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A Review of Numerical Analysis by ABAQUS for Investigated the Behavior of Castellated Steel Beam with Diamond Castellated

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Abstract: A castellated steel beam is a kind of expanded beam that is produced by expanding conventional rolled sections using a process that results in the production of an aperture in the web that is consistent in shape. Castellated beams are not only light and sturdy but also very inexpensive and easy to connect on the job site. It is possible to extend pipes, cables, and other services across the holes in the beam web using the holes on the beam. The use of castellated beams offers a number of benefits, both in terms of design and construction. The major goal of this study is to review a cost-effective cold formed steel castellated-beam with diamond castellation and low buckling. The current review focus on the main concept of castellated beam, advantages and disadvantages along with the failure issues with reasons of failure. However, the review mainly focus on two strengthening ways of castellated beam: first one increase the stiffness of castellated beam by adding intercept stiffeners in (perpendicular and parallel) directions; two second one enhanced of beam by concrete encased the castellated beam. The obtained results show that using normal concrete for improve the strength of castellated beam give better results than intercept stiffeners.

Keywords: Castellated Steel Beam, Concrete encased, intercept stiffeners, ABAQUS

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1. Introduction

A steel beam is a structural element utilized in construction and engineering [1]. It is most commonly utilized to support horizontal or vertical loads, such as the weight of a roof, floor joists, or a wall. Steel beams come in a variety of shapes and sizes, such as I-beams, H-beams, and C-beams [2]–[4]. They are made from structural steel, which is a combination of carbon and iron, and are an important part of any construction project. However, steel beams can be subject to a variety of issues. These include corrosion, fatigue, and stress.

Corrosion occurs when the steel is exposed to moisture and oxygen, which can cause it to weaken and eventually fail [5]. Fatigue occurs when the beam is subjected to repeated loads, which can lead to cracks and fractures [6], [7]. Stress occurs when the beam is loaded beyond its capacity, which can lead to permanent deformation. Additionally, welding can cause internal stresses, which can lead to cracks, warping, and other deformities [8].

Despite these issues, steel beams offer a number of benefits. They are strong, durable, and able to withstand heavy loads. Additionally, they can be tailored to fit nearly any application, providing a versatile solution for construction projects. Steel beams are also relatively easy to install, and can often be welded or bolted together with minimal effort.

Eventually, steel beams are relatively inexpensive compared to other materials, making them an attractive option for many projects [9].

Castellated members are structural members cut with a unique pattern to increase strength and rigidity. The pattern typically consists of a series of slots, or “teeth,” which create a lattice-like structure [10]. This structure increases the shear and bending capacity of the member, as well as increases the surface area for welding or bolting [11].

Castellated members are also much lighter than solid members, as the teeth reduce the material needed to form the member. Castellated members are often utilized to construct bridges, tanks, towers, and other large structures. In addition to providing increased strength and rigidity, castellated members are also often utilized for their aesthetic qualities [12]. The teeth of the member create a unique and visually appealing look, which can be a great addition to any project. Castellated members can also create interesting shapes and patterns, which can be utilized to create unique designs.

A castellated-beam is a beam that has a series of regularly spaced cutouts, usually in the form of a castle's battlements. These cutouts reduce the weight of the beam while maintaining its strength and stiffness. The cutouts are located along the length of the beam and can be either straight or curved [13], [14].

Castellated-beams are commonly utilized in steel structures since their light weight, strength, and stiffness. They are also utilized in composite structures, as they can be utilized to create complex shapes and reduce weight. However, since the cutouts, castellated-beams are prone to failure under certain conditions. One of the most common causes of failure is buckling, which occurs when a beam is subjected to large lateral loads. In this case, the cutouts create weak points in the beam, making it more susceptible to buckling. Other causes of failure include fatigue from cyclic loading, or corrosion from environmental exposure. To prevent failure, it is important to design castellated-beams with adequate stiffness and strength and to ensure they are properly supported [15].

A composite castellated-beam is an engineered beam composed of concrete and steel components. The castellated-beam is designed to provide a lightweight, high-strength structural element for construction and civil engineering projects [16]. The beam combines a steel core's strength with a concrete shell's durability to create robust support. Castellated-beams are utilized in bridge construction, industrial applications, and other large-scale building projects. The structural application requirements typically determine the steel-to-concrete ratio in a composite castellated-beam. Generally, the ratio is between 1:2 and 1:4, with the higher ratio being more typical for beams utilized in bridges and other large-scale building projects.

Castellated members are I-section members made of steel that have web apertures that are round or hexagonal and equally spaced [17]. The vast majority of castellated or cellular members that are utilized today are produced by thermally severing the web of a hot-rolled parent segment in accordance with a specific pattern [18].

Subsequently, the webs of the achieved halves are welded together to produce a member that has a higher web and web openings (Figure 1). The primary benefit of these members is their economical material behavior in severe axis bending; nevertheless, because of their light look, they may also be employed for aesthetic reasons [19]. Last but not least, another significant benefit is that it is possible to route service ducts via the apertures, which findings in a reduction in the required height from floor to floor. The beams represent the most common application for the members, although they are also sometimes employed in beam-column or column configurations. [20].

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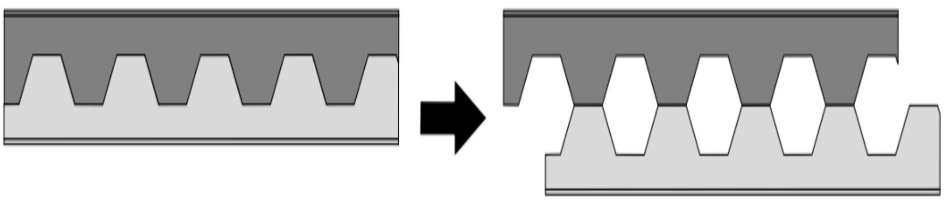

Figure 1. Castellated member fabrication [21].

