ingegneria sismica
International Journal of Earthquake Engineering
Anno XXXV – Num. 2

SEISMIC UPGRADING OF RC STRUCTURES WITH ONLY BEAM CONNECTED STEEL PLATE SHEAR WALLS

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SUMMARY: *Steel Plate Shear Walls (SPSWs) connected to the boundary frame beams only are suitable structural systems to resist lateral loads. These systems allow for designers to avoid the high flexural demands over columns imposed by conventional SPSWs connected to both beams and columns of the surrounding frame. They can be successfully applied for seismic upgrading of existing RC structures to provide them higher levels of strength, ductility and energy dissipation capacity. This paper presents a numerical assessment of the seismic response of an existing RC structure upgraded with only beam connected SPSWs. The structure, designed for resisting vertical loads only, was erected in the district of Bagnoli in Naples. The used numerical approach is based on the simplified strip model with concentrated plasticity links. The achieved results are focused on fundamental seismic performance issues of the upgraded structure, which are compared to the upgrading solution experimentally applied to the same case study.*

KEYWORDS: *Seismic upgrading, Steel Plate Shear Walls (SPSWs), reinforced concrete structures, seismic non-linear response, only beam connected SPSWs.*

1 Introduction

Unstiffened Steel Plate Shear Walls (SPSWs) consist of one or more infill web steel thin plates surrounded by horizontal and vertical boundary frame elements, indicated as HBEs and VBEs, respectively. The beam-to-column connections of the frame can be either hinged joints (shear connections) or moment-resisting ones. Several analytical, numerical and experimental works were developed to attempt a complete and more deep understand of the overall structural behaviour of SPSWs [Thorburn, et.al, 1983; Timler and Kulak, 1983; Tromposch and Kulak, 1987; Sabouri-Ghomi and Roberts, 1992; Purba and Bruneau, 2014; Formisano et al., 2007]. SPSWs have high strength, initial lateral stiffness and very good ductility values under monotonic incremental loads [Alinia and Dastfan, 2005; Berman, 2011]. When these structural systems are subjected to cyclic reversal horizontal loads, they show a good energy dissipation capability and have relatively stable hysteretic cycles [Caccese et.al.,1993; Lubell et.al., 2000; Alinia and Dastfan, 2007; Jalali and Banazadeh, 2016]. In order to carry out a simplified analysis and to represent the non-linear structural response of SPSWs, several decades ago the so-called strip model method was developed [Timler and Kulak, 1983; Shishkin et.al., 2005]. The strip model replaces the web plate by several only tension strips hinged to the frame HBEs and VBEs. This modelling approach has been adopted for structural analysis by several codes [Canadian Standard CSA-S16-01, 2001; ANSI/AISC 341-10, 2010]. Over the years, some

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proposals have been made to modify the original strip model technique, mainly trying to introduce into the structural analysis, other than the diagonal tension field influence, the influence of the compression forces on the behaviour of plates, that are not negligible in most cases [Shishkin et.al., 2005; Guo et.al., 2013; Jalali and Banazadeh, 2016].

In recent years, the novel only beams connected SPSWs (herein called as SPSWs-OBC) were proposed as an interesting alternative to the classical SPSWs in order to reduce the high demands induced over the VBEs [Guo et.al., 2011; Clayton et.al., 2015]. In the SPSWs-OBC, the steel infill web thin plates are connected only to the surrounding frame HBEs by either bolted or welded connections.

The described configuration is appropriate to prevent local or overall buckling failure of the columns, principally at bottom levels of the structure. This proposal, as an alternative to the innovative solution of perforated SPSWs (Formisano and Lombardi, 2016; Formisano et al., 2016a; Formisano et al., 2016b), gives to structural designer the possibility of having greater flexibility and design capability for both new structures and as upgrading solutions for seismically vulnerable existing structures.

For SPSWs-OBC there are only a few numerical and experimental available researches. Some specific strip models have been proposed to take into account such a configuration of connections. They can predict the ultimate load capacity and the hysteretic behaviour of the web infill plate of the structure, when it is subjected to either horizontal incremental loads or a cyclic loading specific pattern [Ozcelik and Clayton, 2017].

The aforementioned characteristics are appropriate to develop seismic protection systems based on SPSWs-OBC to upgrade seismically vulnerable RC framed structures [De Matteis and Brando, 2016].

These kinds of existing structures have been designed either by considering predominant gravitational loads or with obsolete design codes. The structural characteristics of conventional SPSWs and novel SPSWs-OBC are exploited by structural designers to properly control the inter-storey drift of both high-rise and low-rise framed building structures.

The present work provides the first results of a complete research project on SPSWs applied to the seismic improvement of RC buildings.

In particular, it shows a numerical investigation on the structural response and non-linear behaviour of an existing RC structure upgraded by two typologies of SPSWs-OBC. The structure under investigation is a partial module of a full-scale existing RC framed industrial building placed in the Bagnoli district of Naples and already investigated in previous researches [De Matteis et.al., 2009; Formisano et.al, 2006; Formisano et.al, 2008; Formisano et.al, 2010; Formisano and Mazzolani, 2015; Formisano et.al., 2016]. A novel strip model with concentrated plasticity zero length links is used to model the non-linear behaviour of the proposed retrofitting devices. The performed analyses allow to interpret relevant aspects of the seismic response and performance of the upgraded structure, such as the increased load capacity, the initial stiffness variations and the offered ductility under incremental lateral loading static tests.

The numerical implementation of the existing RC structure, as well as the FEM models of upgrading solutions by SPSWs, were performed through the SeismoStruct finite element non-linear structural analysis software [Seismosoft, 2016]. Some of the results obtained are analysed and compared with those available from previous researches on the same structure under investigation.

