TEST CRITERIA AND METHOD FOR SEISMIC QUALIFICATION OF CONCRETE EXPANSION ANCHORS

by

J.H.K. Tang and J.J. Deans
Civil Design Department
Ontario Hydro

ABSTRACT

By nature of the installation procedures employed for expansion anchors, significant relaxation in the preload of the bolt as well as large clearances between various components of the anchorage system exist in the support. These characteristics indicate highly non-linear response during a seismic excitation. As a result, analytical methods or test results for embedded anchors are not applicable for seismic qualification of the expansion anchors.

This paper describes the test criteria and the philosophy behind the procedures used in determining the test input motion for seismic test of expansion anchors. The recommended test motion was derived by resonant response analysis of an artificial time history whose response spectrum envelopes the standard ground response spectrum specified for the design of CANDU structures.

Preliminary pilot tests for these drilled anchors in cyclic loadings have found that cyclic tension tests can be carried out using conventional shaker system with actuator directly attached to the anchor. However, reversed cyclic shear tests met with difficulties. Therefore, an alternative method for applying reversible cyclic shear loadings was devised. The principle on which this approach was based is demonstrated by a simulated analysis of a typical anchorage system.

INTRODUCTION

In a CANDU Nuclear Power Plant, a large number of small equipment such as electrical conduits, instrumentation and control tubings, and some light-weight components have to be connected to the concrete supported by drilled expansion anchors. This is because the locations of these equipment are usually not well defined prior to concrete placement of the primary structure. In case of certain safety-related systems, seismic qualification may be required and the anchors by which they are supported must therefore also be seismically qualified.

Although some research has been carried out for embedded anchors. (1,2,3,4,5), there is practically no information regarding dynamic cyclic withstand capability of drilled anchors especially for seismic qualification under shear loadings.

According to the preliminary CSA Standard N287.3-1978, "Design Requirement for Concrete Containment Structures for CANDU Nuclear Power Plants", expansion anchors are permitted only if they are tested in accordance with the requirements of CSA Standard N287.2, "Material Requirements for Concrete Containment Structures for CANDU Nuclear Power Plants".

This paper summarizes the results of a study for determining the test criteria described in terms of number of cycles, duration, amplitudes and sequence of loadings which will ensure seismic qualification of the anchors for any defined seismic event. This specification forms part of the input into the test requirements discussed by the CSA N287 committee to-date. This paper also proposes an innovative method for testing drilled anchors under reversed cyclic shear loadings.

SEISMIC RESPONSE OF SUPPORTED EQUIPMENT

It must be recognized that in the design phase, the peak seismic inertia force acting on the anchorage will be calculated from the seismic response of each individual piece of equipment and/or system during a seismic event as defined by the Design Basis Earthquake for the particular nuclear plant site (6). Therefore, in order to assure seismic qualification, it is only necessary to subject the anchor system to defined number of seismic cycles which will be representative of the number of times the peak acceleration amplitude will likely occur during a seismic event.

The determination of the number of seismic cycles a system may experience during a seismic event may be demonstrated by the following example using the 1940 El Centro N-S Component time history ground motion as illustrated in Figure 1.

The response of a primary structure to this ground motion can be simulated by considering a 5.1 Hz single degree-of-freedom (SDOF) system. Figure 2 shows the acceleration time history response of this SDOF system and as noted in this figure the peak amplitude is approximately 1.32 g. However, the structure only experiences one cycle of response at this level. In fact, for the El Centro event, this system will not experience more than 5 cycles at amplitudes between 75% and 100% of the peak value.

Since the expansion anchors under consideration attach the equipment to the primary structure, the number of seismic cycles that these anchors will experience must be determined from the response of the equipment to the seismic motion of the primary structure. This can be conservatively estimated by computing the resonate response of a secondary SDOF system to the acceleration time history response of the primary SDOF system. The results of this analysis are presented in Figure 3. In this case, the number of cycles the secondary SDOF system (equipment) will experience accelerations equal to or greater than 75% of the peak value is approximately 20.

