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Seismic performance of post-installed anchors in reinforced concrete structures

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ABSTRACT

Post-installed anchors are widely used in facility fixing and building strengthening. However, designers normally consider the construction details and loadings when selecting anchors. The awareness of the seismic performance of anchors in design or construction usually low. Seismic performance of anchors is far different from static Inappropriate anchorrs selection can directly induce serious damage of structures or fixed building facilities during earthquake. Quality requirements on anchors regarding seismic performance were first introduced in ACI standard [4] in 10 years before. In 2013, European standards further improved the seismic test requirements on anchors. In this paper, seismic qualification requirements specified in European and US standards are compared. The corresponding quality evaluation methods and design methods are also introduced. The application and selection of anchors considering seismic design is recommended which will be helpful for engineering practice.

1. INTRODUCTION

In recent years, with the rapid development of construction industry in Asia countries, post-installed anchors are widely used in concrete buildings construction. They can be used to connect structural elements, fix non-structural components to structural elements and fix temporary supports during construction. Due to their convenient installation and wide applicable scope, post-installed anchors become more and more popular used in new building construction, old building strengthening or building retrofitting. However, although seismic design is emphasized in design standards in many countries, seismic property of anchors is always neglected by designers and contractors. In most engineers' concept, anchor seismic design can be easily reached by safety factor but neglected the fact that the static loading capacity and seismic loading capacity of anchors can't be simply considered as multiplied by a safety factor unless steel failure happened.

Comparing with static tension load or shear load capacity of anchors installed in non-cracked concrete which is easily to be understood by engineers, there are so many parameters influence seismic performance of anchors, such as:

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- Concrete base conditions (cracked/uncracked, strength, crack width and variations during earthquake);
- Loading behavior (load level, direction duration, frequency, shear/tension/combined);
- Types of anchor, material, size and embedment depth of anchor

Seismic design methods and assessment criteria for seismic performance of anchors have been specified in US standards and European Technical Approval (ETA) documents and European technical reports.

2. REQUIREMENTS FOR ANCHORS APPLIED IN SEISMIC CONDITION

In United States and most European countries, there is a complete set of standard system to guarantee the safety application of anchors in seismic area. In Asia and Pacific countries and regions, the seismic design of anchors are mainly oriented by US or European approaches. China and Japan are also high seismic impact countries. But the seismic design requirements are different from either those in US or those in Europe. Currently in China, JG160, which specifies the prequalification of mechanical anchors, is updated and it mainly refers to ETAG 001 Annex E. However, it should be noted that different from US or Europe approval system, there is only pass/fail criteria in Chinese product qualification requirement. Furthermore, in most Asia countries, anchor seismic performance tests can't be performed by local test labs due to lacking experience and capacity. Approvals from US or Europe are mainly referred for design and construction.

Table 1 Seismic anchor guideline system in different countries

Approach			Europe*	US**	China
Anchor resistance	Pre-qualification	Test	ETAG 001 Annex E, TR049	ACI 355.2/ ACI 355.4	JG160/ JGJ145
		Evaluation	ETAG 001 Annex E TR049	ICC-ES AC193/ AC308	-
	Design method		TR045	ACI 318-14 ACI 349/AC 308	JGJ145/ GB50367
Load	Load definition		Eurocode 8	ASCE 7	GB50011

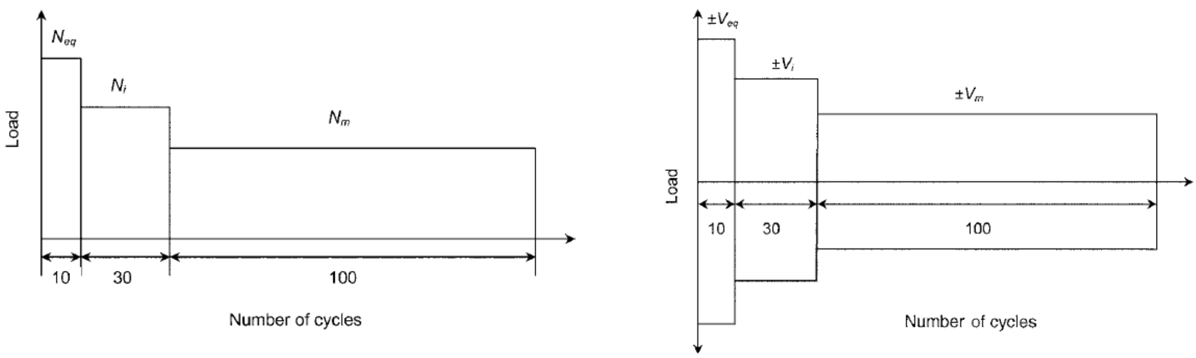
Note:
* Europe oriented countries & regions in Asia Pacific include Hong Kong, Australia, New Zealand, India et al.
** US oriented countries & regions in Asia Pacific include Korea, Taiwan, Philippian, Thailand et al.

3. SEISMIC PERFORMANCE TESTS

No matter in US design standards, ACI 318-14 and ACI 349-13, European design guide TR045 or Chinese design standards, JGJ145 and GB50367, the seismic design of anchors emphasize the design capacity of anchors shall be not less than the largest required strength. Moreover, in these standards, it is emphasized that post-installed structural anchors shall also be tested before use to verify their capability of sustaining their design strength in crack concrete under seismic load. The test conditions shall simulate the intended filed of application.

