C E L CONSULTING

A DIVISION OF CONSOLIDATED ENGINEERING

REPORT OF MAXI-BOLT ANCHOR TESTING
FOR THE

HANFORD RIVER PROTECTION PROJECT
WASTE TREATMENT PLANT

TESTING ACCORDING TO BECHTEL NATIONAL, INC.

Engineering Specification for Purchase of Post Installed Concrete Anchors for Important Safety (ITS) Applications No. 24590-WTP-3PS-FA02-T002

Performed for

Drillco National Group, Inc.
Long Island City, New York

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1. INTRODUCTION

Bechtel National has developed qualification requirements for post-installed anchors to be used in important safety applications. The results of the qualification will be used to develop design requirements for the anchors. The qualification requirements are based on the anchoring requirements of Appendix B, Section B.3.3 of ACI 349-01. Since the ACI 349 requirements are not prescriptive, test procedures were generally based on ACI 355.2-01 requirements. The Drillco Maxi-Bolt Undercut Anchor was selected by Bechtel National for the qualification testing.

2. SCOPE

The test program was divided into three phases. Phase I includes ACI 355.2 Test Nos. 1 (uncracked), 3 (cracked) and 12 (seismic cracked) for the 3/8" through 3/4" sizes. Also included is one series of Test No. 3 in a test member with minimum reinforcement to control the crack width. Phase II includes ACI 355.2 Test No. 10 (uncracked spacing and edge distance verification) and 11 (uncracked shear). Phase III includes ACI 355.2 Test No. 3 for the 1" and 1 1/4" sizes. Anchor embedment was selected to ensure concrete breakout (cone) failures for Test Nos. 1 and 3 so that k factors could be calculated. Embedments used for the other tests were initially specified to be the same for consistency. The results of Test Nos. 1 and 3 were used to develop the k and Ψ_3 factors. Test No. 12 is a pass/fail test to verify acceptability for use in resisting seismic loading. Results of Test No. 10 were used to justify minimum spacing and edge distances.

Direction as to the ACI 355.2 tests, the number of replicates and the concrete strength range was provided by Bechtel National. A concrete strength range of 3000 to 4000 psi was used instead of the ACI 355.2 range of 2500 to 3500 psi. Fewer replicates of Test No. 1 was considered acceptable by Bechtel due to good correlation of test results with previous Drillco tests at a nuclear plant in Arkansas.

The following table provides the scope of the testing program.

Table 1

PHASE	ACI 355.2 Test Number	CEL Procedure	Anchor Size, in.	Number of Tests*	Anchor Embedment, in.
I	1	TP01	3/8	3/5	2 1/2
	1		1/2	3/5	3 1/2
	1		5/8	3/5	4 1/2
	1		3/4	3/5	5 1/2
	3	TP17	3/8	5	2 1/2
	3		1/2	5	3 1/2
	3		5/8	5	4 1/2
	3		3/4	5	5 1/2
	12	TP17/TP15	3/8	5	2 1/2
	12		1/2	5	3 1/2
	12		5/8	5	4 1/2
	12		3/4	5	5 1/2
	3*	TP17	5/8	5	4 1/2
II	10	TP17S2	1/2	3/5	3 1/2
	10		3/4	3/5	5 1/2
	11	TP17	1/2	3/5	3 1/2
	11		3/4	3/5	5 1/2
III	3	TP17	1	3/5	7
	3		1 1/4	3/5	11

*"3/5" means perform 3 tests & evaluate data to determine necessity of 2 additional tests
**Test member with minimum reinforcing ratio

3. TEST SPECIMENS

The Drillco Maxi-Bolt is an undercut-type concrete anchor with an external sleeve that is expanded into a conical undercut hole created by a special undercutting tool. The anchor consists of a threaded stud bolt, an expansion sleeve, a conical nut at the bottom of the stud, a distance (spacer) tube, washer and nut. The anchors used for this program had stud bolts made from ASTM A 193 B7 steel. Anchor lengths were provided to meet the selected anchor embedments. Test anchors and special tooling were supplied by Drillco.

