FFTF REPORT

MASTER

DRILLED-IN EXPANSION BOLTS UNDER
STATIC AND ALTERNATING LOAD

A Report on an Investigation by Bechtel Power
Corporation to Justify the Use of Expansion
Bolts in the Fast Flux Test Facility,
Richland, Washington

United States Atomic Energy Commission

Prepared for

Hanford Engineering Development Laboratory
Richland, Washington

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1.0 INTRODUCTION

1.1 General

For a number of years concrete expansion bolts have been used in Nuclear Facilities for Seismic Category I Structures without special experimental or analytical verification of design loads and load factors for dynamic load applications. Design Loads ranging from 1/4 to 1/10 of the static capacity have been used for general applications of expansion bolts. In May of 1974 an experimental program was carried out at the University of California at Berkeley to investigate the static and dynamic behavior of some expansion bolts, and based on these tests, certain design recommendations were developed (See Reference A).

As a current effort to update the design data for nuclear power plants, Bechtel Power Corporation developed interim criteria for use on all Bechtel Projects. The interim criteria imposed tight limitations and rigid testing requirements on the use of concrete expansion bolts.

The limitations imposed left the FFTF Project no alternative but to use the grouted anchors for the installation of equipment, piping and structural items. Because of the special considerations that water should not come in contact with plant components and the need that cells be kept in a "clean room" condition, the use of the grouted details which must use water for core drilling of the large diameter holes is undesirable. Further, such drilling operations are time consuming and therefore adversely impact cost and schedule.

Furthermore, the large core drilling gives greater probability for drilling through rebar. Because of these objections to core drilling and grouting, in May of 1974 a testing program (Appendix A) was developed by Bechtel and approved by Hanford Engineering Development Laboratory, to substantiate the performance of drilled-in expansion type anchor bolts. The test specimens were cast by Bechtel field personnel at the FFTF site and tested at the Structural Engineering Laboratory of the University of California at Berkeley, under the technical supervision of Bechtel Power Corporation, San Francisco, California.

1.2 Objective and Scope

The objective of this investigation was to establish the allowable design loads (tension, shear, and combined load), for expansion bolts to be installed in regular 4000 psi mix concrete, Magnetite 5000 psi mix concrete, and Steel Shot 5000 psi mix concrete at the Fast Flux Test Facility. The test loads included Static Loads and Alternating Loads which simulate the dynamic loads of vibratory equipment and dynamic earthquake loads.

The investigation included a static and dynamic testing program (Appendix A) and an evaluation of the results to establish criteria for the use of expansion bolts for a nuclear facility. Because of funds and time limitations, only duplicate tests for a few types of expansion bolts were included in the testing program. As the testing progressed the program was modified to concentrate on typical expansion bolts of sleeve type and stud type which are illustrated in Figure 2. These two types of expansion bolts were chosen because they appeared to be least effected by the workmanship of the bolt installation and they both have the flexibility for an adjustment of the embedment depth to set the wedges between/or behind the rebar. No attempt was made to study the influence of concrete strength, embedment depth, the minimum edge distance, minimum spacing between expansion bolts, and the effect of the installation torques.

For the effects of concrete strength, the test results of this investigation represent conservative values for the actual concrete used in FFTF project since test specimens were tested at the age of 21 days to 60 days while the expansion bolts are to be installed on the jobsite from 6 months to two years after placement of the concrete. The effects of embedment depth were minimized by placing the wedges of the expansion bolts in the concrete confined by the rebar. As to the minimum edge distance, minimum spacing between expansion bolts, and the effect of the installation torque the values derived from industry-wide experiences for the static loads were adapted. Since the design values of the expansion bolts were established to have a factor of safety of five (5) or more with respect to the static capacity these values should be adequate for the dynamic loads which are in the elastic range of the bolt/concrete assembly.

The results of this investigation were used to establish the design criteria and the installation specification (Reference C) for the use of expansion bolts on the FFTF project.

The test data represent the anchor values for the expansion bolts installed in the FFTF concrete test blocks under the workmanship of simulated jobsite conditons. The use of these test data for any other facilities should be based on interpretation by the cognizant engineer for validity of data.

• 1.3 Acknowledgment

This investigation was funded by U.S. Atomic Energy Commission through Hanford Engineering Development Laboratory for the support of the engineering activity of the Fast Flux Test Facility at Richland, Washington.

The expansion bolts and drill bits used in this investigation were provided by the bolt manufacturers: Hilti Inc., ITT Phillips Drill Co., The Rawlplug Co., Inc., Star Expansion Company, Inc., Wej-it Corporation, and USM Corporation. The installation tools were provided by Hilti Inc. and ITT Phillips Drill Co.

The Expansion Anchor Manufacturers Institute, Inc. (EAMI) technical committee and dynamic test sub-committee participated in the test program by attending meetings for exchange of technical information for the test program.

2.0 TEST PROGRAM

2.1 Scope

The test program included static tests and dynamic tests for alternating loads on stud and shell type expansion bolts for three bolt diameters (5/8", 3/4" and 1") from six manufacturers (Hilti, Rawl, Parabolt, Wej-it, Phillips, and Star). These are considered representative of the type commonly used in the industry.

The expansion bolts were tested for three types of loads: Tension, Shear, and Combined loads designated as T, V and C loads, respectively.

The dynamic tests included two types of loading sequences. The first type, designated "N loading", is an S-N type fatigue cyclic loading which simulates the dynamic loading of vibratory equipment. The second type, designated as "D loading" is a low cycle alternating load which simulates the dynamic loads of a seismic event.

The Test Schedules are listed in Table 1. As the tests progressed this schedule was modified to concentrate on two types of the most prospective expansion bolts, (Phillips HN series sleeve type anchors and stud type wedge anchors from Rawl, Hilti and Parabolt) for derivation of more complete data. The actual number of tests for each type of bolt are indicated in the parenthesis.

2.2 Specimen Design

The conventional test medium for expansion bolts subjected to a static load is a plain concrete slab. A portable hydraulic jack is generally used for the conventional static tests.

A portable hydraulic system was not readily available for the dynamic load capacity required for this test program, therefore, the test specimen were designed to suit the MTS dynamic test frame of the University of California at Berkeley. Figures 3, 4 and 5 illustrate the specimen for Tension, Shear, and Combined Load tests. The specimen were 15" x 12" x 15" concrete blocks cast from FFTF concrete mixes for Regular 4000 psi concrete, Magnetite 5000 psi concrete, and Steel Shot 5000 psi concrete. A 1-1/4" diameter high strength bolt was embedded into each of the test specimen for connecting to the fixed head of the MTS loading frame. A 10" diameter spiral of #2 bars at 2" pitch was used to reinforce the concrete 3 inches below the surface where the expansion bolt is located. This reinforcement was

provided to simulate the confinement of the reinforcing steel in walls and slabs of FFTF Project. The installation specification (Reference C) specified that the wedge portion of the expansion bolts shall be set between or behind the near face reinforcing steel in the wall or slab to make sure that the wedges are all set in the concrete confined by the rebar.

2.3 Loading Jig and Dynamic Load Simulation

The test specimen was fixed to the fixed head of the MTS Loading Frame by the 1-1/4" bolt embedded into the concrete block as described in Section 2.2. The load was applied to the expansion bolt through a jig which was coupled to the loading head of the MTS Loading Frame. Figures 6, 7 and 8 illustrate the loading jigs for Tension, Shear, and Combined Load Tests.

Vibration-Fatigue

It is difficult to estimate the vibratory characteristics of a piece of equipment during its lifetime. However, the general S-N type fatigue curves for Carbon, Low-Alloy, High-Alloy and High Tensile Steels indicate that for load cycles where $N \geq 10^6$ the value of the fatigue stress, S, does not decrease with the number of the stress cycles (See Fig. 1-9-1 of ASME Code Sec. III). Therefore, the number of load cycles for long duration fatigue tests was conservatively set at 2 million cycles for the investigation of the fatigue characteristics of the expansion bolts. The vibratory loads were simulated by an alternating load of a steady state sine wave which alternated between zero (actually it was set at 500/lbs. to avoid impact effects) and $0.2 S'$, where S' is the approximate static capacity of the expansion bolts. $0.2 S'$ was chosen to establish a factor of safety of 5 for the design capacity.

Seismic Load

A typical cyclic loading for seismic peak response is illustrated in Figure 9. Figure 9 (a) illustrates the El Centro 1940 (North-South) motion ground acceleration/time history. Figure 9 (b) illustrates the ground motion after it was filtered and amplified by a building system which was $5 H_z$ natural frequency and 5% critical damping factor. This is the floor motion time history of the building. Figure 9 (c) represents the equipment motion which is the floor motion filtered and amplified by equipment which has $5 H_z$ natural frequency and 5% critical damping factor. Generally the peak responses of equipment during an earthquake can be represented by five to ten beats of a complex wave. The

number of maximum stress cycles approximately corresponds to the number of these beats. For the FFTF Project, the Seismic Design Criteria, JABE-WADCO-02, specified that the Design Basis Earthquake (DBE) will produce 10 cycles of maximum structural element response and the Operational Basis Earthquake (OBE) will produce 6 cycles of maximum structural element response. The plant is designed for three OBE's and one DBE during its lifetime, therefore the total number of maximum element response cycles is about 30. Considering each maximum element response as a sine beat which consists of 10 cycles of alternating load, the seismic loading was conservatively simulated by about 6800 cycles of a sine wave which varied from zero and $0.2 S'$.

3.0 TESTING PROCEDURES

3.1 Expansion Bolt Installation

Holes for anchor test specimens were drilled with a rotary/percussion type drill such as a Red Head 747 Roto Stop Hammer Drill. In order to simulate the actual field condition, drilling was free-hand without a jig or any other special effort to obtain high degree of accuracy in alignment (see Figure 10). The first twenty-seven holes were drilled by a craftsman from Engineering Testing Service Inc. in Oakland, California. However, the rest of the holes were drilled by a graduate student at the University of California. The holes were drilled by solid core carbide bits of the same nominal diameter as the expansion bolts. The tolerances of these carbide bits are $+0.015''$ -0.0 over the nominal diameters.

