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Research Article

Shear Reinforcement of Concrete Beams Using Iraqi Bamboo

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Abstract

Steel rebars require significant energy to produce and are prone to corrosion when exposed to ambient air. Therefore, Iraqi bamboo replaces steel stirrups and steel rebars in this research. Five reinforced concrete beams are tested using four-point load testing. The first beam was cast without stirrups to achieve shear failure and is labeled a control specimen. Three other beams had Iraqi bamboo instead of steel at the critical sections. The last beam had steel stirrups spaced at a distance half of the effective depth of the beam. It is found that the Iraqi bamboo can increase the load-carrying capacity of the beam by up to 15% if compared with the beam with no stirrups. Also, the ductility of the beam has increased by 17%. However, the maximum load-carrying capacity of the steel stirrup beam was larger than that of the bamboo stirrups by at least 21%. The main reason is the spacing of the stirrups, which is the main factor influencing the beams' behavior prone to shear failure.

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1. Introduction

Cement, steel, glass, and aluminum use increases with urbanization due to conventional building practices. Due to a lack of available resources, production expertise, or the required industry, these materials must mostly be imported to meet the expanding demand created by developing countries [1]. Concrete is one of the most required materials by emerging and developing nations, accounting for over 90% of the global demand for concrete [2]. However, concrete needs reinforcement as it is weak in tension.

Many researchers are investigating material substitutes for steel bars to obtain low-cost and environmentally friendly concrete with low energy consumption. Using bamboo has been one of the options as it is natural, strong in tension, and not sensitive to corrosion [3]. Bamboo grows to full maturity in months and achieves its mechanical strength peak in a matter of years. It is an economically favorable material since it is common in tropical and subtropical areas. It is an outstanding building material because of its advantages, including a lightweight design, improved flexibility, durability, thin walls with discretely distributed nodes, and tremendous strength [4]. Due to its durability, flexibility, lightweight, and low cost, bamboo is a structural material for scaffolding in construction projects in nations like China, India, and others [5].

Also, due to its high cost, steel is hard to produce in developing nations, and its use in the building sector is constrained. Steel manufacturing relies heavily on fossil fuels, searching for a natural alternative to steel essential [6]. However, a lack of adequate knowledge about the components of the composites, including bamboo and their durability, is the fundamental barrier to the implementation of structural composites [7].

Several researchers studied bamboo-reinforced beams in bending [8-11] and shear and bending [8, 9]. However, very few researchers have used bamboo as a replacement for shear stirrups, even though a large quantity of steel would be used for stirrups, as the codes of practice these days require more stirrups to achieve the ductile behavior of the elements. Also, stirrups are wrapped around the element; therefore, it takes a substantial quantity of rebar in any project. Mahzuz et al. are one of the leading researchers who studied the shear behavior of beams when the stirrups are made out of bamboo [8]. They cast and tested four concrete beams in shear, three with shear reinforcement and one without reinforcement. The beams' dimensions were 150 mm x 150 mm x 1025 mm in width, depth, and length, respectively; effective depth and clear cover were 125 mm and 12.5 mm, respectively. The reinforcement consisted of two 16 mm diameter steel rebars at the bottom and two 10 mm diameter steel rebars at the top. All the bamboo samples were cut with a length of 125 mm, and the cross-section area of bamboo was (100, 150, and 250 mm^2) therefore, spacing was not the main variable. The bamboo is used for shear reinforcement at a spacing of 125 mm. Their specimen cages are shown in Figure 1.

Figure 1. Bamboo stirrups [8].

As a result, the crushing load rose as the cross-sectional area of the bamboo in the beam increased. For instance, the crushing load of the beam with a cross-sectional area of 150 mm^2 and a spacing of 125 mm was 173% higher than that of non-shear reinforcing beams. The non-reinforced concrete beam had a crushing load of only 16.55 kN. The crushing load of a beam with a cross-sectional area of 250 mm^2 was 65.04 kN; this enhanced the load-carrying capacity of the reinforced beam by 292.99%.

