Cyclic shear load testing of concrete expansion anchors

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ABSTRACT This paper presents an overview of cyclic shear load testing of single wedge-type concrete expansion anchors in unreinforced concrete. A brief comparison of existing test standards for cyclic shear loads is presented. The development of a test program to simulate seismic and fatigue cyclic shear loading and the results of tests performed in accordance with the test program are summarized. Tests performed confirm a wedge-type concrete expansion anchor can resist alternating shear load cycles.

1. INTRODUCTION

Concrete expansion anchors (CEAs) are utilized for anchorage of various items in nuclear plants. There is currently no widely accepted industry standard usage and performance criteria for concrete expansion anchors which may be subject to various types of dynamic loads. Nor is there an industry standard to ensure that different types of anchors from the same vendor will perform as assumed under various conditions and types of loading applications. ASTM E488[1] provides some standard requirements for testing of CEAs, however the criteria provided are not necessarily complete. ACI 349[2] specifies that the performance criteria required for an expansion anchor must be consistent with the assumptions of the designer. ACI 349 also requires that sufficient testing be performed to ensure the anchor will behave as assumed. Therefore, it is the duty of the designer to ensure a test program encompasses all appropriate factors which may affect the CEA performance. This paper describes the background and development of a test program for single carbon steel wedge-type expansion anchors in unreinforced concrete subjected to alternating shear loading cycles.

2. TEST STANDARDS

ASTM E 488 provides the basic standard for testing CEAs in the U. S. CAN3-N287.2[4] specifies Canadian requirements for CEAs when utilized in nuclear power plants. AFNOR E27-816[5] specifies the French requirements for CEAs. None of these standards explicitly
specify the complete requirements deemed necessary to ensure conformance with the design application investigated by the authors.

Table 1 and 2 provide a summary comparison of the major requirements of these standards applicable to dynamic shear loading for low cycle dynamic and high cycle fatigue conditions, respectively.

3. CEA BEHAVIOR AND PREVIOUS TESTING

Numerous reports[3,10] have been published on the behavior and testing of concrete expansion anchors. The majority of reported tests were conducted either for static tension, static shear, or dynamic tension loading. There are few references to dynamic shear loading tests. The authors have seen a few unpublished reports by various organizations on the dynamic shear load testing of some CEAs. Some of these tests were pulsating shear loading and other tests were performed with alternating shear loading. None of the alternating shear loading tests appeared to address high cyclic fatigue. Most tests were limited to one or two selected CEA diameters.

Ammann[8, 9] discussed many aspects of dynamic loading on CEAs. However, little evidence of any testing for dynamic shear loading could be found in published literature.

4. TEST PROGRAM

A test program was developed to confirm the cyclic load capability consistent with the allowable load criteria used in design. The testing consisted of two separate loading regimes: dynamic and fatigue. The dynamic test loading regime was developed to ensure the CEAs would withstand relatively high load levels for a number of cycles which reasonably could be expected from the design basis seismic events over the life of the facility. The fatigue test loading regime was developed to demonstrate the load level which could be resisted for the number of cycles which could accumulate from vibration sources.

Several significant factors, in beyond those specified in ASTM E488-88, required definition.

Firstly, specification of either a pulsating or alternating shear load was required. Typically, cyclic tensile-compression loads acting on anchorage will only impose pulsating tension on a CEA since the compression force will be carried by bearing on the concrete of the anchored element. However, if an alternating cyclic load is applied to a CEA in shear, then the CEA may experience full load reversals. Cyclic shear loads on CEAs resulting from earthquakes, vibrations, and other transient events may act on the CEA with full load reversal in the configurations commonly used in construction. Where the performance capability of the CEA to resist alternating shear load is required, testing to ensure the adequate performance is prudent.

Alternating shear load on a CEA imposes secondary effects which ultimately govern the
resistance capability of the CEA in shear. It was determined that the diameter of the hole in the loading plate and the concrete can be an important factor in alternating shear load resistance. The shear load acting on the loading plate is resisted by the friction between the loading plate and the concrete at first, and then is transferred to the CEA in bearing under higher load level. Therefore, the CEA must slightly deflect in the hole to bear against the concrete. Over an increasing number of loading cycles, the repeated action of reversed lateral forces induces bending in the CEA. The gap and thus lateral displacement may also increase with the number of repeated loading reversals. This may result in impact load effects. Eventually, the CEA loaded by an alternating shear load may, either displace so much that it becomes ineffective in the resistance of the load, or fracture due to repeated distortion caused by load reversals.

One CEA was tested on a trial basis, with an alternating shear load applied having a peak magnitude of 0.25F_{SU}. F_{SU} was defined as the minimum nominal ultimate static shear strength of the anchor. Based on the trial test it was determined that while the CEA could sustain this alternating shear load level for a significant number of cycles, it was evident that it could not sustain the load level for 2 x 10^6 cycles.

