Proceedings of the Twelfth International Colloquium on Structural and Geotechnical Engineering

December 10-12, 2007

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Structural Engineering Department
Faculty of Engineering
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2007

Innovation In Structural and Geotechnical Engineering

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A STUDY IN THE BEHAVIOUR OF CIRCULAR BASE PLATES
Under Bending Moment

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ABSTRACT

The present study aims at examining the behaviour of circular base plate connections under bending moment. An experimental program is developed and tests are performed on twelve pipe specimens with circular base plate and circular anchor bolt pattern. Pipe diameter, base plate diameter, number of anchor bolts and bolt circle diameter are all kept constant throughout the experimental investigation. Base plate thickness and the presence of plate stiffeners are the varied parameters. The specimens are loaded till failure under vertical tip load and failure mechanism is determined based on the observed deformed shape of the base plate. The results of the bending tests are presented in the paper. The presented experimental data will help in the development of a design model for circular base plates.

KEYWORDS

Circular Base Plate, Moment–Rotation Relationship, Experimental Yield Moment, Tensile Force Distribution.

1 INTRODUCTION

Circular base or flange plates are widely used in pylons in cable-stayed bridges, telecommunication and lighting structures. Self-supporting latticed towers with pipe or solid round legs usually have a round flange plate, which is subjected mainly to tensile/compressive forces in addition to shear force. Straight and tapered poles on the other hand have circular base plate, which is subjected mainly to bending moment.

Several research works have been done which were devoted to the design of circular base plate under axial load (B. Kato and R. Hirose 1985). However, the behaviour of circular base plates under bending moment has not been studied or at least has not been documented in the published literature. This paper presents an experimental test prepared in Benha University to study the behaviour of circular plates under such loading conditions. The main parameters varied in that test were the base plate thickness and the presence of stiffeners in the base plate connection. A total of twelve tests were performed. The tests were divided into two series: Type N connections for non-stiffened base plate; and Type S connection for stiffened base plate. In both series, circular hollow sections were tested. The twelve samples were divided into three groups according to their base plate thickness (10, 12 and 16 mm).

2 EXPERIMENTAL WORK: TEST SPECIMENS AND MATERIAL PROPERTIES

2.1 Base Plate Details

The general layout of the base plates is shown in Figure (1) for Type N and Type S connections respectively, with the thickness (t_p) varied from 10 to 16 mm and dimensions (D_i, D_b) which was constant for all the specimens.

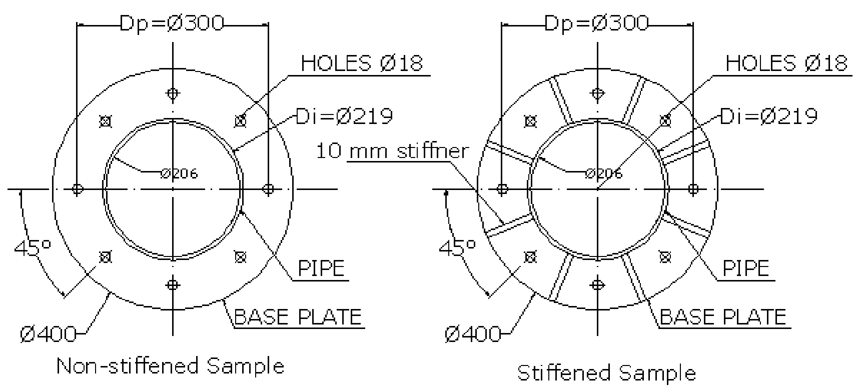

Fig. 1: Base Plate Detail

2.2 Anchor Bolt Details and Material Properties of the Base Plates

The anchor bolt assemblies used in the base were black M14 and M16 high strength grade 60 and 52 respectively.