2 The RC structure under investigation

2.1 General description

The structure under investigation was designed and built at the end of the 70's to sustain predominantly gravity loads according to construction codes of those years. The experimental investigation of this structure was performed within the ILVA-IDEM research project [Mazzolani et.al., 2004; De Matteis et.al., 2009; Formisano et.al, 2010]. The complete original RC structure had a rectangular shape with major and minor dimensions of 41.60m and 6.50m, respectively. The structure developed on two floors in elevation and it was initially divided in six independent sub-structural units (modules) in order to perform on each of them several experimental full-scale tests by using different seismic upgrading techniques. The building foundations were made of reinforced concrete T-inverted cross-section beams placed on the structure perimeter. In the present paper, the independent module n.5 is selected in order to perform a numerical investigation on the inelastic response of the structure seismically upgraded with four different types of SPSWs-OBC. The proposed structural upgrading solutions are placed over the two lateral longitudinal frames at the ground floor of the module. Figure 1 shows a lateral view of the selected module n.5 reinforced with steel reaction frames equipped with hydraulic jacks for loading application.

Figure 1 - *Lateral view of selected module n.5 of the ILVA-IDEM structure [Formisano and Lombardi, 2016].*

2.2 Geometrical configuration of the study structural module

The module n.5 of the ILVA-IDEM structure is characterised by a rectangular plan shape with sides of 6.30m in the longitudinal direction and 5.90m in the transverse one. The structure develops on two levels having distance from the ground of 3.30m and 6.60m, respectively.
The thickness of the first and second floor slabs, built with RC joists and hollow tiles, are respectively of 0.24m and 0.20m. Figure 2 shows the first-floor plan and the in-elevation transverse section of the selected structure.

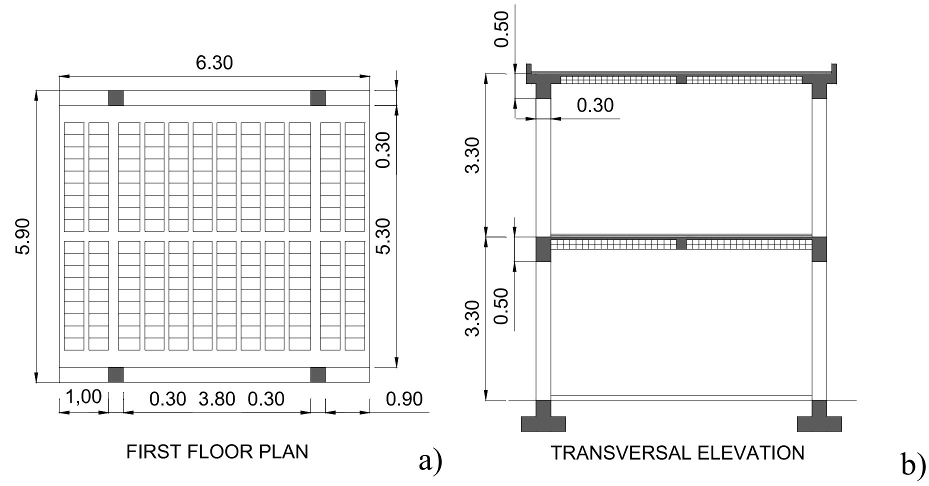


Figure 2 - *First floor plan view (a) and in-elevation transverse section (b) of the module n.5 of the ILVA-IDEM structure*

The module has four columns with square cross-section of 30cm by 30cm (C1 columns) connected by principal beams in the longitudinal direction and only connected by the simple slabs in the transverse direction. The first level slab is supported by rectangular RC beams having 30cm x 50cm (B1 beam) and 25cm x 50 cm (B2 beam) cross-sections. At the second level the slab is supported by T cross-section principal beams (B3 beams) with the same width and height of the B1 beams.
The overall dimensions of the RC structure and those corresponding to the structural frames members and slabs of the selected module were surveyed in situ before the tests performed in the aforementioned ILVA-IDEM research project.
The mechanical properties of concrete and steel of existing members were determined by several specific laboratory tests over specimens extracted from the existing structural members [Mazzolani et. al., 2004; De Matteis et.al., 2009; Formisano et.al, 2010; Formisano and Lombardi, 2016]. Based on several tensile laboratory tests, steel bars had an average yield strength of 443 MPa and an ultimate strength of 693 MPa. On the other hand, the compression tests performed on the available concrete specimens provided 21 MPa as the average compressive strength and 16829 MPa as the average elastic modulus. The specific weight of analysed concrete was 22.39 kN/m^3. Table 1 shows specific details of geometrical dimensions and steel reinforcements for the frame structural members.

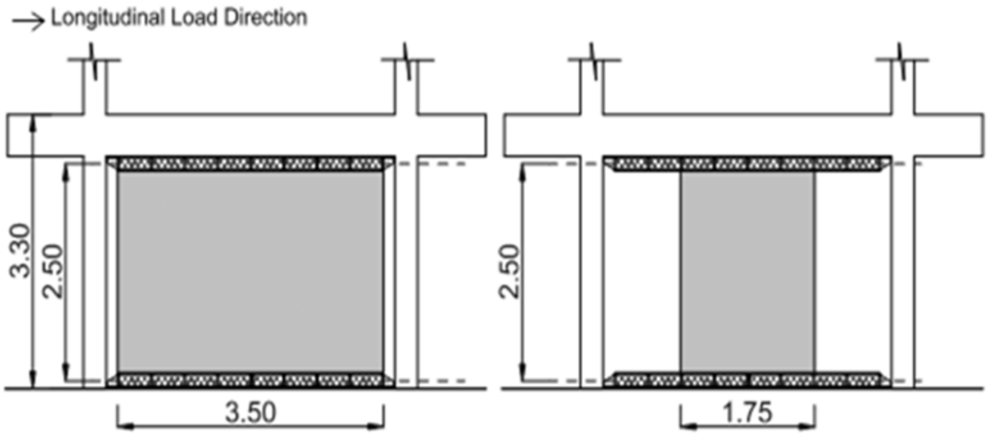
Table 1 - *Geometry and steel reinforcement details of structural members.*

