International Journal of Engineering Research and Development

DOI: 10.29137/ijerad.1490528

Volume:17 Issue:01 Pages:182-197 March/2025

Research Article

The Importance of Reinforcement Placement and Concrete Cover in Reinforced Concrete Beam Performance

Orhan Doğan[1], **Berkay Çakır**[2], **Yunus Genç**[3], **Orhan Gazi Odacıoğlu**[4]

[1]Kırıkkale University, Faculty of Engineering and Natural Sciences, Department of Civil Engineeringy, 71450, Kırıkkale, TURKEY

***Received**: 27/05/2024* ***Accepted**: 25/07/2024* ***Published Online:** 15/03/2025*
***Final Version**: 01/03/2025*

Abstract

Concrete, which has been used as a building material in the construction industry for many years, is a brittle material with high compressive strength and low tensile strength, and is supported by steel reinforcement, which is a ductile material, especially in tensile zones. For this reason, adherence, which is the interface shear stress that provides the interlock between concrete and reinforcement, is the reason for the existence of reinforced concrete. Adherence can only be achieved with appropriate reinforcement placement and concrete cover. For this reason, errors that may occur in the application directly affect adherence. In this study, in order to investigate the consequences of errors in reinforcement placement and concrete cover thickness during application, 8 reinforced concrete beams in 4 different groups of 1/2 scale, with a cross section of 15x30 cm and a length of 205 cm were produced and it was aimed to experimentally determine the effect of the placement of the tensile zone reinforcement in the beam span and the adherence caused by the concrete cover on the beam performance. As a result of the three-point bending test, it was observed that if the concrete cover and reinforcement placement are made in accordance with the standards, the maximum bearing capacity decreases due to the increased adherence, while the leading cracks in reinforced concrete beams occur under higher loads, more number of capillary cracks are formed instead of large cracks and the beams behave more rigid. In cases where adherence is not achieved, ribbed reinforcement behaves similar to the behaviour of plain reinforcement and forms wide cracks by stripping.

Keywords

"Reinforced concrete beam, Concrete cover, Adherence, Reinforcement, Concrete"

***** Corresponding Author: 218806017@kku.edu.tr***

1. Introduction

Beams have been one of the structural elements of a reinforced concrete structure (Doğan et al., 2022). Two of the important issues to be considered when designing a beam have reinforcement placement and adherence due to concrete cover. Although these issues have given due importance in the project, they are not paid much attention during the application (Üstün & Dal, 2016). This affects the performance of the beams.

Concrete cover is the distance between the outer part of the reinforcement and the outer part of the concrete in the beam section (Celep, 2022). Concrete cover in beams is left for three main purposes (Aydın, 2021). These are to protect the beams against fire (Shi et al., 2004; Pinoteau et al., 2011; Khoury, 2000; Demirel and Altındaş, 2005; Akyürek, 2019; Ünlüoğlu et al., 2007) to prevent corrosion of reinforcement (Vu and Stewart, 2005; Cedrim et al., 2019; Oliveira et al., 2023; Dasar et al., 2022) and to ensure adherence between concrete and reinforcement (Akgül et al., 2022; Akgül and Doğan, 2022). The thickness of concrete cover must be greater than 25 mm for columns and beams open to weather conditions and greater than 20 mm for columns and beams inside the structure that are not exposed to external influences (TS 500, 2000).

Adherence is the shear stress that provides interlocking between concrete and steel reinforcement (Alper, 2008). In order for the two materials to interlock better, the surface area they contact should be high. Adherence is affected by variables such as compressive strength of concrete (Doğan et al., 2019; Sartori et al., 2017), yield strength of the reinforcement used, surface geometry and diameter, reinforcement embedment length, transverse reinforcement, concrete cover, type and content of aggregate used in concrete (Atmaca, 2017), additives (Yücel and Erten, 2023; Harmuth, 1995; Topçu et al., 2006) and epoxy adhesives (Tramis et al., 2016) (Başaran and Kalkan, 2021). In addition, reinforcement corrosion, which may occur if the thickness of the concrete cover is not in accordance with the standards, increases the adhesion by filling the gaps in the first place, but decreases the adhesion strength when it progresses (Lee et al., 2002; Ichinose et al., 2004; Topçu and Boğa, 2008; Doğan and Akgül, 2020). Coşkan and Yüksel (2013) conducted an experiment comparing the earthquake behaviour of reinforced concrete frames with and without corrosion and determined that corrosion is a factor that reduces element strength. In reinforced concrete structures, the adherence between concrete and steel occurs in two ways. The first one is bending adherence which is related to the stress in the reinforcement. The second one is the interlock adherence which is determined by the rate of embedment of the reinforcement in the concrete.

In the study conducted by Katz (2018), it has stated that the concrete cover should have a constant average of the concrete cover thicknesses throughout the structure as well as the effect of the concrete cover on the service life of the building. It has shown that when the standard deviation of the concrete cover thicknesses throughout the structure reaches 15 mm, the service life can be reduced by 30%. Jendele and Cervenka (2006) performed a finite element modelling based on the geometry of the reinforcement bars and the interface properties. This model can realistically simulate the bond between the reinforcement and the surrounding concrete. They also validated their model with laboratory tensile tests. Four different bond stress cases were compared and it has stated that a strong bond stress between the reinforcement and concrete would reduce the ultimate load by about 30%. Larrard et al. (1993) conducted many experiments to investigate the bond strength between high strength concrete and reinforcement. Different specimens with high performance concrete and normal concrete, reinforcement diameter ranging from 10 mm to 25 mm and reinforcement surface separated as rough and smooth were subjected to the test. As a result of the test, it has determined that the adherence increased as the tensile strength of the concrete increased, but the most determining factor was the reinforcement diameter. It have been concluded that the smaller the reinforcement diameter, the higher the adherence. Mirza and Houde (1979) carried out pull-out tests for 62 specimens with 4, 6 and 8 mm diameter reinforcement. In all cases, it has observed that cracks formed and propagated and the reinforcement elongated. A bond stress - shear relationship has derived from the experimental data and it has found that this relationship has dependent on concrete strength, concrete cover thickness, reinforcement diameter and load level and that beam performance improved especially when the concrete cover was increased. In the study by Naaman and Najm (1991), different amounts of different admixtures were added to the concretes in the specimens to be subjected to tensile tests. It has determined with the results of the experiments that adherence increased when the additives increased the strength of the concrete. Bouazaoui and Li (2008) studied the pull-out test to determine the shear stress between steel and concrete and to calculate the ultimate force. The relationship between ultimate force, diameter and length embedded in concrete was expressed experimentally. It has concluded that the ultimate force is directly dependent on the steel reinforcement diameter and embedded length. A theoretical model is also proposed to predict the critical shear stress. This model has been also compared with the experimental results and found to give similar results. Biscaia and Soares (2020) identified some inconsistencies in the traditional theory where the adherence between concrete and reinforcement is described as a bond-slip relationship. They performed 33 different tensile test experiments involving 3 different ribbed reinforcements of different diameters and different embedded lengths and developed an analytical solution. A new local bond-slip relationship with friction was proposed by looking at the experimental load and displacement relationship at the pulled end in the tensile test. Başaran and Kalkan (2020) conducted flexural tests on 90 articulated beams to investigate the variables affecting the adherence between FRP reinforcement and concrete. As a result of the study, it has concluded that when the thickness of the concrete cover on the side and bottom exceeds 2.5 times the reinforcement diameter, the contribution of the concrete cover to the adherence strength will be very little or none. In the study conducted by Döndüren et al. (2006), an experiment was carried out to test many factors affecting adhesion. As a result of the experiments, it has concluded that high concrete quality, the use of ribbed reinforcement instead of plain reinforcement, high interlock length and the use of stirrups increase adherence. In their study, Özkal and Uysal (2017) investigated the effect of changing only the reinforcement arrangement on beam performance. With the new design they made on the determination of reinforcement detail, they ensured ductile fracture of a brittle fractured specimen. Ertuç et al. (2018) interpreted the adherence of reinforced concrete beams subjected to corrosion effect by subjecting them to flexural test. As a result of the bending test, the specimen with a corrosion rate of 3.23% behaved more ductile than the non-corroded specimen because it increased adherence. However, as corrosion increased more, negative effects occurred. Sakcalı et al. (2024) investigated the adherence difference between a reinforced concrete beam reinforced with a steel bar with a smooth surface and a steel bar with a sand-coated outer surface by bending test. As a result of the tests, it has found that the adherence of the sand-coated steel bar was higher than that of the steel bar with smooth surface. Tanyıldızı and Yazıcıoğlu (2006) investigated the effect of concrete curing conditions on adherence at 3, 7, 14 and 28 days. As a result of the experiments, it was determined that the highest adherence occurred in water, nylon and air curing conditions, respectively. Arslan and Arslan (2018) investigated the effect of interlock length and reinforcement diameter on the adherence between concrete and reinforcement by performing flexural test. As a result of the study, it has observed that the adherence increased as the clamping length increased, but in cases with the same clamping length, higher adherence occurred between small diameter reinforcement and concrete. Türk and Başsürücü (2021) examined the adherence strength of long and short steel fibre reinforced beam specimens by subjecting them to four-point bending test. As a result of the study, it has concluded that the adherence is 65% higher in mixed fibre reinforced beam specimens.

