Theoretical and Applied Mechanics - AIMETA 2022 Materials Research Forum LLC
Materials Research Proceedings **26** (2023) 151-156 https://doi.org/10.21741/9781644902431-25

Experimental analysis of new moment resisting steel connections

Salvatore Benfratello[1,a*], Luigi Palizzolo[1,b] and Santo Vazzano[1,c]

[1]Department of Engineering, University of Palermo, Viale delle Scienze, Ed. 8, I-90128, Palermo, Italy

[a]salvatore.benfratello@unipa.it, [b]luigi.palizzolo@unipa.it, [c]santo.vazzano@unipa.it

Keywords: Steel Connections, Experimental Analysis, Elastic and Limit Behaviour

Abstract. In the recent past, the authors proposed a new steel device devoted to representing an innovative moment resisting connection for steel frame elements called LRPD (Limited Resistance Plastic Device). It is a steel element characterized by symmetry with respect to three orthogonal barycentric planes and constituted by a sequence of three portions with abrupt cross section changes, each of one identifies a steel element of suitably designed geometry. LRPD possesses the following characterizing features: any elastic flexural stiffness variation with respect to the original selected member must be avoided; the bending moment resistance must be an appropriate reduced percentage of the original beam bending resistance; any local instability phenomenon must be avoided ensuring a full plastic deformation field. In previous papers the deep description of the geometrical and mechanical features of the device and the optimal design formulation are reported. In the present paper a first stage of experimental campaign on the mechanical behaviour of LRPD is presented. Specifically, the pure bending behaviour of LRPD is investigated by performing the four-point bending test. The test is performed monotonically until the selected ultimate plastic bending moment acts on the specimen. The mechanical response of LRPD, both in terms of deflections as well as of axial strains is evaluated by means of suitably positioned displacement and strain gauges. The experimental test is performed on LRPD designed for HEB240 cross section beams. The obtained results confirm the expected performance of LRPD constituting a fundamental step for the subsequent experimental steps mainly constituted by cyclic tests.

Introduction

The analysis and the design of the connections of steel structures is of particular interest in both the scientific and technical fields especially after the 1994 Northridge and 1995 Kobe earthquakes (see e.g. [1-4]). Two main types of connections are available: the rigid connections (also called moment connections) and the simple ones (also called shear connections). Among the moment connections, to avoid the brittle rupture of the connection, the most adopted approach proposes a reduction of the end sections of the frame beams, implementing the so-called “dog-bone” profiles, by cutting portions of the flanges of a I-beam profile (see e.g. [5-7]). The main drawbacks of this approach are that it is usable only with I-beam section elements and, furthermore, that the flanges cutting involves a reduction both in stiffness and strength of the treated element.

In the recent past, the authors proposed a new moment resisting connection for steel frame elements, called LRPD (Limited Resistance Plastic Device) [8-15]. Mainly, LRPD is thought as a steel device replacing a part of the structural elements with the aim to obtain a connection between structural members with preset mechanical and kinematical behaviour. The detailed description of the geometrical description of LRPD can be found in [15], while its leading features are those of the same elastic flexural stiffness as the original selected member, to possess a bending moment resistance reduced with respect to that of the original beam, to avoid any local instability phenomenon. In many papers [8-15] authors proposed different optimal design for LRPD as well performed a lot of numerical analyses to verify the LRPD behaviour and the related computational aspects. In the present paper a first step of experimental campaign on the mechanical behaviour of LRPD is presented by performing the four-point bending test to apply a pure bending moment without shear force in central zone of the specimen. The test is performed monotonically until the selected ultimate plastic bending moment acts on the specimen. The mechanical response of LRPD, both in terms of deflections as well as of axial strains is evaluated by suitably positioned displacement and strain gauges. The test is performed on LRPD designed for HEB240 beams. The obtained results confirm the expected performance of LRPD constituting a fundamental step for the subsequent experimental steps mainly constituted by cyclic tests and by a deep analysis of mechanical behavior of LRPD also adopting full-field contactless analysis method as Electronic Speckle Pattern Interferometry (ESPI) [17-19], to obtain highly accurate strain full-field.