Structural member	Cross-section [cmxcm]	S_L (number of bars and position)	S_T (bar diameter/spacing)
Beam B1	30x50	2ϕ8 Top | 2ϕ8+2ϕ12 Bottom 2ϕ8 Lateral	ϕ8/200 mm
Beam B2	25x50	2ϕ8 Top | 2ϕ8+2ϕ12 Bottom 2ϕ8 Lateral	ϕ8/200 mm
Beam B3	30x50	2ϕ8 Top | 2ϕ8+2ϕ12 Bottom 2ϕ8 Lateral	ϕ8/200 mm
Columns	30x30	4ϕ12	ϕ8/300 mm

In this table S_L and S_T are related to corresponding longitudinal and transverse reinforcement steel bars of the different frame beams and columns of the selected structural module. The soil where the analysed structure is located is of type B with a corresponding peak ground acceleration of 0.25g.

3 The proposed upgrading solutions

In the present research, two upgrading solutions based on the use of SPSWs-OBC are proposed for the inspected RC module. Each solution has been applied by considering two thicknesses of steel infill web plates in order to have comparative information and results. In the first case (upgrading solution A), the SPSW-OBC is placed so as to have the bay width fully occupied by the web panel, while in the second one (upgrading solution B), the SPSW-OBC is placed at the frame centre and occupies 50% of the available bay width. The geometric configurations of selected seismic devices can be seen in Figure 3.
For both proposed solutions, the thin steel plates are connected to the existing RC frame beams by four stiffened steel 140x140x10mm angles. The angles are anchored to the RC beams by chemical fixing systems, whereas they are joined to the steel plate by M16 preloaded high strength bolts. The specific and complete design of connection joints is beyond to the purposes of this paper.



Solution A Solution B

Figure 3 - *Geometrical configurations of proposed seismic upgrading solutions.*

For both upgrading systems the mechanical properties of steel web panels are f_y=310MPa, f_u=340MPa, E=200000MPa and strain hardening factor equal to 1.25. In both proposed upgrading solutions, the effective height (H) of the web steel panels is measured between the upper and bottom centroid axes of the connecting joints between the anchoring steel angles and the web steel plates.

4 Numerical Analyses

4.1 The SPSWs-OBC model

In order to carry out the numerical analysis on the RC structural module upgraded with the proposed solutions, firstly a simplified strip model (called MSM03-BC) has been developed to represent the SPSWs-OBC structural non-linear behaviour. For the purpose of the present paper

the numerical model has been implemented with the SeismoStruct v.7.0.0 finite element non-linear analysis software [SeismoSoft, 2016]. Prior to the numerical analyses on the ILVA-IDEM structure, the proposed simplified strip model has been adequately validated from available experimental research data (see Section 4.2).
A concentrated plasticity physical model with three tension strips and three compression struts for each incremental loading direction has been used to model the steel infill plates. The strips are oriented with a certain angle ϑ with respect to the vertical direction. The inclination of the strips has been taken according to the partial tension field orientation over the plate.
The non-linear structural behaviour and response of the thin infill web plate is concentrated in the links *L1* (see Figure 4), which are zero length links elements with an asymmetric specific bilinear constitutive law. In the same Figure 4 a schematic representation of the physical model of the panel within a typical one floor - one bay RC surrounding frame, having *LF* and *HF* as horizontal and vertical lengths between the neutral axis of beams and columns, respectively, and *Lt* as the total length of the plate-beam steel bolted connection device, is reported.
The implementation of numerical and computational models of the upgraded RC existing vulnerable structure has been developed by the definition of the following structural elements (see Figure 4):

- BE1, BE2 and BE3: inelastic frame force-based fibre elements (SeismoStruct *infrmFB*) discretised with 150 fibres and five integration sections.
- BR1: rigid link orthogonal to the BE3 elements. This element represents the natural eccentricity between the neutral axis of the frame beam and the centroid axis of the beam-plate connection joint device.
- S1 to S6: inelastic truss fibre elements (SeismoStruct *truss_element*) discretised with 100 fibres and 100 total monitoring points.
- L1: zero length non-linear link element. Hinged connection with asymmetrical bilinear constitutive law (SeismoStruct *bl_asm* option) in the strip axis direction and linear symmetrical behaviour (SeismoStruct *lin_sym* option) with very high stiffness for the remaining degree of freedoms.
- H1: Zero length link element representing a perfect hinge connection between frame structures and strips.
- N1 – N2: connection nodes of the structural model.

According to the above description, Figure 4 shows a schematic representation of the proposed MSM03-BC strip model as infill panel, along with its implementation into a typical one floor – one bay frame, made of RC beams and columns, which acts as the existing structure to be upgraded. The same figure shows a general schematic configuration of the upgrading solutions A and B with the inclination angle of the tension strips (see Equations 2 and 3) and the effective width of the infill plate only beam connected.
Figure 5 shows: a) the computational implementation of the described SeismoStruct structural model, b) the corresponding deformed shape of the RC bare structure, subjected to monotonically increased horizontal loads (static pushover analysis) at the first floor, and c) the RC structure upgraded with the SPSWs-OBC schematised with the MSM03-BC strip model.
The accurate characterisation of the strip model to be used involves the careful definition of a specific series of important design parameters. Among these, one of the most important is the inclination angle of the partial tension field θ with respect to the vertical direction. For SPSWs-OBC, the angle θ defines the effective width of the infill web plate *Lf* (see Figure 4).

