HEDL-SA-2048

CONF-800804--32

INSTALLATION OF

CONCRETE EXPANSION ANCHORS

AT THE

FAST FLUX TEST FACILITY

MASTER

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January 1980

For presentation at the American Society of Mechanical Engineers Century II Meeting to be held in San Francisco, California, August 13-15, 1980.

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company, a subsidiary of Westinghouse Electric Corporation, under the Department of Energy Contract No. ~~EY-76-C-14-2170~~
DE-AC14-76FF02170

DISCLAIMER

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ABSTRACT

Installation criteria utilized at the Fast Flux Test Facility for concrete expansion anchors are presented. Static and dynamic load capabilities of various anchor types are discussed in relation to design loads, with particular emphasis placed on the yield load (the proportional limit). Effects of several variables (i.e., installation torque, hole diameter) are also investigated. Resolution and documentation of field problems (e.g., improper spacing, embedment, angularity) are also described. Recommendations for improving and controlling future installations are given.

NOMENCLATURE & TERMINOLOGY

Anchor slough	- Slippage of wedge anchors through the wedge clips or ring until no further load capability exists.
Dynabolt	- A sleeve-type expansion anchor manufactured by Ramset Fastening Systems.
Embedment	- Depth of anchor in the concrete from the anchor point to the concrete surface.
Expansion anchor	- A component installed in hardened concrete for the transfer of loads into structural components by direct bearing and/or friction.
Ferrule	- The tapered end-section of a wedge anchor.
HDI	- Hilti Drop-In: a shell-type anchor manufactured by Hilti Fastening Systems.
Kwik-Bolt	- A wedge-type expansion anchor manufactured by Hilti Fastening Systems.
Self-drilling anchor	- A shell-type anchor that drills its own hole by means of serrated teeth manufactured by ITT Phillips Drill Co.

Shell anchor - A cylindrical anchor that is attached in the concrete by expansion of the lower portion by means of a plug and which has a threaded upper portion for attachment of components by standard bolts and threaded rods.

Sleeve anchor - An expansion anchor that consists of an expanding sleeve and a threaded stud (or pin) which is drawn up into the sleeve. Generally is used to refer to the type manufactured by ITT Phillips Drill Co.

Slip load - The load corresponding to 1/16-in (1.59 mm) deflection.

Stud anchor - A threaded stud that consists of an expanding lower end, which is caused by driving the stud over a plug. Manufactured by ITT Phillips Drill Co.

Ultimate load - The maximum load obtained in the tensile test.

Wedge anchor - An expansion anchor that consists of a threaded stud which has an expanding ring or clips around a tapered end.

Yield load - The proportional limit or the load at which the load-devlection curve departs from a straight line.

INTRODUCTION

Installation of concrete expansion anchors at nuclear facilities has become increasingly more important to the industry and to the regulatory bodies. In response to some concerns, the U. S. Nuclear Regulatory Commission [1]* has requested specific actions to be taken to ensure the structural adequacy of seismic category I (e.g., capable of withstanding a Safe Shutdown Earthquake) pipe supports utilizing this type of anchor.

At the Fast Flux Test Facility (FFTF) a significant amount of work has been expended to ensure safe and structurally sound expansion anchor installations. This work has included static and dynamic load tests, development of special proof loading tools, generic field and engineering fixes for anchors not installed in accordance with the specification, and classroom/laboratory training for craftspersons. Specific criteria and the engineering philosophy utilized for anchor installations at FFTF are discussed for various anchor types.

EXPANSION ANCHOR TESTS

In order to determine the acceptability of expansion anchors for use at FFTF two separate test programs were conducted in support of the specification. The first program was to determine the behavior and capability of commercially available expansion anchors under static and dynamic load conditions. The second test program (controlled variable tests) was performed to examine the effect of embedment, torque, and hole diameter on the static tensile capability of the specified expansion anchors. Additional tensile tests of non-specified expansion anchors were performed for determination of allowable loads.

Primary emphasis of these tests and their subsequent evaluation was placed on the yield load capability of each anchor. For FFTF's expansion anchor installations, the allowable loads are less than the yield loads, and are also lower than those obtained by applying a safety factor of 4 or 5 to the ultimate load. Figure 1 illustrates a typical static tensile behavior and the load-deflection points of interest.