Even if the reinforcement spacing and the thickness of the concrete cover are determined at the project stage, they are open to error during the application. Although some of such errors do not have a numerical equivalent, they directly affect the beam performance. Although reinforced concrete calculation programmes recommend double rows of reinforcement in accordance with the standard reinforcement spacing in the tension zones of densely reinforced beams, it is observed in practice that the spacing is violated in practice and single rows are used, resulting in unexpected early cracks and large deflections. Similarly, if the concrete cover is violated, cracks and deflections due to early adherence loss are observed in these beams, which are open to fire and corrosion threats. Among the literature studies presented above, it has observed that there is no direct literature study on these failures and their consequences.

In this study, in the analysis and design of reinforced concrete beams, 8 1/2 scale reinforced concrete beams were prepared and subjected to flexural tests by changing the thickness of the concrete cover and the reinforcement spacing affecting the adherence based on both the conditions given in the regulations and the situations encountered during the application. The effects of both reinforcement placement and concrete cover on the behaviour and performance (maximum bearing capacity, deflection values, energy dissipation capacity and stiffness) of the beams were observed experimentally. In addition, the experimental results are compared and interpreted with analytical results. Taking the load-deflection behaviour graph of two beams with minimum reinforcement as a reference, the performance of two beams with the same tensile reinforcement in the beam span but with reinforcement placement in accordance with standard spacing and concrete cover, and two beams with reinforcement placement not in accordance with standard spacing and concrete cover, which are frequently encountered in practice, were investigated for loss of adherence and inadequate concrete cover. With this study, it is aimed to contribute to the literature on how the errors to be made during the application of reinforced concrete beams will affect the beam performance.

2. Material and Method

2.1. Test Samples and Materials

In this study, a total of 8 reinforced concrete beams in 4 different groups coded as A, B, C, D with 1/2 scale 15x30 cm section and 205 cm length were produced. While determining the beam dimensions and reinforcements, the required dimensioning dimensions specified in TS 500 and TBDY 2018 were followed (TS500, 2000; TBDY, 2018; Celep, 2022; Turan, 2022). Mould preparation, reinforcement placement and concrete pouring of a total of 8 beam specimens were carried out in the laboratory. All beam specimens were kept in the laboratory at a temperature of 25±2°C until the relevant test day after manufacturing.

Since the subject of the study is related to the reinforcement placement in the tension zone of the beam, 2 Ø8 reinforcements were placed in the compression zone as fixed. In all beam specimens, Ø8 stirrups were used at 15 cm intervals. In specimen A, 12Ø8 reinforcements were used in the tension zone while no concrete cover thickness was left in the tension zone. In specimen B, 12Ø8 reinforcement was used in the tension zone and 1.25 cm concrete cover thickness was left in the tension zone in accordance with the standards. In specimen C, 4Ø8 reinforcement was used in the tensile zone and 1.25 cm concrete cover thickness was left in the tensile zone. In specimen D, a double row of 12Ø8 reinforcement was used in the tension zone and a concrete cover thickness of 1.25 cm was also left in the tension zone. Cross-sectional views and common long-sectional view of all beam specimens are given in Figure 1.

Plywood have used for the moulds of the beam specimens. As shown in Figure 2, after the reinforcements were cut and connected appropriately, the thickness of the concrete cover was adjusted and the beam specimens were placed in the moulds. Then, concrete was poured into the moulds (Bilgil et al., 2005).

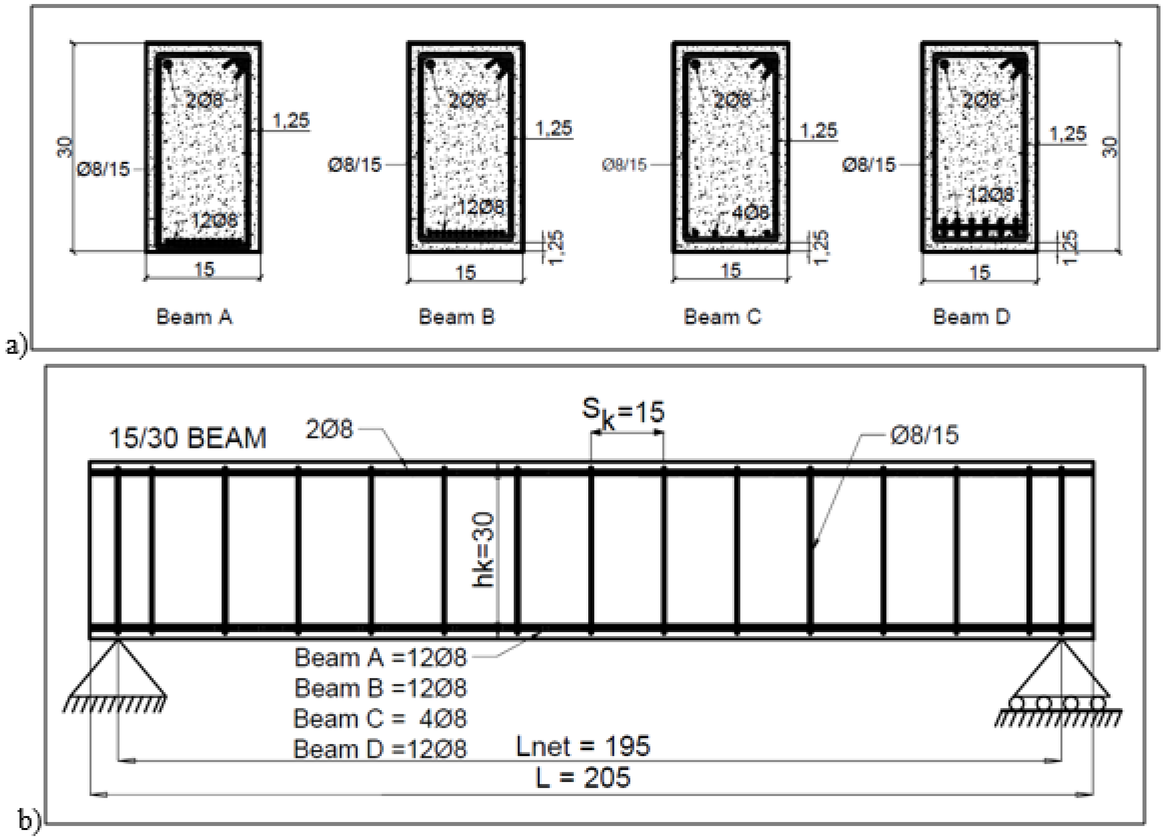

Figure 1. (a) Cross-sectional views of beam specimens, **(b)** Long-sectional views of beam specimens. (Dimensions in cm.)

Figure 2. Preparation of reinforcement of beam specimens and placing them in the mould.

A total of 0.36 m^3 of concrete was used for the production of 8 beam specimens to be used in the experiment. The concrete used in the production of beam specimens was obtained from EZN Mining Manufacturing Company as C30/37 ready-mixed concrete. The C30/37 ready-mixed concrete contains 45% coarse aggregate with a grain size of 5-11 mm and 55% crushed sand. According to the test results performed at the concrete production facility, the water/cement ratio of the concrete has determined as 0.51. The slump value of the concrete has determined as 180 mm and the ready-mixed concrete used is classified as S4 among the 5 slump classes in TS EN 206+A2 (2021) (TS EN 206+A2, 2021; Bilgil et al., 2010).

Nine 15 x 15 x 15 cm cube specimens were produced from the concrete used in beam production. The specimens were demoulded after 24 hours and 3 of them were kept in lime saturated water curing at 20±2°C for 28 days. The other 6 cube specimens were kept together with the beam specimens in the laboratory until the 63rd test day when the beam tests were carried out. The characteristic cube compressive strengths of the cube specimens were calculated by performing uniaxial compressive strength test under constant loading using a computer controlled press in the laboratory. The characteristic cube compressive strength of all cube specimens have converted to the characteristic cylinder compressive strength by equation 1 according to TS EN 206+A2 (Celep, 2022; TS EN 206+A2, 2021).

$$F_{ck}^{cylinder} = 0.85\ F_{ck}^{cube} \tag{1}$$

The modulus of elasticity of concrete has determined as 31118.5 MPa with equation 2 using the characteristic compressive strength of concrete determined according to the results of the specimen subjected to compression test on the test day.

$$E_c = 3250\sqrt{f_{ck}} + 14000\ (\text{MPa}) \tag{2}$$

Tensile tests have performed in accordance with TS EN ISO 6892-1 by taking 3 samples of Ø8 reinforcements to be used in beams (TS EN ISO 6892-1, 2020). As a result of the tensile test, the values found by averaging the 3 samples are given in Table 1.

