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Effect of concrete surface slope on the stress distribution of anchors bolts

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الملخص العربى :

تم اعتماد وصلات العزم مزدوجة الصواميل بشكل كامل لنقل الأحمال من خلال مسامير التثبيت ، حيث تتحرك لوحة القاعدة بعيدًا عن سطح الخرسانة بمسافة الوقوف ، مما يمنحها الصلابة والقدرة على نقل الأحمال العالية إلى الأساس ، وهذه الوصلات هي الأكثر ملاءمة للهياكل الثقيلة. ومن عيوب هذه الوصلات أنها تتأثر بمشاكل الموقع ، ومن أهم هذه المشكلات حدوث ميل إلى سطح الأساس الذي تم تثبيت الاتصال عليه. تؤدي هذه المشكلة إلى توزيع غير متساوٍ للضغط على مسامير التثبيت. يقدم البحث الحالي هذا البحث عن اتصال عزم الجوز المزدوج بمسامير التثبيت مع مسافة موازنة متساوية وغير متساوية كمعامل في دراستنا. تم تحليل سلوك وصلات العزم المزدوجة تجريبياً وقورنت النتائج مع المعادلات التي تم استنتاجها من الأبحاث السابقة. أجريت الدراسة التجريبية على ثلاث عينات تم اختبارها تحت الحمل المتزايد تدريجياً. يتم تسجيل القدرات النهائية بعد تطبيق الأحمال الجانبية ونمط الفشل ونمط التكسير وكذلك الإزاحة الجانبية لكل عينة. تمت دراسة تأثير المعامل على قوة المقاومة المحورية على كل مسمار تثبيت ، وتم تحديده من خلال وضع مقياس إجهاد على كل مسمار تثبيت ورسم منحنى الإجهاد والانفعال. وجد أن القوى المحورية داخل أحد براغي التثبيت زادت بنسبة 18٪ عندما تغيرت زاوية سطح الخرسانة من 0 إلى 4 درجات وعندما وصلت هذه الزاوية إلى 8 درجات زادت القوى المحورية إلى 27٪ .

Abstract:

The double nut moment connections are fully adopted to transfer loads through anchor bolts, where the base plate moves away from the concrete surface by stand-off distance, which gives it rigidity and it is ability to transfer high loads to the foundation, and these connections are most suitable for heavy structures. One of the disadvantages of these connections is that they are affected by site problems, and one of the most important of these problems is the occurrence of a tendency to the surface of the foundation on which the connection is installed. This problem leads to an uneven distribution of stress on the anchor bolts. The current research presents that investigation for double nut moment connection with anchor bolts with even and uneven stand-off distance as a parameter in our study. The behavior of double nut moment connections was analyzed experimentally and the results are compared with the equations inferred from previous researches. The experimental study is conducted on three samples that were tested under gradually increasing loading. The final capacities after applying lateral loads, failure pattern and cracking pattern, as well as lateral displacement are recorded for each sample. The influence of the parameter on the axial resistive force on each anchor bolt was studied, and was determined by placing a strain gauge on each anchor bolt and drawing the stress-strain curve. It was found that the axial forces within one of the anchor bolts increased by 18% when the concrete surface angle changed from 0 ˚ to 4 degree and when this angle reached to 8 degree the axial forces increased to 27%.

Author Keywords

Anchor bolts; anchorage; Standoff distance; Annular base plate; Circular base plate; Base plate; Double nut moment connections and Circular column.

1. Introduction

Recently, dealing with double nut-moment connections to enhance their behavior has become a topic of concern. This connection is characterized by the non-contact of the baseplate with the top of the concrete columns through a distance known as the stand-off distance.

The standoff distance is defined as the distance from the pedestal surface to the bottom level of the leveling nuts located under the base plate, as shown in **Figure 1(a)**.

When designing the anchor bolts, a regular behavior is imposed to distribute the stresses on the anchors due to the imposition of equal stand-off distances, but a problem occurs during the implementation of that connection, which is the occurrence of a tendency to the surface of the concrete, and therefore the behavior of the distribution of stresses on the anchor bolts is irregular, due to the uneven standing distances, as shown in **Figure 1(b)**.