4. FACILITIES AND TEST EQUIPMENT

4.1 General:. All testing was performed at the CEL anchor testing laboratory in Oakland, California. Drawings of the various test configurations with listings of equipment are provided in Appendix 4.

4.2 Static Testing: A hollow-core hydraulic cylinder, controlled by an electric pump with metering valve, was used to apply load to the anchors by linkages of threaded rods and steel fixtures. Loads were measured using an electronic load cell mounted under the hydraulic cylinder and a PC-based data acquisition system. The hydraulic cylinder and load cell were mounted on a steel load frame which provided bridging so that reaction loads were not imposed on the surface of the concrete within the distance, *m*, specified in Table 2 of E 488 from either the anchor axis. Anchor movement during loading was measured using a calibrated linear variable displacement transducer (LVDT) and the data acquisition system.

4.2.1 Tension Testing: A loading plate meeting the requirements of E 488 Section 5.4 was installed on each anchor. A yoke and clevis assembly was used to engage the loading plate. A high strength threaded pulling rod was inserted through the hydraulic cylinder and load cell mounted on the load bridge and connected to the yoke and clevis. A heavy nut and plate washer above the hydraulic cylinder was used to transfer load to the pulling rod. Anchor movement relative to the surface of the concrete test member during loading was measured using the LVDT positioned over the projecting end of a 1:1 displacement balance. The other end of the displacement balance rested on the exposed end of the anchor.

4.2.2 Shear Testing: Loading plates are hollowed, hardened steel cylinders. Anchors were installed into the sides of test members with the loading plate placed over the anchors. An annular ring connected to the pulling rod was placed over the loading plate and connected to the hydraulic cylinder/load bridge assembly in the same configuration as the tension tests. A sheet of teflon 0.020" thick was placed between the shear plate and the concrete surface, in compliance with Section 6.4.3.1 of E 488. The LVDT was positioned to measure displacement of the test anchor relative to the concrete surface in the direction of the applied load.

4.3 Simulated Seismic Tension Testing: Equipment and fixtures for seismic cyclic testing were in compliance with E 488, Section 9.2 "Equipment" in addition to the requirements of Section 4.1 of this report. The loading system is supported on an independent rigid frame with no reactions on the test member. Test members were positioned and securely attached to the concrete reaction floor to resist test load reactions and to prevent movement during testing. Anchors were installed so that they were at least the required distance away from the test member tie downs.

For Test No. 12 a loading plate was installed over the anchor. A yoke and clevis assembly was used to engage the loading plate. A high strength threaded pulling rod was connected to the yoke and clevis assembly and to the hydraulic actuator. Anchor movement relative to the surface of the concrete test member in the direction of loading was measured using a linear variable differential transducer (LVDT) positioned over the projecting end of a 1:1 displacement balance. The other end of the displacement balance rested on the exposed end of the anchor.

A closed loop hydraulic system consisting of a hydraulic ram actuator with integral load cell mounted on a large steel test frame was used to load the test anchors. The 22 kip hydraulic actuator ram was controlled by a MTS 406 controller capable of applying sinusoidal load cycles. A PC-based control and data acquisition system consisting of National Instruments computer board and MTS General Purpose Application software was used to control the loading sequences and record the data.

4.4 Testing in Cracks

4.4.1 Phase I: Two strain gage-type crack measurement transducers were installed across each crack, approximately equidistant on each side of the anchor to measure the crack width.

For the minimum reinforcement test, three steel "stone cutter" wedge splitters were used to create the cracks at the desired locations by installing the split sleeves in holes drilled in the test member and driving the wedge inserts into the sleeves using a heavy hammer.

4.4.1 Phase III: Two large, hardened steel "stone cutter" wedge splitters were used to create the cracks at the desired locations. A custom-fabricated load bridge was used with equipment described in Section 4.2.

Photographs of the various test equipment and configurations are provided in Appendix 5.

5. TEST MEMBERS

5.1 Phase I: Typical test members for cracked tests were rectangular with dimensions 30" wide x 16" deep x 80" long. Four #9 Dywidag Grade 75 reinforcing bars running longitudinally were placed in each corner and projected from each end to allow tensioning to create the cracks. Four or five sheet metal crack inducers were equally spaced along the length of each member and securely held in place during concrete placement by attachment to the wood forms.