A beam is said to be castellated when the depth of the beam is raised without the accompanying rise in the beam's own weight [22]. Castellated-beams are an increasingly common method in contemporary construction. The web of a castellated-beam is created by cutting a normal steel I-shape in half in the centre of the beam at a line that is half of a hexagon [23]. The two halves are first given one space between them, and then they are welded together. This approach enhances the diameter of the beam as well as the bending power and stiffness along the primary axis, and it does so without the need of any additional components. The hole in the web makes castellated-beams more susceptible to lateral-torsional buckling than other kinds of beams [24].

The fact that a castellated-beam has increased buckling strength along the main axis is the primary benefit of utilizing such a beam. Because of the web holes, however, castellated-beams have intricate sectional properties, which makes it very difficult to predict the buckling resistance of these beams analytically [25]. The method of fabricating a castellated-beam may be summed up by looking at Figure (2) that is almost identical to the process of fabricating a castellated-beam. The primary difference between the two members are the uses for which they are utilized [26].

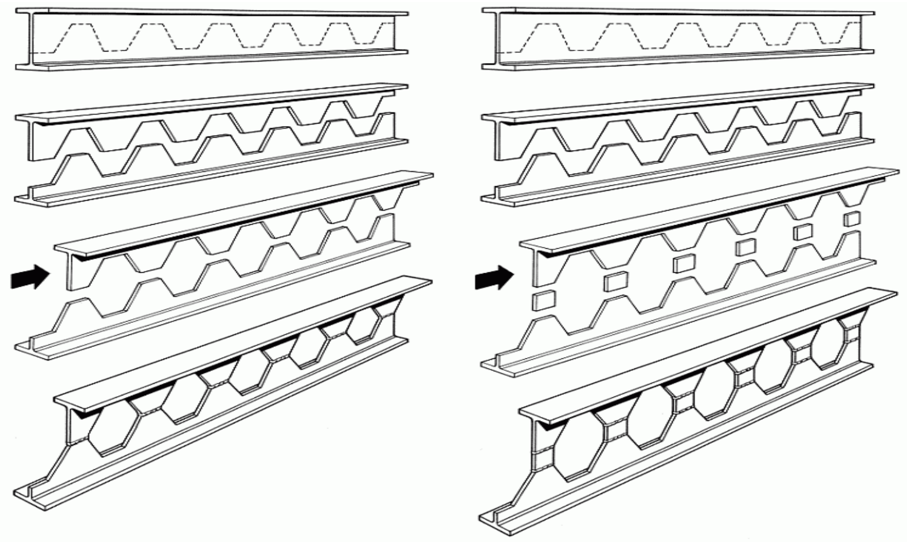

Figure 2. Castellated member fabrication steps.

1.1 Advantages of Castellated-beams

Since the ease with which they could be made by hand in earlier times, castellated-beams were used for just a limited range of purposes [27]. Currently, with the advancement of cutting and welding tools, castellated-beams are becoming more useful in contemporary buildings. This is particularly the case with the growth in the amount of pipe and duct works in new structures. The primary benefit of utilizing a castellated-beam is because it allows for an increase in beam depth without the addition of any extra beam weight; as a result, the beam's strength is improved thanks to an increase in its stiffness; and as a result, the beam's capacity for bending moments is increased [28]. Castellated-beams have illustrated to be effective when utilized for large spans when the design parameters are governed by the capacity for deflection or moment [29].

1.2 Disadvantages of Castellated-beams

The process of fabricating castellated-beams involves cutting and welding of the web, which findings in an increase in the cost of the beams. Because of the potential for instability during construction caused by the use of castellated-beams in long spans, it is important that this aspect of the beams be thoroughly explored [28]. Castellated-beams are regarded as a structure that is somewhat ambiguous since the many ways in which they might break; as a result, this kind of construction cannot be evaluated utilizing straightforward techniques. Since the fact that the shear capacity of the web post is a limiting factor, castellated-beams should not be utilized for short spans that are subject to significant magnitudes of shear pressures. Shear tees deformation and the deflection analysis is more complicated than for webbed beams.

1.3 Mode of Failure of Castellated Steel Beams

The design strategy for castellated steel beams (CSBs) increased the focus on a typical limit state, but the presence of web holes and welding led to more modes of failure than the strategy could have prevented. So as to ensure the design of a safe CSB, the following limit states need to be checked:

•Flexural failure mechanism: The tee parts above and below the aperture give way in compression and tension when subjected to pure bending. This continues until the material becomes totally plastic [30].

•Vierendeel bending for tee sections: The presence of a large magnitude of shear stress causes the formation of plastic hinges in the tee portion above the aperture [31].

•Lateral torsional buckling: Lateral torsional buckling is often linked with longer span beams that do not provide sufficient lateral support to the compression flange [32].

•Failure of the welded joints to hold: Once the horizontal shear stresses surpass the weld joint yield strength, this condition is said to happen [33].

•Buckling of web post owing to shear force The horizontal shear force in the web-post is connected with twofold curvature bending across the height of the web post, which may cause the web post to buckle [34].

•" In a castellated-beam, one inclined edge of the aperture will be strained in tension, and the opposite edge of the opening would be stressed in compression and buckling, which would create a twisting of the web post along its height.

•Buckling caused by compression of the web post.

The geometry of the CSB, the form of the parameters, the kind of stress, and the provision of lateral supports are all closely connected to this manner of failure [35]. The design of a CSB requires the calculation of global forces (shear and bending moment) at each hole and web-post that are the outcome of applied loads. These global forces are then utilized to find local forces at upper and lower tees, web posts, and gross section. Eventually, the failure of web -posts and tees would be checked under local forces. [36].

