns of reinforced concrete beams. Figure (2-7) shows the crack pattern and failure mode of specimens[33].

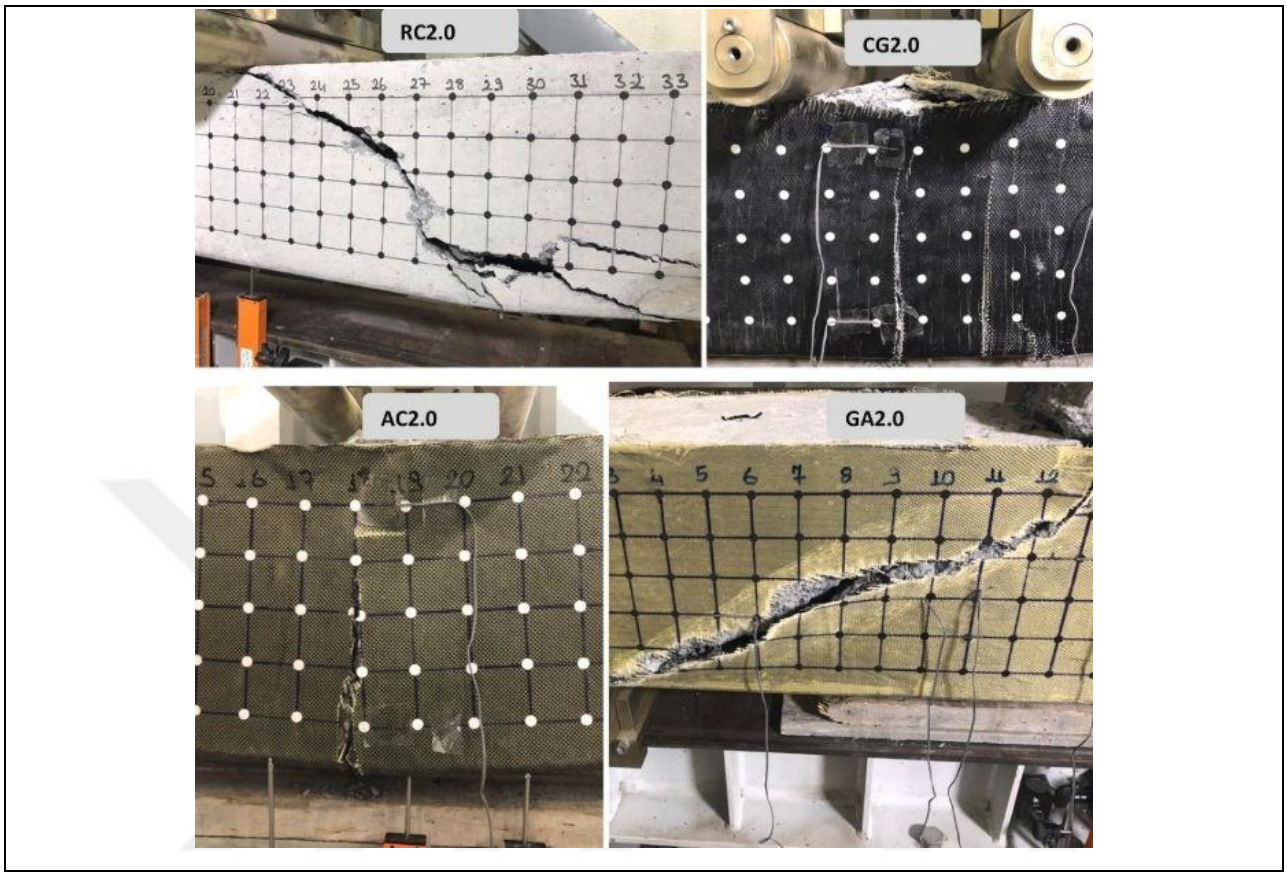


Figure 2.7: Crack Pattern and Failure mode of the specimens [33].

Tested six self-compacted normal concrete beams of a new technic using a shear reinforcement system called steel plate versus normal stirrups. The reinforcement of the specimen is shown in Figures (2-8), while Figure (2-9) shows the internal steel plate which using as a shear reinforcement. Beams had dimensions of 300, 200, and 2000 mm under two-point. One of these beams was reinforced with stirrups and the others were reinforced with shear steel plates as a parametric study, the steel plate thickness is 3, 4, and 6 mm furthermore, the spacing of steel plates is 200, 175, and 150 mm. The results show that using thicker steel plates increased the ultimate load of beams. In all beams using internal steel plates as shear reinforcement, the ductility was lower than the control beam using stirrups about (20.08%) on average[34].

Figure 2.8: Reinforcement of tested specimen [34].

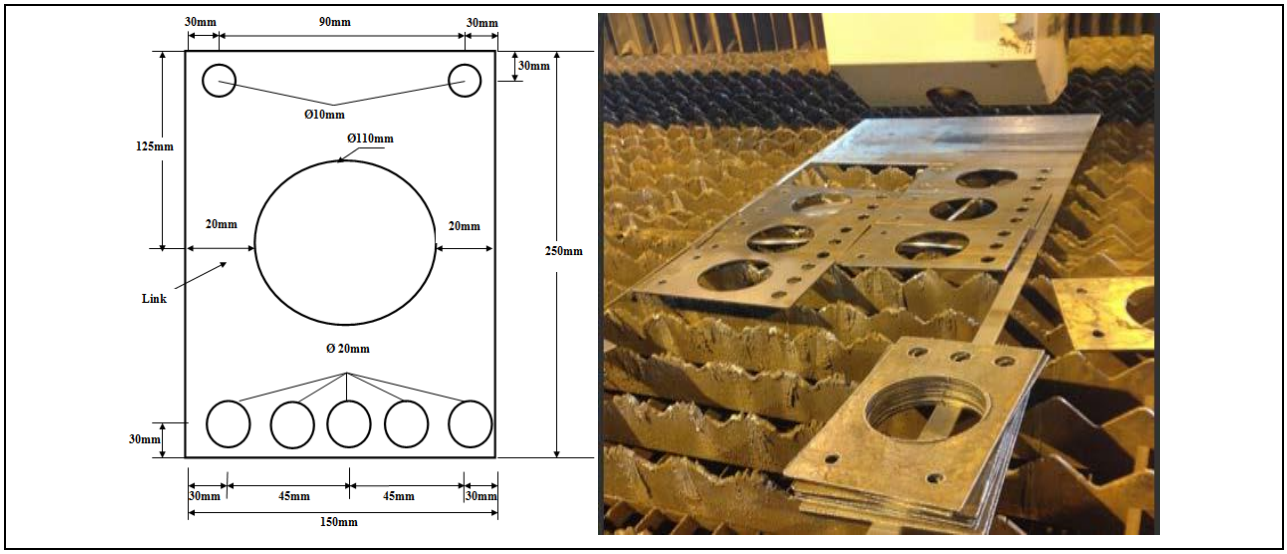


Figure 2.9: Details of Steel Plate [34].

Tested three specimens of concrete beams with dimensions 200, 250, and 2000 mm. The ratio of shear span to effective depth a/d is 2.5, compressive strength 27.29 MPa, longitudinal reinforcement with three steel bars of diameter 14 mm in the top zone and four steel bars of diameter 16 mm in the bottom zone. The shear reinforcement used a new steel bar this type of reinforcement is called swimmer bars. the swimmer's bars are small bars with a certain inclination with two terminal ends that are curved horizontally and tied up and down with the longitudinal bars, Figure (2-10) shows the welded swimmer bars. The results show that the improvement in the shear strength of the reinforced concrete beams with swimming bars has occurred compared with reinforced concrete beams that are reinforced with traditional bars. Also, the beams reinforced with recycled swimming bars gave results similar to the results of bars reinforced with new and bonded swimming bars, whereas the length and width of the cracks in them were less compared to the control beam with conventional reinforcement[35].

Figure 2.10: Welded Swimmer Bars.

Exanimated three reinforced concrete beams using space swimmer bars as a new type of shear reinforcement, this type of shear reinforcement was compared with welded swimmer bars and traditional stirrups. The tested beams have the same dimensions, compressive strength, and a ratio of (a/d) = 2.5. The tested beam shows in Figure (2-11). The study concluded that this type

of reinforcement improved the performance of shear strength by about 5% and in the long run it is considered to be more secure[36].

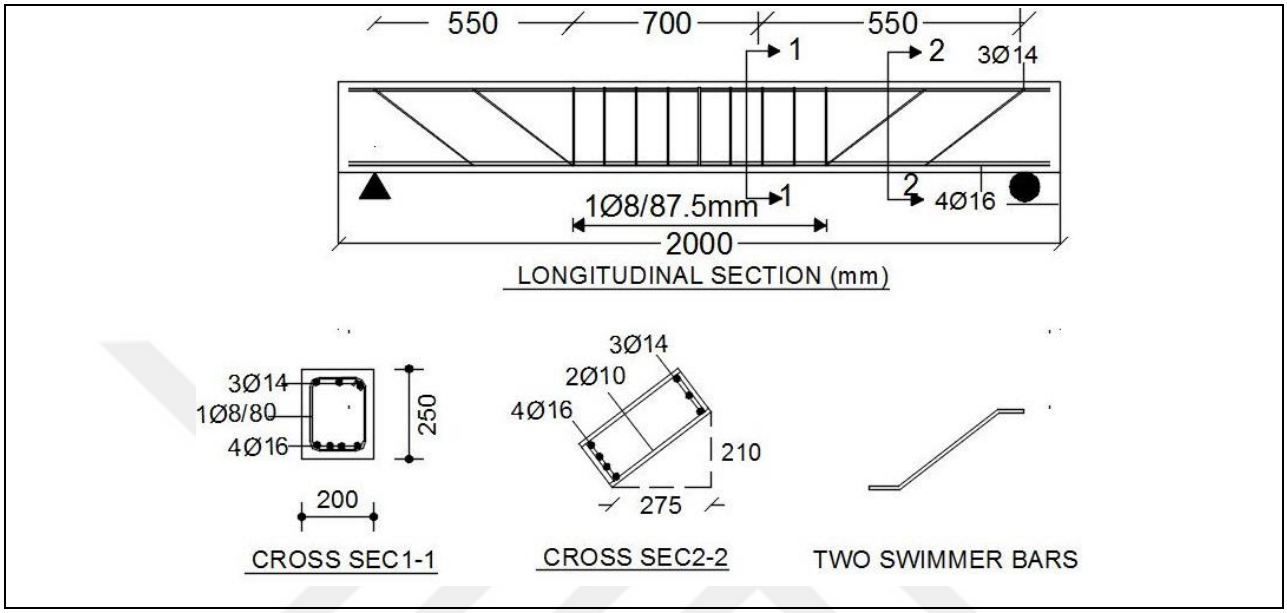


Figure 2.11: Typical Steel Reinforcement used by [36].

Used welded mesh consisting of pre-arranged wires arranged in two directions at a distance of L/4 from both sides of the supports and at a distance of L/3 in the middle area as transverse reinforcement. Five reinforced concrete beams were tested to study the effect of using welded mesh on the shear strength. The results show a slight improvement in the loading capacity and a delay in cracks appearing in tested specimens[37].

Studied nine concrete beams of three different groups of reinforced concrete beams with additional external reinforcement using CFRP-reinforced polymer sheets with no transverse reinforcement and relying only on longitudinal reinforcement, noticed that the shear resistance increased by (13 to 138 %) and that the shear resistance in concrete beams reinforced externally using carbon-reinforced polymer sheets are increased when the longitudinal reinforcement is low[38].

Tested four concrete beams that were reinforced with Carbon Fiber Reinforced Polymer (CFRP) vertically and inclined. The author found the CFRP leads to an increase in strength and stiffness when installed in a vertical (U) shape and also has an effect on increasing the maximum load[39].

Tested five High-Performance Concrete (HPC) beams containing a steel fiber of 0.5%. The specimens have dimensions of 300, 150, and 1400 mm, these specimens were tested under four points load. the major parameter of this study is using steel plates instead of shear reinforcement. Figure (2-12) shows the steel plates used in the study. Figure (2-13) shows the details of tested specimens. The results show that the longitudinal shear steel plates are a good alternative to use instead of normal stirrups. Also, the ultimate strength for all beams which used the steel plates was higher than the reference specimen which used ordinary stirrups[40].