For Test No. 3 with minimum reinforcement, a test member with dimensions 50" wide x 88" long x 12" thick was used. Longitudinal reinforcement consisted of six #4 Grade 60 reinforcing bars in a double layer with two bars near each edge and two in the middle. Transverse #4 bars, similarly located, were installed to provide support for the longitudinal bars.

Test members for uncracked tests were unreinforced with dimensions of 72" by 36" in plan by 24" thick.

5.2 Phase II: For Test No. 11 test members with the same configuration as the Phase I uncracked tests were used.

For Test No. 10 unreinforced test members with plan dimensions of 8' x 4' were used. Thickness was 1.5 times anchor embedment. The initial tests were done with thicknesses of 5 1/4" and 8 1/4" based on the anchor embedments. Final tests were done in 12" thick members based on 8" embedments used for these tests.

5.3 Phase III: A 60" x 60" x 24" thick unreinforced slab was used for a preliminary uncracked test. The final test member dimensions for cracked Test No. 3 were 6' wide x 18' long x 40" thick. The member was reinforced with twenty-four #9 Grade 60 bars. Four sheet metal crack inducers were spaced along the length of each member and securely held in place during concrete placement by attachment to the wood forms.

5.4 Component Materials: Concrete was supplied by RMC Pacific from their ready mix plant in Oakland, CA. The coarse aggregate is a crushed basaltic rock from the RMC Pacific Clayton Quarry approximately fifteen miles east of Oakland. It is described by geologists as a fine-grained, crystalline igneous rock or metavolcanic diabase. The 1" maximum size gradation (No. 57) was used for the test specimens. The fine aggregate is a naturally occurring sand from the Pleasanton area, a major source of concrete aggregates for over fifty years. These aggregates meet the requirements of ASTM C 33 and have a long history of use in the San Francisco area. They have been and continue to be used for a wide variety of concrete construction and, therefore, are representative of typical concrete construction when used as anchor test specimens.

5.5 Concrete Placement: Inspection of the batching, placement, sampling and preparation of compression test specimens was performed under the direct supervision of Lee Mattis, a certified ACI Concrete Field Testing Technician-Grade I and also a registered civil engineer.

5.6 Strength Tests: Compression test specimens were tested by Consolidated Engineering Laboratories Concrete Laboratory. All test specimens were field-cured in the immediate vicinity of the test members under similar environmental conditions until just prior to testing. Compression test specimens were tested on a set schedule at ages of 7, 14, 21, 28, 35 and 47 days and intermediate and later ages as required. Two specimens were tested at each age during the test periods. Compressive strengths at actual test dates were calculated from the strength versus age graphs for each concrete placement using the Excel logarithmic curve fitting function. Graphs for the various concrete placements used for the testing are provided in Appendix 3.

Drawings and photographs of the various types of test members are provided in Appendix 4 and Appendix 5 respectively.

6. TEST PROCEDURES

6.1 Anchor Installation: Anchors were installed by one of the three methods: hydraulic setting, hydraulic tensioning or torque tensioning, in accordance with Drillco standard installation procedures. A representative of Drillco trained our personnel in the proper installation procedures at the start of the testing. All drill bits were provided by Drillco. Primary hole drill bits were measured and undercutting bits were measured or checked with go-nogo gages prior to testing to confirm conformance with Drillco specifications. The table below summarizes the installation for each Test No. A variation of installation procedures was used in some cases to determine differences in performance as noted in the table. Hydraulic tensioning was found to reduce the standard deviation and to increase the average ultimate load, providing a higher k factor. Since the anchors will be fully tensioned for actual field installations, the test results are representative of future field installations. It is noted that for the hydraulic tensioning installations the tension load was applied and then released so that the test fixtures could be installed and was approved by Drillco. For testing this procedure is conservative since a clamping force is not present. For actual installations the tension load would be applied with the item being attached in place and not be released.