The expansion bolts were installed perpendicular to the surface of the test blocks within a tolerance of $+3^\circ$. The anchor embedment depth was set at about $1/2''$ more than the minimum embedment depth recommended by the manufacturers for each size of bolt. Table 2 illustrates the typical embedment depths of this test program. The anchors were set with the torques recommended by the manufacturers.

3.2 Test Set-up

The tests were performed by the Engineering Materials Laboratory of the University of California at Berkeley. The tests were conducted on a 500 Kip capacity MTS Dynamic Test Frame.

Figure 11 illustrates the test set-up with each test component identified by an encircled number. The test specimen (6) was mounted on the MTS Dynamic Test Frame (1) by a pair of $1-1/4''$ diameter bolt couplers. The dynamic load magnitude and frequency were controlled by the MTS Controlling Console (2) and its function generator. A Tektronic 56A storage oscilloscope (3) was used to analyze the loading frequency and the magnitude of the load $P(t)$. Bolt displacement, Δ_B , was measured by a pair of linear transformers monitored by an XY recorder (4). Furthermore, the overall movement, Δ_H , of the cross-head of the MTS loading frame was monitored by an XY recorder (5). The cumulative number of load cycles were recorded by a digital recorder in the MTS control console.

Figure 12 illustrates the specific set-up for the shear, combined, and tension tests. The test specimen were mounted to the stationary part of the MTS Loading Frame by the 1-1/4" diameter bolts embedded on the test block. The shear loads were applied with a loading jig to a pair of expansion bolts installed on the sides of the test specimen (see Figure 7 and Figure 12, A&B). The combined load was applied to the expansion bolt by a loading arm which was installed on the inclined face of the test block. The line of action of the machine load and the axis of the expansion bolt forms 45° angles such that the machine load will exert tension and shear load to the expansion bolt at an arbitrary ratio of 1 to 1 (see Figure 5 and Figure 12D). The tension load was applied to the expansion bolt directly by a coupler on the loading head of the MTS Dynamic Test Frame (see Figure 6 and Figure 12C). The line of action of the machine load coincides with the axes of the 1-1/4" embedded bolts and the expansion bolt.

3.3 Loading Sequences

Static Test

The static load capacity, S' , was determined by a static test at a load rate not exceeding 5 Kips/min. to failure.

Dynamic Tests (Cyclic Loading)

- o Seismic Loading. The seismic loading was simulated by cyclic loads of a sine wave which had a frequency of 5 to 10 H_z and a load magnitude as follows:

Test Period	Maximum Load	Cycle/Second	Total Cycles
1	.2S'	5	2,000
2	.2S'	10	4,000
3	.2S'	15	6,000
4	.3S'	10	6,600
5	.4S'	10	7,200
6	.5S'	10	7,800
7	.6S'	10	100,000
8	.6S' + 2000#	10	102,000
9	.6S' + 4000#	10	104,000
:	:	:	:
i	.6S' + (i-7)2000#	10	100,000 + (i-7)2000

The actual zero was set at about 500 lbs. for avoiding impact effects. The tests for the first few specimen were performed at a frequency of about 2-5 cycles per second because the operator was not familiar with the characteristics of the MTS control console. Subsequently, the machine performance was increased to a frequency of about 10 cycles per second.

o Dynamic S-N Type Fatigue Test (Vibratory Machine Loading)

The vibratory machine loading was also simulated by a sine wave load of two million cycles at about 20% S' , then the maximum load was repeatedly increased arbitrarily by 2000 lbs. every 2000 cycles until failure. 0.2 S' was chosen to establish a factor safety of 5 for the design capacity.

3.4 Recordings

Static Tests

The force vs displacement curve, P vs Δ_B , of the bolt and the force vs cross heads displacement, P vs Δ_H , were recorded by two XY recorders from zero load to the static capacity S' . A typical static force displacement plot is illustrated in Figure 20.

Dynamic Tests

In addition to the recording of the force displacement curves, the load cycles were recorded by a digital counter on the MTS Control Console. The XY recorders were turned on for about a dozen load cycles on each load increment for clarity of the printout. Figure 20 illustrates the typical dynamic force displacement curves.

3.5 Control Tests

For each test a standard 6 x 12-inch control cylinder was tested to determine the static strength, f_c' , of the concrete within 24 hours prior to or after the load test.

4.0 TEST RESULTS AND DISCUSSIONS

The Test Results are presented in Report No. SI-74-1, December 1974 "Test Results on the Dynamic Testing of Expansion Type Concrete Anchors" by the Structural Engineering Laboratory of University of California at Berkeley (Reference B). The edited digest of the test data is presented in Tables 4 through 10, and in Figures 20 through 28.

4.1 Static Tests

Figure 20 illustrates a typical force-displacement plot for the static test. Generally the curve shows a linear relationship from zero load up to point A, which is the yield point of the bolt/concrete assembly. The corresponding values, D_y and P_y , are the yield displacement and yield force. After point A the slope of the curve flattens and then increases slightly near the ultimate point B where the ultimate load P_u drops to zero (failure) at displacement D_u . The ratio of D_u to D_y is the ductility ration, D_R , which is an index for the failure mode: For $D_R = 1.5$, the test generally failed in a brittle mode which was caused either by a bolt failure or some other premature failure. On the other hand a large ductility ratio (say for $D_R > 5$ was generally the result of a slippage of the wedge during testing. The ratio of the ultimate load, P_u , to the yield load, P_y , is P_R which is an index for the margin of safety of the yield value over the ultimate value. The value of P_R is usually less than 1.5. For $P_R = 1$, the test resulted either in bolt failure, or some other premature failure such as wedge slippage due to poor installation. Incidentally, experiment #113 was tested without setting of the wedge. Figure 30 illustrates the force-displacement curve of this test. The bolt slipped about one half of an inch before the wedge was set for a normal loading. The corresponding bolt tension to set the wedge is about 4K which is about 20% of the static capacity of the bolt.

4.2 Dynamic Tests

Figure 21 illustrates a typical force displacement plot for the dynamic tests. The envelope of the plot, represented by the dotted line, is the force displacement curve which also showed an apparent yield point A. After point A, the slope of the curve flattened and then increased again near the ultimate point B. Generally, the yield point A occurred at 6000 to 7800 load cycles of the dynamic load sequence. At this point the force reached about 60% of the static capacity S' . Subsequent alternating loading caused appreciable wedge movement (or "Walking") without an increase in

the maximum load. If the bolt did not fail in a brittle mode due to pullout, or in some other premature failure mode, the "Walking" ceased after a certain number of load cycles and the slope of the force displacement curve showed a significant increase before the ultimate point B was reached (see Figure 30).

4.3 Tension Tests

Figures 22, 25, and 28 are comparative bar charts of the test results on 5/8", 3/4", and 1" expansion bolts. The ultimate load capacities under alternating loading are about the same as the corresponding static load capacities. However, five out of six longterm fatigue tests failed in a premature manner either due to material imperfection or due to stress concentration effects. Since the bolts were installed with a portable drill, free-hand without any special effort to the accuracy in alignment of the bolt there were some offsets and inclinations up to 3° between the line of action of the machine force T and the center line of the expansion bolt (see Figure 3). This is considered typical for field installation. The offset and inclination produced bending in addition to tension on the stud of the expansion bolt. No records on the magnitude of the offset and the inclination were available for a quantitative analysis. In general there was no appreciable difference in the anchor values between the expansion bolts installed in regular concrete and in magnetite concrete. However, the anchor values of the expansion bolts in steel shot concrete were substantially lower than those in the former two types of concrete. This was attributed to the fact that drilling in steel shot concrete was more difficult than in other types of concrete. The hole in steel shot concrete was formed basically by chipping off the steel shots as illustrated in Figure 10-A. Consequently the holes in the steel shot concrete were observed to be of larger average diameter than the holes in ordinary concrete or magnetite concrete. Due to extreme difficulty in measuring the hole diameter, the hole diameter was not measured. Generally there were three types of failure modes. The first failure mode was the cracking of the concrete and the pullout of the bolts. The shell type bolts failed in this mode. Figure 13-A illustrates this mode of failure. The second mode of failure was a simple pullout without cracking of the concrete. However, a shallow piece of concrete spalled off as the bolt was pulled out. Figure 13-B illustrates this mode of failure. This pullout mode usually occurs with steel shot concrete test specimen. The third mode was bolt failure either due to material imperfection or notch effect at the point of discontinuity

near the wedge. Figure 14-A illustrates a tension failure on a Wej-It bolt initiated by the notch effect. Figure 14-B is another mode of bolt failure, and Figures 19-A, B, C and D illustrates some of the bolt failure due to material imperfection.

4.4 Shear Tests

Figures 23, 26, and 28 are comparative bar charts of the test results on 5/8", 3/4", and 1" diameter expansion bolts. The tests were performed on a pair of expansion bolts installed on a test specimen. Again because of free-hand drilling of the holes and since no special adjustment was made to distribute the machine load uniformly between the two bolts, (see Figure 7) the test values indicate the average values for the pairs of bolts when the critical one failed. Three modes of failure were observed. The first failure mode was a bolt failure due to shear loading. The second failure mode was a combined bending and shear failure which was initiated by partial pulling out of the wedge. Figures 15 and 16 illustrate this mode of failure. The third failure mode was concrete failure which occurred only with 3/4" diameter or larger bolts. Although a stud type bolt has a much larger effective shear area and three times larger yield strength than the corresponding sleeve type bolt (see Figure 2) the test results indicated that there is practically no difference in shear capacity between stud type and sleeve type bolts. The shell type bolts had a larger diameter shell embedded in the concrete; however, the test results (Figure 23 Bolt LA's) indicated that they failed prematurely by pullout. Premature failures were observed for the shell type bolts in steel shot concrete (see Figure 26, Bolts LB, in SS). Nevertheless, for expansion bolts in steel shot concrete, the shear values were much better than the tension values.