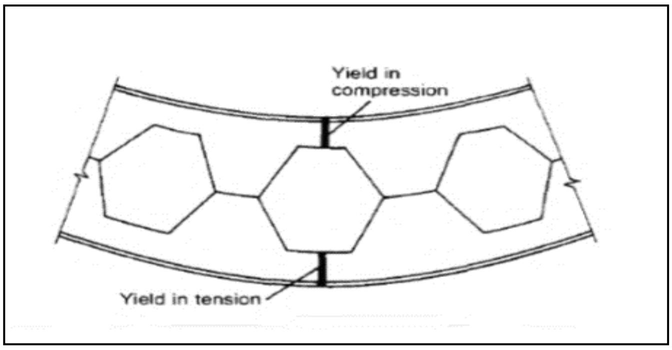

Figure 3. Bending Failure Mode [29]

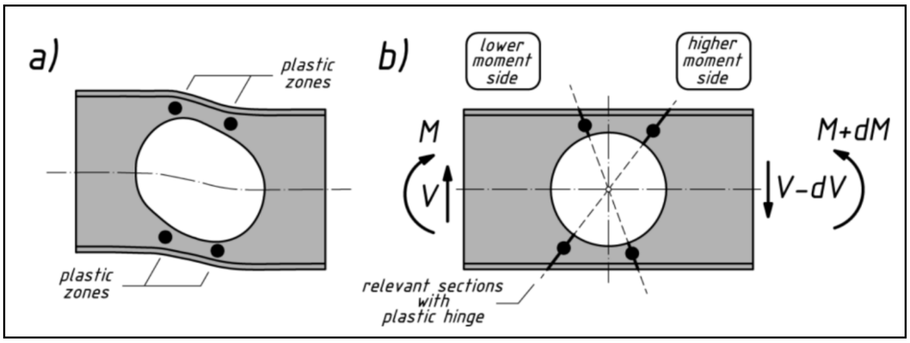

Figure 4. Vierendeel Bending Failure Mode [29]

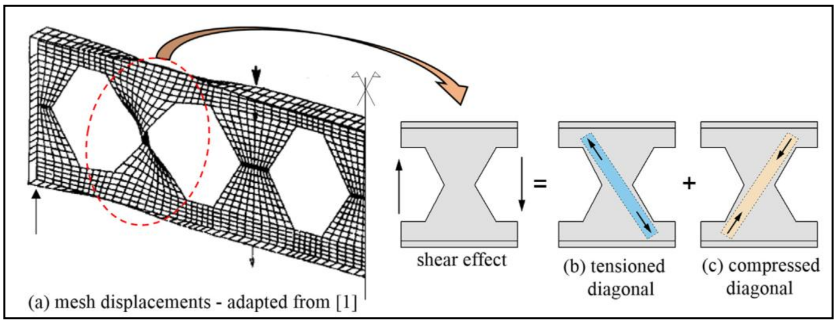

Figure 5. Shear Buckling Mode of Web Post [29]

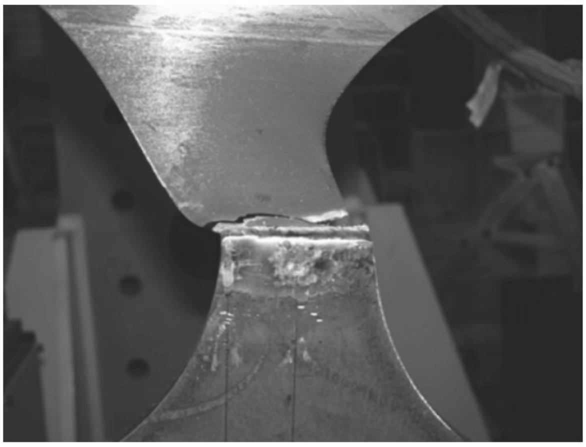

Figure 6. Shear Buckling Mode of Web Post [29]

2. Literature review

Budi and Partono [37] explored how the size and spacing between CSBs with hexagonal web apertures impacted their performance. The finite element (FEM) approach was utilized in the carrying out of the comparative research on CSBs. The findings of the comparative analysis are then obtained by conducting laboratory tests on specimens of CSBs with a height of 225 millimeters. Six samples have been created utilizing IWF section with varying hole angles of 45 degrees, 50 degrees, 55 degrees, 60 degrees, 65 degrees, and 70 degrees respectively. The distance between adjacent holes ranges from 0.052 ho to 3.15 ho, depending on the model. The vertical height holes (ho) on all of the models is 150 mm. All of the beams have a clear span of 3,000 millimeters, and they have two focused load systems and basic supports. The root beam section that was utilized was IWF 15x7.5x0.5x0.7 cm, that resulted in a castellated-beam that was 22.5x7.5x0.5x0.7 cm in size. When compared to the first segment, the findings of the study demonstrate that the capacity for specimens rises by 1.938 to 2.041 percent. The FEM study found that a sample with a 60-degree angle and a spacing between holes that ranged from 0.186 ho to 0.266 ho produced the best findings. The FEM analysis and the lab tests agree with one another quite well, according to the comparison between the two.

Satyarno et al., [38] looked at the flexural strength, shear strength, and load bearing capability of CSBs with total depth rectangular holes and partial encasements of reinforced concrete. So as to explore flexural and shear strength, respectively, two distinct groups of beams were utilized. These groups consisted of one beam with a large span and two beams with small spans. Every beam is held up by a single support and experiences two equal focused loads about in the middle third of its length. According to the findings, the load bearing capability at yield of CSBs with and without encased reinforced concrete for long and short spans was found to be comparable when the vierendeel truss mechanism was in play. For CSBs that were partially encased in reinforcement concrete, the flexural collapse was the same for both short and long span beams. However, moment failure did not occur for beams with short spans since shear breakdown occurs first. For beams with sort spans, the shear failure happened at diagonal struts in the concrete thru the web holes. It was determined that it is possible to avoid the collapse of an is vierendeel truss by use partially enclosed reinforcing concrete for castellated-beams, which led to an increase in flexural strength that was (3.5) times greater than that of the origin section.

