Influence of Tilting Angle and Reinforcement on the Performance of Tilted RC Beams Using Finite Element Analysis

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***Abstract* - The importance of modern structural elements that can meet architectural requirements, such as the study of tilted beams, was one of the essential points for intensive research and study to find and create a unique code for them after theoretical analysis and research of their behavior. The tilting angle is the main point of this theory, so it is necessary to study the behavior of tilted beams under the influence of more than one tilting angle to know the tilted beam's behavior during the tilting angle change. This research paper relied on the theory of levers to impose biaxial shear loads on the tilted beam in addition to the torsional moment. The study focused on studying the difference between tilted beams at an angle of 45 degrees and tilted beams at 60 degrees and comparing their resistance with standard beams. Static analysis was used in the finite element program ABAQUS. These results were presented and discussed in detail in the following paragraphs, which show the extent of the tilted beam's ability to resist biaxial shear loads. Also, whenever the angle changes, the beam's resistance changes. The angle has a noticeable effect on the beam's resistance to twisting and bending moments.**

Keywords: tilted beam, tilting angle, torsional moment, biaxial shear, finite element analysis

I.INTRODUCTION

Tilted RC beams, or flanged walls, are commonly found and widely used in buildings. They are under-researched, and their structural behavior under load is complex. Over the past two decades, a few studies have been done on tilted beams in shear or torsional cases; studying tilted RC beams is crucial for several reasons. Torsional behavior evaluation is a complex phenomenon in RC beams, and understanding it is essential for safe and efficient design; traditional analytical approaches struggle to model torsional fracture mechanisms accurately. For structural safety, torsion affects the overall stability and safety of structures. RC beams subjected to torsion may experience shear cracking, diagonal tension, and twisting deformation.(Zhou et al., 2022). The results of this study on tilted beams may have significant practical implications for real-world structures, such as bridges, buildings, and industrial facilities. Understanding the behavior of these beams may help engineers improve designs, make better use of materials, and increase structural performance. This confirms the importance of researching tilted beams and their potential effects on structural engineering.

Due to the complex geometry of tilted RC beams, their structural behavior and the mode of load transfer are different from the corresponding traditional non-tilted beams. Tilted members are inherently three-dimensional in behavior, particularly when subjected to torsion. This is in contrast to non-tilted beams, which can be assumed to behave mainly in one direction due to their planar geometry. When a member is tilted, the eccentricity of the torsional load from the beam's center of mass is increased. This results in a torsional moment that is superimposed in inclusion to the flexure and shear in the beams. As a result, the mode of load transfer in tilted RC beams combines flexural and torsional effects. (Nie et al., 2023)(Mohaisen & Waryosh, 2021)(Waryosh et al., 2014)

The flexural load-carrying mechanism remains the same as in non-tilted beams, where the members are designed and detailed to carry shear and moments primarily in the direction at 90 degrees to the linear axis of the members. When a load is applied in the non-tilted direction, the load is transferred from the point of application through the shear center to the supports. The load-carrying mechanism in the tilted direction is torsional. The load is transmitted from the point of application of the load to the supports through the twist of the cross-section. The sectional analysis in the tilted direction includes the evaluation of the torsional moment and the shear flow originating from the twist of the cross-section. (Hadhood et al., 2020)

Studying the tilted beam angle to the horizontal has also attracted many researchers. It is generally agreed that the effect of the tilted beam angle becomes more significant as the slenderness of the beam increases. As the tilted angle increases, a tilted RC beam's maximum induced torsional stress rises. The

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theoretical behavior of the structural members subjected to torsion because of eccentric loading is examined. It is suggested that the torsional deformation is another parameter used to determine the effectiveness of the tilted angle.
So, to simulate the behavior of the tilted beams more accurately, both the material non-linearity due to cracking and the geometric non-linearity due to large deformations should be considered in the analysis. Also, considering the difficulty and complexity of conducting the nonlinear analysis, most studies on tilted RC beams have adopted the linear static approach. However, it should be noted that if the load is applied in the non-tilted direction, the so-called different magnitude of the torsional deformation phenomenon will be less significant because the twist angle along the member length will be relatively minor and thus distributed over the length. On the other hand, if the load is applied in the tilted direction, the twist angle will be larger and concentrated across the thickness of the member, which will induce more considerable torsional deformation.(Acharjee, 2023)

II.TORSIONAL MOMENT

In structural engineering, the twisting moment of the structural elements is referred to as the torsional moment. When a structural member is subjected to a torque or twisting of one end relative to the other, the member twists or rotates. The resisting force of a structural member to this type of loading is called torsional moment. The torsional moment is one of the three-moment types in the materials' mechanics, including the bending moment and shear force. A torsional moment acts about the longitudinal axis of a structural member. It is also known as "twisting" or "twisting moment" because it can cause a member's section to twist about its longitudinal axis. (Bhasker & Menon, 2020)
As is in the formula, the polar moment of inertia and modulus of rigidity are material properties. The polar moment of inertia, J, and the shear stress due to torsion, j, are defined for a cross-sectional shape and dimensions of a given shaft. The polar moment and the shear stress determine the maximum shear stress due to torsion, t, on a given shaft. This is known as the torsion equation. By rearranging the terms, we can obtain the formula for the torsional moment, M. The maximum shear stress due to torsion is a critical mechanical property of the material, which represents the most significant load that the material can withstand in a rectangle or square shape. By knowing the value of the maximum shear stress due to torsion for a specific material, we can determine the maximum torsional load that can be occupational before failure. Also, it is the criteria for selecting the materials because this will limit the range of options. For factors that influence the material selection in torsion, the general practice is to choose a material that can carry a high degree of stress. This material has high shear stress. That means a higher yield point but not flexible. The shafts are usually circular due to the shape that best resists the torsion. Also, by rearranging terms, the angle of twist of a given shaft for a known torque can be calculated using the following formula. Right is the formula for the power transmission. The polar ratio and maximum value will be calculated for each cross-section type. I will show the application for finding the maximum shear stress due to torsion for the two cross-section types.(Hailu et al., 2022)

