A Testing Equipment for Seismic Studies of Steel Rack Frames

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Abstract. The strategies worldwide adopted nowadays for static and seismic rack design are based on approaches efficiently developed for the traditional carpentry frames, i.e. realized with hot-rolled bi-symmetric cross-section profiles. An open question is hence related to the effective degree of safety of these design rules when applied to racks, i.e. to structures realized by means of thin-walled cold-formed members, highly sensitive to second order effects. A study is currently in progress to define reliable seismic design procedures accounting for rack key features. In the framework of different planned activities, an ad hoc experimental equipment for testing full-scale racks under variable load conditions was developed. This paper presents the key features of the testing set-up, equipped with independent dynamic actuators, which allow applying vertical and horizontal loads.

INTRODUCTION

An important area of the steel construction industry is nowadays represented by structural systems made of thin-walled cold-formed components [1], which are extensively employed for logistic applications to realize frames used for the long- and medium-term storage of goods and products. One of the most common types of storage solutions are the so-called adjustable selective storage pallet racks (in the following simply identified as “racks”), on which the present paper focuses on.

If the more conventional steel framed buildings [2] and the industrial systems are compared to each other, remarkable differences can be observed:

- the dead-to-live load ratio. Unlike in buildings, where the live loads are always comparable with the dead loads, in the case of racks, the weight of the structure is quite limited and the condition of fully loaded racks generally governs both static and seismic design;
- the joint behaviour. The response of the joints (beam-to-column and base-plate joints) is characterized by a marked non-linear and non-symmetric behaviour. In addition, joints differ from manufacturer to manufacturer, adding difficulty to draw an analytical evaluation of their response. An experimental characterization is hence adopted in order to identify the joints design parameters;
- the use of open thin-walled cross-section with regular perforation systems [3-5];
- the dynamic response of the structures. The flexibility of racks to lateral loads results in high values of the fundamental period of vibrations (T1), up to 3–4 s, typically observed generally only for high-rise and tall steel buildings.

Furthermore, steel storage rack solutions differ from the others thin-walled cold-formed structures, typically employed for housing, industrial and agricultural applications, mainly for the presence of regular perforation systems along the vertical elements (uprights) and for the type of connections, which are often characterized by the absence of bolts and/or fillet welds.

As far as seismic design is concerned, it appears that racks behave like moment-resisting frames, where beam-to-column joints and base-plate connections guarantee an adequate system behaviour in the post-elastic range. In Europe the EN16681 provisions [6] guide the seismic design of racks, although recent studies pointed out the need of further improvements necessary to a more accurate evaluation of the rack design seismic performance.

Owing to the key features of storage pallet racks, an experimental approach is required to develop and calibrate suitable design rules able to guarantee an adequate safety design level.

The main difficulty in performing full-scale tests of structures subjected to gravity loads, increased up to the collapse, is the loading phase. The use of masses directly added during the tests or the use of tanks filled of water are extremely time-consuming and could lead to damages to the testing equipment during the specimen collapse. On the other hand, hydraulic jacks and dynamic actuators need complex electro-mechanical systems to maintain the perfect verticality of loads in each phase of the test. Basing on the Authors' knowledge, a quite limited number of experimental studies on full-scale rack specimens were performed. Full-scale tests under shaking table excitations [7] or pushover loads [8-10] performed with constant masses applied on the beams are reported in literature. No experimental tests with gravity loads have been carried out up to the achievement of the collapse, with the exception of the tests performed at the Cornell University (U.S.A.) twenty years ago [11].

A study of the seismic behaviour of steel storage pallet racks is currently in progress in Italy, with the main aim to define reliable design procedures accounting for the key features of these type of structures. In the framework of the different planned activities, the present paper deals with an experimental equipment developed for testing full-scale racks under different load conditions. In particular, vertical and horizontal loads can be applied by means of a refined system of dynamic actuators allowing the application of different vertical forces in each bay, as well as independent horizontal loads at each load level. The developed set-up permits to solve the aforementioned typical limitations of the full-scale testing set-ups.

THE EXPERIMENTAL EQUIPMENT

The experimental equipment briefly described in this paper has been recently designed, developed and built up by the Research and Development Division of the rack manufacturer company METALSISTEM, which is a leading European manufacturer of industrial steel storage systems as well as integrated material handling solutions and retail sales equipment (such as display shelving and checkout counters). The equipment, calibrated with the contribution of Politecnico di Milano and Università di Trento, consists of a testing tower [12] that permits the study of full-scale racks, as well as of other type of structures, with a maximum height of 22m (Fig. 1).