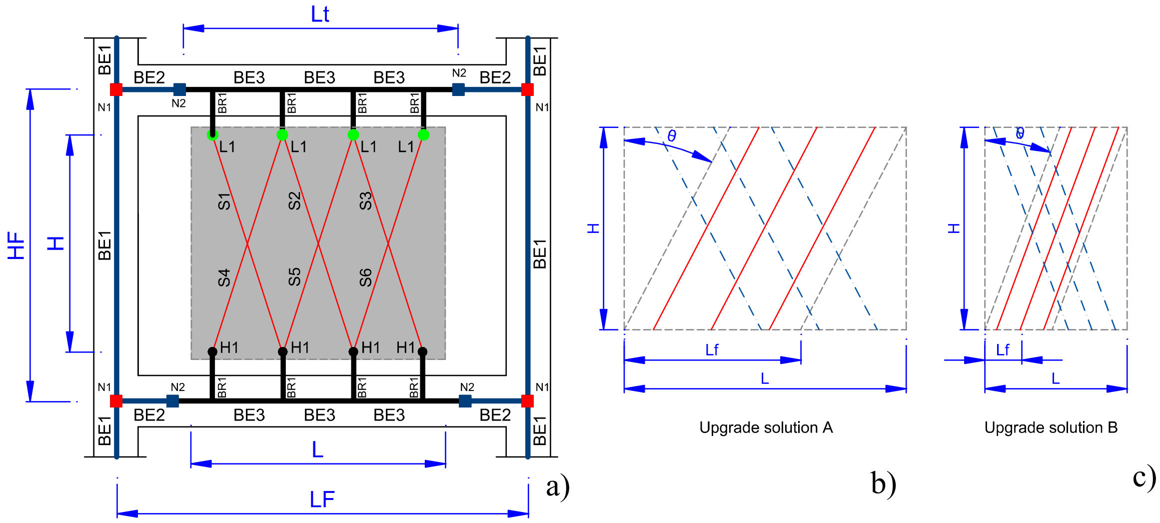


Figure 4 - *Configuration of the MSM03-BC strip model placed into a one floor – one bay RC typical frame (a) and general configuration of strip models corresponding to the upgrading solutions A (b) and B (c).*

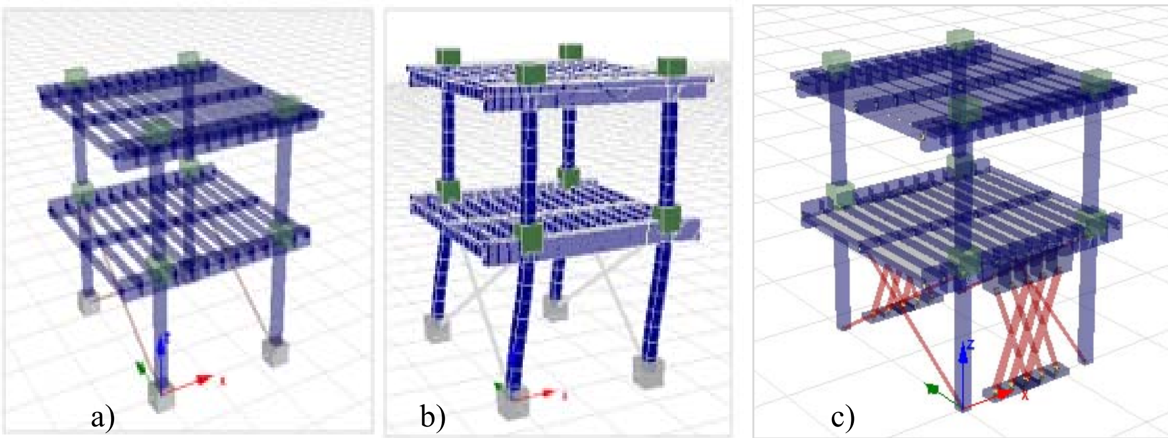


Figure 5 - *SeismoStruct structural model of the ILVA-IDEM module n. 5 (a), deformed shape of the bare structure under monotonic loading at the first floor (b) and the module upgraded with SPSWs (MSM03-BC strip model) (c).*

According to the proposal of previous available research works [Ozcelik and Clayton, 2017], this angle can be obtained from the following expression:

$$\theta = \gamma \, tan^{-1}\left(\frac{L}{H}\right) \tag{1}$$

where γ is a normalised inclination angle parameter calculated according to the following relationship:

$$\gamma = 0.55 - 0.03\left(\frac{L}{H}\right) \geq 0.51 \tag{2}$$

From the definition of the angle θ, the effective width of the tension field in the web thin steel plate can be determined as follows:

$$L_f = L - H \, tan\theta \tag{3}$$

The effective width of each strip (L_s) of the model is evaluated by the following equation:

$$L_s = \frac{L_f}{n_s} \tag{4}$$

where n_s is the number of strips at each loading direction of the numerical model developed. In the present work, the number of strips of both proposed upgrading solutions is three. The values of geometrical parameters of analysed panel devices are listed in Table 2.