4.5 Combined Tension and Shear Tests

Figures 24, 27, and 28 are comparative bar charts of the test results on 5/8", 3/4", and 1" diameter expansion bolts. Three modes of failure were observed. The first mode was a bolt failure due to the combined stresses of tension, shear and bending caused by the prying action of the loading arm (see Figure 8). The second mode was concrete failure as illustrated in Figure 17-B. The third mode was a simple pullout as illustrated in Figure 17-A, attributed to poor installation.

The anchor values for the combined shear and tension tests were somewhat lower than the corresponding values for the tension tests or shear tests; however, because of the fact that the loading arm for the combined load test tends to impose a prying effect on the expansion bolt and the test block was too small to provide adequate strength for the prevention of premature failure, we cannot draw a quantitative conclusion from the test results.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions may be drawn from the test results:

1. All expansion bolts tested have successfully withstood the 6000 cycles of 0 to .2 S' alternating load as designated for seismic qualification.
2. The dynamic load capacities of the expansion bolts are about the same as their corresponding static load capacities.
3. The expansion bolts which had no apparent material imperfections or installation errors withstood two million cycles of long term fatigue loading at about 0.2 S' maximum intensity and then established dynamic load capacities which were as good as or stronger than the corresponding results of the static tests. Even those expansion bolts which failed prematurely due to material defects or installation error withstood a minimum of 386,000 cycles at 0.2 S' maximum intensity.
4. The expansion bolts can take combined tension and shear loading as well as the tension load or the shear load by itself. There seems to be no specific reason to prohibit the use of expansion bolts for combined tension and shear loading.
5. The anchor values of expansion bolts in regular concrete and in magnetite concrete are about equal, however, those in steel shot concrete are about one half to two thirds of the corresponding values in regular or magnetite concrete. The cause of this behavior is attributed to the larger average diameter of the holes in the steel shot concrete.
6. Although shell type expansion bolts tested have a larger diameter shell embedment in the concrete, their anchor strength was only half as good or no better than that of the sleeve type bolts or stud type wedge anchors tested. The cause of the inferior behavior may be attributed to the relatively small expansion required for setting the shell anchors and the shorter length of embedment.
7. A significant number of expansion bolts (about 10% of the test specimens) failed by pull-out or fracture of bolt in a premature manner because of material imperfections. A material imperfection tends to augment the

effects of stress concentration at the notch of the wedge or at the root of the threads. Furthermore, installation quality could also have induced undesirable bending effects on the expansion bolts.

5.2 Recommendations

Based on the above conclusions expansion bolts are considered acceptable for use on the FFTF project with the following provisions:

1. The admissible types of expansion bolts should be limited to sleeve type anchors equal to Phillips Read Head Sleeve anchors and to stud wedge anchors equal to the HILTI QUIK BOLT and similar stud bolts manufactured by Rawl and Parabolt. These two types appear to be least affected by the workmanship of the bolt installation, and they also have the flexibility for an adjustment of their embedment depth to meet the requirement of item 2 below.
2. The wedge of the expansion bolts should be embedded between or behind the near side reinforcing steel.
3. The allowable anchor values should be established with a factor of safety of 5 with respect to the static capacity of the expansion bolts. In no case should the values be greater than the lowest dynamic test data, even if that bolt failed prematurely. The allowable anchor values for each bolt tested are indicated in Figures 22 through 28 with horizontal bars.
4. A redundancy rule should be imposed on the design of the equipment mount anchors such that 50% of the expansion bolts will be able to sustain the design load with a factor of safety not less than 2 with respect to the static capacity. The disc spring washers required in item 1 will serve as a device to identify any impaired expansion bolts during service.

Furthermore, although they are not directly derived from the test results, the following items are recommended for the assurance of the integrity and reliability of the expansion bolts:

1. A pair of spring washers should be placed on every expansion bolt according to Figure 2. These spring washers should be sized to produce a bolt tension of $(1 \pm 0.4) S$, where S is the maximum allowable anchor value.

2. All expansion bolts should be set with the lowest practical torque within the range recommended by the manufacturers. This torque requirement will prevent overstressing the studs beyond the yield point, assure proper setting of the wedges, and partially proof load the studs, (under the manufacturers recommended minimum torque the studs may be stretched to about the yield point of the material for the smaller sizes).
3. A minimum bolt spacing of 12 bolt diameters and minimum edge distance of 6 bolt diameters should be enforced.
4. The smallest bolt diameter should be 1/2" and the allowable anchor values should be extrapolated according to the net cross sectional area of the stud at the root of threads. The maximum bolt size tested was 1 inch diameter, and a larger diameter bolt size should not be used without further investigation.
5. Test requirements for quality assurance. Due to the fact that measurement of the hole diameter will be a laborious and generally fruitless task, it is recommended to apply Q/A to the final product rather than to the workmanship of the bolt installation. The testing procedures shall be established to expose sub-standard workmanship of a craft for corrective action before the same mistake is repeated.

6.0 FUTURE STUDIES

This investigation was conducted to develop and to qualify specific expansion bolts for use on the Fast Flux Test Facility. The tests performed were inadequate in quantity to establish statistical data for general application. Also, due to limited test data, a much higher factor of safety than that commonly used for engineering design are recommended to establish allowable anchor values, and many additional restrictions are recommended to assure the integrity and reliability of the expansion bolts. In order to remove some of these restrictions, additional tests should be performed. Specifically, the following items are of immediate interest for additional investigation.

1. Establishment of verified data for general application of expansion bolts.
2. Establishment of the minimum bolt tension which is required for setting the wedges. The torque requirements established by the manufacturers cannot establish a uniform bolt preload because of possible variation in bolt threads friction. Also setting the expansion bolts to a specified torque will cause additional quality assurance measures such as calibration and maintenance of tools for installation of the expansion bolts. Figure 29 shows that the anchor could possibly be set by a bolt tension of about 0.2 S'. Additional tests should be carried out to establish the minimum bolt tensions which are necessary for setting the wedges. Then the expansion bolts could be installed by turning the nuts to set the gap between the spring washers to match a specified feeler gage.
3. Investigate the effects of embedment depth, and setting the wedge against or near the rebar.
4. Development of a simple jig for minimizing of the human factors in the drilling of holes.

Furthermore, the manufacturers should establish a quality control program to minimize material defects in their bolts and also modify the geometry of the expansion bolts to minimize stress concentration effects.

7.0

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SLEEVE TYPE ANCHORS

STUD TYPE WEDGE ANCHORS

FIG. 1 SLEEVE TYPE ANCHORS AND STUD TYPE WEDGE ANCHORS

FIG. 2 ANCHOR PLATE INSTALLATION USING
DRILLED-IN EXPANSION BOLTS

FIG. 3 SPECIMEN FOR TENSION TEST

FIG. 4 SPECIMEN FOR SHEAR TEST

FIG. 5 SPECIMEN FOR COMBINED LOAD TEST

FIG. 6 COUPLERS FOR TENSION TESTS

FIG. 7 LOADING JIG FOR SHEAR TEST

FIG. 8 LOADING ARM FOR COMBINED LOAD TEST

FIG. 9 CYCLIC LOADING OF SEISMIC PEAK RESPONSE

C CLOSE-UP OF SHEAR
TEST LOADING ARM

B SPECIMEN FOR SHEAR
TEST

A DRILLING FOR SHEAR TEST
ON STEEL SHOT CONCRETE

FIG. 10 DRILLING AND INSTALLATION OF EXPANSION BOLT

LEGEND

- Δ_B : BOLT DISPLACEMENT
 Δ_H : X-HEAD DISPLACEMENT
P : COMBINED LOAD
T : BOLT TENSION
V : BOLT SHEAR

- ① MTS LOADING FRAME
 ② MTS CONTROL CONSOLE
 ③ ELECTRONIC SCOPE, $P(T)$
 ④ XY RECORDER, Δ_B vs P
 ⑤ XY RECORDER, Δ_H vs P
 ⑥ COMBINED LOAD TEST BLOCK

FIG. 11 GENERAL TEST SET-UP

B SHEAR TEST
SIDE VIEW

A SHEAR TEST
FRONT VIEW

D COMBINED LOAD TEST

C TENSION TEST

FIG. 12 TEST SET-UPS FOR SHEAR, TENSION AND COMBINED LOADS

A - TENSION TEST ON REGULAR CONC.

B - TENSION TEST ON STEEL SHOT CONC.

FIG. 13 TYPICAL FAILURE MODES FOR TENSION TESTS

A - TENSION TEST ON WEJ-IT BOLT

B FATIGUE (TENSION) TEST
ON REGULAR CONC.

FIG. 14 FAILURE MODES, TENSION TEST ON WEJ-IT BOLT AND FATIGUE TEST

FIG. 15 TYPICAL FAILURE MODES FOR SHEAR TESTS

FIG. 16 FAILURE MODES FOR SHEAR TESTS ON STEEL SHOT CONCRETE

A COMBINED LOAD FAILURE MODE (STUD BOLT)

B COMBINED LOAD FAILURE MODE
(SLEEVE BOLT)

FIG. 17 FAILURE MODES FOR COMBINED LOAD TESTS

FIG. 18 FATIGUE FAILURES DUE TO STRESS CONCENTRATION

FIG. 19 PREMATURE FAILURES DUE TO MATERIAL IMPERFECTION

FIG. 20 TYPICAL FORCE DISPLACEMENT, P VS Δ_H , PLOT (STATIC TEST)

FIG. 21 TYPICAL FORCE DISPLACEMENT, P VS Δ_B , PLOT (DYNAMIC TEST)

ULTIMATE LOAD, P_u , in Kips

STATIC TEST
DYNAMIC
FATIGUE
N: Number of Total Load Cycles
DR=D₀/D_y=Ductility Ratio
PR=PU/PY

FIG. 22 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. 5/8 INCH, TENSION

ULTIMATE LOAD, P_u , in Kips

FIG. 23 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. 5/8 INCH SHEAR

LEGEND

- o Test Medium
- REGULAR CONC.
- o Type of Load
- COMBINED LOAD
- * For ANCHOR BOLT CODE see Table 3
- Max. Allowable Load

FIG. 24 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. 5/8 INCH COMBINED

FIG. 25 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. $\frac{3}{4}$ INCH TENSION

FIG. 26 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. $\frac{3}{4}$ INCH SHEAR

