JACK CONNECTION: A PROPOSED MECHANICAL JACK IN THE PROCESS OF STRENGTHENING STRUCTURES

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ABSTRACT

The concept of screw jack is developed to produce a connection that can be implemented as a jack for lifting loaded structural members during the process of strengthening structures. The connection consists of two plates and number of bolts with their nuts and washers fixed at the end of steel column. Seven full scale connections were tested. The research is aimed to examine the behavior of the proposed connection experimentally and to know its ultimate loading capacity and different failure modes and to asses its efficiency. The results obtained show that the connection can work as a jack having for lifting loaded structural members. Design recommendations are proposed.

Keywords: Axial loads, Bearings, Bolts, Connections-bolted, Jack repairing jack, Supports.

INTRODUCTION

Different techniques are presented in the literature for strengthening buildings for different reasons such as to sustain their service loads , increasing their loading capacity and/or improving their earthquake resistance. Hydraulic jacks is an important tool in the process of applying these techniques. They are used to carry the loads from the structural elements required to be strengthened, until temporary or permanent supporting system is placed to carry these loads. After the strengthening operation is finished, the jack may be used again to unload the supporting system and removing it. Unloading the hydraulic jack would load the structural elements being considered. Generally, hydraulic jacks are relatively expensive, have certain loading capacities and need regular maintenance. The concept of screw jack is developed to produce a connection that can be implemented as a jack. It is named herein as " Mechanical jack ". It is designed to lift loaded structural elements for temporary purposes and to connect them to additional supporting members for permanent use during the process of strengthening already existing structures. The proposed mechanical jack is seen as a simple and cheap tool that may be considered as an alternative to hydraulic jacks in many situations. The proposed mechanical jack is described below . Seven full scale specimens were tested. The objective of this investigation is to examine the behavior of the proposed mechanical jack experimentally and to know its ultimate capacity, different failure modes and to asses its efficiency as a new tool in the process of strengthening structures. Finally, design recommendations are proposed.

CONNECTION DESCRIPTION

The basic form of the proposed mechanical jack tested for temporary use consists of two plates and four bolts with their nuts and hardened washers, Figure (1). The upper plate is called the bearing plate and used to support the structural element required to be lifted. The second plate is called the supporting plate and fillet welded to a steel column as shown in Figure (1). It contains four holes having diameter larger than that of the bolts. The holes are distributed symmetrical around the column section and as near as possible to the column web, Figure (1). Each nut is turned around its bolt until it reaches the bolt shank forming one unite with the bolt. The distance from bolt head to the supporting plate is called bolt supporting length, L_b. This distance is adjusted to have the same value for all the bolts and nuts unites.

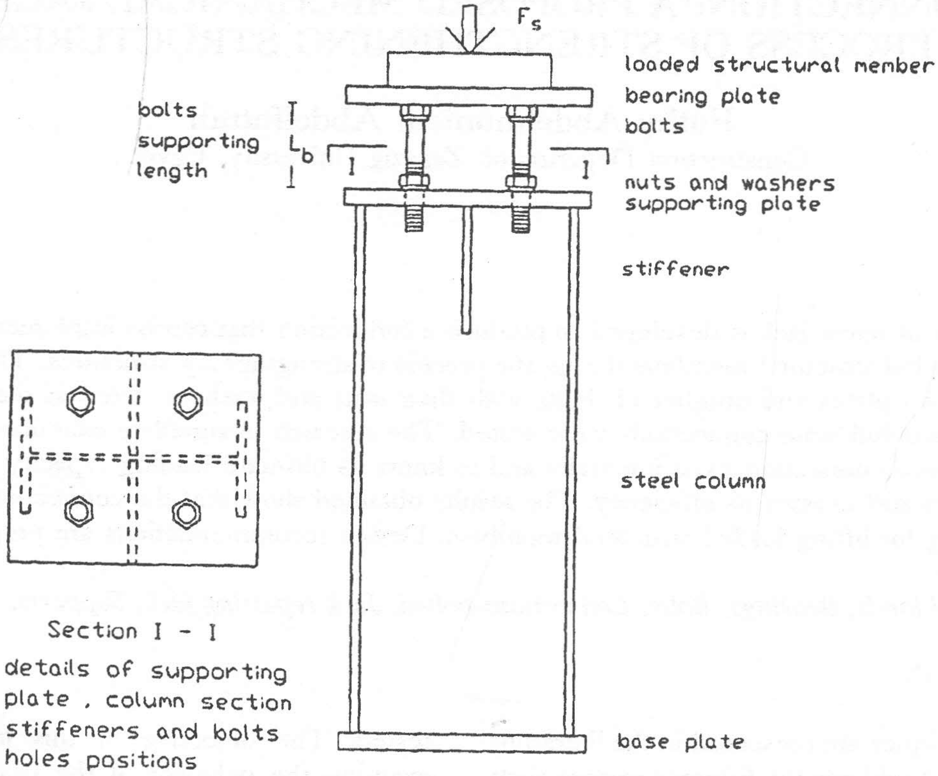


Figure 1. Jack connection details.

