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INVESTIGATING THE BEHAVIOR OF REINFORCED NORMAL CONCRETE V-SHAPED COLUMNS WITH DIFFERENT INCLINATION ANGLES

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Abstract

The purpose of this study is to investigate the behavior of V-shaped reinforced concrete columns under three different angles of inclination (30°, 40°, and 50°), and to clarify the effect of is angle on the load carrying capacity and failure mode of columns. Six experimental specimens were prepared, three of which were equipped with the upper tie beam, while the other three were without the tie beam. The results showed that the bearing capacity of the columns decreased with increasing angle of inclination, as it decreased by 7.5% and 9.3% at angles of 40° and 50°, respectively, compared to angle 30° in the presence of the tie beam. While, the capacity decreased by 6.7% and 8.4% at 40° and 50°, respectively, in the absence of the tie beam compared to angle 30°. The effect of the beams had a clear impact on increasing the ultimate load values and the failure pattern for angles exceeding 40°, as it was noted that the load values for those columns with inclination angles (30°-40°) had the opposite effect, as the failure was concentrated in the joint and tie beam area. These results reflect the importance effect of the angle of inclination and the presence of the tie beam in improving the structural performance of concrete columns, which contributes to the design of more stable and efficient structures under different loads.

Keywords:

V-Shaped column;
Tie beam;
Inclination angle;
Normal concrete column;
Cracks pattern.

1 Introduction

In contemporary civil engineering, reinforced concrete columns are essential structural components that support and distribute loads inside infrastructure and structures. To ensure the stability and integrity of structures under a range of loading circumstances, columns are designed to support a variety of axial loads and bending moments. Any member whose primary purpose is to support the axial compressive load and whose length to minimum lateral dimensions is equal to or more than three is classified as a column under ACI Code 318. Moreover, the column is regarded as the most significant component of the structure since it supports and bears the weight of the foundations, and its collapse could have a significant adverse effect [1,2].

A V-shaped column is one of the types of concrete columns. The V's two legs, typically made of concrete, are reinforced with steel. V-shaped columns are widely used in buildings and bridges to support the structure's weight. In some circumstances, the V-shaped column may also be used to provide lateral support for the structure. The V-shaped column is typically installed in the elevation rather than the section. This suggests the V-shaped column's two legs should be oriented toward the ground. Typically, the base of the building is where the V-shaped column is attached [3 - 5]. V-shaped columns are one of the new structural elements that have appeared as a result of the sharp increase in building and bridge design in recent years. The two main advantages of the V-shaped column are its short middle span and span, which are supported by an assembly of two columns on a single base. Since the V-shaped column design frequently requires more steel reinforcement than the equivalent straight column, it is imperative to raise the tensile strength of concrete [6 - 8]. The design and construction of the V-shaped columns are complicated because the eccentrically loaded reinforced concrete component utilized in their slant legs is prone to the distortional warping of box girders and the shear lag effect. However, the public's increasing need for art and bridge spans has made V-shaped columns more appealing. As a result, there was complex load distribution at both extremities of the slant leg of the V-shaped column. Therefore, it is crucial to do local stress analysis for V-shaped columns using analytical programs to realize stress distribution [9 - 11].

Hassan and Al-Zaidi [12] studied the deformation and strength of inclined reinforced concrete columns using experimental and three-dimensional finite element models. They conducted experimental work investigating the response of two inclined columns with 1000 mm and 1250 mm lengths. The inclination angles of 5°, 7.5°, and 10° were considered for each length. The results showed that the strength loss for inclination angles ranging from 5° to 10° ranged from 0.8% to 3.4%. It was also found that the longer column responds better to the inclination angles. Compared to the shorter columns, the column with a length of 1250 mm shows a greater decrease in axial stiffness.

Hassan et al. [13] conducted a study to investigate the behavior of V-shaped concrete columns by analyzing reinforced concrete columns with different angles of inclination between columns. They constructed two straight columns of 100 mm × 100 mm × 700 mm and three inclined V-shaped columns with three angles (30°, 60° and 90°) between columns. For all V-shaped columns, they used two sizes of deformed steel reinforcing bars, four steel bars with 8 mm diameter for longitudinal reinforcement, and 5 mm diameter steel bars at 60 mm for the closed stirrups, and they used apart for the inclined areas and the base of the V-shaped column. The base of the V-shaped column was 200 mm wide, 150 mm high, and 100 mm deep. The cross-section of the column was square with dimensions of 100*100 mm, and the inclined columns had an internal length of 700 mm. The results showed that the maximum load-bearing capacity of V-shaped columns with inclination angles of 30°, 60°, and 90° decreased by 24%, 23%, and 20%, respectively, with increasing inclination angles for straight columns.

There are no specifications and guidelines for designing V-shaped reinforced concrete columns; therefore, understanding the behavior of V-shaped reinforced concrete columns with different angles between columns is essential due to its recent increase in use, especially in high-rise buildings. This study aims to investigate the behavior of V-shaped reinforced concrete columns with three angles between columns (30°, 40°, and 50°) to use the results in the design and analysis of V-shaped columns. This study used six V-shaped concrete specimens with different inclination angles, three with a tie beam and three without a tie beam. The columns were reinforced based on the minimum reinforcement ratio according to the specifications of ACI Code 318M-19 [1]. The columns in all specimens are constant in a cross-section area of 150*150 mm, and the tie beam cross-section area is constant at 250*150 mm for all specimens with a tie beam. The horizontal displacement at the midpoint of the tested V-column at each loading step is documented, along with the initial cracking and failure loads, as well as the stress-strain of the longitudinal reinforcement at three different locations and the stress-strain of the concrete at each loading step until failure is documented.