ULTIMATE LOAD, P_u , in kips

CONCRETE ANCHOR BOLT*

LEGEND

o Test Medium
AS SHOWN CONC.

o Type of Load
COMBINED LOAD

* For ANCHOR BOLT
CODE see Table 3

Max.
Allowable Load

STATIC TEST
DYNAMIC N, DR, PR
FATIGUE N, DR, PR

N: Number of Total Load Cycles
in 1000 cycles
DR=D_U/D_Y=Ductility Ratio
PR=P_U/P_Y

FIG. 27 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. 3/4 INCH COMBINED

ULTIMATE LOAD, P_u , in Kips

STATIC TEST
 DYNAMIC N, DR, PR
 FATIGUE N, DR, PR
 N: Number of Total Load Cycles
 DR=DU/DY=Ductility Ratio
 PR=PU/PY

LEGEND

- o Test Medium
REGULAR CONC.
- o Type of Load
T, V & C LOADS
- * For ANCHOR BOLT
CODE see Table 3
- Max.
Allowable Load

FIG. 28 COMPARATIVE BAR CHART FOR EXPANSION ANCHOR BOLTS, BOLT DIA. 1 INCH T, V & C

LOAD, P Kip

KIP
USE TO THE INCHES
RECORD, 1 INCHES 20

470780

36

32

28

24

20

16

12

8

4

.10

.20

.30

.40

.50

.60

.70

.80

.90

1.0

1.1

1.2

1.3

1.4

OVERALL DISPLACEMENT

STATIC TENSION TEST

1" STUD BOLT

WESTINGHOUSE
PARABOLT 1" STUD
SPECIMEN #113
STATIC TENSION
7-16-79
REG. CONCRETE

Concrete Failure
max load = 22.5 Kip

Minimum Bolt Tension

bolt was not set before testing

FIG. 29 MINIMUM BOLT TENSION FOR SETTING EXPANSION BOLT

K-2 3/4" x 12 INCH LONG x 1/4 INCHES
HARDENED STEEL CO. MADE IN USA
LOAD - KIPS

FIG. 30 WEDGE MOVEMENT, "WALKING", DURING THE CYCLIC LOADING

8.0

TABLES

- Table 1 - Summary of Test Schedule
- Table 2 - Embedment Depth of Expansion Bolts
- Table 3 - Code for Types of Expansion Bolts Tested
- Table 4 - Results of Anchor Bolt Test Program 5/8 Inch Bolts Tested in Tension
- Table 5 - Results of Anchor Bolt Test Program 5/8 Inch Bolts Tested in Shear
- Table 6 - Results of Anchor Bolt Test Program 5/8 Inch Bolts Tested in Combined Tension and Shear
- Table 7 - Results of Anchor Bolt Test Program 3/4 Inch Bolts Tested in Tension
- Table 8 - Results of Anchor Bolt Test Program 3/4 Inch Bolts Tested in Shear
- Table 9 - Results of Anchor Bolt Test Program 3/4 Inch Bolts Tested in Combined Tension and Shear
- Table 10 - Results of Anchor Bolt Test Program 1 Inch Bolts

**FFTF TESTING-PROGRAM FOR DRILLED-IN
EXPANSION TYPE CONCRETE ANCHORS**

TABLE 1 SUMMARY OF TEST SCHEDULE

Con- crete Mix	Type and Size of Concrete	Code	Type of Testing	Type of Loading		
				Static S'	Dynamic D	Reserve
Regular 4,000 Psi Mix	Phillips Red Head Sleeve Type HN Service 5/8" Dia.	LB-5	NT	-	2(2)	1(0)
			NV	-	2(2)	1(0)
			T	2(1)	2(2)	1(0)
			V	2(2)	2(2)	1(15')
			C	2(2)	2(2)	1(0)
	Parabolt Stud Wedge Anchor 5/8" Dia	SB-6	NT	-	2(0)	1(0)
			NV	-	2(0)	1(0)
			T	2(2)	2(2)	1(0)
			V	2(2)	2(2)	1(0)
			C	2(2)	2(2)	1(0)
	Rawl Stud Type Anchor 5/8" Dia.	SA-6	T		2(2)	1
			V		2(2)	1
			C		2(2)	1
	Wej-it 5/8" Dia.	SC-5	T		2(2)	1
			V		2(2)	1
			C		2(2)	1
	Hilti Shell Type 5/8"	LA-5	T		2(2)	1
			V		2(2)	1
			C		2(2)	1(15')
	Hilti Shell Type 3/4"	LA-6	T		2	1
			V		2	1
			C		2(2)	1
	Typical Stud Type, 3/4"	SP-6	T	2(2)	2(2)	1(2NT)
			V	2(2)	2(2)	1
			C	2(1)	2(2)	1(1NC)
	Phillips Red Head Sleeve Type HN	LB-6	T	2(2)	2(2)	1(2NT)
			V	2(3)	2(2)	1(0)
			C	2(2)	2(2)	1(0)
	Typical Stud Type, 1"	SP-8	T	2(2)	2(2)	1(0)
			V	2(2)	2(2)	1(0)
			C	2(2)	2(2)	1(0)
	Sub-Total			30(28)	62(52)	31(7)

NOTES:

1. Rawl Stud Anchors, Parabolt Stud Anchors or Hilti Kwik-bolt Anchors were used as the Typical Stud Type Expansion Bolts.
2. Type of Loading: S' - Static loading
D - Dynamic loading
3. Type of Testing:
 - o NT, NV, NC: Long term (2×10^6 cycles or more) fatigue test for tension, shear, and Combined Load, respectively.
 - o T, V, C: Tension, Shear, and Combined Loads.
4. Number in parenthesis indicates the actual number of specimens tested.

FFTF TESTING-PROGRAM FOR DRILLED-IN
EXPANSION TYPE CONCRETE ANCHORS

TABLE 1 SUMMARY OF TEST SCHEDULE (Continued)

Con- crete Mix	Type and Size of Concrete	Code	Type of Testing	Type of Loading		
				Static S	Dynamic D	Reserve R
Steel Shot 5,000 Psi Mix	Typical Stud Type, 3/4"	SP-6	T	2(2)	2(2)	1 (1NT)
			V	2(2)	2(2)	1 (1NV)
			C	2(1)	2(2)	1 (1NC)
	Phillip Red Head Sleeve Type HN, 3/4"	LB-6	T	2(2)	2(2)	1
			V	2(2)	2(2)	1
			C	2(2)	2(2)	1
	Sub-Total			12(11)	12(12)	6(3)
Magnetite 500 Psi Mix	Typical Stud Type, 3/4"	SP-6	T	2(2)	2(2)	1
			V	2(2)	2(2)	1
			C	2(2)	2(2)	1
	Phillips Red Head Head Sleeve Type HN, 3/4"	LB-6	T	2(2)	2(2)	1
			V	2(2)	2(2)	1
			C	2(2)	2(2)	1
	Sub-Total			12(12)	12(12)	6(0)
TOTAL	Total Test Specimens			54(51)	76(76)	43(12)
	Total 6" x 12" Control Cylinders			54(51)	76(76)	43(12)

TABLE 2 EMBEDMENT DEPTH OF EXPANSION BOLTS

Bolt Type	Size	Min. Depth Recommended by Manufacturer	Embedment Depth for Tests
Stud Type Wedge Anchor	5/8"	2-3/4"	3-1/2"
	3/4"	3" - 3-1/4"	3-1/2" - 4-1/2"
	1"	4-1/4" - 4-1/2"	4-1/2" - 5-1/2"
Sleeve Type Anchor	5/8"	2"	2-1/2"
	3/4"	2"	3-1/2" - 4-1/2"
Shell Type Anchor	5/8"	2-3/8"	2-1/2"
	3/4"	3-1/4"	3-1/4"

TABLE 3. CODE FOR TYPES OF EXPANSION BOLTS TESTED

Expansion Bolt Type/Size	Code	Manufacturer
Hilti Shell Type 5/8" stud, 27/32" shell	LA-5	Hilti Fastening Systems Stamford, Connecticut
Hilti Shell Type 3/4" stud, 1" shell	LA-6	
Hilti Stud Type 5/8" dia. stud	SH-5	
Hilti Kwik-bolt Stud 3/4" dia. stud	SH-6	
Hilti Kwik-bolt Stud 1" dia. stud	SH-8	
Molly Parabolt Stud 5/8" dia. stud	SB-5	USM Corporation Shelton, Connecticut
Molly Parabolt Stud 3/4" dia. stud	SB-6	
Molly Parabolt Stud 1" dia. stud	SB-8	
Phillips Red-head Sleeve 1/2" dia. stud, 5/8" dia. sleeve	LB-5	Phillips Drill Company, Inc. Michigan City, Indiana
Phillips Red Head Sleeve 5/8" dia. stud, 3/4" dia. sleeve	LB-6	
Rawl Stud Anchor 5/8" dia. stud	SA-5	The Rawlplug Company
Rawl Stud Anchor 3/4" dia. stud	SA-6	
Rawl Stud Anchor 1" dia. stud	SA-8	
Weij-it Stud Anchor 5/8" dia. stud	SC-5	Weij-it Corporation Broomfield, Colorado
Weij-it Stud Anchor 3/4" dia. stud	SC-6	
Weij-it Stud Anchor 1" dia. stud	SC-8	

TABLE 4 - RESULTS OF ANCHOR BOLT TEST PROGRAM 5/8 INCH BOLTS TESTED IN TENSION

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LB-5	REG	5.60	STAT	12.0	.25	--	13.0	.40	--	1.6	1.1	BOLT FAILURE
LA-5	REG	7.49	DYN	6.6	.08	7.8	10.0	.22	102	2.8	1.5	CONC FAILURE
LA-5	REG	6.20	DYN	7.8	.06	7.8	10.6	.14	101	2.3	1.4	CONC FAILURE
LB-5	REG	4.50	DYN	11.0	.20	10.2	11.0	.45	11.7	2.3	1.0	BOLT FAILURE
LB-5	REG	4.40	DYN	6.8	.15	22.0	6.8	.20	71	1.3	1.0	BOLT FAILURE
LB-5	REG	6.10	FAT	2.6	.25	3.0	2.6	.35	504	1.4	1.0	BOLT FAILURE
LB-5	REG	5.50	FAT	9.0	.28	2052	12.8	.47	2056	1.7	1.4	BOLT FAILURE
SB-5	REG	6.54	STAT	8.0	.20	--	14.4	.40	--	2.0	1.8	PULLOUT
SB-5	REG	6.20	STAT	11.6	.35	--	11.6	.80	--	2.3	1.0	PULLOUT
SC-5	REG	6.86	DYN	10.7	.15	7.8	10.7	.20	102	1.4	1.0	PULLOUT
SC-5	REG	6.55	DYN	11.0	.10	100	12.6	.20	101	2.0	1.1	PULLOUT
SA-5	REG	5.50	DYN	15.0	.32	106	18.6	.60	110	1.9	1.2	PULLOUT
SA-5	REG	6.86	DYN	8.6	.50	7.8	12.6	1.0	102	2.0	1.5	CONC FAILURE
SB-5	REG	6.30	DYN	4.0	.10	6.0	16.0	.75	112	7.5	4.0**	PULLOUT
SB-5	REG	6.60	DYN	5.0	.05	6.6	12.0	.50	102	10.0	2.4	PULLOUT

* See Table 3 for anchor bolt code.