The four bolts are inserted into the holes in the supporting plate. For each unite, the nut is bearing on the supporting plate and the bolt threaded part is passing through the hole. Bolts heads are used to support the bearing plate. A hardened washer is used under each nut. Two stiffener plates, fillet welded to the column web and the supporting plate are used as stiffeners. The steel column is fillet welded at its other end to a plate called base plate. The proposed jack may be used for permanent purposes , such as adding a supporting column to a deflected beam. The bearing plate would be prepared exactly typical to the supporting plate in this case. The bearing plate is bolted and/or welded to the structural member required to be supported. Each bolt is substituted by a threaded bar and four nuts. Two nuts are used to tighten the bearing plate to the threaded bar. The third nut is used for turning against the supporting plate as described below . Having lifted the structural member considered, the fourth nut is tightened from below the supporting plate to avoid nuts relaxation and to connect the plate to the threaded bar.

CONNECTION MECHANISM

The length of the supporting column and the connection is adjusted so that the element required to be lifted is beard on the bearing plate. The nuts are turned 1/6 turn , one nut at each time, in a zigzag pattern against the supporting plate and in anti-clockwise direction. The following assumptions are considered :

1- The bolts themselves are not allowed to turn and the supporting plate provides a rigid support to the nuts.
2- When the nuts are turned one turn, the bolts would move upward a distance equal to one pitch of bolt threads, p.
3- The structural element is lifted the same distance.

This would be the case when the structural element load F_s is equal to zero. In practice, the load F_s would have a value and subjects the bolts, column and the plates to axial compressive force causing contractions according to their axial stiffness as follows:

$$\Delta = F_s/E\left(n\frac{A_b}{L_b} + \frac{A_c}{L_c} + n\frac{A_b}{L_p}\right) \qquad (1)$$

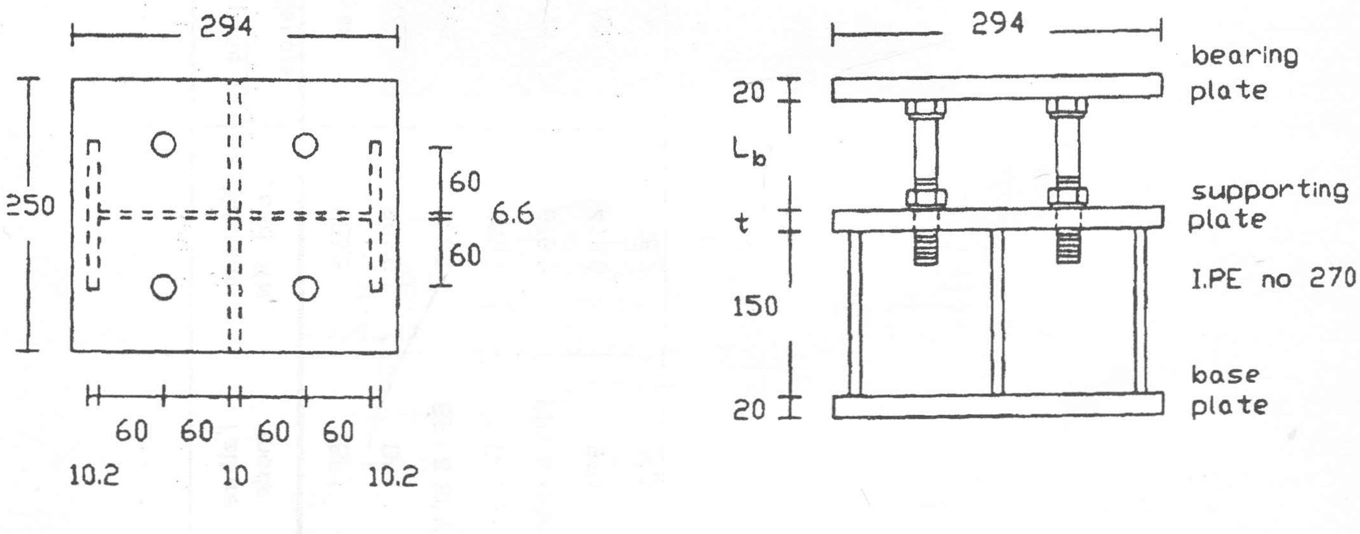
where E is the modulus of elasticity, n is the number of bolts used and L_b, L_c and L_p are bolt supporting length , column length and plates thicknesses respectively . The symbols A_b , A_c and Ap are the cross sectional areas of one bolt and column and the effective compressed areas of the plates per bolt respectively. The value of Δ is nearly constant as all the parameters in the equation are constants for a certain connection and load except L_b which changes slightly due to nuts turning. By turning the nuts N number of turns ,the structural element would be lifted a distance d equal to :

