State of Art: High Strength Reinforced Concrete T Beam

Prof. Dr. Hussam Ali Mohammed*
com.hus@atu.edu.iq
Noor Alhuda Abdulrheam
nooralhuda.raheem.tcm76@student.atu.edu.iq
*Al-Furat Al-Awsat Technical University- Al-Mussaib Technical Collage - Building & Construction Department
nooralhuda.raheem.tcm76@student.atu.edu.iq

Abstract

This research presents a numerical analysis to simulate the flexural behavior of reinforced concrete beams with high strength, hybrid strength, and normal strength. Well-crafted constraint functions comply with the ACI 318-08 Code's structural concrete design specifications. The flexural behavior of T-section beams cast with self-compacting concrete (SCC), which partially replaces coarse aggregate with recycled concrete aggregate, is examined in this study. The hybrid beam is composed of two layers: regular strength concrete makes up the tension layer and high strength concrete makes up the compression layer. Using a commercial finite element code, a finite element model was used for the simulation. The beam is evaluated and simulated in a non-linear fashion using ANSYS V.14.5 computer software.

KeyWords: T-beam, High strength concrete, Self-Compacting Concrete, Flexural Behavior

الخرسانة عالية المقاومة في تي بيم

أ.د.حسام علي محمد
com.hus@atu.edu.iq
نور الهدى عبد الرحيم حمزه
جامعة الفرات الأوسط التقنية – الكلية التقنية المسيب – قسم البناء والتشييد

خلاصة"

يقدم هذا البحث تحليلاً عددياً لمحاكاة سلوك الانحناء للعتبات الخرسانية المسلحة ذات القوة العالية والقوة الهجينة والقوة العادية. تتوافق وظائف القيد جيدة الصنع مع مواصفات التصميم الإنشائي للخرسانة ACI 318-08 Code. تم في هذه الدراسة دراسة سلوك الانحناء للعتبات المقطعية T المصبوبة بالخرسانة ذاتية الدمك (SCC)، والتي تستبدل جزئيًا الركام الخشن بركام الخرسانة المعاد تدويره. يتكون العوارض الهجينة من طبقتين: الخرسانة ذات القوة العادية تشكل طبقة الشد والخرسانة عالية القوة تشكل طبقة الضغط. باستخدام رمز العناصر المحدودة التجارية، تم استخدام نموذج العناصر المحدودة للمحاكاة. يتم تقييم الشعاع ومحاكاته بطريقة غير خطية باستخدام برنامج الكمبيوتر ANSYS V.14.5.

الكلمات المفتاحية: عارضة T ، الخرسانة عالية القوة، الخرسانة ذاتية الضغط، سلوك الانحناء

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1- Introduction

In the twenty-first century, more structures, bridges, and roads are being built, particularly in places where the population is constantly increasing. Due to population growth, existing highways and structures must be replaced or repaired as they reach the end of their useful lives or just can't serve the intended function. Two critical challenges will become increasingly evident to societies as contemporary construction continues: the growing need for building materials, particularly concrete and asphalt aggregates, and the rising amount of garbage generated during construction and removal. Due to the enormous demand for new aggregates, there is worry about the availability of new aggregate sources as well as the depletion of existing natural aggregate sources. At the moment, landfills are the most popular place to dispose of this waste.

T-beams are crucial for bridge decks and play a role in simply supported slabs on load-bearing walls or girders for floors or roofs. This commonly utilized construction method is appropriate for huge spans in residential, commercial, prefabricated, and industrial buildings. Utilizing T-beams is crucial because they provide a large compressive area, which increases the area allocated for reinforcing, hence boosting the section's capacity.

Concrete's compressive strength has been increasing recently. For structural purposes, concrete with a compressive strength more than 100 MPa is available [1]. High and complex buildings can be built with High Strength Concrete (HSC), but as concrete strength increases, it is generally known that the concrete becomes more brittle.

Large span bridges, sky-spacers, high towers, and other intricate modern structures with great height and span—structures more susceptible to wind and seismic damage—often use hybrid superstructures (HSC). Because HSC can lower structural member dimensions and save space, it is being used in these buildings more and more. The brittle nature of HSC fractures makes it necessary to examine the flexural behavior of HSC components. Some of the features and engineering properties of concrete change when its strength increases from that of concrete with a typical strength. These variations in material characteristics could have significant effects on the structural behavior and design of HSC elements.