*Number in Brackets Designate References at End of paper.

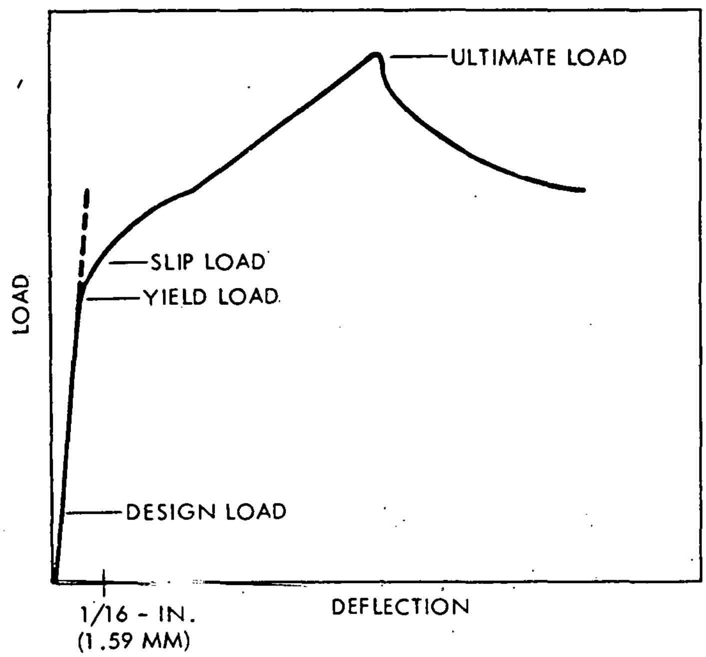

Fig.1 Static tensile behavior

The two types of expansion anchors primarily tested were wedge anchors and sleeve anchors. Sleeve anchors utilized at FFTF are Phillips Red-Head Sleeve Anchors, while the wedge anchors used are Hilti Kwik-Bolts, Phillips Red-Head WS series wedge anchors, USM Parabolts, and Rawlplug RAWL-studs. Table 1 lists the primary installation requirements for expansion anchors at FFTF.

ANCHOR TYPE	CONCRETE MIX	DIAMETER "D" IN.(mm)	LENGTH IN.(mm)	"T" IN.(mm)	EMBED IN.(mm)	TORQUE FT-LBS(N-M)
WEDGE	REGULAR 4 KSI (28 MPa) and MAGNETITE 5 KSI (35 MPa)	1/4 (6)	2-1/4 (57)	1/2 (13)	1-3/8 (35)	7-10 (9-14)
		3/8 (10)	3-1/2 (89)	3/4 (19)	1-3/4 (45)	25-35 (34-47)
		1/2 (13)	5-1/2 (140)	3/4 (19)	3-1/4 (83)	45-65 (61-88)
		5/8 (16)	6 (152)	3/4 (19)	3-1/2 (89)	80-90 (108-122)
		3/4 (19)	8-1/2 (216)	3/4 (19)	4 (102)	125-175 (169-237)
PHILLIPS SLEEVE ANCHORS	STEEL SHOT 5 KSI (35 MPa)	5/8[1] (16)	6 (152)	1/2 (13)	4 (102)	30-37 (41-50)
		3/4[1] (19)	6-1/4 (159)	1/2 (13)	4 (102)	47-55 (64-75)

[1]Pull test to twice design load with 1/16-inch (1.59 mm) maximum allowable movement.

The initial test program was performed at the University of California at Berkeley (UCB) under the direction of Bechtel Power Corporation. Using a 500 Kip (2224 KN) MTS Dynamic Test Frame, various sleeve and wedge anchor specimens were subjected to tensile, shear, and combined dynamic loads. The amplitude of the dynamic load was varied from 500 lbs (2224 N) to 20 percent of the average ultimate static capacity (S') at frequency intervals of 5 Hz for 2000 cycles. After the 15 Hz load cycle, the load amplitude was increased by 10 percent S' and cycled again at 10 Hz. The load amplitude increase cycle was then repeated until a failure occurred. Long-term fatigue tests of two million cycles at 0.2 S' were also performed.