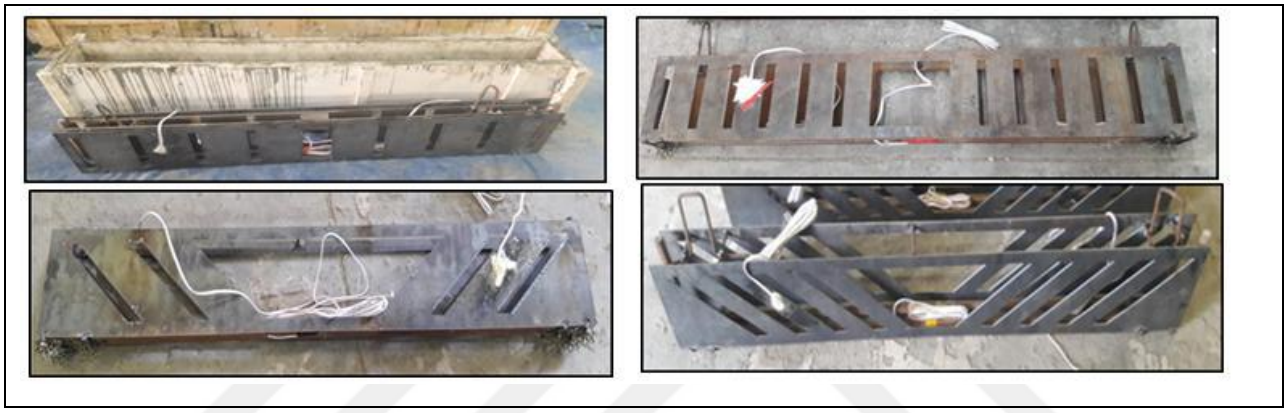


Figure 2.12: Steel Plates used as a shear reinforcement [40].

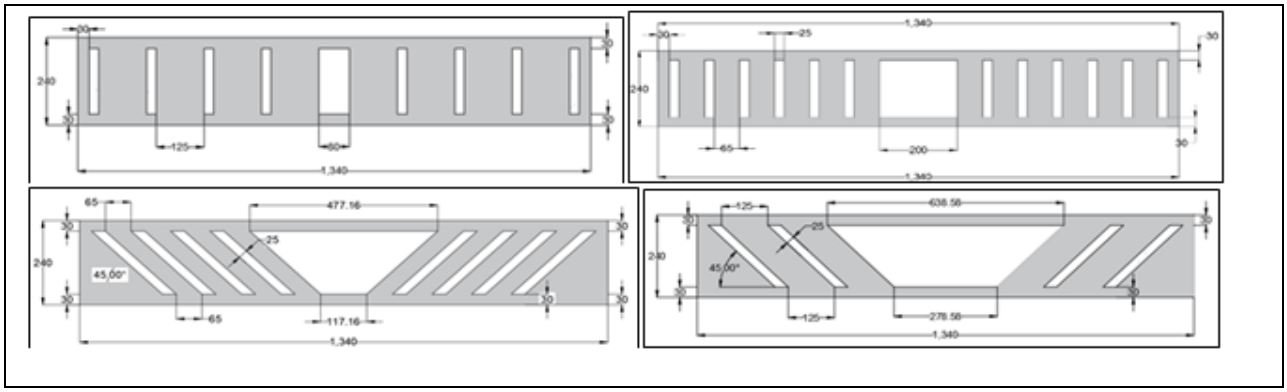


Figure 2.13: Details Steel Plate used in the tested specimens[40].

2.3 SUMMARY

Previous studies on the shear strength of reinforced concrete beams can be summarized in two main sections. The first section deals with improving the strength of the shear stress of concrete and this can be made by using steel fiber. Where the mechanical properties of concrete (compressive strength, splitting strength, and rapture stress) of concrete were studied. The

second section deals with using alternative shear reinforcement (different types of steel plates, and swimming bars) instead of steel stirrup. This study focus on using a new type of shear reinforcement (steel tube) instead of a steel stirrup.

3. EXPERIMENTAL STUDY

3.1 GENERAL

The main purpose of the present work is to find the shear strength of the reinforced concrete beams with ordinary steel bars and study the development of alternatives to it, such as steel tubes. The investigated specimens were ten reinforced concrete beams, forth of the specimens were reinforced with ordinary steel bars for shear resistance in the reinforced concrete beams, while the other six of the specimens were reinforced using steel tubes as alternatives to the steel bars. The normal concrete type is used to construct the specimens.

This chapter deals with the experimental work starting with the experimental test program, construction method, materials properties, like properties of steel tube, steel bars, gravel, sand, and cement. Additionally, this chapter shows the curing methods of specimens and the methods of test that have been used to investigate the specimens.

3.2 EXPERIMENTAL PROGRAM

Ten specimens tested, the main variables in this study are the compressive strength of concrete, type of steel reinforcement (steel tube or steel bar), and angle of steel reinforcement (90 or 45 deg.). Table (3-1) shows the investigated specimens. The nomenclature consists of three sections. The first section represented type of shear steel reinforcement (S = steel tube or B = steel bar), the second section represented concrete strength of specimen (30, and 50 MPa), the last section refers to the angle of shear steel reinforcement (90 or 45 deg.). The steel tubes used instead of the steel reinforcement bar were filled with concrete materials, except for two specimens (S30PH, and S30IH) in which empty tubes were used. The letter H denotes the use of empty steel tubes.

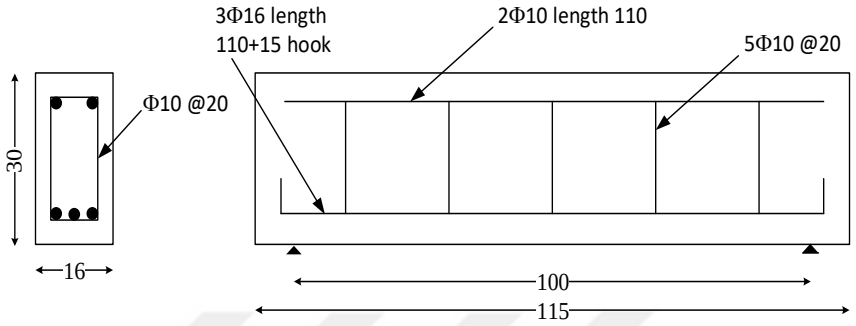
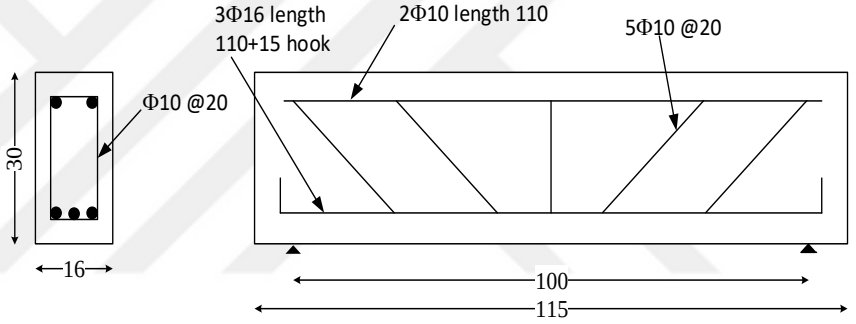
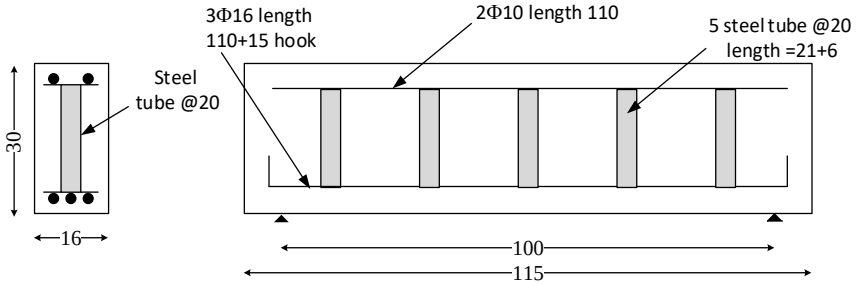
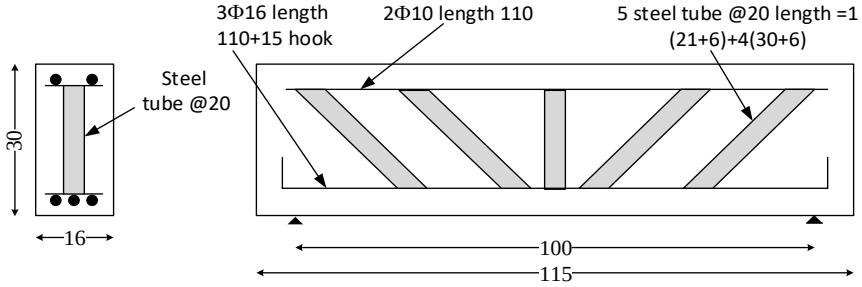
The details of the tested specimen are shown in Table (3-2). The dimensions of the beam are 160*300* 1150 mm for width, height, and length respectively. The clear span of the test specimen is 1000 mm. the longitudinal reinforcements are 3 Φ 16 mm in the bottom layer and 2 Φ 8 mm in the top layer. The longitudinal reinforcements are chosen to prevent flexural failure. Two types of shear stirrups are used in this study (steel reinforcement bar and steel tube), both types of shear stirrups are placed at a vertical angle and 45 degrees and repeated every 200 mm. The steel tube which is used as a shear stirrup is filled with the cement material except for two

specimens (S30PH, and S30IH) used without filling (empty steel tubes). Two compressive strengths of concrete are used in this study.

Table 3.1: Specimens Test.

No.	ID	fcu (MPa)	Shear reinforcement type	Angle
1	S30I	30	Steel tube @200	45
2	S30P	30	Steel tube @200	90
3	S50I	50	Steel tube @200	45
4	S50P	50	Steel tube @200	90
5	S30IH	30	Steel tube @200	45
6	S30PH	30	Steel tube @200	90
7	B30I	30	Steel bar @200	45
8	B30P	30	Steel bar @200	90
9	B50I	50	Steel bar @200	45
10	B50P	50	Steel bar @200	90

Table 3.2: Details of Specimens.

Specimen	Details
B30P, B50P	
B30I, B50I	
S30P, S50P, S30PH	
S30I, S50I, S30IH	

3.3 MATERIAL PROPERTIES

All the materials tests agreed with the ASTM or Iraqi specification. All of the investigations performed at the concrete laboratory of Al-Qadisiyah University.

3.3.1 Cement

The cement that used in this work is produce in Al-Najaf Al-Ashraf cement plant that knows as (Al-Asad). The type of cement is ordinary Portland cement (OPC). Table (3-3) shows the cement chemical compounds, while the cement physical properties displayed in Table (3-4). All the cement tests are done consistent with the Iraqi Standards No.5/1984 [41].

Table 3.3: Chemical Composition of Cement.

Compound composition	Result (%)	Limitation [41]
lime saturation factor	0.9	1.02-0.66
Tri-calcium aluminates (C3A)	9.3	-
Sulfate content (SO3)	2.6	< 2.5 if C3A <5
		< 2.8 if C3A >5
Magnesium oxide (Mgo)	3.69	≤ 5.0%
Non soluble substance	0.53	≤1.5
Loss of ignition	1.69	≤ 4.0

Table 3.4: Cement Physical Properties.

Physical properties		Result	Iraqi Specification [41]
Soundness, %		0.3	≤ 0.8
Setting time Initial, (minute) Final, (hours)		 120 3:01	 ≥ 45 ≤ 10
Fineness (Blaine), (m^2/kg)		279	≥ 230
Compressive strength, (MPa)	3 days	15.1	≥ 15
	7 days	37.2	≥ 23

3.3.2 Fine Aggregate

The sand used in this study was natural sand. Table)3.5) shows the sand results were within the Iraqi Specification limits (IQS 45/1984) [42]. Figure (3.1) shows the curve of passing percentage verse sieve size of sand used compared with the limits of Iraqi Specification. The sand grading was within the limits of zone 3.

Table 3.5: Limitations and Sand Results [42].