$$d = N p - \Delta$$

The distance d is required in most cases not to exceed centimeters or even millimeters in some cases. The behavior described above is true if the fore- mentioned assumptions are fulfilled. The first assumption is satisfied initially by using a spanner to fix the bolts against rotations. When the loading process starts, the bolts become axially loaded in compression due to the force F_s through the bearing plate. This induces friction forces between bolts heads and the bearing plate which prevent bolts rotation. The second assumption is partially satisfied when using stiffeners as shown in Figure (1) and suitable thickness for the supporting plate as described later.

TEST SPECIMEN

A total of 7 specimens as that shown in Figure (2) were tested . The details of the connections tested and the results obtained are summarized in Table (1). A steel section of IPE 270 according to the German specifications DIN 1025 and length 150.0 mm was used for the supporting Jack. Both the bearing and base plates have the dimensions 250 X 294 mm and thickness of 20.0 mm. The supporting plate has the same dimensions but different thicknesses as shown in Table (1). Two plates of 10.0 mm thickness were used as stiffeners in connections CT4 ,CT4L , CT416 ,CT4O and MT4. The specimens were made of steel 37 to the Egyptian code of practice with minimum specified yield strength 235 N/mm^2. Fillet welds of equal leg size 6.0 mm were made to join the supporting and base plates and stiffeners. The welding was carried out by the manual metal arc welding process. The electrode was of diameter 3.25 mm, length 350 mm and class E4332 R complying with DIN 1913. Bolts were supplied in grade 8.8 and size M20 in accordance with DIN 931. The nuts used were of grade 8 complying with DIN 934.



supporting plate details

Figure 2. Test specimen details.

Table 1 : Connections details, ultimate loading capacity and failure modes

Connection	Bolts M20			Nut grade	Supporting plate		Ultimate Load KN	Failure mode
	number	L_b *	grade		t *	stiffeners		
CT4	4	105	8.8	8	20	yes	823.3	BF1
CT4L	4	150	8.8	8	20	yes	852.6	BF1
CT416	4	105	8.8	8	16	yes	823.2	BF1 & SPY
CT4O	4	105	5.6	black	20	yes	469.2	BF2
CT4NS	4	105	8.8	8	20	No	676.2	SPY & CWb
CT2	2	105	8.8	8	20	No	411.6	BF1
MT4	4	105	8.8	8	20	yes	485.7	ND

Notes :

- * = Dimensions in millimeters
- BF1 = Mode 1 of bolts failure
- BF2 = Mode 2 of bolts failure
- SPY = Yielding of supporting plate
- CWb = Buckling of column web
- ND = Distortion of nut from outside.

The yield and ultimate strengths specified in the DIN 18800 for 8.8 bolts are 640 and 800 N/mm^2 respectively. In BS 3692, the minimum ultimate tensile load specified for this grade of bolts and nuts is 192.3 KN. The experimental results presented by Godley and Needham (1982) confirmed this value. In one connection , black bolts of grade 5.6 and size M20 with black nuts were used. The yield and ultimate strengths of this type of bolts specified in DIN 18800 are 300 and 500 N/mm^2 respectively. Hardened washers were used under the nuts in all the tests . All the connections were coated with lacquer

TEST ARRANGEMENTS

Six connections were subjected to direct compression load until failure. A universal testing machine of 500 tons loading capacity was used. The specimen was put down in the machine upside down as shown in Figure (3a) to exclude any deflections that might occur in the bearing plate. The displacements in the direction of the applied load were recorded at positions 1 and 2, Figure (3b). In one experiment MT4 , the testing machine was used as a test rig. The specimen was put as described above. The lower jaw of the machine is fixed in its position. The upper jaw was lowered until the load cell recorded 48 KN and then fixed at its position. This load was applied to prevent the upper jaw movement and to induce friction forces between the bolts heads and the bearing plate when the nuts are turned . The distance between the two jaws of the machine became constant. Turning the nuts in this condition would induce forces in the bolts due to the contractions occurred in their supporting lengths and the deformations occurred in the specimen. These forces were measured by the load cell, Figure (3a), and shows the success of the connection mechanism.