Table 2 - *Variables and parameters of strip models for SPSWs-OBC types A and B*

Id	L [cm]	H [cm]	Lt [cm]	Θ [°]	n	Lf [cm]	Ls [cm]	t [mm]
A	350	250	380	27.7	3	219	73.0	2
A	350	250	380	27.7	3	219	73.0	1.2
B	175	250	380	18.5	3	91	30.3	2
B	175	250	380	18.5	3	91	30.3	1.2

In order to calibrate the bilinear constitutive law used in the characterization of the link *L1*, a non-linear incremental load analysis in compression for the braces under analysis has been performed. The intermediate crossing points of the analysed compression strut with the tension strips are laterally restrained. The numerical computational model of compression struts is developed with initial imperfection patterns close to the first buckling mode of the same strut with the described boundary conditions. The incremental compression analysis has been performed over a steel strip *S2* with a rectangular cross section of 0.002m x 0.730m. Figure 6 shows: a) the compression behaviour of the central strip *S2* for an initial imperfection *Lr*/500, where *Lr* is the strip length, and b) the tension-compression load vs. longitudinal displacement response diagram of the strip *S2* of the MSM03-BC strip model.

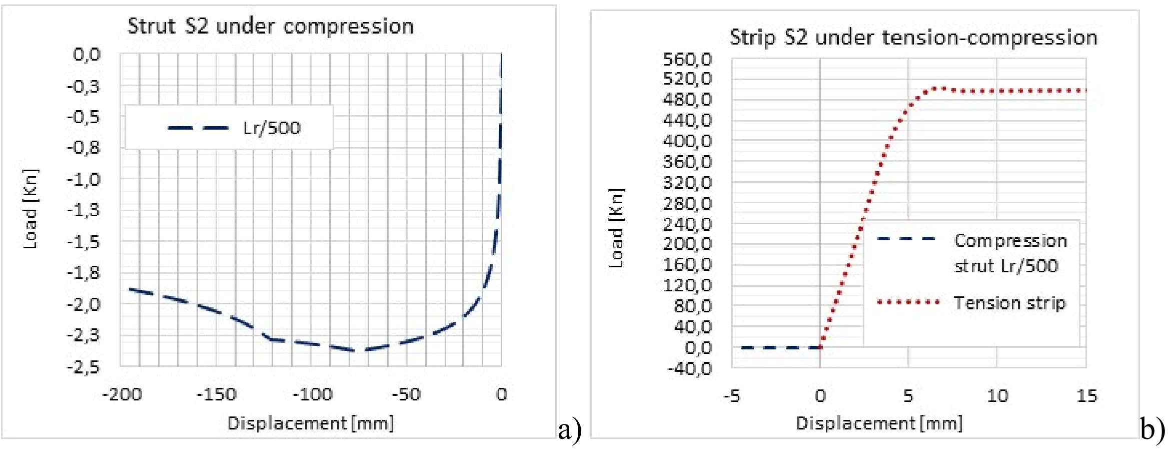


Figure 6 - *Compression (a) and tension-compression (b) response curves of the central strip S2 of the MSM03-BC strip model.*

4.2 Validation of the real structure numerical model

The vibration periods of the real RC structure and those of the implemented SeismoStruct numerical model have been herein compared for the validation of the used analysis technique. The natural periods of the real structure have been obtained by the available impact hammer dynamic test performed within the ILVA-IDEM research project [Mazzolani et.al, 2004, Formisano and Lombardi, 2016]. On the other hand, a SeismoStruct eigenvalues analysis with the structural damages detected in the existing structure has been carried out to obtain the corresponding vibration periods of the numerical model. The structural deterioration because of the age of the structure and the damage pattern noticed after a previous loading test on the same module retrofitted by means of shape memory alloys braces have been considered from an adequate reduction factor of the concrete elastic modulus. Figure 7 shows the comparison chart between the periods corresponding to the first three vibration modes of the real structure versus the numerical model ones. A very good match is observed among the values shown.

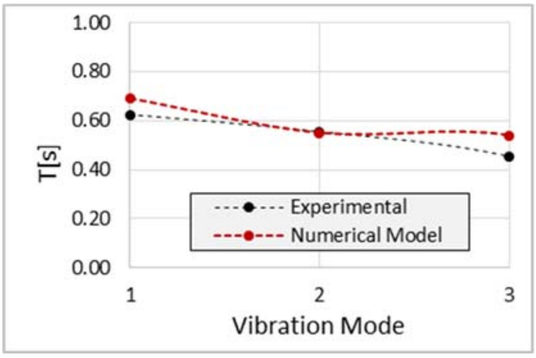


Figure 7 - *Experimental - numerical comparison in terms of free vibrations periods of the module n. 5*

Moreover, aiming at having a more complete validation of the proposed model, a pushover analysis test has been developed to compare the numerical response against the result of the previous full-scale test performed on the RC bare structure in the ILVA-IDEM research project. Figure 8 shows a comparison diagram illustrating the base shear vs. the first level lateral displacement between the experimental case and the numerical one obtained by the SeismoStruct numerical model. From this comparison it appears that the two curves are very close each to other, so to confirm the reliability of the setup numerical model.

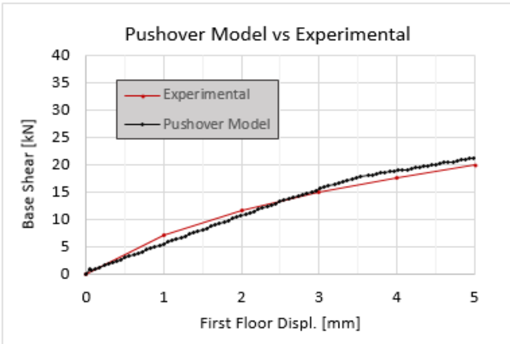


Figure 8 - *Comparison between the experimental pushover curve and the numerical one of the RC bare structure*

4.3 Validation of the MSM03-BC strip model

In order to have an adequate validation of the accuracy level of the developed MSM03-BC strip model, it has been used to replicate the response of a panel device experimentally tested into a previous research work.

