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Influence of test parameters/methods on qualification of expansion anchors

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ABSTRACT

Recently tests were performed in Canada, the USA and Europe on sleeve type expansion anchors by applying dynamic tensile and shear loads on these anchors installed in concrete blocks. These dynamic load tests were followed by static tensile and shear load tests to establish the failure loads and the failure modes. From a comparison of the test results regarding failure modes and failure loads, a method is proposed to derive the anchor spacing and edge distances in anchor installations.

1. INTRODUCTION

One of the requirements for the use of expansion anchors in Nuclear Power Plants is that they shall be able to withstand the seismic loads prescribed in the design of the plant and still maintain the integrity of anchoring of equipment and components to the concrete structurers of the plant.

The use of expansion anchors involves proper selection of the anchors and the correct installation of these in accordance with the specifications. Proper selection requires careful consideration of the load carrying capabilities based on their ability to withstand the prescribed seismic loads. The load carrying capabilities are established by testing the expansion anchors installed in concrete blocks to the specified dynamic tensile and shear loads representative of the seismic loads.

Following these dynamic load tests, the installed anchors are subjected to static tensile and shear loads until failure of the installed anchor itself or of the concrete block occurs. The maximum static tensile and shear loads sustained by the anchor before failure occurs are defined as the anchor failure loads. These failure loads are used as the basis for establishing the load capacities of the expansion anchors for use in Nuclear Power Plants.

The test requirements, procedures and methods specified are outlined for the testing of expansion anchors used in the CANDU Nuclear Power Plants located in the Republic of South Korea. The tests were conducted in both Canada and Europe. The results of these tests are briefly described. A comparison is made of these test results with the results of the similar tests done in the USA to assess the influence of test parameters and methods on installed anchors. The conclusions drawn from this comparison are presented with respect to the failure modes and failure loads of the installed anchors. From this comparison, a new method is presented for establishing the anchor spacing and edge distances in group anchor installations.

2. EXPANSION ANCHOR TESTS :

Sleeve type expansion anchors, made of high strength carbon steel, were tested.
For the tests conducted in Canada and Europe [1,2], the testing requirements and procedures were in accordance with the CSA Standards-CAN/CSA-N287.2-M91 [4].
For the other tests conducted in the USA [3], the test criteria specified by the anchor manufacturer were followed.

2.1 *Test Requirements and Procedures* :

For the Canadian and European tests, the following requirements were specified :

a) Concrete test blocks : Unreinforced, with 20MPa compressive strength, and the dimensions of the concrete blocks in accordance with the ASTM-E488-90 [5].
b) Pretorque : In accordance with the anchor manufacturer's specifications.
c) Dynamic, tensile and shear loading : Varying loads and load cycles with increasing number of cycles at decreasing loads ; Test frequency = 5Hz.
d) Static tensile and shear loading : Loading until failure of the anchorage system occurs.

The anchor load vs displacement (deformation), failure loads and failure modes were recorded. For the tests in the USA [3], the concrete strength (Table 1.b.2) and the dynamic tensile and shear loadings specified were different from those for the Canadian and European tests. The failure loads and the failure modes were recorded from these tests.

2.2 *Testing Methods and Apparatus* :

For all the tests, the methods employed and the apparatus used were generally in accordance with the ASTM-488-90 Standards [5].

Although the load application, load measurement and the displacement measurement methods for the installed anchors were generally the same, the equipment and apparatus used for these purposes were understandably different between the tests in Canada, Europe and the USA.

3. COMPARIOSN OF TEST RESULTS

Summaries of the tests results on failure loads in tension and test parameters are shown in Tables 1.a, 1.b1 and 1.b.2. From these tables, the following observations are made :

a) *Concrete strength, test block size and anchor embodiment depth*

From the Canadian and European test, for the same concrete strength and anchor embedment depth, the failure loads in tension are generally higher for larger block sizes than they are for smaller block sizes. (It is to be noted that the ASTM-E488 does not specify the upper limit for block sizes).

However, the test results from the USA indicate that the failure loads are, generally, lower than the values from the Canadian tests eventhough the concrete block size is relatively larger and the concrete strength is higher.