The results of these tests demonstrated that expansion anchors can withstand dynamic and cyclic loads without ratchetting or failure provided the imposed loads are held below a particular point. Figure 2 illustrates the dynamic behavior of a wedge or sleeve anchor in comparison to its static behavior.

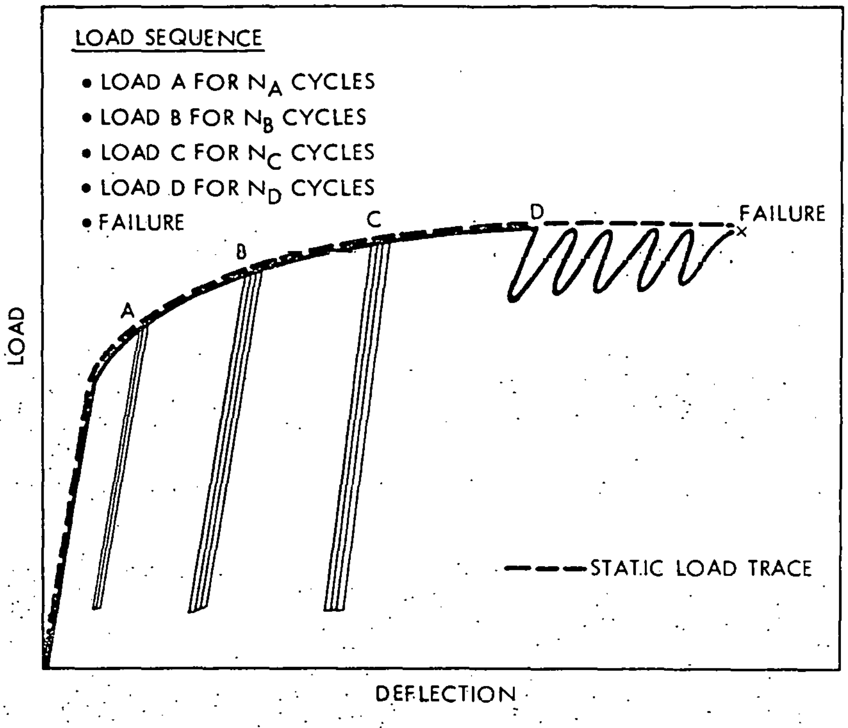

Fig.2 Dynamic tensile behavior

Dynamic load-deflections held below point D produce no ratchetting of the anchor. However, at point D, cyclic loading causes ratchetting of the anchor until failure occurs. For this reason and to avoid impact loads, it is desirable to maintain the anchor within the elastic region (at or below the yield load).

The controlled variable tests were performed on site under the direction of the Hanford Engineering Development Laboratory, utilizing Bechtel craftspersons and equipment to simulate field conditions as close as possible. Since the majority of expansion anchors installed at FFTF are Phillips Sleeve anchors and Hilti Kwik-Bolts, only these two types were tested. However, all permitted wedge anchors are expected to behave similar to Kwik-bolts.

Of the three variables tested, the installation torque had the most effect on the yield load of the Kwik-Bolts. An increase in the tensile yield load was noted as the torque was increased. Although the 1/2-inch (13 mm) Sleeve anchors demonstrated similar behavior, the other Sleeve anchor sizes tested did not behave in this manner for the considered torque values.

Tensile yield loads of both Sleeve anchors and Kwik-Bolts were affected by the diameter of the hole. Utilizing the vendor's drill bit, smaller hole diameters were obtained, which produced larger and more consistent yield loads. However, these larger yield loads corresponded to larger displacements of the anchor. In addition, the smaller holes required more force to drive the anchor into the hole. Also, Sleeve anchors installed in the larger diameter holes exhibited torsion of the sleeve while the smaller hole installations did not show sleeve torsion.

The results of the embedment tests have shown that neither the yield or slip loads of Sleeve anchors or Kwik-Bolts are significantly affected by this variable. However, both anchor types installed with a shallow embedment tended to have ultimate failures by concrete spalling. Deeper embedments produces ultimate failures by pull-out or anchor slough.