A rational basis for the load magnitude and number of load cycles had to be established. It is well established to consider 2 x 10^6 load cycles as number of cycles associated with the fatigue endurance limit of ferrous metals. However, for seismic events this number of load cycles is unrealistically large. The number of significant seismic load stress reversals over the design basis forty year life of a nuclear power plant facility can be estimated from the requirements specified in U.S. NRC Standard Review Plan Sections 3.7.3 [6] and Section 3.9.2 [7]. A lower bound for the possible number of seismic shear load cycles in the facility’s design life was determined as follows:

\[
\begin{align*}
\text{Safe Shutdown Earthquake} & = 1 \\
\text{Operating Basis Earthquakes} & = 5 \\
\text{Total Earthquake Events} & = 6
\end{align*}
\]

assume a minimum of 10 maximum stress cycles per earthquake event
number of maximum seismic cycles = 6 x 10 = 60 cycles

Upon consideration of the lower bound developed above, review of testing previously performed by others for seismic performance, and assessing the results of the trial alternating shear load test performed at a peak magnitude of 0.25F_{SU}, it was concluded that 200 cycles should be sufficient to establish a resonable seismic load resistance capability.

The final factor to be established was the peak load magnitude for the shear fatigue load tests. Based on the trial test, the load magnitude of 0.25F was not deemed to be likely achieved, due to the impact loading experienced by the CEA and subsequent repeated reversing distortions in the CEA. It was postulated that if the load magnitude remained below the slip resistance capability developed between the anchorage base plate and the concrete surface, then the gap, impact and other adverse behaviors exhibited at higher load
levels could be avoided. Calculations were performed to estimate the likely slip load resistance capability which could be developed for each anchor size and for various values of residual pretension in the CEA. It was established that the CEA at 50% of the original installation pretension should resist at least $0.06F_{su}$ without experiencing slip. Prior to performing the shear fatigue load test, slip resistance testing was developed similar to that specified for the slip coefficient for the faying surfaces of slip-critical structural steel connections as shown in Figure 1. Slip load tests were performed with the faying surfaces of both the concrete block and loading plate uncoated. Additional slip tests were performed on coated concrete surfaces, because the sequence of construction may require concrete surfaces to be coated prior to installation of CEA anchorage.

5. TEST RESULT

Dimensional and material considerations followed the requirements of ASTM E 488-88. The concrete was a typical mix used in construction of a nuclear power plant, designed to achieve a compressive strength of 4000 psi in 28 days.

A minimum of three zinc plated carbon steel wedge-type expansion anchors were tested for each diameter which ranged in size from 3/8 inch to 1 inch in diameter. The testing of all anchor sizes required a large number of specimens and approximately four months of testing time.

The CEA's were installed in accordance with the manufacturer's requirements, including the specified setting torque. Just prior to testing each specimen, the torque on each CEA was reduced to 50% of the installation torque to simulate long-term pretension force loss in the CEA. The value of reduced torque was selected based on tests performed by others as noted in ACI 355.1R.

The shear dynamic and fatigue cyclic load tests were successful in demonstrating the capability of the CEA's to resist alternating shear dynamic and fatigue loads. During the actual shear fatigue load test, displacements of the CEA and loading plate were too small to be measured throughout the $2 \times 10^6$ loading cycle history. The residual static shear load capacity test performed after completion of the dynamic and fatigue shear cyclic loading also revealed no specimens were degraded below the minimum nominal static shear strength $F_{su}$.

6. CONCLUSIONS

Existing test standards do not define all of the requirements or characteristics that may be necessary to demonstrate required performance of concrete expansion anchors. The specifying authority must delineate the requirements of a testing program which are consistent with the CEA application in design. Tests on zinc plate carbon steel wedge-type expansion anchors in unreinforced concrete performed in accordance with a testing program described herein revealed: 1) CEA's are capable of resisting at least an alternating load for
2x10^6 cycles, 2) the static shear slip load resistance capability is a conservative indicator of the peak alternating shear fatigue load which can be reasonably resisted.

REFERENCES


2. ACI committee 349, Code Requirements for Nuclear Safety Related Concrete Structures, ACI 349, Appendix B - Steel Embedments, American Concrete Institute, 1985