Table 1. Reinforcement steel material properties.

Diameter, Φ (mm)	Reinforcement Area, A_s (mm^2)	Average Yield Strength, f_{yk} (MPa)	Average Tensile Strength, f_u (MPa)	Average Tensile Strength/Average Yield Strength
8	50.24	481.19	582.24	1.21

According to TS 708 (2016), the ratio of reinforcement tensile strength to reinforcement yield strength should be between 1.15 and 1.35 (TS 708, 2016). As a result of the test, it has seen that the reinforcements used in the test met this condition.

In order to prevent oblique tension fracture in the beams, the ratio of the distance of the loading point to the support at the midpoint of the beam, which is the beam shear span, to the useful height of the beam (a/d) was determined to be greater than 3. It was calculated as 3.29 for specimen A with a useful height of 296 mm, 3.44 for specimen B with a useful height of 283.5 mm, 3.44 for specimen C with a useful height of 283.5 mm and 3.55 for specimen D with a useful height of 274.5 mm.

2.2. Preparation of the Experimental Setup

In order to make the necessary loads within the scope of the experiment, the steel frame system available in the laboratory was used as a device. Beams were loaded with the help of a hydraulic jack located in the centre of the steel frame system. Ø40 solid iron was placed at the bearing points and the moving and fixed state of the bearings was adjusted. In order to measure the deflection of the beams during loading, a mechanical comparator was placed at the bottom of the beam in the middle of the beam. A representative image of the experimental setup in the laboratory environment is given in Figure 3.
Figure 4 shows a specimen ready for loading on the experimental setup.

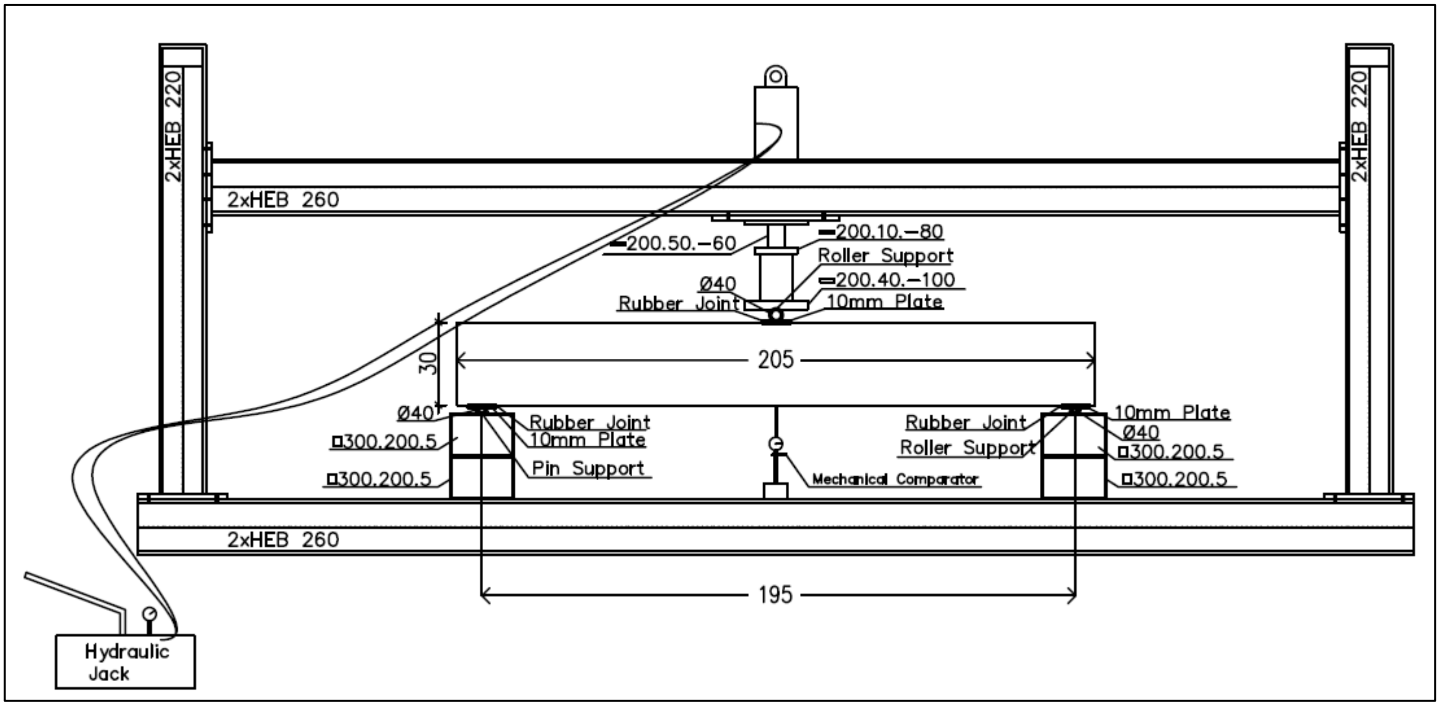

Figure 3. Representative experimental setup representation (dimensions in cm).

Figure 4. Beam specimen test.

After the beam specimens reached the load carrying capacity, the tests were continued until approximately 5% strength loss and then terminated.

2.3. Reinforced Concrete Calculations of Beams

Reinforced concrete theoretical calculations were performed for beam specimens. From the values shown in Table 2, the concrete shear capacity (Vc) was calculated as 80% of the concrete critical shear capacity (Vcr) by Equation 3 and Equation 4. The stirrup shear capacity (Vw) was calculated by the formula given in equation 5. In the equations, n is the number of stirrup arms, Asw is the cross-sectional area of the stirrup vertical arms, d is the useful height of the beam, Sk is the stirrup spacing, fctk is the characteristic axial tensile strength of concrete, bw is the beam width and fywk is the characteristic yield strength of the stirrup reinforcement (Ersoy et al., 2019).

$$V_c = 0.8\, V_{cr} \tag{3}$$

$$V_{cr} = 0.65\, f_{ctk}\, b_w\, d \tag{4}$$

$$V_w = (n\, A_{sw}\, f_{ywk}\, d) / S_k \tag{5}$$

Table 2. Reinforced concrete calculations for beam specimens.

Test Specimen	Theoretical Max. Load P (kN)	Moment of Bearing Strength, M_r (kN.m)	Beam Shear Force, $V_{kiriş}$ (kN)	Concrete Shear Capacity, V_c (kN)	Stirrup Shear Capacity, V_w (kN)
A	151.74	73.97	52.84	42.48	95.41
B	145.79	71.07	51.51	41.14	92.19
C	54.02	26.33	19.09	41.14	92.19
D	140.44	68.46	50.27	39.84	89.29

It is also important to analyse the crack formation and development in reinforced concrete beams (Wang et al., 2016; Picandet et al., 2009; Merkle et al., 2023; Ayhan et al., 2022). For this reason, according to the calculations made with Equation 6, the moment (Mcr) at which the beams will start to crack first was calculated as 4.149 kN.m (Ersoy et al., 2019).

$$M_{cr} = f_{ctk}\, I / y_{max} \tag{6}$$

Tensile zone reinforcement ratios of the beams were calculated by Equation 7 (TS500, 2000). The tensile zone reinforcement ratios of beam specimens A, B and D were calculated as 0.0134, while the tensile zone reinforcement ratio of beam specimen C was determined as 0.0044.

$$\rho = A_s/(b_w d) \tag{7}$$

The minimum reinforcement ratio required for reinforced concrete beams was calculated by Equation 8 (TS500, 2000). The minimum reinforcement ratio of the beams was determined as 0,0030 for all beams. The maximum reinforcement ratio in the tension zone of the beams is 0.02 (TS500, 2000). Although all beams meet the reinforcement ratio conditions, specimen C is equipped with a reinforcement ratio closer to the minimum reinforcement ratio (Severcan et al., 2016; Foroughi and Yüksel, 2023).

$$\rho_{min} = 0.8\, \left(\frac{f_{ctd}}{f_{yd}}\right) \tag{8}$$

3. Findings

3.1. Observational Findings and Evaluation

Within the scope of the study, bending tests were carried out on 8 reinforced concrete beams in 4 different groups with a 1/2 scale section of 15x30 cm and a length of 205 cm. One side of the beams was connected as a fixed support, while the other side and the middle part where the maximum load was applied were connected as movable supports. As expected, the beams behaved like a single span simple beam under three point loading. In the flexural tests, the collapse of beam A specimens with 12Ø8 reinforcement in the tension zone and no concrete cover is shown in Figure 5-a, and the collapse of beam B specimens with 12Ø8 reinforcement in the tension zone and concrete cover thickness in accordance with the standards is shown in Figure 5-b, The collapse pattern of C beam specimens with 4Ø8 reinforcement in the tensile zone and concrete cover thickness in accordance with the standards is given in Figure 5-c, and the collapse pattern of D beam specimens with double rows of 12Ø8 reinforcement in the tensile zone and concrete cover thickness in accordance with the standards is given in Figure 5-d.