Noticeably, the load-carrying capacity increases with an increase in the stirrup area. However, this study examines the impact of larger spacing of bamboo on the load-carrying capacity of the beams by casting five steel-reinforced concrete beams. Also, the whole cross-section of the Iraqi bamboo is used, which has not been tested in the literature.

2. Materials and Methods

Cement and fine and coarse aggregate were the main ingredients for creating the concrete mix with a 25 MPa strength. The primary steel bars were 1100 mm long and 10 mm in diameter, featuring 100 mm-hooks on either side of the bars to avoid slippage. The top reinforcements measured 1200 mm in length and 8 mm in diameter. The tensile strength of the rebars was 500 MPa on average. Bamboo stirrups are used in three beams, and two vertical legs are used for the shear reinforcement. The specific species of bamboo found in Iraq has been utilized for centuries by indigenous communities for various purposes, ranging from construction to crafts. In Iraq, bamboo typically propagates through rhizomes, underground stems that give rise to new shoots. The bamboo sticks used were collected at the University of Sulaimani's new campus in Sulaymaniyah, Iraq. The length of bamboo sticks was 170 mm, and the bamboo's diameter was between 8-12 mm, with an average of 10 mm, as shown in Figure 2.

Figure 2. Bamboo cut to be used as vertical legs

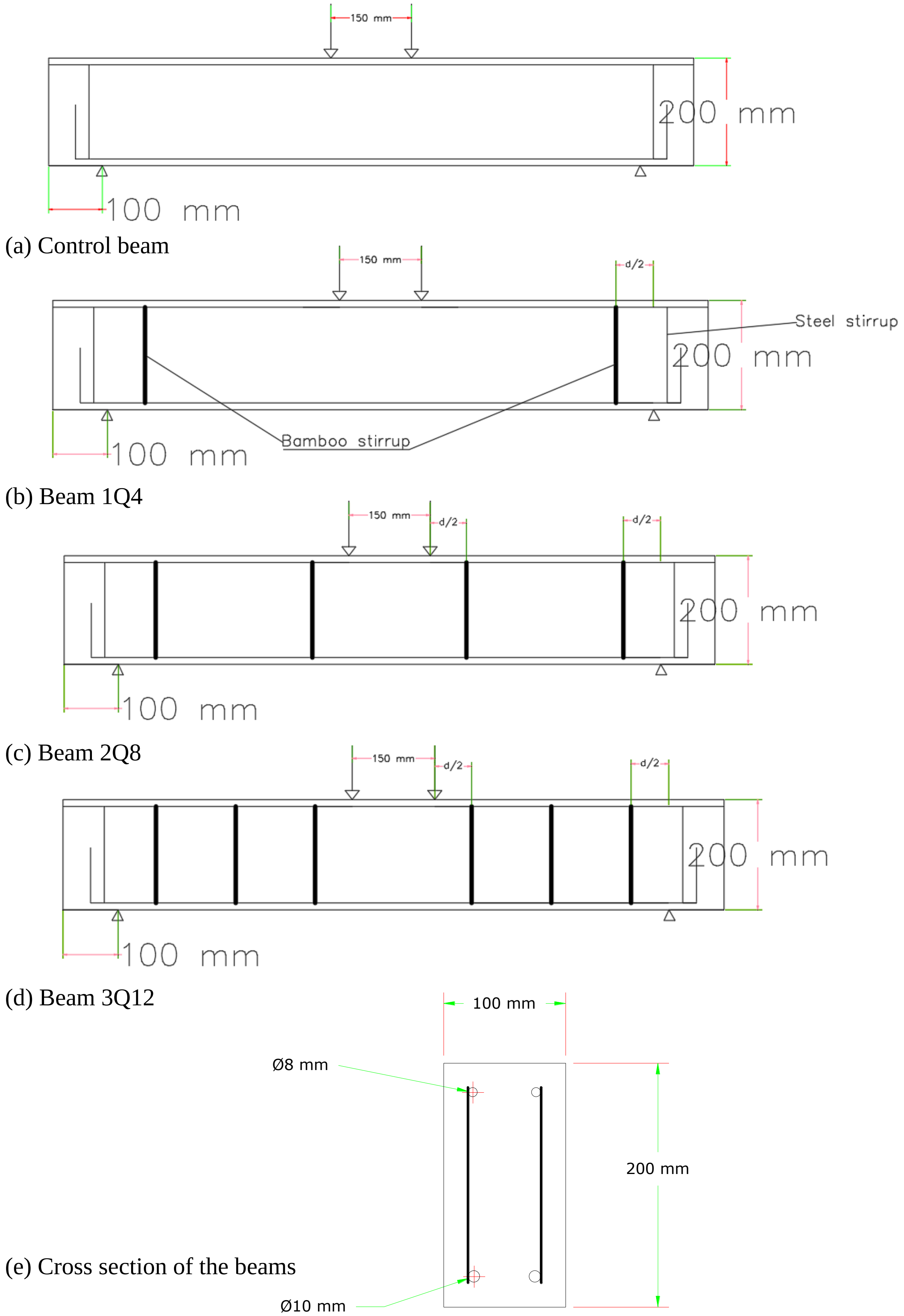


Figure 3. Detail of the beams

Five beams with dimensions of 100 mm x 200 mm x 1200 mm are named 1C, 1Q4, 2Q8, and 3Q12, and the "Steel" beam. Beam 1C was the control specimen with only two main rebars at the bottom and no stirrups designed to fail in the shear. Beam 1Q4 had four bamboo stirrups at a distance of $d/2$ from the supports as the critical section, where d is the effective depth of the beam. Beam 2Q8 had eight bamboo stirrups, four similar to beam 1Q4, and the other four stirrups were at a distance of two $d/2$ from the loading