Frans et al. [39] performed a numerical analysis to explore the behavior of a composite CSB when it was exposed to monotonic loading with a two-point load and simple support conditions, and they compared the findings with those of a solid and a composite solid beam (without castellation). The castellated-beam that has an enlarged section depth of 306.6 and a clear span length of 380 cm was fabricated utilizing hot rolled steel (HRS) I-section. In comparison, the reinforcing slab of concrete for composite sections has a width of 66.5 cm and a depth of 15 cm. The ABAQUS application was utilized to do simulations on each and every beam. According to the findings, the load bearing capacity of the composite castellated-beam improved by 6.24 times when compared to the weight carrying capacity of the solid origin I-beam and by 1.2 times when comparing to the load carrying capacity of the composite solid beam.

An analytical research comparing the load-carrying capability of castellated and solid steel beams was performed by [40]. The use of a steel I-section of ISMB 200 with straightforward support requirements and one central load applied at the span's center was thus decided upon. The new ratios for the castellation are going to be 1.5, 1.6, and 1.8. ANSYS version 12 was utilized so as to perform the finite element analysis (FEA). According to the findings, the optimal expansion proportion was 1.5, and the minimal hole height should not be less than 50 percent of the section's depth. In addition, the max hole depth should not be larger than 75 percent of the section's depth.

Elaiwi [41] conducted the effect of web holes on the vertical deflection of CSBs. They utilized theoretical analysis which is depending on potential energy technique and numerically by ANSYS. The goal of the research was to predict the deflection resulted from shear for CSBs with varying span lengths and flange breadths that were subjected to uniform distributed load. Nevertheless, it was seen that the difference between analytical and numerical approach did not surpass 6 percent for short beam lengths having narrow or wide sections. The findings demonstrate that shear impact on the CSB deflection have major impact especially for short and medium beams. It is also indicated that the impact of web shear on the deflection reduced once CSB length raised.

Hadeed and Alshimmeri [42] compared the Structural Behavior of Rolled and CSBs That Have Been Strengthened in a Variety of Ways The purpose of this research is to explore the influence of castellation on the structural behavior of castellated-beams, both with and without the addition of reinforcing, and to contrast those findings with those obtained from the initial solid steel beam. Analyzed numerically utilizing FEA performed by Abaqus virgin (6.14.5) have been three castellated-beams with various configurations, in addition to a solid beam, which were exposed to two equal point loads at the middle third of the span while having a simple support situation. According to the findings, the load carrying capacity magnitudes of CSBs which recognize (2nd, 3rd, and 4th) models have been enhanced by (39.11, 105.95, and 124.77) percent respectively in comparison with the origin solid beam because of a rise in beams stiffness after the castellation and strengthening process. On the other hand, the findings illustrate that the mid-spa deflection magnitudes at service load have been reduced by (36.36, 9.10, and 27.27) percent respectively. Furthermore, it was recognized that the max ultimate moment and ductility have been identified in the 4th model that was reinforced by high strength concrete and lacing reinforcement, so they increased by 124.79 and 165.65 percent respectively as compared to the reference beam, while the 3rd model that was reinforced by high strength concrete was stiffer than the other beams.

A research titled "Web buckling investigation of the behavior and strength of perforation steel beams with various new web opening forms" was conducted by [43]. The failure mechanism and web post's load strength that is located between two web apertures that are contiguous were explored (ANSYS). Moment and shear forces work together to bring to the failure of the samples. It is concluded that the shear forces capacities boost as the web-post width has been improved, and [44], utilized the FEA to study the continuous composite behavior castellated-beams having distinct instability impact pertically in hogging moment area. In overall, once novel elliptical web openings have been regarded, the critical openings length is shorter, and as a result, the Vierendeel capacity is high. The statically failure load indeterminate composite beams was explored by studying a variety of variables including the negative moment span length, the web openings' shape, the arrangement of the openings on the both beam support sides, and the web opening spacing. All of these factors have the potential to influence the failure load. The study looked at openings that had the same opening area but were of a various shape and were spaced c/c at the same distances. These openings included rectangular, hexagonal, and circular openings. According to the findings of the performed computational research, castellated composite beams seem to be more susceptible to a variety of distortional buckling modes when they are located in the negative moment area. Failure modes observed connected with bending and shear as well as the stress concentration in the region of openings, which caused early yielding and stiffness deterioration impacts. These impacts were most pronounced once openings were of sharp corner configuration. It was discovered that circular apertures were the most efficient in terms of load transmission as well as the resistance to distortional buckling. In light of this, the numerical studies that make up the current work take into account this particular kind of opening.

Ismail et al [45], explored the influence of various factors on the ultimate resistance and buckling load of continuous partly composite castellated-beams when subjected to vertical loads utilizing a numerical method. In this investigation, the ABAQUS program was utilized. The purpose of the research was to determine how the ultimate strength, ductility and elastic stiffness of continuous composite castellated-beams are affected when web geometry, material characteristics, and the thickness of the concrete slab are altered. According to the findings of that investigation, the application of stiffeners around the web apertures findings in an increase of the ultimate loads of 12, 17, and 25 percent respectively. The initial ductility of the composite castellated-beam reduced by 50, 61.2, and 68.6 percent while the first initial stiffness rose by 2, 10.5, and 18 percent respectively. The ultimate load capacity of steel increases by 6.5 and 18.5

percent, respectively, when its strength is increased from fy =275& fu =430 MPa to fy =355& fu=510 MPa. However, the ductility of steel decreases by 18.5 and 31 percent, respectively, when its strength is increased to these levels. The change in concrete strength had essentially no effect on the initial stiffness, however raising the concrete strength from 34 to 40 MPa resulted in a 4 percent increase in the strength and a 23 percent increase in the ductility of the structure. Because an increase in the slab thickness will indeed raise the neutral axis of the composite beams, reducing the slab slenderness findings in a rise in the ultimate load by 7 and 14 percent for bs/ts =8.6 and bs/ts =7.5. In addition, the ductility increases by 18.5 percent and 34 percent and the initial stiffness increases by 6.5 percent and 15 percent when the slab thickness is increased.