These lower values are perhaps attributable to the condition of the anchor embedment following the dynamic tensile load test. The dynamic tensile loading of the expansion anchors in the USA tests was significantly different from that of the Canadian and European tests.

The embedment depths and pretorquing of the anchors in the test block for each anchor size was maintained the same in all the three tests.

b) *Dynamic tensile loads* :

The influence of dynamic tensile loading on the anchors installed and pertorqued in concrete would be to relax the mechanical binding forces between the expansion cone metal of the installed anchor and the walls of the hole in the concrete block. The magnitude of relaxation depends on the dynamic load, number of load cycles at each load level and the frequency at which the cyclic load is applied. The greater the relaxation, lower will be the subsequent static failure load in tension. Such an influence provides a possible explanation for the lower failure loads in static tension recorded in the USA tests, eventhough the concrete strength is higher and the concrete test block size is larger than those in the Canadian tests.

c) *Failure modes* :

The majority of the failure modes in all the tests is seen to be concrete failures - either concrete cracks or concrete cone failures. In general, with the larger concrete test block sizes, most of the failures are concrete cone failures.

From the following equations available in the ACI report and EOTA guide lines [6,7], the failure loads in static tension and the failure cone angle can be calculated.

i) For failure loads in tension : $Fs = 4\varnothing(\sqrt{fc'})\ A$, 1b............[6, Eqn.3.2]

$Fu = 13.5(Id)^{1.5}\sqrt{fc'}$, 1b..........[7, Eqn B-3]

ii) For concrete failure cone angle : $\propto = 62\text{-}1.1\ (Id)^2$, deg.......[6, Eqn 3.4]

$\propto = 45+0.79\ (6\text{-}Id)^2$, deg..[6, Eqn 3.5]

The concrete failure cone angles are calculated from the equations in (ii) above. Using these calculated failure cone angles, the failure loads in tension can be calculated from the equations in (i) above.

Table 2 lists the calculated failure loads and the concrete failure cone angles. The actual test values of failure loads in tension from the European tests [2] and the calculated failure cone angles using the actual failure loads are also listed in Table 2 for comparison. It is noted that the failure loads predicted by the ACI equation are closer to the actual test values recorded in the European tests than are the failure loads predicted by the EOTA equation.

The following conclusions are drawn from the foregoing comparison of test results :

a) The concrete strength has little influence on the concrete failure cone angle ;
b) The concrete test block size, and also the anchor to concrete edge distance have a significant influence on the failure load and the concrete failure cone angle ;
c) Dynamic loading, viz.load levels and the number of cycles at each load level, have an impact on the failure loads, and, hence, the static load capacities of the anchors.

4. PROPOSED METHOD TO DERIVE THE ANCHOR SPACING AND EDGE DISTANCES

Based on the results of the tests in Europe [2] and on the Tables 1 and 2, the following formula is proposed to derive the anchor spacing and edge distances in anchor installations.

$$\theta = 60 - 1.5\ (Id_1 - Id)^2 + (Id_2 - Id_1),\ \text{...deg.....(4.1)}$$

Where, Id = Embedment depth for first anchor size

Id_1 = Embedment depth for second larger anchor size

Id_2 = Embedment depth for 3rd larger anchor size

Where, When Id < 5 in → Follow equation 4.1

When 5 in ≤ Id → $(Id_1 - Id) = (C - Id)$

and $(Id_2 - Id_1) = 0.9$

Example : Id = 5.89 → C = 6

Id = 6.2 → C = 7

The calculated anchor spacing and edge distances are listed in Table 3.

TABLES :

1. Test Results and Comparison of Test Results for HSL/HSLG (ASTM 449.GR.5) Sleeve Expansion Anchors

Table - 1.a. *Average Failure Load in Tension* Unit : lbs

Anchor Size	M8	M10	M12	M16	M20	M24
Manufacturer's Recommended Load	4339	6519	9419	16073	21716	28550
Schann in Switzerland	6047	7284	10363	15151	28291	36473
McMaster in Canada	5504	8285	8377	16344	19306	24777
Texas in U.S.A.	4460	8100	9460	15060	25680	25700