points. Additionally, beam 3Q12 had six pairs of bamboo stirrups, four pairs like the ones of 2Q8, and the other two pairs of stirrups were right in the middle of the provided stirrups. Finally, the "Steel" beam had steel stirrups with a spacing of half of the effective depth across the beam's length. This study aims to compare the effectiveness of bamboo stirrups with steel stirrups. A section of the beam is shown in Figure 3, and all the beam cages are shown in Figure 4. The beams had two steel stirrups at their ends beyond the supports to help fix the bamboo stirrups; otherwise, they were outside the clear span. The clear span of the beams was 1000 mm, and the total length was 1200 mm, so there were 100 mm of the beams out of the support from each side.

Figure 4. Beam cages

According to ASTM-C33 standards, the fine and coarse aggregates passed the sieve analysis test [12]. Also, ACI-211 was used to attain the concrete mix design of 25 MPa [13]. The actual water-to-cement ratio was 0.46, and the final mix design ratio was 1:2.67:2.16 (cement: fine aggregate: coarse aggregate). Concrete cubes of 150 mm x 150 mm x 150 mm were collected during casting for compressive testing. The coarse aggregate's maximum size was 12 mm, with a bulk specific gravity of 2.63 and a water absorption rate of 1.37%. The greatest size of the fine aggregate was 4.75 mm, with a fineness module of 3.31 and a water absorption of 1.83%. During casting, the slump test of the concrete was taken, and it was 170 mm. All the cages were prepared and put in greased beam forms. After casting, they were cured for 28 days. These procedures are shown in Figure 5 (a) to (c).

(a) (b) (c)

Figure 5. Different stages of the work: (a) caging, (b) casting concrete, and (c) curing the beams

The length of 170 mm was used for the bamboo to be used as vertical legs in shear resisting the beams. The bamboos were cut from the University of Sulaimani, Sulaymaniyah, Iraq. The diameter of the bamboo was 10 mm on average.

