Available online at www.sciencedirect.com

ScienceDirect

Procedia Environmental Sciences 38 (2017) 461 – 468

Procedia Environmental Sciences

International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16

Seismic Vulnerability of RC Buildings under the Effect of Aging

S.T. Karapetrou[a,]*, S.D. Fotopoulou[a], K.D. Pitilakis[a]

[a]*Aristotle University of Thessaloniki/ Department of Civil Engineering, Thessaloniki 54124, Greece*

Abstract

The present study aims at the assessment of the seismic vulnerability of reinforced concrete (RC) buildings considering performance degradation over time due to aging effects. Chloride induced corrosion is taken into account based on probabilistic modeling of corrosion initiation time and corrosion rate. Two-dimensional incremental dynamic analysis (IDA) is performed to assess the seismic performance of the initial uncorroded (t=0 years) and corroded (t= 25, 50, 75 years) RC fixed base frame structures designed based on different seismic code levels. The time-dependent fragility functions are derived at the various time periods in terms of spectral acceleration corresponding to the fundamental mode of the structure Sa(T_1,5%) for the immediate occupancy (IO) and collapse prevention (CP) limit states. Results show an overall increase in seismic vulnerability over time due to corrosion indicating the significant effect of deterioration due to aging effects on structural behavior.

Peer-review under responsibility of the organizing committee of SBE16.

Keywords: RC buildings; seismic vulnerability; time-dependent fragility curves; aging effects; IDA

1. Introduction

In order to design efficient assessment tools that could be utilized by civil protection authorities, decision makers and end users, a reliable risk model for a region or for a specific structure under consideration needs to be compiled in order to predict future losses due to seismic events with a high accuracy level. In this context, the reliable vulnerability assessment of existing structures and infrastructures is a prerequisite for seismic loss estimation, risk mitigation and management. Vulnerability is commonly expressed through fragility functions representing the probability of exceeding a prescribed level of damage for a wide range of ground motion intensities. Traditionally, it is implicitly assumed that the structures are optimally maintained during their lifetime and the impact of the progressive deterioration due to various time-dependent mechanisms on structural performance is commonly

* Corresponding author. Tel.: +30 2310 994208; fax: +30 2310 994208.
*E-mail address:*gkarapet@civil.auth.gr

Peer-review under responsibility of the organizing committee of SBE16.
doi:10.1016/j.proenv.2017.03.137

neglected. Two different sources of deterioration, which cause damage to accumulate with time are generally recognized (e.g. [1]): one has substantially slow, progressive effects and is usually linked to environmental and operating conditions (e.g. aging); the other has effects that are superposed occasionally to the first effects, and are usually related to external sudden changes in the structural capacity (e.g. due to cumulative earthquake damage, e.g. [2]).Owing to deterioration, the physical vulnerability of the system, as may be estimated at the time of construction and at different points in time, is actually time-dependent, and may increase with time, thus causing the risk of structural failure to accelerate.

On this basis deterioration of the material properties caused by aggressive environmental attack is not accounted for. One of the primary sources of structural degradation is the corrosion of reinforced concrete (RC) members, generally associated to carbonation process and chloride penetration, leading to the variation of the mechanical properties of steel and concrete over time. In the case of significant loss of ductility due to high corrosion levels, a reduction in the load-carrying capacity of the structure, as well as a shift to more brittle failure mechanisms is expected. Consequently, both safety and serviceability of RC structures may be affected under the action of seismic (or even static) loading, compromising the capability of the structures to withstand the loads for which they are designed. This study aims to highlight the effects of chloride induced reinforcement corrosion on the response and vulnerability of structures subjected to seismic excitation and to derive time-dependent fragility functions for different time-scenarios and building typologies. Different corrosion effects are considered in the analysis including the loss of reinforcement cross-sectional area, the degradation of concrete cover and the reduction of steel ultimate deformation.

2. Aging effects: Corrosion of reinforcement

Aging of structures can be defined as partial or total loss of their capacity via a slow, progressive and irreversible process that occurs over a period of time. The effects caused by aging processes lead to the degradation of engineering properties, affecting the static and dynamic response of the structures, their resistance/capacity and failure mode as well as the location of failure initiation. Thus, the ability of the structural system to withstand various challenges from operation, environment and natural events may be reduced. Once the structural capacity falls below a given performance threshold, the structure may be intervened, leading to a new initial capacity, diminishing progressively over time the ability to withstand future operating conditions.

Aging processes decrease the reliability of the structural systems over time, accelerating the risk of structural failure. Since the time-dependent changes are random in nature, the safety evaluation of the existing structures can be conducted rationally within a probabilistic framework [3], taking into account various sources of uncertainty with respect to the deterioration process and rate. The rate of degradation of the structural components generally depends on the age of the structure as well as on the exposure conditions, and for its efficient determination stochastic approaches are possible. Overall, the identification of aging structural components and their probabilistic modeling over time may play a significant role in mitigating structural risk.

Among the most common environmental deterioration factors, reinforcement corrosion, generally associated to carbonation and chloride ingress, is considered the most significant degradation mechanism, leading to the adverse variation of the mechanical properties of steel and concrete over time [4]. Corrosion is a complex process that may affect a RC structure in a variety of ways, including, among others, cover spalling, loss of steel-concrete bond strength and loss of reinforcement cross sectional area, potentially resulting to the reduction of the resistance and load bearing capacity of the structure and to the variation of the failure mechanism from ductile to fragile type (e.g. [5-7]).The corrosion mechanism is a time-dependent process leading progressively to reduction of the strength and serviceability of structures in relation to their as-built state.

The deterioration related to the corrosion of reinforcement steel bars in concrete structures, called hereafter “aging effect”, is basically a two-phase process consisting of the initiation and the propagation phase. As soon as the concentration of chlorides or carbon dioxides exceeds a critical value, the so called “passive layer” protecting the outer reinforcement is destroyed signifying the initiation of corrosion. Then the corrosion is gradually propagating causing the formation of corrosion products (rust), leading progressively to concrete cracking and spalling as the volume of rust increases and finally resulting to significant structural damage. The parameters that affect the corrosion initiation and its progress in time may be categorized based on whether they are associated with the design