Thus, if the anchors of the resonate equipment having a predominant frequency of 5.1 Hz are to be tested for this seismic event, a conservative value of 20 cycles at the peak acceleration amplitude would be sufficient. However, in addition to this a realistic test should consider fatique effects due to the number of cycles the anchors may see over the complete 30 seconds of the ground motion. Table 1 summarizes the number of cycles the 5.1 Hz equipment would experience at amplitudes equal to or greater than the specified percentage of the peak acceleration.

For this case, the number of test cycles at each acceleration amplitude can be estimated as shown in the first column of Table 2. This test is considered adequate since the cumulative number of cycles at each level exceed those as determined from Figure 3 as tabulated in Table 1.

DETERMINATION OF TEST INPUT MOTION

The above example outlines the basic philosphy that can be applied to determine the seismic test input for seismic qualification of the anchors. However, the number of response cycles calculated in the previous example is valid only for a structure having a predominant frequency of 5.1 Hz subjected to a specific seismic event which has its own characteristics relative to other seismic events. It is well known that different recorded seismic motions have energy levels concentrated at different frequency ranges. Thus, in order to determine the number of cycles for a series of system whose natural frequencies are within the range of interest, a representative time history should be used instead of a particular time motion. For this purpose, an artificial time history whose response spectrum envelopes the standard ground response spectrum is considered appropriate (7). Figure 4 shows an artificial time history that satisfies the above requirement as illustrated in Figure 5.

The artificial time history was applied as seismic input to a series of SDOF systems whose natural frequencies of 1.7, 2.1, 2.4, 3.0, 3.8 4.2,4.4,5.0,5.5,6.28,6.75,7.7,9.5and 10.0 could be considered as representative of the possible variation in the predominant frequencies of structures encountered in Nuclear Power Plant design. A damping ratio of 2% was assumed. The acceleration responses of these systems were then applied to an identical set of secondary SDOF system in order to stimulate the resonate equipment response to the structural seismic motion. The acceleration time history responses of this second series of SDOF systems were assessed to evaluate the number of cumulative cycles at various levels of acceleration amplitudes. The results of the analysis are tabulated in Table 3.

Table 4 lists the mean plus one standard deviation of those values recorded in Table 3 for the various SDOF systems at which the number of cycles equals or exceeds the specified percentage of the peak acceleration amplitudes.

Table 5 lists the recommended number of test cycles at each percentage of acceleration amplitude which will ensure seismic qualification of the anchors. This table also lists the cumulative number of cycles experienced at each percentage for comparison purposes. The number of cycles recommended have been selected based on the statistic evaluation resulting in Table 3 and 4 as well as on judgement and are believed to be a reasonable representation of the number of cycles the anchor will experience at each particular stress level during a seismic event. An upper limit of 300 cycles for the 30 second seismic duration has been selected since the predominant frequency of the primary system representing the structure will not likely exceed 10 Hz for a nuclear plant. This upper frequency will filter out the higher frequency components of the ground motion, limiting the response of those secondary systems whose frequencies exceed 10 Hz to a forced vibration at this frequency.

RECOMMENDED TEST PROCEDURES

In order to qualify the anchorage for any specified Design Basis Earthquake, the loading on the bolt should be limited to the permissible design stresses for tension and shear which are related to the yeild strength of the anchor bolt in accordance with the preliminary CSA standard N287.3 for abnormal/environmental category (8). Recognizing that the peak inertia force would be calculated from the peak acceleration amplitude, the recommended test load would also be governed by the number of cycles as determined from Table 5. However should the test results indicate that a reduction in the allowable stress is warrented then the test value will govern as is the case presented herein for shear test limits.

