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Finite Element Analysis of Buckling Capacity of Pretwisted Steel Bars: A Review

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Abstract - Any structure's support system is its column, which bears the weight of all the other structural parts. They thus constitute a crucial component of any structural design. Because of structural instability, buckling is the major form of failure for compression members. Pretwisted bars are those that have had their central axis twisted, strengthening the weak flexural plane and weakening the strong flexural plane. The structural part can be pretwisted to increase its ability to carry buckling loads. This research project will provide a finite element study utilizing the commercial programme ABAQUS to investigate the buckling capability of pretwisted steel bars. Studies show that the twist angle affects how easily the steel bars buckle. The main focus of this paper is the investigation of the behavior of pre-twisted bar.

Keywords- Pretwisting, Steel bars, Buckling, ABAQUS, Finite element analysis

I. INTRODUCTION

The stability of column has more significance as in comparison to other structural elements because of the truth that the instability of a column will result in the full destruction of the structure. Columns use compression to transmit the load that passes over them. A long, thin, flexible rod loaded longitudinally in compression deflects noticeably somewhere towards the middle of its length with a significant amount of displacement, hence the form of the column is critical. The phenomenon is referred to as buckling and takes place while the stresses within the rod are still well below the ones required to cause a shearing type failure. The length and the lateral measurement play a crucial position in figuring out the mode of failure of a normal compression element. Because for a short and squatty column, one with a low length to breadth ratio, the failure is much more likely to be through crushing than buckling. For a given section there will be a critical length of the compression member below which it will be crushed and above which it will buckle.

II. BUCKLING

As a result of structural instability, buckling is a mechanism of failure that is frequently seen in members that are in compression. It is a abrupt sideway failure of a structural member subjected to high compressive stress, whereas the compressive stress at the point of failure is less than the ultimate compressive stress of the material is capable of withstanding. As the load on the member increases at some point it become enough to cause the member unstable which in turn results in the buckling of the member. Further increment of the load will motive huge and extremely unpredictable deformations. The instability of the member result in the complete loss of the members load carrying capability. The axial load that causes buckling is referred to as the critical load.

III. PRETWISTED STEEL BARS

A method to increase the element's buckling capability is to pretwist it. Pretwisting can be defined as the rotation of a cross section's principal axes with respect to its centroidal axes along the member's length. As a result, the member's flexural planes have a coupling influence that strengthens the weak flexural plane and weakens the strong flexural plane**[8].** Inducing a natural pretwist alongside the length of a column section makes the column have a different resistance at every point along its centroidal axis. The column commonly buckles across the susceptible axis, however with pretwisting the buckling mode of the column may no longer be perpendicular to the weak axis. The pretwisted column in the 3D space has its strong flexural plane weakened and its weak flexural plane strengthened which caused to a net favorable impact at the buckling strength of the pretwisted column **[8]** To examine the pretwisted columns' ability to buckle, the total potential energy principle was used. It was found that for the majority of the boundary conditions investigated, the first mode's buckling capacity significantly increased while the second mode's buckling capacity significantly decreased at a faster pace than the first mode's **[3].** Pretwisted structural members are broadly utilized in engineering industry which include propeller, helicopter and wind turbine. In construction industry pretwisted structural members have been increasingly used because of the improvement of design, the pursuit of elegance. Pretwisted structural steel members have been utilized in engineering structures which

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include the Beijing National stadium which is known as the "Bird's Nest" and the world Expo Museum in shanghai **[10].** Investigating the buckling capacity of uniformly and non-uniformly pretwisted beams under fixed end boundary condition found that the optimum twist to be 225^0 also revealed that with uniform twist the principal axis which governs buckling is the weaker axis. Fig.1. shows the prismatic UB 100×50×9.3 and pretwisted UB 100×50×9.3 at 45^o, 90^o and 180^o. **[4]**

