CHAPTER 117

PROTECTION OF BUILDINGS FROM EARTHQUAKE-INDUCED VIBRATION

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1 INTRODUCTION

Earthquakes are generated wherever the accumulation of strain at geological *faults* leads to their rupture and slip, until a new stable state is reached. There are essentially two types of faults, those associated with horizontal (*strike-slip*) and those associated with vertical (*dip-slip*) movement. The waves generated propagate either by compression and dilation with the ground particle motion in the same direction as the propagation (*longitudinal* or *P waves*) or by shear (*transverse* or *S waves*); both types are referred to as *body waves*. When body waves reach the Earth's surface, they are reflected back into the crust, and a vibration of the surface is initiated, which propagates through *surface waves*. Surface waves, along with S waves, account for the strongest part of seismic motion, that is, these are the potentially more destructive. Protection of buildings from earthquake-induced vibration, therefore, is the process to estimate the amount of energy (often related to *magnitude*) that is expected with a specific probability to be released at the *source*, to establish methods for determining the *frequency content, duration,* and *intensity* of ground motion that finally excites the structure, and to define methods for calculating and optimizing the structural dynamic response to this vibration.

2 CONCEPT OF SEISMIC DESIGN OF STRUCTURES

Protection of buildings from earthquake-induced vibration is achieved through their *seismic design*. The goal of seismic design is to ensure that a structure behaves "satisfactorily" when subjected to earthquake loading. As is the case with most loading types, the anticipated behavior or performance levels for the structure are different for different levels of the loading. Ideally, and taking into account the large uncertainty associated with earthquake loading, several levels of performance should be considered in design, each one corresponding to a different probability of exceedance of the seismic loading. According to most current seismic codes, the structure should resist minor earthquakes (i.e., remain serviceable at its serviceability limit state) without significant damage, sustain moderate earthquakes (i.e., at its ultimate limit state) with repairable damage, while avoiding collapse during major earthquakes. This points to the need to design a structure for a set of performance objectives (limit states), recently referred to as performance-based design (PBD). [1] Through the code-defined design procedure, therefore, the engineer is provided with the seismic loads that the structure should be able to withstand in order to meet the above objectives, the minimum design requirements and the detailing rules that ensure the desired performance as well as with the methods of structural analysis to be employed in order to determine the response of the structure under the design loads.

For a given level of seismic exposure, it can be generally claimed that structures built in industrialized countries aware of the seismic risk are in general adequately safe (less vulnerable), but the expected actual cost of damage inflicted, as well as the indirect cost resulting from business disruption, need for relocation, and the like can be significantly higher. As a result, the *seismic risk* of potential economic losses is in fact a qualitative product of *seismic hazard* (i.e., the level of seismic exposure), structural *vulnerability* (i.e., the level of expected damage), and element *value at risk* (defined by the importance of the structure). It has to be noted though that seismic risk modeling is a useful decision-making and risk management diagnostic tool that does not provide solutions alone; it is the code-prescribed design and assessment process that guarantees compliance with the structural performance criteria.

3 FUNDAMENTALS OF BUILDING RESPONSE TO EARTHQUAKE

3.1 Single and Multiple-Degree-of-Freedom Systems

The simplest model of a structure that can be considered is a single-degree-of-freedom (SDOF) pendulum having its mass concentrated on top and vibrating laterally under base excitation, while its resistance is exclusively provided by the total stiffness k of its vertical elements (a one-storey building or an elevated water tank are some typical examples). When a force that varies with time $p(t)$ is applied on this structure with mass m, the resulting displacement, denoted by $u(t)$, is a function of the system damping force f_D and the stiffness-related resisting force f_s. Newton's second law of motion leads to the fundamental equation:

$$m\ddot{u} + c\dot{u} + ku = p(t) \tag{1}$$

which for the particular case of base excitation (due to earthquake) is written in the form:

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g(t) \tag{2}$$