Table 1: Material Property of the Base Plates

Sample	Yield Stress (MPa)	Ultimate Tensile Strength (MPa)
10 mm	251	397
12 mm	284	461
16 mm	288	464

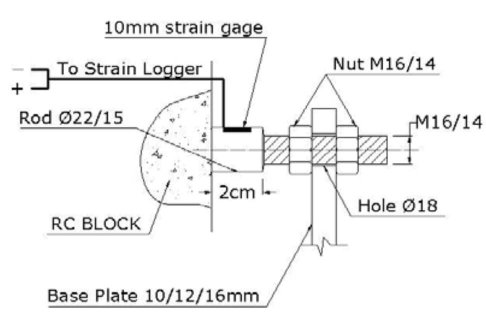

Fig. 2: Anchor Bolt Detail

For the 10 mm base plate a total of 8 Nos. M14 anchor bolts were used, for the other two categories a set of 8 bolts with M16 anchors were used. For M14 bolts the nominal yield stress was 786 MPa and 437 MPa for the M16. Tensile coupons were taken from the base plates and tested. Table 1 shows the material property of the base plates used in the tests.

2.3. Testing Procedure

Each test consisted of a specimen, pipe welded to its circular base plate, attached to anchor bolts embedded in RC block, Figures (3) and (4).

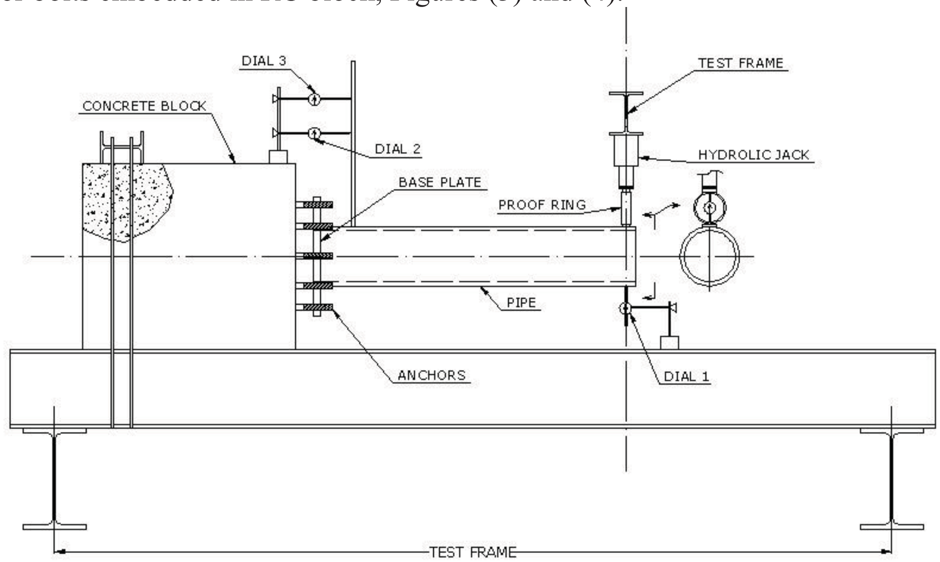

Fig. 3: Test Setup

The specimens were rested on levelling nuts to adjust its horizontality and no grouting was applied, therefore there was no prying force to affect the plate. The specimens were tested by applying load at the tip point at the end of the pipe using a hydraulic jack until failure.

