# SEISMIC DESIGN OF REINFORCED CONCRETE STRUCTURES

World's First Performance-Based Design Method

## 1 Introduction

When the Hyogo-ken Nambu Earthquake struck in 1995, it was the most disastrous earthquake experienced since the use of reinforced concrete structures became common in Japan. Based on experience with this earthquake, the seismic design code of JSCE's Standard Specifications for Concrete Structures was revised in 1996 into a performance-based design method, the first of its type in the world.

## 2 History

The seismic coefficient method had been used for earthquake design in JSCE's Standard Specifications for Concrete Structures since 1931. In the 1986 revision, the concept of the limit state under the design earthquake was introduced. The concept of performance-based design for concrete structures first came up for discussion in the global design arena in around 1990.

## 3 Background

The practical utility of dynamic numerical analysis enhanced rapidly with advances in computing during the 1990s and it became possible to routinely model the earthquake response of concrete structures. Techniques were developed for time history earthquake response analysis of structures and the surrounding ground, using linear models and finite element analysis. These included nonlinear models for concrete, reinforcing bars and the bonds between them as well as nonlinear member models under reversed loading.

## 4 Concept of Design Method

The concept of performance-based design is to first decide on the performance required for the structure and then to verify that the given design satisfies the required performance. JSCE's Standard Specifications for Concrete Structures define three grades of seismic performance as follows.

(i) Seismic Performance 1: The structure remains functional and usable without repairs after the earthquake.
(ii) Seismic Performance 2: The functions of the structure can be restored within a short period after an earthquake and no strengthening is required.
(iii) Seismic Performance 3: There is no overall collapse of the structural system due to an earthquake.

The earthquake ground motions considered are of two levels: those likely to occur a few times within the lifetime of a structure (Level 1) and very strong earthquake ground motion that has only a rare probability of occurrence within the lifetime of a structure (Level 2). The relationship between the ground motion and required seismic performance is described as follows.

(i) The structure satisfies Seismic Performance 1 against Level 1 earthquake ground motions.
(ii) The structure satisfies Seismic Performance 2 or 3 against Level 2 earthquake ground motions.

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## 6 Reference

[1] Standard Specifications for Concrete Structures, 2002 "Seismic Performance Verification", JSCE Guidelines for Concrete, No. 5, Japan Society of Civil Engineers, 2005.