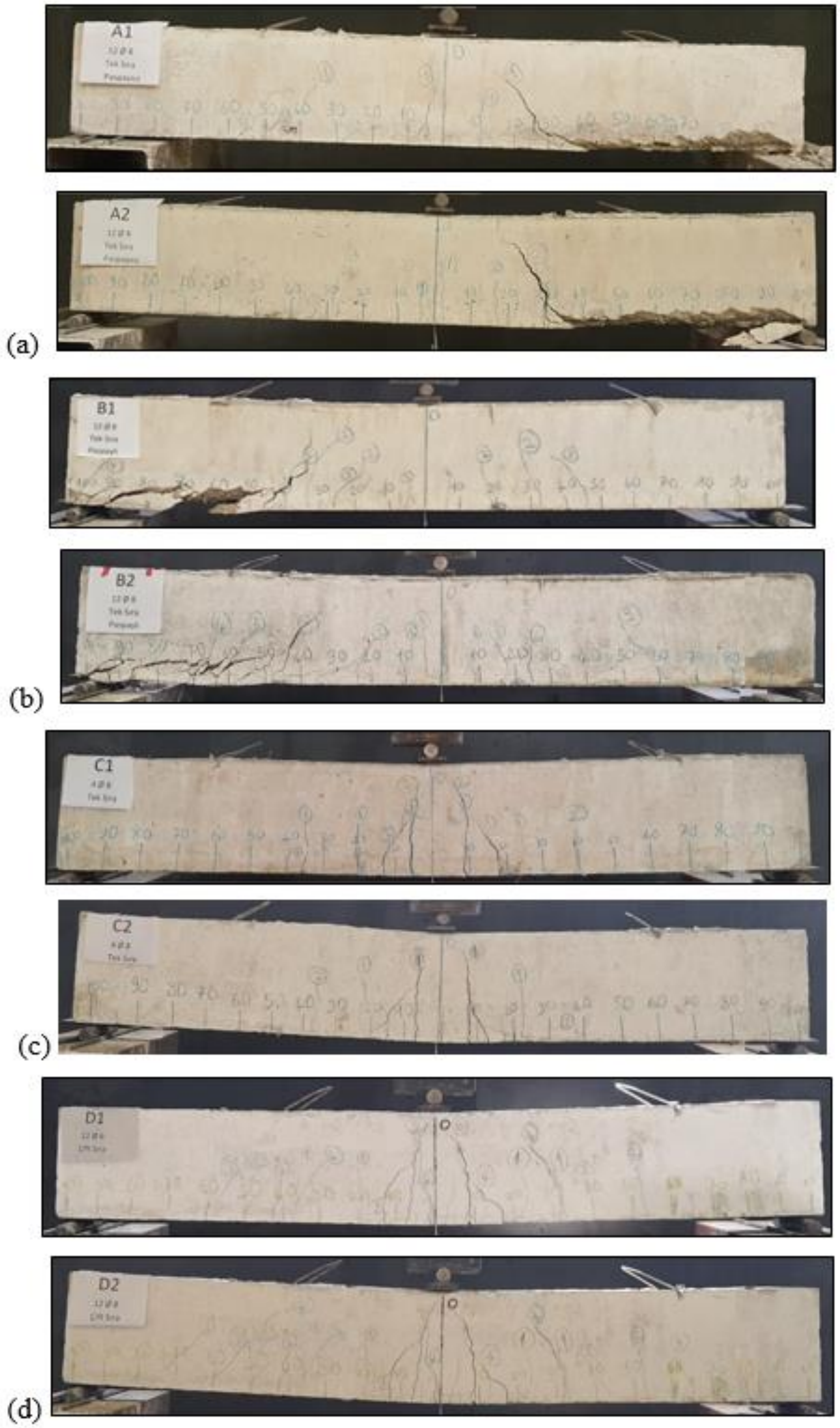

Figure 5. Collapse pattern of beam specimens **(a)** specimen A, **(b)** specimen B, **(c)** specimen C, **(d)** specimen D.

When the test specimens and collapse patterns were analysed, no crushing of the concrete was observed in the compression zones of the specimens, indicating that the compressive strength of the concretes was sufficient. As a result of the test, shear collapse due to lack of stirrups did not occur in the specimens. No tensile fracture and arching effect were observed in the specimens.

In specimen C, which has less tensile reinforcement, and specimen D, which has double rows of reinforcement, while the initial cracks appeared as flexural cracks in the lower centre of the beam, the maximum bearing capacity was reached with shear flexural cracks near the centre. In the other single-row reinforced beams A and B, it was observed that large shear cracks close to the supports were the effective collapse cracks of the beams due to adherence weakness caused by reinforcement placement. In addition, when the crack formation in the beam specimens is observed, it is seen that there are fewer and larger cracks in specimens A and B where reinforcement placement and concrete cover are not in compliance with the standards, while more capillary and more cracks are formed in specimens C and D where reinforcement placement and concrete cover are in compliance with the standards.

Premature cracks in beams receiving vibration will change the structural behaviour of the system by increasing the period of the beam (Kassem et al., 2022).

3.2. Experimental Results and Evaluation

The cube specimens formed during concrete casting were subjected to compressive tests in the laboratory with the help of a computer controlled press. The average characteristic cube compressive strength of 3 cube specimens kept in lime saturated water for 28 days was determined as 35.16 MPa and the characteristic cylinder compressive strength was determined as 29.89 MPa. The average characteristic cube compressive strength of 6 cube specimens kept in the laboratory until the test day was 32.64 MPa and the characteristic cylinder compressive strength was 27.74 MPa. In all reinforced concrete calculations, 27.74 MPa value was used as concrete compressive strength.

Considering the test results of 8 beam specimens in 4 different groups used in the experiment, specimens A and B were compared to measure the effect of concrete cover on beam strength, specimens B and D were compared to measure the effect of adherence due to reinforcement placement, and specimens A and D were compared to see the effect of reinforcement placement and concrete cover at the same time. A comparison was made between specimens C and D only in terms of different reinforcement ratios. As a result of the experiment, the force-displacement graph of 8 beam specimens in 4 different groups from the moment they reached the load carrying capacity to the moment of flexural collapse is shown in Figure 6. While other graphs are given for beam specimens, the graphs were created by taking the average of the specimens in the same group. The experiments were continued until approximately 5% strength loss after the beam specimens reached the load carrying capacity. The usable deflection limit (L/240 = 8.125 mm) is indicated with a line on the graph.

