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Review Research

SHEAR CAPACITY OF REINFORCED CONCRETE BEAMS WITHOUT SHEAR REINFORCEMENT: REVIEW

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Abstract: Shear failure in reinforced concrete beams has gained excessive study, particularly beams without stirrups. Because shear failure is considered the most serious due to it occurring suddenly without warning. Because of the seriousness of the matter concerning shear failure, many researchers are looking to use additive materials that differ from traditional concrete constituents in order to improve the shear resistance of the beams, such as the use of silica fume, steel fiber, metakaolin, and many others. The current studies focused on understanding the resistance provided by the interlocking forces between the aggregate and that provided by the non-cracked compression zone, with the use of some materials that are intended to improve the properties of concrete. This paper presents a review of the previous literature that included studying the mechanism and behavior of shear failure of concrete beams without web reinforcement and also includes a presentation of the most important equations used to predict the shear capacity of concrete beams, especially those without stirrups, to understand the mechanism of failure and to know the most important factors affecting the failure of shear.

Keywords: Shear; beams; without stirrups; aggregate interlock; uncracked concrete

1. Introduction

Shear is a term that describes a force that has the possibility of causing a sliding failure on a long plane parallel to the force direction. Because many factors are involved, the shear failure of R.C. beams is a complicated event. The ratio of the longitudinal reinforcement (ρ_s), shear span/effective depth ratio (a/d), compressive strength of concrete (f_c'), the density of concrete, the maximum size of coarse aggregate, beam size, clear length-to-depth ratio (L/d), the split tensile strength of concrete, the number of layers of longitudinal reinforcement, and other parameters that affect the shear resistance of beams [1]. After flexural fractures have formed, the compression zone of the concrete absorbs a certain amount of shear stress. Failure is brought on by a combination of shear and compressive loads because the concrete is not fractured. This means that the reinforcement ratio and compressive strength may both be used to describe shear force [2]. Many experiments on reinforced concrete beams subjected to concentrated loads demonstrate that the shear strength declined as the depth of the beam rose. Depending on the a/d ratio, reinforced concrete beams are divided into three categories [3]:

- Deep beam for a/d < 1
- Short beam for 1 < a/d < 2.5
- Normal beam for a/d > 2.5

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Although there has been a lot of study on the shear strength of beams without stirrups, it is still up for discussion how the key factors affect the ultimate shear strength V_u and cracking shear strengths V_c. In many cases, the a/d ratio has a great effect on V_u, but it has little effect on V_c [4]. However, the shear resistance of the beam typically declines as beam section height rises [5]–[8]. High-reinforced concrete beams lacking transverse reinforcement are susceptible to brittle failure due to shear pressures and the development of diagonal fractures. After cracking has taken place, concrete still has some tensile stress-carrying capacity. This ability only matters for cracks that are less than 0.1 mm, which enable tensile ties to be produced across the cracks [9]. However, strain softening of the tensile concrete is not the only factor that affects the progression of an inclined fracture. More significantly, mechanisms such as steel bar action, dowel action, and aggregate interlock contribute to the development of failure fractures [10]. It would be nonsensical to assume that different equations would govern failure in concrete because concrete is merely one of many quasi-brittle materials that have a brittle failure when subjected to loads [11]. Most of the codes and equations proposed by the researchers work to reduce the shear resistance of beams without stirrups [12]. According to Kani's studies, there is a considerable difference between the behavior of real structural elements and a test specimen created in a lab [13]. Although members without stirrups generally understand the role of aggregate interlock, there is little experimental data available for members without web reinforcement [14]. Despite the difference of opinions about the parameters affecting the failure of shear, the important thing to know is that the failure is caused by the semi-fibrous behavior of concrete, and the maximum load is not achieved until after the crack growth and development not since the beginning of the crack formation [11]. This review aims to collect as much information as possible and present the most important factors affecting the shear behavior of beams without stirrups, in addition to knowing the opinions of researchers in terms of mathematical expressions to predict shear strength.