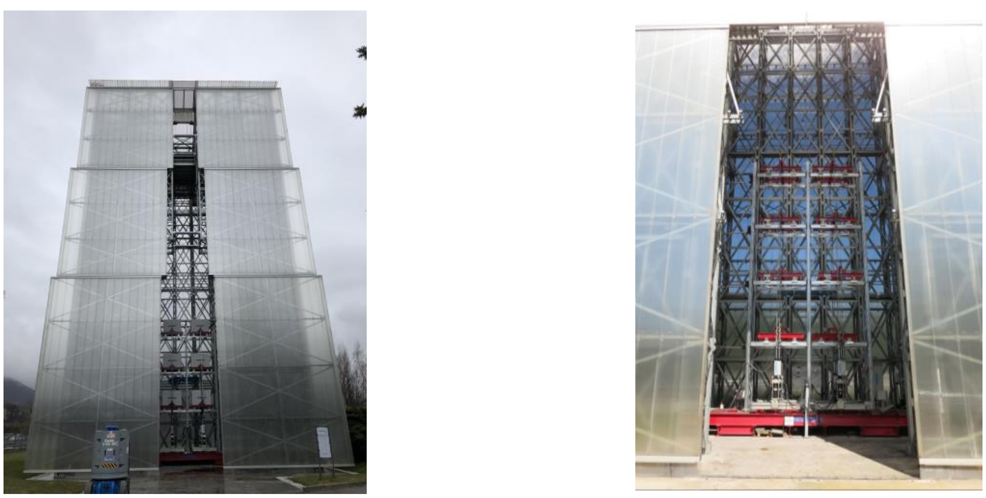


FIGURE 1. The testing tower: external view and detail of a specimen in the tower [12]

The tower is a rigid trussed-tower, realized by using only Metalsistem rack cold-formed components. This rigid truss-frame, that acts as a reaction frame, has a total height of 24.5m and has plane dimensions of 12.35m x 12.35m and a 'thickness' of 4.9m (Fig. 2).

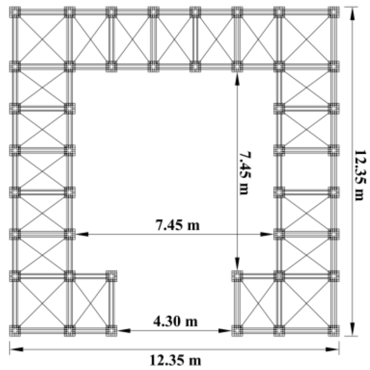
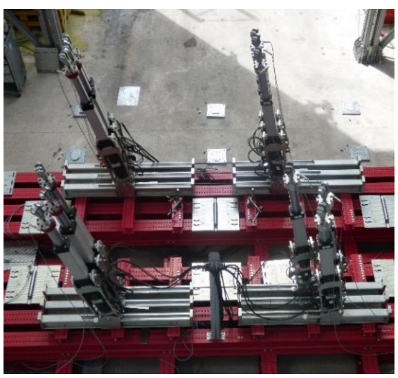


FIGURE 2. The testing tower: plane view of the counter-frame [12]

To apply the vertical loads to the rack structure, vertical actuators are used (Fig. 3). Since the key point of this kind of testing is maintaining the verticality of the loads during the all phases of the test, the set-up is composed as follows. A steel grid, fixed to the concrete foundation, supports rail beams, on which six couples of dynamic actuators can horizontally translate (up to 1 m) on motorized sliders that follow the sway of the test specimen, maintaining hence the verticality of the gravity loads applied during the tests (Fig. 3a). As showed in Fig. 3b, each pallet beam is pinned connected to a counter-beams system which applies at the quarters of the beam the vertical loads transmitted by two independent actuators.



(a)

(b)

FIGURE 3. View of the beam rails supporting the vertical actuators (a) and details of the loads transfer system (b)

The great stiffness and resistance of the reaction frame allow also the application of horizontal forces, i.e. the installation of dynamic actuators, at different heights. This permits the application of different cyclic forces on each rack floor level (Fig. 4), allowing for the execution of pushover dynamic tests, as planned for the near future.