Equations and design guidelines for anchor bolts were provided in the case of equal stand-off distances, to calculate the tensile and compression stresses on the anchor bolts in addition to the shear stresses by the AASHTO supports specifications [1], as shown in the following Equations.

$$F_t = F_c = 0.5F_y \qquad \text{Eq. 1}$$

$$\left(\frac{f_t}{F_t}\right)^2 + \left(\frac{f_v}{F_v}\right)^2 \le 1 \qquad \text{Eq.2}$$

$$\left(\frac{f_c}{F_c}\right)^2 + \left(\frac{f_v}{F_v}\right)^2 \le 1 \qquad \text{Eq3}$$

Where: Ft = allowable tension stress,
Fc = allowable compression stress,
Fy = yield stress,
fv = applied shear stress on the individual anchor,
ft = applied tension stress on the individual anchor,
and fc = applied compression stress on the individual anchor.

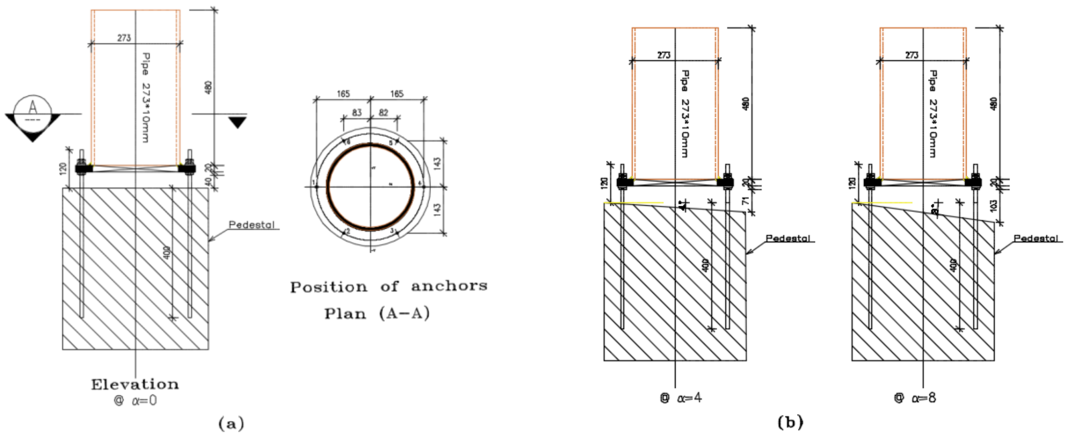


Fig.1 (a) Even standoff distance of anchor bolts. (**b)**Anchor bolts with uneven stand-off distance.

Another design approach has been developed by McBride (2014) [2] for anchor bolts with uniform stand-off distances, in order to calculate both shear and tensile stresses as shown in equation (4).

$$\left(\frac{F_{t,1}+F_{t,2}}{F_t}\right)^2+\left(\frac{f_v}{F_v}\right)^2\leq 1 \qquad \text{Eq.4}$$

Where: $F_{t,1}$=tensile Stresses for group of moment on the individual anchor bolts (MPA, KSI),
$F_{t,2}$=tensile Stresses for bending of moment on the individual anchor bolts on the stand-off distance (MPA, KSI),
fv=Shear Stress (MPA, KSI),
Ft=allowable tension stresses (MPA, KSI)
and Fv=allowable shear stresses (MPA, KSI).

While in the case of unequal stand-off distance Ahmed and Hosch (2017) [3] evaluated axial resistive forces of anchor bolts to resist different loads applied on the double nut moment connections which resolve to axial forces within individual anchor bolts, as shown in Equations (5).

$$N_{t,i} = \pm N_{1,i} \pm N_{2,i} \pm N_{3,i} \qquad \text{Eq5}$$

Where: $N_{t,i}$= total axial resistive forces on the individual anchor bolt (N, K), $N_{1,i}$= axial resistive forces on the individual anchor bolt due to the own weight of the super structure(N, K), $N_{2,i}$= axial resistive forces on the individual anchor bolt due to the bending of moment about the x-axis from the external loads (N, K) and $N_{3,i}$= axial resistive forces on the individual anchor bolt due to the bending of moment about the y-axis from the external loads (N, K).

Fisher and Kloiber, 2006 [4] provided an equation to calculate compression strength for anchor bolts in double nut moment connection. This equation is valid for a regular and uniform stand-off distance not greater than three times of anchor bolts diameter. When the stand-off distance exceeded that limit, buckling of anchor bolts shall be considered.