2 Materials and mix proportions

2.1 Materials and concrete ingredients

Ordinary Portland Cement (OPC) of 42.5 MPa grade,3.1 specific gravity,310 (m^2/kg) Specific surface area (Blaine fineness), initial setting time 130 min, final setting time 257 min, compressive strength at 3day 22.5 MPa and compressive strength at 7day 35.07 MPa, the results of its examination conformed with the Iraqi standard specification (IQS No.5/1984) [14]. It was considered for manufacturing V-shaped columns with a compressive strength of 30 MPa. The maximum aggregate size of 12.5 mm for gravel was suitable for concreting the samples. River sand and gravel were compared with the Iraqi Standard Specification. No. (45) of 1984 [15] used as fine and coarse raw materials in concrete mixes. Table 1 shows the concrete mixing ratios used throughout the research.

Table 1: Concrete mix properties per one cubic meter.

Materials	Cement	Water	Fine Aggregate	Coarse aggregate
Weights [Kg/m^3]	350	160	825	960

2.2 Properties of steel reinforcement

Deformed steel bars were used in the reinforcement of the experimental specimens with a diameter of 10 mm for the main longitudinal reinforcement, 8 mm for the shear stirrups, and 8 mm for the base of V-shaped columns. Table 2 shows the mechanical parameters of the deformed steel bars, which are in accordance with ASTM A615/A615M -19b standards [16].

Table 2: Mechanical properties of steel reinforcement.

Rebar diameter [mm]	8	10
Yield Tensile Stress [N/mm^2]	440	447
Ultimate Tensile Strength [N/mm^2]	620	635
Elongation at Breaking [%]	12	14

3 Experimental program

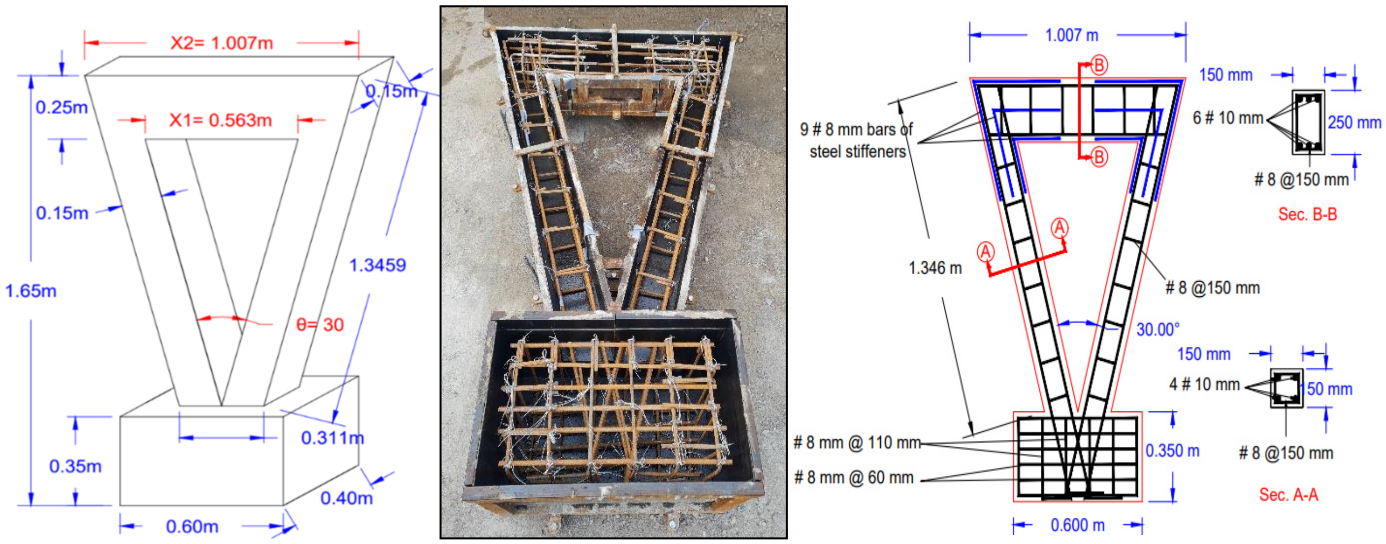
3.1 Geometry and reinforcing details of columns

Six normal strength reinforced concrete (NSC) V-shaped columns with three angles of inclination (30º, 40 º, and 50º) were cast and tested to study the effect of inclination angle on the structural behaviour, three V-shaped specimens with a tie beam, and the other three specimens without a tie beam. The inclination angle between the columns (*θ*), the clear distance from the end columns (*X1*), and the distance from the external edge of the end columns (*X2*) are listed in Table 3. The dimensions of the V-shaped column base are 600 mm wide, 350 mm high, and 400 mm deep, with inclined columns with variable internal lengths with the angle change and a constant height of 1650 mm and a square cross-section of 150 mm. Two sizes of deformed steel reinforcement bars were used for all V-shaped columns. Four bars with Ø10 mm diameter were used as longitudinal reinforcement, and bars with Ø8 mm diameter and 150 mm spacing were used as closed stirrups for the inclined parts of the V-shaped column. The main reinforcement of inclined columns was continued and bent horizontally at both ends by 100 mm inside the column. Horizontal and vertical stirrups with Ø8 with 60 mm and 110 mm spacing were placed at the base of the V-shaped column. The stirrups of the inclined V-shaped part were placed perpendicular to the longitudinal reinforcement, as shown in Fig. 1 and 2.

Table 3: Specimen details.