In particular, an experimental laboratory test carried out by Guo et. al. [2011] on a 1100x1100mm specimen (named specimen S1) with thickness of 2.7 mm has been selected as the reference investigation.
Figure 9 shows the comparison in terms of load-displacement behaviour between the experimental skeleton curve and the non-linear numerical one achieved by using the developed MSM03-BC strip model.

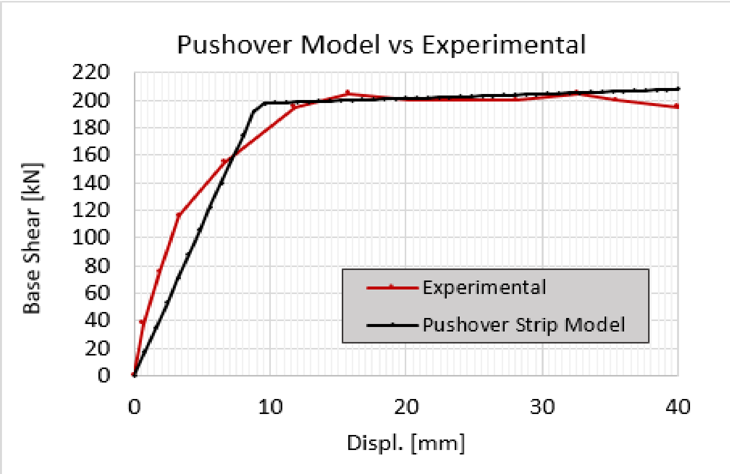


Figure 9 - *Experimental-numerical comparison in terms of pushover curves related to the Guo et al.'s test [2011]*

From this picture it is possible to appreciate the very good coincidence between the analysed curves, with the same strength attained and a numerical stiffness less than the experimental one. The difference between the initial branch of the experimental curve (displacement range between 0 and 4.5 mm) and that of the experimental curve is attributed to the simplified modelling of the constitutive law of tension strips and compression struts in order to obtain a simple and expeditious strip model with an accurate prediction of the ultimate load capacity. Therefore, the achieved comparison says that the numerical model setup is able to predict on the safe side the structural response of the examined seismic device.

5 Incremental load analyses on the upgraded RC structure

Aiming at evaluating the seismic performance of the upgraded RC structure, a series of numerical analyses on different panel systems having different thicknesses has been performed. Figure 10 shows a comparative diagram among pushover curves corresponding to the four upgrading solutions of Table 2 and the corresponding experimental curves of both the bare RC structure and the same structure retrofitted with steel panels investigated in the ILVA-IDEM research project [Formisano et.al, 2010].
In this picture, the maximum displacement considered corresponds to the inter-storey drift of 1.5%.

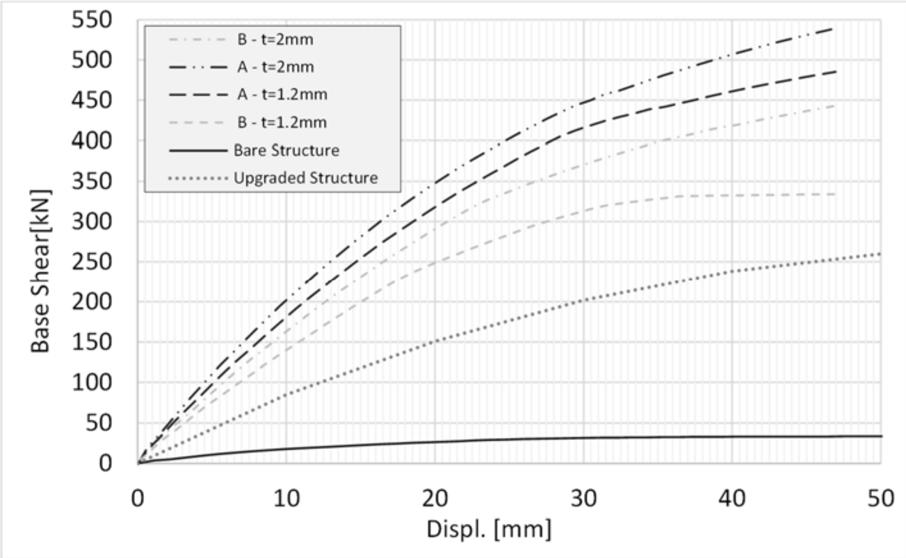


Figure 10 - *Comparison in terms of structural non-linear response among the four proposed upgrading solutions of SPSWs-OBC*

From the comparison it is apparent that the solution of steel plates connected to the beams only provides to the retrofitted RC structure strength and stiffness parameters greater than those of the real RC structure equipped with steel plates investigated in the ILVA-IDEM research project under the experimental point of view.

In the same way, Figures 11 and 12 show the comparative curves of the structural response of the four analysed retrofitted structures in terms of both bending moment and shear force values in the upper part of the left column with respect to the same internal actions detected in the equivalent column section of the bare RC structure. From this comparison it is observed: - a small increase of the bending moment in the column top end of the retrofitted structure, not dependent on the panel type and its thickness, against the large increase of the global load capacity with respect to that of the bare structure; - a reduction of the shear force in the column and, therefore, a decrease of a possible brittle failure.