The shear strength of T-Beams with and without stirrups, which have been gathered from several structural concrete journals, are utilized to comprehend the undervaluation that occurs when the shear design equation (ACI) for rectangular beams is used to T-Beams without taking into account the presence of concrete top flanges. It was discovered that the accuracy of the shear design equations currently in use for T-Beams with stirrups is approximately 60% and

80%, respectively. This indicates that the safety factor of T-Beams with stirrup is higher than that of those without.

2- Literature Review

KWAN, A. K. H. (2004) To increase the structural efficiency of long-span concrete beams, flanged sections are frequently utilized. But while a flanged section might provide more flexural strength for the same sectional area, it would also result in less flexural ductility, particularly if it were strongly reinforced. Therefore, it is necessary to take into account both flexural strength and ductility when assessing the flexural performance of a beam section. This work employs an analytical method that accounts for strain reversal of the tension reinforcement and analyzes the actual stress-strain curves of the materials to evaluate the post-peak flexural behavior of flanged sections. An analysis of the flexural strength–ductility performance of flanged sections based on numerical data is possible by plotting the strength and ductility that could be simultaneously reached in the form of design graphs. Findings show that a flanged section performs worse than a rectangular section in terms of strength and ductility at the same overall dimensions, that a flanged section performs better than a rectangular section in terms of strength and ductility at the same sectional area, and that a flanged section has less flexural ductility than a rectangular section at the same overall dimensions and with the same amount of reinforcement.

The post-peak flexural behavior of flanged beam sections cast of normal- and high-strength concrete has been analytically studied, taking into account strain reversal of the tension reinforcement and the actual stress-strain curves of the materials. According to the results, the concrete in the web contributes to the residual resisting moment in the post-peak stage, which improves the section's flexural ductility but has no effect on the peak resisting moment. Stated simply, a flanged section would generally have less flexural ductility than a rectangular section with the same material composition and overall dimensions. Furthermore, it was found that flexural ductility reduces with concrete grade at the same tension to balanced steel ratio but increases significantly with concrete grade at the same tension steel area, regardless of sectional shape.

Omer Q. Aziz, M.D. (2006) The behavior and ultimate strength of L-shaped reinforced high strength concrete beams under combined bending and shear are investigated experimentally and numerically in this study. Nine beams were made and evaluated for bending and shearing as part of the experimental examination. It is investigated how compressive strength, longitudinal reinforcement, and transverse reinforcement affect load carrying capacity and shear strength, respectively. Shear strength at cracking load increases by 162.9 percent and load carrying capacity increases by 21.47% when compressive strength increases by 65.56%. When the longitudinal reinforcement ratio remains constant, an increase in the transverse reinforcement index of 59.25% % results in an increase in the shear strength at the ultimate load of 6.55%. Similarly, an increase in the longitudinal reinforcement ratio for bending of 153.8%) caused an increase in the load carrying capacity by 46.37%. Based on data from this study and other literature, equations were developed for estimating shear strength at cracking and ultimate loads using the multiple nonlinear stepwise regression method. When compared to equations provided by codes of practice, these suggested equations exhibit good agreement and are conservative.

According to In-Hee, Jung (2007), high-strength lightweight concrete has financial benefits such as cost savings through a reduction in the structure's dead load. However, high-strength lightweight concrete has a tendency to break easily. Therefore, a character like that presents a safety risk and is challenging to implement in buildings. The study aims to investigate the factors that impact the flexural behavior of members made of reinforced concrete. Generally speaking, the ratio of tensile steel to concrete strength determines the flexural strength and ductility of high-strength lightweight concrete beams. In a flexural test, the flexural capacity and flexural behavior of nine lightweight, high-strength concrete beams with three factors were examined. According to the test results, the flexural strength rises as the tensile steel ratio does, and the cracking pattern appears quickly. High-strength lightweight concrete has roughly 75–88% less ductility than high-strength conventional concrete. It is important to alter the maximum steel ratio.

The followings are the flexural test result of high-strength lightweight concrete beam

1- The load-deflection curve illustrates how different types of concrete behave in similar ways. The ultimate load of lightweight concrete was generally equal to or slightly less than that of regular concrete. About 97% of regular concrete can support the same ultimate load as lightweight concrete.
2- The ultimate load of the specimen increased as the maximum reinforcement ratio increased. However, once the ultimate stress and specimen demonstrate brittle failure, a sharp downward slope was displayed.
3- Compared to regular concrete, the ductility index of lightweight concrete is between 75% and 88% higher.