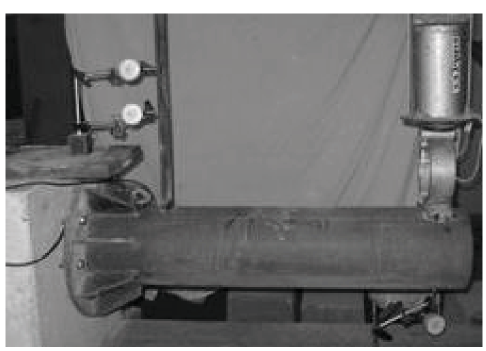

Fig. 4: Stiffened Sample Being Tested

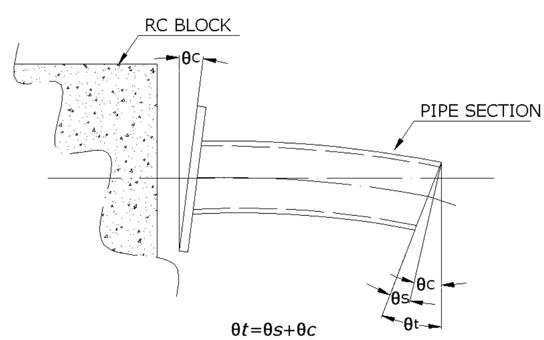

Fig. 5: Connection Rotation Angle

The distance between the loading point and the base plate was kept constant and equals 930 mm for all specimens. The load was applied on equal steps of 2.45 kN. For each step, the strain gauge readings were recorded using a strain data logger connected to the system. To measure the vertical displacement of the tip point Dial 1 was placed under the tip point from the bottom side of the pipe. Dials 2 and 3 were placed to measure the slope of the vertical bar attached to the pipe hence the total rotation of the connection, θ_t, can be obtained. The total measured rotation of the connection θ_t is the sum of the connection rotation θ_c, and the rotation generated by the curvature of the beam cross section θ_s, Figure (5). The rotation of the beam section, θ_s, was determined using the measured values of strain of the pipe and assuming the curvature is uniform over the length of the pipe. Forces in the critical bolt expected to be in tension zone were determined using the measurement of a 1 cm long strain gauge placed over the clear distance between the nut and the RC block.

3 TEST RESULTS AND DISCUSSION:

The twelve specimens were loaded till failure in the test setup shown in Figure 3. The applied load, tip displacement, specimen rotation, pipe strain and anchor bolt strains were all recorded or calculated and are presented in Figs. (6) to (13) and Tables (2) and (3). It should be noted that each tested specimen is given a legend using the following format XX-Y-Z, where XX is the base plate thickness, Y is either N or S for non-stiffened and stiffened specimens respectively and Z is the specimen number in the current XX-Y series. For example 10-S-2 means: Second sample with 10 mm base plate with stiffeners.

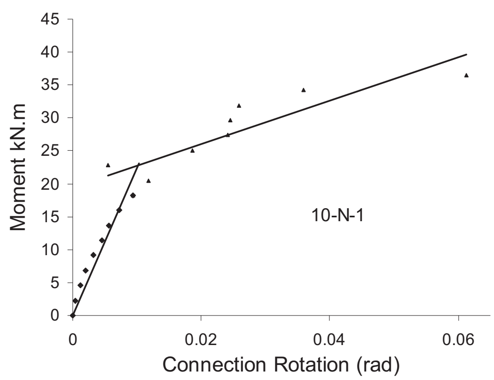

Fig. 6: Moment- Rotation (10-N-1)

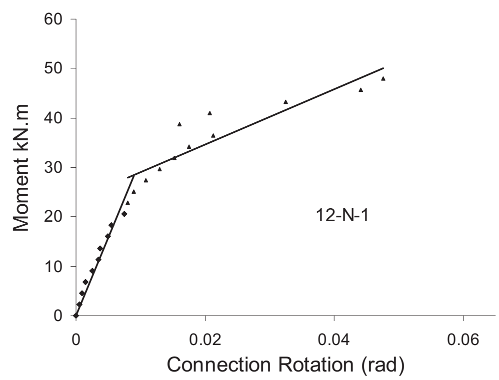

Fig. 7: Moment- Rotation (12-N-1)

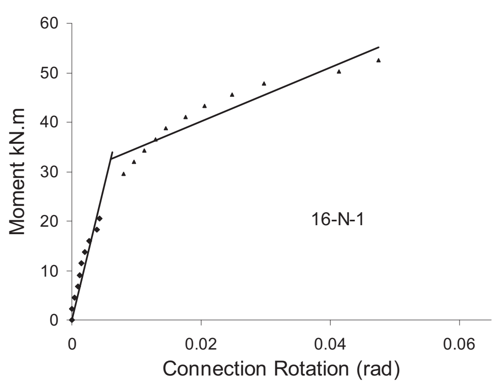

Fig. 8: Moment-Rotation (16-N-1)