Sieve size (mm)	Passing percentage (%)	
	results	Zone No III.
9.5	100	100
4.75	98	100-90
2.36	90.9	100-85
1.18	84.8	100-75
0.6	68.9	79-60
0.3	29.6	40-12
0.15	7.3	10-0

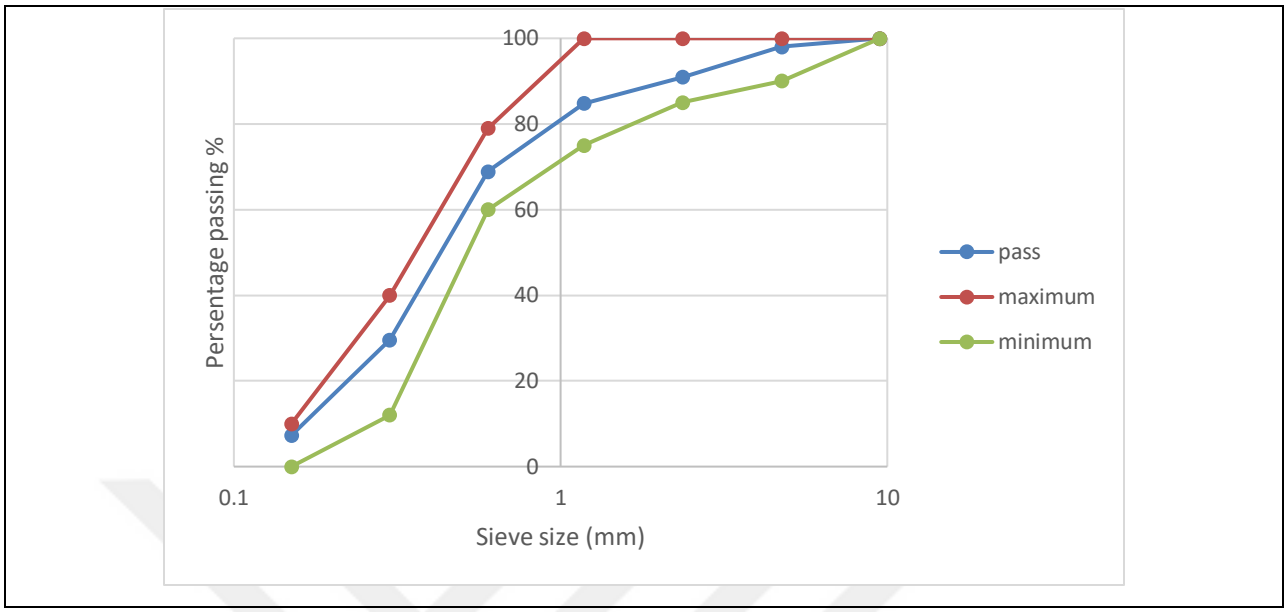


Figure 3.1: Sieve Analysis of Fine Aggregate.

3.3.3 Coarse Aggregate

The coarse aggregate used was crushed gravel, the gravel washed to remove dust and stored just in case of saturated surface dry. Table (3-6) show the gravel testing results were within the requirement of the Iraqi Specification limits (IQS 45/1984) [42]. Figure (3-2) shows the curve of the passing percentage of gravel used compared with the boundaries of the Iraqi Specification of 20-5 mm gravel type.

Table 3.6: Coarse Aggregate Size Testing Results [42].

Sieve size (mm)	Passing percentage (%)	
	Gravel	Limitations (20-5)
37.5	100	100
20	97	95 - 100
10	42	30 - 60
5	3	0 - 10

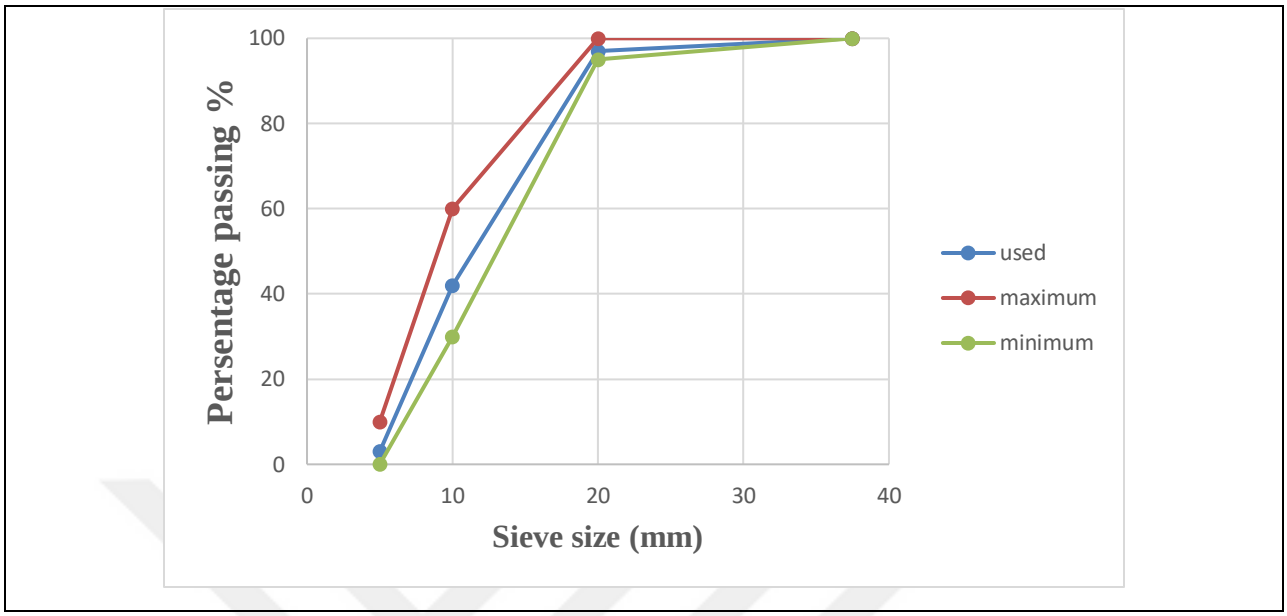


Figure 3.2: Coarse Aggregate Sieve Analysis.

3.3.4 Steel Reinforcement Bar

The test method of reinforcement bar done according to ASTM 996M-05 [43]. Two size of steel reinforcement bar used in the present work (Φ10 mm, and Φ16mm). The bar diameter Φ10 used as a shear reinforcement while Φ16 mm used as a reinforcement bar in the longitudinal direction (bottom layer). Table (3-7) shows the properties of steel bars.

3.3.5 Steel Tubes

The dimensions of steel tube are 50*50*1.4 mm. The test method of steel tube in the present work done according to ASTM 996M-05 [43]. The yield stress (fy) was 254 MPa and the ultimate stress (fu) was 407 MPa.

Table 3.7: Steel Bar Properties.

Component	fy (MPa)	fu (MPa)
Reinforcement bar Φ 16 mm	465	595
Reinforcement bar Φ 10 mm	515	643

3.3.6 Cempatch S

Cempatch S is a one-component polymer modified and fiber-reinforced repair mortar. It is a mixture of selected aggregates, dry powders, and fibers that when mixed with water produces a thixotropic mortar proper for vertical and overhead application. Cempatch S was used to fill steel tubes that were used as shear reinforcement, this material was mixed gradually by adding a bag of this material weighing (25) kg to (4.5) liters of water with rapid and continuous mixing for 3 minutes, then the next day the open surface of the filling steel tube was sealed with insulating material to complete the curing of the material. Figure (3-3) shows the use of Cempatch S material.

Figure 3.3: The Using Stages of Cempatch S Material.

3.3.7 Water

Tap water is used for mixing and curing the concrete mixture.

3.4 CONCRETE MIXING RATIO

Two normal concrete mixes are used in the present work (M1, and M2); the planning compressive strength (fcu) of these mixes at 28 days is 30, and 50 MPa respectively. The normal

concrete was designed consistent with American Concrete Institute 211.1-91 [44]. Table (3-8) shows the quantities of materials utilized in these mixtures.

Table 3.8: Normal Concrete Mixing Proportion.

Mix	M1=30	M2=50
Cement (kg/m^3)	350	480
Sand (kg/m^3)	644	595
Gravel (kg/m^3)	1278	1176
Water (kg/m^3)	158	183
w/c	0.45	0.38

The mixing drum surface should be clean and wet before starting the mixing process. The procedure of the normal concrete mix has sequent steps as follows (i) Adding gravel within the mixer. (ii) Adding Fine aggregate to the mixer. (iii) Mixing dry materials for two minutes. (iv) Adding the cement to the mixer. (v) Adding water to materials within the drum while the drum is functioning and mixing for 3 minutes after adding.

3.5 CASTING AND CURING PROCESS

Plywood was used in order to obtain a smooth concrete surface in the construction of ten molds with dimensions 160*300 *1150 mm, where the wooden panels with the thickness of 18 mm were well fixed by using steel nails to avoid loosening during pouring the mixture. Figure (3.4) shows the molds used to construct the test specimens.

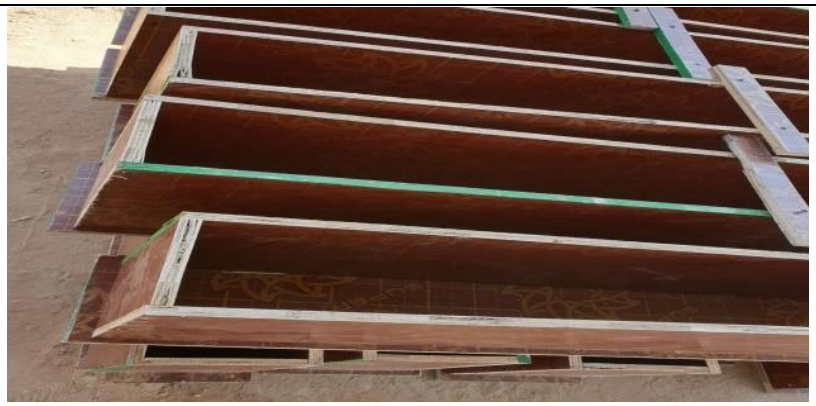


Figure 3.4: Molds of The Test Specimens.

During this period, reinforcing steel was prepared for the test specimens. In all specimens, the longitudinal steel reinforcement was fixed (3Φ16) on the bottom layer and (2Φ8) on the top layer. While the reinforcing bars and steel tubes were used as a shear reinforcement were placed at an angle of 90 and 45 degrees, after installing the steel reinforcement according to the scheme, it was placed within the wood mold designated for it to be ready for casting.

The wood formworks are placed on the horizontal ground to casting the test specimens. Concrete was gradually placed within the formwork and a vibrator was used to remove the voids inside the concrete then the surface of the concrete was leveled. After 24 hours, the surface of the concrete was covered with pieces of fabric then moisten with water inside the wood formwork, and each day the water was added for ensuring that the concrete is curing as needed. Figure (3-5) shows the casting of the test specimens.

Nine cubes from each mixture were taken (150*150*150) mm to measure the compressive strength (fcu). Three prisms (100x100x500) mm were cast to evaluate the modulus of rupture of concrete also three cylinders (100x200 mm) to evaluate the splitting tensile strength.

Figure 3.5: Casting of The Test Specimens.

3.6 TEST OF HARDENED CONCRETE

3.6.1 Compressive Strength

The test concrete compressive strength has done according to BS 1881-Part 1 [45]. Sixteen cubes tested; the test instrument is shown in Figure (3-6).

Figure 3.6: Compressive Strength Instrument.

3.6.2 Splitting Tensile Strength

The tensile strength test was conducted within the same compression test machine according to ASTM C496 [46] Three cylinders (100×200 mm) for every concrete mix were tested. Figure (3-7) shows the device of the splitting test.

Figure 3.7: Splitting Tensile Strength Instrument.

3.6.3 Flexural Strength Test

The prism of concrete was used to test the modulus of rupture with dimensions 100×100×500 mm, three prisms were tested for each concrete mix, this test was consistent with ASTM C 78 [47]. Figure (3-8) shows the device of the modulus of rupture test.

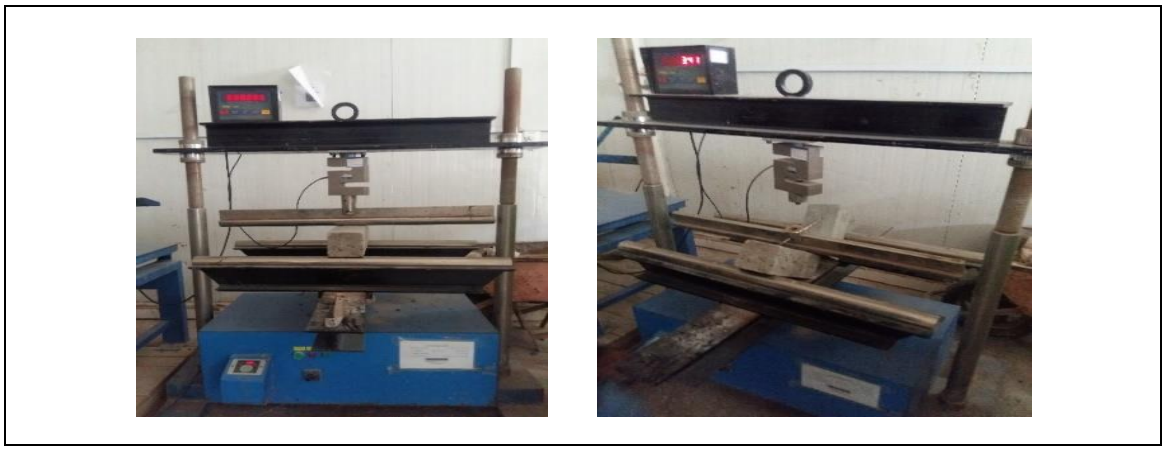


Figure 3.8: Flexural Tensile Strength Test.