Qarani Aziz, Dr. Omar (2012) The behavior and strength of high-strength concrete thin beams reinforced with vertical shear reinforcement are examined experimentally in this work. Ten reinforced concrete beams with stirrups positioned differently were tested with high-strength concrete (compressive strength about 85.0 MPa). The beams were evaluated with two point loads and had dimensions of 2000 mm in length, 100 mm in width, and 200 mm in depth. Position and amount of web reinforcement were the test variables; the longitudinal reinforcement in this study was provided by ordinary steel bars. According to the test results, shear-reinforced beams (ρvfy = 1.65 to 4.24MPa) failed in shear within the shear span (G1) and along the beam length (G2) .

Shear-reinforced beams (ρvfy = 1.65 to 4.24MPa) failed in shear between two point loads (G3) and the shear-reinforced beam without shear reinforcement (G4). For high strength concrete beams and for varying amounts of concrete, the shear span is the ideal location for stirrups.

Qingli Dai (2012) The non-invasive and non-destructive Acoustic Emission (AE) techniques gather and evaluate the signals emitted by the deformation or fracture of materials under external loading. utilizing AE techniques in conjunction with statistical analysis, this study investigated the damage process of single-edge notched beam (SEB) tests utilizing specimens of normal strength concrete (NSC) and ultra high performance concrete (UHPC). The SEB tests were performed using a clip-gauge controlled servo-hydraulic testing system and an AE damage detection system on lab-prepared NSC and UHPC specimens. It was found that the specimens' mechanical loading and the cumulative AE events correlated with either the crack tip opening displacement (CTOD) or the crack mouth opening displacement (CMOD). It was suggested that a Weibull rupture probability distribution could provide a quantitative description of the mechanical damage behavior during the SEB test. A bi-logarithmic regression analysis was carried out to predict the damage process as a function of the crack opening displacements and to calibrate the Weibull damage distribution using recorded AE signals. The calibrated Weibull damage functions of specimens from the NSC and UHPC, with different notch locations and depths, were compared. More AE damage events were seen in the specimen with the larger notch-depth at the beginning of the damage process since it had a greater initial stress concentration factor (KI). In addition, the offset-notched specimen produced more AE damage events as a result of the effects of shear damage. The findings imply that the calibrated Weibull rupture probability functions using AE event data can be used to study damage processes under mechanical loads for brittle materials like concrete.

Jasim, Muhammad Nura (2012) This study presents a numerical analysis of the flexural behavior of reinforced concrete beams with two different reinforcement ratios—normal strength, high strength, and hybrid—under two point loads. The hybrid beam is composed of two layers: regular strength concrete makes up the tension layer and high strength concrete makes up the compression layer. ANSYS (v.9.0), a commercial finite element code, was used to simulate a finite element model. The substance of the concrete component and the internal steel reinforcement are modeled using LINK components. The modeled behavior and the experimental findings agreed fairly well. The ultimate load-carrying capacity can vary by a maximum of 8% at the ultimate load level.

The behavior and load carrying capacity of the hybrid reinforced concrete beams were also analytically investigated in relation to the effects of deepening the normal strength concrete in the beam and increasing the compressive strength of the high strength and normal strength concrete, respectively.

Khudhair, Emad Yassin (2012) Numerous attempts to restore damaged reinforced concrete structures have been made in recent years. Research on the performance of reinforced concrete elements that have been repaired and strengthened but fail primarily because of large flexural fractures is few for standard strength concrete (NSC) and extremely scarce for high strength concrete (HSC).

Investigating the strength and deformation properties in flexure of reinforced HSC and NSC beams repaired with concrete alone, fiber-reinforced concrete, or welded wire mesh (W.W.M.) is the main goal of the current work.

Based on the acquired results, it was determined that the beams were sufficiently repaired and that flexural failure was the predominant mode of failure. When compared to the original beams, the restored beams were stronger. The deflection of every restored beam was significantly less than that of the original beams.