** Wedge walked 0.35" from 4K load at 6000 cycles to 7K load at 8000 cycles. See Fig. 3|.

TABLE 5 - RESULTS OF ANCHOR BOLT TEST PROGRAM 5/8 INCH BOLTS TESTED IN SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LB-5	REG	4.90	STAT	9.5	.45	--	10.0	.70	--	1.6	1.1	BOLT SHEARED
LB-5	REG	5.00	STAT	8.5	.20	--	12.0	.70	--	3.5	1.4	BOLT SHEARED
LB-5	REG	6.87	STAT	8.0	.30	--	8.6	.40	--	1.3	1.1	BOLT SHEARED
LA-5	REG	6.22	DYN	4.8	.15	7.8	4.8	.30	51.0	2.0	1.0	BOLT SHEARED
LA-5	REG	6.52	DYN	4.8	.15	7.8	4.8	.25	39.0	1.7	1.0	BOLT SHEARED
LB-5	REG	4.50	DYN	7.2	.20	7.8	7.2	.40	31.6	2.0	1.0	BOLT SHEARED
LB-5	REG	5.50	DYN	7.2	.35	7.8	7.2	.65	32.0	1.9	1.0	BOLT SHEARED
LB-5	REG	5.80	FAT	8.2	.30	2006	13.2	1.10	2000	3.7	1.6	BOLT SHEARED
LB-5	REG	7.17	FAT	7.3	.30	2000	13.3	1.0	2010	3.3	1.8	BOLT SHEARED
SB-5	REG	6.20	STAT	14.0	.15	--	16.5	.45	--	3.0	1.2	BOLT SHEARED
SB-5	REG	5.90	STAT	8.0	.10	--	10.5	.17	--	1.7	1.3	BOLT SHEARED
SB-5	REG	6.40	DYN	10.0	.10	7.8	10.0	.20	9.2	2.0	1.0	BOLT SHEARED
SB-5	REG	--	DYN	9.0	.22	7.8	9.0	--	10.2	-	1.0	BOLT SHEARED
SC-5	REG	6.40	DYN	7.2	.15	7.8	7.2	.23	33.9	1.5	1.0	BOLT SHEARED
SC-5	REG	6.64	DYN	7.2	.25	7.8	7.2	.75	23.0	3.0	1.0	BOLT SHEARED
SA-5	REG	7.16	DYN	9.6	.17	7.8	9.6	.45	17.9	2.6	1.0	BOLT SHEARED
SA-5	REG	6.77	DYN	9.6	.30	7.8	9.6	.35	8.0	1.2	1.0	BOLT SHEARED

* See Table 3 for anchor bolt code.

TABLE 6 - RESULTS OF ANCHOR BOLT TEST PROGRAM 5/8 INCH BOLTS TESTED IN COMBINED TENSION AND SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LA-5	REG	6.11	STAT	10.0	.20	--	11.2	.95	--	4.7	1.1	BOLT FAILURE
LB-5	REG	5.80	STAT	8.0	.20	--	11.8	1.0	--	5.0	1.5	PULLOUT
LB-5	REG	5.30	STAT	8.0	.30	--	11.4	1.1	--	3.7	1.4	PULLOUT
LB-5	REG	5.70	DYN	7.0	.05	7.2	7.0	.46	41	9.2	1.0	PULLOUT
LB-5	REG	5.00	DYN	7.2	.15	7.8	7.2	.40	16.5	2.7	1.0	BOLT SHEARED
LA-5	REG	6.61	DYN	6.6	.07	7.8	6.6	.07	7.8	1.0	1.0	PULLOUT
LA-5	REG	5.92	DYN	6.6	.07	7.8	6.6	.07	7.8	1.0	1.0	PULLOUT
SB-5	REG	4.90	STAT	11.6	.07	--	11.6	.10	--	1.4	1.0	CONC FAILURE
SB-5	REG	--	STAT	6.8	.12	--	10.6	.43	--	3.6	1.6	CONC FAILURE
SB-5	REG	5.80	DYN	6.6	.07	7.8	6.6	--	17.9	--	1.0	BOLT SHEARED
SB-5	REG	6.10	DYN	6.6	.10	7.8	9.6	.35	102	3.5	1.5	BOLT SHEARED
SC-5	REG	6.70	DYN	6.6	.27	7.8	6.6	--	28.0	--	1.0	PULLOUT
SC-5	REG	6.20	DYN	6.6	.05	7.8	6.6	.07	15.6	1.4	1.0	PULLOUT
SA-5	REG	6.50	DYN	6.6	.09	7.8	6.6	.10	22.0	1.1	1.0	PULLOUT
SA-5	REG	6.30	DYN	6.6	.15	7.8	6.6	.45	37.0	3.0	1.0	PULLOUT

* See Table 3 for anchor bolt code.

TABLE 7 - RESULTS OF ANCHOR BOLT TEST PROGRAM 3/4 INCH BOLTS TESTED IN TENSION

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LB-6	REG	7.16	STAT	14.8	.78	--	15.4	.98	--	1.3	1.1	PULLOUT
LB-6	REG	6.91	STAT	--	--	--	9.4	--	--	--	--	PULLOUT
LB-6	REG	5.51	DYN	7.8	.15	7.8	15.6	1.01	103	6.7	2.0	PULLOUT
LB-6	REG	7.24	DYN	7.0	.40	7.2	9.7	.96	9.7	2.4	1.4	PULLOUT
LB-6	REG	6.08	FAT	2.6	.02	1.0	4.2	.03	2000	1.5	1.6	BOLT FAILURE
LB-6	REG	6.38	FAT	2.6	.05	1.0	2.6	.15	535	3.0	1.0	BOLT FAILURE
LB-6	MAG	6.17	STAT	--	--	--	16.6	--	--	--	--	PULLOUT
LB-6	MAG	6.20	STAT	3.7	.01	--	5.6	--	--	--	1.5	PULLOUT
LB-6	MAG	6.17	DYN	4.0	.05	6.0	13.0	1.26	107.8	25	3.2**	CONC FAILURE
LB-6	MAG	6.15	DYN	5.0	.03	7.2	12.5	.76	103	29	2.5***	CONC FAILURE
LB-6	SS	6.27	STAT	2.8	.02	--	4.0	--	--	--	1.4	PULLOUT
LB-6	SS	6.29	STAT	4.8	.38	--	7.2	1.05	--	2.8	1.5	PULLOUT
LB-6	SS	6.20	DYN	3.4	.38	7.8	6.4	.97	110	2.6	1.9	PULLOUT
LB-6	SS	6.24	DYN	--	--	--	2.2	.83	6.8	--	--	PULLOUT
SB-6	REG	7.49	STAT	17.3	.50	--	17.3	.50	--	1.0	1.0	PULLOUT
SA-6	REG	7.44	STAT	22.0	.35	--	22.0	.35	--	1.0	1.0	PULLOUT
SA-6	REG	6.86	DYN	10.0	.25	7.8	18.2	.45	105	1.8	1.8	PULLOUT
SA-6	REG	7.12	DYN	10.0	.18	7.8	21.8	.45	108	2.5	2.2	CONC FAILURE
SA-6	REG	--	FAT	4.0	.01	--	4.0	.03	386	3.0	1.0	BOLT SHEAR
SA-6	REG	--	FAT									
SB-6	MAG	6.93	STAT	8.0	.04	--	14.2	.15	--	3.7	1.8	CONC FAILURE
SA-6	MAG	7.05	STAT	8.0	.05	--	25.5	.42	--	8.4	3.2	CONC FAILURE
SB-6	MAG	6.78	DYN	13.6	.10	7.8	15.7	.42	100	4.2	1.2	BOLT FAILURE
SA-6	MAG	7.07	DYN	13.6	.18	7.8	13.6	.26	94	1.4	1.0	BOLT FAILURE

* See Table 3 for anchor bolt code.

** Wedge walked 1.0" from 4K load at 6000 cycles to 7K load at 8000 cycles.

*** Wedge walked 0.45" from 5K load at 6000 cycles to 7K load at 8000 cycles.

TABLE 7 - RESULTS OF ANCHOR BOLT TEST PROGRAM 3/4 INCH BOLTS TESTED IN TENSION

(Continued)

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
SA-6	SS	6.50	STAT	12.0	.30	--	15.6	.60	--	2.0	1.3	PULLOUT
SB-6	SS	7.38	STAT	6.0	.40	--	7.6	.60	--	1.5	1.3	PULLOUT
SA-6	SS	7.33	DYN	9.6	.21	7.8	13.6	.30	101	1.5	1.4	PULLOUT
SA-6	SS	7.58	DYN	8.4	.27	7.8	14.4	.40	102	1.5	1.7	PULLOUT
SB-6	SS	7.61	FAT	3.2	.05	--	3.2	.70	1440	14.0	1.0	BOLT FAILED

* See Table 3 for anchor bolt code.