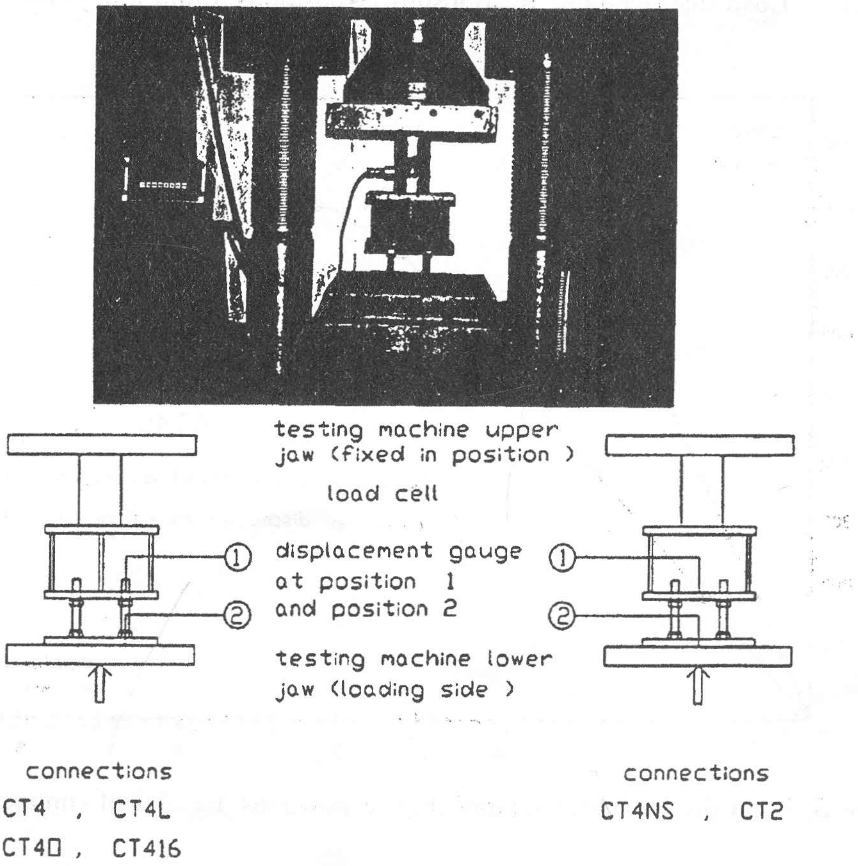


Figure 3. Test arrangements.

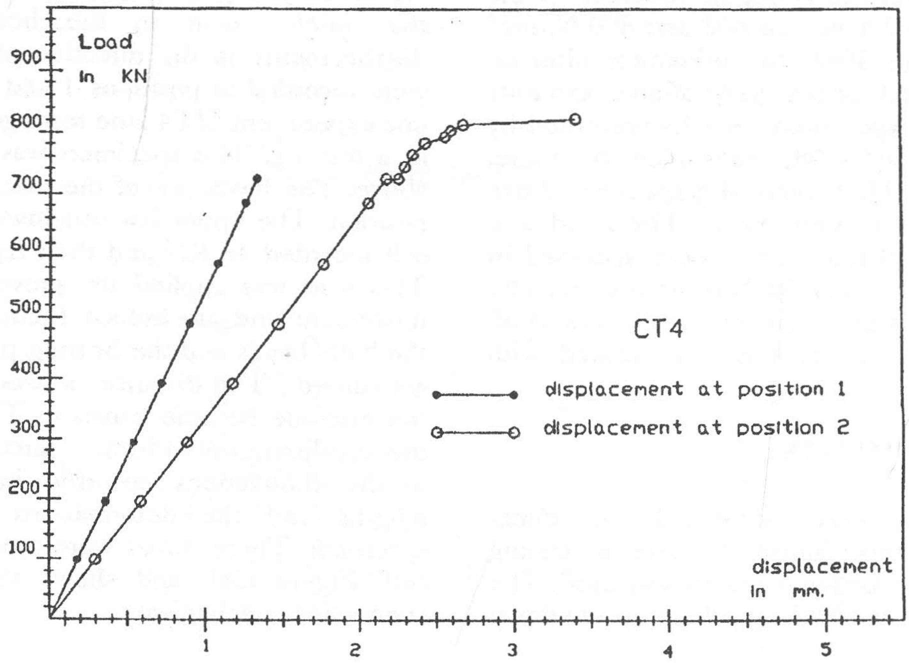


Figure 4. Load displacement relationship at positions 1 and 2 of connection CT4.