3. ACI Committee 355, State-of-the-Art Report on Anchorage to Concrete, ACI 355.1R, American Concrete Institute, 1991


9. Ammann, W.J., Static and Dynamic Long-Term Behavior of Anchors, SP 130, American Concrete Institute, 1992

Table 1. Dynamic Shear Load Test Requirements

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<tbody>
<tr>
<td>Frequency of Applied Cyclic Loading</td>
<td>constant frequency or sweep between 1 to 15 Hz or by specifier</td>
<td>by specifier, test program to simulate specific seismic requirements</td>
<td>by specifier, test program to simulate specific seismic requirements</td>
<td>Dynamic and fatigue test are represented by one test regime.</td>
<td></td>
</tr>
<tr>
<td>Number of Load Cycles</td>
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<td></td>
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<td></td>
<td>5 Hz</td>
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<tr>
<td>Maximum Load Amplitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 cycles at ±0.16Fy</td>
</tr>
<tr>
<td>Minimum Load Amplitude</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30 cycles at ±0.12Fy</td>
</tr>
<tr>
<td>Wave Form</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80 cycles at ±0.08Fy</td>
</tr>
<tr>
<td>Initial Static Shear Load on Anchor</td>
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<td></td>
<td></td>
<td></td>
<td>200 cycles at ±0.04Fy</td>
</tr>
<tr>
<td>Anchor Tensile Preload at Time of Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.16Fy</td>
</tr>
<tr>
<td>Residue Strength Test Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>–0.16Fy</td>
</tr>
<tr>
<td>Remarks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>alternating</td>
</tr>
<tr>
<td>Static Shear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>none</td>
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* Fy: anchor bolt yield strength
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<tbody>
<tr>
<td>Frequency of Applied Cyclic Loading</td>
<td>constant frequency between 1 to 10 Hz</td>
<td>constant frequency or sweep between 1 to 20 Hz</td>
<td>by specifier, suitable number as determined by consideration of intended design load and field conditions</td>
<td>2 x 10^6 unless otherwise specified</td>
<td>approximately 3 Hz</td>
</tr>
<tr>
<td>Number of Load Cycles</td>
<td>by specifier, suitable number as determined by consideration of intended design load and field conditions</td>
<td>2 x 10^6 unless otherwise specified</td>
<td>by specifier, test program shall include loading method, load amplitudes, frequency, and number of cycles</td>
<td>1 x 10^6</td>
<td>not specified</td>
</tr>
<tr>
<td>Maximum Load Amplitude</td>
<td>by specifier, to be held constant throughout test</td>
<td>1.0Fs</td>
<td>by specifier, test program shall include loading method, load amplitudes, frequency, and number of cycles</td>
<td>0.5F</td>
<td>not specified</td>
</tr>
<tr>
<td>Minimum Load Amplitude</td>
<td>0.03F, to be held constant throughout test</td>
<td>0.2Fs</td>
<td>by specifier, test program shall include loading method, load amplitudes, frequency, and number of cycles</td>
<td>0.2F</td>
<td>not specified</td>
</tr>
<tr>
<td>Wave Form</td>
<td>not specified (but pulsating is implied)</td>
<td>not specified (but alternating is implied)</td>
<td>pulsating</td>
<td>0.2F</td>
<td>not specified</td>
</tr>
<tr>
<td>Initial Static Shear Load on Anchor</td>
<td>0.03F</td>
<td>0.2Fs</td>
<td>0.2F</td>
<td>not specified</td>
<td>not specified</td>
</tr>
<tr>
<td>Anchor Tensile Preload at Time of Test</td>
<td>Not explicitly stated. Requires test specimen to reflect appropriate conditions which affect capacity of the installed anchor.</td>
<td>Not explicitly stated. Requires test specimen to reflect appropriate conditions which affect capacity of the installed anchor.</td>
<td>Not explicitly stated. Requires test specimen to reflect appropriate conditions which affect capacity of the installed anchor.</td>
<td>20% of installation torque</td>
<td>not specified</td>
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<tr>
<td>Residue Strength Test Method</td>
<td>not specified</td>
<td>not specified</td>
<td>Static Tension</td>
<td>Static Shear</td>
<td>not specified</td>
</tr>
<tr>
<td>Remarks</td>
<td>Evaluation method includes the determination of the amount of slip displacement. Acceptance criteria for slippage is by specifier.</td>
<td></td>
<td></td>
<td></td>
<td>This standard is not explicit as to whether it is applicable to tension anchor shear loading. As with other standards, it appears this procedure was intended for tensile load tests. The summary above assumes the standard is also applicable to shear load tests.</td>
</tr>
</tbody>
</table>

* F: static ultimate capacity of anchor, Fs: safe working load = F / S.F. (safety factor)
Figure 1. Shear Slip Resistance Loading Test

Notes

1. Apply the shear load by pulling on the Loading Plate with a monotonically increasing shear load.
2. The loading rate shall not exceed 0.076 mm/minute (0.003 in./min.)
3. The test shall be performed until a displacement of 1.27 mm (0.05 in.) is achieved at which time the test shall be terminated. The load-displacement shall be continuously recorded on an X-Y plotter throughout the test until the 1.27 mm displacement is achieved.
4. Orient the CEA and hole in the Loading Plate so that the shear load must overcome sliding friction. Ensure that the Loading Plate does not bear against the CEA throughout the testing.
5. The CEA shall be set at 100% of the specified setting torque and then reduced to 50% of the setting.
6. The edges of the Loading Plate and the hole in the Loading Plate shall be free of burrs, lips, or rough edges.
7. The contact surfaces of the Loading Plate and concrete shall be uncoated.