Engineering Structures 33 (2011) 3471–3482

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Seismic analysis of an asymmetric fixed base and base-isolated high-rack steel structure

Vojko Kilar [a,*], Simon Petrovčič [a], David Koren [a], Simon Šilih [b]

[a] University of Ljubljana, Faculty of Architecture, Zoisova 12, SI-1000 Ljubljana, Slovenia

[b] University of Maribor, Faculty of Civil Engineering, Smetanova 17, SI-2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 27 August 2010
Received in revised form
10 June 2011
Accepted 1 July 2011
Available online 5 August 2011

Keywords:
Seismic analysis
Braced steel frame
High-rack warehouse
Pushover analysis
N2 method
Mass eccentricity
Torsion
Base isolation

ABSTRACT

Since, in the case of plan-eccentric, externally-braced, high-rack storage structures made of steel, damage to the central part of the structure can cause damage to the stored goods, and thus higher earthquake-induced costs, an investigation has been performed into the seismic performance of such structures. An actual structure was analysed both as a fixed base variant, and as a base-isolated variant. The extended N2 method (pushover analysis) was used, and the results obtained were compared with selected results obtained by nonlinear-dynamic analysis. The response of several different mass-asymmetric structural variants, corresponding to different occupancy levels of the structure, was analysed, and the results obtained are presented as floor plan projection envelopes of the top, relative and base displacements, as well as the storey drifts. An interesting result obtained in the research was that asymmetry can increase the damage in the supporting structure on the flexible side, and that the central part of the rack structure remains in the elastic region only when the eccentricity is small. In fact, from the seismic point of view, full occupancy is not the most critical condition, but rather lower occupancy, which could cause eccentricities ranging up to 10% or 15% of the larger floor plan dimension; this could lead to damage propagation in some of the columns. The application of base isolation has a positive effect on the management of seismic performance, even in the case of higher levels of occupancy and larger mass eccentricities. It is pointed out that an eccentricity of 5%, which is prescribed in Eurocode 8, might not be sufficient in such structural types, and that similar concerns could be present in other types of industrial structures with a similar ratio between live and dead loads.

1. Introduction and overview

Steel frame storage rack structures are special structures which usually carry much larger live loads than their self-weight. They can be built to considerable heights, similar to ordinary multi storey buildings. In zones of high seismicity they can therefore be subjected to significant horizontal loads, as well as to an additional risk associated with the shedding of merchandise [1,2]. Rack structures are usually made of thin-walled cold-formed steel sections, where the columns (uprights) are generally manufactured as open mono-symmetric (in some cases perforated) sections and the beams (stringers) are usually manufactured as closed, boxed cross-sections [3–6]. The uprights and stringers are joined together to form a frame system. One of the shortcomings of such structures is that the bracings can only be used to prevent longitudinal sway in the cross-aisle direction, whereas in the down-aisle direction bracing cannot be used since access has to be provided to the pallets containing the stored merchandise. In this direction sway resistance can only be provided by the base-plate joints and by the joints between the stringers and uprights, which are usually joined together by bolts or boltless beam-end (i.e. tab) connectors. Both types of connections are semi-rigid and might not be able to provide sufficient rotational capacity to prevent longitudinal sway [6].

The influence of these connections on the overall performance of a rack system has been numerically analysed by, for example [7], and experimentally by Aguirre and Abdel-Jaber et al. [8,9]. It has been shown that the inelastic response of most commonly used rack structures is very different from that of conventional steel buildings, where moment-resisting connections are designed to cause inelastic deformations at the beam ends rather than in the upright-stringer connections.

Another option which can be used to provide storage racks with adequate horizontal stiffness is to support the typical rack structure with one or more additional external bracing structures, designed as ductile 3D moment resisting frames. This solution overcomes, to a certain extent, the above-mentioned

* Corresponding author. Tel.: +386 1 2000720; fax: +386 1 4257 414.
E-mail addresses: vojko.kilar@fa.uni-lj.si (V. Kilar), simon.petrovcic@fa.uni-lj.si (S. Petrovčič), david.koren@fa.uni-lj.si (D. Koren), simon.silih@uni-mb.si (S. Šilih).

0141-0296/$ – see front matter
doi:10.1016/j.engstruct.2011.07.010