A study of the response of the secondary system has found that in general the peak acceleration occurs within the first four seconds. This suggests that the system will experience its peak load prior to cyclic response a lower levels. This sequence of loadings is particularly important in the case of shear resistance which is primarily dependent upon the dynamic friction factor which in turn is strongly dependent upon the prestressing of the anchor bolt. If the peak load is applied initially, as would be likely the case during a seismic event, the shear friction factor may be exceeded at this level resulting in a non-linear response of the system. This condition could also release the preload in the bolt. Based on this, the sequence of test loadings and number of cycles should be in accordance with Figure 6.

Recognizing that the secondary system may respond at any frequency probably between 1 to 10 Hz during a seismic event, the frequency at which the cyclic loads should be applied during testing becomes a matter of judgement. Considering that the average predominant frequency of nuclear structures will be in the vicinity of 5 Hz, this value appears to be appropriate for test purpose. However, it may prove instructive to carry out one or more seismic tests at other frequencies in order to demonstrate the effects of frequency response for a particular anchor being tested.

PROPOSED TEST METHODS

The load arrangement and control system shown in Figure 7 was used to try out the tension or shear test. It was immediately discovered that the tension test can be carried out successfully using this test set-up. However, during the shear test, the test apparatus would lose its control because the feed-back controlled servo-system fails to maintain the chosen loading rate when the rate of deflection is sufficiently rapid.

Alternative suggestion to use displacement controlled signal was also not successful since a very small displacement may impose unacceptably high loads on the anchorage and they would fail the system prematurely. Therefore, in order to seismically qualify the anchors in shear, another method to perform the cyclic shear test is required.

The cyclic loads that must be transferred to the anchorage in reality are derived from the inertial response of the attached equipment during an earthquake. If the equipment is rigidly connected to the structure the loading on the anchorage would be strictly that computed for the equipment. However, if the system is "attached" to the base structure by a force limiting device (eg. friction), the response of the anchorage system may fall into three categories, namely:

(1) elastic response when friction is not exceeded,
(2) free movement when the equipment slides through the gap,
(3) impact when the movement is brought to rest at contact.

The forces tranferred at the interface between the attached equipment and the base is governed by the modes of response as described above (Figure 8). The first type is fully elastic and the second type is limited by the frictional resistance. The peak value of the sharp spikes, as a result of the impact for the third type, is highly indeterminate since it depends on the width of the gap, acceleration level, frequency of the excitation and stiffness of the bolt etc.

The proposed test method for revised cyclic shear makes use of the above phenomenon by using an anchor block connected to the driving block by the expansion anchor under investigation. The driving block is then mounted rigidly onto a shaker table which would supply the necessary base acceleration to the system (Figure 9). For testing ½" anchor, for example, the mass of the anchor block would be 200 lbs., the acceleration required in the first test cycle shall be 1.5 g followed by 1.125 g, 0.75 g and 0.375 g respectively.

The typical response of a simulated system can be demonstrated by a simple analysis using a single degree-of-freedom system subjected to a base motion consisting of 20 cycles at 1.0 g, 8 cycles at 1.5 g, 3 cycles at 2.5 g and 3 cycles at 5.0 g. The simple rigid block weighs 200 lbs., the frictional resistance was assumed to be 200 lbs. and the gap was taken as 1/16 inch. The computed response is shown in Figure 10.

It can be seen that the proposed test method described herein is rather complex and the mechanism or behaviour of the anchor in the sliding mode is unpredictable. Therefore, this test technique should only be applied with extensive measurement of the system response. If the test is properly monitored however, it is believed that it would represent a more realistic testing of expansion anchors.

REFERENCES

(1) R.W. Cannon, E.G. Burdette, R.R. Funk, "Anchorage to Concrete", Tennessee Valley Authority, Knoxville, December 1975.

(2) ACI Committee 349, "1979 Supplement to: Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-76)", August 1979.

(3) R.R. Funk, "Testing Anchorage to Concrete", Proceedings of ASCE Conference on Civil Engineering and Nuclear Power, Knoxville, Tennessee, September 15-17, 1980.