Four additional anchor types were tested at FFTF. Hilti HDI, Phillips Self-Drilling and Stud anchors, and Ramset Dynabolts. With the exception of the Self-drilling anchor, all anchors were installed in accordance with manufacturers instructions. Self-drilling anchors were not capable of drilling their own hole due to the hardness of the concrete, and therefore required a hole to be drilled by a bit. In general, the shell-type anchor's behavior approached perfectly elastic-plastic behavior (e.g., small displacements until the yield load is reached). Dynabolt performance was similar to Phillips Sleeve anchors.

In order to provide a high degree of confidence in the allowable load, statistical methods were utilized for evaluating test data. Although the allowable loads were initially set at 20 percent of the ultimate tensile capability, the UCB and subsequent tests performed at FFTF demonstrated that adequate safety factors exist between the design loads and the yield loads for the wedge and Sleeve anchors.

INSTALLATION ACCEPTANCE CRITERIA

As with any other construction activity, minimum acceptance criteria must be developed to account for field installation problems. At FFTF, a series of inspection criteria was developed that enable inspection personnel to verify the adequacy of previous installed expansion anchors. Anchors not meeting these requirements were then identified on a Concrete Expansion Anchor Problem Sheet for a standard field fix or engineering evaluation. This inspection process was performed on all Seismic Category I or Seismic Category III-over-I equipment utilizing expansion anchors. Figure 3 illustrates some of the acceptance criteria utilized for the anchor inspection. Methods for resolving typical anchor problems are given in the Appendix.

CONTROL OF INSTALLATIONS

The most positive method of assuring properly installed expansion anchors is to control the installation process. A great savings in time and money can be realized if proper precautions are in place to control the construction crafts. At FFTF, these controls have led to the requirement that all expansion anchors be installed in accordance with the specification. To further enforce this requirement, only anchors permitted by the specification are stocked at the site. Deviations from the specification require approval from engineering.

To enhance the construction side, seminars are given to craftspersons, supervisors, material buyers, and quality control personnel to familiarize people with the anchor types, requirements and objectives of the specification. Rework documents for installation problems are also presented to close the cycle. To develop confidence and technique, craftspersons are required to install a number of

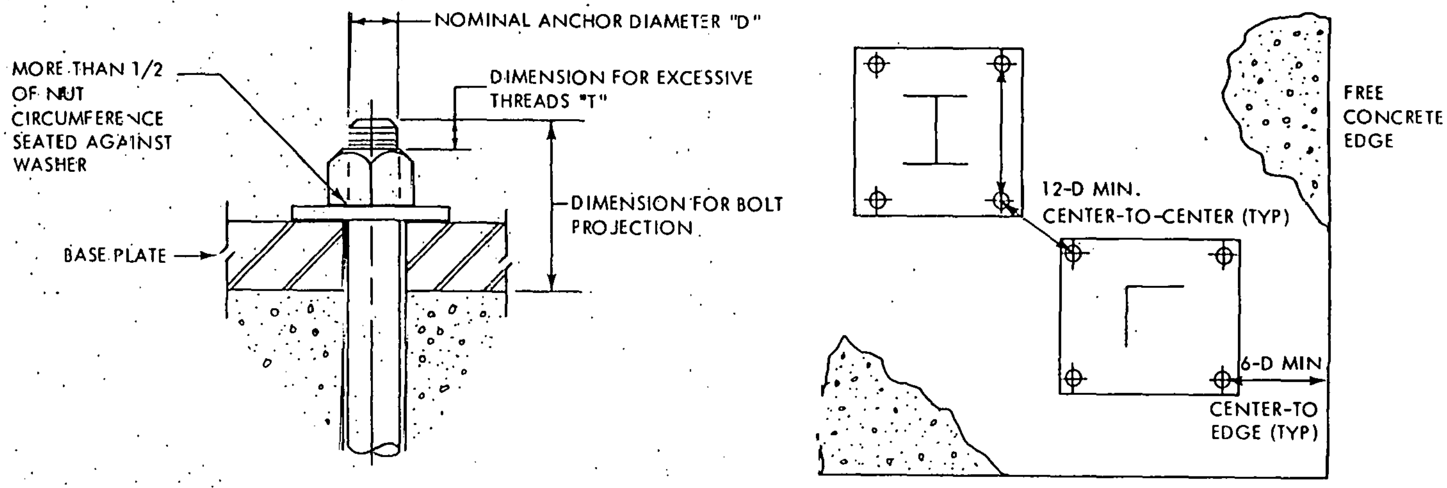

Fig.3 FFTF Expansion Anchor Acceptence Criteria

anchors in concrete test blocks, which are inspected by quality control personnel as if it were an anchor installed in the plant. Through these measures, it is believed that the majority of rework problems can be prevented.