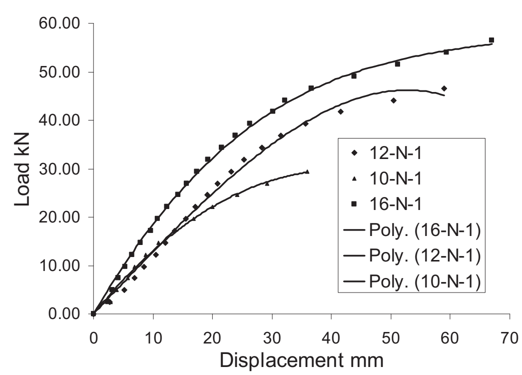

Fig. 9: Load-Displacement Non-Stiffened

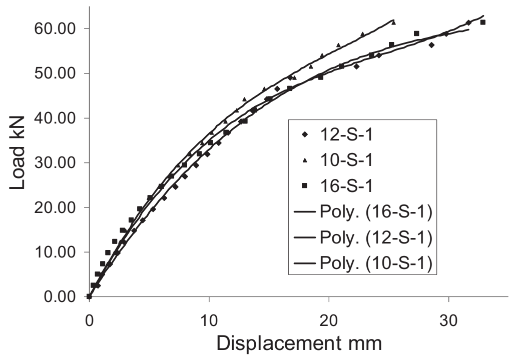

Fig. 10: Load-Displacement, Stiffened

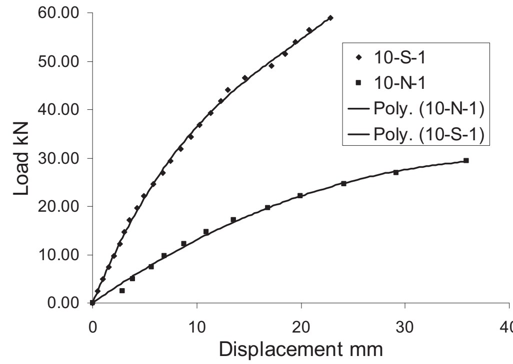

Fig. 11: Load-Displacement (10-N & S)

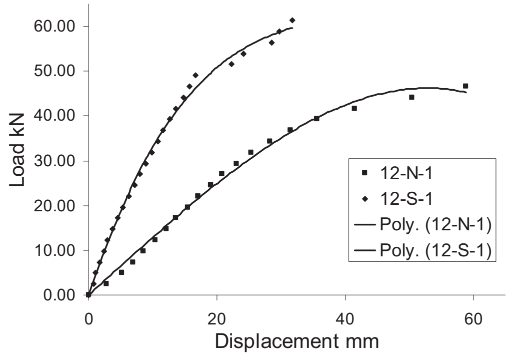

Fig. 12: Load-Displacement (12-N & S)

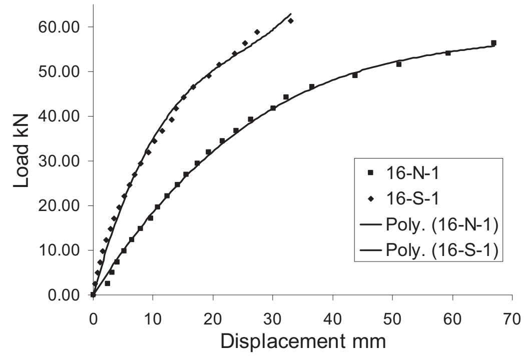

Fig. 13: Load-Displacement (16-N & S)

3.1 Description of failure modes

Several failure modes were observed due to the presence of deferent conditions associated with each tested sample. The following outlines the main observations:

A- For the non-stiffened samples, the normal failure mode took place after the base plate started to experience inelastic behaviour, see Figure (14).

B- In the case of stiffened samples, the failure modes have changed from base plate failure to two other forms as described below:

a. Failure in the shaft of the specimen

b. Fracture of the upper bolt carrying the highest tension force, see Figure (15)

C- Pre mature failures have also been experienced and corrected such as:

a. Bond failure between anchor bolts and the concrete block

b. Nut slippage due to manufacturing defects, see Figure (16)

c. Excessive local deformation in the pipe underneath the point of load application, Sample 10-S-1

Table 2: Yield Load Comparison

Sample	Yield load (P_y) kN	Yield load (P_{cy}) kN	Ratio
10-N-1	18.63	22.32	1.19
12-N-2	29.42	30.66	1.04
16-N-2	31.87	35.2	1.1

Table 3: Load – Displacement Slope Comparison

Slope (N Samples) kN/mm	Slope (S Samples) kN/mm	Ratio
128.2	462.96	3.611
128.67	400	3.1
212.76	528.17	2.48