Dr. Omar Qarani Aziz in 2013 In this work, the behavior and strength of deep beams of high-strength concrete reinforced by shear reinforcement are investigated experimentally. High-strength concrete (compressive strength of about 85.0 MPa) was used to test eight deep reinforced concrete beams with different types and locations of stirrups. The beams, which measured 1400 mm in length, 100 mm in width, and 300 mm in depth, were assessed using two point loads. The nature and placement of web reinforcements, namely the shear stress of the inclined stirrups ($\rho\alpha fy$), horizontal stirrups (ρhfy), and vertical stirrups (ρvfy), all within the shear span, middle span (between two point loads), and beam, were the factors under investigation. Conventional steel bars were used as longitudinal reinforcement in this investigation. The test findings showed that beams inside the shear span (B4) with inclined and vertical shear reinforcement could support an ultimate load of about 417.90kN. The horizontal shear reinforcement (B3), the shear reinforcement-free beam (B8), and the shear reinforcement between two point loads (B7) can withstand 255.77, 260.18, and 250.55 kN, respectively. The shear span, when paired with both vertical and inclined stirrups, is the optimal stirrup placement for deep, high-strength concrete beams, as all of the beams failed under shear.

The behavior and shear strength of high strength reinforced concrete T-beams were investigated by ARUN M (2013), which included shear testing on eight simply supported high strength T-beams with minimum shear reinforcement in compliance with ACI 318-05. There were two symmetric point loads applied during the testing. The study's primary variables were the ratio of flange width to web width (bf/bw=1, 2.4, 3.2, 4), the longitudinal steel percentage (ρl= 2.78 and 3.43), and the shear reinforcement percentage (ρv= 0.496 to 0.582), with a constant value of compressive strength (fck=60MPa) and shear span to effective depth ratio a/d=2.6. Every specimen was found to have a diagonal tension mechanism of failure.

A simple formula that differentiates between the shear strength of the thin T-beams without shear reinforcement and the shear strength that the shear reinforcement provides is obtained from the shear strength of thin T-beams reinforced by concrete (for a/d > 2.5), according to a hypothesis proposed by Zararis. The effective width used in this calculation is suitable for predicting the shear strength of T-beams. Experimental testing of T-beams with minimum shear reinforcement has validated this and shown that this is a conservative approach. Additionally, Robert Frosh put up a design strategy for figuring out the shear strength of rectangular and flanged sections with a shear span to effective depth ratio greater than 2.5. Shear capacity is related to strength in the compression zone and the area of the beam below the neutral axis, according to a theory based on elastic cracked section analysis. It makes a negligible contribution in situations where the ACI code ignores the flanges of T-beams in calculations of concrete shear strength. Such behavior suggests shear resistance of T-beams with web reinforcement with a/d >2.5.

Experimental verification shows that the shear strength of narrow T beams with shear reinforcement is much higher than that of rectangular beams with the same rib width. Only the expansion of the compression zone is to blame for this. Research has shown that the shear strength of reinforced concrete T-beams with shear reinforcement rises with an increase in the ratio of flange width to web width. Thus, the exclusive focus of this work will be on how concrete top flanges affect the shear resistance of T-beams with shear reinforcement with a/d bigger than 2.5. However, in the case of T-beams without shear reinforcement, the flange width essentially has no effect on the shear capacity.

Chenxing Yang (2013) Based on experimental study on a shear-strengthened reinforced concrete rectangular beam reinforced by high-strength steel wire mesh and polymer mortar, a finite element extended analysis was carried out. The program for finite element analysis showed that as the dosage and length of the reinforcing strand rose, so did the shear strength and stiffness of the strengthened parts. However, there was a noticeable decline in shear strength and stiffness as the shear span ratio rose.

This study examines the impact of strand dose, shear span ratio, and reinforcement length on the shear behavior of reinforced concrete beams reinforced with polymer mortar and high-strength steel wire mesh using a nonlinear finite element method. In the identical settings of reinforcement pattern and loads, we obtained the following conclusions by comparing with the experimental data:

1- The finite element analysis result shown a notable improvement in the shear strength and stiffness of reinforced concrete beams reinforced using shear reinforcement technique. Furthermore, it's clear that reinforcement works. The experimental results reported in the literature are in good agreement with the finite element analysis results. Additionally, the shear behavior of reinforcing beams can be simulated using finite elements.
2- There was a considerable reduction in the ultimate load of the reinforcing element as the shear span ratio increased. Although there has been a small fall, the mid-span's maximum deflection has also decreased.

