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(STEEL-EARTH)

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Steel-based applications in earthquake-prone areas

(STEEL-EARTH)

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Final Summary

STEEL-EARTH (*Steel-based applications in earthquake prone areas*, RFS2-CT-2014-00022) dissemination project is based on the results obtained inside three finished and approved RFCS projects:

- PrecaSteel (RFSR-CT-2007-00038, 2007-2010): *Prefabricated steel structures for low-rise buildings in seismic areas.*
- SteelRetro (RFSR-CT-2007-00050, 2007-2010): *Steel solutions for seismic retrofit and upgrade of existing constructions.*
- Opus (RFSR-CT-2007-00039, 2007-2010): *Optimizing the seismic performance of steel and steel-concrete structures by Standardizing material quality control.*

In the framework of *PrecaSteel* project, a deep investigation about the industrial and commercial buildings diffused in Europe, including technical and economic aspects, was executed. The project aimed to define pre-designed steel solutions for the realization of single-storey industrial and low-rise commercial buildings in earthquake-prone areas. Specific practical tools were developed for the preliminary design and cost estimation of considered buildings; the cost model adopted for the analyses was based on specific investigations executed at European level including construction, transportation and assembly economic efforts.

SteelRetro research project aimed to design innovative steel-based solutions for the rehabilitation of existing r.c. and masonry buildings, reducing seismic vulnerabilities and satisfying the actual safety requirements. The selection of the optimal retrofit technique shall account for feasibility and economic aspects, limiting the post-earthquake intervention costs and providing, if possible, the increase of the degree of standardization. The Performance Based Seismic Design (PBSD) approach was suitably modified for the application to existing buildings.

Opus research project aimed to analyze the influence of the variability of materials' mechanical properties on the ductile behaviour of steel and steel/concrete composite structures. Basing on the results of statistical investigations and numerical analyses, recommendations for the design of different structural typologies were developed. The effectiveness of introducing an upper limitation on yielding strength R_e as additional check for the seismic qualification of EN10025, the influence of the overstrength material factor γ_{ov} (EN 1998-1:2005) and the efficiency of the capacity design procedure for the design of new buildings were investigated.

The dissemination project *Steel-Earth* aims to spread the results obtained inside *SteelRetro*, *PrecaSteel* and *Opus* among engineers, technicians, construction companies, standardization bodies and institutes through the elaboration of technical sheets (TS), practical applications (WE), background documents and design guidelines to be proposed to national and international committees as well as to the commissions for the improvement of actual Eurocodes.

One of the main topics of the project concerns the design of steel and steel/concrete commercial and industrial buildings: simple procedures, able to optimize the structural dissipative behaviour of buildings designed for earthquake prone areas as well as the economic effort for their realization, have been elaborated. The procedures developed inside *PrecaSteel* for the design of commercial and industrial buildings have been applied to selected representative case study buildings, allowing the elaboration of a codified methodology usable by technicians and engineers. Technical sheets (TS) and corresponding working examples (WE) concerning the seismic design of buildings with different structural typology, functional destination, elements' section (Hot-Rolled profiles – HR, Light Gauges Steel profiles – LGS and Welded Tapered profiles – WT) and bracing systems (traditional braces, r.c. precast shear walls, passive protection devices) have been developed and detailed with executive drawings in Work Package 1.

Practical indications regarding the application of steel-based rehabilitation techniques to existing buildings, including both r.c. and masonry constructions, have been developed in Work Package 1. Basing on the solutions developed inside *SteelRetro* and following the modified PBSD procedure, technical sheets (TS) and practical examples (WE) have been elaborated analysing the application of several different techniques (traditional bracing systems, dissipative self-centering devices, steel shear walls, Buckling Restrained Braces, etc.), evaluating the feasibility and the economic impact of proposed rehabilitation operations.

All the TS have been collected in the deliverable D.1.1, while the WE are grouped in deliverable D.1.2 (in English language). The results obtained in WP1 concerning the design and the rehabilitation of buildings have been used to elaborate background documents and general guidelines, mainly devoted to industrial and commercial constructions, according to what foreseen in Work Package 2 (WP2).