A. Torsional Moment Distribution in Different Structural Elements

This section provides a detailed analysis of the distribution of torsional moment in different structural elements and the impact on the entire structure. Given that the torsional moment is predominantly induced by lateral loads in a building, frames will usually have a considerable amount of torsion. In addition to frames, other structures (e.g., bridges) can also experience torsion, and the principles we will discuss here will persist. Nevertheless, the main focus will be on frames. First, consider a building or a bridge frame under torsional loading. Let's take a beam in the frame, for instance. As explored earlier, torsion is caused by the misalignment between the shear center and the center of rigidity. This misalignment induces a torsional moment on a cross-section about its shear center. (Ju & Lee, 2021)

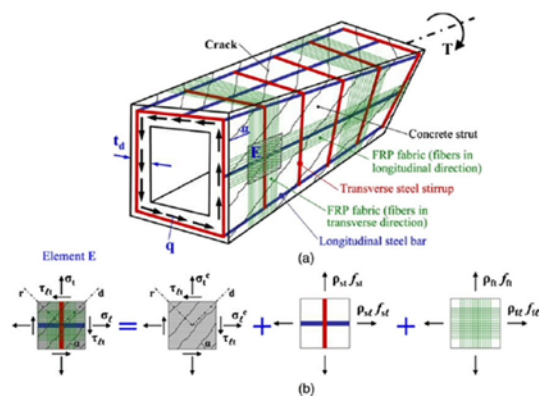

Figure of how torsion distribution on all faces of RC beam and how shear flow done(Worked Example _ Design of RC Beams for Torsion (EN 1992-1_2004) - Structville, n.d.)
Figure - 1 Torsional moment distribution

Given that the torsional stress varies linearly from the shear center to the ends of the cross-section, the resultant maximum shear stress will peak at the farthest point from the shear center. It's also worth mentioning that the maximum shear stress due to torsion will always lie on the perimeter of the cross-sectional area. This is very different from everyday stress in a material subjected to tensile or compressive loading, where the maximum stress can occur anywhere in the material. For example, in a solid circular cross-section, the maximum shear stress will be at the surface of the section, while the minimum seeking principal planes (where no shear stress exists) will pass through the center of the cross-section. Also, it is easier to visualize this by considering a hollow circular section. Since the shear stress is non-zero only on the perimeter, the value of the

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torsional moment will reduce linearly towards the center of the section till it reaches zero. On the other hand, since the shear stress is constantly acting on the perimeter, the resultant torsional shear force will be constant anywhere along the length of the beam. Such force varies linearly from one end to the other of the beam, and its maximum value can be obtained by simply multiplying the maximum shear stress by the polar area over which the shear stress acts. By visualizing how the torsional moment is distributed within a beam, one can realize that each beam portion will contribute to the overall resistance against the applied torsional loading. This can be seen from the conventional method to determine the resistance of a material to torsion, otherwise known as the 'Polar Moment of Inertia' (J). For an area A with a known distance r from a polar axis, J can be calculated using the formula J = r^2 dA, where dA is an elemental area of the section. Summing all elemental contributions to J will give the overall J value for the section, which can provide helpful information when comparing the resistance to torsion of different sections. Such a concept also forms the principle for torsion testing using a thin-walled tube. The distribution of torsional moment in circular and non-circular cross-sections is explored separately. By examining the two cases, it is intuitive to see that flanges in an I-shaped section will significantly increase the resistance to torsion, as flanges are located furthest away from the shear center. Therefore, the I section is ubiquitous in the application when a torsion resistance design is worried.(Casinos et al., 2020)(Lin, 2021)

B. Cases of torsional cracks

Material defects can be divided into two main categories: service-induced and inherent. The terminology is somewhat misleading, as even inherent defects can remain undetected throughout a material's service life. Occur during the manufacture or subsequent processing of the material. Inherent defects result from an unwanted chemical reaction, while processing defects result from an incorrect mechanical working of the material. In both cases, the defect will cause a localized weakening in the material. If the weakening is not too severe, it will not be noticed until the affected part of the material is subjected to stress. Depending on the severity of the stress and the weakening, the loaded part of the material may deform plastically or even fracture. This essentially happens when a material defect causes a torsional crack. There is no real difference in how torsional cracks are caused between ductile and brittle materials. However, due to the crack's nature and the application field, it is more likely to harm a pliable material. A ductile material is more likely to deform plastically when a crack is initiated, and a torsional crack can continue to grow as cracks in ductile materials tend to propagate without an increase in the load on the material. This is due to the crack blunting and the stress concentration in the material ahead of the crack tip. This detrimental effect makes it even more essential to avoid torsional cracks when using ductile materials. Any part of a component near a crack likely to undergo further plastic debris will likely experience excessive torsional stress and thus could also become affected by a secondary torsional crack. (Foti et al., 2023) (Waryosh et al., 2018)