2. Factors Affected the Shear Strength of R.C. Beams Without Stirrups

Many factors affect the shear strength of beams, including:

2.1. Effect of Additive Materials

Some materials help to increase the strength and durability of concrete, especially those that do not contain shear reinforcement, as researchers are looking to use additional materials to replace accidental reinforcement, including fibers. Steel fibers provide additional shear capacity for concrete members [15]. Dennison and Simon, 2014 [16] presented research on the effect of using metakaolin and steel fibers on the structural behavior of R.C. beams with a rectangular cross-section. The metakaolin adds with 5%, 7.5%, 10%, and 12% from the weight of cement, while the percentages of steel fiber were 1.5%, 2%, and 2.5% by weight of concrete. Four beams were tested for shear, they found that the final shear strength of the samples containing metakaolin and crimped fibers is 32% greater than the reference beam. Also, the best percentage of metakaolin and steel fiber was 10% and 1.5%, respectively.

AL-Hamdani, 2018 [17] presented a study on the shear capacity of modified reactive powder concrete (MRPC). Under two concentrated point loads, the shear behavior of twelve simply supported lightweight MRPC beams with a/d

ratio equal to 2.5, 3.5, and 4 were tested up to failure. Shear reinforcement is not present in the beams, and only longitudinal reinforcement is present to prevent shear failure. Increases in friction fiber volume V_f by 0.5%, 1%, and 2%, silica fume content (SF) by 5%, 10%, and 15%, and longitudinal reinforcement (ρ_s) with 0.0329, 0.0426, and 0.0523 leading to increases in diagonal cracking load and ultimate shear load, according to experimental results. For example, increasing the V_f from 1.0 % to 2.0% leads to increases in diagonal cracking load V_{cr} from 59% to 81% and maximum shear load Vu from 20% to 146%, respectively.

Hassan, 2020 [18] studied the shear conduct of sixteen high-strength concrete (HSC) beams with a/d ratio equal to 2.5 and 3.5 made of recycled aggregates (RCA) together with steel fibers. The researcher used two percentages of recycled aggregates 50% and 100%. The treatment had the aggregate placed in tanks containing hydraulic acid HCL for 24 hr. After that, he immersed the recycled aggregate in a tank containing sodium metasilicate pentahydrate to get rid of the mortar residue stuck to the aggregate. When steel fibers were added, the test results showed a significant increase in shear capacity as well as a significant delay in the cracking load. When comparing beams with a 2% content of steel fibers to beams without steel fibers for the same type of aggregate, the ultimate load increase was roughly 36%. When compared to tests containing natural aggregates, the shear resistance of specimens containing 50% and 100% untreated RCA fell by 10.5% and 27.5%, respectively. Using treated aggregates, on the other hand, led to a considerable increase in shear resistance, with treated aggregates performing similarly to conventional aggregates. The discrepancy in ultimate load for mixtures with 50 percent and

100 percent treated RCA was just 1.9% and 9%, respectively, compared to the reference.

Ali, 2021 [19] studied the behavior of shear in beams by using polyethylene terephthalate (PET) waste fibers in different percentages. Six beams designed for shear failure were cast and tested. According to the findings, adding 1% and 1.25% PET fiber volume increased the shear capacity of reinforced concrete beams by 11.1% and 43.5%, respectively. The PET fiber also helped to change the mode of failure from shear failure to flexural failure.

Daoud and Fadul, 2021 [20] studied the shear failure of reinforced concrete beams without stirrups by using glass-fiber reinforced polymer bars (GFRB). Six beams (1400×300×500)mm were tested under two-point loads with a/d ratio equal to 1.37. The test beams consisted of three tension control beams (TC) with GFRP bars and three compression control (CC) beams with GFRP bars. The test findings showed that the shear capacity of FRP bars was decreased due to their comparatively low elasticity modulus. In TC beams, the failure mechanism is diagonal tension by bond failure rather than FRP rupture, and in CC beams, the failure mechanism is shearing compression by crushing the web in extreme fiber.