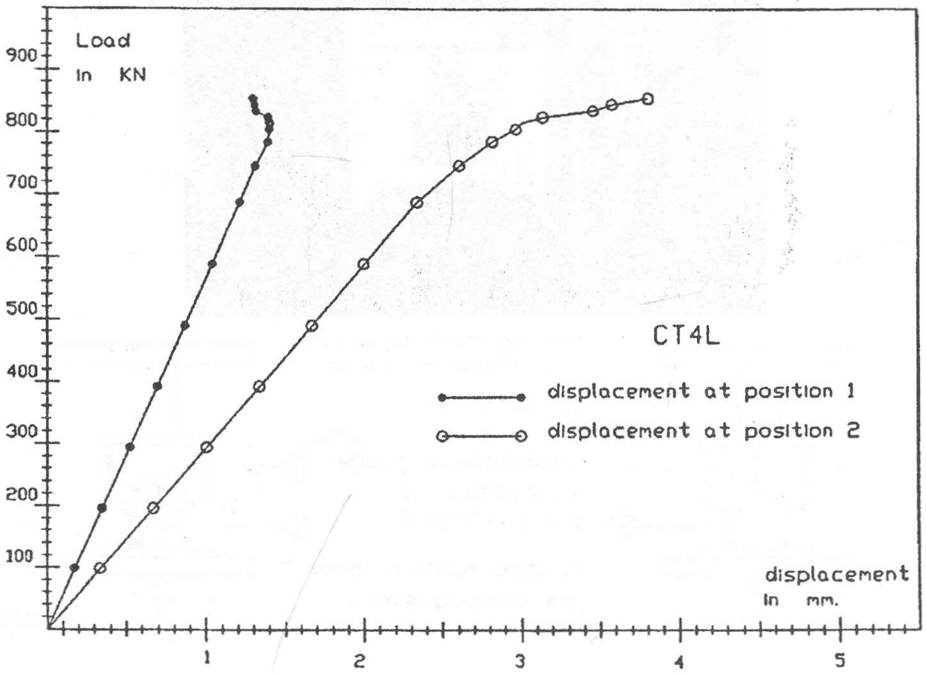


Figure 5. Load displacement relationship at positions 1 and 2 of connection CT4L.

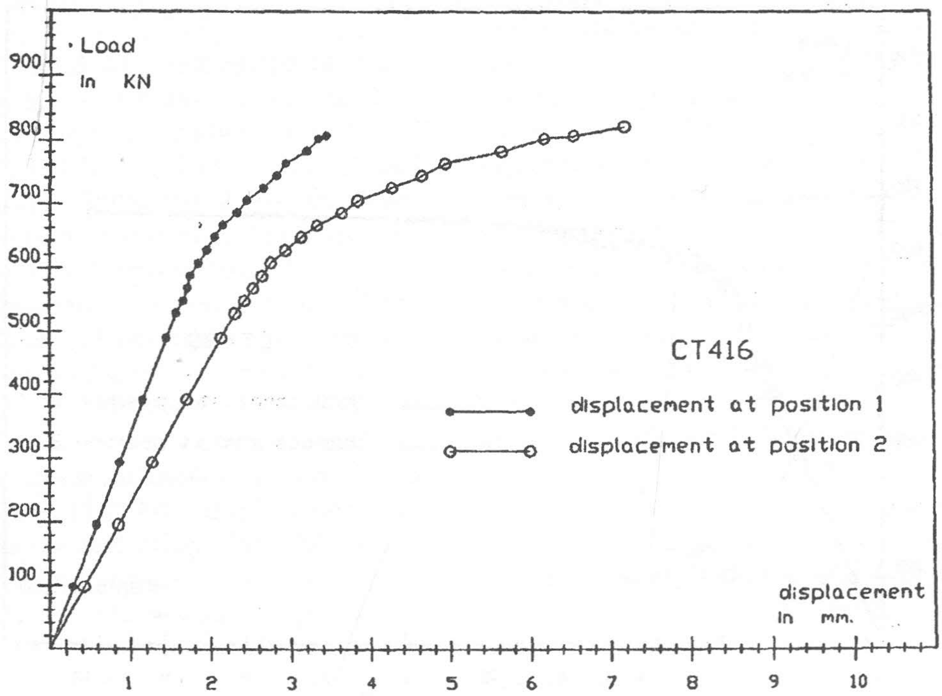


Figure 6. Load displacement relationship at positions 1 and 2 of connection CT416.