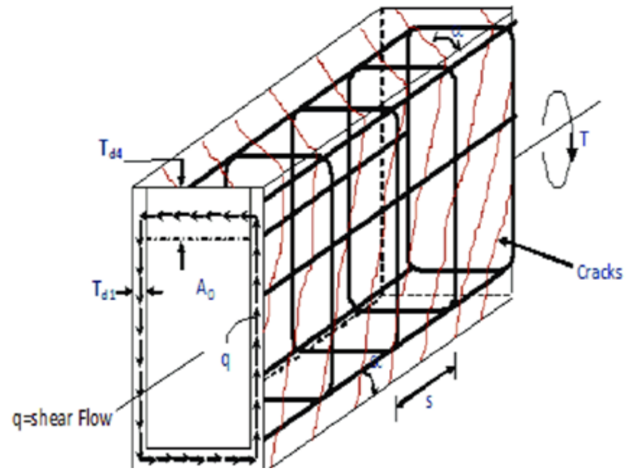

Figure explains the shear flow and how the crack pattern would be made.(Behera et al., 2014)

Figure - 2 Cracked beam section due to torsion

1. III.THEORETICAL OF ANALYSIS

Previous research revolved around studying tilted beams at an angle of 45 degrees with an eccentricity of the load applied from the shear center of the concrete section. In these studies, models with a rectangular concrete section were used, with different dimensions for each survey.(Chaisomphob et al., 2003)(Waryosh et al., 2014) (Tinini et al., 2016) In the other research, work was done on changing the inclination angle pattern on models with a square concrete section and loading without eccentricity of the load from the shear center to test biaxial shear on the sides, whether equally when using a tilted angle of a 45-degree or unevenly when using other angles. Research related to torsion focused on highlighting pure torsion and studying its effects on the behavior of concrete beams. The research was based on static loading on beams using simultaneous biaxial shear and torsional moments and pure torsion for one group.

IV.PROGRAM ANALYSIS

In this research paper, the aim of which was to study the effect of changing the tilting angle of the tilted beam on its behavior when subjected to external loads represented by biaxial shear and torsional moment, it was decided to use a lever system to apply biaxial shear stresses and torsional moment. Two sets of models were worked on, one tilted at an angle of 45 degrees from the horizon and the other at 60 degrees from the horizon. The reason behind choosing these angles is that at an angle of 45 degrees, the shear area is flat in both directions, and there is a moment of inertia. However, when using a tilted beam at an angle of 60 degrees, the physical properties of the shear area and moment of inertia will be different on both axes, and it will be possible to study the behavior of the tilted beam when changing the angle.

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➢ **Set 1**

Use a tilted rectangular beam angle of 45˚ degrees (b 200 mm & h 500 mm) with a cantilever (b 200mm & h 200 mm) carry point load that causes shear & torsional stresses on a tilted beam longitudinal section with the same three types of reinforcements: -

❖ Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen-1 (B1) Primary reinforcements 8 bar Ø 20 mm
stirrups Ø 12 mm @ 100 mm C/C

➢ **set 2**

Use a tilted rectangular beam angle of 60˚ degrees (b 200 mm & h 500 mm) with a cantilever (b 200mm & h 200 mm) carry point load that causes shear and torsional stresses on a tilted beam longitudinal section with the same three types of reinforcements: -

❖ Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen-4 (B4) Primary reinforcements 8 bar Ø 20 mm
stirrups Ø 12 mm @ 100 mm C/C

➢ **references set**

Specimen B.R: A standard beam with no tilted angle, a cantilever subjected to 50 Kn at the end, and the same reinforcement as Specimen-10 (B10).

Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen reinforcement

Primary reinforcements 8 bar Ø 20 mm
stirrups Ø 12 mm @ 100 mm C/C

Specimen B 7: used the same specimen **B – 4** with a tilted angle of 60 degrees but no transverse reinforcement (stirrups), only longitudinal flexure and torsional reinforcement, to study the effects of tilt angle and transverse reinforcements.

Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen reinforcement

Primary reinforcements 8 bar Ø 20 mm

Specimen B 8: used the same specimen **B – 4** with a tilted angle of 60 degrees but no transverse reinforcement (stirrups) and torsional longitudinal reinforcement, only longitudinal flexure, to study the effects of tilt angle and torsional reinforcements.

Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen reinforcement

Primary reinforcements 2 bar Ø 12 mm

Specimen B 9: The same specimen **B – 4** with a tilted angle of 60 degrees but no longitudinal reinforcement, only transverse reinforcement, was used to study the effects of tilt angle and torsional transverse reinforcements.

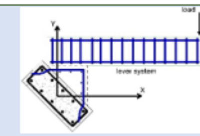
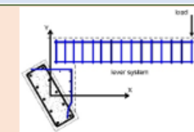
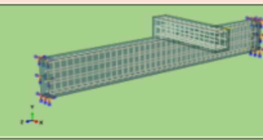
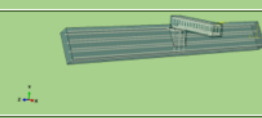
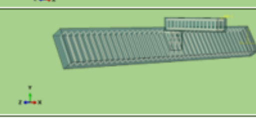
Cantilever reinforcement

Primary reinforcements 4 bar Ø 20 mm
stirrups Ø 12 mm @ 80 mm C/C

Specimen reinforcement

stirrups Ø 12 mm @ 100 mm C/C

Table- 1 List of finite elements program specimens

B1	Primary reinforcements 8 bar Ø 20 mm stirrups Ø 12 mm @ 100 mm C/C	
B2	Primary reinforcements 8 bar Ø 16 mm stirrups Ø 12 mm @ 200 mm C/C	
B3	Primary reinforcements 8 bar Ø 12 mm stirrups Ø 12 mm @ 300 mm C/C	
B4	Primary reinforcements 8 bar Ø 20 mm stirrups Ø 12 mm @ 100 mm C/C	
B5	Primary reinforcements 8 bar Ø 16 mm stirrups Ø 12 mm @ 200 mm C/C	
B6	Primary reinforcements 8 bar Ø 12 mm stirrups Ø 12 mm @ 300 mm C/C	
BR	Primary reinforcements 8 bar Ø 20 mm stirrups Ø 12 mm @ 100 mm C/C no tilt angle same lever arm same boundary conditions	
B 7	Primary reinforcements 8 bar Ø 20 mm	
B 8	Primary reinforcements 2 bar Ø 20 mm	
B 9	stirrups Ø 12 mm @ 300 mm C/C	

Figures explain specimen shapes defined by the ABAQUS program.