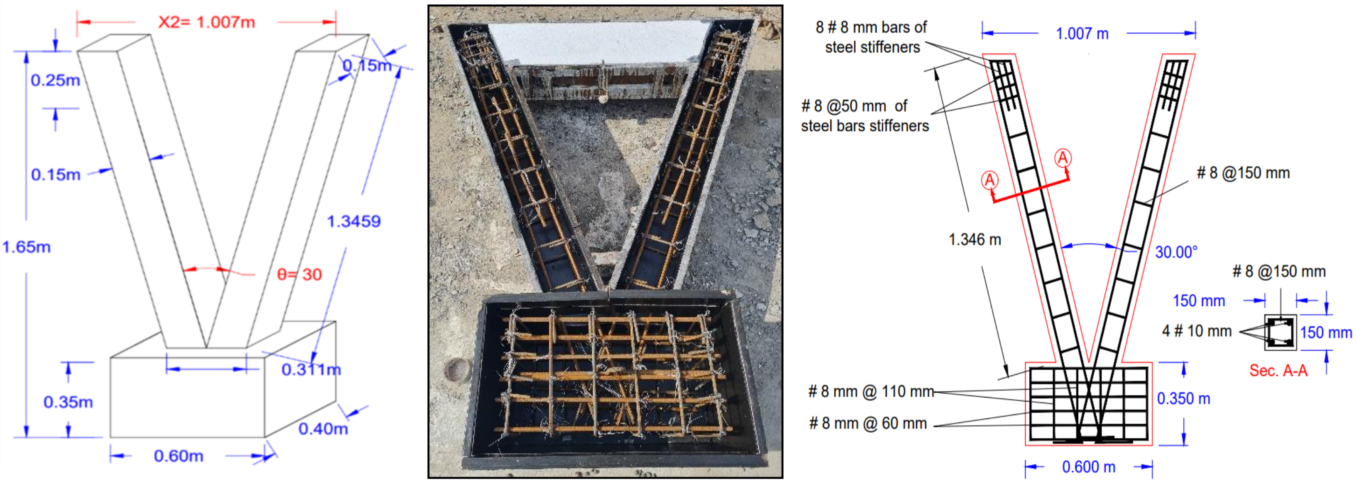
No.	Specimen ID	*θ* (degree)	*X1* [m]	*X2* [m]
1	NC-30-T	30	0.563	1.007
2	NC-40-T	40	0.764	1.226
3	NC-50-T	50	0.979	1.543
4	NC-30	30	0.563	1.007
5	NC-40	40	0.764	1.226
6	NC-50	50	0.979	1.543

* NC: Normal strength concrete. T: Tie beam.



a) b) c)

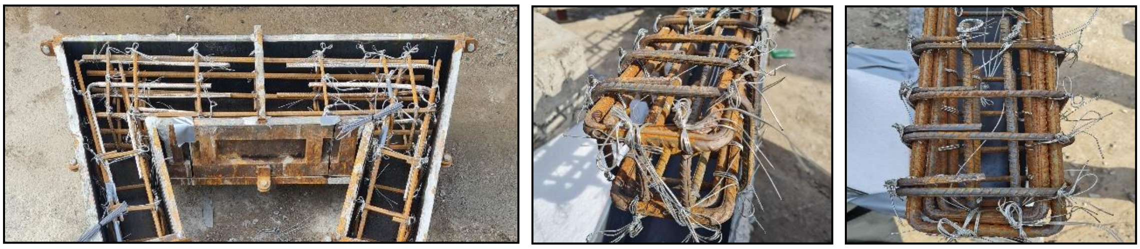
Fig. 1: a) Configurations of V-shaped column with tie beam, b) Casting mold and c) Reinforcement details.



a) b) c)

Fig. 2: a) Configurations of V-shaped column without tie beam, b) Casting mold and c) Reinforcement details.

It is worth noting that additional steel bars were placed in the joint at both ends in the upper part, with nine L-shaped reinforcing bars with a diameter of 8 mm for each end of the column specimen with tie beam and four U-shaped reinforcing bars with a diameter of 8 mm for each end of the column specimen without tie beam, to strengthen these areas [17], as shown in Fig. 3.



a) b) c)

Fig. 3: Additional steel bars in tip of column a) with tie beam, b) and c) without tie beam.

Three strain gauges were installed at the top, at the middle and at the bottom of the inclined column, as shown in Fig. 4, to determine the strain behaviour of the longitudinal steel bar in the column. All strain gauges were connected to a sensitive electronic device (data logger) that is linked to a computer to read the stress-strain of the steel in each step of the loading until reaching the ultimate load and the of column's failure.

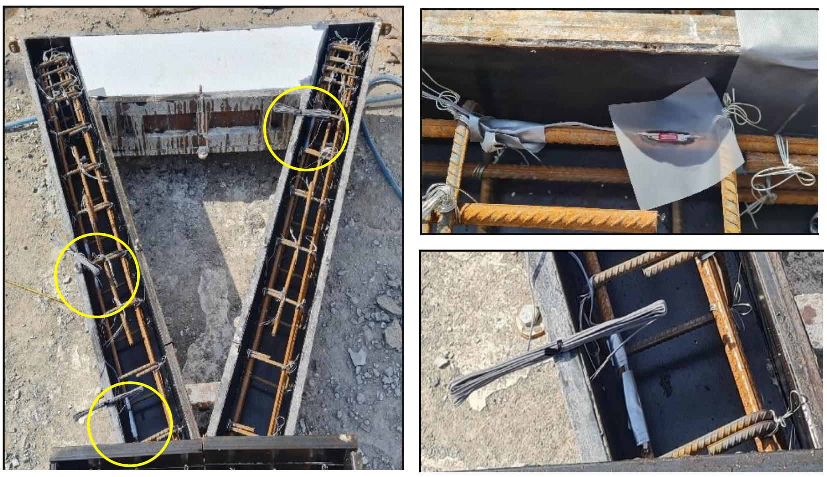


Fig. 4: Strain gauges for steel reinforcement bar.

The joint areas were also supported with steel plates with dimensions of 450 mm x 250 mm and a thickness of 15 mm due to the increased stress concentration in this area, as shown in Fig. 5

Fig. 5: Strengthening the joint by steel plate.

3.2 Instrumentation and test setup

One LVDT (Linear Variable Displacement Transducers) was used to detect horizontal displacement; it was attached laterally at the mid-height of the V column shape by magnetic base. The LVDT used is a sensitive meter consisting of a primary coil and two secondary coils placed on either side of it, in addition to a magnetic core moving inside the primary coil, used to measure linear variable displacement with an accuracy of 0.01 mm and linearity up to 0.075%, and is insensitive to shocks and vibrations. It is calibrated according to the procedure of the data logger user manual for the part connected to the LVDT. The compression set depicted in Fig. 6 was used to measure the load-carrying capacity of the specimen. The load cell used was constructed from stainless steel with a capacity of 1000 kN.