(4) R.E. Klingner, J.A. Mendonca, J.B. Malik, "Effect of Reinforcing Details on the Shear Resistance of Anchor Bolts under Reversed Cyclic Loading", ACI Journal, January-February 1982.

(5) ACI Committee 355, "Symposium on Anchorage to Concrete," ACI Annual Convention, Atlanta, Georgia, January 1982.

(6) CSA Standard CAN3-N289.3-M81, "Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants", September 1981.

(7) N.C. Tsai, "Spectrum-Compatible Motions for Design Purposes", ASME Eng. Mech., April 1972.

(8) J.H.K. Tang, J.J. Deans, "Test Requirement for Seismic Qualification of Expansion Anchors", Ontario Hydro Design and Development Report No. 80385, November 1980.

Table 1: Number of Resonant Cycles for 5.1 Hz to El Centro

Cumulative No. of Cycles	% of Peak Acceleration Amplitude
1	100
20	75
37	50
77	25
153	1

Table 2: Assumed Number of Test Cycles

No. of Cycles at Each Level	Cumulative No. of Cycles	% of Peak Acceleration Amplitude
20	20	100
20	40	75
37	77	50
100	177	25

Table 3: Number of Cycles vs. Acceleration Amplitudes

	Peak Acceleration Amplitudes			
Frequencies	75%	50%	25%	1%
1.7	27	40	42	51
2.1	18	28	45	63
2.4	14	31	60	72
3.0	5	26	52	90
3.8	16	49	85	114
4.2	17	33	30	125
4.4	12	54	95	132
5.0	29	28	103	150
5.5	20	73	130	165
6.28	22	48	92	188
6.75	16	22	78	202
7.7	14	46	128	231
9.5	24	83	238	285
10.0	15	51	180	300
mean	17.86	45.93	100.57	154.86
standard deviation	6.26	17.62	54.51	78.75

Table 4: Mean Plus One Standard Deviation Number of Cycles

Cumulative No. of Cycles	% of Peak Acceleration Amplitudes
24	75%
63	50%
155	25%
234	1%

Table 5: Recommended Number of Test Cycles

No. of Cycles at Each Level	Cumulative No. of Cycles	% of Peak Amplitude
30	30	100%
30	60	75%
80	140	50%
200	340	25%