Liu (2014) [5] studied the effect of bending stresses on anchor bolts by making a numerical model and found that when using a base plate with a thickness equal to the diameter of the anchor bolt with a number of six bolts in the joint, it achieves a reasonable level of bending stress while McBride et al. (2014) [2] made adjustments regarding AASHTO tolerance for ignoring the bending of anchors with stand-off distance equal or less than the diameter of the anchors in double nut-moment connections

Ahmed and Hosch (2016) [6] presented equations for calculating the horizontal and vertical shear force for anchor bolts with uneven stand-off distances, as shown in Equations (6 to 8)

$$F_{tx,i} = \pm F_{1x,i} \pm F_{2x,i} \qquad \text{Eq6}$$

$$F_{ty,i} = \pm F_{1y,i} \pm F_{2y,i} \qquad \text{Eq7}$$

$$F_{R,i} = \sqrt{(F_{tx,i})^2 + (F_{ty,i})^2} \qquad \text{Eq8}$$

Where: $F_{tx,i}$ = x-component of the total lateral resistive force of anchor bolt i ; $F_{1x,i}$ =x-component of the direct shear loading on the individual anchor bolts ; $F_{2x,i}$ = x-component of the lateral resistive force on anchor i due to total torsion. $F_{ty,i}$ = y-component of the total lateral resistive force of anchor bolt i ; $F_{1y,i}$ =y-component of the direct shear loading on the individual anchor bolts; $F_{2y,i}$ = y-component of the lateral resistive force on anchor i due to total torsion and $F_{R,i}$ = total resultant lateral resistive force of anchor bolt i to direct shear and total torsion.

Lin et al., 2011 [7] studied the behavior of exposed anchor bolts in shear with uneven stand-off distance by performed experimental tests. The boundary condition of anchor bolts with various stand-off distance and exposed length of anchor bolt affects its failure mode and strength. Experimental tests are performed, which included two group of double shear tests on changing stand-off distances for anchor bolts. The first group: the end conditions of anchor bolt were restrained. The secondary group: the end rotations of anchor bolt were allowed. Results of experimental test showed that for specimens fixed at both ends conditions, increase exposed length of the anchor bolts decrease both capacity and stiffness, thus changing the uniform stand-off distance for anchor bolts affects the efficiency of connections. Lin et al., 2011 used ABAQUS software to study efficient of individual anchor bolt with changing of uniform stand-off distance of anchor bolts.

Budynas et al., 2015 [8] illustrated the stress distribution of the base plate stiffness, which called a frusta, shaped as a part of cone, extending out from the washer.

Cook and Bobo (2001) [9] Provide a method for evaluating rotation due to deformation of the base plate or anchor bolts, as well as an equation for calculating the diameter of the anchor bolts and the required thickness of the base plate. While Eligehausen et al., (2006) [10] Developed the double nut-moment connections using adhesive anchors.

Dietrich et al., 2020 [11] reviewed laboratory tests and methods of implementation and concluded that there is a possibility of loss of fastening anchor bolts and pretension loss and appeared from the constructability of procedures. Where the pre-tensioning loss of anchor bolts is due to relaxation rather than fatigue loading and to make the connection retain the pre-tensioning by making the procedures more efficient, buildable and achievable.

Culpepper et al., 2009 [12] present the effective of baseplate and A.B that located between top and bottom nut on the behavior of A.B by represent stiffness of base plate as Kb and stiffness of A.B as Kr. The stiffness of connection is shown up in figure (2).

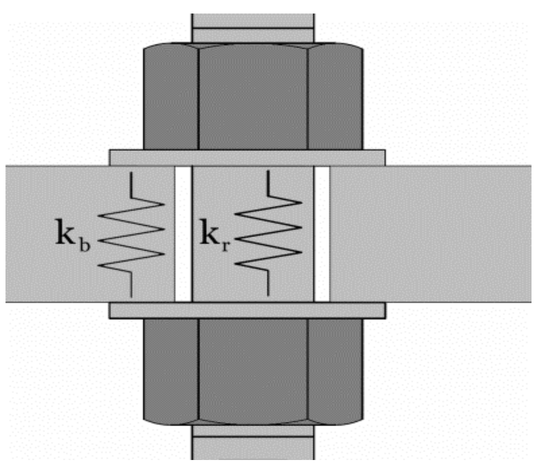


Figure (2) Stiffness of base plate and A.B

From mechanics of material, the calculation of A.B stiffness is illustrated with equation 2.1

$$Kr = \frac{AE}{L} \quad \text{Eq.2.1}$$

Where:
A = Cross section area of the A.B
E = Young's modulus
L = Grip length

1.2. Objective

The main purposes of this paper are firstly to evaluate the increasing of the axial forces within the anchor bolts after the inclination of the concrete surface by testing three samples with a change in the angle of inclination of the concrete surface with increasing the loading on each sample gradually. Then comparing the experimental results with the equations deduced from previous researches for uneven stand-off distances.