The data logger utilized in this investigation was locally constructed, had five channels, and was compatible with strain gauges, load cells, and LVDTs. It takes readings at a rate of one per second and stores data on an external hard disk. The information is automatically saved in memory before being transferred to the computer.

Fig. 6: Testing set up with all used instrument.

4 The results and discussion

4.1 Ultimate load and failure modes

All columns were tested until failure, the load and displacement data of testing specimen, as shown in Table 4. Failure patterns depend on the column shape (with or without tie beam) and the inclination angle of (30, 40, 50), as shown in Table 5 and Fig. 7 shows the interaction diagram for the tested column. When following the load on the normal concrete models (NC-30-T, NC-40-T, NC-50-T) for the samples with tie beam, we find that cracks in these models start in the middle of the tie beam and then appear at the joint. As the rate of axial loading increases, cracks progress, causing concrete cover spalling in the joint and deformation of the steel reinforcement. This is attributed to the natural compressive strength value of normal concrete and the absorption of part of the momentum by the tie beam, which greatly limited the transfer of the effective stresses to the parts of the inclined column [18]. As shown in Fig. 8.

As for the models (NC-30, NC-40, NC-50) that do not contain a tie beam, we find that cracks start at the two points of load application and then in the lower part of the column near the support. These cracks increase with the increase in the rate of axial loading, causing de-bonding in the concrete cover at the upper part of the two inclined columns until the ultimate load is reached and the model fails due to the natural compressive strength value of normal concrete. It was also observed that hairline cracks appeared in the lower part of the NC-40 column near the support when approaching the ultimate load for failure, and a slight spalling occurred in the lower outer part of the column, as is apparent in Fig. 9. As for the NC-50 model, it was observed that cracks began to appear in the lower part of the column and increased with increasing the load rate until reaching to the ultimate load and failure the model near the support, noting the crushing of the model in the lower outer part of the column due to compression as a result of a large increase in the angle of inclination compared to the two previous models NC-30, NC-40 [19,20].

Table 4: Load and displacement for experimental specimens.

Specimen ID	Ultimate load [kN]	Load at first crack [kN]	Percent of load at first crack [%]	Displacement at ultimate load [mm]	Displacement at first crack load [mm]	Location of first crack
NC-30-T	805.8	423	52.5	-0.63	-0.20	At mid span of tie beam
NC-40-T	745.2	381	51.1	-0.73	-0.049	At mid span of tie beam
NC-50-T	730.9	205	28.0	-4.98	+0.12	At mid span of tie beam
NC-30	837.8	387	46.2	-0.93	+0.61	At joint of load applying
NC-40	781.3	110	14.1	-1.77	+0.33	At joint of load applying
NC-50	715.8	59	8.24	-9.31	-0.21	At near support

* Percent of load at first crack is with respect to ultimate load value.

It is worth noting that the negative sign in the table above and the following curves mean that the columns are far apart from each other with respect to the point of intersection. Conversely, the positive sign indicates that the columns are close to each other with respect to the point of intersection.

Table 5: Axial load and bending moment at failure of column (for one leg).

Specimen ID	Axial load [kN]	Bending moment [kN.m]
NC-30-T	389.17	113.35
NC-40-T	350.13	142.40
NC-50-T	331.21	178.93
NC-30	404.62	145.92
NC-40	367.09	184.84
NC-50	324.37	216.96

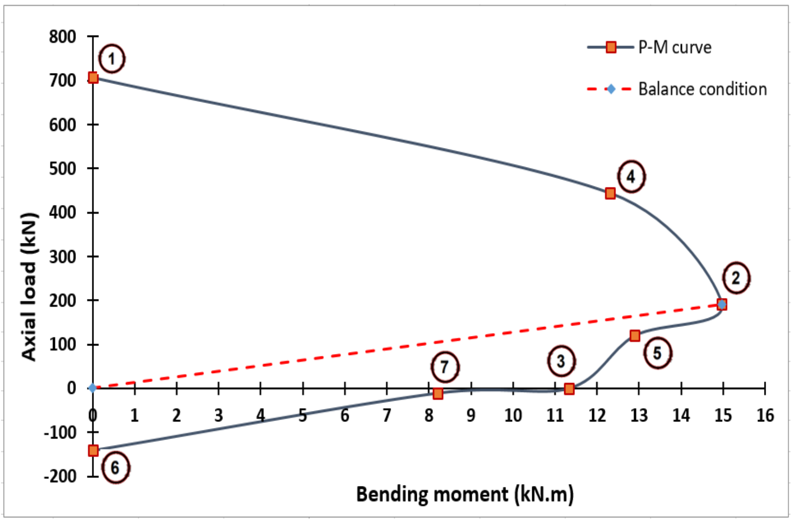


Fig. 7: Interaction diagram for the tested column

a) (θ=30°) b) (θ=40°) c) (θ=50°)

Fig. 8: Damage development for V-shaped normal concrete columns with tie beam.

a) (θ=30°) b) (θ=40°) c) (θ=50°)

Fig. 9: Damage development for V-shaped normal concrete columns without tie beam.

4.2 The loading at first cracks

4.2.1 With tie beam

When following the first cracks of the models containing tie beam, we notice the appearance of the first cracks for NC-30-T column at a load of 423 kN, which is equivalent to 52.5% from the ultimate load and a displacement of -0.2 mm, and the appearance of the first cracks for NC-40-T column at a load of 381 kN, which is equivalent to 51.1% from the ultimate load and a displacement of -0.049 mm, and the appearance of the first cracks for NC-50-T column at a load of 205 kN, which is equivalent to 28% from the ultimate load and a displacement of 0.12 mm. See the Fig. 10.