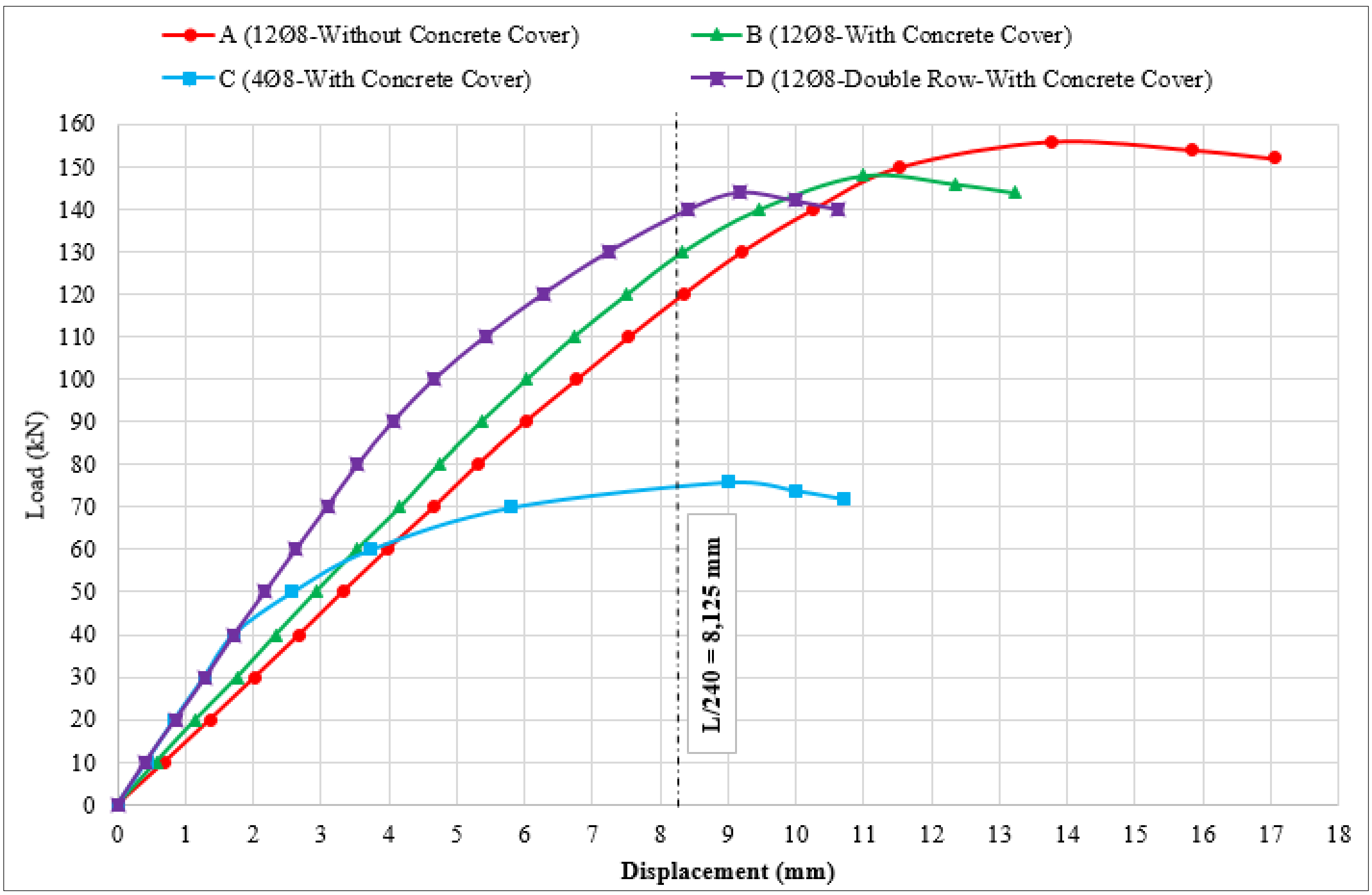

Figure 6. Load-displacement graph of beam specimens.

Figure 7 shows the slope of the load-displacement graph for beam specimens in the linear elastic region. The P- δ slope of specimen B is 14.74% (17.13/14.93) higher than that of specimen A. The P- δ slope of sample D is 35.79% (23.26/17.13) higher than that of sample B. The P- δ slope of sample D is 55.79% (23.26/14.93) higher than that of sample A. The P- δ slope of specimen C is 0.86% (23.46/23.26) higher than that of specimen D. Considering these results, it is seen that specimen A, whose reinforcement placement and concrete cover do not comply with the standards, has the lowest slope and stiffness in the linear region. The fact that the stiffness of specimen B with concrete cover is higher than specimens A and B with only concrete cover difference between them supports the study of Mirza and Houde (1979).

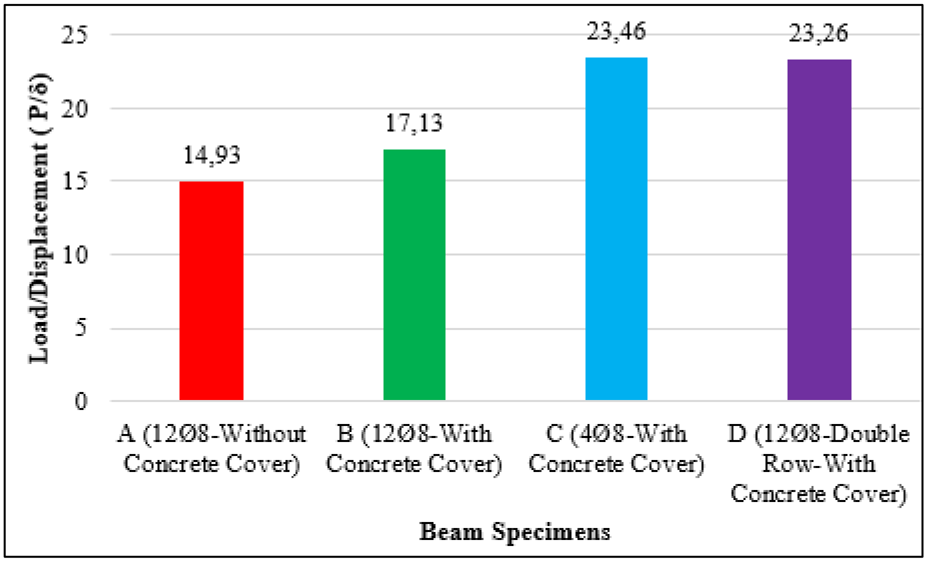

Figure 7. Load-displacement (P-δ) slope plot in linear elastic region.

Figure 8 shows the graph of the amount of load at the usable deflection limit of the beams. The load at the usability deflection limit of specimen B is 8.82% (128.30/117.90) higher than that of specimen A. The amount of load at the usability deflection limit of specimen D is 6.94% (137.20/128.30) more than specimen B. The load at the usable deflection limit of specimen D is 16.37% (137.20/117.90) higher than that of specimen A. Among the two specimens with different reinforcement ratios only in the tensile zone, the load at the usable deflection limit of specimen D is 85.91% (137.20/73.80) higher than that of specimen C. From this point of view, it is seen that in the case of equal reinforcement ratios, the amount of load at the usable deflection limit of the specimens increases as the reinforcement placement and concrete cover are brought into compliance with the standards. As in the study of Jendele and Cervenka (2006), the increase in adherence increases the amount of load that the beams can carry before the cracks in the beams grow.

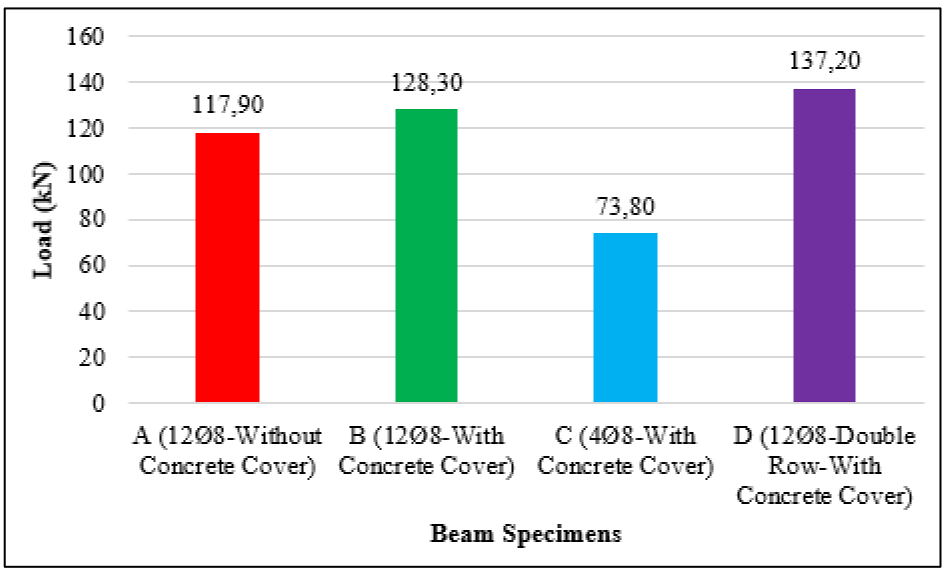

Figure 8. Load amount at the availability deflection limit (L/240).

Figure 9 shows the graph of energy consumption at the usable deflection limit of the beam specimens. The amount of energy consumption at the usability deflection limit of specimen B is 11.30% (573.93/515.65) higher than that of specimen A. The energy consumption of specimen D at the usability deflection limit is 22.49% (703.00/573.93) more than that of specimen B. The energy consumption of specimen D at the usability deflection limit is 36.33% (703.00/515.65) higher than that of specimen A. The energy consumption of specimen D at the usable deflection limit is 59.89% (703.00/439.68) higher than that of specimen C. It was observed that the amount of energy consumption at the usable deflection limit is higher if the reinforcement placement and concrete cover are made in accordance with the standards.