Hussein, 2022 [21] presented a study on the effect of iron slag (IS) and steel slag (SS) on the shear strength of R.C. beams without web reinforcement. Seventeen R.C. beams without shear reinforcement with a/d ratio equal to 3.01 were studied using the two kinds of slag, iron, and steel in different proportions. Each kind was utilized as a replacement for coarse aggregate (up to 40%), fine aggregate (up to 30%), or both fine and coarse aggregate (up to 15%). According to the test results, it was found that the optimal proportion of replacing iron slag with coarse

aggregate is 20%, which resulted in a 24.58% increase in peak load. While the optimal proportion of replacing steel slag with fine aggregate by 20%, resulting in a 10% increase in peak load. However, he found that the use of slag exhibited an indicator before the model failed, unlike the reference beam that failed suddenly and without warning.

The researchers have noticed that the use of other types of materials such as carbon fiber-reinforced polymer (CFRP) to strengthen the beams, especially beams without stirrups, has a very great benefit in supporting and increasing the bearing capacity of the beam. CFRB has excellent properties, including corrosion resistance, high tensile strength, hardness, resistance to fungi and insects, resistance to chemical attack, simple installation, and others [22].

2.2. Effect of Shear Span/Depth Ratio (a/d)

The distance (a) between the support and the main concentrated load operating on the span is known as the shear span [23]. The a/d ratio should make a significant contribution to the resistance of the beams. Fathifazl, et al., 2009 [24] have noted that the beams with an a/d ratio of 1.5 to 2 reacted after inclined cracking in a way similar to a linked arch, bearing the load by direct compression using struts running from the loading plates to the supports and by the longitudinal tension reinforcement serving as a tie. As a result, they have a lot of shear capacity. The beams with an a/d ratio of 2.7 to 4.0, on the other hand, did not establish the same shear resistance mechanism and collapsed soon after the primary diagonal fracture formed. These findings are in accordance with the behavior of normal concrete beams with comparable a/d ratios. Generally, the shear strengths of R.C. beams with and without stirrups were

dramatically decreased by raising a/d [25]. Arowojolu, et al., 2021 [26] presented a study on the impact of a/d ratio on the shear strength of high-strength reinforced concrete beams with or without stirrups. Cracks may propagate between aggregate particles in HSC, resulting in brittle failure, which is averse to conventional design requirements. The study data of six HSC beams, with and without stirrups, tested under four-point loading with a/d ranging between 2.0 to 3.0, are offered and compared with several model equations used in design programs. In reinforced HSC beams without web reinforcement, the a/d ratio has a greater impact on shear strength than in beams with web reinforcement in comparison with normal-strength concrete beams. Shear strength prediction methods generally decrease the concrete shear resistance of beams while overestimating the shear capacity of beams with stirrups. Compared to beams without stirrups, the influence of the a/d ratio on shear strength was greater in stirrup beams. Most shear models overlooked the influence of the a/d ratio in addition to the effect of aggregate interlock.

2.3. Effect of Longitudinal Reinforcement

The longitudinal reinforcement ratio has an important role in curbing the failure caused by the bending of the beams, especially those that do not contain stirrups, so attention must be paid to the longitudinal reinforcement of the beam. It is assumed that the shear strength is directly proportional to the longitudinal reinforcement ratio. Therefore, lower diagonal cracking shear strength is exhibited by the beam with a lower flexural reinforcement ratio [27], [28].
Azam, et al., 2015 [29] presented a paper to study the failure behavior of concrete beams without reinforcement in the web with three values of the longitudinal reinforcement ratio 0.91%, 1.21%, and 1.82%. The models were examined under

one point load. All models failed in shear, and they found that the peak load was equal to 66.13 kN, 72.02 kN, and 88.52 kN when the reinforcement ratio is equal to 0.91%, 1.21%, and 1.82%, respectively.