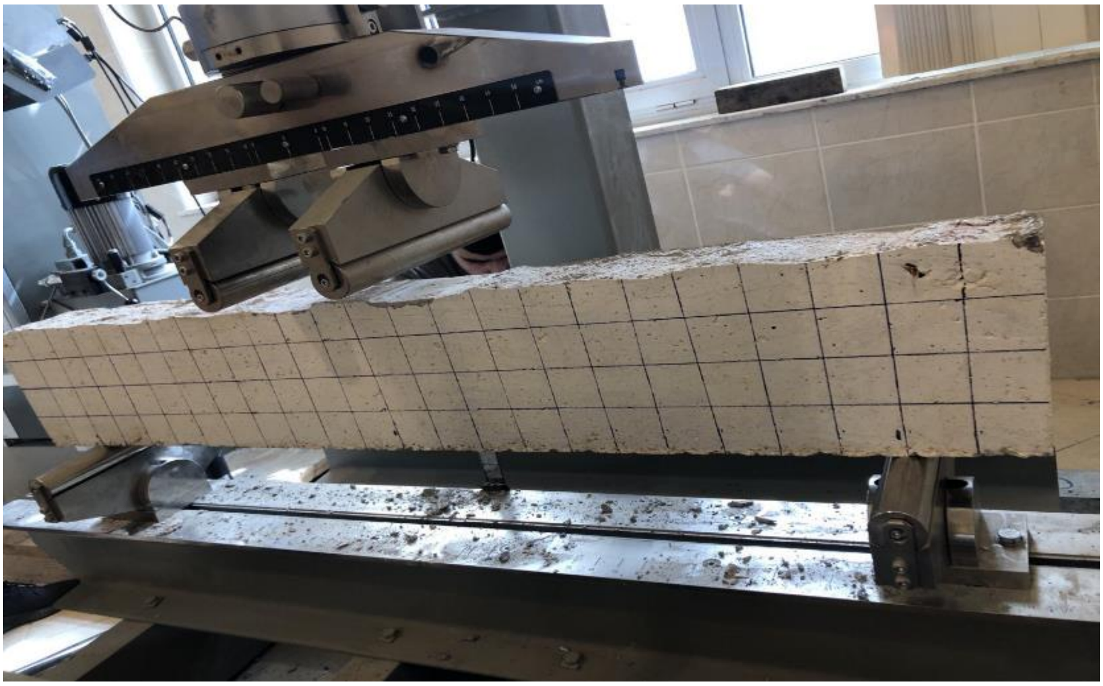


Figure 6. A specimen under the loading machine

This test was done on an instrument that included two supports and a hydraulic jack in the middle of the instrument. The clear span for setting the beams was one meter, and the loading rate was 0.01 MPa/sec. All the beams were placed under the hydraulic jack, the load was applied in the middle for the beam, and the beams' deflection was recorded in the middle. A beam under the instrument is shown in Figure 6.

4. Results and Discussions

The minimum reinforcement for the beam is 0.3%, while the provided reinforcement yields a ratio of 0.8%. After using a correction factor of 0.8 to convert the cube strength to cylindrical, the concrete's average compressive strength was 27.52 MPa. The bending test results on the beams are shown in Table 1. The maximum load carried by the beams increased with the number of bamboo stirrups in the beams. For instance, the load-carrying capacity increased from only 39 kN to 47.3 kN when bamboo stirrups were used in closer spacings. It is also shown that the beams' deflection capacity increased with the number of bamboo sticks as the deflection hit 3.5 mm after using three stirrups as bamboo. The maximum permissible deflection based on ACI318-19 is *l*/360, where *l* is the clear span of the beam, and it is only 2.77 mm; therefore, any deflection beyond this limit will not be allowed. As the target was to increase the shear capacity until bending failure, the test was continued just beyond the allowable limit.