V.ACI LIMITATION DESIGN

The models are designed according to the requirements of the ACI code by calculating the ultimate torsional moment and checking the shear and flexural design to avoid failure under shear force or bending moments so that the models can be tested and analyzed in the ABAQUS program. Started calculation for torsion with the minimum spacing between bars and maximum reinforcement area (**S_{min} = 300 – d/4 – d/2**) and from this ultimate torsional moment can calculate the load needed to be subjected to the lever arm to make torsion action plus the by axial shear and flexural.

d= 460 / S_{min} = 300 – 460/4 – 460/2 / S_{min} = 300 – 115 – 230
so for over-designed in shear, use S = (100 – 200 – 300)

VI.PROGRAM ANALYSIS CRITERIA

The analysis criteria are divided into several introductory paragraphs, starting from the requirements of the materials used for the sections until reaching the final analysis, which will be

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presented in detail below. These criteria were fixed according to the static to create the best analysis conditions and be as close as possible to resembling objective reality—the actual loading conditions of the static analysis. This static load is direct. The nonlinear properties of concrete were defined to try to study its behavior well in the theoretical analysis and the extent of its impact on the behavior of structural elements.

- **Material criteria**

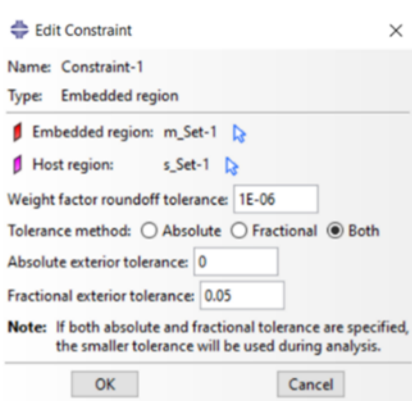
The analysis criteria for the materials were chosen based on the material properties from the actual sites in the construction work, as also explained in the practical analysis chapter, without any reduction or safety factors to reach the maximum limits of the material. Because the first step in the research was based on theoretical analysis, the concrete properties were taken from a ready file of the program library uploaded on public sites. These properties were fixed in all the models used in the theoretical static analysis to study the behavior of the tilted beam, as well as to try to study the nonlinear behavior of concrete in these structural elements. All material properties are shown in Appendix C

- **Step criteria**

The step used: type static, Riks with the maximum number of **increments 20** and used equation solver – matrix storage **unsymmetric**. Made convert severe discontinuity iteration **(on)** and extrapolation of the previous state as the start of each increment was **(parabolic)** not linear.

- **Interaction criteria**

Used embedded interaction between concrete section and rebar reinforcement



A plate of interaction criteria in the ABAQUS program was defined

Plate - 1 Constraint features

- **Mesh criteria**

For the static analysis, the mesh used for concrete 25 mm was **Tet** shape, and the geometric order was Quadratic. For bars, reinforcement mesh is used at 50 mm with standard type and linear geometric order with family type truss to ensure the reinforcement is just tension and compression.

- **Boundary conditions criteria**

Fixed-end faces prevent displacement and rotations at the end to simulate the actual cases of tilted beams in concrete structures with continuous or linked ends in frame structures. The load was divided into several types. For static analysis, 50 KN was used at the end of the lever arm or on the notch, which acts as a 60 KN/m pure torsional moment.

VII.THE GENERAL BEHAVIOR OF STATIC ANALYSIS USED IN ABAQUS

The models were analyzed by using the finite element program ABAQUS. The load acted on the cantilever beam, and that point load transferred to the support of the cantilever, which is the tilted beam as a load with a transverse torsional moment at mid-section where the cantilever is linked with the tilted beam as the lever system. "The lever system is one of the mechanical systems found in nature whose operation requires the presence of a solid physical body, i.e., the lever, capable of rotating around an axis or a fixed fulcrum, and is affected by force (effort) and resistance, and both the line of action of the effort and the line of action are far apart. Resistance is a perpendicular distance from the axis of rotation, where this distance is known as the arm.(Artobolevsky, 1975)". These combined loads simulate real cases that can affect the tilted beam. This behavior helped make analysis more accessible and took us to known points that calculate displacement and rotation. Perhaps the most common case in structural designs and the most complex models used in this research is when using a cantilever plate supported by an inclined beam that produces a continuous torsional moment along the entire span, and more equations are needed to solve this situation. In addition, ensure that the cantilever beam does not fail before the tilted beam uses a rigid beam (over-designed beam in flexure, shear, and torsion), so ensure no losses approximately when the static load acts on the system and make can three types of cracks (flexural, shear and torsional cracks) when the beam high reinforced for flexural and shear that help to be just torsional crack clear appearance in the field test. At laboratory and program analysis, the foremost parameters to be measured were load displacement at the cantilever, angle of twist at the mid-section, and displacement of the mid-section.

VIII.OVERALL PROGRAM ABAQUS STATIC ANALYSIS RESULTS.