The results coming from *Opus*, about the influence of material mechanical properties on the ductile behaviour of different structural typologies and the problems due to the differences among design and production standards, have been elaborated in WP2 and collected in a useful pre-normative document (deliverable D.1.2). In particular, three main design aspects have been further investigated inside *Steel-Earth*. The first one concerns the possibility to adopt "real" values of the material overstrength factor γ_{ov} (i.e. values coming from the statistical investigations executed in *Opus*) in the design of structural elements following Eurocode 8; the influence of γ_{ov} in the design of details and connections, especially for what concerns beam to column connections and foundation joints, has been also taken into consideration (second topic). The third aspect investigated is related to the effect of the variability of mechanical properties on the global behaviour of buildings designed considering nominal properties, analysing the efficiency of the capacity design approach in the protection of non-dissipative members.

The results of the above mentioned elaborations (including TS, WE, background and pre-normative documents) have been translated several languages, including French, German, Italian, Greek and Romanian (these last two ones only for TS and WE), according to what foreseen in Work Package 3 (WP3).

In order to better disseminate the activities developed inside *Steel-Earth* and to distribute the knowledge and obtained results among engineers, technicians, academic people etc., a website of the project (https://www.steelconstruct.com/site/) has been organized and translated into several languages, according to what foreseen in Work Package 3 (WP3). A Facebook and a LinkedIn profiles have been created to be adopted as mean of communication able to attract young engineers, students, etc.

According to WP5, 11 workshops, 5 conferences and 2 training courses have been organized. Workshops have been held in Tampere (Finland), Volos (Greece), Timisoara (Romania), Ljubljana (Slovenia), Hasselt (Belgium), Aachen (Germany), L'Aquila (Italy), Coimbra (Portugal), Cluj-Napoca (Romania) and Madrid (Spain); the 5 conferences have been held in Emilia – Romagna (in Parma, Bologna, Ferrara, Modena and Mantova, Italy) and the two training courses for engineers at EUCENTRE (Pavia, Italy). The events have been published through the website, Facebook, LinkedIn and through the distribution of brochures opportunely prepared in different languages.

During the events, booklets, CDs/DVDs and pen drives containing the technical sheets, working examples, background documents and presentations executed have been provided to the attending people.

Objectives of the project

The Steel-Earth dissemination project aims at distributing among technicians, engineers, design companies and standardization bodies the results achieved into three past research projects dealing with the design of new steel and composite buildings and the retrofit of existing r.c. and masonry constructions using new developed methodologies and enhanced steel-based systems.

In ***Work Package 1*** technical documents related to both design and rehabilitation have been prepared on the base of previous results of *PrecaSteel* [1] (i.e. design) and *SteelRetro* [3] (i.e. retrofit) projects; for each of the presented design approaches as well as for each of the steel-based retrofit systems specific practical applications (i.e. Working Example – WE) have been developed. All the documents of WP1, summarized in deliverables D.1.1 and D.1.2, have been collected in the final proceedings of Steel-Earth final workshop and distributed to the attending people, providing full dissemination of the obtained results.

In ***Work Package 2***, on the base of the design and retrofit indications adopted for new and existing buildings coming from the practical applications of WP1, background documents have been prepared (deliverables D.2.2 and D.2.3). The analysis of the efficiency of the actual overstrength coefficient factors (γ_{ov} and Ω) in the design of ductile buildings in seismic areas, based on the results obtained in *Opus* [2] with further investigations executed inside *Steel-Earth*, has been translated into a pre-normative document (deliverable D.2.1), also concerning problems due to the actual differences among design and production standards.

In ***Work Package 3*** translations of technical sheets (TS), working examples, background and pre-normative documents coming from WP1 and WP2 into several languages (including French, German, Italian, Greek and Romanian) have been executed (deliverables D.3.1 and D.3.4). Translations allow the spread of obtained results and indications among European technicians, engineers and design companies. All the documents are available at the website opportunely organized inside the project (https://www.steelconstruct.com/site/), providing information regarding the partnership, dissemination activities, objectives and results.

The dynamic web-pages elaborated in the framework of *PrecaSteel* [1] research project have been made available at the link http://riv-precasteel.rivagroup.com/ constituting a relevant tool for the design of steel and composite solutions for industrial and commercial buildings (***Work Package 4***).