Experimental investigations

Aim of the experimental investigations is the check of the bending behaviour of the LRPD by performing a four-point bending test on a suitable specimen. To this goal the first step has been to optimally design an LRPD following [3,4] to be adopted with a HEB240 profile and with an ultimate bending reduction equal to 0.67. The next step has been to design the specimen avoiding welding along the cross section which constitute a possible weakness. The final choice has been that of realizing a specimen simply by extending on both sides the flanges and the web of the LRPD to reach the desired length of the specimen. The experimental investigations have been performed on the specimen sketched in Fig. 1 where the corresponding main geometric characteristics and the location of displacement measuring point are also reported.

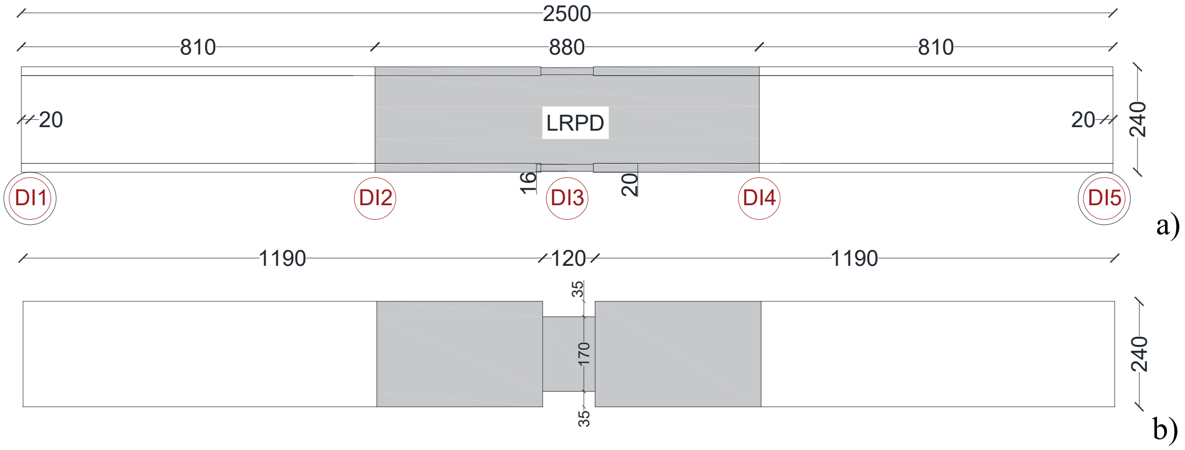

Fig. 1 – Sketch of the specimen under investigation: a) lateral view; b) upper view

The specimen is constituted by three different parts, two corresponding to the flanges (equal each other) and the other one for the web. Each part has been derived by a S275 steel slab, shaped following the results of the optimal design reported in [15] with an assigned ultimate bending moment equal to 0.67 of the corresponding one of HEB240 (dimensions in Fig. 1). The overall assembly has been obtained by factory welding the single parts and it has been performed by Tecnozinco s.r.l., whose contribution is gratefully acknowledged. The mechanical characterization of the material constituted the slab has been performed by tensile tests on suitable specimens following [15] and the results are reported in Table 1. Assuming the geometrical characteristics of the specimen, the mean value of f_y, the consequent ultimate bending moment of LRPD is equal to 241.8 kNm corresponding to a load of 306 kN. The experimental setup is sketched in Fig. 2

Table 1 – Results of the mechanical characterization of the material

Part	E [MPa]	f_y [MPa]	f_u [MPa]	A_g [%]	A_{gt} [%]
Web	208426	348.85	466.19	17.86	18.08
Flanges	231822	339.71	477.56	15.63	15.83