Installation Procedures – Phases I and III

Anchor Size, in.	Test Number/Installation Procedure		
	1	3	12
3/8	3 Hydraulic Tensioned	5 Hydraulic Tensioned	5 Hydraulic Tensioned
1/2	1 Hydraulic Set 1 Torque Tensioned 1 Hydraulic Tensioned	5 Hydraulic Set	3 Hydraulic Set
5/8	2 Hydraulic Tensioned 1 Torque Tensioned	7 Hydraulic Set 5 Hydraulic Tensioned	1 Hydraulic Tensioned
3/4	1 Hydraulic Set 1 Torque Tensioned 1 Hydraulic Tensioned	6 Hydraulic Set	3 Hydraulic Set
1		4 Hydraulic Tensioned	
1 1/4		3 Hydraulic Tensioned	

Installation Procedures – Phase II

Anchor Size, in.	Test Number/Installation Procedure	
	10	11
1/2	All Torqued	3 Hydraulic Set
3/4	All Torqued	2 Hydraulic Set

6.2 Static Testing: The loading system and LVDT were positioned as described in Section 4.2. An initial load up to a maximum of 5% of the expected ultimate capacity of the anchor was applied to the test anchor according to Section 8.5 of E 488. The continuous load application method described in Section 8.6.1 of E 488 was used. The required loading rate of 25% to 100% of the expected ultimate capacity of the anchor system per minute was achieved by controlling the hydraulic flow from the pump with an adjustable valve. Load application was continued until failure of the anchor. Test information was documented in an Excel computer data spreadsheet file for each test series. Descriptive information was recorded manually on an anchor test data form, and test data was imported to it after each test. Load versus displacement graphs were plotted from the test data in the same computer file.

6.3 Simulated Seismic Tension Testing: The Neq value was determined as 50% of the mean ultimate load for Test No. 3 for each size. Minimum test loads, Nm, were determined as one-fourth of the Test No. 3 mean ultimate load. The intermediate test loads, Ni, were developed by averaging the Neq and Nm values. Calculation of these load levels was as specified in Section 9.6.2 of ACI 355.2.

Test members were positioned and restrained as described in Section 4 of this report. Load was applied by connecting the hydraulic actuator to the yolk assembly with a threaded rod and engaging the yolk and clevis assembly with the loading plate. Displacement was measured using an LVDT and displacement balance as described in Section 4. Load was applied in the increments and number of cycles prescribed by ACI 355.2. The load was cycled sinusoidally at a frequency of 0.2 Hz between a load no greater than 5% of the Test No. 3 mean ultimate load and the required load increment. After the cyclic sequence, a static test to ultimate load was performed. Test data was imported from the data acquisition program to an Excel computer file for each test.

6.4 Testing in Cracks: CEL Test protocols, based on ACI 355.2-01, were used for testing in cracks. The typical procedure is summarized as follows:

- The test member is cracked and the cracks are opened to be visible
- Crack locations are marked on the surface and then closed
- The hole is drilled at the surface location of the crack
- Two crack measurement transducers installed approximately equidistant from the hole
- The anchor is installed
- The crack is opened by the required amount
- The test is performed while monitoring, but not controlling the crack width.
- Visual confirmation that the anchor force transfer mechanism is located in the crack is done after the anchor is removed

6.4.1 Phase I: To create the cracks the four hydraulic rams were simultaneously energized using a manifold to apply tension to the reinforcing bars. The resulting elongation of the steel transfers forces to the concrete and creates tension within the concrete member. The tensile forces are relieved at the crack inducer locations when the tensile forces exceed the tensile capacity of the concrete. The crack width is controlled by increasing or decreasing the pressure to the hydraulic rams. The output from each crack measurement transducer was recorded and averaged. A plot of the individual and average widths versus test time is included in the test data.

6.4.2 Phase III: The two split sleeves of the wedge splitter assemblies were installed in holes core-drilled at the location of the crack inducers. Cracks were initiated and controlled by simultaneously pulling the projecting threaded ends of the wedge inserts through the split sleeves using hydraulic rams. Crack width was measured and recorded as described for Phase I.

Anchor test data forms and corresponding graphs for each phase and test series are located in Appedix 2.