TABLE 8 - RESULTS OF ANCHOR BOLT TEST PROGRAM 3/4 INCH BOLTS TESTED IN SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LB-6	REG	6.78	STAT	10.7	.30	--	14.6	.85	--	2.8	1.4	BOLT FAILURE
LB-6	REG	6.67	STAT	14.0	.40	--	15.8	.65	--	1.6	1.1	BOLT FAILURE
LB-6	REG	7.35	DYN	8.9	.27	7.8	8.9	.80	27.5	3.0	1.0	BOLT FAILURE
LB-6	REG	6.54	DYN	8.9	1.10	7.8	8.9	--	19.8	--	1.0	BOLT FAILURE
LB-6	MAG	6.54	STAT	11.5	.34	--	16.2	--	--	--	1.4	BOLT FAILURE
LB-6	MAG	6.57	STAT	12.5	.40	--	14.1	.90	--	2.3	1.1	BOLT FAILURE
LB-6	MAG	6.48	DYN	8.7	.25	7.8	8.7	.55	39.6	2.2	1.0	BOLT FAILURE
LB-6	MAG	6.70	DYN	8.7	.27	7.8	8.7	1.25	26.9	4.6	1.0**	BOLT FAILURE
LB-6	SS	6.40	STAT	9.4	.17	--	11.0	1.20	--	7.0	1.2**	PULLOUT
LB-6	SS	6.96	STAT	13.0	.40	--	14.0	.60	--	1.5	1.1**	PULLOUT
LB-6	SS	5.16	DYN	5.4	.22	7.8	5.4	--	34	--	1.0**	PULLOUT
LB-6	SS	6.43	DYN	5.4	1.10	7.8	5.4	--	7.8	--	1.0**	PULLOUT
SH-6	REG	5.87	STAT	15.0	.23	--	16.4	.30	--	1.3	1.1	BOLT SHEAR
SA-6	REG	6.10	STAT	15.1	.15	--	17.0	.20	--	1.3	1.1	BOLT SHEAR
SB-6	REG	6.38	DYN	10.0	.13	7.8	11.7	.25	101	1.9	1.2	BOLT SHEAR
SA-6	REG	6.68	DYN	10.0	.20	7.8	10.0	.25	18.7	1.3	1.0	BOLT SHEAR
SA-6	MAG	5.81	STAT	19.0	.25	--	21.0	.33	--	1.3	1.0	CONC FAILURE
SH-6	MAG	6.08	STAT	17.0	.30	--	18.9	.70	--	2.3	1.1	BOLT FAILURE
SH-6	MAG	5.87	DYN	12.0	.30	7.8	12.0	.80	8.1	2.7	1.0	BOLT FAILURE
SB-6	MAG	5.49	DYN	12.0	.20	7.8	12.0	.25	8.1	1.3	1.0	BOLT FAILURE
SA-6	SS	7.30	STAT	12.0	.20	--	16.0	.30	--	1.5	1.3	CONC FAILURE
SH-6	SS	6.84	STAT	10.0	.15	--	13.0	.22	--	1.5	1.3	CONC FAILURE
SB-6	SS	7.44	DYN	9.2	.20	7.8	9.2	.40	36.4	2.0	1.0	PULLOUT
SA-6	SS	7.10	DYN	9.0	.10	7.8	13.1	.19	103	1.9	1.5	CONC FAILURE
SA-6	SS	7.23	FAT	2.9	.05	17.0	10.0	.16	1504	3.2	1.0	

* See Table 3 for anchor bolt code.

** Wedge slipped after P_y

TABLE 9 - RESULTS OF ANCHOR BOLT TEST PROGRAM 3/4 INCH BOLTS TESTED IN COMBINED TENSION AND SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
LA-6	REG	7.10	STAT	13.3	.55	--	13.3	.55	--	1.0	1.0	PULLOUT
LA-6	REG	7.12	STAT	12.0	.16	--	12.0	.16	--	1.0	1.0	CONC FAILURE
LB-6	REG	--	STAT	6.0	.15	--	10.4	.50	--	3.3	1.7	CONC FAILURE
LB-6	REG	5.85	STAT	8.4	.14	--	14.5	--	--	--	1.7	CONC FAILURE
LB-6	REG	6.43	DYN	6.0	.10	6.6	7.2	.80	39.5	8.0	1.2**	BOLT SHEAR
LB-6	REG	7.01	DYN	7.2	.32	7.8	7.2	--	63.3	--	1.0**	BOLT SHEAR
LB-6	MAG	8.14	STAT	5.8	.08	--	15.4	.46	--	5.5	2.7**	CONC FAILURE
LB-6	MAG	8.07	STAT	7.2	.09	--	14.2	.93	--	10.3	2.0**	CONC FAILURE
LB-6	MAG	8.07	DYN	6.4	.07	7.8	6.4	.07	67	1.0	1.0	PULLOUT
LB-6	MAG	7.90	DYN	6.4	.09	7.8	6.2	.15	95.5	1.7	1.0	BOLT SHEAR
LB-6	SS	7.65	STAT	9.6	.11	--	11.2	.94	--	8.5	1.2**	CONC FAILURE
LB-6	SS	6.38	STAT	8.6	.12	--	11.2	.41	--	3.4	1.3**	CONC FAILURE
LB-6	SS	8.77	DYN	6.3	.11	7.8	6.25	.60	44.6	5.5	1.0**	STUD SHEAR
LB-6	SS	5.86	DYN	6.4	.14	7.8	6.40	.14	7.9	1.0	1.0**	PULLOUT
SB-6	REG	7.17	STAT	13.0	.30	--	13.0	.30	--	1.0	1.0**	PULLOUT
SA-6	REG	6.86	DYN	13.2	.50	7.8	13.2	.50	107	1.0	1.0**	PULLOUT
SB-6	REG	6.71	DYN	6.5	.10	7.2	11.8	1.0	102	10.0	1.8***	PULLOUT
SA-6	REG	6.22	FAT	8.0	.13	2000	10.3	.29	2005	2.2	1.3	CONC FAILURE
SA-6	MAG	--	STAT	11.4	.20	--	11.4	.20	--	1.0	1.0	CONC FAILURE
SB-6	MAG	--	STAT	12.0	.02	--	15.4	.23	--	11.5	1.3**	CONC FAILURE
SB-6	MAG	--	DYN	8.0	.20	7.8	14.6	.24	104	1.2	1.8	CONC FAILURE
SA-6	MAG	8.62	DYN	8.2	.04	7.8	12.0	.08	102	2.0	1.5	CONC FAILURE
SB-6	SS	7.90	STAT	10.4	.17	--	10.4	.17	--	1.0	1.0	BOLT FAILURE
SA-6	SS	8.14	DYN	5.0	.08	7.2	10.0	.43	71.8	5.4	2.0***	BOLT FAILURE
SA-6	SS	8.53	DYN	6.1	.17	7.8	6.1	.26	84.0	1.5	1.0	BOLT FAILURE
SA-6	SS	8.09	FAT	5.0	.24	2000	6.0	.35	2006	1.4	1.2	BOLT SHEAR

* See Table 3 for anchor bolt code.

** Wedge slipped after P_y

*** Wedge walked after P_y

TABLE 10 - RESULTS OF ANCHOR BOLT TEST PROGRAM 1 INCH BOLTS

1 INCH BOLTS TESTED IN TENSION

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
SA-8	REG	6.96	STAT	26.4	.60	--	26.4	.60	--	1.0	1.0	CONC FAILURE
SB-8	REG	6.13	STAT	16.0	1.0	--	22.5	1.20	--	1.2	1.4	CONC FAILURE
SB-8	REG	7.00	DYN	15.8	.65	7.8	20.8	.85	101	1.3	1.3	CONC FAILURE
SA-8	REG	5.69	DYN	16.0	.10	7.8	26.0	.33	103	3.3	1.6	CONC FAILURE

1 INCH BOLTS TESTED IN SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
SA-8	REG	6.66	STAT	18.4	.20	--	18.4	.20	--	1.0	1.0	CONC FAILURE
SA-8	REG	7.14	STAT	17.0	.20	--	17.2	.40	--	2.0	1.0	CONC FAILURE
SA-8	REG	6.36	DYN	10.9	.25	7.8	19.0	.66	76	2.6	1.7	BOLT FAILURE
SA-8	REG	6.10	DYN	10.9	.10	7.8	15.2	.25	106	2.5	1.4	CONC FAILURE

1 INCH BOLTS TESTED IN COMBINED TENSION AND SHEAR

BOLT* TYPE	CONC TYPE	F'C KSI	TEST TYPE	PY KIP	DY IN	CYCLE KC	PU KIP	DU IN	CYCLE KC	DR = DU/DY	PR = PU/PY	FAILURE MODE
SB-8	REG	6.02	STAT	7.5	.10	--	13.0	.25	--	2.5	2.6	CONC FAILURE
SA-8	REG	7.14	STAT	12.6	.25	--	12.6	.25	--	1.0	1.0	CONC FAILURE
SA-8	REG	6.52	DYN	8.0	.14	7.8	8.0	.34	74	2.4	1.0	CONC FAILURE
SA-8	REG	6.77	DYN	8.0	.36	7.8	11.6	.57	102	1.6	1.5	CONC FAILURE

* See Table 3 for anchor bolt code.

9.0

REFERENCES

- A. Static and Dynamic Loading of 5/8-inch Concrete Anchors, an unpublished report No. 7745.10-72, August 10, 1972, Pacific Gas and Electric Company, Department of Engineering Research.
- B. Test Results on Dynamic Testing of Expansion Type Concrete Anchors, Report No. SI-74-1, December, 1974, Structural Engineering Laboratory, University of California, Berkeley, California.
- C. Specification 5853-C-81 (HWS-2230) Installation of Drilled-in Expansion Bolts, for the Fast Flux Test Facility of the U.S. Atomic Energy Commission, Richland, Washington by Bechtel Power Corporation, San Francisco, California.

10.0

APPENDICES

- A. Use of Expansion Anchors, Document ID C-1450, Bechtel Power Corporation Interoffice Memorandum from H.W. Wahl to Group Supervisors, dated May 10, 1973.