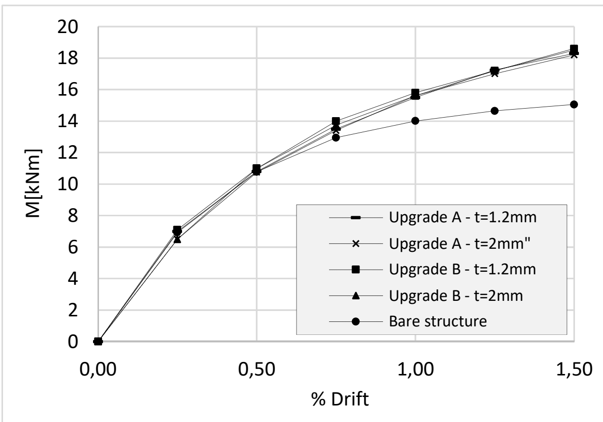


Figure 11 - *Bending moments in the left column upper section under incremental load analysis: comparison between the original RC structure and the retrofitted ones*

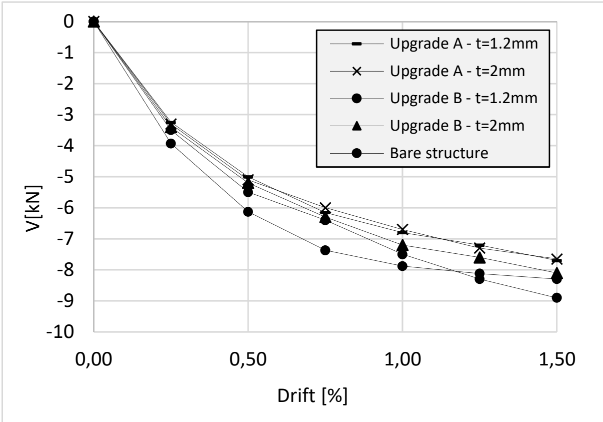


Figure 12 - S*hear forces in the left column upper section under incremental load analysis: comparison between the original RC structure and the retrofitted ones*

6 Conclusions

A numerical non-linear investigation on the behaviour of an existing RC framed structure upgraded with four solutions of SPSWs-OBC has been herein presented. A simplified MSM03-BC strip model has been developed to schematise steel thin web infill plates in the numerical analysis. The analyses performed with the SeismoStruct software on the upgraded RC structure have confirmed the effectiveness of all the upgrading solutions, since all they provide to the bare building significant increases of ultimate load capacity, initial stiffness and ductility, which are very similar each to other. In addition, the important increase of aforementioned factors is accompanied only by small variations (<11%) of both bending moments and shear forces in the column of retrofitted structures.
It is interesting to note that in the cases of SPSWs-OBC that have thin infill web plates with very small thickness, compressive forces on the plate have less influence than those detected in conventional SPSWs.
On the basis of both promising results and above considerations, it is stated that SPSWs-OBC are effective strengthening and stiffening devices of seismically vulnerable RC framed structures. However, in the present work only incremental static non-linear analyses were performed to simply evaluate the improved load capacity of RC structures equipped with SPSWs-OBC devices. Aiming at obtaining a more accurate prediction of the seismic behaviour of examined panels, nonlinear time-history analyses should be performed by modelling the hysteretic response of tension strips and compressions struts. A deeper research on this issue, with the purpose to know the hysteretic behaviour of investigated devices, will be a further study development to upgrade the simplified model herein presented. In addition, additional researches to know the influence of several factors, such as the connection type between plates and HBEs and its impact over both the global response of the structure and the local distribution of bending moments and shear forces in the frame members, on the seismic non-linear response of SPSWs-OBC are needed.

7 Acknowledgements

The first Author would like to acknowledge both the Department of Structures for the Engineering and Architecture of the University of Naples Federico II, for the hospitality received during the period as visiting researcher, and the International Relationship Secretariat of National University of Cuyo (Mendoza, Argentina) for the financial support to the present research.

References

Alinia, M.M., Dastfan, M. (2005). Behaviour of thin steel plate shear walls regarding frame members. Journal of Constructional Steel Research, 62: 730-738.

Alinia, M.M., Dastfan, M. (2007). Cyclic behaviour deformability and rigidity of stiffened steel shear panels. Journal of Constructional Steel Research, 63: 554-563.

ANSI/AISC 341/10, (2010). Seismic Provisions for Structural Steel Buildings, Chicago, USA.

Berman, J.W. (2011). Seismic behavior of code designed steel plate shear walls. Engineering Structures, 33: 230-244.

Caccese, V., Elgaaly, M., Chen, R. (1993). Experimental study of thin steel plate shear walls under cyclic loads. Journal of Structural Engineering. Vol. 119, Nro.2.

Canadian Standard CSA-S16-01, (2001). Design of steel structures. Canadian Standards Association.

Clayton, P.M., Berman, J.W., Lowes, L.N. (2015). Seismic performance of self-centering steel plate shear walls with beam-only-connected web plates. Journal of Constructional Steel Research 106: 198-208.

De Matteis, G., Formisano, A., Mazzolani, F.M. (2009). An innovative methodology for seismic retrofitting of existing RC buildings by metal shear panels. Earthquake Engineering and Structural Dynamics, 38: 61-78.

De Matteis, G., Brando, G. (2016). Metal shear panels for seismic protection of buildings: Recent findings and perspectives. Ingegneria Sismica, 33 (3), pp. 5-27.

Formisano, A., De Matteis, G., Mazzolani, F.M. (2010). Numerical and experimental behaviour of a full-scale RC structure upgraded with steel and aluminium shear panels. Computers and Structures 88: 1348–1360.

Formisano, A., De Matteis, G., Panico, S., Calderoni, B., Mazzolani, F.M. (2006). Full-scale test on existing RC frame reinforced with slender shear steel plates, Proc. of the 5th International Conference on Behaviour of Steel Structures in Seismic Areas (STESSA 2006), pp. 827-834.