The result shown in the tables for concrete was a maximum range of stresses at the mid-section of the tilted beam and figures for steel rebar stresses, which can be compared in each group of specimens and between groups. This clear and concise presentation of the results keeps the audience interested in the findings. Before presenting the results, clarifying what they mean and their significance in structural design and analysis is necessary. The results were divided into the stresses of the concrete section at the applied load point (the mid-section of the tilted beam), representing the stresses in the three-dimensional axis, and the three-dimensional plans. This facilitates the

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comparison of each model's effect and behavior. The steel reinforcement stresses were presented in the figures to clarify the stress distribution at all bars. These practical implications of the results provide valuable insights for future structural designs and analyses. It was decided to display the tilted beam's displacement and angle of rotation for each node. The highest individual displacement for each node is represented by the angle, which also means the node's rotation angle. The significance of these results in the context of structural design and analysis cannot be overstated, as they provide a solid foundation for future research and practical applications.

❖ **Set – 1**

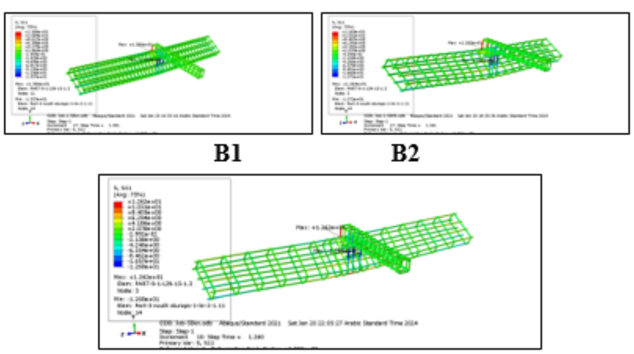
When the three types of loads - shear, bending, and torsion - are combined, this leads to the actual loading state so that the effect of the forces on each other and the effect of the tilted angle of the beam are observed. The stress in the tensile reinforcement increased to its maximum in the third model, which had the smallest reinforcement area. The stresses on the tilted beam can be explained as complex overlapping stresses based on shear flow and compressive stress in the upper layers and shear flow in the lower layers with the biaxial shear stress and the presence of tensile stresses on the tilted beam acting together at the same time. The critical factor that increases the efficiency of the tilted beam that bears these stresses together compared to standard models is the moment of inertia of the section, which changes with a change in shape or angle of inclination so that the section can withstand a higher degree of bearing.

Table- 2 Stresses at mid-section / set 1

Concrete stresses

No.	SXX	SYY	SZZ	SXY	SYZ	SXZ	UX	UY	UR
B1	+2.429	+3.129	+1.286	+1.261	+0.264	+0.397	+0.1273 -0.3104	+0.0346 -0.3186	+1.116×10-3
B2	+2.309	+2.499	+1.237	+1.067	+0.3959	+0.355	+0.1030 -0.2722	+0.0227 -0.2822	+0.958×10-3
B3	+1.863	+2.486	+1.968	+1.065	+0.3872	+0.358	+0.1100 -0.3126	+0.0182 -0.3219	+1.07×10-3

Steel rebar stresses



B1 B2

B3

Figure Explain steel reinforcement stress distribution

Figure - 3 Reinforcement stresses B 1-2-3

❖ **Set – 2**

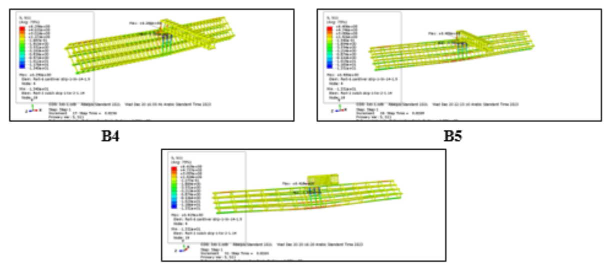
In the process of trying to understand the complex behavior of the system. The behavior of these models is as in the previous group, taking into account the increase in the ability to resist bending and shear loads due to the increase in the shear area in the Y direction and the increase in the moment of inertia in the same direction. As the angle of inclination increases towards the standard vertical shape of the beam, the bearing capacity increases in the bending direction. A decrease in the shear area in the X direction by 9.6% and keeping the shear flow constant affects the reduction of the torsional resistance.

Table- 1 Stresses at mid-section / set 2

Concrete stresses

No.	S_{XX}	S_{YY}	S_{ZZ}	S_{XY}	S_{YZ}	S_{XZ}	U_X	U_Y	UR
B4	+2.156	+1.917	+0.914	+1.833	+0.792	+0.231	+0.1142 -0.1904	+0.0364 -0.1203	$+8.072\times10^{-4}$
B5	+1.84	+1.978	+1.008	+1.795	+0.7909	+0.236	+0.1153 -0.1907	+0.0363 -0.1214	$+8.135\times10^{-4}$
B6	+1.461	+1.976	+1.273	+1.804	+0.7913	+0.235	+0.1153 -0.1906	+0.0362 -0.1214	$+8.137\times10^{-4}$
BR	0.412	4.462	1.399	1.011	0.5424	0.0964	+0.9514 -0.2995	+0.1242 -0.0843	1.924×10^{-3}

Steel rebar stresses



B4 B5

B6

Figure Explain steel reinforcement stress distribution

Figure - 4 Reinforcement stresses B 4-5-6-BR

 References set

Refer to the specimen defined in the ABAQUS program to compare the behavior of a tilted beam with a standard beam with no tilt angle and, in many cases, with a tilted beam without reinforcement to study the effect of reinforcement on a tilted beam underloading.

 Compression standard specimen with tilted beam 45&60 degrees.