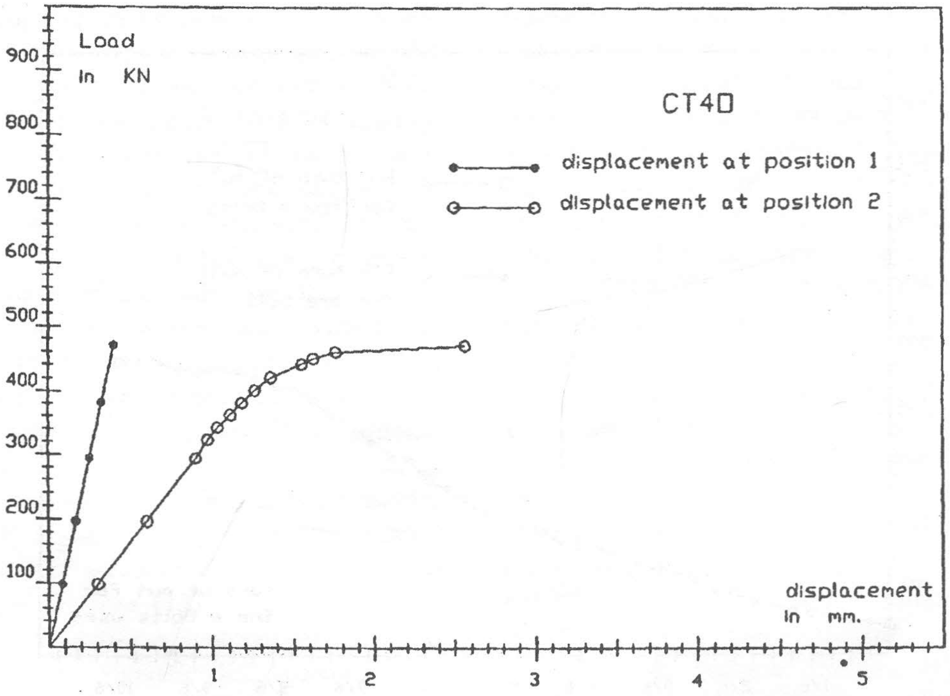


Figure 7. Load displacement relationship at positions 1 and 2 of connection CT4O.

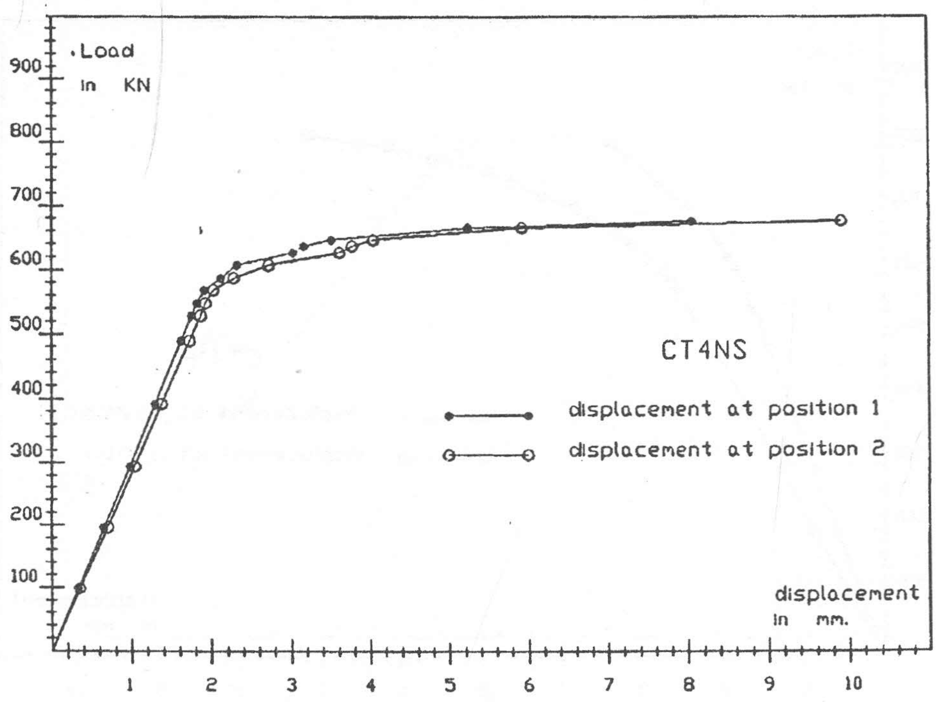


Figure 8. Load displacement relationship at positions 1 and 2 of connection CT4NS.