A FEA of composite beams and columns with castellated elements with full height web apertures is presented by [46]. Through the use of the ANSYS16.1, a numerical study of composite beams and columns had been performed. In this study, several configurations of web apertures, including rectangular, hexagonal, and elliptical openings, were taken into consideration for both partly and completely enclosed concrete structures. The findings that were obtained demonstrated that the elliptical web opening is effective for producing improved behavior. when strong Vierendeel bending forces are applied to them, there is a very minor reduction in their overall strength.

It is important to improve the load-bearing capabilities of buildings already in operation in several circumstances. The encasement strength of Asymmetrical Castellated-beams is large and crucial in traditional applications of asymmetrical CSBs and encasement of Asymmetrical Castellated-beams. As a result of the three constituent materials being combined in such a way as to maximize their benefits, confined concrete Asymmetrical Castellated-beams can possess superior performance in comparison to other existing beam forms. These superior characteristics include fire resistance, corrosion resistance, excellent ductility, and ease of construction. Therefore, the current study reviews castellated beams as structural members have many benefits and some drawbacks related to failure loads. Moreover, use paper to compare two types of strengthening mechanisms for castellated steel beams first one is related to adding steel stiffer in one or two directions, while the second one is related to encased Castellated-beams with normal concrete under static loads.

3. Numerical Simulation of Tested Specimen

3.1.Case 1

Prabhakaran and S. A. Maboob [47] were successful in developing a cost-effective cold-formed steel castellated beam with diamond castellation that exhibited reduced buckling. As a result, one of the primary goals of this work is to investigate the behavior of a cold-formed steel castellated beam with diamond castellation. This will be accomplished by offering a variety of techniques for the placement of the stiffeners in the sections. It is possible to do this by reading this work, which presents a numerical study, an analytical study, and an experimental inquiry on the performance of cold-formed steel CBs with Diamond Castellation shape. In order to determine the structural behavior of the web as a simply supported beam subjected to pure bending, perforations have been made in the web. The CB with perforated web are exemplary of a new innovative trend that has emerged over the course of the previous span for the short- and medium-length beams. As compared to hot-rolled beams, the ColdFormed Steel beams with castellation benefit from a significant weight reduction due to the material's use of castellation. The CB is constructed out of CFS Steel that has a thickness of 2 millimeters all the way through. The CB was being tested in the research with three different Stifener Design kinds at the web of the Beam. Beam that uses Stifeners to intercept plates at the web has been employed. For the computational and experimental testing, both a stifened and an unstifened Castellated beam (beam with parallel, perpendicular, and intercept Stifeners) were used.

The primary goal of the majority of numerical analyses performed on a variety of engineering issues is to forecast the failure modes. The fundamental concept that underpins FEA is that the structural model must be broken up into a large number of individual elements. This breaks down the structural integrity of the model by reducing the total number of degrees of freedom into a smaller set of accountable degrees of freedom, that also allows for minute analysis (Table 1-2).

Table 1. Requirements of sample specimen

Beam ID	L (cm)	D (cm)	Do (cm)
1	120	22.5	20.625

Table 2. Specimen details with varying stiffeners

Beam ID	Requirements
SCB1	Castellated-beam 1 with thickness=2mm and stiffeners in parallel direction
SCB2	Castellated-beam 1 with thickness=2mm and stiffeners in perpendicular direction
SCB3	Castellated-beam 1 with thickness=2mm with intercept stiffeners in (perpendicular and parallel) directions
SCB4	Castellated-beam 1 with thickness=2mm with absence stiffeners

3.2. Case 2

Hadeed and Alshimmeri [42] look into the impact of castellation with and without strengthening on the structural behavior of castellated beams encased with normal concrete. They then compare the results of their investigation with the solid steel beam that served as the basis for their investigation. Analyzed numerically utilizing finite element analysis carried out by Abaqus software virgin (6.14.5) were three castellated beams with different configurations, in addition to a solid beam, which were subjected to two equal point loads at the middle third of the span while having a simple support condition.

Rolled standard section IPE 200 was utilized as a root section to fabricate six specimens of CSBs. All beams with a span length of (319.2 cm) and simply supports. Descriptions and designations of the made-up samples adopted in the current study are clarified in Table (3).

Table 3. Designations and Descriptions of the fabricated specimens

Specimen No.	Specimen designation	Description
1	CB1	Unconfined CSB (reference specimen).
2	CB2	CSB (flange and web) encasing by high strength concrete only of (29 mm) width for each side.
3	CB3	High strength concrete with a (2.9 cm) width for every side and (0.6 cm) laced reinforcing that uses inclined continuous reinforcement in two layers on either side of the CSB web surrounds the CSB (flange and web). With regard to the longitudinal axis, the lacing reinforcing is inclined at a 45° angle.
4	CB4	Same CB3 and without utilizing welding between two part of CSB
5	CB5	Same CB 3 with increase the depth, dg (total depth of castellated-beam) by 10 percent, (30 mm) as a gap between top and bottom parts of CSB at web post. The inclination angle of lacing reinforcement with respect to the longitudinal axis is 48°
6	CB6	Same CB3 with increase the depth, dg (total depth of castellated-beam) by 20 percent, (60 mm) as a gap between top and bottom parts of CSB at web post. The inclination angle of lacing reinforcement with respect to the longitudinal axis is 51°

One hole for specimens (CB1, CB2 and CB3) while two holes for specimens (CB4, CB5 and CB6) for each side near the supports were filled and closed to prevent initial uncontrolled failure, noting that theoretical design calculations. All details of specimens and their sections were illustrated in figure 7.