Table 1. Results of the flexural test on the beams

Beam Name	Maximum load (kN)	Maximum deflection (mm)	First Crack Load (kN)
1C	41.5	3	19
1Q-4	39	1.5	17
2Q-8	44	2	16
3Q-12	47.3	3.5	16

The control beam could support a load of 41.53 kN, experiencing a deflection of 3 mm, demonstrating a brittle failure as anticipated because of the absence of stirrups. The first crack emerged at a load measurement of 19 kN.

The beam 1Q4 showed an ultimate load-carrying capacity of 39 kN, where the first crack appeared at a load of 17 kN while the maximum deflection was 1.5 mm. This can be interpreted as the bamboo being unable to capture the propagation of the shear cracks due to their large spacings, as there were only four bamboo stirrups in the beam close to the supports. Also, the hollow section of the bamboo made resisting the lateral loads on the bamboo sticks difficult.

As for the beam 2Q8, the maximum load it could carry was 44 kN, which is more than that carried by the control specimen by 6%. It deflected only 2 mm, below the allowable limit of ACI318-19. This indicates that the bamboo next to the loading points could partially capture the cracks and increase the load-carrying capacity of the beams due to the blockage of the path of the cracks. Finally, beam 3Q12 sustained 47.3 kN of load with a maximum deflection of 3.5 mm. This is a sign that the load-carrying capacity increases with a decrease in the spacing of the shear reinforcement. However, compared with the beam reinforced with steel stirrups, the maximum load-carrying capacity of the bamboo stirrups was nearly 21% less than that of the steel stirrups. The main reason is the spacing of the steel stirrups, as they were spaced at 85 mm, while the spacing of the bamboo stirrups was substantially larger (70%).