Zhang HaiLong (2015) We investigate the impact-span moment and deflection of high strength recycled concrete beams in varying states of yield and initial cracking using ANSYS finite element analysis. We also examine the effects of varying recycled coarse aggregate replacement rates and water-cement ratios. The outcomes demonstrated that:

1- The deflection is increasing as a result of an increase in the water-to-cement ratio and the replacement rate of recycled coarse aggregate.
2- There is a little upward trend in the yield moment with an increase in the replacement rate of recycled coarse aggregate. Additionally, there is an increasing tendency in the span deflection at the yield state with increases in the water-cement ratio and the rate at which recycled coarse aggregate is replaced..

Seven beams totaling 1500 mm in length, 1200 mm in net span, and 150 mm by 250 mm in section were designed for the experiment. Using the parameters from Table 1 (water-cement ratio and recycled coarse aggregate rate), this study compared the flexural properties of high strength recycled concrete beams and used ANSYS finite element simulation to test the moment and deflection of seven beams in the initial stages of cracking and yield.

Changes in the ratio of recycled coarse aggregate to cement or water did not impact the original crack's mid-span moment. This was because, according to ANSYS, the first crack appeared when the tension zone of the concrete beams' tensile stress reached its design value. Furthermore, in the nonlinear analysis, the load step was 60. The crack moments were nearly the same since each sub-step before the main crack was made for the same load. When the recycled coarse aggregate replacement rate was set at 30%, the change in the water-cement ratio did not significantly alter the moment of yield. Furthermore, when the water-to-cement ratio was 0.3, the yield moment displayed a trend that increased progressively in tandem with the rise in the rate of recycled coarse aggregate. The carrying capacity of newly constructed concrete beams would be larger than that of regular high-strength concrete beams primarily because of the higher strength of recycled coarse material. 4.2 Deceleration in mid-span.

The flexural behavior of six T-section beams cast with self-compacting concrete (SCC), which contains recycled concrete aggregate as a partial replacement of coarse aggregate, is examined (both experimentally and analytically) by Ali K. Khtar (2018). There are two concentrated loads on the beams. The longitudinal steel ratios for beams are $\rho 1=0.0004$ and $\rho 2=0.00077$. Depending on the longitudinal steel ratio and the span to effective depth (a/d) ratio, the tested beams were split into two groups. Three distinct types of mixes with varying RCA replacement ratios (0%, 50%, and 75%) were used to cast each group. The SCC T-beams are 2.1 meters long overall, with an a/d ratio of 3, and a gross section area of 0.504 meters per beam . Additionally, the nonlinear finite element approach was utilized to evaluate these beams using the ANSYS-14 program. According to test results, the ultimate load remained unaffected and the cracking load reduced by an average of 15.5% when the RCA replacement ratio was increased to 50%. The deflection and crack width of the tested beams increase with increasing RCA replacement ratio; when the steel ratio increased from ρ1 to ρ2, the first cracking load and ultimate load increased by average 20.5% and 46.2%, respectively. When the RCA replacement ratio was increased to 75%, the cracking load and ultimate load decreased by 31% and 9.4%, respectively. As the longitudinal steel ratio increases, the tested beams' deflection and fracture width decrease. The finite element model and the experimental data agree well, with a discrepancy of less than 8%.

Aziz Zana Abdalla (2019) This paper presents a numerical analysis of a three-dimensional T-beam with circular apertures at varying distances from the support in the web and/or flange. The beam is evaluated and simulated in a non-linear fashion using ANSYS V.14.5 computer software. After comparing the results with the experimental work, the simulation's calibration for the model is completed by examining the impact of openings—both in terms of number and location inside the beam—on the behavior of the beams generally and their shear strength specifically. In order to examine crack patterns and load capacity, 13 instances are examined, and each case's load-displacement envelope is graphed. One of these thirteen situations involves a control beam that has holes punctured through it. The apertures in the webs and/or flanges of the remaining samples, on the other hand, vary in distance from the support. To compare high strength concrete with regular concrete, a parametric analysis is conducted.

Following calibration, there is a strong match between the numerical results of the fracture pattern, ultimate load, and load-displacement curve and the experimental results. The findings demonstrate a significant reduction in load carrying capability of up to 11.7% when the apertures distance from support is reduced from d (the T-beam's effective depth) to (d/3). However, by lowering the distance between the apertures and the support to (d/4), the beam's capacity to support the weight increases by 17.6%.

