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Inelastic seismic behavior of post-installed anchors for nuclear safety related structures: Generation of experimental database

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HIGHLIGHTS

- Experiments for evaluating seismic behavior of anchors were performed.
- Two undercut anchor products in use in nuclear facilities were considered.
- Monotonic tension, shear and cycling tension tests at different crack widths.
- Crack cycling tests at constant, in-phase and out-of phase tension loads.
- Characteristics for the two anchors as a function of crack width were identified.

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ABSTRACT

Post installed (PI) anchors are often employed for connections between concrete structure and components or systems in nuclear power plants (NPP) and related facilities. Standardized practices for nuclear related structures demand stringent criteria, which an anchor has to satisfy in order to qualify for use in NPP related structures. In NPP and related facilities, the structure–component interaction in the event of an earthquake depends on the inelastic behavior of the concrete structure, the component system and also the anchorage system that connects them.

For analysis, anchorages are usually assumed to be rigid. Under seismic actions, however, it is known that anchors may undergo significant plastic displacement and strength degradation. Analysis of structure–component interaction under seismic loads calls for numerical models simulating inelastic behavior of anchorage systems. A testing program covering different seismic loading scenarios in a reasonably conservative manner is required to establish a basis for generating numerical models of anchorage systems. Currently there is a general lack of modeling techniques to consider the inelastic behavior of anchorages in structure–component interaction under seismic loads.

In this work, in view of establishing a basis for development of numerical models simulating the inelastic behavior of anchors, seismic tests on two different undercut anchors qualified for their use in NPP related structures were carried out. The test program was primarily based on the DIBt-KKW-Leitfaden (2010) guidelines for testing of fastening for use in NPP. The testing program consisted of monotonic and cyclic tests in non-cracked and cracked concrete specimens with different crack widths. In addition, crack cycling tests at design tension load, and simultaneous tension and crack cycling tests (in-phase and out-of-phase) were also conducted. The present paper deals with the details of the tests performed and the results obtained. The development of numerical models simulating anchor inelastic behavior based on the results given in the present paper will be presented in another paper.

1. Introduction

Nuclear power plants (NPP) and related structures are usually provided with embedded parts (EPs) anchored using headed studs, for establishing structural connections with various non-structural components essential for their functioning and operation. Wall EP are used to facilitate structural connections of piping

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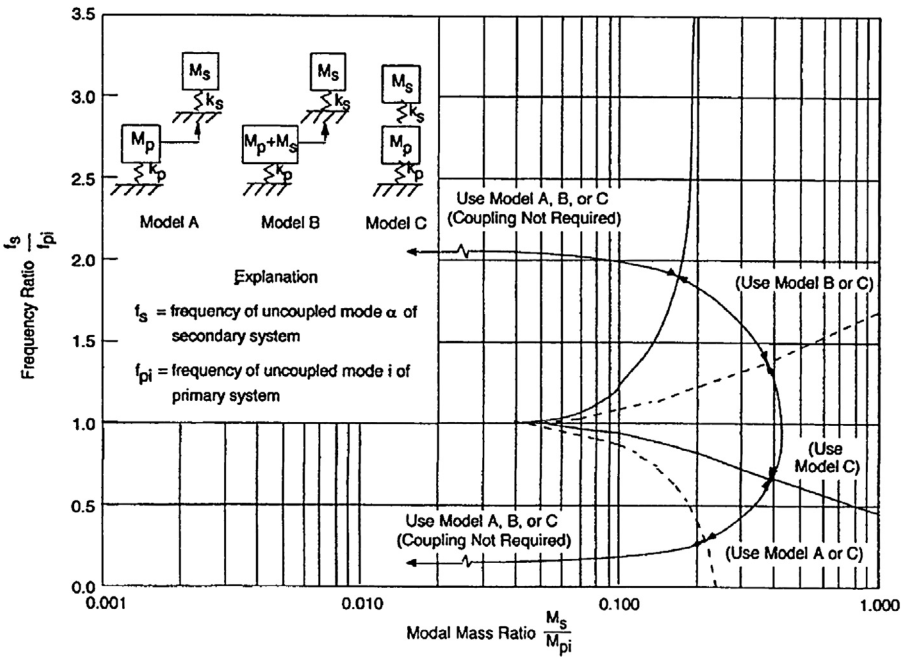