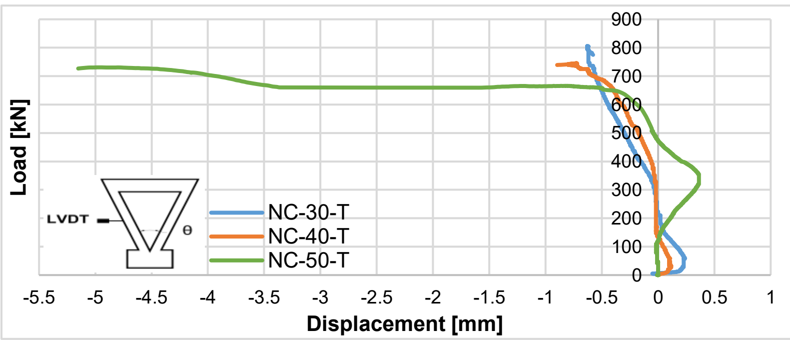


Fig. 10: Load-deflection curve for V-shaped columns behavior with tie beam.

4.2.2 Without tie beam

When following the first cracks of the samples without the tie beam, we notice the appearance of the first cracks for NC-30 column at a load of 387 kN, equivalent to 46.2% from the ultimate load and a displacement of -0.61 mm, and the appearance of the first cracks for NC-40 column at a load of 110 kN, equivalent to 14.1% from the ultimate load and a displacement of 0.33 mm, and the appearance of the first cracks of the NC-50 column at a load of 59 kN, equivalent to 8.24% from the ultimate load and a displacement of -0.46 mm. See the Table 4 and Fig. 11.

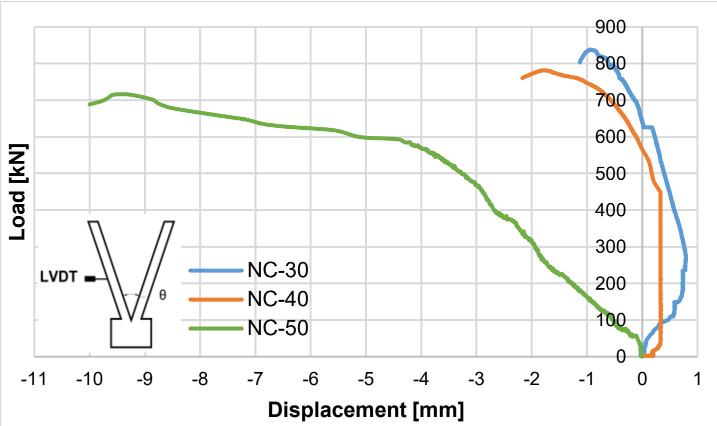
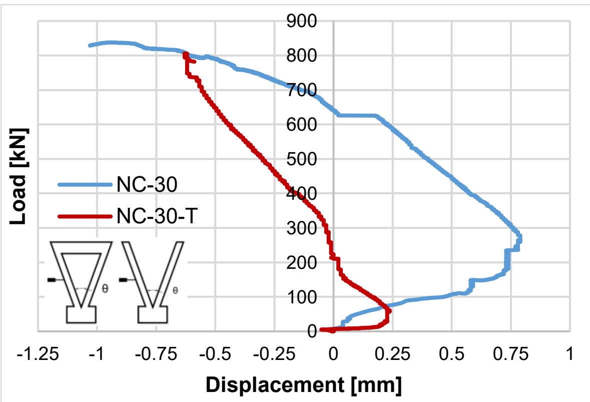


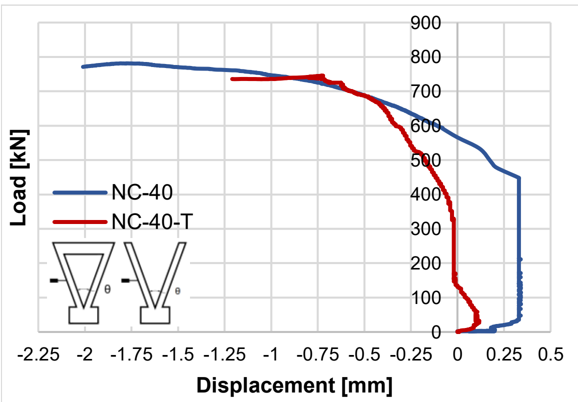
Fig. 11: Load-deflection curve for V-shaped columns behavior without tie beam.

4.3 Load-deflection curves

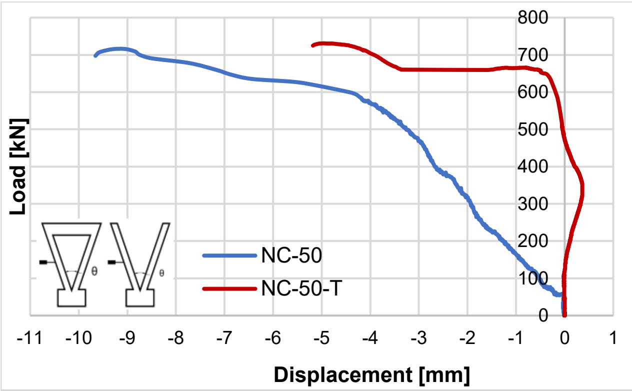
When comparing the behavior of the models with tie beams with models without tie beams, we find that the bearing capacity of the NC-30-T model is 4% less than the bearing capacity of the NC-30 model. The bearing capacity of the NC-40-T model is 4.8% less than the bearing capacity of the NC-40 model due to the weakness of the joint area, but in the case without tie beam, the load behavior was almost vertical, closer to being compression and the failure occurred when the outer cover of the column cracked and shattered from the top. As for the NC-50-T model, its capacity was 2.1% higher than the bearing capacity of the NC-50 model due to the increase in the angle of inclination compared to the previous samples, and thus the increase in the moments on the lower part of the column as a result of the load-deflection and the failure of the sample in its lower part. When comparing the first cracks, we notice the appearance of the first cracks for the NC-30-T model at 52.5% and for the NC-30 model at 46.2% of the ultimate load, and the appearance of the first cracks for the NC-40-T model at 51.1% and for the NC-40 model at 14.1% of the ultimate load, and the appearance of the first cracks for the NC-50-T model at 28% and for the NC-50 model at 8.24% of the ultimate load, i.e., the appearance of the first cracks was delayed in the case of tie beam presence due to the absorption of a large part of the momentum by the tie beam as shown in Fig. 12. We also notice that the lateral horizontal displacement was less for the models with the tie beam compared to the models without the tie beam. Also, this displacement decreases with decreasing the angle of inclination, this is consistent with what researchers Al-Rawe and Hamed mentioned [21,22].