When searching and comparing the standard beam model B.R and the tilted beam models B 1 – 6, it becomes clear that the shear stresses that the tilted beam can bear are higher due to the approximation of the total shear area in the two directions X-Y of the tilted beam, as well as the focus on the fact that the standard beam can bear bending stresses in one direction mainly and is very weak in the second direction. This is clear from the stresses it can bear in both directions, while the tilted beam can bear bending stresses that are close in values. With the stability of the shear flow that causes the torsional moment in both models, it is noted that the standard beam is generally weaker than the tilted beam.

9. Effect of reinforcement

The principal affection of longitudinal reinforcements was apparent in specimens B – 8 & 9; when reinforcements were removed, stresses increased in concrete members before sudden

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flexural failure. The central affection of transverse reinforcements was apparent in specimens B – 7; when reinforcements were removed, stresses increased in concrete members before sudden shear–torsional failure. The average stress in steel reinforcement at specimen B 7 – 8 – 9 was 1.4 MPa, so when removing any reinforcement, the yielding of the longitudinal reinforcement results in the redistribution of loads to the non-yielded bars and helps improve the flexibility of the structural element. Breaking the reinforcement or premature fracture failure is undesirable as it results in a loss of beam strength without adequate warning. This condition is generally associated with brittle behavior, with little or no deflection before failure. As beams can carry high loads, it is crucial to understand the load distribution and factors that influence it to properly understand the response of such structural members to various service and severe loads. It is essential to establish relationships between the load-bearing capacity, structural deformation, and direct factors of structures, design, and construction of heavy loads and bridges, as well as practical applications of natural earthquakes, for proper preventive measures. Design is generally based on the expected load distribution and is typically influenced by the beam's location and expected geometric characteristics, such as height and reinforcement ratio.

Table- 4 Stresses at mid-section / references set

No.	SXX	SYY	SZZ	SXY	SYZ	SXZ	UX	UY	UR
B13	0.412	4.462	1.399	1.011	0.5424	0.0964	+0.9514 -0.2995	+0.1242 -0.0843	1.924×10-3
B14-A	2.177	3.860	1.599	2.707	0.7821	0.4357	+0.1497 -0.1909	+0.0362 -0.1219	8.162×10-4
B14-B	2.203	3.863	1.565	2.706	0.8582	0.446	+0.1419 -0.1977	+0.0283 -0.1292	8.124×10-4
B14-C	2.181	3.855	1.505	2.679	0.9221	0.459	+0.1365 -0.2035	+0.0219 -0.1355	8.115×10-4

Steel rebar stresses

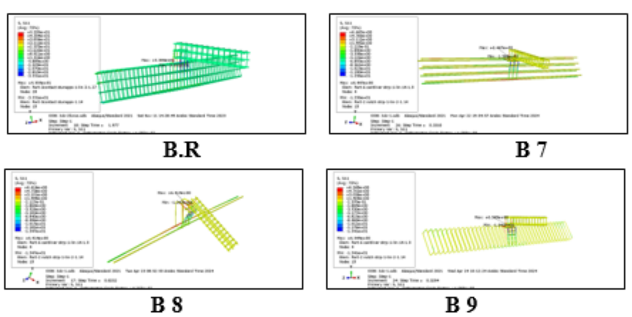

Figure Explain steel reinforcement stress distribution
Figure - 5 Reinforcement stresses B.R, B 7, B 8, B 9

X.EFFECT OF TILT ANGLE 45˚ & 60˚ ON STRESSES AND

When the tilted angle of the beam changes, there are changes in the properties of the section, and because of these changes, the behavior of the beam changes according to the angle and its effect. One of the most important properties that is affected by changing the angle is the shear area, which is equal in value in both directions at an angle of 45 and when there is no tilted angle. As for angles between 45-90, the shear area increases in the x direction and decreases in the y direction. While the moment of inertia is very high around the X axis and very little about the Y axis, it decreases around the X axis and increases around the Y axis to be equaled at a 45-tilt angle. The section modulus (positive-negative), the radius of gyrations, and the elastic modulus are equaled at a tilt angle of 45 degrees, and it increases about the X-axis and decreases about the Y-axis with approximately constant torsional modulus for each specimen. The tension and compression zones change with tilt angle changes, and more research is needed to find a new style of calculating tension and compression zones and parameters of flexural calculations (a – c – d) in the ACI code. All of that can affect the behavior of tilted beams and how the stresses will distribute in each case.

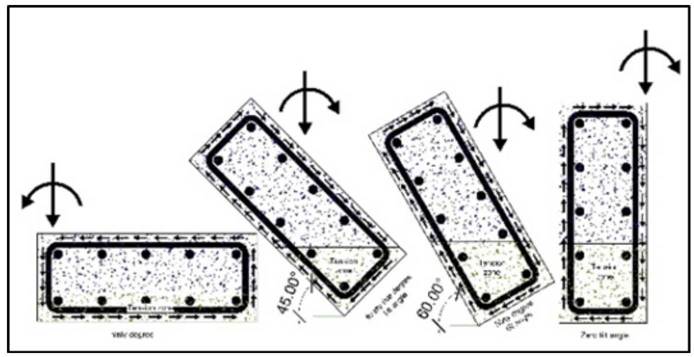

Figure Explain how tension and compression areas changed with a tilting angle change.
Figure - 6 Expected distribution of tension-compression stresses area.