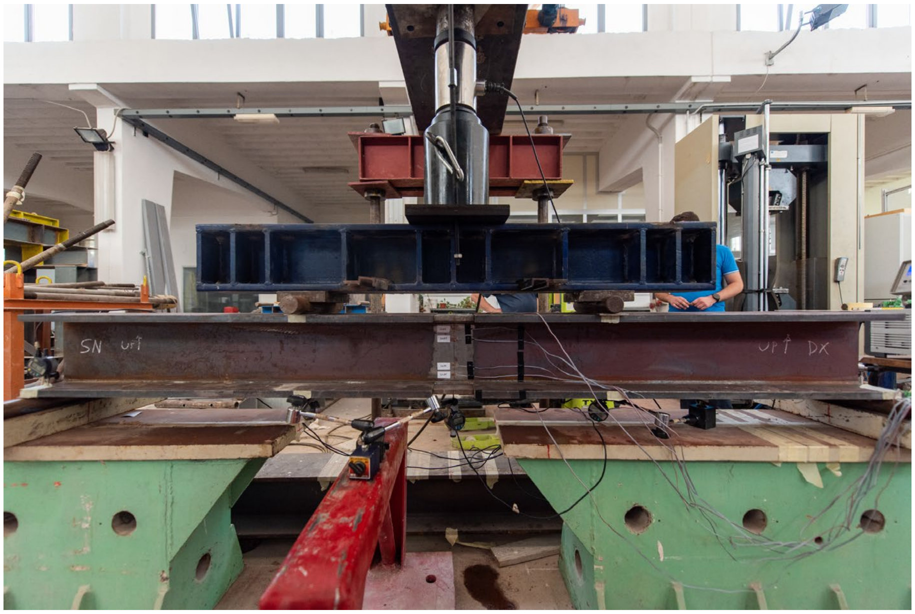

Fig. 2 – Sketch of the experimental setup

The experimental setup is constituted by a hydraulic jack (payload = 1 MN), driven by a ENERPAC pump; the acting load is measured by a CLF-1 class 1 AEP load cell (payload = 1 MN) connected to AEP MP-10 digital indicator, and the load is set on the specimen by means of a rigid beam and two steel semi-cylinders. Two steel cylinders are suitably positioned at the extreme of the specimen to obtain the simply supported scheme. The deflection is measured at three different locations (corresponding to the beginning, the middle section and the end section of the LRPD) by means of Mitutoyo DIGIMATIC Digital indicator (25 mm stroke) and two other indicators have been positioned in correspondence of the supports of the specimen. The strain acting on the LRPD has been measured by seven different HBM K-CLY-41/120 strain gages (6 mm length), arranged as sketched in Fig. 3, and connected to HBM MGCPlus. All the measurement values have been collected by a suitable virtual instrument developed in LabView 2020 environment.

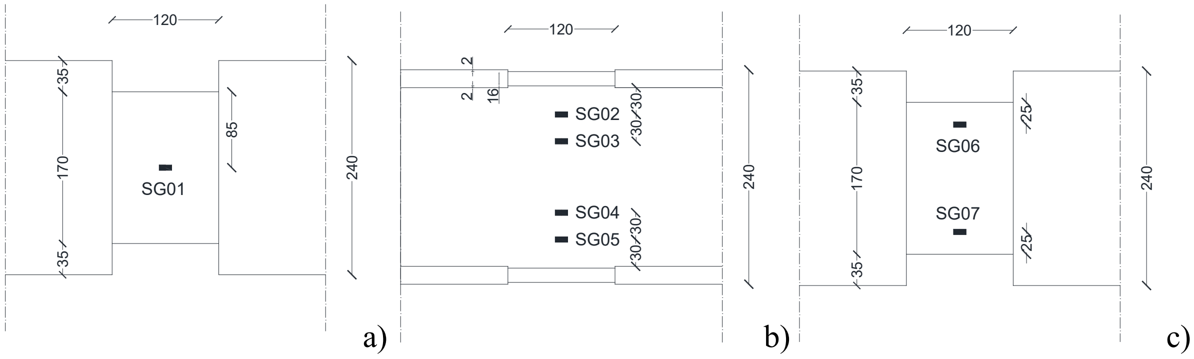

Fig. 3 – Arrangement of the strain gages: a) upper flange; b) web; c) lower flange.

Numerical model

The experimental test of the specimen described in the foregoing section has been analyzed by means of a suitable FEM model developed in ABAQUS environment and sketched in Fig. 4. The adopted mesh is equal to 4 mm, the mechanical model of the material is that of elastic perfectly plastic one with mechanical characteristics equal to that reported in Table 1 (i.e. two different materials have been adopted) while an elastic material with E 1000 times greater than that of the steel has been adopted for the support and loading cylinders. The support cylinders have been fully constrained (encastre condition), friction (0.125) has been assumed between the specimen and support and loading cylinders. The acting load is a concentrated one applied on the reference point for each loading cylinder, the reference points are rigidly linked to the surface of the cylinders.