3.7 INSTRUMENT AND TEST PROCEDURE

All concrete beams tested untie to the failure as a simply supported beam. A single concentrated force was applied on the top surface of the concrete beam at the mid-span. The universal testing machine, load cell, and digital dial gauge sensors are shown in Figure (3.9). The digital dial gauge was placed under the beam to measure the deflection of the tested beam at mid-span.

The specimens were coated with white plastic dyes for easy observation and tracking of cracks during the examination. The concrete beams were tested by using a universal testing Machine (1000 KN). The rate of the load was 10 KN applied continuously then reduced to 5 KN when the load reaches 100 KN until the specimen failed.

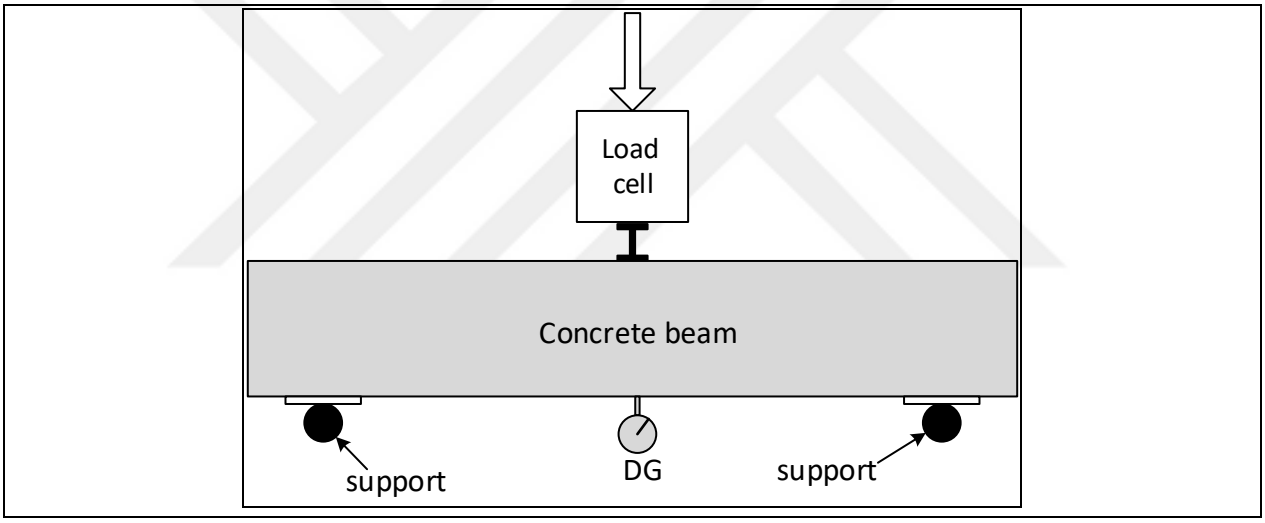


Figure 3.9: Schematic Diagram Of The Testing Sensors.

4. RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter presents the experimental results of ten reinforced concrete beams that were either transversely reinforced using conventional steel bars, which are considered as reference specimens, or using steel tubes as shear reinforcement. The specimens test covered many parameters such as the type of the shear reinforcement used in specimens, the compressive strength of the specimens (30, 50) MPa, and shear steel inclination angles (90 and 45 deg.). This chapter has discussed the effect of the parameters on the ultimate load and the type of failure that occurs by observing the shear failer behavior of each specimen. The comparison between specimens by the experimental results (maximum load, deflection) was performed.

4.2 CONCRETE TEST RESULTS

The compression test of concrete was carried out in accordance with the requirements of BS1881-part 1, the test included nine cubics with dimensions (15*15*15) cm at the age of (28) days. Table (4-1) shows the compressive strength results of the two mixtures (M1 and M2). The table showed that the mixture (M2) gave a higher compressive strength than the mixture (M1) of 38.5%. The average compressive strength was 29.35 and 48.77 MPa for concrete mix M1 and M2 respectively.

Table 4.1: Cube Compressive Strength of Concrete Mixes.

Cube	Compression strength (MPa)	
	M1≈30 MPa	M2≈50 MPa
1	27.87	48.03
2	27.06	47.43
3	27.32	49.08
4	28.91	47.83
5	29.22	50.75
6	32.48	49.63

Table 4.1: Cube Compressive Strength of Concrete Mixes 'Table Contied'.

Cube	Compression strength (MPa)	
	M1≈30 MPa	M2≈50 MPa
7	28.70	49.29
8	30.91	48.93
9	31.71	47.99
Average	29.35	48.77

The split tensile test for the two mixtures was carried out according to the requirements of ASTM C496. The split tensile test used three cylinders with dimensions (100*200 mm) for each mixture at the age of (28) days. Table (4-2) shows the results of the test, it was observed that the tensile strength of mixture (M2) increased by 26% compared to the mixture (M1). The average splitting tensile was 3.64 and 4.93 MPa for concrete mix M1 and M2 respectively.

The flexural tensile test was carried out in accordance with the requirements of ASTMC 78. The flexural tensile test used three prisms with dimensions of (100*100*500 mm) for each concrete mix at the age of (28) days. The comparison was made between the flexural strength of the two mixtures through Table (4-3). Flexural tensile results show that the mixture (M2) was superior to the mixture (M2) of 27.25%. The average flexural tensile was 2.99 and 4.11 MPa for concrete mix M1 and M2 respectively.

Table 4.2: Tensile Strength Results.

Cylinder	Splitting tensile strength (MPa)	
	M1≈30 MPa	M2≈50 MPa
1	3.76	5.01
2	3.55	4.84
3	3.62	4.94
Average	3.64	4.93

Table 4.3: Flexural Strength Test Results.

Prism	Modulus of rupture (MPa)	
	M1≈30 MPa	M2≈50 MPa
1	3.08	4.11
2	2.96	4.21
3	2.92	4.01
Average	2.99	4.11

4.3 RESULTS OF SPECIMENS

In this section cracks types, and the first cracking loads are presented for the tested specimens. Also, failure modes, and ultimate load, will be discussed. Finally, the load-deflection curves will be shown. The results of the test specimens will be discussed due to changes in the concrete compressive strength, shear reinforcement type, and inclined angle of it.

4.3.1 Cracks and Failure Modes

The major types of cracks are shear and flexure cracks, Table 4-4 shows the first cracking load of these types. Figure (4-1) shows the cracks of the specimens after failure. From Table (4-4) all shear cracks appear before flexure cracks, with the exception of two specimens, in the first specimen (S30IH) cracks appear at the same stage of load, and in the second specimen (B30I) flexural cracks loads are higher. Specimens are designed to fail by shearing, so most specimens have a higher resistance to flexure cracks, while shear cracks appear before them.

Table 4.4: Specimens Test Results.

No.	ID	First cracking load (kN)		Percent (shear/flexural) cracking load	Ultimate load Pu (kN)
		Shear	Flexural		
1	B30P	85	97	87.63	207
2	B30I	90	76	118.42	243
3	B50P	94	143	65.73	261
4	B50I	88	99	88.89	291
5	S30P	73	90	81.11	186
6	S30I	85	115	73.91	219
7	S50P	105	138	76.09	246
8	S50I	84	91	92.31	270
9	S30PH	81	103	78.64	192
10	S30IH	71	71	100.00	211

The minimum load in which the cracks appear was 71 kN, which is for the specimen (S30IH), in this specimen, both types of cracks (shear and flexion) appear at the same loading stage. The maximum load in which the flexure cracks appear was 143 kN, which is for the specimen (B50P), while the maximum load in which the shear cracks appear was 105kN, which is for the specimen (S50P). The minimum cracking load that appears in the specimen has 30 MPa as concrete compressive strength, while the maximum cracking load that appears in the specimen has 50 MPa as concrete compressive strength, these results are normal and expected.

Figures (4-1 to 4-10) shows the failure modes of the tested specimens. When studying failure modes, it can be found that all specimens have failed under the influence of shear loads, and this type of failure can be classified as a brittle failure. This type of failure was expected because the specimens were designed to fail by shear forces.

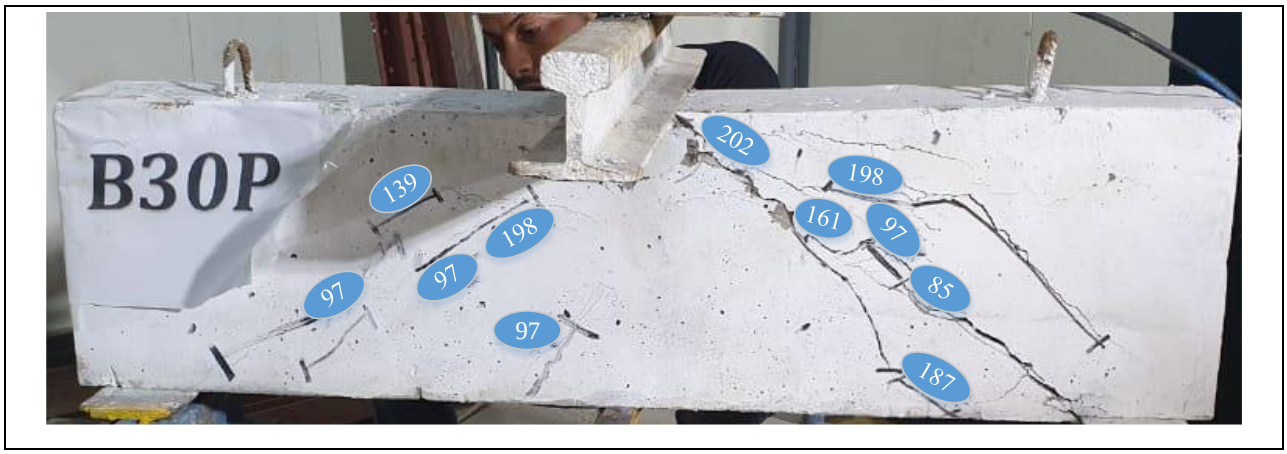


Figure 4.1: Cracks of Test Specimens (Specimen B30P)

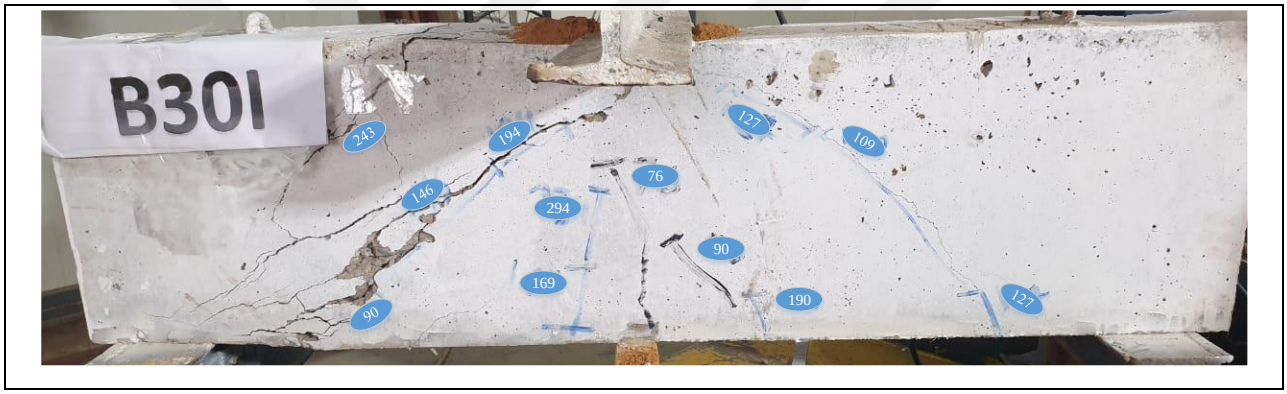


Figure 4.2: Cracks of Test Specimens (Specimen B30I)