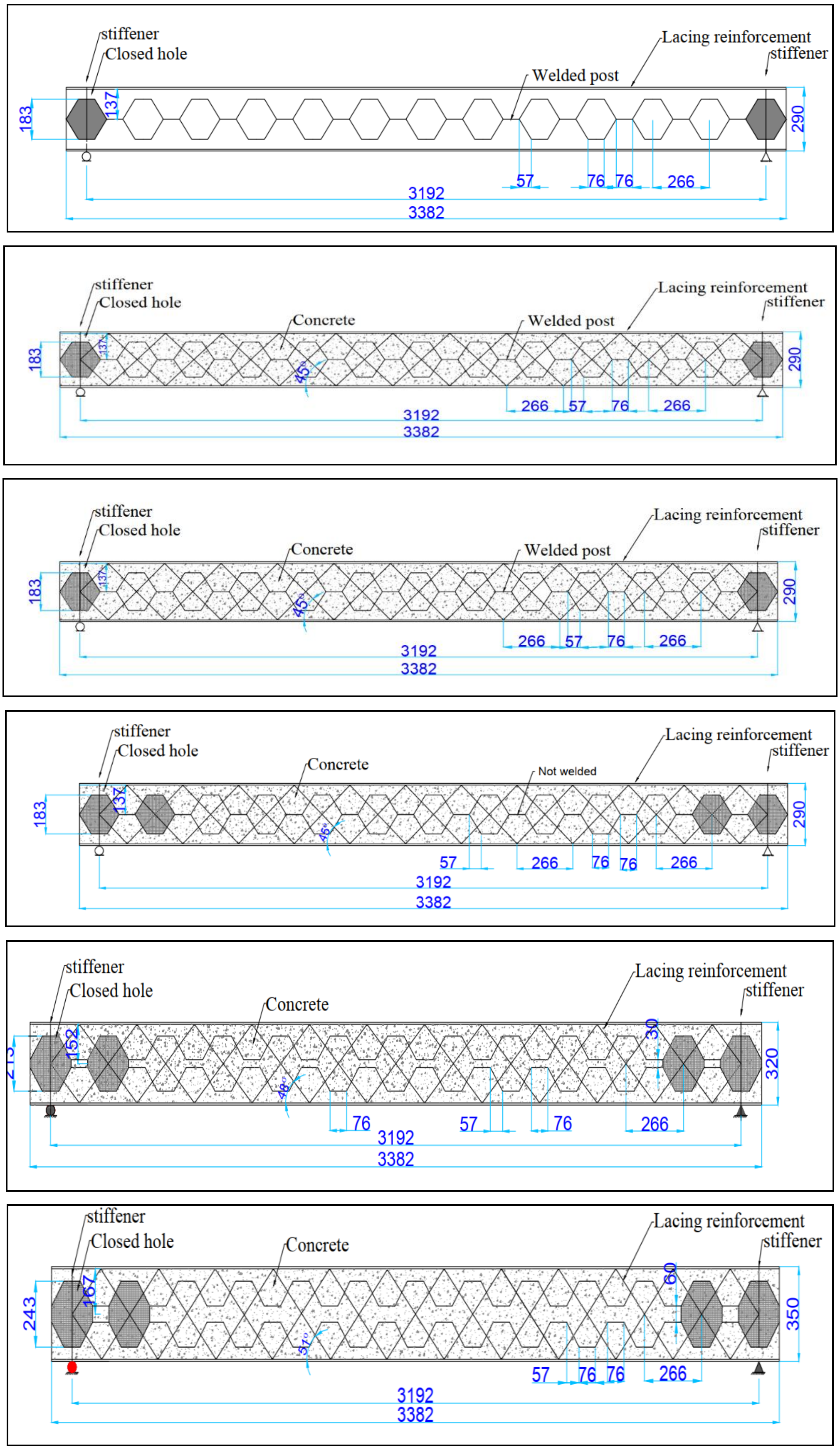

Figure 7. Dimension Details of CSBs and Sections for CB1, CB2, CB3, CB4, CB5 and CB6

3.3. Meshing of Beam

The construction of a three-dimensional finite element model often calls for the use of a wide range of mesh generating strategies. The amount of time it takes to process data in the system may change depending on the ranges of fine and dense meshing. The following illustration depicts the sample model with the size of meshing as 2.5 to 5 cm with the web section of castellated-beam in diamond kind opening. These components are first synthesized independently, and then the pieces are welded together with the assistance of tie restrictions. At long last, the nodes were chosen, and the tie connections were put in place.

3.4. Boundary Conditions Application

In most cases, the Boundary conditions are applied to the finite element solid model in ABAQUS by determining the index of the nodal point and restricting the necessary displacement element. In the context of this inquiry, a simply supported end condition is utilized for the analysis of the castellated-beam. As a result, the parts of displacement Uz, Uy, and Ux are made to be constrained at one end, and the components of displacement Uy and Ux have been maintained as restrained at the other end. These components of displacement are then given to corresponding nodes in accordance with the sets that have been created (Figure 8).

3.5. Loads Application

Loads may be applied to the finite element model in a variety of various ways, such as by putting loads to the key points, lines, regions, and elements at the nodes. During the course of the research, an analysis for two point loading on a castellated-beam was performed. The loads are placed at a distance that is one-third of the way from both ends (Figure 9).