a) (θ=30°)



b) (θ=40°)



c) (θ=50°)

Fig. 12: Load-deflection curves for V-shaped columns behavior (with tie beam & without tie beam)

4.4 Strain behaviour for steel reinforcement

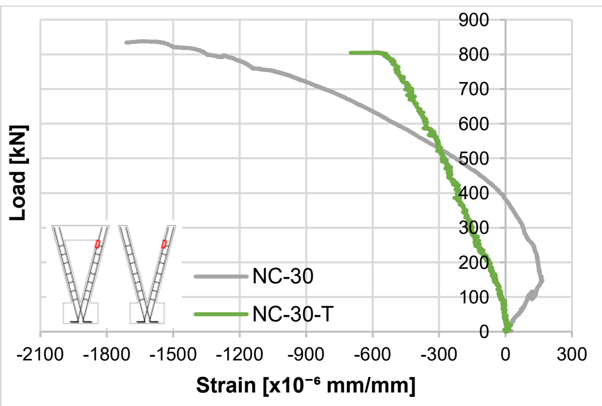
For each specimen, three steel strain gauges were positioned in three distinct locations to investigate the impact of the applied load on the behaviour of the longitudinal reinforcement of the inclined portion of the V-shaped column. The details of strains are explained according to inclination angles of columns as bellow:

4.4.1 Inclination Angle of Columns (*θ*=30)

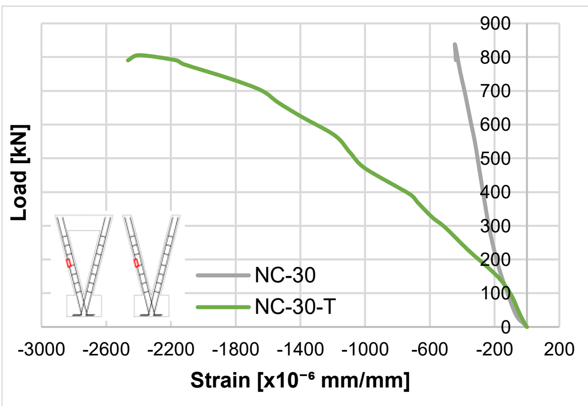
The strain in the longitudinal reinforcement bar at the top of the column was measured for all specimens where part of the stresses in specimen NC-30 was in the tension region up to 17.69% of the total load with a strain of 1.67 $x10^{-4}$ and the most significant part of the stress was in the compression region due to the apparent failure in the load application region and the destruction of the concrete cover until failure at a load of 837.8 kN with a strain of -1.622 $x10^{-3}$. As for specimen NC-30-T, all the stresses were compressive until failure occurred in the joint region due to shear and peeling at a load of 805.8 kN and a strain of $-5.76x10^{-4}$, as shown in Fig. 13.a.

When the strain gauge was placed in the middle part of the longitudinal bar, the disturbances in the strain values for all models were negative (compression) as shown in Fig. 13.b, where the strain for model NC-30 was equal to $-4.45x10^{-4}$ at the failure load and for model NC-30-T was equal to $-2.396x10^{-3}$ at the failure load.

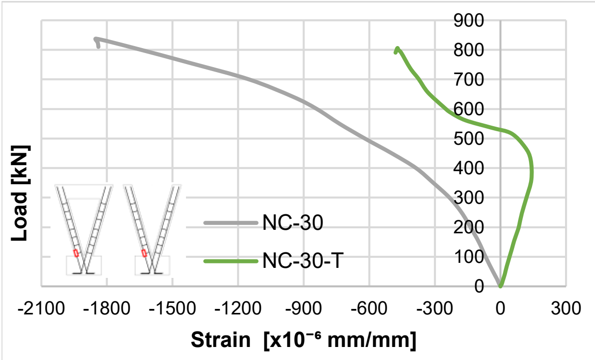
The strain was also measured at the bottom of the longitudinal bar, as shown in Fig. 13.c. The disturbances in the strain values for the NC-30 model were all negative (compression) by $-1.850x10^{-3}$ at the failure load. Some strains were tensile up to 44.83% of the ultimate load, with a tensile strain of $1.414x10^{-4}$ in the NC-30-T model. Then, the strains after this load were transformed into compression due to the connecting bridge until reaching the failure load with a compressive strain of $-4.714x10^{-4}$.



a) At the top



b) At the middle



c) At the bottom

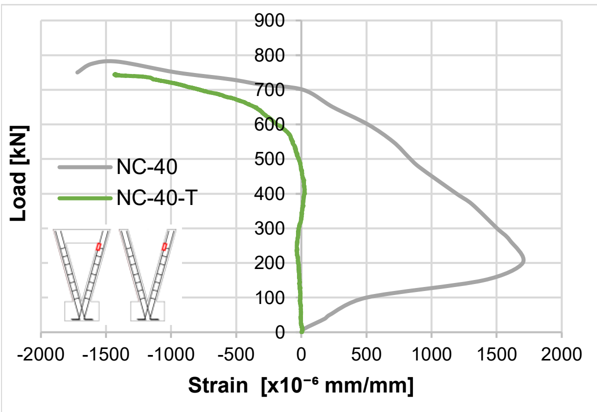
Fig. 13: Load - strain curves for longitudinal steel bar (θ=30)

4.4.2 Inclination Angle of Columns (θ=40)

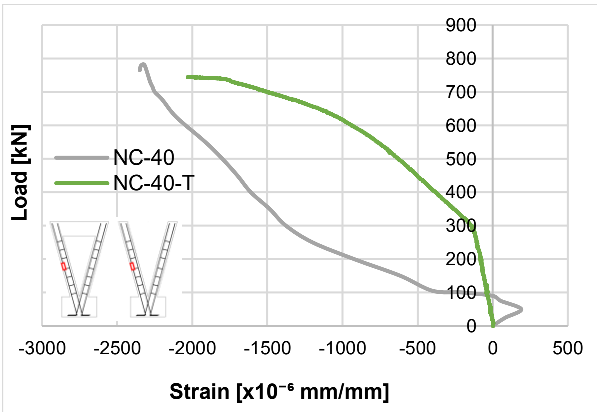
It is also apparent from the failure picture shown in Fig. 14.a that the strains in the NC-40 model were positive up to 25.6% of the ultimate load with a strain of 1.7 x 10^{-3}, and then the strains were converted to compression until reaching the ultimate load with a compressive strain of -1.413 x 10^{-3}. As for the NC-40-T model, most of the strain was in compression until reaching the failure load with a strain of 1.43 x 10^{-3}.