Dissemination activities were organized inside ***Work Package 5***, including workshops all around Europe, conferences and training courses for engineers, designers, technicians and academic people. During dissemination activities, the technical documents, the practical applications and the guidelines concerning both design and rehabilitation of buildings were provided to the attending people though the distribution of USB flash drives, brochures and printed proceedings. Such documents were also distributed during the final workshop of the dissemination project, held in Napoli in April 2016, in occasion of the meeting of CEN/TC 250/SC 8/WG 2 *"Steel and Composite Structures"*, whose members took part to the final conference and discussion of obtained results.

Description of the activities developed inside STEEL-EARTH project

1. WP1: arrangement of technical sheets and working examples

1.1 Design of steel and steel-concrete buildings

In WP1 technical documents (TS) regarding design approaches for industrial and commercial buildings in seismic area were elaborated; the corresponding practical applications (WE) provided a codified methodology to be followed for the different proposed structural solutions.

Prefabricated steel and steel/concrete composite buildings for industrial and commercial activities, characterized by different plan and elevation configurations, different number of storeys, different adopted elements' typology and different seismicity levels were considered and deeply analyzed. The feasibility of the different proposed solutions was also considered, analysing the possibility to realize connections, executive details and, if possible, evaluating the production costs.

The work was based on the results of *PrecaSteel* project [1]: the structural solutions defined during the research, further improved by the practical applications developed inside *Steel-Earth*, were conceived in order to represent an effective alternative to r.c. solutions, coupling structural efficiency and costs' control of the construction.

The produced documentation, globally collected into deliverables D.1.1 (for TS) and D.1.2 (for WE) and, moreover, in the proceedings of the final workshop of the project, constitutes a useful tool for engineers involved in the design of selected structural typologies, providing indications for design optimization and executive details for applications.

The TS and corresponding WE show the design procedures defined and applied to three different solutions for *steel* industrial buildings, mainly varying from one another for the adopted sections' profiles, and to three *composite* solutions for commercial buildings, differing for the typology of adopted bracing system.

The list of considered structures is presented below:

- Steel industrial building with hot-rolled profiles (HR).
- Steel industrial building with light gauge profiles (LGS).
- Steel industrial building with welded-tapered sections (WT).
- Steel-concrete commercial building with steel braces.
- Steel-concrete commercial building with prefabricated r.c. walls.
- Steel-concrete commercial building with enhanced passive dissipative system.

1.1.1 Steel industrial building with HR profiles

HR profiles (IPE, IPN, HE and L) are usually adopted as primary elements for steel industrial buildings designed in seismic areas; several structural configurations with different number of bays and span length, different height, different materials, bolts, typology of non-structural elements, etc. can be used, resulting in a large variety of possible combinations.

Basing on the results of *PrecaSteel* project [1] and reducing the number of combinations between the various parameters due to practical considerations, a design methodology for the design of industrial buildings with HR sections is proposed in *Steel-Earth*, also including economic aspects. The design process can be summarized in the following steps:

[1] *Definition of the structural geometry:* single or double span frames with different length (16.0÷32.0 m), repeated in the out-of-plane direction with constant distance, columns' height between 6.0 m and 8.0 m, roofing slope equal to 15%, etc. can be considered.

[2] *Definition of the structural typology:* a combined MRF (in-plane direction) and CBF (out-of-plane direction) has been selected as convenient configuration. The bracing system is generally placed at the middle of the structure.

[3] *Selection of elements sections:* HR sections for the main structural elements (HEA for columns and IPE for beams) and truss girders instead of simple beams in case of large span have been used. CHS profiles for the bracing system of the structure, IPE and UPN for all the purlins supporting the roof and side cladding, truss girder and/or simple beams in relation to length for the horizontal elements of the MRF can be adopted.

[4] *Material choice:* S275 (preferred); higher steel grades can be adopted.

[5] *Modelling and analysis:* linear elastic analysis of the building (static and/or dynamic) following Eurocode rules (EN1993-1-1:2005 [4], EN1998-1:2005 [4]) and considering ULS and SLS requirements can be used. A behaviour factor q equal to 1.50 is suggested. Additional checks through more refined nonlinear analyses can be executed.

[6] *Selection of non-structural elements:* the typology of claddings and infill panels shall be selected in relation to use requirements.

[7] *Design of structural elements and connections:* structural members (beams, columns, braces and purlins) and connections shall be designed according to actual standards (EN1993-1-1:2005 [4], EN1998-1:2005 [4]). Analysis of the performance of the purlin bracing system (as recommended by prEN1993-1-1) to prevent the main beams against lateral-torsional buckling shall be executed.

