



# Evaluation of drift demands in existing steel frames under as-recorded far-field and near-fault mainshock–aftershock seismic sequences

Jorge Ruiz-García\*, Juan C. Negrete-Manriquez

Facultad de Ingeniería Civil, Universidad Michoacana de San Nicolás de Hidalgo, Edificio C, Planta Baja, Cd. Universitaria, 58040 Morelia, Mexico

## ARTICLE INFO

### Article history:

Received 20 July 2010

Received in revised form

13 October 2010

Accepted 10 November 2010

Available online 13 December 2010

### Keywords:

Aftershocks

Seismic sequences

Artificial seismic sequences

Peak drift demands

Residual drift demands

## ABSTRACT

This paper presents results of a study aimed at evaluating the effect of aftershocks in steel framed buildings. For that purpose, three frame models representing existing steel moment-resisting frames were subjected to a set of as-recorded mainshock–aftershock seismic sequences. For this purpose, 64 as-recorded seismic sequences registered as a consequence of the 1994 Northridge and 1980 Mammoth Lakes earthquakes were considered in this study. In particular, this investigation employed 14 seismic sequences recorded in 7 accelerographic stations in the near-fault region. An examination of the as-recorded seismic sequences shows that the frequency content of the mainshock and the main aftershock is weakly correlated. The response of the frame models was measured in terms of the peak and residual (permanent) drift demands at the end of the earthquake's excitation. From the results of this investigation, unlike previous results based on artificial seismic sequences, it was found that as-recorded aftershocks do not significantly increase peak and residual drift demands since the predominant period of the aftershocks (i.e. frequency content) is very different from the period of vibration of the frame models. In addition, it was shown that artificial seismic sequences could significantly overestimate median peak and residual drift demands as well as the record-to-record variability.

© 2010 Elsevier Ltd. All rights reserved.

## 1. Introduction

There is a consensus among the earthquake engineering community that damage in structural elements, and some drift-sensitive nonstructural components, is primarily the result of lateral deformation demands induced by earthquake ground shaking in the structure. As a consequence, modern performance-based assessment methodologies for evaluation of existing structures (e.g. FEMA 356 [1]) are based on the estimation of peak lateral displacement demands that man-made structures could suffer under seismic excitation. However, man-made structures located in seismic regions are not exposed to a single seismic event (i.e. mainshock), but also to a seismic sequence consisting of foreshocks, mainshock and aftershocks. For example, after the mainshock on February 27, 2010 ( $M_w = 8.8$ ) that struck the central-southern region of Chile, 306 aftershocks having magnitudes greater than 5.0 were recorded between February 27 and April 26. Among them, 21 aftershocks had magnitudes greater than 6.0. In particular, historical earthquakes have shown that the aftershocks may increase the damage state at the end of the mainshock. For example, several dozen damaged reinforced concrete (RC) buildings in Mexico City had to be demolished after the September 1985 earthquakes

because of the technical difficulties in straightening and repairing buildings with large permanent drifts and the future threat due to aftershocks [2]. Another example of the consequence of significant permanent lateral displacements is a two-story steel office building that was severely damaged during the 1994 Northridge earthquake ( $M_w = 6.7$ ) [3]. The excessive permanent displacements were a consequence of concentrated structural damage in the first story, with yielding noted at the base plate connections, and a number of column fractures at the second floor moment connections. The extent of this damage was such that the building's owner decided to demolish the structure above the foundation level. However, earthquake field reconnaissance reports after the 1994 Northridge earthquake mentioned that other existing steel buildings could have experienced permanent lateral deformations as a consequence of the strong mainshock that affected the Los Angeles area [4], but they did not report that the following aftershocks could have increased the level of damage, or even to drive damaged buildings to the risk of collapse. Therefore, there is a need to further understand the effects of as-recorded mainshock–aftershock seismic sequences in the seismic response of existing structures.

There have been several investigations aimed at studying the effect of seismic sequences on the response of civil engineering structures [5–15]; some of them have been focused on the nonlinear response of single-degree-of-freedom (SDOF) systems [5–10] while

\* Corresponding author. Tel.: +52 443 2278545; fax: +52 443 3221002.

E-mail address: [jruizgar@stanfordalumni.org](mailto:jruizgar@stanfordalumni.org) (J. Ruiz-García).