2.4. Effect of Compressive Strength

A significant consideration for the shear behavior of R.C. beams without web reinforcement is the strength of the concrete, particularly its compressive strength [30]. Because of the brittle behavior of high-strength concrete mix, the shear strength of high-strength reinforced concrete (HSRC) beam does not rise in proportion to compressive resistance compared with normal-strength reinforced concrete (NSRC) beam, the researchers in the field of structural engineering and concrete technology agree that. As a result, most building and bridge codes' existing empirical equations for the shear capacity of HSRC beams are lower conservative than those for ordinary strength reinforced concrete (NSRC) beams. Shear failure of HSC beams with higher longitudinal steel values and shear span-to-depth ratios, on the other hand, was more sudden and brittle, with no clear warning before failure, as has been found in the shear failure of HSC beams [31].

2.5. Effect of Size of Beam

A variety of already-existing design rules and models include several formulas that take the size influence on the shear strength of reinforced concrete beams into consideration [32]. Ghadhban, 2005 [33] presented a study on the effect of a/d, reinforcement ratio, beam size, vertical web stress, and compressive strength on 402 unreinforced concrete beams in the web area. He concluded that the relative shear strength values (RSSV) change with the change of f_c', decrease with an increase of a/d, increase with an increase of ρ_s, and do not decrease by increasing the beam size ($b_w d$)) due to the presence of the exponent in his proposed equation to predict the shear amplitude for beams without stirrups is as follows:

$$V_c = 65 f_c'^{0.37} \rho_s^{0.44} \left(\frac{d}{a}\right)^{0.79} (b_w d)^{0.77} \qquad (1)$$

Althin and Lippe, 2018 [34] noticed that the size of the beam (depth and width) affects the shear capacity of the beams, whether they are reinforced or not reinforced with transverse reinforcement, and they concluded that when the depth of the beam was big, the stress decreased when reaching the collapse stage, while other parameters remain constant. Therefore, the size of the beam (depth and width) has an important effect on the shear.

2.6. Effect of Aggregate Size

The coarse aggregate factor has a very important effect on gaining shear strength, especially for members without stirrups, because it provides a good percentage of the resistance gained due to the bonding between the aggregate and the cement paste. Deng, et al., 2017 [35] studied the influence of aggregate size on the shear capacity of beams without stirrups. Four values of the maximum size of aggregate (10, 20, 31.5, and 40 mm) and two values of a/d (2.2 and 3) were used. Also, they used finite element analysis to evaluate the shear failure mechanism. The findings demonstrated that, although increasing the shear capacity of RC beams, the maximum aggregate size had little to no impact on the tensile strength of concrete. The shear strength (V_u) was equal to 101.5, 101.5, 108, and 123.2 kN for 10, 20, 31.5, and 40 mm maximum size of aggregate, respectively with a/d equal to 2.2. However, the shear strength (V_u) was equal to 97, 81, 72, and 99 kN for the models that have a maximum size of aggregate 10, 20, 31.5, and 40

mm, respectively with a/d equal to 3. It can be seen that the maximum load rose along with an increase in the maximum aggregate size. Because of the rougher crack surface created by the big aggregate, the interlocking action was enhanced.

3. Shear Strength Prediction

3.1. Zsutty Expression

The empirical equation set by (Zsutty, 1968) cited by [36] is one of the first attempts to forecast the shear resistance of conventional concrete beams with a shear span/depth ratio (a/d) more than (2.5), using the following formula:

$$V_u = 2.2(f_c' \rho_s \frac{d}{a})^{\frac{1}{3}} b_w d \qquad (2)$$

3.2. BS 8110 Code

The BS 8110, 1997 [37] code states that the shear resistance of beams without web reinforcement shall be calculated using the following expression:

$$V_c = \frac{0.79}{\gamma_m} (\frac{100A_s}{b_w d})^{\frac{1}{3}} (\frac{400}{d})^{\frac{1}{4}} (\frac{f_{cu}}{25})^{\frac{1}{3}} \qquad (3)$$