[8] *Costs' Estimation:* construction cost estimation, based on the total weight of steel derived by the design solution, has been executed. The cost of workmanship, as well as the cost of transportation, have been also estimated.

The above described design methodology has been directly applied to the industrial one bay steel building case study represented in Figure 1. The design actions coming from linear analyses are presented, as an example, in Figure 2.

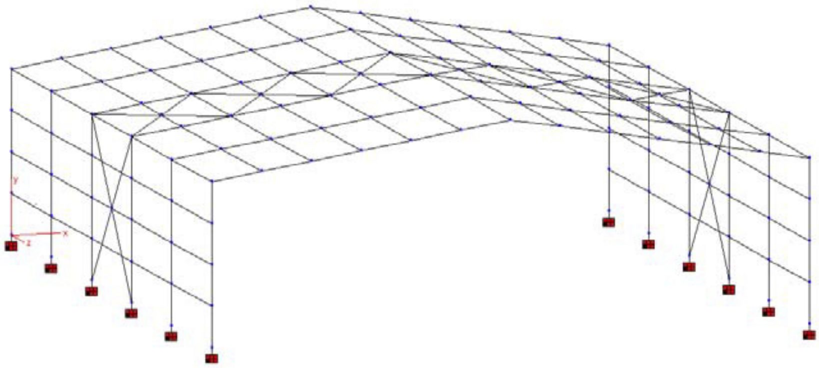


Figure 1: Single bay steel industrial building (3-D view) designed adopting HR sections.

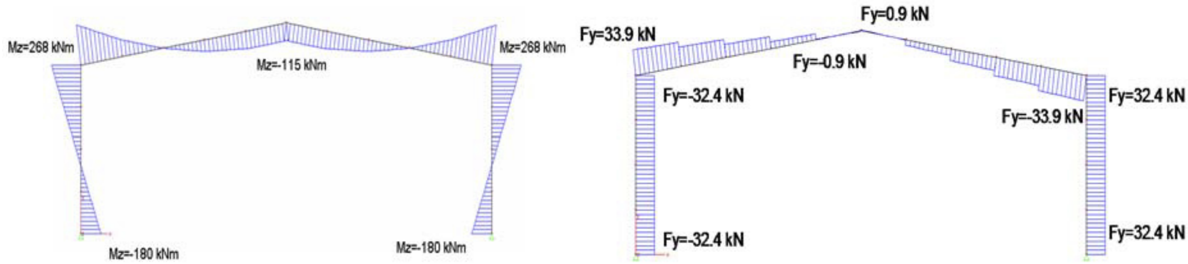


Figure 2: Bending and shear forces on the typical MRF frame coming from analysis.

The TS and the corresponding WE evidenced, beside the efficacy of the traditional approach for the design of an industrial building in high seismicity region, the need of providing the purlins with bracing systems to improve the performance of the main beams against lateral-torsional buckling.

In the case of the typical beam presented in Figure 3, two different layouts have been considered and analyzed concerning the type of connection between purlin and main beam (i.e. purlin continuous over the main beam and purlin consisting of two parts pinned on the main beam). Two different support conditions have been moreover examined and compared for the main beam: in the first case, the main beam has been assumed "simply supported" (condition typical of buildings with vertical braces resisting the horizontal actions and beams bearing only the vertical loads); in the second case, the beam acts as part of the main frame (i.e. the left end is fixed, the right one is free in the vertical direction, all the rotations are restrained).

The execution of more refined nonlinear static analyses (Figure 4), as presented in the WE, allowed to evaluate the influence of the purlin-to-beam connection on the buckling behaviour of the beam as well as the influence of the role of imperfections in the modelling procedure and in the following expected results. More details and the whole application of the procedure presented can be found in the TS and corresponding WE in deliverables D.1.1 and D.1.2.