7. RESULTS and ANALYSIS

7.1 Phases I and III: Table 2A summarizes the results of the testing and calculations needed to develop the design specification. Actual average ultimate results for each test series, average loads normalized to 3000 psi concrete strength, 5% fractile loads for Test Nos. 1 and 3, comparison of ultimate tensile test results performed after the cyclic sequences to the reference loads and the calculated k, Ψ_3 and β factors are provided. Table 2B provides results for the minimum reinforcement series.

All tests exhibited predictable load-displacement behavior as required by ACI 355.2. The failure mode for all tests was a concrete breakout (cone). Pullout or pull-through type failures as defined by ACI 349 were not observed for any tests.

Table 2A

Anchor Specifications						
Anchor nominal size, in.	**3/8**	**1/2**	**5/8**	**3/4**	**1**	**1 1/4**
Embedment depth, $h_{ef,}$ in.	2.5	3.5	4.5	5.5	7	11
Outside diameter, d_0, in	0.630	0.805	0.905	1.100	1.625	2.000
Test Results[1], lbs. $f_{c,test}$ = Actual Concrete Strength						
Test No. 1 - Reference uncracked	8493	14207	19474	33816	-	-
Test No. 1 - Number of tests[6]	3	3	3	3	-	-
Test No. 3 - Reference cracked	7320	13615	18517	27091	44890	91053
Test No. 3 - Number of tests[6]	5	6	6	6	4	3
Test No. 12 - Seismic tension	7058	12179	16274	24986	-	-
Test No. 12 - Number of tests[6]	5	3	1	3	-	-
Test Results[1], lbs. Normalized to $f_{c,m}$ = 3000 psi						
Test No. 1 - Reference uncracked	7776	12815	18303	30607	-	-
Test No. 1 - COV	2.18%	5.60%	5.55%	7.84%	-	-
Test No. 1 - 5% level, $F_{5\%}$[2]	6875	9002	12911	17865	-	-
Test No. 3 - Reference cracked	6675	12105	16670	25946	42875	88063
Test No. 3 - COV	4.50%	8.29%	7.13%	10.72%	7.24%	5.51%
Test No. 3 - 5% level, $F_{5\%}$[2]	5653	9001	12993	17343	30599	62303
Test No. 3 - 80% of reference ult.	5340	9684	13336	20757	-	-
Test No. 12 - Seismic tension[3]	6421	10848	14630	23811	-	-
Calculated Factors						
k, Uncracked effectiveness factor	31.8	25.1	24.7	25.3	-	-
k, Cracked effectiveness factor	26.1	25.1	24.9	24.5	30.2	31.2
Ψ_3, Cracked modification factor[4]	1.22	1.00	0.99	1.03	-	-
Stiffness Values, kips/in.						
β, Anchor stiffness, Test no. 1[5]	173.4	478.3	375.9	915.5	-	-
β, Anchor stiffness, Test no. 3[5]	78.1	118.6	196.1	500.1	410.5	862.8

[1] Results represent average of test values for each Test No.

[2] Represents 5% probability of nonexceedence with a confidence of 90% (ACI 355.2 Section A2)

[3] Test No. 12 (residual capacity after cyclic) must be greater than 80% of Test No. 3

[4] Represents ratio of Test No. 1, 5% to Test No. 3, 5%

[5] Average stiffness for anchors not fully tensioned, excluding outliers

[6] Represents number of tests used in calculations; excludes improper tests

Table 2B – Test Member with Minimum Reinforcement

Anchor & Testing Specifications	
Reinforcement ratio, ρ, %	0.20
Anchor nominal size, in.	5/8
Embedment depth, h_{ef}, in.	4.5
Outside diameter, d_0, in	0.905
Test No. 3 Results[1], lbs.	
Actual Results	16154
Number of tests	5
Results normalized to $f_{c,m}$ = 3000psi	15905
COV	9.50%
5% level, $F_{5\%}$[2]	10766
Calculated Factors	
k, Cracked effectiveness factor	20.6
Stiffness Value[3], kips/in.	
β, Anchor stiffness	637.4

[1] Results represent average of test values
[2] Represents 5% probability of nonexceedence with a confidence of 90% (ACI 355.2 Section A2)
[3] Average stiffness for anchors not fully tensioned, excluding outliers

Test results were normalized to 3000 psi using ACI 355.2 Formula A1-1. The k factors were calculated using ACI 355.2 Formula 7-1 and the normalized 5% fractile results. Ψ_3 factors were calculated using the 5% fractile results of Test No. 1 and dividing by the Test No. 3 5% fractile results for each size.