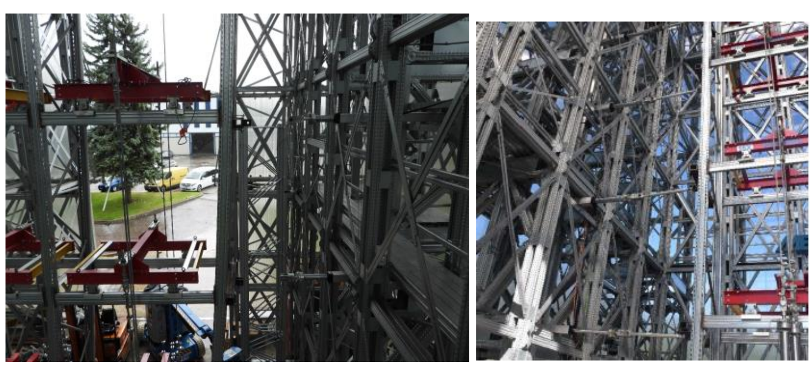


FIGURE 4. Two views of the horizontal actuators

CONCLUDING REMARKS

Earthquake events recently happened pointed out the importance of an accurate seismic design of steel storage pallet racks. Although the EN16681 provisions [6] focuses on this topic, additional studies are required for the definition of suitable design rules. At this aim, an experimental approach can be suitably adopted focusing on the seismic behaviour of the sub-assemblies and of the whole structure. As a contribution to the study of the full-scale rack response, a full-scale testing set-up allowing the application of both vertical and horizontal loads was recently designed and realized. The main features of this testing equipment are described in this paper. The potentialities of this testing facility will allow for performing in the near future push-over full-scale tests and also studying the robustness in accordance with the well-known procedures commonly adopted for traditional carpentry frames [13].

REFERENCES

1. N. Baldassino, C. Bernuzzi and M. Simoncelli, "Evaluation of European approaches applied to design of TWCF steel members", in *Thin-Walled Structures*, **143**, 106186 (2019).
2. C. Bernuzzi, D. Rodigari and M. Simoncelli "Post-earthquake damage assessment of moment resisting steel frames" in *Ingegneria Sismica*, **36(4)**, pp. 35-55 (2019).
3. N. Baldassino, C. Bernuzzi, A. Di Gioia and M. Simoncelli, "An experimental investigation on solid and perforated steel storage racks uprights", in *Journal of Constructional Steel Research*, **155**, pp. 409-425 (2019).
4. N. Baldassino, C. Bernuzzi and M. Simoncelli, "Experimental vs. theoretical design approaches for thin-walled cold-formed steel beam-columns", in *Advanced Steel Construction*, **15(1)**, pp. 55-65 (2019).
5. R. Montuori, G. Gabbianelli, E. Nastri and M. Simoncelli "Rigid plastic analysis for the seismic performance evaluation of steel storage racks", in *Steel and composite structures*, **32(1)**, pp. 1-19 (2019).
6. CEN, *EN16681, Steel static storage systems – Adjustable pallet racking systems – Principles for seismic design*, (European Committee for Standardization, Brusselles (2016).
7. E. Jacobsen and R. Tremblay "Shake-Table testing and numerical modelling of inelastic seismic response of semi-rigid cold-formed rack moment frames", in *Thin-walled structures*, **119**, pp. 190-210 (2017).
8. A. Kanyilmaz A., C.A. Castiglioni, G. Brambilla and G.P. Chiarelli "Assessment of the seismic behaviour of braced steel storage racking systems by means of full scale push over tests", in *Thin-walled structures*, **107**, pp. 138-155 (2016).
9. C. Bernuzzi, A. di Gioia, G. Gabbianelli and M. Simoncelli "Pushover analyses of hand-loaded steel storage shelving racks", in *Journal of Earthquake Engineering*, **21(8)**, pp. 1256-1282 (2017).
10. G. Gabbianelli, A. Kanyilmaz, C. Bernuzzi and C. A. Castiglioni "A combined experimental-numerical study on unbraced pallet rack under pushover loads", in *Ingegneria Sismica*, **34(1)**, pp. 18-38 (2017).
11. T. Pekoz and K. Rao "Design of industrial storage racks", in *Progress in Structural Engineering and Materials*, **3**, pp. 28-35 (2001).
12. L. Gelmini and A. di Gioia "The test tower of Metalsistem S.p.A. R&D division" (in Italian), in *Costruzioni Metalliche*, **6**, pp. 38-44 (2017).
13. R. Zandonini, N. Baldassino and F. Freddi "Robustness of steel concrete flooring systems – An experimental assessment", in *Stahlbau*, **83(9)**, 608-613 (2014).