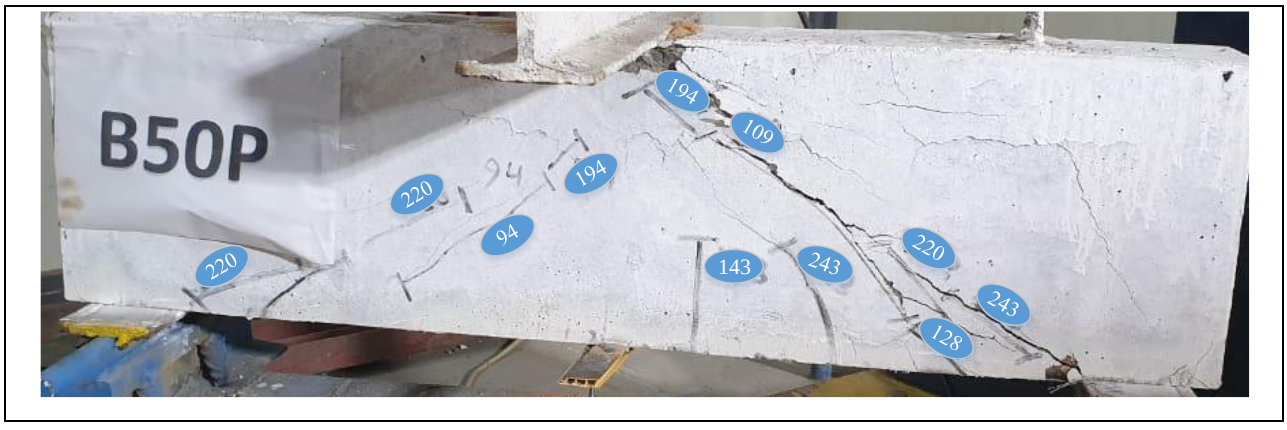


Figure 4.3: Cracks of Test Specimens (Specimen B50P)

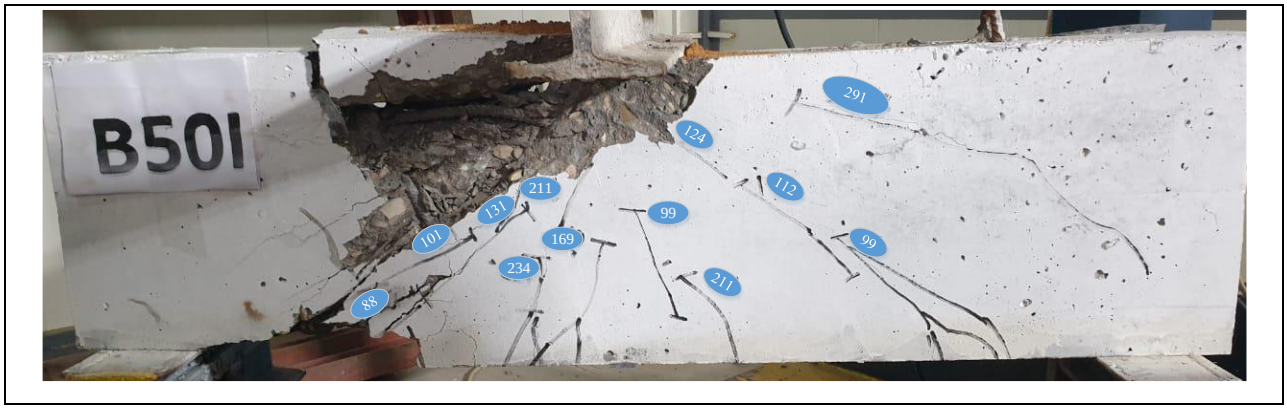


Figure 4.4: Cracks of Test Specimens (Specimen B50I)

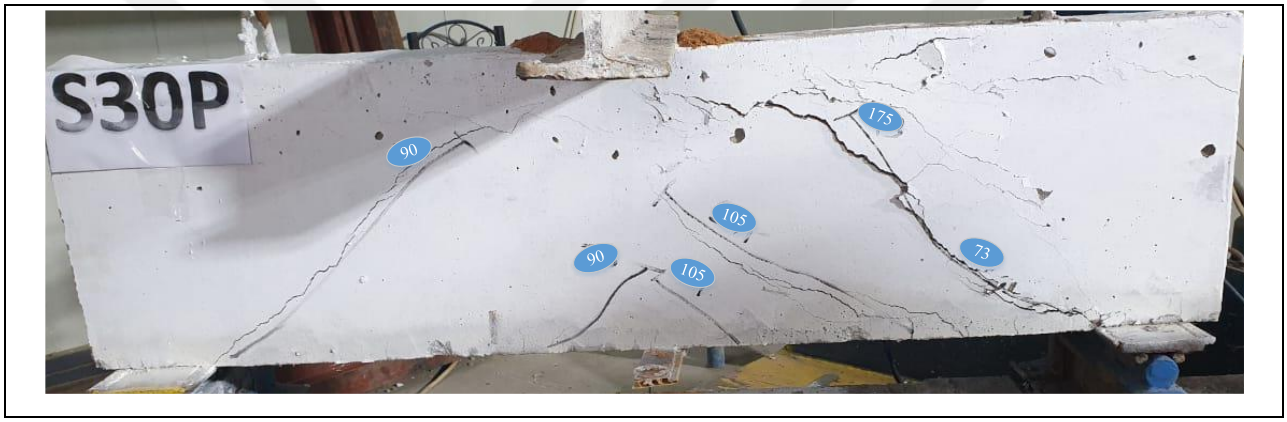


Figure 4.5: Cracks of Test Specimens (Specimen S30P)

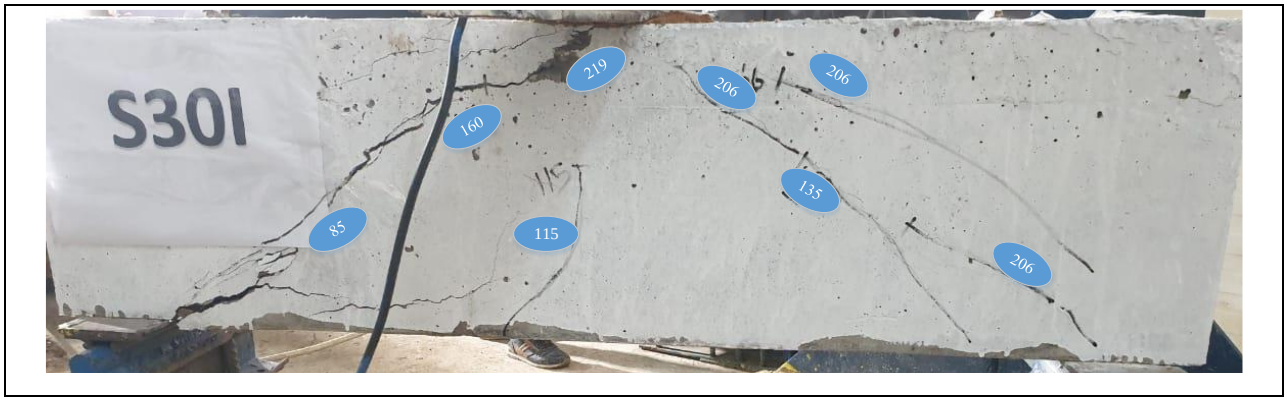


Figure 4.6: Cracks of Test Specimens (Specimen S30I)

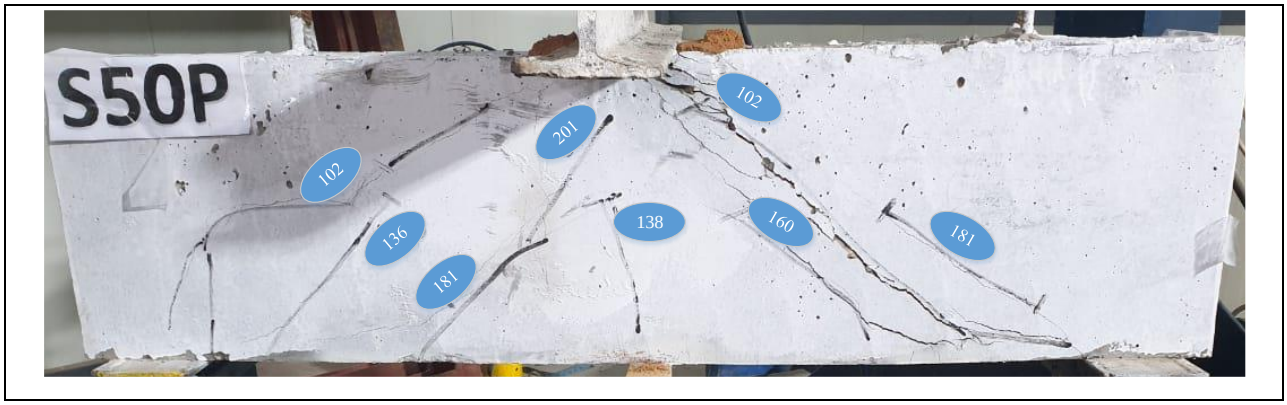


Figure 4.7: Cracks of Test Specimens (Specimen S50P)

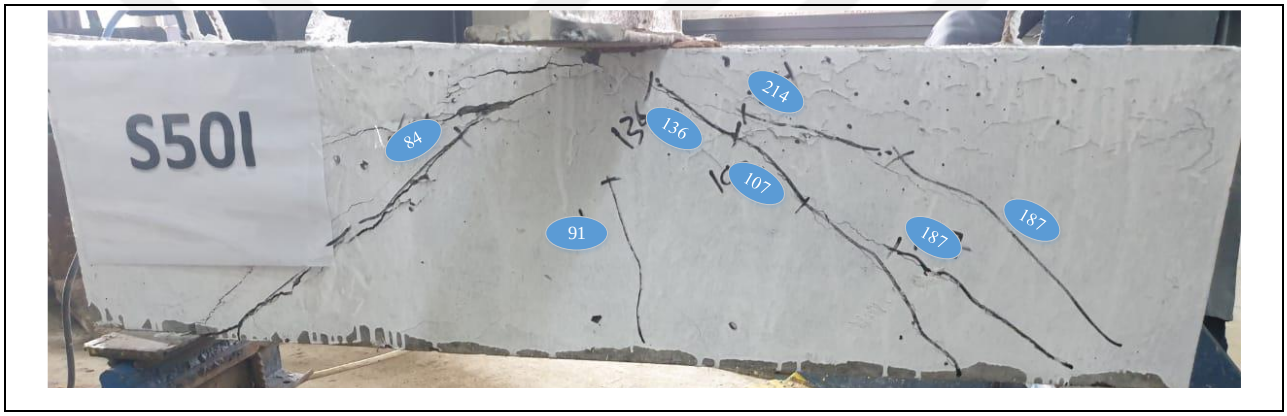


Figure 4.8: Cracks of Test Specimens (Specimen S50I)

Figure 4.9: Cracks of Test Specimens (Specimen S30PH)

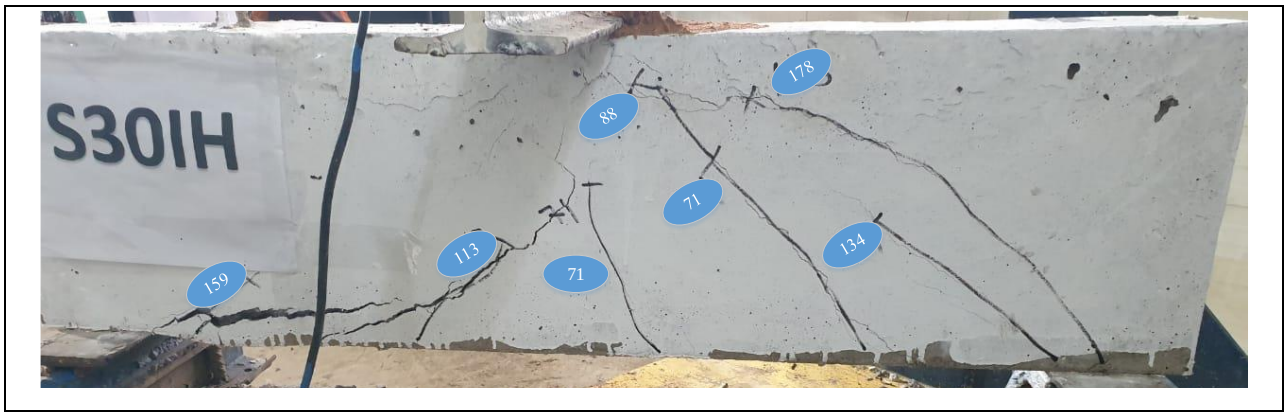


Figure 4.10: Cracks of Test Specimens (Specimen S30IH)

4.3.2 Ultimate Loads

Table(4-5) shows the ultimate load of all specimens. when study the change of concrete compressive strength the reference specimens (B30P) and (B30I) have a maximum load of 207 KN and 243 KN. In general, it can be noted that changing the compressive strength from 29.35 MPa to 48.77 increases the failure loads of the specimens. specimens (B50P) and (S50P) have failure loads of 261 KN and 246 KN, and when comparing them with the reference specimen (B30P) it can be found that the percentage increase in the failure load is 26.09% and 18.84%, respectively. This increase in loads is due to an increase in concrete compressive strength. Also, specimens (B50I) and (S50I) have failure loads of 291 KN and 270 KN, and when comparing them with the reference specimen (B30I) it can be found that the percentage increase in the failure load is 19.75% and 11.11%, respectively.