3.3. Eurocode 2

In the Eurocode 2, 2004 [38], the shear capacity of the member without stirrups is calculated by:

$$V_{Rd,c} = [C_{Rd,c} K (100\rho_s f_c')^{\frac{1}{3}} + 0.15\sigma_{cp}] b_w d \quad (4)$$

$$C_{Rd,c} = \frac{0.18}{\gamma_c} \qquad (4A)$$

$$K = 1 + \sqrt{\frac{200}{d}} \leq 2 \qquad (4B)$$

$$\rho_s = \frac{A_s}{b_w d} \leq 0.02 \qquad (4C)$$

$$\sigma_{cp} = \frac{N_{Ed}}{A_c} \qquad (4D)$$

3.4. Model Code

According to Model code 2010 [39], the concrete design shear resistance may be calculated as follows:

$$V_{Rd,c} = K_v \frac{\sqrt{f_c'}}{\gamma_c} z b_w \qquad (5)$$

Where $\sqrt{f_c'}$ is not to be taken as more than 8 MPa, and z = 0.9d. The term K_v refers to the impact of strain on the web as well as the aggregate size. To compute K_v in beams without shear reinforcement, Model Code 2010 provides two levels of approximation, levels I and II. For approximation at level II,

$$K_v = \frac{0.4}{1+1500\varepsilon_x} \cdot \frac{1300}{(1000+0.7K_{dg}z)} \qquad (5A)$$

K_{dg} is the aggregate size factor and can determined as follows:

$$K_{dg} = \frac{48}{16+d_g} \geq 1.15 \qquad (5B)$$

For level I, the assumption is that the strain in the reinforcement stays elastic at the grade of shear failure, and the value of K_{dg} is equal to 1.25.

3.5. Canadian Code

Canadian Equation of shear force for a member without shear reinforcement cited by [40] given as follows:

$$V_c = 0.2\sqrt{f_c'} b_w d \qquad (6)$$

a/d ratio and the impact of longitudinal reinforcement on the shear resistance of beams are not considered by Canadian standards.

3.6. ACI Code

ACI 318, 2019 [41], non-prestressed concrete beams without web reinforcement have a shear resistance predicted by:

$$V_c = 0.17\lambda\sqrt{f_c'} b_w d \qquad (7)$$

In many cases, the American code equation is used to evaluate the shear strength because it produces discreet results compared to the real results, and this provides a considerable safety coefficient. This is what Thorhallsson and Birgisson, 2014 [42] concluded from their studies, where they presented an experiment about eighteen beams without stirrups, and also compared the result with three codes, ACI Code, Model Code 2010, and Eurocode 2. The results revealed that the three codes produced varying shear resistance estimations. The shear design value computed by EC2, and Model Code was less than the value when the first shear fracture developed. In every case, the ACI code yields the least shear resistance estimate, thus enhancing the safety level. Model Code's revised shear estimates result in results that are 5% to 20% lower than those estimated using EC2. It should be noted that, unlike the EC2 and Model Code, the ACI code does not take into consideration the size impact or the longitudinal reinforcement effect. Harry and Ekop, 2016 [43] used 435 concrete beams without web reinforcement from previous studies and compared the equations that predict the shear strength for five codes (BS code, Eurocode, Model code 2010, Canadian code, and ACI code), and they found that Model code 2010 is the most conservative compared with the other codes, this may be as a result of the flexural reinforcement being considered to be in a linear elastic condition at the point of shear failure. The Canadian code gave the most unsafe predictors of the thresholds studied.

Bogdandy, 2021 [44] presented a study on the shear capacity of the beam without reinforcement in the web zone depending on the EC2 expression. This equation, since the majority of design code expressions are often utilized to estimate the nominal shear strength, has been created depending on experimental investigations. It will be verified that in the state of a non-prestressed RC beam without reinforcement in the web, the shear resistance of the compression zone resists the shear in this type of beam, and the shear strength given by the empirical equation of Eurocode 2 is the shear strength of the compressive zone. Under certain assumptions, the final results of the analysis show that the equation of shear strength given by Eurocode 2 can be derived. Knowing the mechanical foundation of the empirical equation of Eurocode, it can be established that if the stress in the extreme compression fiber is less than 60% of the mean compressive strength value ($0.6f_{cm}$) When a shear failure occurs, Eurocode 2 provides a prediction for shear resistance overrating the amount of shear strength. As a result, the shear resistance predictions should be modified in these conditions. As a result, it is suggested that the minimal value of shear strength, as shown in Eq. (8).

$$V_{Rd,c\,min} = \frac{0.7}{\gamma_c} 0.035 K^{\frac{3}{2}} b_w d \qquad (8)$$

Where K was calculated from Eq. (4B).