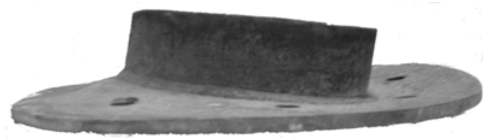

Fig. 14: Deformed Shape of the Base Plate

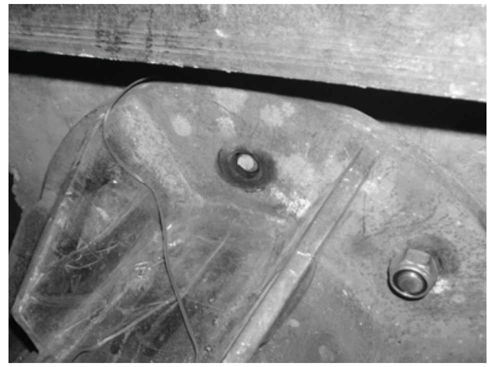

Fig. 15: Bolt Fracture in Stiffened Sample

Fig. 16: Nut Slippage

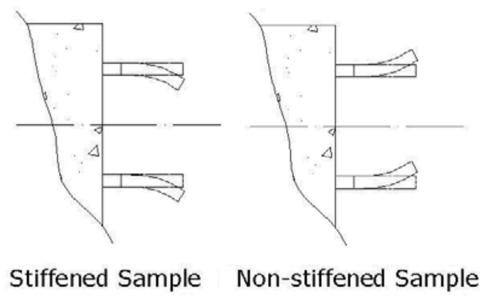

Fig. 17: Deformed Shape of the Bolts

3.2 Analysis of the Results and Observations:

Studying the results collected from the tests performed on the twelve specimens, the following observations are made:

1. For the non-stiffened samples, two important values were studied; the first value is the yield load (P_y) which is obtained from the load – displacement charts by determining the value of the load that created a longer displacement step than its predecessor. The other value is the yield load (P_{cy}) which is obtained form the experimental yield moment (M_{cy}). The (M_{cy}) value is defined as the intersection of the initial stiffness and the strain hardening stiffness as shown in Figures (6) to (8) and Table (2). The importance of this comparison is to verify that the displacement of the tip point caused by the yield of the connection and not by premature failures. This comparison is also important to verify the experimental (M_{cy}) value in order to use it in classifying the connection rigidity.
2. Following the Bjorhovde classification scheme for the non-stiffened samples the $\overline{m}-\overline{\theta}$ curves shown in Figure (18) were plotted. In this Figure, θ_c is the rotation of the connection relative to the attached beam, M_p is the plastic moment capacity of the beam cross section, d is the beam depth and EI_b is flexural rigidity of the beam section. From this figure one can state that, according to stiffness, the 10mm sample can be classified as flexible while the 12 and 16mm samples can be classified as semi-rigid.