Two angles are used to study the steel arrangement (90º, and 45º). Table (4-5) shows the compression of ultimate load between tested specimens when change the shearing steel arrangement. In general, specimens containing 45° shearing steel reinforcement had higher resistance than specimens containing 90° shearing steel reinforcement. The largest increase percentage was 17.74%, while the lowest percentage was 9.76%. When comparing the percentage increase as a result of changing the arrangement of the shear reinforcement, it can be found that it is less than expected, as it should be 41%. The ACI 318-14 Code used the coefficient below (F) to calculate the effect of the shearing steel when it is inclined at a certain angle.

$F = \sin \propto + \cos \propto$

if α is 45º led to F=1.41, this mean the increasing percent is 41%.

Table 4.5: Compression between Ultimate Load of Tested Specimens.

specimens ID[1]	Ultimate load Pu (kN)	specimens ID[2]	Ultimate load Pu (kN)	Increasing precent
B30P	207	B30I	243	117.39
B50P	261	B50I	291	111.49
S30P	186	S30I	219	117.74
S50P	246	S50I	270	109.76
S30PH	192	S30IH	211	109.90

a. specimens have shear reinforcement of 90º arrangement.

b. specimens have shear reinforcement of 45º arrangement.

From Table (4-4), it can be noticed that when using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 10.14 %, while it decreases by 7.25 when the tube is hollow. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 9.88 %, while it decreases by 13.17 when the tube is hollow. Also, Table (4-4) shows that when using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 5.74 %. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 7.24 %. The percentages of decrease in ultimate load are considered acceptable when compared to the percentage of decrease in (As*fy), so this type of steel reinforcement (steel tube) is considered acceptable to resist shear stresses.

Figure (4-2) shows the comparison between the cracking load (shear and flexural) and the ultimate load.

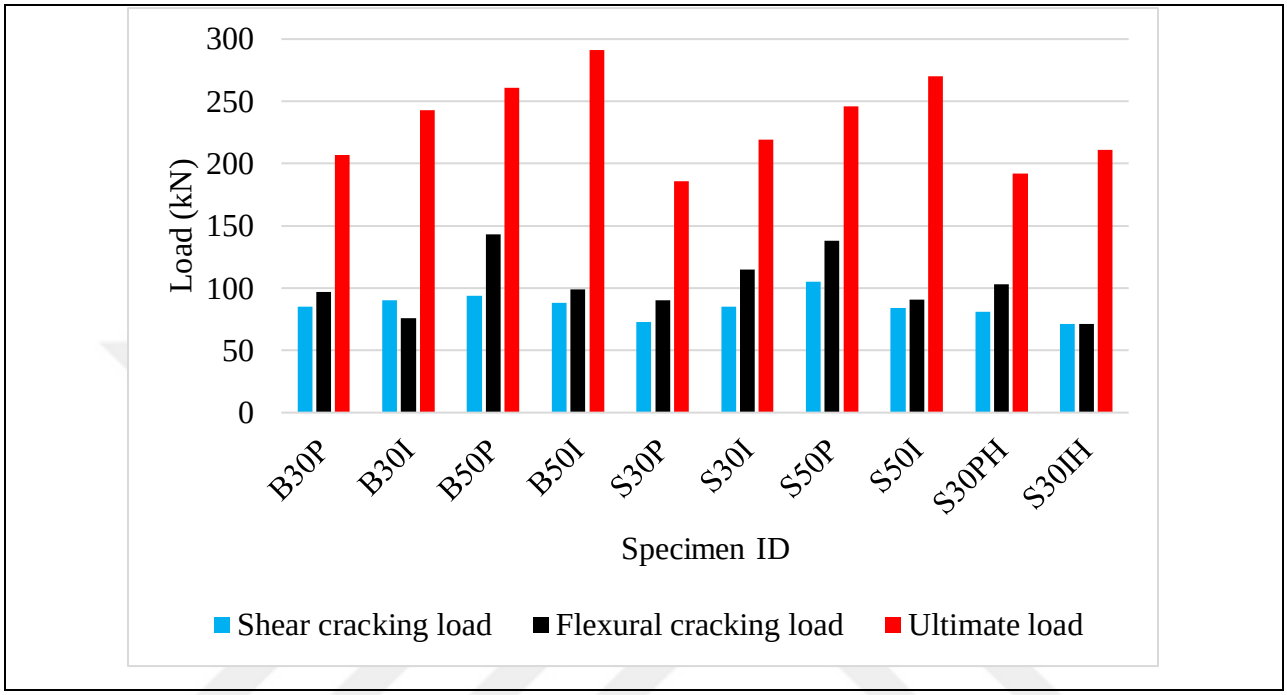


Figure 4.11: Cracking Loads and Ultimate Loads of Test Specimens.

4.3.3 Load vs Deflection Curves

The load vs deflection are very important curves to read the changes that occur to specimens at continuous and gradually increasing loading until failure occurs, and through it will be try in this part to make comparisons of specimens in terms of load and deflection. Figure (4-12) shows the load vs deflection curves for all tested specimens.

By noting Figure (4-12), the load vs deflection curves can be divided into three stages. The first stage is linear (elastic) and continues until cracks appear in the tested specimen. The second stage is also linear in most cases, starting from the appearance of cracks and continuing until the yielding of the reinforcing steel occurs. As for the third and final stage, it is mostly non-linear and continues until the failure of the specimen. This stage is often short and some specimens are difficult to distinguish in this stage because the specimens fail suddenly and the failure is accompanied by a loud explosion sound.

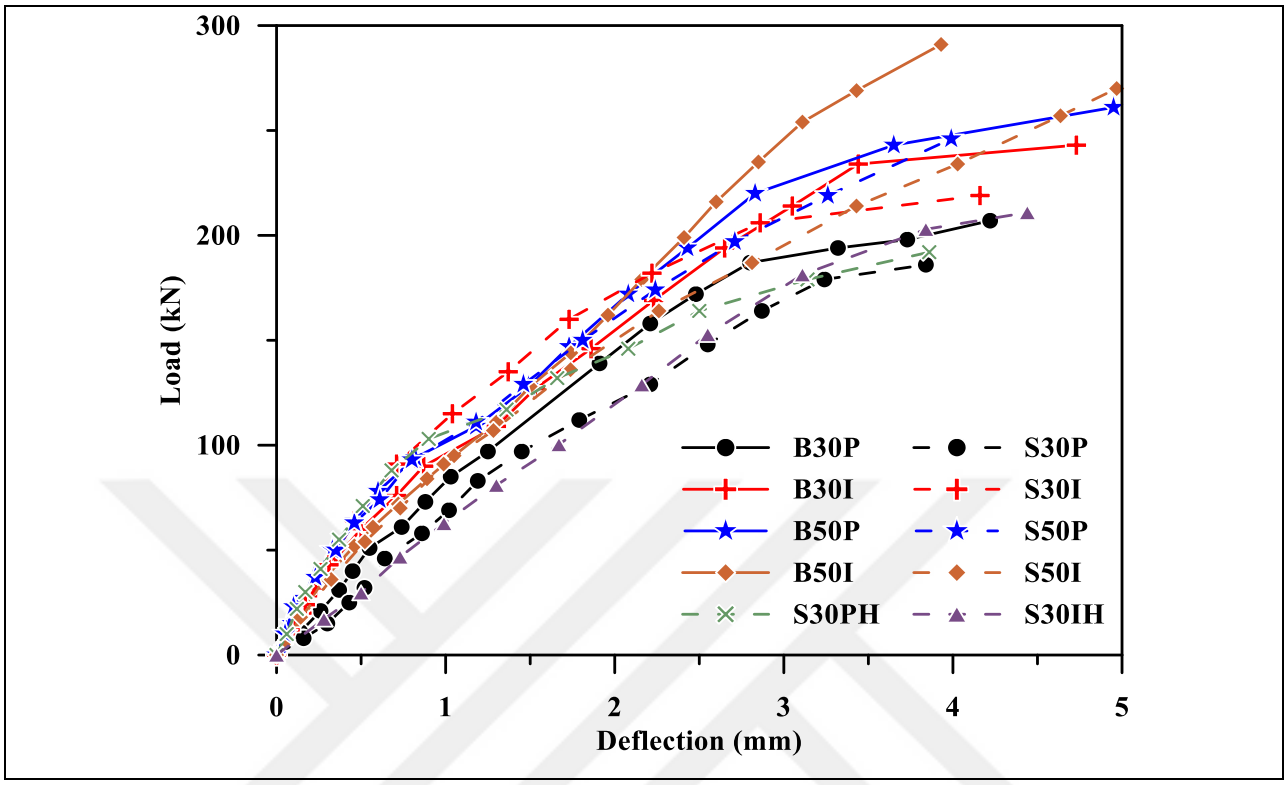


Figure 4.12: Load Deflection of All Specimens.

Figure (4-13) shows the effect of concrete compressive strength for specimens reinforced with steel bars as a shear reinforcement, while Figure (4-14) shows the effect of concrete compressive strength for specimens reinforced with steel tube as a shear reinforcement. Figure (4-15) study the change of concrete compressive strength the reference specimens (B30P) and (B30I) have a maximum load of 207 KN and 243 KN. In general, it can be note that changing the compressive strength from 29.35 MPa to 48.77 increases the failure loads of the specimens. Specimens (B50P) and (B50I) have failure loads of 261 KN and 291 KN, and when compare them with the reference specimens it can be find that the percentage increase in the failure load is 26.09% and 19.75%, respectively. This increase in loads is due to an increase in concrete compressive strength.

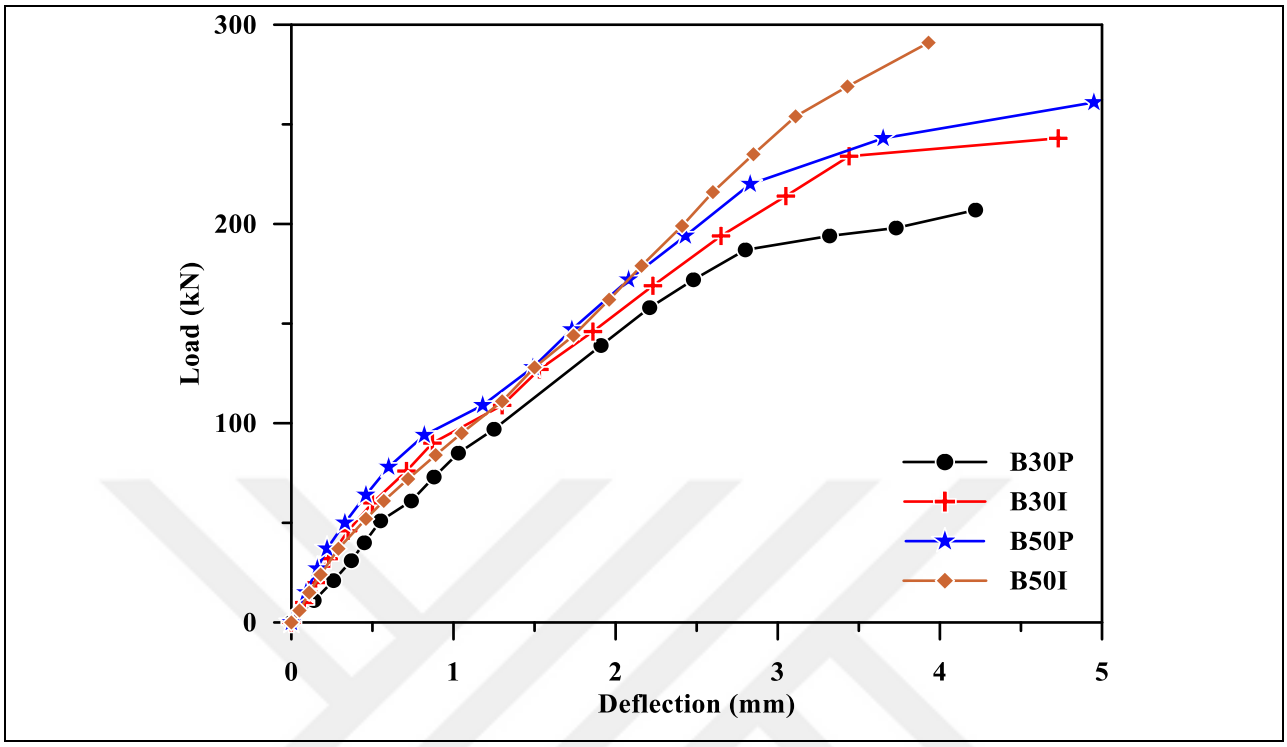


Figure 4.13: Effect of Compressive Strength on Load Deflection Curves of Specimens Reinforced with steel bars.