4. Mechanism of Shear Failure in Beams Without Shear Reinforcement

Depending on the theory of elasticity, if each point in a body is taken into consideration, its plane stress condition can either be characterized by three parameters ($\sigma_x, \sigma_y, and, \tau_{xy}$) or by two principle stresses (principal tensile stress σ_2 and principal compressive stress σ_1). The direction of the primary tensile stress is inclined to the neutral axis of the member if shear stresses τ_{xy} occur, as Fig.1 [45] illustrates.

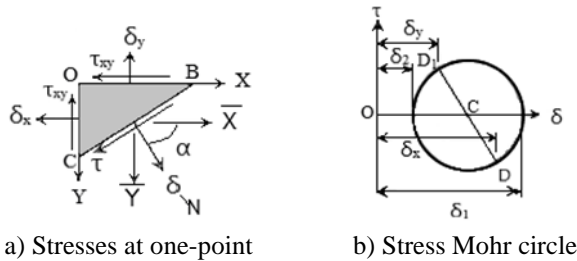a) Stresses at one-point   b) Stress Mohr circle

Figure 1. Principal Stresses in any point of the body [45]

The shear strength is calculated using average stress applied to the cross-section. Shear is supposed to be transmitted by the web zone of concrete in a member without stirrups. A part of the shear resistance is expected to be given by the concrete and the remainder by the shear reinforcement in a member having shear reinforcement. Shear stress can be parallel or tangential to a beam section. When a simply supported beam bends, the fibers above the neutral axis are compressed, while those below the neutral axis are tensioned. When a concrete beam with longitudinal steel is subjected to external loads, diagonal tensile stresses develop, which can lead to crack initiation. These cracks are upward in the middle of the beam and become diagonal as they access the beam support. Diagonal tension stresses are the stress that causes the inclined cracks in the beams. If the resistance of the member in diagonal tension is less than its resistance in flexural tension, diagonal tension cracks may cause the beam to fail. This kind of crack begins with a few vertical flexural cracks in the middle of the beam. After that, at the support, the connection between longitudinal reinforcement and its surrounding concrete starts to fail. In the end, two or three inclined cracks appear at a distance of 1/2 to 2d from the support face [46]–[48].

When tensile stresses in concrete above the modulus of rupture of concrete (f_r), expressed by Eq. (9) vertical flexural cracks occurred at the section of highest bending moment. Later, at a place extremely near to the support, inclined cracks in the web appeared. Shear capacity in R.C. beams is achieved through a set of the mechanisms listed below [49], [50]:

$$f_r = 7.5\lambda\sqrt{f_c'} \tag{9}$$

- Shear transmission at the interface (Va) is caused by aggregate interlocking tangentially along the rough surface of the crack. The possibility of shear transmission between two opposing crack surfaces is referred to as "aggregate interlock," and it mostly depends on the kinematics of the fracture and the roughness of the fracture surface [51]. During the loading procedure, the aggregate interlock is activated somewhat late. Nevertheless, the resistance provided by the aggregate interlock is up to 40% when the beam fails, making it the most effective performance at that time [52]. So, the geometry and kinematics of the crack play a major role in the aggregate interlock "with the vertical upper parts of the crack carrying more shear forces" [53].

- Shear strength of uncracked concrete zone (V_z). The contribution of the uncracked concrete area in providing shear strength reaches 100% when the loading level is very low and decreases to 30% when the beam reaches the failure stage [50]. As a result of the increased load and the development of cracks, it will reduce the uncracked concrete area [54].