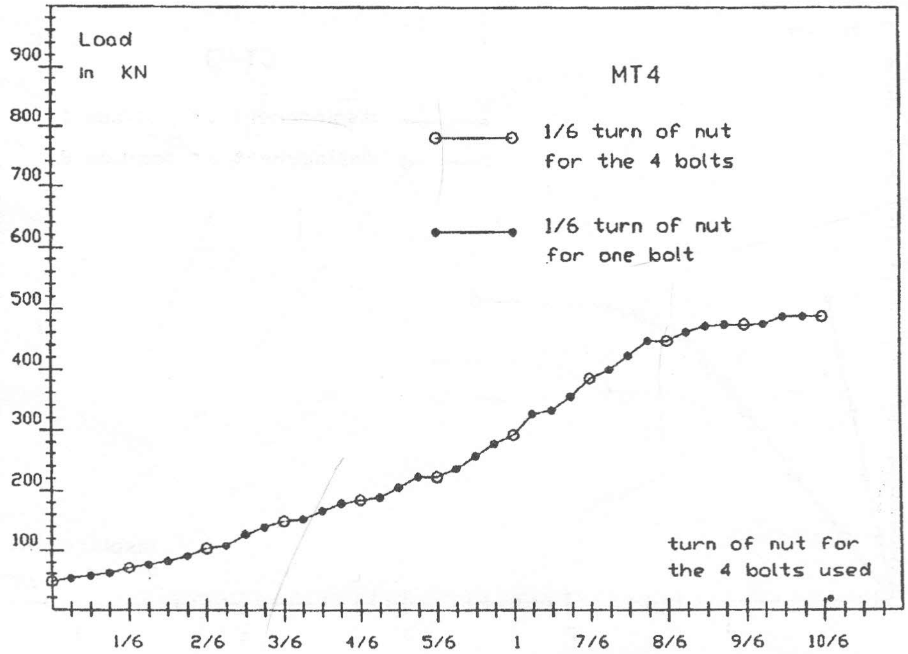


Figure 9. Load-nuts rotations relation of connection MT4.

RESULTS AND ANALYSIS

All the results obtained are summarized in Table (1). Figures (4, 5, 6, 7) and (8) show the load displacement relationships at positions 1 and 2 of connections CT4, CT4L , CT416 , CT4O and CT4NS respectively. Figure (9) shows the loads produced in the bolts of connection MT4 and the amount of nuts rotations. Figures (10), (11) and (12) show the plastic deformations in connections CT416 and CT4NS. Figures (13,14) and (15) show the different failure modes of bolts and nuts observed. Figure (16) shows three collapsed mechanisms for different details of the supporting plate. Connection CT4 deviates from linear to nonlinear behavior at load 725 KN, Figure (4). The displacements at position 1 represents the deflection of the supporting plate in addition to its deformation with the column and base plate. The displacements at position 2 represents the overall deformation of the specimen. The loads are presented in KN and the displacements in millimeters. When the applied load reached 823.2 KN, rapid and continuous increase in the displacements at position 2 associated with reduction in the applied load was recorded. The test was stopped and this load is considered as the ultimate loading capacity of the connection. Bolts failure determined the connection ultimate capacity. At failure, the threads in three of the bolts and their nuts were found distorted as described below. It is noticeable, that the ultimate capacity of the connection is 107% in value of the minimum ultimate tensile loads of the bolts specified in BS 3692. This type of comparison was carried out because no data are available in codes of practice and specifications about the mechanical properties of bolts when subjected to compressive loads and the need to refer bolts compression ultimate capacity to standard values. Connection CT4L showed similar behavior but with higher ultimate capacity, Figure (5). At load 852.6 KN sudden loud voice occurred due to bolts failure, Figure (13). The reduction in the displacements at position 1 at failure indicates the specimen recovery of elastic deformations. The inclination of the load displacement relation at position 2 is less than its counterpart of CT4 because the bolts supporting length in this case is 150.0 mm. The difference between the relations at positions 1 and 2 indicates that bolts failure determined the connection capacity and caused the nonlinearity and then the horizontal plateau in the load displacement relation at position 2. The results obtained of connections CT4 and CT4L were used with equation 1 to determine a value for the term A_p. The displacement and load values were taken from the linear part of the relations. The deflection of the supporting plate is assumed to have a value that can be neglected and the displacements occurred at position 1 were mainly due to axial deformations in the column and the plates. The ratio of the effective compressed area of the plates per one bolt to bolt cross sectional area is found to have values between 3.8 and 4.4. This is found to be in the range of 3 to 8 which was defined by Kato and Mc Guire (1973) for T-stub flange to column connections when tightened using high strength friction grip bolts .

Connection CT416 deviated early from linear to nonlinear behavior at load 607.6 KN, Figure (6). Above this load , each increment in load caused relatively large increase in the displacements. This is explained by the early yielding of the supporting plate. However, bolts failure determined the connection capacity. At load 823.2 KN, the bolts and nuts were found distorted as described below. Figure (10) shows the plastic deformations that occurred in the supporting plate. Local dishing is observed at the positions of the nuts and washers, Figure (11). Connection CT4O showed similar behavior to that of CT4, Figure (7). However , the ultimate loading capacity of the connection is 57% of that of CT4. The value of this load is 96% of the bolts ultimate tensile loads . The bolts deformed as shown in Figure (15).