XI. Compeer capacity of tilted beams 45˚ & 60˚

Table- 5 Stresses of specimens in Set 1 & 2

No.	S_{XX}	S_{YY}	S_{ZZ}	S_{XY}	S_{YZ}	S_{XZ}
B4	**+2.156**	**+1.917**	**+0.914**	**+1.833**	**+0.792**	**+0.231**
B1	**+2.429**	**+3.129**	**+1.286**	**+1.261**	**+0.264**	**+0.397**
B5	**+1.84**	**+1.978**	**+1.008**	**+1.795**	**+0.7909**	**+0.236**
B2	**+2.309**	**+2.499**	**+1.237**	**+1.067**	**+0.3959**	**+0.355**
B6	**+1.461**	**+1.976**	**+1.273**	**+1.804**	**+0.7913**	**+0.235**
B3	**+1.863**	**+2.486**	**+1.968**	**+1.065**	**+0.3872**	**+0.358**

From the first observation of shear stresses and with the equal load value on the arm of equal length that causes equal amounts of moments on the two models, it becomes clear that the effect of stress is variable according to the shear area in both directions. The more equal the shear area is, the less stress is formed on the section of the inclined beam. While when the angle of inclination changes, the shear area changes to be more prominent in one direction and less in the other direction, higher shear stresses are formed than the previous ones because the load is constant and the shear area changes as in the relationship $\boldsymbol{S = F/A}$.

- S is stress and F force and A area force subjected to it.

As the shear area changes in both directions, this leads to noticing the change in the rest of the section properties, the most

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important of which is the moment of inertia in both directions of the tilted beam. In the case of a beam tilted at an angle of 45 degrees, the moment of inertia in both directions is equal. As the angle changes, there is a higher moment of inertia than in the other direction. The beam has a higher capacity if used correctly so that each moment is directed appropriately. These observations facilitate and benefit the structural designer in taking full advantage of the properties of inclined beams. In a final word, to summarize the above, if the tilting angle of the beam is equal, the biaxial shear stress tolerance will be equal in both directions, which provides higher shear tolerance, but in the direction of the bending moment, it will be weaker than in beams with an angle of inclination from the horizontal higher than 45 degrees, so the moment of inertia in the main direction will be higher, so the tolerance of the bending moment will be higher with the same concrete and reinforcement.

12. Conclusions

After exhaustive research, some conclusions were reached that could become a fixed law through intensive theoretical experiments using finite element analysis methods. These results and findings revolve around the ability of the tilted beam to withstand bending moments, shear forces, and torsional moments simultaneously and in more than one direction of the biaxial shear and bending, which gives the ability to operate such a structural element in more than one direction at the same time.

Such structural elements, which seem somewhat strange in shape, maybe a sign of the beginning of new concepts in the science of structural engineering, which require more studies, research, and scrutiny of all aspects of the subject to arrive at the pure facts without any embellishments that may cause ambiguity in the subject, to make it easier for structural design engineers in the future to deal with irregular structural elements in which curves and huge spaces are used.

A.Tilt angle effect:

a) The change in the tilting angle is the main reason for changing the physical properties of the shear area in both directions, as well as the moment of inertia in both directions and changing the shear center location, etc.

b) This change in the physical properties strengthens or weakens the structural element according to the tilting angle and the direction of the load applied to the tilted beam, thereby benefiting from the section's ability to bear.

c) This effect was evident in the element in which the lever system was used, in which the tilting angle was changed between 45˚ and 60˚ degrees. The change in the angle led to a change in the shear area, which made the models tilted at 60˚ degrees have a higher capacity to bear the bending moment in the main direction and the biaxial shear if it is not equal.

d) This shape is more suitable for use compared to the models tilted at an angle of 45˚ degrees, which gave indicators that were almost equal in bearing the biaxial shear and weaker in bearing the bending moment in the main direction due to the decrease in the inertia moment according to the change in the tilting angle of the beam, which will be of more significant benefit in cases where there are biaxial shear forces of similar magnitude in both directions.

B. Torsional moment capacity:

a) The ability of the tilted beam to withstand pure torsional moment is not affected by whether it is tilted or not, and the same is true for beams without a tilting angle.

b) The reason is that the torsional moment is interpreted as a shear flow in the outer layer of the section, which will not be affected by the tilt of the element.

c) Suppose the torsional moment is applied with shear forces. In that case, there will be a change in the shear forces with the shear flow due to the torsional moment, which brings us back to the fact that the tilting angle affects the biaxial shear area.

d) Suppose the bending moment is applied to them as the actual case. In that case, compressive stresses will occur in the upper part, which contributes to increasing the strength of the section against the resulting shear stresses and weakness in the section in the lower part, the tension area, which will cause an increase in the stresses on the concrete section.

e) Here, it is clear that reinforcing steel or strengthening the tension area with carbon fiber sheets may be a good step in not increasing the areas of the concrete sections and making the best use of the section properties.

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APPENDIX A

Sx = Stress components at integration points in X directions.
SY = Stress components at integration points in Y directions.
SZ = Stress components at integration points in Z directions.
UX = Spatial displacement at nodes in X directions.
UY = Spatial displacement at nodes in Y directions.
UR = Rotational displacement at nodes.