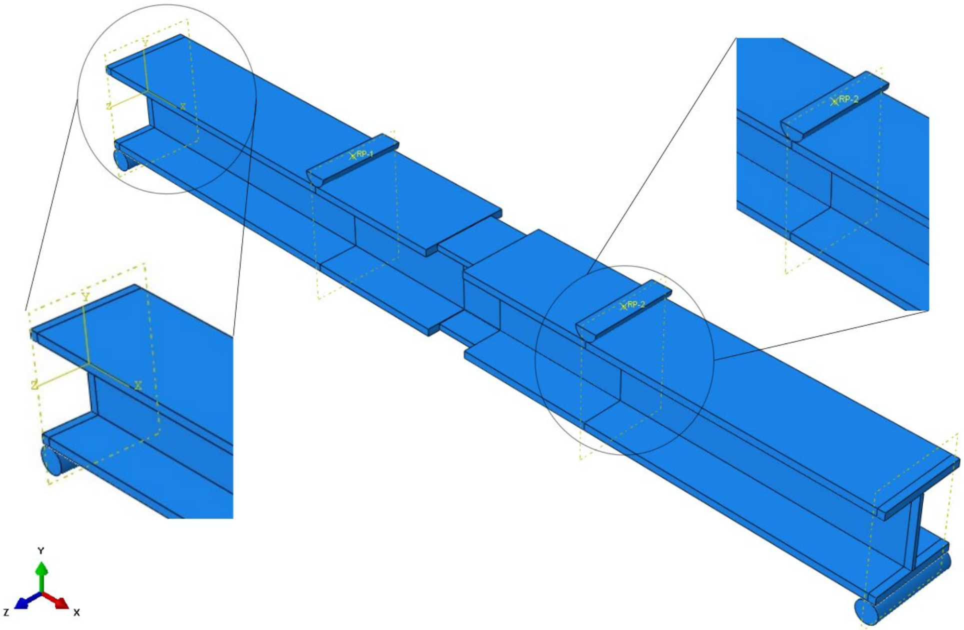

Fig. 4 – FE model of the experimental test in ABAQUS environment.

Results

The experimental results, in terms of axial stress σ_x evaluated from the axial strains ε_x at the locations indicated in Fig. 3, compared with those arising from the numerical analysis are reported in Fig. 5a. The kinematic behaviour of LRPD is evaluated defining as parameter $\Delta_{LRPD} = v_3 - \mathrm{mean}(v_2; v_4)$ (being v_2, v_3 and v_4 the vertical displacement of DI1, DI2 and DI3 in Fig. 1a). In Fig. 5b the experimental Δ_{LRPD} is reported and compared with those arised from the numerical analysis and the theoretical one.

An examination of Fig. 5a confirms the expected mechanical behaviour of LRPD. The first points which undergo to yield are those corresponding to SG01, SG06 and SG07; the next points are SG02 and SG05, while the last points are SG03 and SG04. Finally, the numerical results are in well agreement with the experimental ones. The results of Fig. 5b confirm that the kinematic behaviour of LRPD is the expected one, being the overall behaviour practically coincident with the theoretical ones of the HEB240.

Conclusions

In the paper the experimental characterization of new moment resisting steel connections recently proposed by the authors and called LRPD has been proposed. The experimental results, both in terms of axial stress, axial strain and displacement confirm that the device behaves as expected following the constraints imposed in the optimal design. The experimental champaign will be enriched and completed soon studying other devices designed for different commercial profile.

