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Earthquake early warning: Concepts, methods and physical grounds

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ABSTRACT

Modern technology allows real-time seismic monitoring facilities to evolve into earthquake early warning (EEW) systems, capable of reducing deaths, injuries, and economic losses, as well as of speeding up rescue response and damage recovery. The objective of an EEW system is to estimate in a fast and reliable way the earthquake's damage potential, before the strong shaking hits a given target.

The necessary framework for EEW implementation is provided by the observed relationships between different parameters measured on the signal onsets and the final earthquake size. The implication of these observations on the physics of fracture processes has given rise to a significant debate in the seismological community.

Currently, EEW systems are implemented or under testing in many countries of the world, and different methodologies and procedures have been studied and developed. The leading experience of countries like Japan or Mexico shows that, with a proper education of population and end-users, and with the design of real-time systems for the reduction of vulnerability/exposure, EEW can be an effective approach to the mitigation of the seismic risk at short time-scales.

1. Introduction

Earthquakes are among the most damaging events caused by the Earth itself. As urbanization progresses worldwide, earthquakes pose serious threat to lives and properties for urban areas near major active faults on land or subduction zones offshore.

The mitigation of the seismic risk is a complex task, which requires the cooperation of scientists, engineers and decision makers, and that has to be approached at different time scales ([1,2]; Fig. 1). These range from *years*, where long-term forecast and scenarios should drive the improvement of urban planning and building codes, to *months* or *weeks*, when anomalous seismicity patterns can rise the level of alertness in a certain area, down to the short term (*days* to *hours*), where the availability of reliable predictions of size, location and time of an incoming earthquake would be required.

However, the processes of earthquake preparation and generation are extremely complex and our observations cover a relatively short period compared to large earthquake cycles. As a result of this, reliable earthquake prediction is not currently possible [3,4]. Even if such predictions were available, it is desirable to implement measures to protect large urban areas from damages and losses.

For this reason a new approach to the short-term risk mitigation has emerged in the last two decades, based on the advent of digital seismology, and on the advances in communications and automatic processing. This new paradigm is founded on the concept of *real-time earthquake information systems* [5], namely networks of computerized seismic stations that integrate rapid telemetry and automatic processing, in order to provide fast and reliable information on earthquake parameters (location, time and size) and on the expected ground motion, supporting and improving the emergency response. Thanks to continuous theoretical and computational improvements, the reporting time of these systems has evolved from a few minutes to a few seconds after the earthquake occurrence, making it possible, in certain conditions, to provide earthquake information before the ground shaking has actually reached a certain target.

This procedure is known as *earthquake early warning* (EEW) and is today becoming one of the practical and promising approaches to reduce the loss caused by large earthquakes [1,6–11].

2. The concept of early warning

The term "early warning" was born during the cold war for describing a military strategy to prevent the potential threat from

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