CONCLUSIONS AND RECOMMENDATIONS

This paper has presented the program utilized at FFTF for installation of concrete expansion anchors. A proper program requires a number of specific items, which have been shown to be:

- Test data and its subsequent evaluation
- Development of minimum acceptance criteria and rework documents
- Seminars and field test work to familiarize personnel with installation criteria
- Institution of controls to minimize rework and assure quality installations.

Based on the experience at FFTF, specific recommendations can be formulated for the installation of concrete expansion anchors:

- Selection of allowable design loads should be selected on the basis of yielding and not on ultimate capability. The allowable load should also be chosen considering effects of shock and/or vibration (i.e., seismic event). Statistical considerations of test data should be utilized to establish adequate safety factors and allowable loads.
- The concrete strength and hardness of aggregate used should be considered in allowable load selection. Extrapolation of tests results from one concrete aggregate to another, even though both concretes may have the same compressive strength, may lead to erroneous design loads. Specific test data for a given concrete aggregate must be available for proper evaluation.
- Installations of concrete expansion anchors should be carefully controlled to ensure good anchor capability. Additional assurance can be obtained by requiring craftspersons to be qualified, similar to qualifying welders.

With adequate technical and quality control bases, concrete expansion anchors can provide the necessary anchoring capability for many applications in a nuclear facility.

ACKNOWLEDGMENT

The author is grateful to L. K. Severud for his assistance in the preparation of this paper, which is based on work performed at the Hanford Engineering Development Laboratory, Richland, Washington operated by Westinghouse Hanford Company, for the United States Department of Energy under Contract DE-AC14-76FF02170. Further details and information regarding the work herein reported are available to the United States Nuclear Industry and foreign country interests and Companies through the Exchange Programs coordinated by the Director, Division of Reactor Research and Technology, United States Department of Energy.

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1. U. S. Nuclear Regulatory Commission, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts," USNRC, IE Bulletin No. 79-02, March 1979.

2. American Concrete Institute, "Proposed Appendix B - Steel Embedments of ACI-349," ACI, March 1977.

APPENDIX

During the course of FFTF Construction, specific expansion anchor bolt problems occurred which required resolutions for adequate installations. Examples of problems and associated resolutions that can be applied are as follows:

1. Lack of evidence that anchor had been torqued.

<u>Resolution</u>. Retorque anchor with calibrated torque wrench and apply torque paint (TP) to enable visual inspection that the anchor is properly tightened. This requirement also permits assurance that the anchor has not been disassembled at a later date.

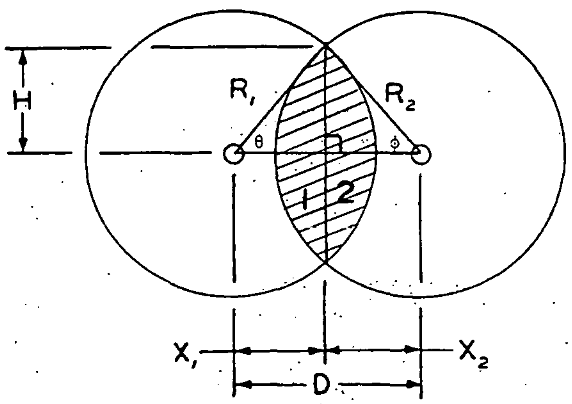
2. Excessive angularity of anchor, resulting in loss of bearing area under nut.

<u>Resolution</u>. Install Belville Spring washers or tapered shims below nut to provide the necessary bearing surface.