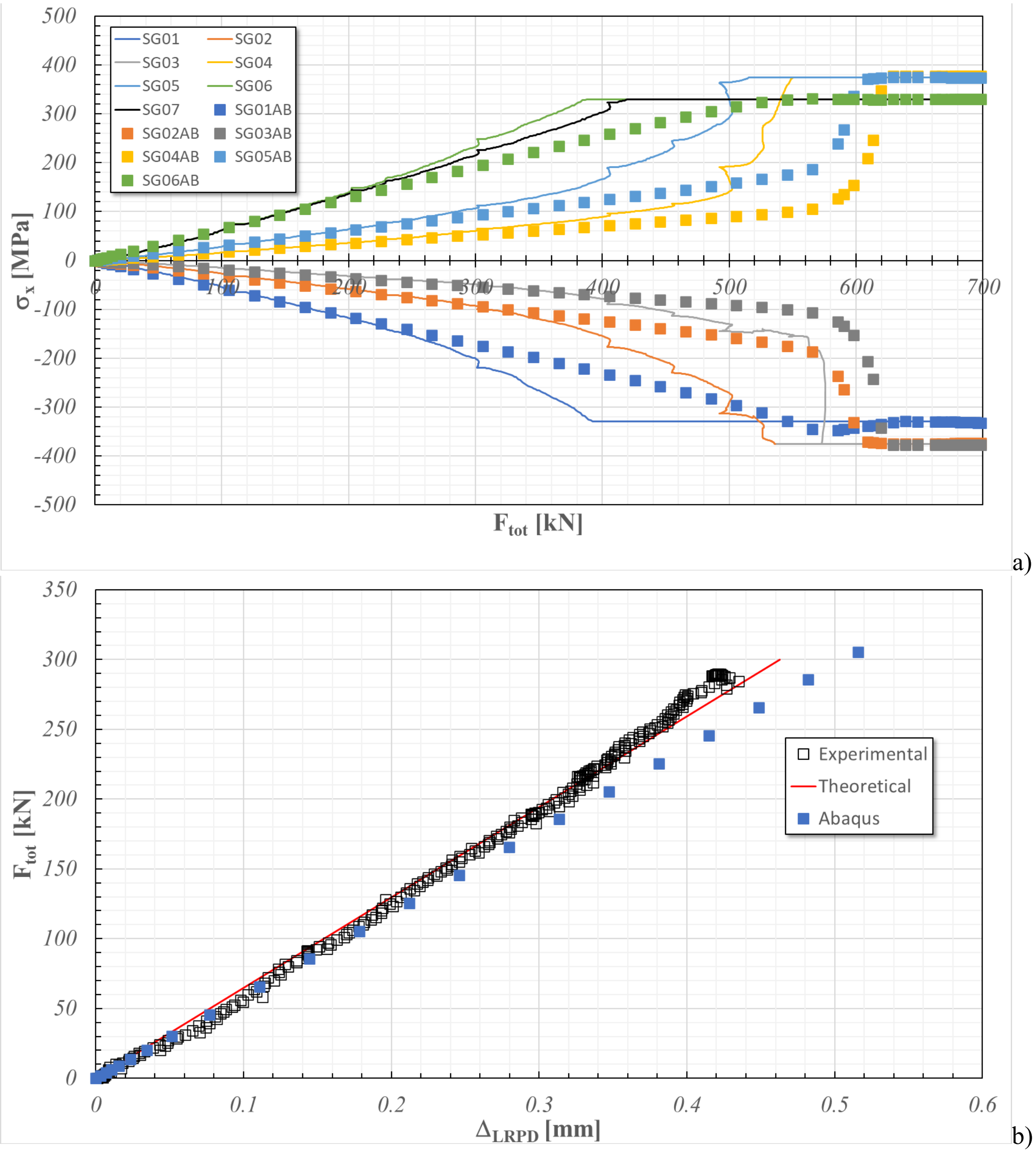

Fig. 5 – Experimental results compared with the numerical ones a) σ_x vs F_{tot}; b) Δ_{LRPD} vs F_{tot}.

References

[1] D.K. Miller, Lessons learned from the Northridge earthquake,Eng. Struc. 20 (1998), 249–260. https://doi.org/10.1016/S0141-0296(97)00031-X

[2] E.P. Popov, T.S. Yang, S.P. Chang, Design of steel MRF connections before and after 1994 Northridge earthquake. Eng Struct, 20 (1998) 1030-1038. https://doi.org/10.1016/S0141-0296(97)00200-9

[3] AISC 2016, Prequalified connections for special and intermediate steel moment frames for seismic applications. ANSI/AISC 358-16. Chicago.

[4] EN 1993-1-8:2006, Eurocode 3: Design of Steel Structures Part 1-8: Design of Joints, 2006.

[5] A. Plumier, The dogbone: back to the future. Eng. J. 34 (1997) 61-67.