The load displacement relations at positions 1 and 2 of connection CT4NS are nearly typical, Figure (8). This is different to the results obtained and presented before for the other connections. No stiffeners were used in this connection and the supporting plate became in this case relatively flexible in comparison to the bolts. This depends on the thickness of the supporting plate and the span between the column flanges. The plate would transmit nearly all the displacements that occurred at position 2 to the displacement gauge at position 1 producing these similar load displacement relations. The connection failed at load 676.2 KN which is

82.1% of connection CT4 ultimate capacity. At this load, failure was due to buckling of the column web and yielding of the supporting plate and base plate, Figure (12). These caused the horizontal plateau shown in the load displacements relations, Figure (8). The deformations of the base plate were found higher in magnitude than that of the supporting plate. The load is transmitted from the bolts to the supporting plate at four positions while it is transmitted from the column section to the base plate ,mainly through the column web and then to the load cell, at one limited area. Connection CT2 exhibited a capacity equal to 50% of that of CT4. The distortion of the bolts and nuts threads determined the connection failure .

Figure (9) shows the relation of the load affecting the bolts of connection MT4 and the amount of nuts rotations when the distance between the jaws of the testing machine was made constant. The horizontal axis represents the amount of nuts rotation. One unite of this axis represents one full turn of the nut against the supporting plate . The vertical axis represents the forces produced in the bolts. The maximum load induced in the bolts is equal to 59% of connection CT4 ultimate capacity. At this load the nuts were distorted from outside. When turning the nuts after this load, the bolts themselves turned with their nuts and no increase in the load was recorded. The friction between bolts and nuts threads is expected to exceed that between the bolts heads and the bearing plate . When using spanners designed for tightening high strength bolts and nuts of higher grade than the bolts grade, the loading capacity of the connection is expected to increase to a value comparable to the yielding loads of the bolts.

BOLTS FAILURE

Two modes of failure were observed for the bolts. The first occurred in connections CT4 , CT4L, CT416 and CT2. In this mode the threads of the bolts are compressed in direction opposite to the direction of the applied load. Threads stripping occurred in the nuts, Figure (13). This failure mode is explained as follows. When thread in nut is subjected to stresses causing its yielding or initiating its stripping, the thread deforms in the direction of the applied load and no longer react against its counterpart bolt thread. The load is transmitted from the bolt to its nut through less number of threads subjecting them to high stresses and finally causing their yielding and / or stripping. Bolts threads would deform in direction opposite to the applied load and the bolt tends to pass through the bolt hole. This would cause the horizontal plateau shown in the load displacement relations at position 2 of connections CT4 and CT4L. The interaction of the nonlinear behavior of the supporting plate in connection CT416 and the bolts at failure did not cause the horizontal plateau in the load displacement relation as described above. Figure (14) shows slight inclination in the threaded part of the bolts in CT416 and a stripped thread of a nut which was compressed under bolt threads , the third bolt in the figure . The bolts in connection CT4O exhibited different failure mode as shown in Figure (15). This most properly refers to the existence of slight inclination of the bolts axes to the applied load axis. At failure, each bolt was subjected to moment in addition to axial load causing this failure shape .

COLLAPSE MECHANISM

For the range of the specimens tested, it can be seen that three collapse mechanisms for the supporting plate exits, Figure (16). Mechanism C1 is formed for connections with four bolts and stiffeners. Mechanism C2 is formed when no stiffeners were used while mechanism C3 is formed for connection with two bolts. The ultimate force of the supporting plate F_u is calculated as follows:

$$F_u=2t^2\sigma_y[(m+n-d')(i)+(v+w-d'/j)(1/m)] \quad (2)$$

where $i=(1/v+1/w)$ and $j=1$ for mechanism C1, $i=(1/v)$ and $j=1$ for C2 and $i=(1/v+w)$ and $j=2$ for C3. The distances m, n, v and w are shown in Figure (16) and d' is bolts hole diameter. The symbols σ_y and t are the design yield strength and supporting plate thickness respectively. Mechanisms C1 and C3 are conservative. The full plastic mechanism of the supporting plates in connections CT416 and CT2 are predicted to be formed at loads 590 KN and 461 KN respectively. However, the bolts ultimate capacity determined the failure in these two specimens at higher loads. Mechanism C2 predicts the failure of connection CT4NS at load 614.65 KN which is 90.8% of the experimental result. This margin in the results may refer to the possibility that the supporting plate material has a yield strength value higher than that specified in the codes .