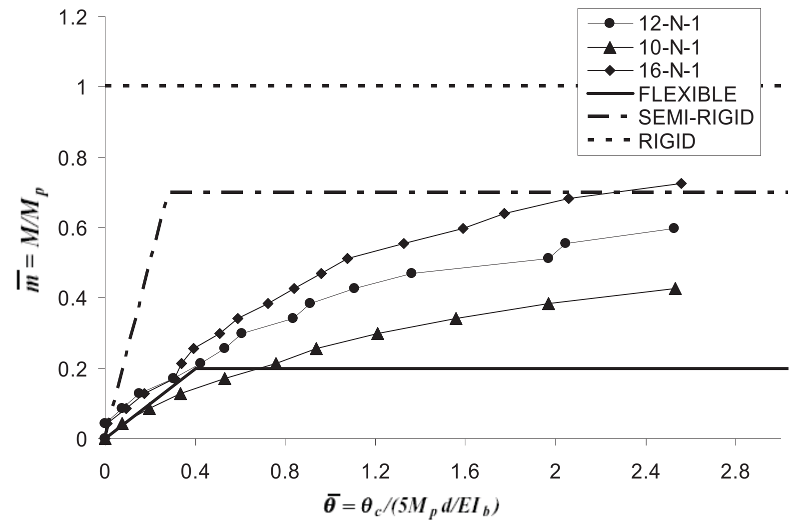

Fig. 18: N Sample Connection Classification

3. It is obvious that adding stiffeners to the samples increased the rigidity of the connection and reduced the displacement of the tip point. Table (3) shows a comparison between the slope of the N and S samples with an average ratio of 3.1.
4. From Figure (10) it is noticed that the load deflection curves of the three stiffened samples are very similar. This is due to the fact that the presence of the stiffeners contributed more to the rigidity of the connection than the contribution of the base plate thickness to its rigidity.
5. A very important difference between the stiffened and the non-stiffened sample is the behaviour of anchor bolts in the plastic stage. Figure (15) shows the two deformation patterns of the anchor bolts in both cases. For the N samples, the anchor bolts in the tension zone tend to bend outward while the anchor bolts in the compression zone tend to bend inward. However, in case of the S samples all the anchors tend to bend downward.
6. For the N samples and during the early stage of loading, the three upper bolts underwent a positive strain due to the tension force. After the base plate started inelastic behaviour, the strain readings became to show negative sign, especially on the first bolt. This is due to the plate pushing the anchors upward due to its inelastic deformation. As a result, the uppermost anchor bolt is acted upon by a combination of tension force and bending moment created by the plastic coupling of the two nuts and deformed shape of the plate. Figure (19) shows the strain readings for sample 10-N uppermost anchor bolt. The strain readings of the bolts were higher than the readings of the non stiffened samples. Because there was no deformation in the base plate, there was no coupling around the anchor bolts to force the anchor bolts to perform negative strain. Figure (20) shows strain readings for sample 16-N anchor bolt which is considered as an example of how the anchor bolt behave in rigid connections.

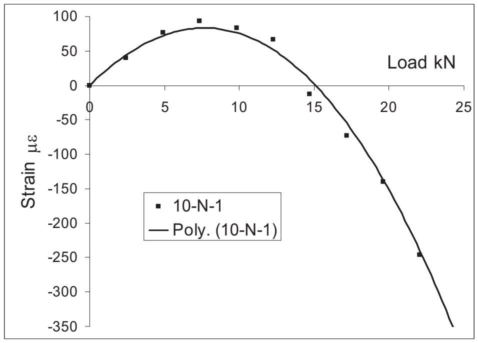

Fig. 19: Typical Strain in Top Bolt (Flexible Connection)

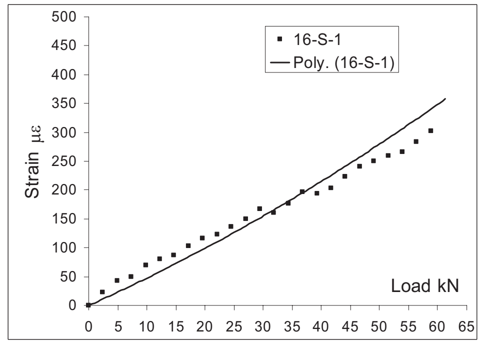

Fig. 20: Typical Strain in Top Bolt (Rigid Connection)

4 CONCLUSIONS

4.1 Non-Stiffened Samples

For all the non stiffened samples, the yield line has formed between the pipe body and the anchor bolts leading to a helical shape of the base plate.

Figure (9) shows the Load-Displacement relationship for the N samples. It is noticed that increasing the thickness of the base plate from 10 mm to 12 mm has increased the stiffness of the connection 100%.

Increasing the thickness from 12 mm to 16 mm redistributed the axial force on the anchors which lead to increasing the stress on the uppermost bolt.

It was found that the rotation of the pipe body can be neglected and the rotation of the connection can be considered as the base plate Rotation combined with the rotation of the anchor bolts.

It is recommended to use a minimum thickness of base plate for such type of connections of 16mm in order to achieve the rigidity required for the design.

4.2 Stiffened Samples:

For stiffened samples, no yield occurred in the end plate. The stiffeners welded to the base plate completely prevented any deformation.

Adding stiffeners to the 10 mm sample converted the connection type from flexible to rigid.

For the 16 mm sample, the effect was not as dramatic but 250% increase in the stiffness of the connection was observed.

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