1.3 Appendix A

Material

Steel	A36
Concrete	4000 psi

Design

Name	CON1
Description	
Analysis	Stress, strain/ simplified loading
Design code	AISC - LRFD

Table 1: Beams and columns

Name	Cross-section	β – Direction [°]	γ - Pitch [°]	α - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]	Forces in
M1	CHS273,4	0.0	-90.0	0.0	0	0	0	Node

Table 2: Cross-sections

Name	Material
CHS273,4	A36

Table 3: Cross-sections

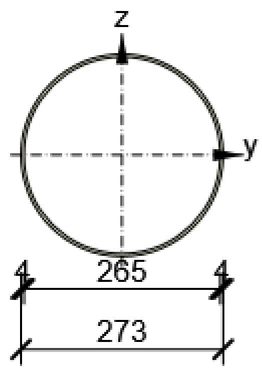
Name	Material	Drawing
2 - CHS273,4	A36	

Table 4: Anchor bolts

Name	A.B assembly	Diameter [mm]	fu [MPa]	Gross area [mm^2]
10 Gr. 4.6	10 Gr. 4.6	10	392.3	79

Table 5: Load effects (equilibrium not required)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	M1	0.0	0.0	0.0	0.0	0.0	5.0

Table 6: Foundation block

Item	Value	Unit
CB 1		
Dimensions	450 x 450	mm
Depth	500	mm
Anchor	10 Gr. 4.6	
Anchoring length	400	mm
Shear force transfer	A. Bs	
Gap	40	mm

Table 7: A. Bs in tension

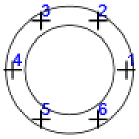
Shape	Item	Loads	N_f [kN]	V [kN]	M [kNm]	ϕN_{cbg} [kN]	ϕV_{cp} [kN]	Ut_t [%]	Ut_s [%]	$Ut_{ts,s}$ [%]	$Ut_{ts,c}$ [%]	Status
	A3	LE1	5.9	0.0	0.0	33.7	69.7	62.5	0.5	59.9	45.7	OK
	A4	LE1	9.3	0.0	0.0	33.7	69.7	86.8	0.3	90.6	45.7	OK
	A5	LE1	5.9	0.0	0.0	33.7	69.7	62.5	0.5	60.0	45.7	OK

Table 8: Design data

Grade	ϕN_{sa} [kN]	ϕV_{sa} [kN]	ϕM_n [kNm]
10 Gr. 4.6	10.8	5.5	0.0

Table 9: A. Bs in compression

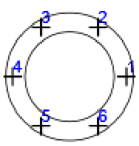
Shape	Item	Loads	F_c [kN]	V [kN]	M [kNm]	V_{cp} [kN]	Ut_s [%]	$Ut_{ts,s}$ [%]	Status
	A1	LE1	-9.1	0.0	0.0	69.7	0.3	98.6	OK
	A2	LE1	-6.0	0.0	0.0	69.7	0.5	68.2	OK
	A6	LE1	-6.0	0.0	0.0	69.7	0.5	68.2	OK

Table 10: Design data

Grade	ϕP_{nc} [kN]	ϕV_n [kN]	ϕM_n [kNm]
10 Gr. 4.6 - 1	10.3	5.5	0.0

Table 11: Welds

Item	Edge	Xu	T_h [mm]	L_s [mm]	L [mm]	L_c [mm]	Loads	F_n [kN]	ϕR_n [kN]	Ut [%]	Status
BP1	M1	E70xx	◢3.5◣	◢5.0◣	845	13	LE1	1.9	11.3	16.5	OK
		E70xx	◢3.5◣	◢5.0◣	845	13	LE1	2.3	13.7	16.5	OK

1.4 Appendix B

Table 12: Fixed Base Design Acc. To AISC-ASD (Mx) N=6 for θ=0 ∝=0

Design A. Bs			
1- input data			
Use M ϕ =	10 mm Gr.4.6	F_{ub}	=370 MPA
A. Bs vertical Spacin S=	173 mm	F_y	=2.4 t/cm^2
Area of Anchor A=	0.61 Cm²		
Inertia I=	0.049 Cm4	E=	2100 t/cm^2
Embedded length heff=	20.0 Cm	G=	784 t/cm^2
do=	330 mm	μ [Poisson's ratio]=	0.3
Column Sec.			
Column Profile			
D= 273 mm			
t= 4 mm			
base plate Dim.			
D= 370 mm			
t= 20 mm			
Shaft Sec.			
d_C= 500 mm			
F_{cu}= 25 MPA			
;= 0.0 Degree			
h_{min}= 40 mm			
APPLIED FORCES	ASD		
Vy= 0.000 Ton	=0.00 KN		
Vx= 0.00 Ton	=0.00 KN		
N= 0.000 Ton	=0.00 KN	Compression +ve	
Mx= 0.500 T.m	=5.00 KN	^^	
My= 0.00 T.m	=0.00 KN	>>	
T= 0.00 T.m	=0.00 KN		