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SXX – for steel reinforcement, it is defined as stresses in one direction of each bar.
T = torsion moment
tu = ultimate torsional moment
At = torsion reinforcement area
Al = torsion longitudinal reinforcement area
Av = shear reinforcement area
S = spacing of reinforcement
A0h = the circumference area has stirrups
Ph = perimeter of stirrups
Fy = reinforcement ultimate stress
Mn = ultimate flexural moment
As = flexural reinforcement area
Vc = shear capacity of a concrete section
fc' = concrete ultimate stress
bw = section width
d = depth of flexural reinforcement layer
c = depth parabola shape of compression area at stress diagram of a concrete section
a = depth equivalent shape of compression area at stress diagram of a concrete section

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APPENDIX B
For Torsion
T=(2A_t×Λ_0 h×fy×cotθ)/(s) 〖×10〗^(-6)
T_1=(2×113.1×(160×460)×371)/100×〖10〗^(-6)=61.76 kN.
T_2=(2×113.1×(160×460)×371)/200×〖10〗^(-6)=30.8 kN.m
T_3=(2×113.1×(160×460)×371)/300×〖10〗^(-6)=20.6 kN.m
A_t/s=(τ_u×〖10〗^6)/(2f_y A_° h) S=(2×113.1×160×460×371)/(50×〖10〗^6)=123.53 …... spacing needed
S=Ph/8=1400/8=175mm , s=300 ……………………….. Smin for torsion
s=(2 π/4 ∅_bar^2)/(Av/s+(2A_t)/s)=(2×π/4×〖12〗^2)/((113.1)/300+(2×113.1)/(123.53))=103.445 …... S needed for shear-torsion
A_L=A_t/s P_0 h×f_yt/f_y ×cotθ
A_L= (113.1)/100×(2×160+2×460)×371/371×1
A_L=1402〖mm〗^2
For Ø 20 mm 4.4 bar need 8 bars provided with flexural
For Ø 16 mm 6.9 bar need 8 bars provided with flexural
For Ø 12 mm 12.3 bar need 8 bars provided with flexural
For flexural Load, the total load was 60 KN.
M_n=PL/8=(60×4)/8=30 kN.m ,
A_s=(M_n×〖10〗^6)/fy(d-a/2) =(30×〖10〗^6)/371x(458) =201.32 〖mm〗^2
c=0.375×d=0.375×458=171.75mm,
a=〖0.85〗^c=0.85×171.75=145.9≈145mm
n_bar=As/A_bar =(210.32)/((〖12〗^2×π)/4)=1.8594~ 2 bar ∅ 12 mm
For Shear
v_(c_1)=0.17×√(2&f_c^')b_ω d
v_(c_1)=0.17 ×√3 5×200×458=92.125 KN
v_(c_2)=0.17×√(2&f_c^')b_ω d
v_(c_2)=0.17×√3 5×500×158=79.45 KN
v_u=30 KN There is no need for shear reinforcement.
A_(v,min)=0.062 √(f_c^')×bw/f_yt 〖=A〗_(v,min)=0.062 √35×200/371×〖10〗^3=197.73 〖mm〗^2
Reinforcement bars size used in the program
Ø 20 mm Used as main bars
Ø 16 mm Used as main bars

Ø 12 mm Used as main bars
Used for stirrups

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APPENDIX C

Table- 1 Steel rebar properties

Mass density	Young modulus	Poisson's ratio	Yield stress	Plastic strain
8E-09	200000	0.3	371 MPa	0
			509 MPa	0.28

Table- 2 Concrete Properties (*Cdpmkt-Pdf-Free @ Pdfcoffee.Com*, n.d.)

Mass density	Young modulus	Poisson's ratio
2.3E-09	18888.99236	0.18

Dilation angle	eccentricity	Fb0/fc0	K	Viscosity parameter
35	0.1	1.16	0.667	0

Yield stress compression	Inelastic strain	Damage parameter	Inelastic strain	Yield stress tension	cracking strain	Damage parameter	Inelastic strain
17.5	0	0	0	4.2	0	0	0
20.420381	9E-06	0	9E-06	2.330096	0.000321	0.445215	0.000321
23.201699	2.6E-05	0	2.6E-05	1.650807	0.00058	0.606951	0.00058
25.79471	5.3E-05	0	5.3E-05	1.292702	0.000821	0.692214	0.000821
28.147291	9.2E-05	0	9.2E-05	1.069362	0.001055	0.74539	0.001055
30.208536	0.000147	0	0.000147	0.915842	0.001286	0.781942	0.001286
31.9334	0.000219	0	0.000219	0.803371	0.001514	0.808721	0.001514
33.287268	0.000312	0	0.000312	0.717171	0.001741	0.829245	0.001741
34.249664	0.000425	0	0.000425	0.648848	0.001967	0.845512	0.001967
34.816428	0.000559	0	0.000559	0.593266	0.002192	0.858746	0.002192
35	0.000713	0	0.000713				
34.827785	0.000886	0.00492	0.000886				
34.339025	0.001076	0.018885	0.001076				
33.580805	0.00128	0.040548	0.00128				
32.60388	0.001495	0.068461	0.001495				
31.458944	0.00172	0.101173	0.00172				
30.193679	0.001951	0.137323	0.001951				
28.85076	0.002186	0.175693	0.002186				
27.466761	0.002423	0.215235	0.002423				
26.071812	0.002661	0.255091	0.002661				
24.689812	0.002898	0.294577	0.002898				
23.338987	0.003133	0.333172	0.003133				
22.032631	0.003367	0.370496	0.003367				
20.779913	0.003597	0.406288	0.003597				
19.586658	0.003824	0.440381	0.003824				
18.456056	0.004048	0.472684	0.004048				
17.389276	0.004268	0.503164	0.004268				
16.385982	0.004485	0.531829	0.004485				
15.44475	0.004699	0.558721	0.004699				
14.563403	0.00491	0.583903	0.00491				
13.739267	0.005117	0.60745	0.005117				
12.969369	0.005322	0.629447	0.005322				
12.250587	0.005524	0.649983	0.005524				
11.579755	0.005723	0.66915	0.005723				

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10.953744	0.00592	0.687036	0.00592				
10.5	0.006072	0.7	0.006072				

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