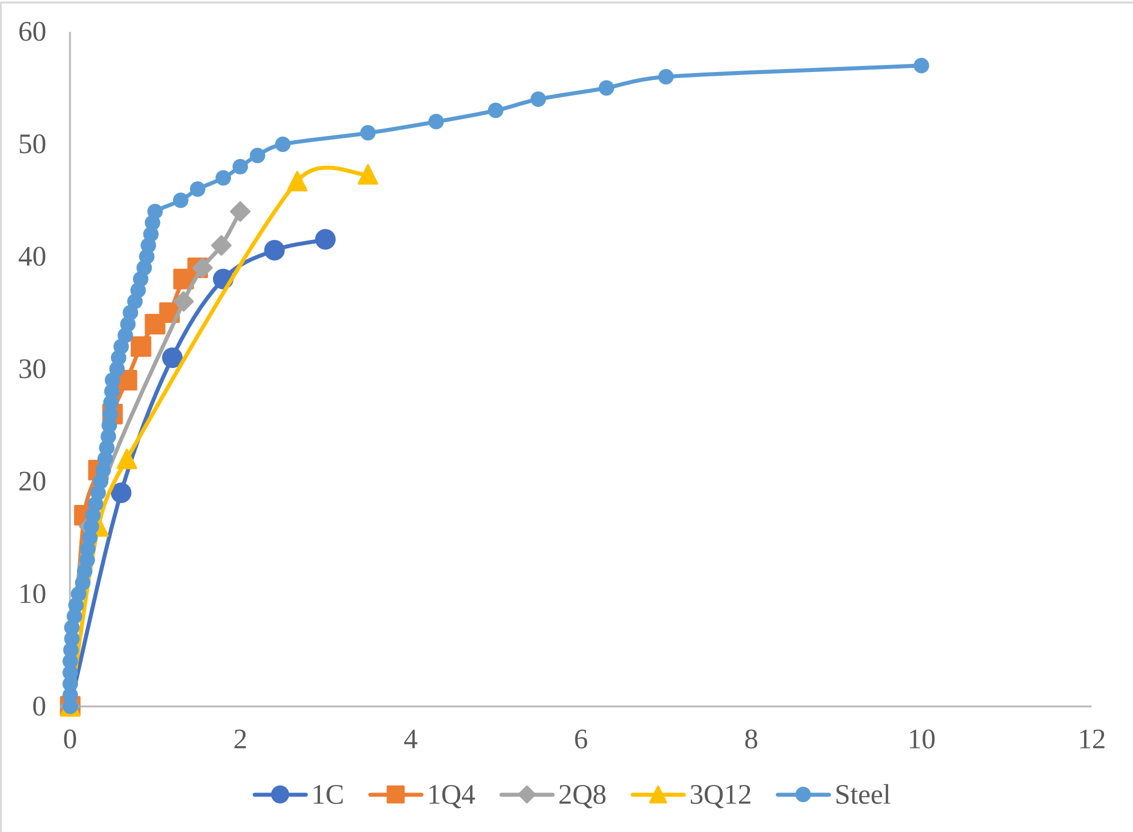
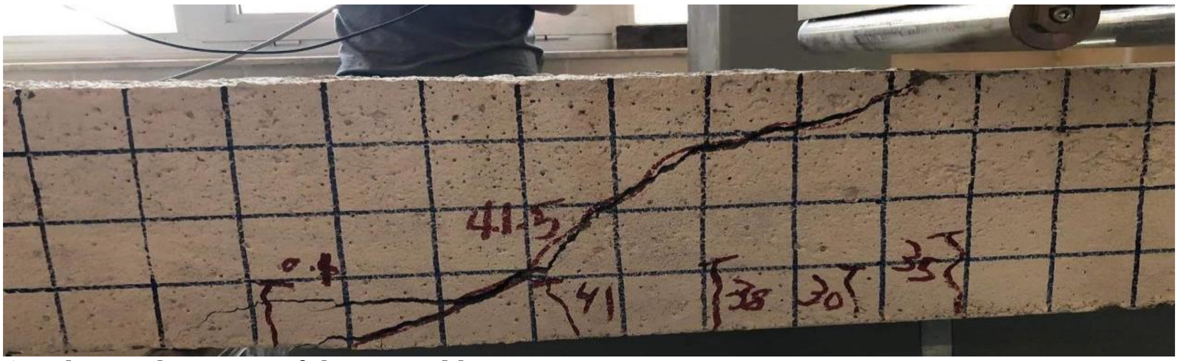
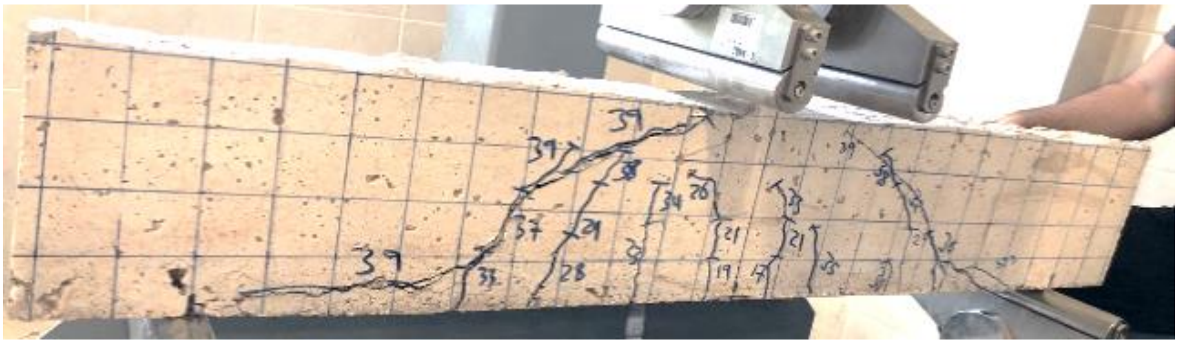