FFTF REPORT
DRILLED-IN EXPANSION BOLTS UNDER
STATIC AND ALTERNATING LOAD

APPENDIX A

TESTING PROGRAM FOR DRILLED-IN
EXPANSION TYPE CONCRETE ANCHORS

FOR THE

FAST FLUX TEST FACILITY
RICHLAND, WASHINGTON

FOR THE

UNITED STATES ATOMIC ENERGY COMMISSION

BECHTEL POWER CORPORATION
SAN FRANCISCO, CALIFORNIA

TESTING PROGRAM FOR DRILLED-IN EXPANSION TYPE CONCRETE ANCHORS

1. Objectives and Scopes

The objective of this test program is to establish the design loads (tension, shear, and combined) of a drilled-in expansion type anchors. The design loads will be established from a fatigue S-N testing program for 1. installation of vibratory equipments, 2. seismic anchors for ASME Code Section III Class 1 pipings and vessels, and 3. general equipment and piping anchors.

The scope of this testing program includes a dynamic testing of stud and shell type expansion bolts for three bolt diameters (5/8", 3/4", and 1"), from five makers (Hilti, Parabolts, Wej-it, Phillips, and Star), embedded in test block made of FFTF concrete mixes. The details of testing are presented in the Testing Schedules of this program.

The dynamic testing will be carried out by the Engineering Material Laboratory of University of California at Berkeley. The test blocks and control cylinders will be cast and shipped to the testing laboratory by Bechtel Field Engineers. The test data will be analyzed as soon as they are available for establishment of the design values for the anchor bolts.

2. Test Program

Basic data on dynamic behavior will be obtained from two types of fatigue S-N testing; NT and NV series for long term fatigue which may be caused by dynamic loads of steady state machine vibrations; T (tension), V (shear), and C (combined) series for low cycle fatigue which may be caused by dynamic loads similar to those experienced during an earthquake. Static tests will also be conducted to establish the static capacity, S', of the anchor values as the basis for establishment of the magnitude of the dynamic loads for the fatigue S-N testing.

2.1 Variable parameters considered in this test program are as follows:

- o Diameters - 5/8", 3/4", and 1"
- o Types of Anchors:
 - SA = Rawl Stud Type Expansion Anchors
 - SB = Parabolts Stud Type (wedge type)
 - SC = Wej-it standard anchor bolt

SP = Typical Stud Anchors TBD based on test results
 LA = Hilti Shell Type Expansion Anchors (HDI)
 LB = Phillips Read Head Expansion Anchors (HN)
 LC = Star Shell Type Expansion Anchors
 LP = Typical Shell Anchors TBD based on test results

o Concrete Types:

R = FFTF Regular Concrete 4000 psi Mix
 M = FFTF Magnetite Concrete 5000 psi Mix
 SS = FFTF Steel Shot Concrete 5000 psi Mix

2.2 Test Specimens and Loading Jigs

Figures 1, 2, and 3 illustrates the test specimens for Tension (T), Shear (V) and Combined (C) loading test. The combined loading consists of a constant T and V ratio which is set equal to one. The loading couplers and loading jigs for the T, V, and C type loading are illustrated in Figures 4, 5 and 6. For each test specimen one 6 x 12 in. control cylinder will be prepared.

The test specimens, loading jigs and couplers, and the control cylinders will be prepared by Bechtel Field Engineers and shipped to Davis Hall, University of California (Attention: Roy Stephens) for testing.

2.3 Static and Dynamic Loading Sequences

- 2.3.1 Static Test. The static load capacity, S' , is determined by a static test at a loading rate not exceeding 5K/min.
- 2.3.2 NT and NV long term fatigue test. This test starts with a cyclic load of 10 cycle/sec. with magnitude of $0.1 S'$ for two million load cycles ($N=2 \times 10^6$). If the specimen does not fail, increase the magnitude of the cyclic load by $0.05 S'$ and apply the load at 5 cps for a duration of 60 seconds. Repeat this later loading process until failure.
- 2.3.3 T.V. and C low cycles fatigue test. These dynamic loads are applied according to the following sequence:

<u>n</u>	<u>Load Magnitude</u>	<u>Cycles/Sec.</u>	<u>Duration Sec.</u>	<u>Cumulative Cycles, N</u>
0	0.1 S'	5	30	150
		10	30	450
		15	30	900
		5	30	1050
		10	30	1350
		15	30	1800
		5	60	2100
		10	60	2700
		15	60	3600
1	0.15 S'	5	60	3900
2	0.20 S'	5	60	4200
3	0.25 S'	5	60	4500
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
n	(0.1+0.05n) S'	5	60	3600+300n

Remark: The initial load and the load increments will be adjusted according to the initial test results to expedite the testing.

2.4 Test Schedule

Table 1 illustrates a summary of the test schedule for 60 static testings and 82 dynamic testings. For each dynamic testing a duplicate test will be performed. If the results of the two tests fall within $\pm 15\%$ of the average value, the average value will be used for derivation of the design value. If the results of the two test varies more than 15% from the average value, a stand-by specimen is reserved for the third testing. In this instance the average value of the three tests will be used for derivation of the design value.

The test specimens will be cast on the weeks of June 3, June 24, and July 15. Testing will be started on the weeks of June 24, July 15, and August 5. If there is any delay on the casting date the testing will be delayed on day-by-day basis. The tests are scheduled to be finished by the end of August, however, the test results will be analyzed for project use as soon as they are available. The detail casting and testing schedules are listed in Table 2. (Only schedule for the first casting is prepared by May 31, 1974. The rest will be transmitted as soon as they are complete.)

3. Testing Medium

The test specimens are cast from concrete mixes for Regular 4000 psi concrete, Magnetite 5000 psi concrete, and Steel Shop 5000 psi concrete. The proportions of the corresponding concrete mixes are specified in Mixes C-1P, M-225-C, and IM-290-C of Specification HWS-1420 (5853-C-21) for FFTF project.

For each test specimen an accompanying 6 x 12 in. control cylinder shall be cast from the same batch of concrete. The test specimen and its control cylinder shall be marked with the same identification number and batch number. The test specimens and control cylinders will be prepared and shipped to Davis Hall, University of California at Berkeley by Bechtel Field Engineers.

The testing will be conducted at a minimum of 21 days of concrete age. Testing of three to eight specimens (4 static and up to 4 dynamic), from the same batch of concrete, will be conducted in a day.

Three control cylinders shall be crushed and average compressive strength noted during a twelve-hour period immediately proceeding and/or following any testing series.

4. Testing Procedures

4.1 Anchor Installation

- 4.1.1 Holes for anchor test specimens shall be drilled in accordance with published recommendations of manufacturer as to hole diameters and depths. Equipment used for hole drilling should be of the type commonly used for field installations and testing data should note brand, model number, and size of power tool and drill bit used. Hole drilling shall be done without using special drilling jig not commonly used for field installations.
- 4.1.2 Test holes for anchors of the self-drilling type shall be drilled with the anchor to be tested in accordance with the published recommendations of the manufacturer as to drilling procedures and equipment.
- 4.1.3 The test holes shall be thoroughly cleaned out and the diameter of each hole shall be considered as the average of measurements taken at a point equivalent to one anchor diameter or one-quarter

of the depth of maximum imbedment, whichever is smaller, from the face of the test block, and at approximately the point of maximum imbedment of the anchor. These diameters shall be noted and regarded as part of the test data.

- 4.1.4 All test anchors shall be installed perpendicular to the surface of the test block.
- 4.1.5 Installation and "setting" of the anchors shall be in accordance with published recommendation of the manufacturer and such pertinent data as anchor imbedment depth (if appropriate, torque required for setting), etc. shall be observed and noted by the testing laboratory and/or other witnessing agency.

4.2 Testing and Equipment

- 4.2.1 Tests are to be conducted using the 500k MTS Dynamic Testing Frame and its related control equipment and instrumentation located in Davis Hall, University of California, Berkeley campus.

- 4.2.2 Test Arrangement and Readings

The test set-up is shown on Figure 7. The readings consist of dial gage readings, D, for anchor displacement, load magnitude, F, and cumulative load cycles, N. A XY recorder shall be used to record the overall displacement of the MTS loading frame versus the applied load.

- 4.2.3 Testing

A static test shall be performed to determine the static load capacity, S', prior to the dynamic test. The loading sequences for dynamic tests are described in Section 2.3 of this test program.

During dynamic testing the dial gage shall be read at the maximum loads and at mean load values. For the first three tests on each type of concrete (Regular, Magnetite, and Steel Shot), the displacement readings shall be continued up to failure load. Thereafter, the displacement readings may be discontinued at about 1/8 inch of displacement.

The total numbers of testing are 60 and 82 for static and dynamic testing respectively. A tentative casting and testing schedule is presented in Table 2.

4.2.4 Test Data and Test Reports

A copy of test data shall be transmitted to Bechtel, San Francisco Home Office (SFHO) as soon as they are available. SFHO Engineers will process these data for derivation of the design values for FFTF project use. At the end of this test program, U.C. will submit a test report to Bechtel. The U.C. Test Report shall include all reduced test data and photographs of test equipments, test set-ups, and typical failure modes of the test specimens.

**FFTF TESTING-PROGRAM FOR DRILLED-IN
EXPANSION TYPE CONCRETE ANCHORS**

TABLE 1 SUMMARY OF TEST SCHEDULE

Con- crete Mix	Type And Size of Anchors	Type of Testing	Static S'	Dynamic D	Reserve R
Regular 4,000 Psi Mix	LB 5 (6+10+5)	NT	-	2	1
		NV	-	2	1
		T	2	2	1
		V	2	2	1
		C	2	2	1
	SB 5 (6+10+5)	NT	-	2	1
		NV	-	2	1
		T	2	2	1
		V	2	2	1
		C	2	2	1
	SA 5 SC 2 (0+6+3)	T		2	1
		V		2	1
		C		2	1
	LA 5 LC 2 (0+6+3)	T		2	1
		V		2	1
		C		2	1
	Sp 6 Lp 2 (6+6+3)	T (NT) *	2	2	1
		V (NV) *	2	2	1
		C	2	2	1
	Sp 8 2 (6+6+3)	T	2	2	1
		V	2	2	1
		C	2	2	1
	Sub-Total		30	52	31
Steel Shot 5,000 Psi Mix	Sp 6 Lp 2 (6+6+3)	T (NT) *	2	2	1
		V (NV) *	2	2	1
		C	2	2	1
	Sub-Total		12	12	6
Magnetite 5,000 Psi Mix	Sp 6 Lp 2 (6+6+3)	T (NT) *	2	2	1
		V (NV) *	2	2	1
		C	2	2	1
	Sub-Total		12	12	6
Total	Total Test Specimens		54	76	43
	Total 6"x12" Control Cylinders		54	76	43

*These tests will be performed using reserve specimen if time permits.
Otherwise these tests will be deferred to September 1974.