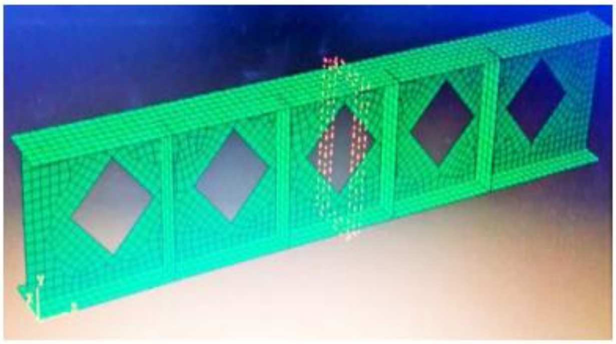

Figure 8. Meshing of castellated-beam

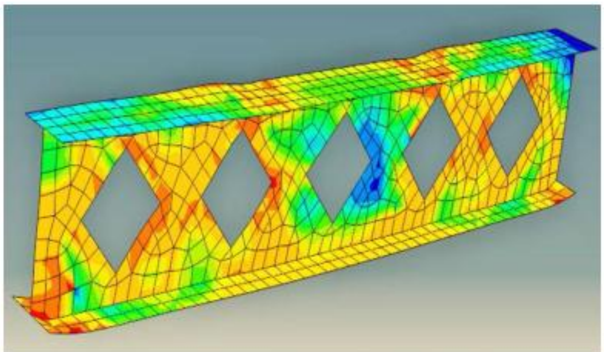

Figure 9. Deflected shape of castellated-beam

4. Results and Discussion

4.1. Behaviour in Linear Analysis

The linear analysis has been performed. The errors and warnings are noted for further clearance complete rectification of all errors are made, then the analysis findings are extracted to study the variations in deformations.

4.2. Behaviour in Non linear Analysis

The non-linear analysis was performed by maintaining the step procedure kind in a static and also risky fashion throughout the process. NLGEOM option is activated. The findings of running ABAQUS with the max number of increments set to 100, the length of the arc set to 0.5, and the overall length of the arc set to 1.0 are illustrated in the following figures for SCB1, SCB2, SCB3, and SCB4. Every force is measured in kilonewton-centimeters, and the displacement is in millimeters (Figure. 10). The findings that were obtained from the numerical analysis of the diamond castellated-beam were compared with the findings that were acquired from the experimental analysis. Figure 11 illustrates the values of SCB1, SCB2, SCB3, and SCB4 respectively. The inclusion of a thickness of 2 millimeters in the numerical study demonstrates that it has a greater load bearing capability and that buckling is less severe in comparison. At the castellated section of the component, parallel, perpendicular, and intercept stiffeners have also been provided. After conducting the experiment, the researchers discovered that the addition of stiffeners significantly increased the load carrying capability of the sample. It is possible to focus it by the provision of stiffeners at the end or support of beam with preferable support conditions, and the beams' load capacity enhances from SCB1 to SCB3 owing to the impacts and placement of intermediate stiffeners at the right orientation and position. The beam SCB1, SCB2, and SCB3 probably demonstrate the torsional buckling behavior, and that is mainly since the laterally unsupported condition of beams in testing. It could be significantly reduced by the provision of additional 2 mm cover plate over the top flange, that aims the scope of future research in Cold formed steel Castellated-beams. The beam SCB4 primarily undergoes local buckling in nature, that also provides a strong effect on the top flange of the beam. This is because of the limited thickness of Cold formed steel sheet.

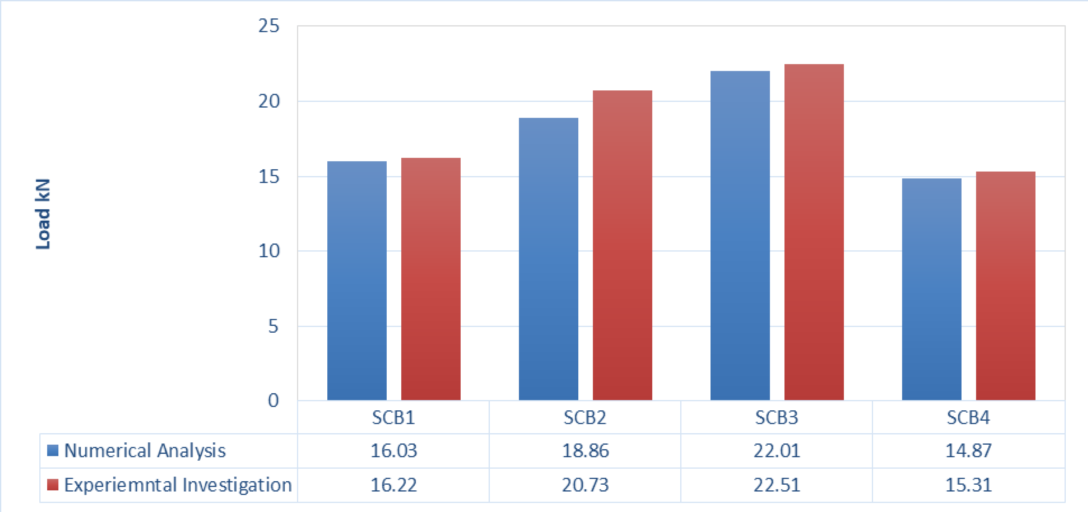

Figure 10. Comparison of findings SCB1, SCB2 SCB3 and SCB4

4.3. Using concrete in Castellated-beam

Normal Strength Concrete (NSC) having compressive strength of (30) MPa was utilized to explore numerically the influence of this parameter on a structural conduct of tested beam while, all other parameters are proposed constant. Depending on numerical findings getting from ABAQUS and compared with the corresponding tested specimens, the findings illustrate that the decreasing of compressive strength of concrete to (30) MPa has no significant effect on the total values of deflection at mid-span beam at ultimate load for all specimens while load carrying capacity was decrease from (4.49-5.14) percent. The values of ultimate loads and total deflection at mid-span beam for all specimens were sorted in figure 11 illustrate the load- deflection curves at various load stage until failure and also the numerical load carrying capacity values for parametric and tested specimen.