3. Expansion anchors installed closer than the required distance to other expansion anchors or a free concrete edge.

<u>Resolution</u>. Spacing reduction factors were applied to the allowable load. The revised allowable load was then compared to the actual anchor load and reworked as necessary. The reduction factors, developed in accordance with Reference [2], were determined by the following method.

The strength of a concrete anchor is related to the projected surface area of a 45° cone, commencing at the embedded end. For this reason, the strength can be reduced by the amount of overlapping surface area from each anchor's cone.



Known variables for the given anchors are the center-to-center distance (D) and the respective embedment depths (R_1 and R_2). By geometry,

$$H^2 = R_1^2 - X_1^2 = R_2^2 - X_2^2 \tag{1}$$

$$X_1 = D - X_2 \tag{2}$$

Substituting Equation (2) into (1) yields:

$$R_1^2 - (D^2 - 2D\,X_2 + X_2^2) = R_2^2 - X_2^2 \tag{3}$$

Solving for X_2:

$$X_2 = (R_2^2 + D^2 - R_1^2)/2D \tag{4}$$

The angle ϕ can now be determined:

$$\phi = \cos^{-1} (X_2/R_2) \tag{5}$$

Noting that X_1 is also known, the angle θ can be determined.

$$\theta = \cos^{-1} (X_1/R_1) \tag{6}$$

The overlap area for each surface area can be determined knowing the radius and the angle (area of a circular sector):

$$\text{Area}_1 = R_2^{\,2} (\phi - \sin\phi \cos\phi) \tag{7}$$

$$\text{Area}_2 = R_1^{\,2} (\theta - \sin\theta \cos\theta) \tag{8}$$

The total overlapping surface area is the sum of the individual areas:

$$\text{Total lost area} = R_1^{\,2} (\theta - \sin\theta \cos\theta) + R_2^{\,2} (\phi - \sin\phi \cos\phi) \tag{9}$$

The net projected surface area for each anchor then becomes:

$$(\text{Net Area})_1 = \pi R_1^{\,2} - (R_1^{\,2} (\theta - \sin\theta \cos\theta) + R_2^{\,2} (\phi - \sin\phi \cos\phi)) \tag{10}$$

$$(\text{Net Area})_2 = \pi R_2^{\,2} - (R_1^{\,2} (\theta - \sin\theta \cos\theta) + R_2^{\,2} (\phi - \sin\phi \cos\phi)) \tag{11}$$

The area fraction, defined as the net area divided by the gross area, becomes the reduction factor:

$$(\text{Area Fraction})_1 = 1 - \frac{R_1^{\,2}(\theta - \sin\theta\cos\theta) + R_2^{\,2}(\phi - \sin\phi\cos\phi)}{\pi R_1^{\,2}} \tag{12}$$

$$(\text{Area Fraction})_2 = 1 - \frac{R_1^{\,2}(\theta - \sin\theta\cos\theta) + R_2^{\,2}(\phi - \sin\phi\cos\phi)}{\pi R_2^{\,2}} \tag{13}$$

The revised allowable load for each anchor is determined by multiplying the allowable load by the area fraction. This procedure is performed for each spacing problem for a given anchor.

For an anchor installed closer to a free concrete edge (FE) than the required distance, the area fraction becomes

$$(\text{Area Fraction})_{FE} = 1 - \frac{(\theta - \sin\theta\cos\theta)}{\pi} \tag{14}$$

4. Excessive threads exist above nut, indicating potentially bottoming of nut on anchor shank.

   Resolution. Install a single solid shim plate under nut to bring excessive threads within specification requirements.

5. Excessive anchor projection above concrete, indicating inadequate embedment.

   Resolution. Ultrasonically test (UT) anchor to determine actual embedment. Derate anchors not satisfying minimum embedment requirements, based on ratios of projected surface areas (actual/required). Rework anchors as required.

6. Washers stacked under nut are not welded together. Stacked washers add slip planes and therefore proper installation torque cannot be assured.

Resolution. Tack weld washers together or replace washers with a single solid shim plate.

7. Anchor shank has been cutoff, indicating potentially inadequate embedment or damaged anchor. Expansion anchor identification is also prevented.

Resolution. UT and pull test anchor. If necessary, derate and/or replace anchor.