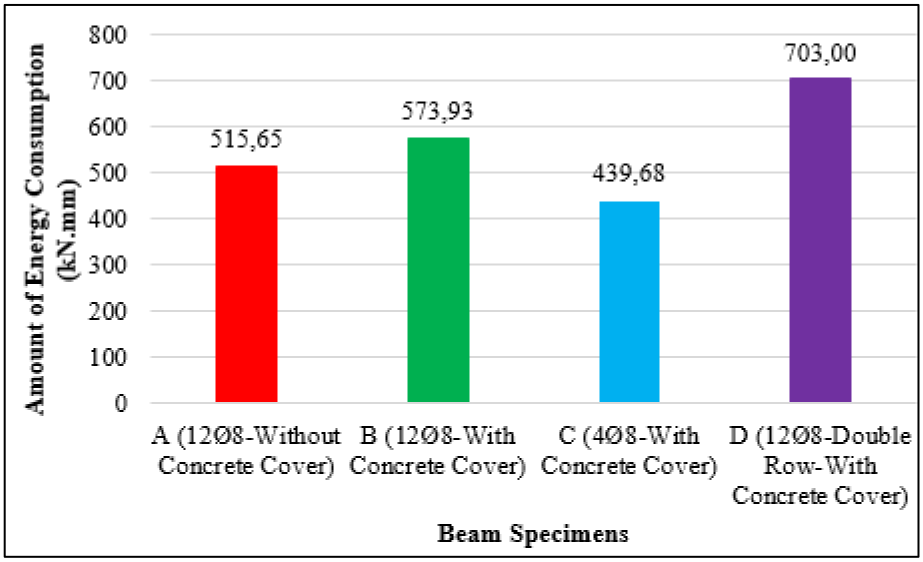

Figure 9. Graph of the amount of energy consumed in case of availability deflection limit.

Figure 10 shows the load carrying capacity graph of the beam specimens. As a result of the experiment, the load carrying capacity of specimen A was 156.00 kN, specimen B was 148.00 kN, specimen C was 76.00 kN and specimen D was 144.00 kN. The load carrying capacity of specimen A is 5.41% (156.00/148.00) higher than that of specimen B. Since the useful height (d) of specimen B is higher, its load carrying capacity is 2.78% (148.00/144.00) higher than specimen D. The load carrying capacity of specimen D is 89.47% (144.00/76.00) higher than that of specimen C due to the reinforcement ratio between specimens C and D, which have equal conditions in terms of reinforcement placement and concrete cover. The load carrying capacity of specimen A was 8.33% (156.00/144.00) higher than that of specimen D. Since the load carrying capacity is dependent on the reinforcement ratio and useful height in the 4 specimen groups where identical reinforcement and concrete are used as materials, it is seen that the adherence stress has no direct effect on the load carrying capacity. The load carrying capacities obtained after the test are consistent with the reinforced concrete calculations for beam specimens A, B and D. However, although the reinforcement ratio of beam specimen D is 3 times that of beam specimen C, there is a difference of about 2 times between the load carrying capacities. However, although the reinforcement ratio of beam specimen D is 3 times that of beam specimen C, there is a difference of about 2 times between the load carrying capacities. Although the first reason for this is the decrease in the useful height of the second row of reinforcement in specimen D, it is thought to be due to the more frequent spacing of the reinforcement.

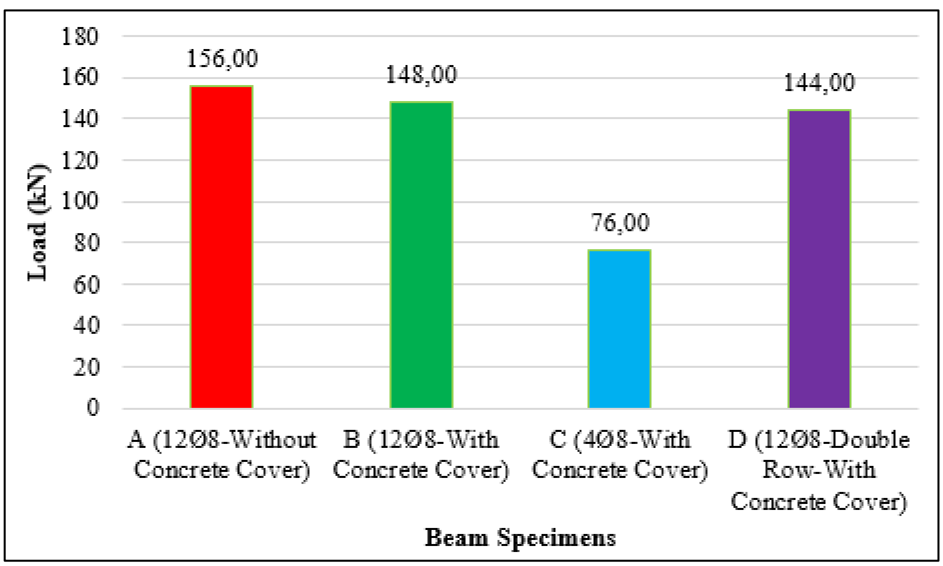

Figure 10. Load carrying capacity (Pmax) graph.

Figure 11 shows the displacement (δopt) graph when the load carrying capacity is reached. It was observed that specimen A deflected 25.30% (13.77/10.99) more than specimen B when the load carrying capacity was reached. Specimen B deflected 19.59% (10.99/9.19) more than specimen D. When the load carrying capacity was reached, specimen A deflected 49.84% (13.77/9.19) more than specimen D. Specimen D deflected 1.99% (9.19/9.01) more than specimen C. If the reinforcement placement and concrete cover are made in accordance with the standards, it is seen that the beams reach the load carrying capacity with less deflection. As in the study of Özkal and Uysal (2017), it was observed that the beam performance changed by changing only the reinforcement placement of the specimens formed with identical materials.

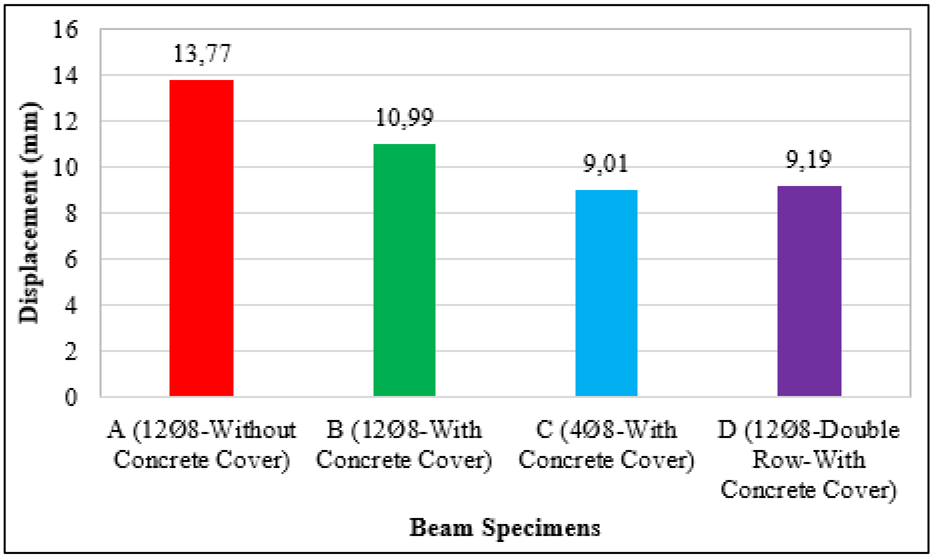

Figure 11. Displacement (δopt) graph when the load carrying capacity is reached.

Figure 12 shows the graph of the amount of energy consumption in the load carrying capacity of the beams. As a result of the experiment, the amount of energy consumption in the load carrying capacity of specimen A was found to be 1293.04 kN.mm, 946.17 kN.mm for specimen B, 505.57 kN.mm for specimen C and 811,63 kN.mm for specimen D. The energy consumption of specimen A is 36.66% (1293.04/946.17) higher than that of specimen B. The amount of energy consumption in the load carrying capacity of specimen B is 16.58% (946.17/811.63) more than specimen D. The amount of energy consumption at load carrying capacity of specimen A is 59.31% (1293.04/811.63) more than specimen D. The energy consumption at load carrying capacity of specimen D is 60.54% (811.63/505.57) higher than that of specimen C. Since the load carrying capacity and deflection amount of the beams whose reinforcement placement and concrete cover are not in accordance with the standards are high, the amount of energy consumption in the load carrying capacity is also high.

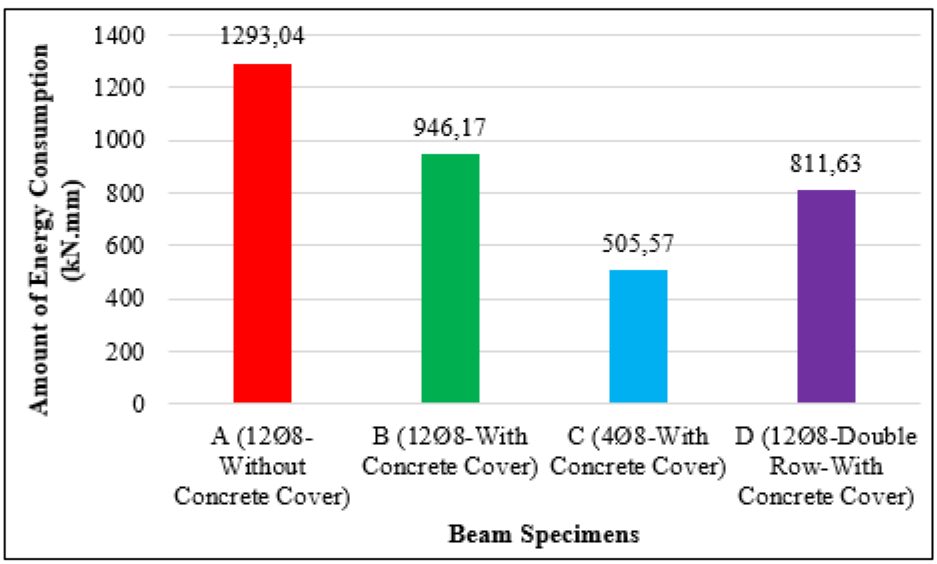

Figure 12. Graph of the amount of energy consumed in load carrying capacity.