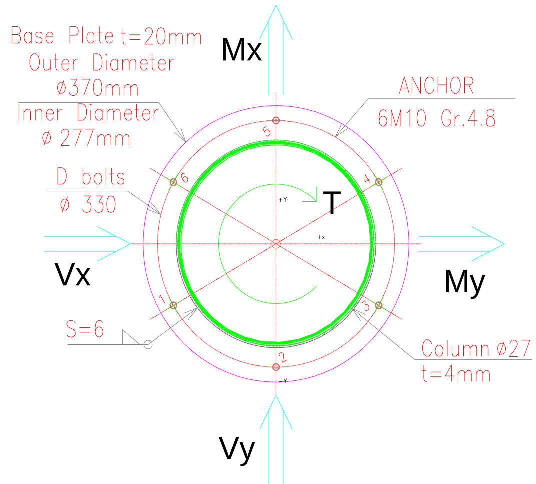


Figure (3) LAYOUT FOR THE CONNECTION

2- Output data

Table 13: Axial and lateral Stiffness of each A. Bs

anchor label	x mm	y mm	h mm	$K_{L\ t/cm}$	$K_{a\ t/cm}$
1	-142.89	-82.5	40.00	16.396	321.621
2	0	-165	40.00	16.396	321.621
3	142.89	-82.5	40.00	16.396	321.621
4	142.89	82.5	40.00	16.396	321.621
5	0	165	40.00	16.396	321.621
6	-142.89	82.5	40.00	16.396	321.621
			Sum=	98.378	1929.723

Table 14: Center of rigidity calculation

anchor label	K_L * X	K_L * Y	K_a * X	K_a * Y
1	-234.286	-135.269	-4595.636	-2653.370
2	0.000	-270.539	0.000	-5306.739
3	234.286	-135.269	4595.636	-2653.370
4	234.286	135.269	4595.636	2653.370
5	0.000	270.539	0.000	5306.739
6	-234.286	135.269	-4595.636	2653.370
Sum	0.000	0.000	0.000	0.000

Table 15: Center of rigidity for the connection

$X`_{lat.}$=	0.00 Cm	
$Y`_{lat.}$=	0.00 Cm	
$X`_{axial.}$=	0.00 Cm	
$Y`_{axial.}$=	0.00 Cm	
$T_{sub.}$=	0.00 T.m	C.W
T=	0.00 T.m	C.W

Since there is no eccentricity, no additional loads will be generated

Table 16: Axial Forces Due to N, Mx and My

anchor label	$X_{CR\ cm}$	$Y_{CR\ cm}$	X_{CR}^2 $_{cm2}$	Y_{CR}^2 $_{cm2}$	$K_{lat}(X_{Cr}2+Y_{Cr}2)$
1	-14.29	-8.25	204.176	68.063	4463.691
2	0.00	-16.50	0.000	272.250	4463.888
3	14.29	-8.25	204.176	68.063	4463.691
4	14.29	8.25	204.176	68.063	4463.691
5	0.00	16.50	0.000	272.250	4463.888
6	-14.29	8.25	204.176	68.063	4463.691
				Sum	26782.540

Table 17: Mx and My

M_{Gxt} =	50.00 t.cm	^^
M_{Gyt} =	0.00 t.cm	>>

Table 18: Resultant of axial forces

anchor label	X_{CR} cm	Y_{CR} cm	$K_{a\ t/cm}$	K_a * X_{CR^2}	K_a * Y_{CR^2}	N_1 ton	N_2 ton	N3 ton
1	-14.3	-8.3	321.6	65667	21890	0.00	0.51	0.00
2	0.0	16.5	321.6	0.00	87561	0.00	1.01	0.00
3	14.3	-8.3	321.6	65667	21890	0.00	0.51	0.00
4	14.3	8.3	321.6	65667	21890	0.00	-0.51	0.00
5	0.0	16.5	321.6	0.00	87561	0.00	-1.01	0.00
6	-14.3	8.3	321.6	65667	21890	0.00	-0.51	0.00
Sum	0.000	0.000	1929.7	262668	262684	0.00	0.00	0.00

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