Figure (4-15) have two reference specimens (S30P) and (S30I), these specimens failed at load equal to 186 KN and 219 KN, respectively. Specimens (S50P) and (S50I) have failure loads of 246 KN and 270 KN respectively, and when compare them with the reference specimens it can be find that the percentage increase in the failure load is 32.26% and 23.29%, respectively.

Figure (4-14) shows the effect of shear reinforcement type and arrangement angle of shear reinforcement on load-deflection curves of specimens has concrete compressive strength equal to 30 MPa. While Figure (4-16) shows the effect of shear reinforcement type and arrangement angle of shear reinforcement on load-deflection curves of specimens has concrete compressive strength equal to 50 MPa.

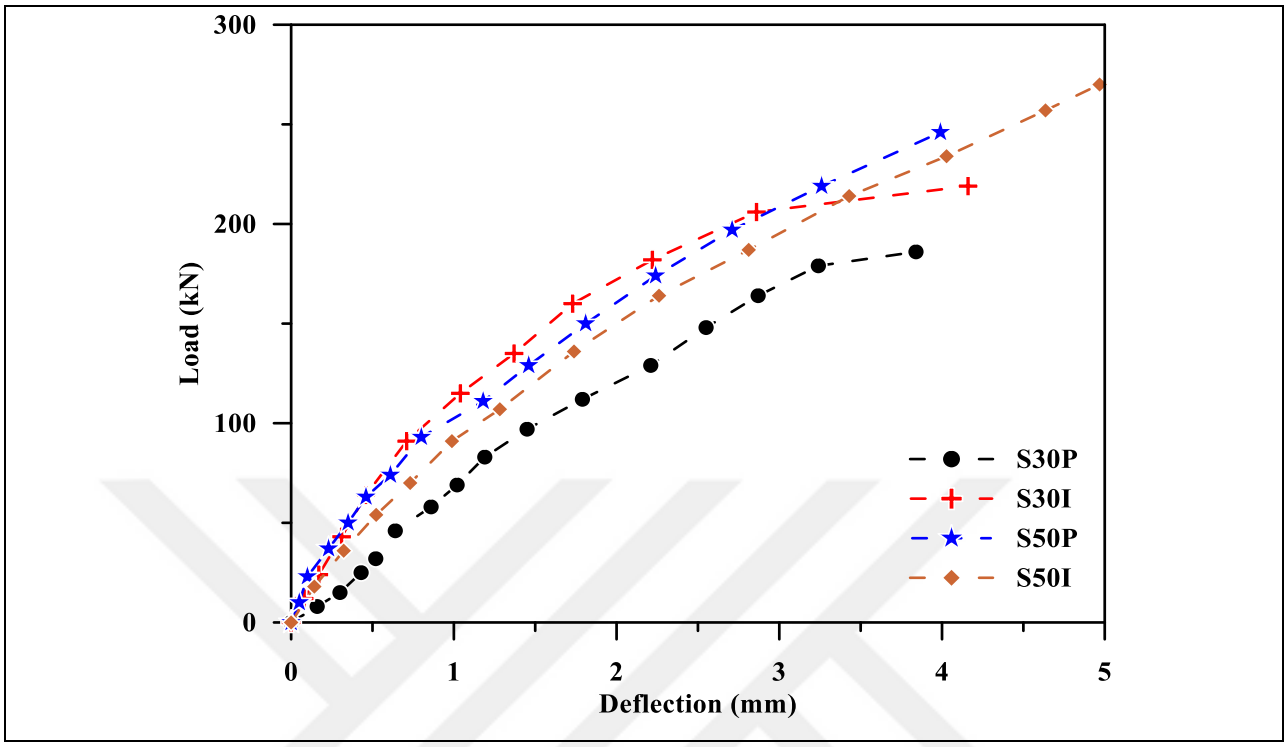


Figure 4.14: Effect of Compressive Strength on Load Deflection curves of specimens reinforced with steel tubes.

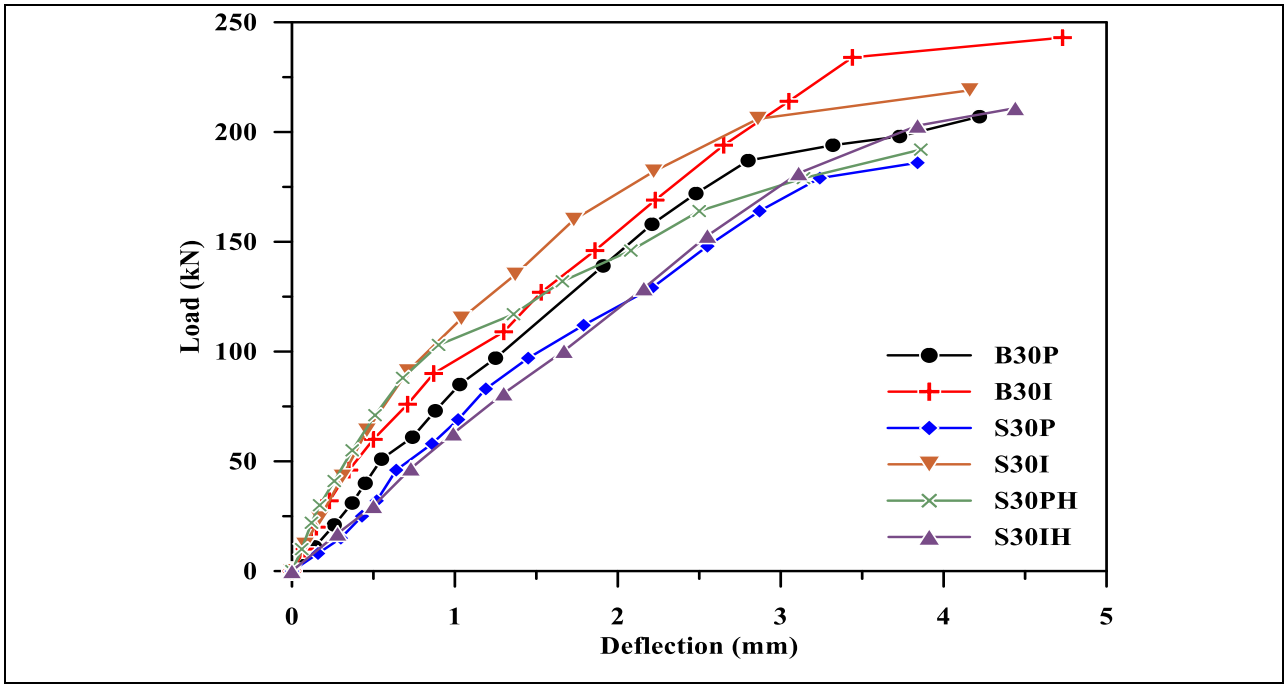


Figure 4.15: Effect of Shear Reinforcement Type on Load-Deflection Curves of specimens has compressive strength = 30 MPa.

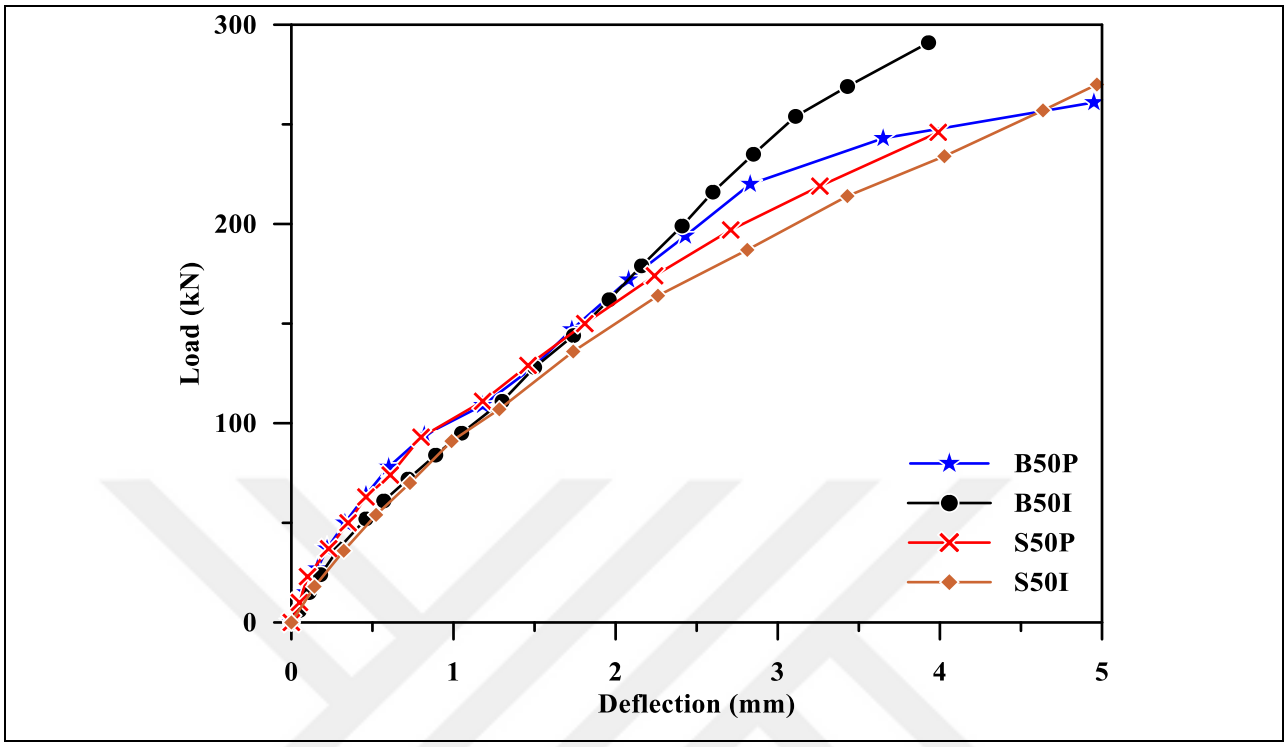


Figure 4.16: Effect of Shear Reinforcement Type on Load-Deflection Curves of specimens has compressive strength = 50 MPa.

Figures (4-15) and (4-16) can show two types of parameters when comparing the results of the specimens. The first type is the arrangement of the reinforcing steel at different angles (45 and 90), while the second type of parameters is the use of a new type of shear reinforcement as an alternative to the usual shear steel reinforcement bars (filled tubes or empty tubes). In general, it can be noticed when reinforcing the specimens with shear reinforcement at an angle of 45º that the specimens give a higher resistance than the specimens that have been reinforced at an angle of 90º. Figure (4-15) shows that the increase in the final load ranges from 9.9 % to 17.74 %, while Figure (4-16) shows that the increase in the final load ranges from 9.76 % to 11.49 %.

When studying the use of steel tubes as an alternative to usual steel reinforcement to resist shear forces, it can be found that the final resistance of the tested specimens has decreased. Before deciding that the alternative of steel reinforcement bar is not useful, it is necessary to know the value of (As*fy) for both types (steel bar and steel tube), which is equal to 77250 N for the steel bar, while for the steel tube is 68580 N. Therefore, it is considered that there is a decrease in the strength of the steel tube that resists shear stresses, and the percentage of this decrease is 11.22%.