[6] J. Shen, T. Kitjasateanphun, W. Srivanich, Seismic performance of steel moment frames with reduced beam sections, Eng. Struct. 22 (8) (2000) 968–983. https://doi.org/10.1016/S0141-0296(99)00048-6

[7] T. A. Horton, I. Hajirasouliha, B. Davison, Z. Ozdemir, More efficient design of reduced beam sections (RBS) for maximum seismic performance, J. of Constr. Steel Res., 183 (2021) 106728. https://doi.org/10.1016/j.jcsr.2021.106728

[8] S. Benfratello, L. Palizzolo, Limited resistance rigid perfectly plastic hinges for steel frames, Intern. Rev. Civ. Eng. 8 (6) (2017) 286–298. https://doi.org/10.15866/irece.v8i6.13190

[9] S. Benfratello, C. Cucchiara, P. Tabbuso, Fixed strength and stiffness hinges for steel frames, in: Feo L., Ascione L., Berardi V.P., Fraternali F., Tralli A.M. (Eds.), AIMETA 2017 – Proc. of the 23rd Conf. of the Italian Association of Theoretical and Applied Mechanics, pp. 1287–1296.

[10] S. Benfratello, L. Palizzolo, P. Tabbuso, S. Vazzano, On the post elastic behavior of LRPH connections, International Review on Modelling and Simulations, 12 (2019) 341-353. https://doi.org/10.15866/iremos.v12i6.18294

[11] L. Palizzolo, S. Benfratello, P. Tabbuso, S. Vazzano, Numerical validation of LRPH behaviour by fem analysis, Advances in Engineering Materials, Structures and Systems: Innovations, Mechanics and Applications - Proceedings of the 7th International Conference on Structural Engineering, Mechanics and Computation, 2019, 2019, 1224–1229. https://doi.org/10.1201/9780429426506-212

[12] S. Benfratello, L. Palizzolo, P. Tabbuso, S. Vazzano, LRPH device optimization for axial and shear stresses, Intern. Rev. Civ. Eng. 11 (4) (2020) 152–163. https://doi.org/10.15866/irece.v11i4.18100

[13] S. Benfratello, S. Caddemi, L. Palizzolo, B. Pantò, D. Rapicavoli, S. Vazzano, Smart beam element approach for lrph device, in: Carcaterra A., Graziani G., Paolone A. (Eds), 24th Conference of the Italian Association of Theoretical and Applied Mechanics, AIMETA 2019, Lecture Notes in Mechanical Engineering (2020), 197-213. https://doi.org/10.1007/978-3-030-41057-5_16

[14] S. Benfratello, S. Caddemi, L. Palizzolo, B. Pantò, D. Rapicavoli, S. Vazzano, Targeted steel frames by means of innovative moment resisting connections, Journal of Constructional Steel Research, 183 (2021) 106695. https://doi.org/10.1016/j.jcsr.2021.106695

[15] S. Benfratello, L. Palizzolo, S. Vazzano, A New Design Problem in the Formulation of a Special Moment Resisting Connection Device for Preventing Local Buckling, Journal of Applied Sciences, 12 (2022) 202. https://doi.org/10.3390/app12010202

[16] UNI EN 10002-1 (2004), Metallic materials - Tensile testing - Part 1: Method of test at ambient temperature.

[17] S. Benfratello, V. Fiore, L. Palizzolo, P. Tabbuso, Speckle Interferometry Analysis of Full-bending Behavior of GFRP Pultruded Material, Procedia Engineering, 161 (2016), 439-444. https://doi.org/10.1016/j.proeng.2016.08.587

[18] S. Benfratello, V. Fiore, L. Palizzolo, T. Scalici, Evaluation of continuous filament mat influence on the bending behaviour of GFRP pultruded material via Electronic Speckle Pattern Interferometry, Arch. Civ. Mech. Eng., 17 (2017), 169-177. https://doi.org/10.1016/j.acme.2016.09.009

[19] S. Benfratello, L. Palizzolo, P. Tabbuso, Evaluation of the bending behaviour of laminated glass beams via electronic speckle pattern interferometry, International Review on Modelling and Simulations, 10 (2017), 279-288. https://doi.org/10.15866/iremos.v10i4.12220