Stiffness factors were calculated using ACI 355.2 Equation 6-1 for each individual test and averaged for the test series. Anchors that were fully tensioned as well as outliers were excluded from the averages. The load and displacement values used in each calculation are located in Appendix 2.

7.2 Phase II

7.2.1 Test No. 10 (minimum spacing and edge distances): Test members with thickness of 1.5 x embedment used for the other tests were initially used. The first test of the 1/2" size performed at edge and spacing distances of 6 x nominal anchor diameter was not successful. Subsequent tests were done with 6 x and 8 x the outside sleeve diameter with mixed results.

Based on these results, it was apparent that the test member thickness had to be increased. Bechtel directed that tests be performed with the 1/2" size at 8" embedment in a test member 12" thick (1.5 x embedment). After successful results for the 1/2" size, the 3/4" size at 8" embedment was tested in members with the same dimensions. The following table summarizes the tests performed and the edge and spacing parameters. Sheet 4 in Appendix 4 shows the locations for each Test Series No.

Table 3 – Phase II Spacing/Edge Results

Test Series No.	Test No.	Anchor		Tinst ft-lbs	Distances, in.		Maximum Torque[1]	Comments
		Size, in.	Embed, in.		Edge	Spacing		
3DMA081	1	1/2	8	85	12	7 1/8	1.2 Tinst	24" end distance
	2						1.6 Tinst	12" end distance
3DMA083	1	1/2	8	85	4 3/4[2]	4 3/4[2]	1.6 Tinst	12" end distance
	2					1 anch.	2.0 Tinst	In corner-4 3/4" edge
	3					4 3/4[2]	1.4 Tinst	4 3/4" end distance
3DMA121	1	3/4	8	350	6 5/8[2]	n/a	1.4 Tinst	In corner-6 5/8" edge
3DMA122	1	3/4	8	350	6 5/8[2]	6 5/8[2]	1.0 Tinst+100	1 in corner-6 5/8" edge
	2						1.0 Tinst	1 in corner-6 5/8" edge
	3					8 7/8[3]	1.2 Tinst	1 in corner-6 5/8" edge
	4						Tinst+100	1 in corner-6 5/8" edge

[1]Maximum torque achieved (to prevent damage to the test member not all anchors were torqued to failure)
[2] =6 d_0
[3] =8 d_0

7.2.2 Test No. 11 (shear): Shear tests were performed for the 1/2" and 3/4" sizes only to provide evidence of ability to attain minimum shear strength. Table 4 summarizes the results.

Table 4 – Phase II Shear Results

Anchor Specifications		
Anchor nominal size, in.	1/2	3/4
Embedment depth, $h_{ef,}$ in.	3.5	5.5
Outside diameter, d_0, in	0.805	1.100
Test Results[1], lbs.		
Actual Results	11692	26140
Number of tests	3	2
Results normalized to $f_{c,m}$ = 3000psi	11048	24693
COV	7.61%	6.37%
Stiffness Values[2], kips/in.		
β, Anchor stiffness (shear)	80.7	171.4

[1] Results represent average of test values for each Test no.

[2] Average stiffness for anchors not fully tensioned, excluding outliers

8. CONCLUSIONS

The testing program was conducted in conformance with the requirements of the applicable specifications and the technical direction of Bechtel National.

9. REFERENCES

1. American Society for Testing and Materials, West Conshohocken, Pennsylvania: ASTM E 488-96, *Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements*
2. American Concrete Institute, Farmington Hills, Michigan: ACI 349-01, *Code Requirements for Nuclear Safety Related Concrete Structures*
3. American Concrete Institute, Farmington Hills, Michigan: ACI 355.2-01, *Evaluating the Performance of Post-Installed Mechanical Anchors in Concrete*
4. Bechtel National, Richland, Washington: *Engineering Specification for Purchase of Post Installed Concrete Anchors for Important Safety (ITS) Applications No. 24590-WTP-3PS-FA02-T002*