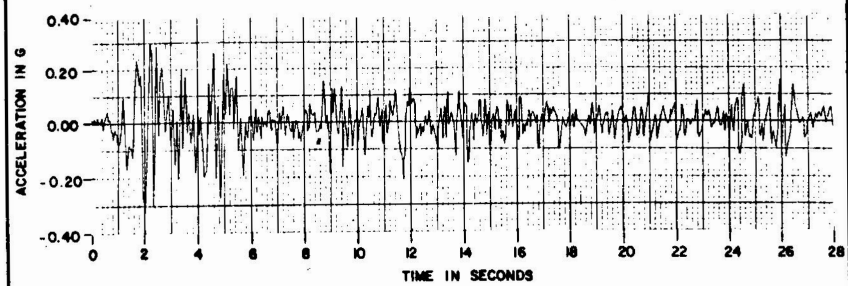

FIGURE I: EL CENTRO 1940 N.S. COMPONENT

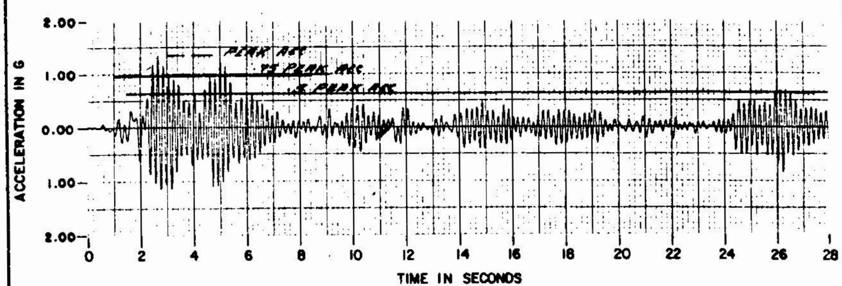

FIGURE 2: PRIMARY STRUCTURE (5.1Hz) RESPONSE TO EL CENTRO

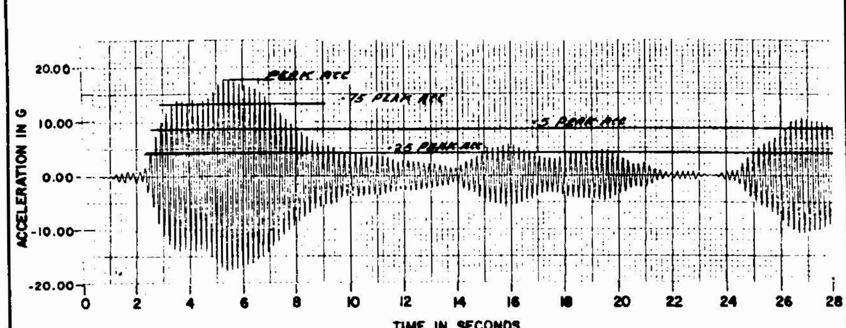

FIGURE 3: SECONDARY SYSTEM (5.1Hz) RESPONSE TO EL CENTRO

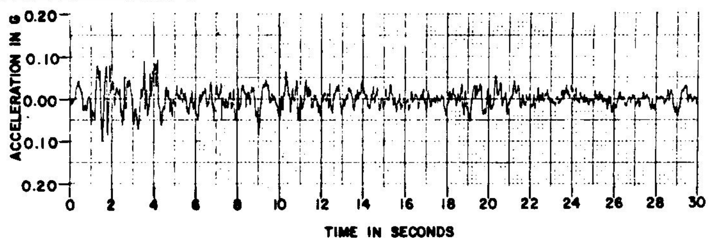

FIGURE 4: ARTIFICIAL TIME HISTORY COMPATIBLE WITH SGRS

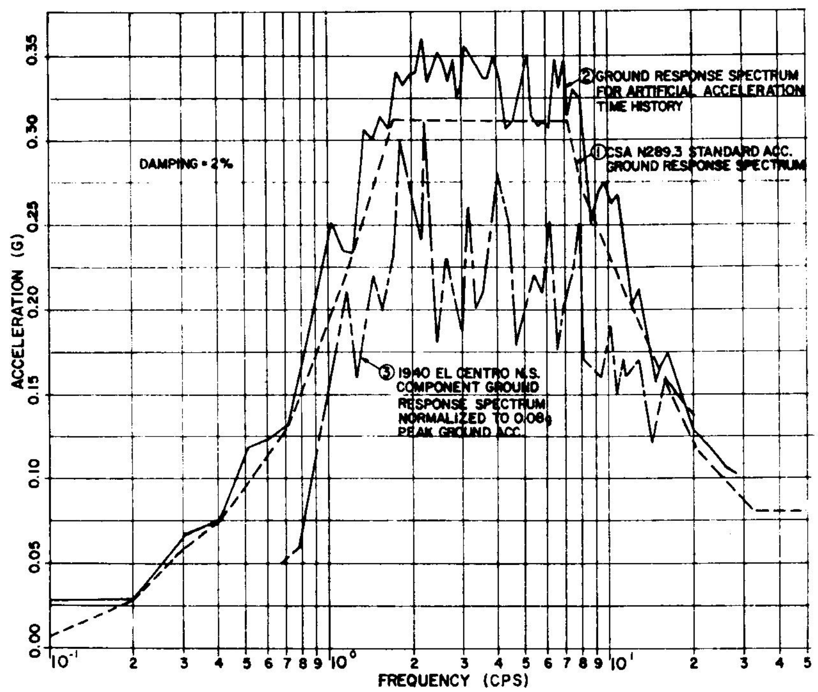

FIGURE 5: REPONSE SPECTRUM