- Arch action, because of the loss of link between longitudinal reinforcement and concrete, the arching action is a different shear-transfer mechanism that might appear in a reinforced concrete beam. This shear-carrying action, initially observed by Morsch in 1908 and later confirmed by

Drucker in 1961, corresponds to a plasticity-stress field where the load is carried directly by an inclined direct strut and the force in the reinforcing bars is constant. [55]. In beams, arch action happens not just between diagonal tension fractures but also outside the outermost cracks. Splitting fractures may form along the bars because the dowel pressures partially resist the compression of the arch [56].

- Dowel action (V_d) is caused by the longitudinal reinforcement resistance to the transverse shearing force, or in other words, dowel action describes the interplay between the rough surfaces of the fracture caused by aggregate interlock and shear resisted by the reinforcement [57]. Long acknowledged as an important element of the total shear strength capability of reinforced concrete beams, is the phenomena of dowel action as a shear transfer mechanism across cracks. The dowel action contributes to the post-peak phase and also contributes to the member's gaining flexibility during the loading period [58].

Only the concrete in contact with the longitudinal reinforcement limits the vertical displacement of the longitudinal reinforcement outward in beams without stirrups. The resistance provided by plain concrete to stop the movement of the longitudinal reinforcement outward in standard RC beams is minimal. Additionally, a horizontal crack quickly spreads if the tensile strength is surpassed at any point, leading to a brittle failure [59]. The percentages of shear resistance for the different mechanisms for a rectangular beam without shear reinforcement are 20% to 40% for V_z, 35% to 50% for V_a, and 15% to 25% for V_d. Fig.2 shows the shear failure.

a) Form generic   b) Shear crack in web

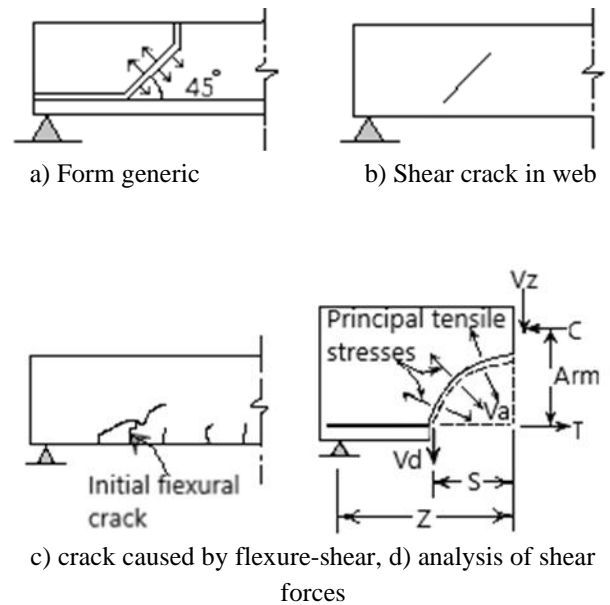c) crack caused by flexure-shear, d) analysis of shear forces

Figure 2. Shear Failure: (Va = interface shear from aggregate interlock, Vz = shear resistance from uncracked zone, Vd =dowel force from longitudinal reinforcement), [50].

5. Modes of Failure

There are four types of shear failure in reinforced concrete beams that can be explained as follows [60]:

1. Splitting Failure (True Failure):
   This type of failure occurs in deep beams where the a/d ratio is less than one. Shear is conveyed as an inclined thrust between the load and the reaction point and acts as a tied arch once inclined cracking forms. The ultimate failure either splits or fails in compression.

2. Tension and Compression Failure:
   This type of failure occurs in short beams where the a/d ratio is between 1 and 2.5. Shear compression failure occurs when the concrete portion above the crack is crushed under the combined effect of shear and compression, and shear tension failure occurs when additional cracks

appear along the tension reinforcing, as shown in Fig.3.
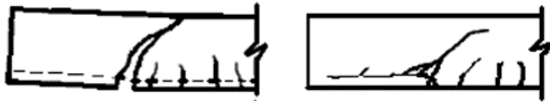
a) Shear-compression failure b) Shear-tension failure
Figure 3. Compression and tension failure [61]

3. Diagonal Tension Failure:
   This type of failure occurs in normal beams and where the a/d ratio is between 2.5 and 6. Flexural cracks first occur, and then from the ultimate flexural crack, flexure shear cracks develop. This kind of crack gradually develops until it reaches the loading point as a result of the increase in load. This kind of failure crack pattern often has a wider crack and originates from the supports of the beam. Sato, et al., 2004 [62] mentioned that the mechanism of diagonal tension failure is complex and difficult to control, as shown in Fig.4.