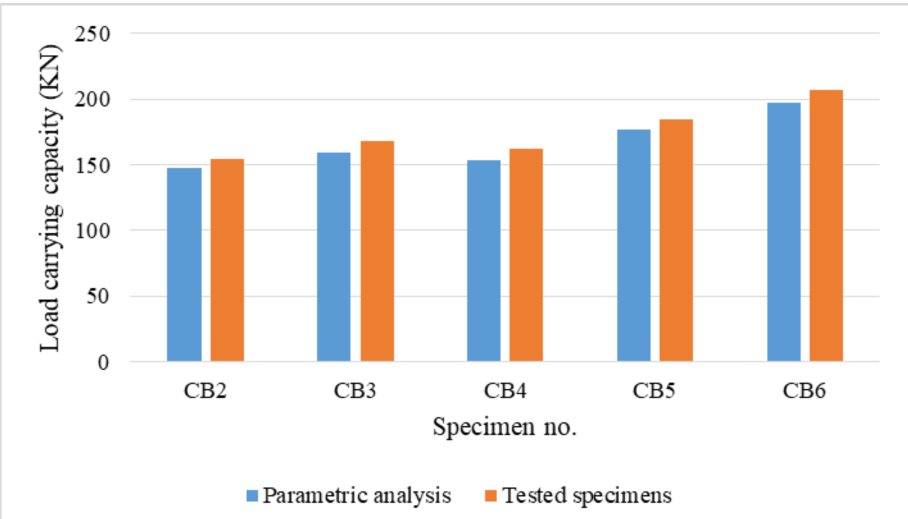

Figure 11. Numerical Load Carrying Capacity values for Parametric and Tested Specimen

The ultimate load values obtained from ABAQUS program and experimental findings illustrate that the strengthening of CSB with high strength concrete with and without lacing reinforcement bars, increasing the value of failure load since increasing the stiffness of beam section after strengthening and composite action between steel beams and laced reinforced concrete. Figure 12 illustrate the influence of various strengthening techniques on the experimental and numerical load carrying capacity values. The variance between experimental and numerical findings of the load carrying capacity were between (0.45-3) percent, that considered reasonable various.

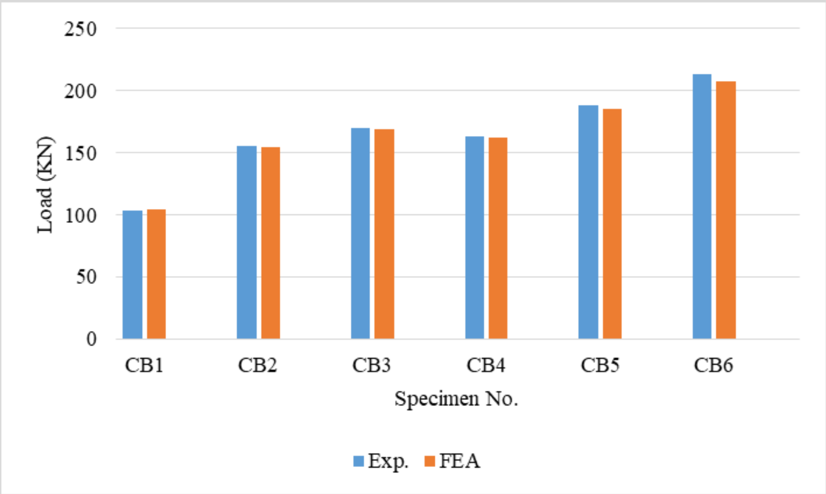

Figure 12. Experimental and Numerical Load Carrying Capacity for All Specimens

5. Conclusion

An analysis of a castellated-beam with parallel, perpendicular, and intercept (along the web), as well as an analysis of a beam without a stiffener, was performed utilizing the ABAQUS program. According to the findings of the numerical analysis, the standard stiffener beam with a thickness of 1.6 mm has not been able to achieve the same level of strength as the 2 mm thick variant.

In both the simulated and experimental analyses, we saw that all of these beams buckled at the flange location. As a result, a cover plate is required on the flange so as to demonstrate an improvement in load bearing capacity and to avoid local buckling. It was determined via computational and experimental study that the primary failure mechanism is torsional buckling. In specifically, it was found through experimental investigation that the section was unable to accept any load once torsional buckling had occurred. It was concluded that the web buckling and crippling of beams may be halted by the supply of stiffeners at the end or support of the beam that offers an eye open and the scope of future study work. This gives an eye open and the scope of future research work. It has also been deduced that the economical castellated-beam with parallel, perpendicular, and intercept stiffeners (along the web) has an increased capacity of load bearing in comparison to the castellated-beam that does not have a stiffener.

The diamond castellated-beam that has an intercept stiffener (both parallel and perpendicular) has achieved a higher load-taking capability than the other beams. When comparison to other beams, the SCB3 (Intercept Beam—both perpendicular and parallel Stiffener) has a higher load bearing capacity of 22.51 kN. This makes it the optimum portion to use when trying to boost the loading capacity of the structure. As a result of experimental research, it has been illustrated without a reasonable doubt that load-bearing capacity improves simultaneously with the provision of perpendicular and intercepting (both perpendicular and parallel) stiffeners that are 24.14 percent more than those of the other beams. The ability of a structure to bear a load is improved by placing stiffeners in the appropriate positions and orientations.

- For specimen CB2, Strengthening the castellated-beam by high strength concrete leaded to an enhance in the load carrying capacity by (49.86) percent.

- For specimen CB3, the strengthening by high strength concrete and laced reinforcement, enhanced the load carrying capacity by (64.2) percent.
- For specimen CB4, the strengthening by high strength concrete and laced reinforcement without welding the two parts of beam, enhanced the load carrying capacity by (55.2) percent.
- For CB5 and CB6 specimen, the strengthening by high strength concrete and laced reinforcement with increasing depth by (10) percent and (20) percent respectively.

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