Comparing with static load behavior of anchors in uncracked concrete, anchor may be subjected to a combination of dynamic tension and shear forces during earthquake and crack concrete condition shall also be considered as a conservative situation since concrete cracks may be generated during earthquake and there is a high possibility that the cracks cross anchors when load applied. Moreover, crack width may also vary corresponding to the seismic response of structural elements during earthquake.

The first test methods for evaluating seismic performance of anchors were specified for mechanical anchors in ACI355.2 in 2001. Then the test methods extended to adhesive anchors as ACI 355.4 in 2010. These test methods in US standards only consider the dynamic loads and a constant crack width of 0.5mm is applied for anchors during tests. However, the crack behavior during earthquake is neglected.



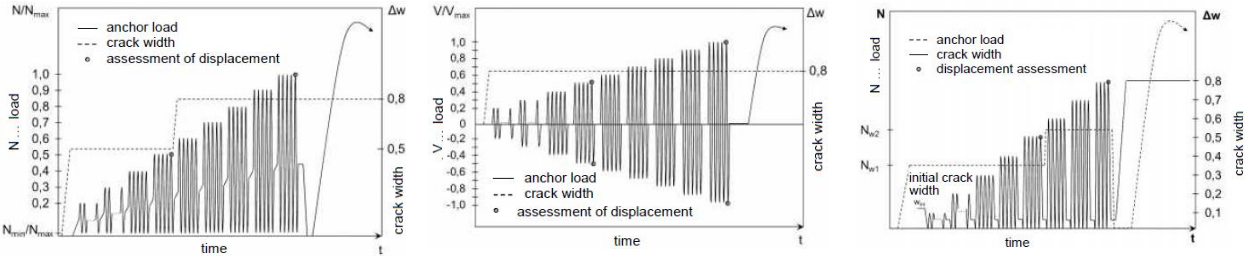
(a) Pulsating tensile loading test (b) Alternative shear loading test

Figure 1 Required history of seismic loading test in ACI 355.2 & ACI 355.4

In European standards ETAG 001 Annex E and TR049, the test methods are further developed to have a better simulation of actual seismic response of anchors and the base concrete elements. The standard extend from C1 level tests to more severe condition C2 level tests and the test program includes:

1) Static-crack tension and shear tests with larger crack width Δw=0.8mm. Anchors shall be tested under static tension/shear to get the reference load capacity in larger crack width and to decide load values applied on anchors for other C2 level tests.
2) Pulsating tension and alternating shear tests with a stepwise increasing loading pattern to simulated seismic load (Figure 2).

3) Seismic crack cycling tests to simulate anchor installed concrete member behavior during earthquake (Figure 3).



(a) Tests under pulsating tension load

(b) Tests under alternating shear load

(c) Tests with tension load under varying crack width

Figure 2 Simulated C2 level seismic tests specified in European standards [1], [3]

Comparing with C1 level test, there are three main differences in C2 tests:

(1) Crack width

Crack width may strongly influence seismic performance of anchors. It is mainly determined by the deformation of members in earthquake. Anchors may be subjected to large number of small crack movement between 0.1mm and 0.3mm under service conditions in service life of structure. However, during earthquake, crack amplitude may be significantly increased. In all seismic design standards in different countries, no anchor is permitted to be used in plastic hinge region. One reason is that concrete spalling is always happen in plastic hinge during heavy earthquake and the other reason is that the rack widths within plastic hinge region may be significantly enlarged in earthquake due to deformation concentration of the member, either of the above issue may reduce loading capacity of anchors. Out of plastic hinge, the maximum crack width can be limited to the state that rebar just reaches yield strain. It simplified the method of deciding a standard crack width independent of specific earthquake and structure members. The crack width of Dw=0.8mm is calculated based on the assumption that crack at steel yield strain stage and in accordance with concrete design requirement on structural members.

(2) Load pattern

In US standards and C1 level test program in ETAG 001 Annex E and TR049, loading pattern for simulated seismic load cycling tests is stepwise decreasing. It can simulate the seismic load behavior during earthquake. However, stepwise increasing load is preferable because it allows the calculation of stiffness through the entire anchor load

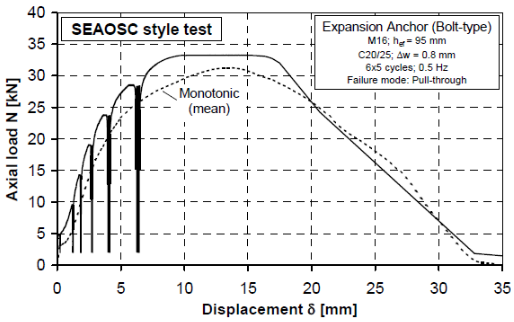


Figure 2 Typical load-displacement response for anchors subject to stepwise increasing load and monotonic load

cycle range. As shown in Figure 2, load-displacement curves during stepwise increasing load cycle tended to follow the monotonic envelopes. Such load pattern can also avoid the difficulty of having to specify a load level for cycling at a fraction of the ultimate strength.

(3) Crack cycling tests

Different from the crack movement test, which the anchor is tested in a crack which is cycled between two constant widths, in simulated seismic crack cycling tests a stepwise increasing crack width is also used which can simulate the crack width cumulation of concrete member during earthquake.

4. CONCLUSIONS

Although the new seismic test program C2 specified in European standards can't completely simulate actual situation of anchors during earthquake, which are subjected to dynamic load cycling and simultaneously to opening and closing of cracks, it could be used to evaluate anchor seismic performance in uniform and close to real conditions especially when severe damage of structure in rare earthquake is assumed in structure design. Test program C2 is recommended in evaluating seismic performance of post-installed anchors in RC structures.

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