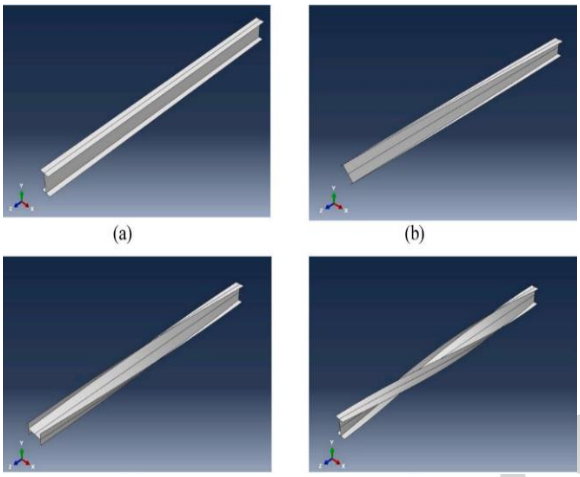

Fig. 1. Pretwisted UB100×50×9.3 models at (a) 0^0, (b) 45^0, (c) 90^0 and (d)180^0 [7]

III. EXPERIMENTAL PROGRAM

Zero degree twisting angle specimen constitute the reference ones. For the test the specimens have been examined under compression. Grips are provided for the fixation and to facilitate the machine griping. In the experimental setup as a way to result in a uniform twist alongside the length pure torque is applied using torsion machine is shown in Fig 2. Data acquisition gadget have been used to report the axial load and axial deformation. The loading rate was turned into 0.5mm/min **[5]**

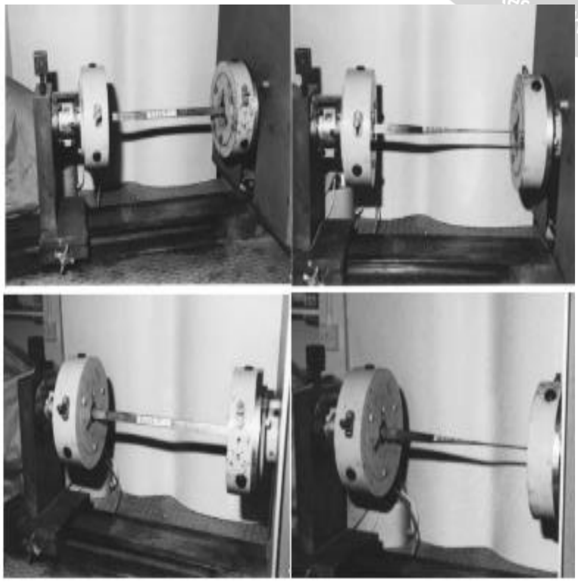

Fig.2. Torsion machine: Stages of twisting steel bars before buckling [5]

1.MATERIAL PROPERTIES

The material properties for all series of specimens have been decided through carrying out longitudinal tensile coupon tests to discover the yield stress of the tested specimen materials and additionally to decide the elastic-plastic behavior of the material through the stress-strain curves is shown in Fig.3. **[5]**

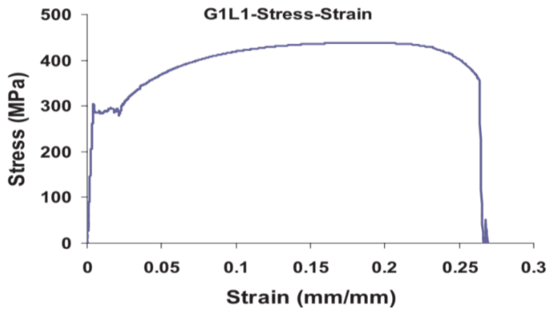

Fig. 3. Material properties from the coupon tests [5]

2. TEST RESULT

0,30,45,90,10,150,180,225^0 were the angle of twist taken into consideration for each group of the tested rectangular tested steel bars. After the experimental investigation on the pretwisted steel bars of rectangular cross section under fixed end boundary condition revealed that the effect of pretwisting is to increase the critical buckling load such that the buckling load of a pretwisted bar is always higher than that of the corresponding prismatic bar with unequal principal moment of inertia. In the case of bars with larger ratio of principal moments of inertia of the cross section and for certain range of plastic angle of twist. The optimization of pretwisted columns consists of finding the optimum cross section and angle of twist **[5].**