Table-1. b.1. *Embedment Depth and Failure Mode*

Location / Anchor Size (mm)	SCHANN	MCMASTER	TEXAS	REMARKS
M8 (65)	Qt'y ⓐ 7=cone	ⓐ 4 = cone 2 = Anchor Slip then Block Fracture	ⓐ 5 = cone	(ASTBF)
M10 (75)	ⓐ 6 = cone	ⓐ 2 = Anchor Pullout 4 = ASTBF	ⓐ 5 = cone	(AP)
M12 (80)	ⓐ 6 = cone	ⓐ 3 = Anchor Pullout 3 = ASTBF	ⓐ 4 = cone 1 = A.P	
M16 (105)	ⓐ 10 = cone	ⓐ 1 = A.P 1 = ASTBF 2 = Radiating Crack 2 = cone	ⓐ 5 = cone	(RC)
M20 (130)	ⓐ 7 = cone	ⓐ 3 = A.P 3 = ASTBF	ⓐ 4 = cone 1 = A.P	
M24 (155)	ⓐ 6 = cone ⓐ 2 = concrete crack	ⓐ 1 = R.C 1 = A.P 1 = ASTBF	ⓐ 5 = cone	

Table - 1.b.2. *Concrete Compressive Strength and Block Dimension*

	SCHANN	MCMASTER	TEXAS
Concrete Strength			
- Specified	3000 psi (20 MPa)	3000 psi (20 MPa)	4000 psi (28 MPa)
- Actual	2400~3400 psi	3500 psi	4393~5516 psi
Concrete block Dimension (mm) L×W×T - Actual	4700×1300×320	For Sizes up to M12 533×305×152 For sizes from M16 to M24 533×410×305	2200×1000×600

	Embedment (E)	Spacing between anchors (s)	Distance to edge of test frame (M)	Structural member thickness (T)
- Specified (ASTM E488-90)	〈6.0d 6.0d 〈8.0d〉 8 .0d	3.50E 2.00E 1.50E	1.75E 1.00E 0.75E	1.5E 1.5E 1.5E

2. Calculated and Actual Expansion Anchor Failure Values

Table - 2 : *Calculated and Actual Failure Loads and Concrete Failure Cone Angles*

Anchor Size (Calculated and Actual)		ACI 355.IR-91 Equation (3.2,3.4,3.5)	Actual Test Result in Schann	EOTA doc' t No. 164.2 Equation (B.3)	ASTM E488-91
M8 (65)	U. F. L (lbs)	5344	6047	2976	3767
	C. F. Cone Angle	54.8°	58.01°	36.38°	45°
	Con'c cone radius (R) mm	92.1	104.1	47.9	65
M10 (75)	U. F. L (lbs)	6500	7284	3689	5015
	C. F. Cone Angle	50.4°	55.45°	36.96°	45°
	Con'c cone radius (R) mm	90.7	109	56.4	75
M12 (80)	U. F. L (lbs)	7155	10363	4064	5706
	C. F. Cone Angle	51.42°	61.15°	35.45°	45°
	Con'c cone radius (R) mm	100.3	145.2	57	80
M16 (105)	U. F. L (lbs)	10801	15151	6110	9830
	C. F. Cone Angle	47.75°	57.03°	31.91°	45°
	Con'c cone radius (R) mm	115.6	161.9	65.4	105
M20 (130)	U. F. L (lbs)	15403	28291	8418	15068
	C. F. Cone Angle	45.61°	61.96°	29.17°	45°
	Con'c cone radius (R) mm	132.8	244.1	72.6	130
M24 (155)	U. F. L (lbs)	21420	36473	10959	21420
	C. F. Cone Angle	45°	59.57°	27.11	45°
	Con'c cone radius (R) mm	155	263.9	79.4	155

Table - 3 *Recommended Minimum Anchor Spacing and Edge Distance Requirements.*

Con'c Cone Radius (R)	Expansion Anchors	
	Spacing Between Anchors (S)	Distance Edge (M). min.
< 11.0d (Shallow)	5.50 E	2.75 E
11.0d < R < 13.0d (Standard)	3.15 E	1.57 E
> 13.0d (Deep)	2.37 E	1.18 E

Where, $R = E/\tan\alpha$; E = Embedment depth

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