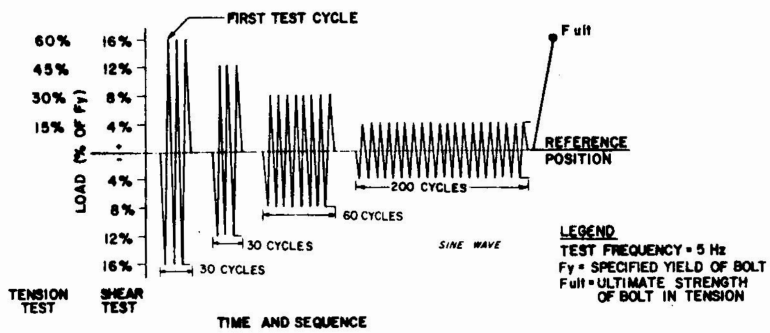

FIGURE 6: CYCLICAL TEST LOAD FOR SEISMIC QUALIFICATION OF EXPANSION ANCHORS

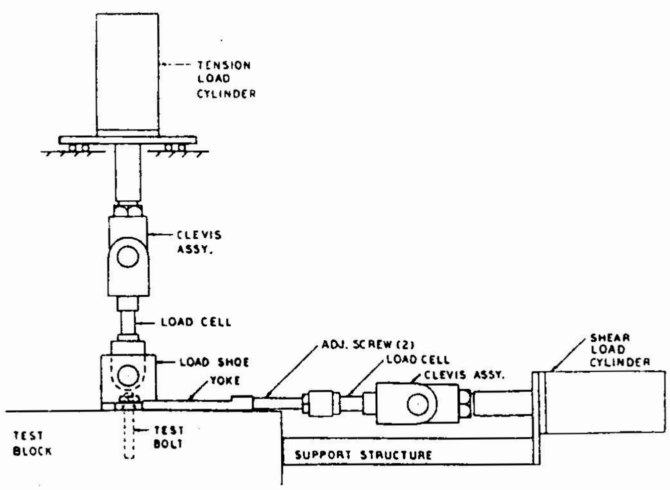

FIGURE 7: ANCHOR TEST LOAD ARRANGEMENT

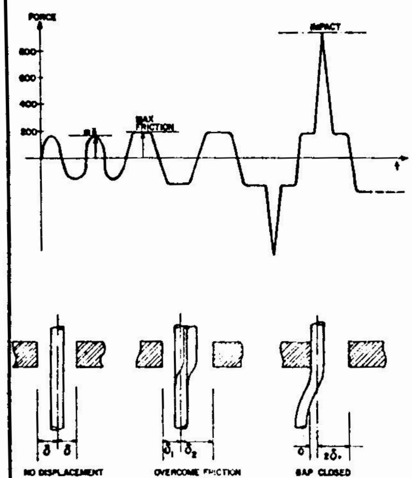

FIGURE 8: TYPICAL RESPONSE

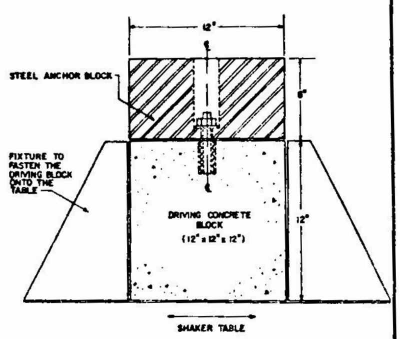

FIGURE 9: PROPOSED TEST SET UP

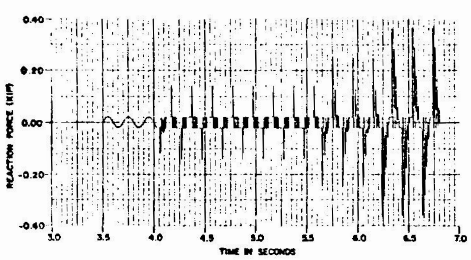

FIGURE 10: COMPUTER SIMULATION
OF SEISMIC SHEAR RESPONSE