From Figure (4-15), it can be noticed that when using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 10.14 %, while it decreases by 7.25 when the tube is hollow. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 9.88 %, while it decreases by 13.17 when the tube is hollow. From Figure (4-16), it can be noticed that when using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 5.74 %. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 7.24 %. The percentages of decrease in ultimate load are considered acceptable when compared to the percentage of decrease in (As*fy), so this type of steel reinforcement (steel tube) is considered acceptable to resist shear stresses.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Depending on the test results of this study, the following conclusions were drawn**:**

a. In general, all the tested specimens showed cracks resulting from bending and shearing stress, but the shear cracks appear before flexure cracks, with the exception of two specimens, in the first specimen (S30IH) cracks appear at the same stage of load, and in the second specimen (B30I) flexural cracks loads are higher. The minimum cracking load that appears in the specimen has 30 MPa as concrete compressive strength, while the maximum cracking load that appears in the specimen has 50 MPa as concrete compressive strength.

b. All tested specimens have failed under the influence of shear stresses, and the type of failure can be classified as a brittle failure (shear failure modes).

c. Three stages are shown in the load vs deflection curves. The first stage is linear (elastic) and continues until cracks appear in the tested specimen. The second stage is also linear in most cases, starting from the appearance of cracks and continuing until the yielding of the reinforcing steel occurs. The final stage is mostly non-linear and continues until the failure of the specimen. This stage is often short and some specimens are difficult to distinguish in this stage because the specimens fail suddenly and the failure is accompanied by a loud explosion sound.

d. One of the variables of the study was the compressive strength of concrete, where the first values of 29.35 MPa and 48.77 MPa were taken. As a result of the increase in the compressive strength of concrete, the ultimate load is higher for the tested specimens. As the percentage of increase ranged from 18.84 % to 26.09 %for the specimens in which the shear steel reinforcement was at an angle of 90º, while the percentage of increase ranged from 11.11 % to 19.75 % in the models that have shear steel at an angle of 45º.

e. The arrangement of shear steel reinforcement is taken in this study as a parameter, two angles are used (90º, and 45º) to study this effect. In general, specimens containing 45° shearing steel reinforcement had higher resistance than specimens containing 90° shearing steel

reinforcement. The largest increase percentage was 17.74%, while the lowest percentage was 9.76% when using ordinary steel bars to reinforce the specimens against shear stresses. When using steel tubes to reinforce the specimens against shear stresses the largest increase percentage was 17.74%, while the lowest percentage was 9.76%.

f. For specimens with compressive strength 30 MPa, using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 10.14 %, while it decreases by 7.25 when the tube is hollow. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 9.88 %, while it decreases by 13.17 when the tube is hollow. The above-decreased percentages are considered acceptable when compared to the steel tube resistance (As*fy) decrease, which is 11.22%.

g. For specimens with compressive strength of 50 MPa, using a filled steel tube as an alternative to a steel reinforcement bar at an angle of 90º, the ultimate load of the specimen decreases by 5.74 %. When used the steel reinforcement at an angle of 45º, the ultimate load of the specimen decreases by 7.24 %. The above-decreased percentages are considered less than the steel tube resistance (As*fy) decrease, which is 11.22%. Therefore, this type of steel reinforcement (steel tube) is considered an acceptable alternative to ordinary steel bars.

h. The alternative shear reinforcement (steel tube) instead of ordinary steel bar is considered acceptable to resist shear stresses

5.2 SUGGESTIONS FOR FUTURE STUDIES

Through the experimental work, the following suggestions are recommended:

a. Studying the performance of reinforced concrete beam by using concrete with steel fiber.

b. Studying the cost-benefit analysis for the use of replacing stirrups with a steel tube in reinforced concrete beams in coincidence with productivity and time factor.

c. Studying the behavior of beams using steel tubes as a shear reinforcement subjected to fire.

d. Studying the behavior of beams using steel tubes as a shear reinforcement using ultra-high-performance concrete.

e. Studying the behavior of beams using steel tubes as a shear reinforcement subjected to repeated load.

REFERENCES

[1] J. Jeong and W. Kim, “Shear Resistant Mechanism into Base Components : Beam Action and Arch Action in Shear-Critical RC Members,” vol. 8, no. 1, pp. 1–14, 2014, doi: 10.1007/s40069-013-0064-x.

[2] A. Lampropoulos, “CN229 - Design of Reinforced Concrete Members.”

[3] W. Nadir, “Design of Reinforced Concrete Structures I Torsion Chapter six Torsion,” 2006.

[4] G. Arslan and Z. Polat, “Contribution of concrete to shear strength of RC beams failing in shear,” *J. Civ. Eng. Manag.*, vol. 19, no. 3, pp. 400–408, 2013, doi: 10.3846/13923730.2012.757560.

[5] S. Pezeshk, “Chapter 9. Shear and Diagonal Tension,” *CIVL4135 Des. Reinf. Concr. Struct.*, pp. 168–183, 2014.

[6] F. Cakir, V. Acar, M. R. Aydin, B. Aksar, and P. Yildirim, “Strengthening of reinforced concrete beams without transverse reinforcement by using intraply hybrid composites,” *Case Stud. Constr. Mater.*, vol. 15, no. September, p. e00700, 2021, doi: 10.1016/j.cscm.2021.e00700.

[7] ACI Committee 318, *Building Code Requirements for Structural Concrete*. 2014.

[8] S. O. F. The, O. F. Shear, S. For, E. Control, J. Nath, and G. O. Sain, “A STUDY OF THE APPLICATION OF SHEAR STRENGTH Department of Civil Engineering AUt,” 1969.

[9] A. Feldman and C. P. Siess, “Effect of moment-shear ratio on diagonal tension cracking and strength in shear of reinforced concrete beams,” *Univ. Illinois Urbana*, no. 107, 1955, [Online]. Available: https://www.ideals.illinois.edu/handle/2142/13989.

[10] A.-A. C. 426, “The Shear Strength of Reinforced Concrete Members,” *J. Struct. Div. ASCE*, vol. 99, no. ST6, pp. 1091–1187, 1973.

[11] S. Strength *et al.*, “N in Civil Engineering,” 2018.

[12] L. H. Sneed and J. A. Ramirez, “Influence of effective depth on shear strength of concrete beams - Experimental study,” *ACI Struct. J.*, vol. 107, no. 5, pp. 554–562, 2010, doi: 10.14359/51663906.

[13] M. Słowik, “The analysis of failure in concrete and reinforced concrete beams with different reinforcement ratio,” *Arch. Appl. Mech.*, vol. 89, no. 5, pp. 885–895, 2019, doi: 10.1007/s00419-018-1476-5.

[14] M. Słowik, “Shear Failure Mechanism in Concrete Beams,” *Procedia Mater. Sci.*, vol. 3, no. Vd, pp. 1977–1982, 2014, doi: 10.1016/j.mspro.2014.06.318.

[15] P. S. Chana, “Investigation of the mechanism of shear failure of reinforced concrete beams,” *Mag. Concr. Res.*, vol. 39, no. 141, pp. 196–204, 1987, doi: 10.1680/macr.1987.39.141.196.

[16] G. J. P.-M. CHU- KIA WANG, CHARLES G. SALMON, JOSÉ A. PINCHEIRA, *REINFORCED CONCRETE DESIGN*. New York: OXFORD UNIVERSITY PRESS, 2018.

[17] A. Sunderland, “The strength of reinforced concrete beams in shear,” *Mag. Concr. Res.*, vol. 1, no. 1, pp. 3–8, 1949, doi: 10.1680/macr.1959.1.1.3.

[18] S. Furlan and J. B. De Hanai, “Shear behaviour of fiber reinforced concrete beams,” *Cem. Concr. Compos.*, vol. 19, no. 4, pp. 359–366, 1997, doi: 10.1016/S0958-9465(97)00031-0.

[19] C. Arya, *Design of structural elements: Concreate, steelwork, masonry and timber designs to british standards and eurocodes*. 2009.

[20] G. Savaris and I. de G. Laufer, “Shear strength of steel fiber self-compacting concrete beams,” *Semin. Ciências Exatas e Tecnológicas*, vol. 42, no. 1, p. 45, 2021, doi: 10.5433/1679-0375.2021v42n1p45.

[21] J. A. Torres and E. O. L. Lantsoght, “Influence of fiber content on shear capacity of steel fiber-reinforced concrete beams,” *Fibers*, vol. 7, no. 12, 2019, doi: 10.3390/?b7120102.

[22] K. N. Rahal and Y. T. Alrefaei, “Shear strength of longitudinally reinforced recycled aggregate concrete beams,” *Eng. Struct.*, vol. 145, pp. 273–282, 2017, doi: 10.1016/j.engstruct.2017.05.028.

[23] H. Do Yun, G. Y. Jeong, and W. C. Choi, “Shear strengthening of high strength concrete beams that contain hooked-end steel fiber,” *Materials (Basel).*, vol. 15, no. 1, pp. 1–13, 2022, doi: 10.3390/ma15010017.

[24] S. P. Patil and K. K. Sangle, “Shear and flexural behaviour of prestressed and non-prestressed plain and SFRC concrete beams,” *J. King Saud Univ. - Eng. Sci.*, vol. 29, no. 4, pp. 321–328, 2017, doi: 10.1016/j.jksues.2016.01.005.

[25] M. Kaszubska, R. Kotynia, and J. A. O. Barros, “Shear deformation and failure modes of gfrp reinforced concrete beams without stirrups,” *fib Symp.*, no. Kani 1964, pp. 3921–3935, 2018.

[26] A. Prof and K. Medhlom, “Shear Capacity of Steel Fiber Non-Metallic (GFRP) Reinforced Concrete Beams Strengthened in Shear Using CFRP Laminates,” vol. 8, no. 8, pp. 104–119, 2016.

[27] C. A. Juárez Alvarado, J. M. Mendoza Rangel, B. T. Terán Torres, P. L. Valdez Tamez, and G. Castruita Velázquez, “Theoretical-experimental behavior of steel fibers as a partial replacement for shear reinforcement in reinforced concrete beams,” *Rev. ALCONPAT*, vol. 11, no. 3, pp. 31–41, Sep. 2021, doi: 10.21041/ra.v11i3.548.

[28] Muhaned A. Shallal, “Evaluation of ACI Shear Provisions for Concrete Beams Without Web Reinforcement Using Stepwise Regression,” *J. Eng. Appl. Sci.*, vol. 13, no. 11, pp. 3965–3978, 2018.

[29] V. C. A. Suhaib Jamal Al, Amer M. Ibrahim, “Effect of Steel Plate in Shear Reinforced Wide Beam Concrete,” *Int. J. Sci. Res.*, vol. 4, no. 2, pp. 596–601, 2015.

[30] A. Q. W. Ibrahim, A. M., Salman W. D., “Effect of steel plates on shear strength of wide reinforced concrete beams,” *J. Eng. Sustain. Dev.*, vol. 19, no. 3, pp. 96–109, 2015.

[31] and A. A. M. Amer M. Ibrahim, Mohammed J. Hamood, “BEHAVIOUR OF WIDE REINFORCED CONCRETE BEAMS WITH DIFFERENT SHEAR STEEL PLATES SPACING,” *J. Eng. Sustain. Dev.*, vol. 20, no. 05, pp. 120–135, 2016.

[32] N. S. Galip, R. Noor Mohamed, and R. Abdullah, “Shear resistance of welded inclined bars in rectangular reinforced concrete beams,” *MATEC Web Conf.*, vol. 250, 2018, doi: 10.1051/matecconf/201825003003.

[33] F. Cakir, V. Acar, M. R. Aydin, B. Aksar, and P. Yildirim, “Strengthening of reinforced concrete beams without transverse reinforcement by using intraply hybrid composites,” *Case Stud. Constr. Mater.*, vol. 15, no. May, p. e00700, 2021, doi: 10.1016/j.cscm.2021.e00700.

[34] I. M. A. A. Amer M. Ibrahim, Zeyad S. M. Khaled, “Effect of Using Internal Steel Plates for Shear Reinforcement on Flexural Behavior of Self-Compacting Concrete Beams,” *Al-Nahrain J. Eng. Sci.*, vol. 20, no. 5, pp. 1071–1082, 2017.

[35] jeetu, “B4337125215,” no. 2, pp. 42–47, 2015.

[36] M. Al-Nasra, “The Use of Space Swimmer Bars as Shear Reinforcement in Reinforced Concrete Beams,” *Int. J. Eng. Technol.*, vol. 9, no. 2, pp. 946–954, 2017, doi: 10.21817/ijet/2017/v9i2/170902235.

[37] P. Anima, “STUDY ON SELF COMPACTING BEAM WITH WELDED WIRE MESH AS SHEAR,” vol. 9, no. 8, pp. 792–797, 2021.

[38] W. Nawaz, R. A. Hawileh, E. I. Saqan, and J. A. Abdalla, “Effect of longitudinal carbon fiber-reinforced polymer plates on shear strength of reinforced concrete beams,” *ACI Struct. J.*, vol. 113, no. 3, pp. 577–586, 2016, doi: 10.14359/51688475.

[39] A. Laftah Abass, “Shear behavior of reinforced concrete wide beams strengthened with CFRP sheet without stirrups,” *Djes*, vol. 12, no. 1, pp. 80–98, 2019, doi: 10.24237/djes.2019.12110.

[40] H. A. Khudhair and A. L. Abbas, “Replacing traditional stirrups by shear steel pate with high performance sustainable concrete beams under static load,” *J. Green Eng.*, vol. 10, no. 9, pp. 5837–5850, 2020.

[41] Specification IS. 1984 No. 5/1984, Portland Cement. Central Organization for Standardization & Quality Control (COSQC), Baghdad, Iraq

[42] Central Organization for Standardization & Quality Control (COSQC), Baghdad 1984 Iraqi Specifications No. (45), 1984 for Aggregates of Natural Resources used for Concrete and Construction.

[43] ASTM 996M-05 2004: Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement.

[44] American Concrete Institute ACI 211.1-91 Standard Practice for Selecting Proportions for Normal Heavyweight, and Mass Concrete.

[45] BSI 1983 British Standard 1881-116 Test method for determination of compressive strength of concrete cubes.

[46] ASTM C496 2011: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

[47] ASTM C78 / C78M - 18 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)