Experimental investigation on the pretwisted universal column 100×100×17 was carried out to examine the improvement in the buckling capacity of pretwisted column under pinned end condition. The experimental results discovered that the pretwisting doesn't have a considerable impact on the pinned end columns. With the higher length column under pinned end condition the failure mode turned into shifted from inelastic to elastic buckling. Even then, for the highest slenderness ratio at pinned-ended boundaries, the highest increase in buckling capacity, as in comparison to straight columns, did not surpass 15%. This is due to the fact the effect of pretwisting at the buckling capacity of the columns was restrained by the permitted rotation at the ends of the columns **[8].**

A series of tests was conducted on pre-twisted steel box-section columns by applying axial loads at the column ends. All tested columns confirmed clear peak loads from the load-deformation curves. The short columns have been failed in plastic yielding of the cross section. However, the long columns have been failed in elastic flexural buckling, and quite huge flexural deformation turned into found even earlier than the ultimate. The pre-twisted column could produce the torsional deformation together with its axial

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deformation and flexural deformation. The torsional deformation affected the free rotation of the pin-ends during testing, which made the columns ends towards fix-end boundary conditions, ensuring in better flexural buckling load **[10].**

IV. FINITE ELEMENT ANALYSIS

Finite element model (FEM) was developed using finite element application ABAQUS to simulate the buckling behavior of pretwisted columns. Simulations have been executed via the "BUCKLE" linear perturbation procedure available on the software.

1.MODELING

The 3-dimensional bars have been modeled using 8 node solid elements and the grip have been created as analytical rigid part. Reference point have been described for each grip to impose the boundary conditions. The end of each grip was fixed against all degrees of freedom expect for the displacement at the loaded end in the direction of the applied load/displacement for the rectangular steel bars **[6]**. The universal beam turned into modeled through extruding 3-dimensional shell of the predefined sections. For pinned end boundary condition translation turned into allowed withinside the direction of the unit load, similarly to rotation across the weak axis **[8].**

2.MESH SENSITIVITY ANALYSIS

To determine on the appropriate mesh that offers the maximum correct results whilst minimizing the wanted computational time, different mesh configurations should be examined. Mesh sensitivity analysis was conducted in the study by considering three mesh size configuration of size 20mm,25mm and 50mm respectively and used to stimulate the buckling analysis of both untwisted and twisted UC152×152×30 column of 6m length. Mesh 1 and Mesh 2 deliver comparable accuracy while as in comparison to the calculated values using Euler Equations **[7].** Fig .4. represent the three-mesh configuration used for the mesh sensitivity analysis. Coarse mesh caused a stiffer finite element response whilst finer mesh displayed better comparisons with appreciate to the experimental results, with a variation of much less than 0.5% **[8].**

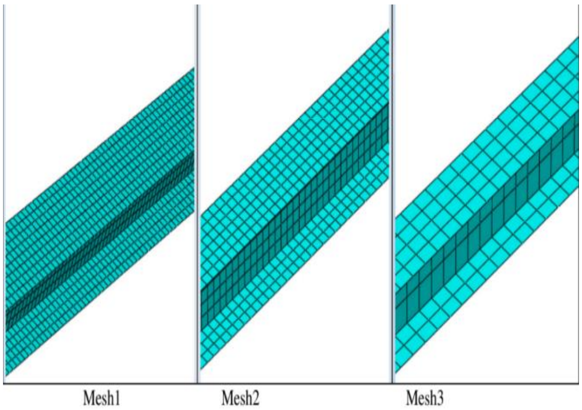

Fig.4. Three different mesh configurations used in the mesh sensitivity analysis [7]

3 RESULTS AND DISCUSSION

The linear perturbation analysis was run on ABAQUS and the critical load have been recorded, and the load was then compared to that of the prismatic members

3.1 FIXED END CONDITION

Under this boundary condition the percentage increase in buckling capacity rises regularly till a pretwist angle of 90^0 before experiencing a moderate relative decrease of approximately 4%. The fundamental focus of the fixed end-conditions models is the pretwist angle range below100◦. It can for this reason be stated that the finest pretwist angle is 90^0 **[8].** For the fixed-ended boundary conditions, yielding turned into found earlier than buckling for the 3-meter length columns at all pretwist angles and the 4-meter length columns at pretwist angles 60° to 180°. On the opposite side, for all twist angles, the FE models showed that buckling occurred before yielding for the 5- and 6-meter length columns. For this boundary condition, increasing pretwisting angles caused a uniform increase in the critical load capability. This fashion turned into effortlessly observable for higher slenderness ratios **[9].** The models twisted under higher twist angle experienced flexural-torsional buckling **[7].**