4. Discussion and Conclusion

In this study, the effect of reinforcement placement and adherence due to concrete cover on the performance of reinforced concrete beams was investigated. Three point loading tests were carried out on 8 1/2 scale beam specimens with different reinforcement placement and concrete cover and the behaviour and performance of the beams were compared. As a result of the tests, the following conclusions were reached.

- It has observed that the load-displacement slope in the linear elastic region increased in the beam specimens with reinforcement placement and concrete cover prepared in accordance with the standards.

- In specimens with inadequate reinforcement placement and concrete cover, beyond the vulnerability to fire and corrosion, the deflection at the centre of the beam reached the usable deflection limit (L/240) earlier. In addition, it has observed that the cracks in the beams would be earlier and wider when the reinforcement placement and concrete cover were not taken into consideration.
- Since the usable deflection limit was reached under higher loads in specimens with reinforcement placement and concrete cover in accordance with the standards, it has observed that the amount of energy consumption was higher in this case.
- Since the load carrying capacity depends on the section properties and useful height independently of the adherence, it has observed that the load carrying capacity was higher in cases where the concrete cover was less.
- When the load carrying capacity was reached, the least displacement occurred in the specimen where the reinforcement placement and concrete cover were adjusted in accordance with the standards. The maximum displacement occurred in the specimen where the reinforcement placement and concrete cover were not in accordance with the standards.
- It has observed that when the load carrying capacity was reached, the amount of energy consumption was also higher as more displacement occurred if the reinforcement placement and concrete cover were not in accordance with the standards.
- In the case where the reinforcement placement was not in accordance with the standards, it was observed that the reinforcement in the tensile zone peeled off under lower loads similar to the behaviour of plain reinforcement although it was ribbed.
- Earlier and larger crack formation was observed in beams where reinforcement placement and concrete cover did not comply with the standards, whereas more numerous but capillary cracks were observed when the standards were complied with.
- The reinforcement placement and concrete cover in beams conforming to the standards enabled the beams to reach the usable deflection limit at a point closer to the load carrying capacity. Although the amount of energy consumption in the case of non-compliance with the standards was high, it was observed that most of this energy consumption was in the region after reaching the usable deflection limit until reaching the load carrying capacity.

It will be complementary to this study to determine the unexpected behaviour and loss of performance of similar non-standard beams against fire and corrosion.

References

Akgül, M., Doğan, O., & Odacıoğlu, O.G. (2022). A review on adherence in reinforced concrete. Civil Engineering Beyond Limits, 3(4), 1-7. DOI: 10.36937/cebel.2022.1765

Akgül, M., & Doğan, O. (2022). Determination of Reinforcement Adherence Loss by Accelerated Corrosion Test for Normal and 4% NaCl Solubility Cured Flat and Ribbed Reinforced Concretes with Different Strengths. International Journal of Engineering Research and Development, 14(2), 691-704. https://doi.org/10.29137/umagd.1092523

Akyürek, M. (2019). The Effect of Concrete Cover and Concrete Strength on Concrete with FRP Bars Exposed to High Temperature. Doctoral Thesis. Sakarya University, Institute of Science and Technology, Sakarya.

Alper, D. (2008). Adhesive and Fatigue of Reinforcement in Concrete. Master’s Thesis. Kırıkkale University, Institute of Science and Technology, Kırıkkale.

Arslan, M.E., & Arslan, T. (2018). Investigation of Development Length and Rebar Diameter Effects on Bond Strength by Using Hinged Beam Test. Science and Engineering Journal of Fırat University, 30(2), 1-11.

Atmaca, G. (2017). Effect of Aggregate Clay Content on Concrete Mechanical Properties and Its Bond with Reinforcement. Master’s Thesis. Ege University, Institute of Science and Technology, İzmir.

Aydın, S. (2021). Investigation of High Performance Concrete Cover Production. Master’s Thesis. Düzce University, Institute of Postgraduate Education, Düzce.

Ayhan, B., Lale, E., & Çelik, N. (2022). Size Effect Analysis of Concrete Beams Under Bending Using Crack-Band Approach. Journal of Polytechnic, 25(2), 605-613. https://doi.org/10.2339/politeknik.762634

Başaran, B., & Kalkan, İ. (2021). Comparison of Different FRP Reinforcement-Concrete Bon Test Methods According to Parameters Affecting This Bond. Journal of The Faculty of Engineering and Architecture of Gazi University, 36(3), 1581-1594. https://doi.org/10.17341/gazimmfd.656823

Başaran, B., & Kalkan, İ. (2020). Investigation on Variables Affecting Bond Strength Between FRP Reinforcing Bar and Concrete by Modified Hinged Beam Tests. Composite Structures, 242(15). https://doi.org/10.1016/j.compstruct.2020.112185112185

Bilgil, A., Öztürk, B., & Bilgil, H. (2005). A numerical approach to determine viscosity-dependent segregation in fresh concrete. Applied Mathematics and Computation, 162(1), 225-241. https://doi.org/10.1016/j.amc.2003.12.086

Bilgil, A., Öztürk, B., & Şamandar, A. (2010). Application of numerical analysis for investigation of relationship between slump values and other rheological properties of fresh concrete. Scientific Research and Essays, 5(10), 1111-1121. https://doi.org/10.1016/j.amc.2003.12.086

Biscaia, H.C., & Soares, S. (2020). Adherence Prediction Between Ribbed Steel Rebars and Concrete: A New Perspective and Comparison with Codes. Structures, 25, 979-999. https://doi.org/10.1016/j.istruc.2020.04.019

Bouazaoui, L., & Li, A. (2008). Analysis of Steel/Concrete Interfacial Shear Stress by means of Pull Out Test. International Journal of Adhesion and Adhesives, 28(3), 101-108. DOI: 10.1016/j.ijadhadh.2007.02.006

Cedrim, F.A., Almeida, V.L.S., Souza, C.A.C., Lima, P.R.L., Jesus, M.D., & Ribeiro, D.V. (2019). Corrodobility and Adherence of Reinforced Concrete Rebars Electroplated with Zinc and Zinc-Nickel Alloys. Materials Research, 22(4). https://doi.org/10.1590/1980-5373-MR-2018-0915

Celep, Z. (2022). Reinforced Concrete Structures. 12th Edition, Beta Printing and Publishing, Ankara,

Coşkan, S., & Yüksel, İ. (2013). Effects of The Rebar Corrosion to Structural System Behavio of Frames. SDU International Journal of Technologic Science, 5(3), 77-88.

Dasar, A., Patah, D., Hamada, H., Yamamoto, D., & Sagawa, Y. (2022). Life Performance of 40 Year Old RC Beams with Different Concrete Covers and Bar Diameters in Natural Corrosion Environments. Structures, 46, 2031-2046. https://doi.org/10.1016/j.istruc.2022.11.033

Demirel, F., & Altındaş, S. (2005). Classification of Fire Resistance of Building Elements According to European Union Directives and Comparison Between Turkey and Europe. Journal of Polytechnic, 8(4), 381-395.

Doğan, O., & Akgül, M. (2020). The Effect of Reinforcement Corrosion on Durability and Adherence of Reinforced Concrete. 5th International Applied Science Congress, Diyarbakır, Türkiye, 251-265.

Doğan, O., Genç, Y., & Akgül, M. (2022). Comparison of Cross-Sectional Effects of Reinforce Concrete Frame and Anchored / Secondary Beams within The Scope of DBYBHY-2007 and TBDY-2018. Dicle University Journal of Engineering, 13(2), 295-305. https://doi.org/10.24012/dumf.1053898

Doğan, O., Koç, Ö., & Akgül, M. (2019). Effect of the Concrete Compressive Strength on Fatigue of the Bond Between Concrete and Reinforcement. 5nd International Congress on Engineering, Architecture and Design, İstanbul, Türkiye, 1161-1169.