TABLE -1 (Continued)LEGEND● Type of Anchors

LA: Hilti Shell Type
 LB: Phillips Shell Type
 LC: Star " "
 LP: Typical " "*

SA: Hilti Stud Type
 SB: Parabolt Stud Type
 SC: Wej-it Stud Type
 SP: Typical Stud Type*

*Typical anchors to be determined based on test results

● Size of Anchors

5: 5/8" dia.
 6: 3/4" dia.
 8: 1" dia.

● Type of Testing

NT, NV: Long term (2×10^6 cycles or more) fatigue test for tension and shear respectively.

T,V,C : Low cycle (5000 + cycles) fatigue test for tension, shear and combined loading respectively.

TABLE 2
TESTING SCHEDULE FOR FIRST CASTING

TEST NO.	TYPE OF ANCHOR	TYPE OF TEST	JUNE				JULY				AUGUST			
			10	17	24	31	8	15	22	29	6	13	20	27
1	R 1R5	T							O					
2		V							O					
3		C							O					
4		C							O					
5		T							Δ					
6		T							Δ					
7		V												
8		V							Δ					
9		C							Δ					
10		C							Δ					
11	S45	T							O					
12		V							O					
13		T							Δ					
14		T							Δ					
15		V							Δ					
16		V							Δ					
17		C							O					
18		C							O					
19		C							Δ					
20		C							Δ					
21	S45	C							Δ					
22	"	C							Δ					
23	S45	C							Δ					
24	"	C							Δ					
25	1R5	C							Δ					
26	"	C							Δ					
27	1R5	C							Δ					
28	1R5	T							O					
29	"	NT												

LEGEND

O STATIC
Δ DYNAMIC
— FATIGUE

Fri - Mon.

TABLE 2
TESTING SCHEDULE FOR FIRST CASTING

TEST NO.	TYPE OF ANCHOR	TYPE OF TEST	JUNE			JULY				AUGUST		
			10	17	24	1	8	15	22	29	5	12
31	R Sp6	C S'										
32		C S'										
33		C D										
34		C D										
35	R Lp6	C S'										
36		C S'										
37		C D										
38		C D										
39	R Sp8	C S'										
40		C S'										
41		C D										
42		C D										
43	SS Sp6	C S'										
44		C S'										
45		C D										
46		C D										
47	SS Lp6	C S'										
48		C S'										
49		C D										
50		C D										
51	M Sp5	C S'										
52		C S'										
53		C D										
54		C D										
55	M Lp6	C S'										
56		C S'										
57		C D										
58		C D										
59	R LBS NY	D										

LEGEND

- O STATIC
- Δ DYNAMIC
- FATIGUE

FIRST CASTING JUNE 28

Fri - Mon.

BR-5853-C-4, Rev. 1

TABLE 2
TESTING SCHEDULE FOR SECOND CASTING

TEST NO.	TYPE OF ANCHOR	TYPE OF TEST	JULY				AUGUST				SEPTEMBER	
			1	2	3	4	5	6	7	8	9	10
1	R 185	T	S'									
2	P 555	T	S'									
3	P 545		D									
4	"		D									
5	P 5C5											
6	"											
7	P 1A5											
8	"											
9	R 1C5											
10	"											
11	R 506	S'										
12	"	S'										
13	"	D										
14	"	D										
15	R 185	S'										
16	"	S'										
17	"	D										
18	"	D										
19	P 508	S'										
20	"	S'										
21	"	D										
22	"	D										
23	55 506	S'										
24	"	S'										
25	"	D										
26	"	D										
27	P 585	NY										
28	TS 185	T	S'									
29	"	T	S'									
30	"	T	D									

LEGEND

O STATIC
Δ DYNAMIC
□ FATIGUE

SECOND CASTING JULY 22

Fri - Mon.

BR-5853-C-4, Rev. 1

TABLE 2
TESTING SCHEDULE FOR THIRD CASTING

TEST NO.	TYPE OF ANCHOR	TYPE OF TEST	JULY				AUGUST				SEPTEMBER			
			SMTWTFS	1	2	3	SMTWTFS	1	2	3	SMTWTFS	1	2	3
1	R LB5 V	S'												
2	R SB5	S'												
3	R SA5	D												
4	"													
5	D SC5													
6	"													
7	R LA5													
8	"													
9	R LC5													
10	"													
11	R Sp5	S'												
12		S'												
13		D												
14		D												
15	R Lp5	S'												
16		S'												
17		D												
18		D												
19	R Sp8	S'												
20		S'												
21		D												
22		D												
23	SS Sp5	S'												
24		S'												
25		D												
26		D												
27	R Sp6 NT	D												
28	SS Lp6 V	S'												
29		S'												
30		D												

LEGEND

O STATIC
Δ DYNAMIC
FATIGUE

THIRD CASTING AUGUST 12

Fri. - Mon.

TABLE 2
TESTING SCHEDULE FOR THIRD CASTING

TEST NO.	TYPE OF ANCHOR	TYPE OF TEST	AUGUST				SEPTEMBER			OCTOBER		OCTOBER	
			1	2	3	4	9	16	23	7	14	21	
31	SS Lp6 V	D					Δ						
32	11 Sp6	S'					0						
33		S'					0						
34		D					Δ						
35		D					Δ						
36	R Sp6 NY	D				Tues. - Fri.	■						
37	11 Lp6 V	S'					0						
38		S'					0						
39		D					Δ						
40		D					Δ						
41	SS Sp6 NY	D				Fri. - Mon.	■						
42	" NT	D				Mon. - Thur.	■						
RESERVE													
43	11 Sp6 NT	D				Fri. - Mon.	■						
	" NY	D				Mon. - Thur.	■						
RESERVE													
44	R Sp6 NT	D				Fri. - Mon.	■						
	" NY	D				Mon. - Thur.	■						
RESERVE													
45	SS Sp6 NT	D				Fri. - Mon.	■						
	" NY	D				Mon. - Thur.	■						

THIRD CASTING AUGUST 12

LEGEND
 O STATIC
 Δ DYNAMIC
 ■ FATIGUE

TABLE 2
TESTING SCHEDULE FOR THIRD CASTING

[illegible]

CALCULATION SHEET

FAST FLUX TEST FACILITY

URE _____ DATE _____
 E _____ JOB NO. _____
 DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR SHEET NO. _____

CASTING SCHEDULE	REGULAR 4,000 PSI MIX	MAGNETITE 5,000 PSI MIX	STEEL SHOT 5,000 PSI MIX
DATE	6-28-74	_____	_____
QUANTITY	14	NONE	NONE
DATE	7-22-74	_____	_____
QUANTITY	36	10	10
DATE	8-12-74	_____	_____
QUANTITY	NONE	3	3

FIG. 1. SPECIMEN FOR TENSION TEST

CALCULATION SHEET

FAST FLUX TEST FACILITY

130 100131 0-00

PRE _____

DATE _____

JOB NO. _____

DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR

SHEET NO. _____

CASTING SCHEDULE	REGULAR 4,000 PSI MIX	MAGNETITE 5,000 PSI MIX	STEEL SHOT 5,000 PSI MIX
DATE	6-28-74	—	—
QUANTITY	13	NONE	NONE
DATE	7-22-74	—	—
QUANTITY	7	4	4
DATE	8-12-74	—	—
QUANTITY	28	9	9

FIG. 2 SPECIMEN FOR SHEAR TEST

CALCULATION SHEET

FAST FLUX TEST FACILITY

TURE _____ DATE _____
 LE _____ JOB NO. _____
 CT DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR SHEET NO. _____

CASTING SCHEDULE	REGULAR 4,000 PSI MIX	MAGNETITE 5,000 PSI MIX	STEEL SHOT 5,000 PSI MIX
DATE	6-28-74		
QUANTITY	36	10	10
DATE	7-22-74		
QUANTITY	6	NONE	NONE
DATE	8-12-74		
QUANTITY	6	NONE	NONE

FIG. 3 SPECIMEN FOR COMBINED TEST

CALCULATION SHEET

120-145121-6-78

FAST FLUX TEST FACILITY

NATURE _____ DATE _____

TITLE _____ JOB NO. _____

SUBJECT DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR SHEET NO. _____

MALE-FEMALE (MF)
COUPLER

FEMALE-FEMALE (FF)
COUPLER

FIG. 4 LOADING COUPLERS FOR TENSION TEST

FAST FLUX TEST FACILITY

NATURE _____ DATE _____

TITLE _____ JOB NO _____

PROJECT DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR SHEET NO.

FIG 5 LOADING JIG FOR SHEAR TEST
(2 JIGS REQUIRED)

CALCULATION SHEET

13D-08121-6-01

FAST FLUX TEST FACILITY

NATURE _____ DATE _____
TITLE _____ JOB NO. _____
SUBJECT DRILLED-IN EXPANSION TYPE CONCRETE ANCHGR SHEET NO. _____

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FIG. 6 LOADING JIG FOR COMBINED TEST
(2 JIGS REQUIRED)

CALCULATION SHEET

17-00127-000

FAST FLUX TEST FACILITY

AUTHOR _____ DATE _____

TITLE _____ JOB NO. _____

SUBJECT DRILLED-IN EXPANSION TYPE CONCRETE ANCHOR SHEET NO. _____

N = CUMULATIVE LOAD CYCLES

FIG. 7 TEST SET-UP & READINGS, D, F, N