Figure 7. Load-deflection diagram of the beams

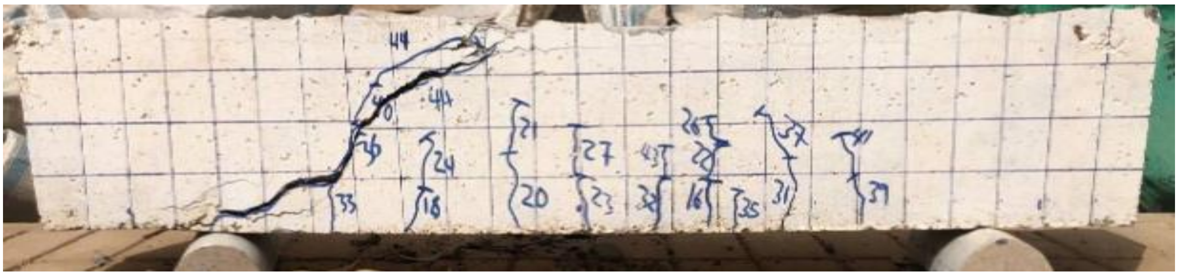
The crack patterns of the beams are shown in Figures 8 (a)- (e). The failure of the control beam was in shear and sudden without any warning, as predicted. The number of cracks was smaller than the other beams, which had extra confinement from the bamboo because of the engagement of the whole section of the beam. Unfortunately, the shear failure was controlled in all of the beams as the confinement due to the bamboo was not sufficient enough to fully change the failure of the beams to bending failure due to the large spacings. The crack patterns of the steel-reinforced beam and the bamboo-confined beams are similar, apart from the largest shear crack in the beam, which caused the failure of the bamboo-confined beams. However, compared to the control specimen, the number of flexural cracks increased, indicating the bamboo sticks' active involvement in arresting the shear cracks; nevertheless, due to large stirrup spacings, the beams failed in shear.



a) The crack pattern of the control beam

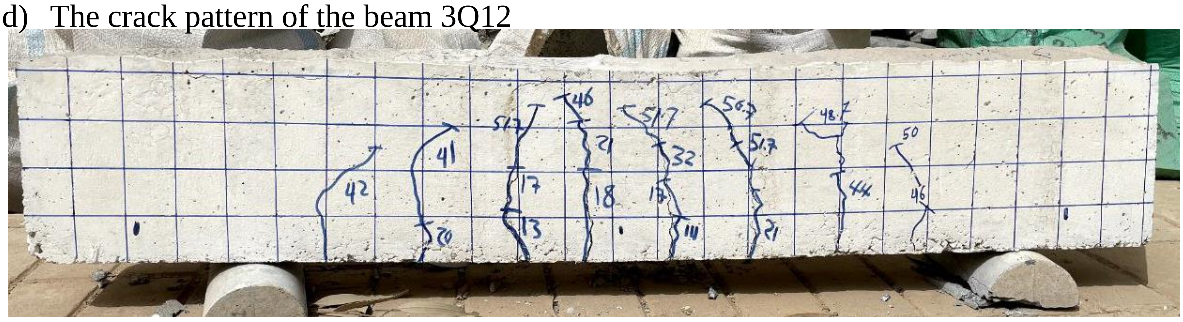


b) The crack pattern of the beam 1Q4



c) The crack pattern of the beam 2Q8

d) The crack pattern of the beam 3Q12



e) The crack pattern of the Steel beam

Figure 8. The crack pattern of the beams

5. Conclusions

The comparative analysis of beams with bamboo and steel stirrups reveals significant insights into their structural performance. Beams equipped with bamboo stirrups exhibit a load-carrying capacity that is 21% lower than those with steel stirrups, a difference attributed to the spacing of the stirrups rather than the material itself. Despite this reduction, the load-carrying ability of beams with bamboo stirrups still surpasses that of beams without stirrups by up to 15%. Notably, the presence of bamboo stirrups increases the number of flexural cracks; however, the predominant failure mechanism remains a shear failure, primarily due to the substantial spacing between the bamboo sticks. Remarkably, the formation of these flexural cracks is exclusively triggered by the vertical legs of the stirrups, underscoring a specific area of vulnerability in the beam's structural integrity.

Declaration of Competing Interest: The authors declare they have no known competing interests.

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