4. Flexural Failure:
   This type of failure occurs in beams that have a large length (shallow beams) and when the a/d ratio is more than six. Flexural tension failure is the name for the type of failure that occurs when concrete is crushed in the compression zone after yielding the reinforcement in an under-reinforced beam. Whereas flexural compression failure happens when the compressive zone of concrete is crushed, yielding the reinforcement in an over-reinforced beam. So, this type of failure was brittle as illustrated in Fig.4.
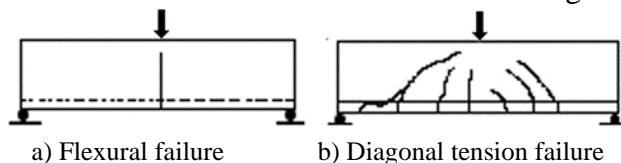
 a) Flexural failure   b) Diagonal tension failure
Figure 4. Flexural and diagonal tension failure in beam [63]

6. Conclusions

Because of the high probability of shear failure in concrete beams without stirrups in addition to the complex mechanism and the brittle mode of shear failure, the mechanical study was conducted to understand the shear failure mechanism in a simplified way. As a result of the stress increase on the beam, cracks begin to appear and develop with increasing load until failure occurs, this failure is brittle as a result of the semi-fibrous behavior of the concrete. After the appearance of cracks in the beam, concrete still can resist tensile stresses and this ability is important only for cracks that have a small width of less than 0.1 mm. Many materials contribute to extremely strengthening the concrete members such as silica fume, metakaolin, steel fibers, slag, and many others. As for the parameters of the beam structure, most researchers agreed that the shear strength increases with an increase in the proportion of longitudinal reinforcing steel, while it decreases with an increase in the a/d ratio and beam depth. Moreover, by increasing the compressive strength of concrete, the concrete becomes more brittle, so it is important to use some additives such as steel fibers to obtain the required strength. The coarse aggregate factor has an important role in gaining shear resistance, especially for beams without stirrups, as it was previously explained that increasing the volume of coarse aggregate contributes to increasing the final failure load of the beams as a result of providing considerable interconnection between the concrete components. Nevertheless, the important mechanisms that provide resistance to beams without stirrups are the aggregate interlock and the uncracked concrete zone, if the rectangular beam does not have shear reinforcement. Based on previous studies, it was seen as contradictory regarding the safest expression for predicting the shear strength for

beams without stirrups. It requires extensive studies on this subject to determine the safest equation.

Acknowledgments

Abbreviations

A_c	Cross section area
a/d	Shear span/depth ratio
b_w	Width of web
d	Effective depth
d_g	Diameter of aggregate
f_c'	Compressive strength
f_r	Modulus of rupture
L/d	Clear span/depth ratio
N_{Ed}	Axial force in the cross section of beam
V_a	Interface shear from aggregate interlock
V_{cr}	Diagonal cracking load
V_d	Dowel force
V_u	Ultimate shear strength
V_z	Shear resistance from uncracked Zone
z	Effective shear span depth
σ_1	Principal compressive stress
σ_2	Principal tensile stress
ε_x	Longitudinal strain in the web
τ_{xy}	Shear stress
λ	Lightweight concrete modification factor
γ_c	Concrete aspect factor of safety
γ_m	Partial safety concrete factor
ρ_s	Longitudinal reinforcement ratio

Conflict of interest

The authors would like to stress that the publication of this article causes no conflict of interest.

Author Contribution Statement

The authors contributed to collecting and summarizing many sources and studying the proposed topic thoroughly and from all aspects to produce a helpful research paper for researchers that would guide them in the field of review and information gathering.

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