When placing the strain gauge in the middle part of the longitudinal reinforcement, we notice that the strain in NC-40 was initially tensile loading up to 6.4% with a tensile strain of 1.91 x 10^{-4}, and then it turns into compressive strain until the ultimate load with a strain of -2.32 x 10^{-3}, and all the strains were compressive in the NC-40-T model until the failure load with a strain of -2.016 x 10^{-3}, as shown in Fig. 14.b.

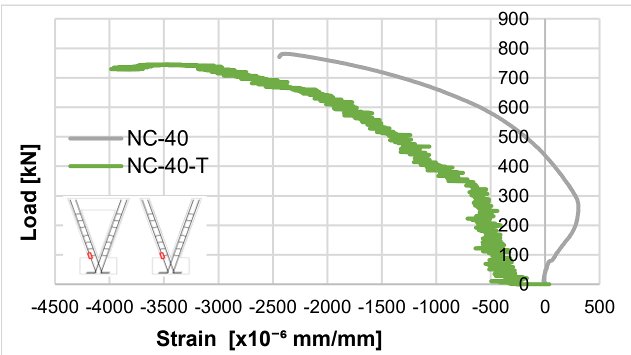
While the strain at the bottom of the reinforcement, we find that most of the strains are negative in the NC-40-T model up to the ultimate load with a strain of -3.513x10^{-3}, while the NC-40 model had a tensile strain of 3.07x10^{-4} at 33.84% of the ultimate load, then became compression until reaching the failure load with a strain of -2.403x10^{-3}, as shown in Fig. 14.c.



a) At the top



b) At the middle



c) At the bottom

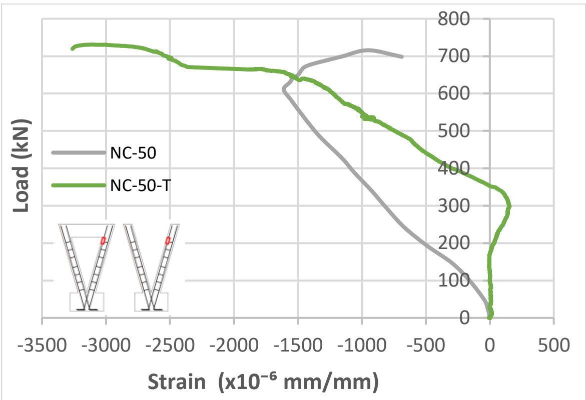
Fig. 14: Load - strain curves for longitudinal steel bar (θ=40)

4.4.3 Inclination Angle of Columns (θ=50)

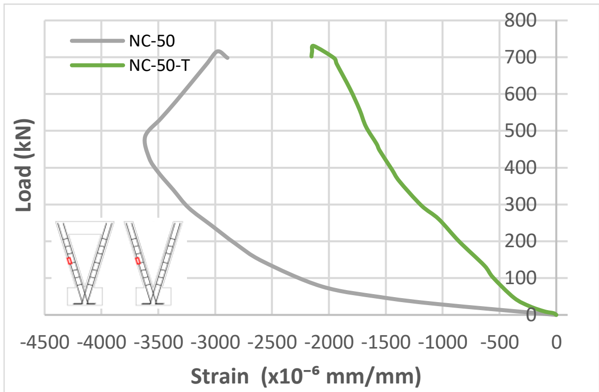
From the Fig.15. a. for measuring the strains in the upper part of the reinforcement, we noticed that the strains were tensile in the NC-50-T model up to 40.9% with a strain of 1.555×10^{-4}, and then became compression until the failure load with a strain of -3.104×10^{-3}, unlike the NC-50 model, in which the strains were compression up to 85.37% of the ultimate load with a compressive strain of -1.610×10^{-3}, and then became tensile until the failure load with a strain of -9.505×10^{-4}.

When the strain gauge was placed in the middle part of the reinforcement, as shown in Fig. 15.b., the strain in the NC-50-T model was compression until the ultimate load, with a strain of -2.295×10^{-3}. In the NC-50 model, the largest part of the strain was compression until 76.75% of the ultimate load, with a compressive strain of -3.6151×10^{-3}. Then, it became tensile until the model failed, with a strain of -2.134×10^{-3}.

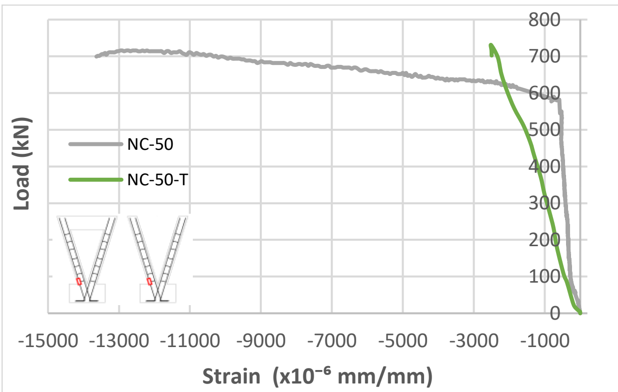
Also, when placing the strain gauge at the bottom of the longitudinal reinforcement, as shown in Fig. 15.c, we notice that the strains in the regular concrete models were all compression up to the failure load, whereas the strain in the NC-50 model at the failure load was equal to -1.273×10^{-2} and the



a) At the top



b) At the middle



c) At the bottom

Fig. 15: Load - strain curves for longitudinal steel bar (θ=50)

5 Conclusions

1) The study showed that the angle of inclination and the presence of the tie beam affect the load-bearing capacity of normal concrete columns.