3.2 PINNED END CONDITION

Applying pin end boundary condition proved an incredibly negligible development in comparison with the fixed end boundary condition. This low development can be attributed to the fact that under pinned end condition the rotation isn't restrained at the two ends. The member is free to rotate starting at the two supports, wherein the least impact of pretwisting is noted. All the twisted models have been failed because of flexural buckling **[7]**. Prior to buckling, failure turned into initiated through material yielding in pinned-ended modeled for short columns for the pretwist angles. The most crucial load turned into reached earlier than yielding for the larger length's columns **[9].**

3.3 BOXED AND NON-BOXED SECTION

The increase in the buckling capacity turned into higher for the case of the non-boxed sections in comparison to the boxed sections. For the non-boxed section, the maximum development turned into achieved at an angle 120^0. Further twisting appears to present much less axial capability for all the sections. In the case of boxed sections flexural-torsional buckling modes have been attained due to the everlasting twist for a range of angles between 105^0-150^0. The fundamental failure mode for non-boxed sections turned into flexural buckling and no torsional failure mode have been found for the angle and the length taken into consideration. Fig.5. shows the representation of buckling modes of pin ended columns for both boxed and non-boxed sections **[7].**

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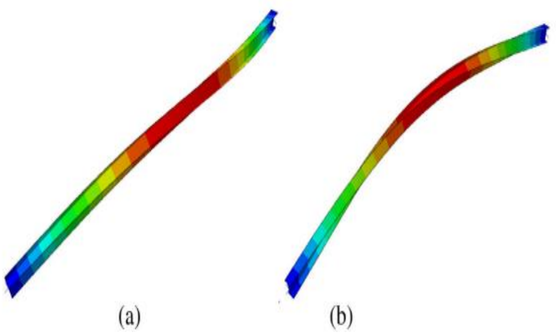

Fig. 5. Buckling modes of pin ended columns (a) non-boxed, $\phi = 90^0$, (b) boxed $\phi = 180^0$ [7].

V. STABILITY OF PRETWISTED BARS

A bar may also turn out to be unstable under the action of a torque. When a bar is twisted before any load is applied, the impact of pretwist must be taken into consideration. When the impact of the application of end torque on the stableness of pretwisted bars are studied the results validate that the sections of the pretwsited beams behaved as circular cross sections when the applied pretwist values approached infinity. Moreover, the buckling strength of a member of equal moment of inertia turned into unaffected through an initial pretwist **[2].** The study on the stability of pretwisted simply supported column subjected to static and periodic axial load revealed that the rigidity ratio of certain cross section approaches unity, the effect of pretwist almost vanishes. The study also revealed that the load from the second buckling mode reaches a minimum before the first buckling load is reached and also showed that medium pretwisting had the greatest effect on the lowest critical loads **[1].**

VI. CONCLUSIONS

The buckling capability of pretwisted steel bars under axial compression has been studied experimentally and numerically. Analysis shows that elastic buckling occurs before yielding of material. In the case of pretwisted steel bars the deformed configuration is not perpendicular to the axis of least resistance. The evaluation of the results discovered that the pretwisting doesn't have full size impact at the pinned end boundary condition. It results in little development over 25% within the buckling capacity. Under fixed end condition a boom increase in the buckling capacity in comparison to the non-twisted sections have been found. A pretwist angle of 90^0 results in the finest development in the buckling capacity. For all the stimulated steel bars, the effect of pretwisting turned into boom the critical buckling load such that the buckling load of a pretwisted bar is usually better than that of the corresponding prismatic bar with unequal principal moment of inertia. Therefore, pretwisting may be taken into consideration as an easy manner of strengthening thin column with same strength. With the increase in the slenderness ratio the improvement in the axial load carrying capacity reaches its maximum value at smaller angle of twist. And also found that the buckling capacity improvement increase with increase in the slenderness ratio.

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