Formisano, A., De Matteis, G., Panico, S., Mazzolani, F.M. (2008). Seismic upgrading of existing RC buildings by slender steel shear panels: A full-scale experimental investigation. Advanced Steel Construction, 4 (1), pp. 26-45.

Formisano, A., Lombardi, L. (2016). Numerical prediction of the non-linear behaviour of perforated metal shear panels. Cogent Engineering, 3: 1156279, pp. 1-16, available at: https://www.cogentoa.com/article/10.1080/23311916.2016.1156279.pdf.

Formisano, A., Lombardi, L., Mazzolani, F.M. (2016a). Full and perforated metal plate shear walls as bracing systems for seismic upgrading of existing RC buildings. Ingegneria Sismica, 33 (1-2), pp. 16-34.

Formisano, A., Lombardi, L., Mazzolani, F.M. (2016b). Perforated metal shear panels as bracing devices of seismic-resistant structures. Journal of Constructional Steel Research, 126, pp. 37-49.

Formisano, A., Mazzolani, F.M. (2015). On the selection by MCDM methods of the optimal system for seismic retrofitting and vertical addition of existing buildings. Computers and Structures, 159, pp. 1-13.

Formisano, A., Mazzolani, F.M., De Matteis, G. (2007). Numerical analysis of slender steel shear panels for assessing design formulas. International Journal of Structural Stability and Dynamics, 7 (2), pp. 273-294.

Guo, L., Rong, Q., Ma, X., Zhang, S. (2011). Behavior of steel plate shear wall connected to frame beams only. International Journal of Steel Structures, 11 (4): 467-479.

Guo, L., Jia, M., Li, R., Zhang, S. (2013). Hysteretic analysis of thin steel plate shear walls. International Journal of Steel Structures, 13 (1): 163-174.

Jalali, S.A., Banazadeh, M. (2016). Development of a new deteriorating hysteresis model for seismic collapse assessment of thin steel plate shear walls. Thin-Walled Structures, 106: 244-257.

Lubell, A.S., Prion, H.G.L., Ventura, C.E., Rezai, M. (2000). Unstiffened steel plate shear wall performance under cyclic loading. Journal of Structural Engineering, 126:453-460.

Mazzolani, F.M., Della Corte, G., Faggiano, B. (2004). Seismic upgrading of RC buildings by means of advanced techniques: The ILVA-IDEM Project, Proc. of the 13th World Conference of Earthquake Engineering, paper 2703. Vancouver, Canada.

Ozcelik, Y., Clayton, P.M. (2017). Streep model for steel plate shear walls with beam-connected web plate. Engineering Structures 136: 369-379.

Purba, R., Bruneau, M. (2014). Seismic performance of steel plate shear walls considering various design approaches. Proc. of the 10th National Conference in Earthquake Engineering, Earthquake Engineering Research Institute, Anchorage, AK, 136, 369-379.

Sabouri-Ghomi, S., Roberts, T.M. (1992). Nonlinear dynamic analysis of steel plate shear walls including shear and bending deformations. Engineering Structures, 14 (5): 309-317.

Seismosoft, SeismoStruct, (2016). A computer program for static and dynamic nonlinear analysis of framed structures, available from http://www.seismosoft.com.

Shishkin, J., Driver, R., Grondin, G. (2005). Analysis of steel plate shear walls using the modified strip model. Structural Engineering Report N. 261, Dept. of Civil Eng., University of Alberta, Canada.

Thorburn, L.J., Kulak, G.L., Montgomery, C.J. (1983). Analysis of steel plate shear walls. Structural Engineering Rep. N. 107, Department of Civil Engineering, University of Alberta, Canada.

Timler, P.A., Kulak, G.L. (1983). Experimental study of steel plate shear walls. Structural Engineering Report N. 114, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada.

Tromposch, E.W., Kulak, G.L. (1987). Cyclic and static behaviour of thin panel steel plate shear walls. Structural Engineering Report N. 145. Department of Civil Engineering. University of Alberta. Edmonton, Alberta, Canada.

ingegneria sismica
International Journal of Earthquake Engineering
Anno XXXV – Num. 2

ADEGUAMENTO SISMICO DI STRUTTURE IN C.A. CON PARETI A TAGLIO DI ACCIAIO COLLEGATE SOLO ALLE TRAVI

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SOMMARIO: *Le pareti a taglio in acciaio collegate solo alle travi del telaio perimetrale rappresentano efficaci sistemi strutturali adatti a resistere alle azioni laterali. Questi sistemi consentono ai progettisti di evitare le elevate richieste flessionali sulle colonne imposte dalle pareti a taglio convenzionali collegate sia alle travi che alle colonne. Essi possono essere applicati con successo per l'adeguamento sismico delle strutture in c.a. allo scopo di fornire loro più elevati livelli di resistenza, duttilità e capacità di dissipazione energetica. La memoria presenta la valutazione numerica della risposta sismica di una struttura esistente in c.a. adeguata con pareti a taglio in acciaio collegate solo alle travi del telaio perimetrale. La struttura, progettata per soli carichi verticali, è stata realizzata nel quartiere di Bagnoli in Napoli. L'approccio numerico impiegato si basa sul modello semplificato a strisce con link a plasticità concentrata. I risultati ottenuti si focalizzano sugli aspetti fondamentali delle prestazioni sismiche della struttura adeguata e vengono confrontati con una soluzione di adeguamento sismico in precedenza applicata allo stesso caso studio.*

PAROLE CHIAVE: *Adeguamento sismico, pareti a taglio di acciaio, strutture in cemento armato, risposta sismica non lineare, pannelli collegati solo alle travi.*

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