Döndüren, M. S., Çöğürcü, M. T., & Altın, M. (2006). An Experimental Study For on The Bond Behavior of Reinforcing Steel and Concrete. Journal of Faculty of Engineering and Architecture Selçuk University, 21(3-4), 57-68.

Ersoy, U., Özcebe, G., & Canbay, E. (2019). Reinforced Concrete Volume 1-Behaviour and Calculation Principles. 9th Edition, Evrim Publications, İstanbul.

Ertuç, İ., Yalçıner, H., & Kumbasaroğlu, A. (2018). Flexural Behavior of Reinforced Concrete Beams Subjected to Corrosion. Erzincan University Journal of Science and Technology, 11(1), 1-10.

Foroughi, S., & Yüksel, S. B. (2023). Moment-Curvature and Effective Section Stiffness of Reinforced Concrete Beams. Journal of Polytechnic, 26(1), 169-177.

Harmuth, H. (1995). Investigation of the Adherence and the Fracture Behaviour of Polymer Cement Concrete. Cement and Concrete Research, 25(3), 497-502.

Ichinose, T., Kanayama, Y., Inoue, Y., & Bolander, Jr. J. E. (2004). Size Effect on Bond Strength of Deformed Bars. Construction and Building Materials, 18(7), 549-558.

Jendele, L., & Cervenka, J. (2006). Finite Element Modelling of Reinforcement with Bond. Computers and Structures, 84(28), 1780-1791.

Kassem, M. M., Nazri, F. M., Farsangi, E. N., & Öztürk, B. (2022). Development of a uniform seismic vulnerability index framework for reinforced concrete building typology. Journal of Building Engineering, 47(15), 103838. https://doi.org/10.1016/j.jobe.2021.103838

Katz, A. (2018). Statistical Variations of Rebar Placement and Its Effect on Service Life. Practice Periodical on Structural Design and Construction, 23(3). https://doi.org/10.1061/(ASCE)SC.1943-5576.0000379

Khoury, G. A. (2000). Effect of Fire on Concrete and Concrete Structures. Progress in Structural Engineering and Materials, 2(4), 429-447.

Larrard, F., Schaller, I., & Fuchs, J. (1993). Effect of the Bar Diameter on the Bond Strength of Passive Reinforcement in High-Performance Concrete. ACI Materials Journal, 90(4), 333-339.

Lee, H. S., Noguchi, T., & Tomosawa, F. (2002). Evaluation of the Bond Properties Between Concrete and Reinforcement as a Function of the Degree of Reinforcement Corrosion. Cement and Concrete Research, 32(8), 1313-1318.

Merkle, D., Solass, J., Schmitt, A., Rosin, J., Reiterer, A., & Stolz, A. (2023). Semi-Automatic 3D Crack Map Generation and Width Evaluation For Structural Monitoring of Reinforced Concrete Structures. Journal of Information Technology in Construction (ITcon), 28, 774-805.

Mirza, S. M., & Houde, J. (1979). Study of Bond Stress-Slip Relationships in Reinforced Concrete. ACI Journal, 76(1), 19-46.

Naaman, A. E., & Najm, H. (1991). Bond-Slip Mechanisms of Steel Fibers in Concrete. ACI Materials Journal, 88(2), 135-145.

Oliveira, T. C., Simonetti, E. A. N., & Cividanes, L. S. (2023). Graphene Derivatives as Reinforcement in Coatings Based on Epoxy and Silane for Enhancing Its Corrosion Resistance - A Latest Advances Review. International Journal of Adhesion and Adhesives, 126. https://doi.org/10.1016/j.ijadhadh.2023.103484

Özkal, F. M., & Uysal, H. (2017). Determination of the Optimum Reinforcement Layout in RC Structural Members: Cantilever Beam Example. Iğdır University Journal of The Institute of Science and Technology, 7(2), 157-169.

Picandet, V., Khelidj, A., & Bellegou, H. (2009). Crack Effects on Gas and Water Permeability of Concretes. Cement and Concrete Research, 39(6), 537-547. DOI: 10.1016/j.cemconres.2009.03.009

Pinoteau, N., Pimienta, P., Guillet, T., Rivillon, P., & Remond, S. (2011). Effect of Heating Rate on Bond Failure of Rebars into Concrete Using Polymer Adhesives to Simulate Exposure to Fire. International Journal of Adhesion and Adhesives, 31(8), 851-861. DOI: 10.1016/j.ijadhadh.2011.08.005

Sakcalı, G. B., Yüksel, İ., & Sağıroğlu, S. (2024). Experimental and Numerical Investigation of The Bond Behavior of Smooth and Sand-Coated Rebar in Concrete by Flexural Bond Test Method. Journal of Polytechnic, 27(2), 709-720. https://doi.org/10.2339/politeknik.1097459

Sartori, A. L., Pinheiro, L. M., Silva, R. M., Freitas, S. B., & Cesar, T. G. (2017). Adherence Between Steel Bars and Lightweight Concrete with EPS Beads. Ibracon Structures and Materials Journal, 10(1), 122-159. DOI: 10.1590/s1983-41952017000100007

Severcan, M. H., Kara, İ. F., & Akçaözoğlu, K. (2016). Experimental Investigation of Deflections of Reinforced Concrete Beams With Different Reinforcement Ratios and Loading Types. Niğde University Journal of Engineering Sciences, 5(2), 135-147. https://doi.org/10.28948/ngumuh.295004

Shi, X., Tan, T. H., Tan, K. H., & Guo, Z. (2004). Influence of Concrete Cover on Fire Resistance of Reinforced Concrete Flexural Members. Journal of Structural Engineering, 130(8), 1225-1232. DOI: 10.1061/(ASCE)0733-9445(2004)130:8(1225)

Tanyıldızı, H., & Yazıcıoğlu, S. (2006). Effect of Curing Conditions on Bond Strength Between Concrete and Reinforcement Steel. Fırat University Journal of Eastern Studies, 5(1), 11-14.

TBDY (2018). Turkey Building Earthquake Regulations.

Topçu, İ. B., & Boğa, A. R. (2008). Effect of Corrosion on Adherence Between Reinforcement and Concrete for Reinforced Concrete. Journal of Engineering & Architecture Faculty Eskişehir Osmangazi University, 21(1), 23-38.

Topçu, İ. B., Canbaz, M., & Karakurt, C. (2006). Utilization of Chemical Admixtures for Concrete Production. Journal of Polytechnic, 9(1), 59-63.

Tramis, O., Brethous, R., Hassoune-Rhabbour, B., Fazzini, M., & Nassiet, V. (2016). Experimental Investigation on the Effect of Nanostructuration on the Adherence Properties of Epoxy Adhesives by a Probe Tack Test. International Journal of Adhesion and Adhesives, 67, 22-30. DOI: 10.1016/j.ijadhadh.2015.12.021

TS EN 206+A2 (2021). Concrete - Properties, Performance, Manufacturing and Compliance.

TS EN ISO 6892-1 (2020). Metallic Materials - Tensile Testing - Part 1: Test Method at Ambient Temperature.

TS500 (2000). Design and Construction Rules of Reinforced Concrete Structures.

TS 708 (2016). Steel - Reinforcing Steel for Reinforced Concrete.

Turan, A. F. (2022). Effects of Reinforcement Ratio and Widit / Height Ratio on Beam Behavior in Reinforced Concrete Beams. Master's Thesis, Bursa Uludağ University, Institute of Science and Technology, Bursa.

Türk, K., & Başsürücü, M. (2021). Bond Strength of Full-Scale Beams with Blended Short and Long Steel Fiber. Pamukkale University Journal of Engineering Sciences, 27(3), 274-280.

Ünlüoğlu, E., Topçu, İ. B., & Yalaman, B. (2007). Concrete Cover Effect on Reinforced Concrete Bars Exposed to High Temperatures. İMO Journal of Technic, 18(87), 4145-4155.

Üstün, B., & Dal, M. (2016). Evaluation of Reinforced Concrete Reinforcement Applications. Journal of Science and Youth, 4(1), 8-19.

Vu, K. A. T., & Stewart, M. G. (2005). Predicting the Likelihood and Extent of Reinforced Concrete Corrosion-Induced Cracking. Journal of Structural Engineering, 131(11), 1681-1689. https://doi.org/10.1061/(ASCE)0733-9445(2005)131:11(1681)

Wang, H. L., Dai, J. G., Sun, X. Y., & Zhang, X. L. (2016). Characteristics of Concrete Cracks and Their Influence on Chloride Penetration. Construction and Building Materials, 107, 216-225. https://doi.org/10.1016/j.conbuildmat.2016.01.002

Yücel, K. T., & Erten, K. M. (2023). Effects of Additives on Concrete-Rebar Adherence. International Scientific and Vocational Journal (ISVOS Journal), 7(1), 47-54. https://doi.org/10.47897/bilmes.1293025