Yaseen, Sinan Abdulkhaleq (2020) In order to compare the behavior of self-compacted concrete (SCC) T-beams reinforced with aramid fiber reinforced polymer (AFRP) and steel bars with experimental data, finite element models were built. Three beams reinforced with steel bars and nine T-beam specimens reinforced with ARFP were modeled and examined. Different high strength self-compacted concrete compressive strengths and various ratios of AFRP and conventional steel bars for comparison were the main influencing factors. Consideration is given to the comparison of the flexural strain output, the load-deflection relationship, and the fracture propagation. The FE models created with ANSYS software accord well with the experimental results from Yaseen's (2020) earlier study. All of the FE models had fewer cracks overall, and by maintaining the ultimate deflection, the final crack spacing was less than in the experimental samples. Compared to beams reinforced with AFRP, beams reinforced with steel bars have superior load capability. The experimental beams were not as rigid as the FE models. When compared to experimental data of SCC AFRP reinforced beams, the overall trend of analytical and experimental beam capacity vs. reinforcement ratio reveals that the ANSYS response was conservative.

Sultan, Hussein Kareem (2023) This research introduces a new design cost optimization method for reinforced high strength concrete (HSC) grade T-beams that includes formwork, steel, and HSC costs in the model's objective function. Carefully specified constraint functions adhere to the ACI 318-08 Code design requirements for structural concrete. The cost optimization process is developed through the use of mathematical applications. An example problem is used to show the usefulness and efficiency of the suggested design model and approach. The study's conclusions imply that the current approach, which results in significant cost reductions in the building materials used (concrete and steel reinforcement), has a number of financial advantages over traditional design techniques . Additionally, this strategy may be used to different industries with little change, therefore enhancing its practical applicability.

According to ACI 318-08 code, Figures 1-b and 1-c, respectively, indicate the assumptions used in the ULS for the stress and strain distributions in the standard reinforced high strength concrete with the T-section of beam shown in Figure 1-a.

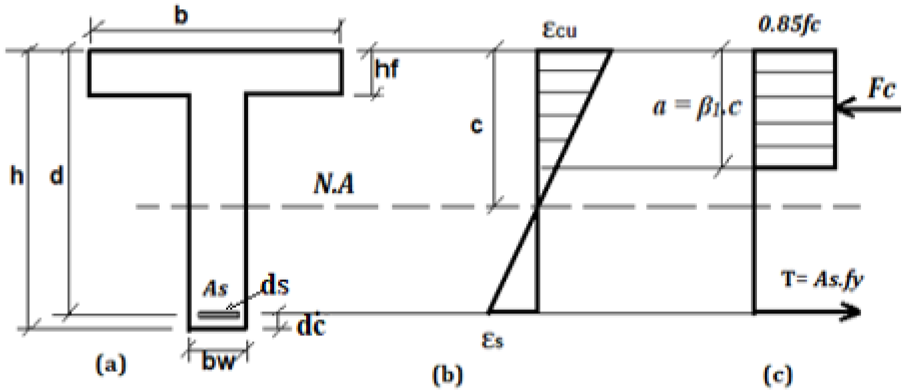

Figure 1. (a) Typical cross-section of T-beam; (b) strains at the ultimate limit state and (c) stresses at the ultimate limit state

To show the applicability of the optimal design derived using the current formulation, a reinforced high strength concrete beam with a T-section is created using the minimal cost design technique. The ACI 318-08 design code served as the foundation for this beam's comprehensive design solution. The preset parameters and limitations are listed in the previously mentioned section. The related total material cost per unit of length for the beam is then calculated using equation (1).

3- Conclusions

1- Shear strength and behavior of reinforced concrete T-beams can be simulated and analyzed using non-linear finite element modeling with ANSYS 14.5.

2- The load displacement curve, crack pattern, and ultimate load carrying capacity of the numerical results agree with the experimental data.

3- Strengthening the concrete increases the T section beam's stiffness and shear strength.

4- It can be demonstrated that computer modeling is an effective means of predicting the structural response and load carrying capability of such beams by comparing the results of existing experimental testing with those derived from ANSYS's finite element analysis.

5- The finite element solution shows that raising the concrete's compressive strength results in an increase in the ultimate load carrying capacity.

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