Fig. 1. Decoupling criteria for secondary systems with single point attachment to primary (ASCE-4-98, 2000).

supports with the concrete walls or beams. However, problems are faced during welding on site in view of quality and accessibility. Since it is hard to remove welded connections, revision of system layouts is often not allowed. If new facilities are additionally connected for some reason, the capacity of headed studs limits the amount of load that is allowed to be transferred on to the embedded plates. It is also not possible to provide all required locations in advance, where such structural connections will be required during the whole lifetime of the structure. Hence post installed (PI) anchors are often required for establishing such connection requirements. Standardized practices for nuclear related structures demand certain stringent criteria, which an anchor has to satisfy in order to qualify for use in NPP related structures. Post installed undercut anchors provide robust load transfer mechanism owing to the mechanical interlock of the undercut. Detailed description of the load transfer behavior of this anchor can be found in the literature (Eligehausen et al., 2013a). The present work is sponsored by the German Federal Ministry of Economic Affairs and Energy with an aim to study the seismic behavior of post installed anchorages used in nuclear safety related applications. In Germany, Hilti® HDA and Fischer® FZA undercut anchors are the only qualified post installed anchor products as per DIBt-KKW-Leitfaden (2010) for use in nuclear safety related applications. The present work deals with experimental testing of two such undercut anchors qualified for their use in NPP applications: (i) the Hilti® HDA-T-22-M12 × 125/30 self-undercut anchor and (ii) the Fischer® FZA-18 × 80-M12/25 anchor installed in a predrilled undercut hole. The experimental program highlights the issues with assumption of rigid anchorages, and the necessity for consideration of inelasticity of anchorages. The different experiments provide a complete set of information required for generation of numerical models simulating seismic behavior of these anchors.

In NPP related structures, there are several non-structural systems like infill walls, false ceilings, machinery, equipment, piping etc., loads of which are transferred to the primary reinforced concrete (RC) structure. There can also be a need to connect additional structural components like steel frames, damping systems, retrofitting measures like haunches, braces, dampers etc., to the primary RC structures. These structural and non-structural components are normally connected to the primary RC structure using post installed anchors. All of these secondary systems transferring their loads (gravity as well as seismic) on to the primary RC structure are termed as component systems. For NPP related structures it is mandatory (ASCE-4-98, 2000) to perform a structure–component interaction analysis subjected to operating basis earthquake (OBE) as well as safe shutdown earthquake (SSE). ASCE-4-98 (2000) provides the criteria (Fig. 1) for deciding significance of such interaction, and also prescribes various ways to model such interaction in each case. The criterion applies to components supported at a single location of the primary structure. Components like piping systems, which are very common in NPP related structures, are supported at more than one location in the primary structure. For such component systems with multiple supports, ASCE-4-98 (2000) suggests a consideration of relative stiffness of the secondary system to the structure in addition to the criteria shown in Fig. 1.

Irrespective of cases A, B or C as described in Fig. 1 it is required to perform a structural analysis of the component system (coupled or decoupled with the primary structural system). The present state-of-the-art seismic analysis assumes rigid anchorages and is focused on the inelasticity in the structural system of the connected component. In case of piping systems for example, early studies (Hahn et al., 1984; Lin, 1970) were based on stiffness and flexibility formulations for modeling of piping systems in lumped mass framework. The flexibility of pipes was modeled with suitable springs and the anchorages were considered to be rigid. With advancement of computational technology lumped plasticity model idealizing moment rotation behavior observed in dynamic tests on piping systems (EPRI-NP-6809, 1990; Hahn et al., 1984; Jaquay et al., 1988) were developed. Touboul et al. (1999) established simplified methods to consider the inelastic piping behavior and developed seismic criteria for piping systems. Now-a-days detailed 3D finite element structural analysis of the pipe structures also accounting for effects of temperature and internal pressure are performed for seismic evaluation (Bursi et al., 2015; Chang et al., 2014). These advanced analyses reported extensively in literature focus on modeling inelastic behavior of the piping (component) system. Normally, the studies consider anchorages with primary structural system as rigid.

A large number of seismic structure–component-interaction studies performed so far, focused on inelastic structural