2) The load-bearing capacity decreases with increasing angle of inclination, where columns with an angle of 30 degrees had the highest capacity, which reflects that the small angle provides greater stability.

3) The decrease in load-bearing capacity at angles of 40 and 50 degrees indicates the weakness of the structure as the angle of inclination increases, whether with the tie beam present or not.

4) The presence of the tie beam contributes to improving the load-bearing capacity. The load-bearing capacity increased by 2.1% for angles greater than 40 degrees, which indicates the provision of additional support at larger angles of inclination.

5) The difference in the bearing capacity at angles 30º and 40º with the presence of the tie beam (4% and 4.8% less compared to the absence of the beam).

6) The results confirm the importance of the angles of inclination and the presence of the tie beam when designing concrete columns, especially in structures that require high levels of stability under vertical loads, which enhances the structures' bearing efficiency and structural performance.

7) The appearance of the first cracks was delayed at the smaller inclination angle, as the ratio of the appearance of the first cracks to the ultimate load was higher at the smaller angle. In the models with the tie beam, this ratio reached 52.5% at the angle of 30º degrees, then decreased to 51.1% at the angle of 40º and to 28% at the angle of 50º. In the models without a tie beam, the percentage of first cracks was 46.2% at 30º, then decreased significantly to 14.1% at 40 º and 8.24% at 50 º.

8) Increasing the inclination angle decreases columns' resistance to first cracks, especially in the models without a tie beam.

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References

[1] ACI Committee, 318. "Building code requirements for structural concrete (ACI 318-08) and commentary." American Concrete Institute, 2019.

[2] DEWI, SRI HARTATI, et al. Tensile Forces Behavior on Longitudinal Reinforcement and CFRP Strips on Circular Hollow Reinforced Concrete Columns. Civil And Environmental Engineering, 2024, 20.1: 86-97.

[3] PHILLIPPI, DONALD J.; HEGEMIER, GILBERT A. Shear loading in two-column bridge bents. ACI Structural Journal, 2014, 111.6: 1497.

[4] PHILLIPPI, DONALD J.; HEGEMIER, GILBERT A. Simplified Two-Column Analytically Based Fiber Model. ACI Struct. J, 2017, 114: 349-359.

[5] TOMA, A.; STANILA, ANETA; STANILA, OANA. The V-shaped Columns. Bul. Stiint. Univ. Politeh. Timis, 2013, 58: 75-78.

[6] LIU, MING. "Static and Dynamic Behaviors of Long-Span Arch Bridge with V-Shaped Column and Detailed Analysis of V-Shaped Column." [D]. Chengdu: Southwest Jiaotong University, 2008.

[7] SONG, Yu, et al. Spatial Analysis on Continuous Rigid Frame Prestressed Box Girder Bridge with V Piers. China Municipal Engineering, 2003, 2: 28-30.

[8] SHUKUR, MOHAMMED H., et al. Mechanical properties of concrete using different types of recycled plastic as an aggregate replacement. Cogent Engineering, 2023, 10.1: 2243735.

[9] SONG, Yu, et al. Spatial Analysis on Continuous Rigid Frame Prestressed Box Girder Bridge with V Piers. China Municipal Engineering, 2003, 2: 28-30.

[10] JARQUIO, RAMON V. Analytical method of predicting the ultimate strength of CFT columns. In: Structures 2004: Building on the Past, Securing the Future. 2004. p. 1-10.

[11] KWAK, HYO-GYOUNG; KIM, JIN-KOOK. Ultimate resisting capacity of slender RC columns. Computers & Structures, 2004, 82.11-12: 901-915.

[12] HASSAN, FIRAS F.; AL ZAIDEE, SALAH R. Deformation and strength of inclined RC isolated columns using experimental and three-dimensional finite element analyses. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020. p. 012129.

[13] HASSAN, RAFEA F., et al. Experimental study on performance of steel fiber-reinforced concrete v-shaped columns. Buildings, 2021, 11.12: 648.

[14] Iraqi Specifications. Portland cement. Baghdad-Iraq. Iraqi Central Organization for Standardization and Quality Control, 2015, NO. 5.

[15] Iraqi Specifications. Aggregate of the natural sources used in concrete. Baghdad-Iraq. Iraqi Central Organization for Standardization and Quality Control, 2015, NO. 45.

[16] American Society of Testing and Materials (ASTM). Standard specification for deformed and plain carbon-steel bars for concrete reinforcement ASTM A615. A615M-09b (West Conshohocken: American Society for Testing and Materials), 2019.

[17] HASAN, AHMED T.; MASHREI, MOHAMMED A.; MAKKI, JAMAL S. Behavior of Circular Reinforced Concrete Columns Strengthened by Different Techniques Subjected to Axial Loading. *Civil And Environmental Engineering*, 2024, 20.1: 319-331.

[18] LOMIENTO, G., et al. Capacity Assessment of V-Shaped RC Bridge Bents. Journal of Bridge Engineering, 2014, 19.2: 266-280.
[19] KIM, YONG-WAN; PARK, JIN SUN. Performance Evaluation of FR welded connections to Inclined Column.
[20] SULTAN, WISAM HULAIL; HAMZA, DINA MUKHEEF. Formulation of Mathematical Model for Stress-Strain Relationship of Normal and High Strength Concrete Under Compression. Civil and Environmental Engineering, 2023, 19.1: 119-133.
[21] AL-RAWE, HESHAM SALIM; AHMED, SOFYAN Y.; ABDULLAH, SALWA MUBARAK. Retrofitting of reinforced concrete columns under eccentric loads using enhanced ferrocement. Asian Journal of Civil Engineering, 2024, 1-13.
[22] HAMED, RUSUL Z.; HASSAN, HASSAN F. Structural Behavior of GFRP-RC Slender Columns Under Various Eccentricity Loading Conditions. Civil and Environmental Engineering, 2023, 19.1: 1-16.