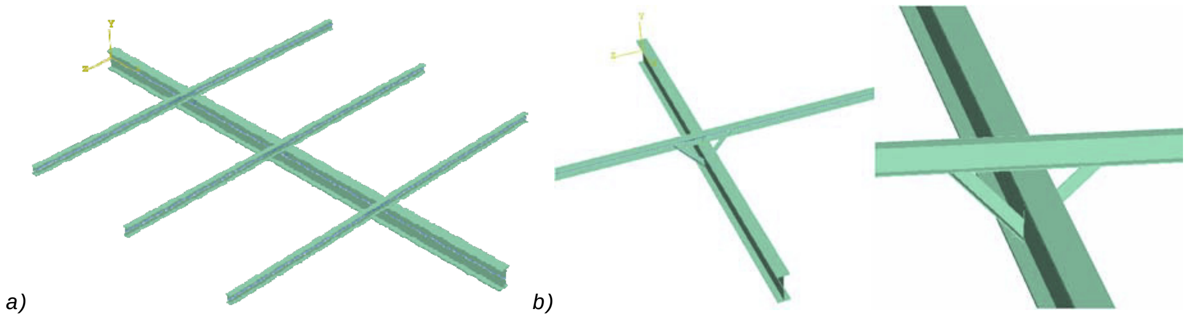
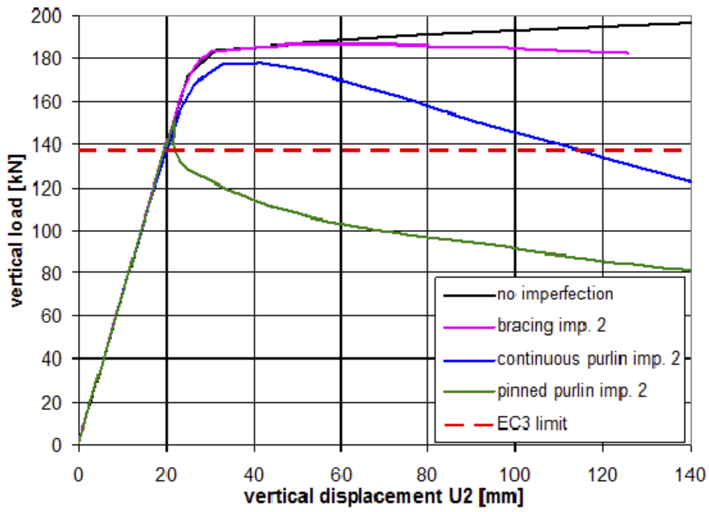
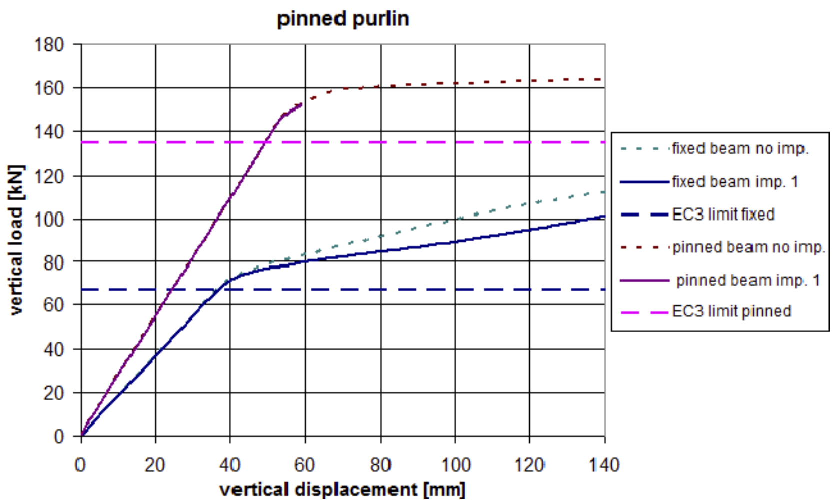


Figure 3: The geometry of the problem examined.



a)



b)

Figure 4: a) Force - vertical displacement curve for different configurations; b) Force - vertical displacement curve comparing the behaviour of main beam with different purlin-to-beam connections,

1.1.2 Steel industrial building with LGS profiles

Light-Gauge Steel (LGS) profiles are commonly used as secondary structural elements for buildings, including industrial applications (e.g. purlins, side-rails, sheeting); more recently, LGS profiles have been introduced for the design of primary structural elements (Figure 5) partially replacing HR sections, also in the case of high span length (using LGS truss systems).

Since pinned connections are generally adopted, the most conditioning design aspect is the fulfilment of SLS limitations, even in the case of portals with truss-beams with higher stiffness. The role of the roof and of wall sheeting is, therefore, fundamental to contribute to the global stiffness of the building.

The main advantage of the adoption of such systems consists in the easy manufacturing of LGS elements, despite the higher costs of the production process respect to traditional solutions.

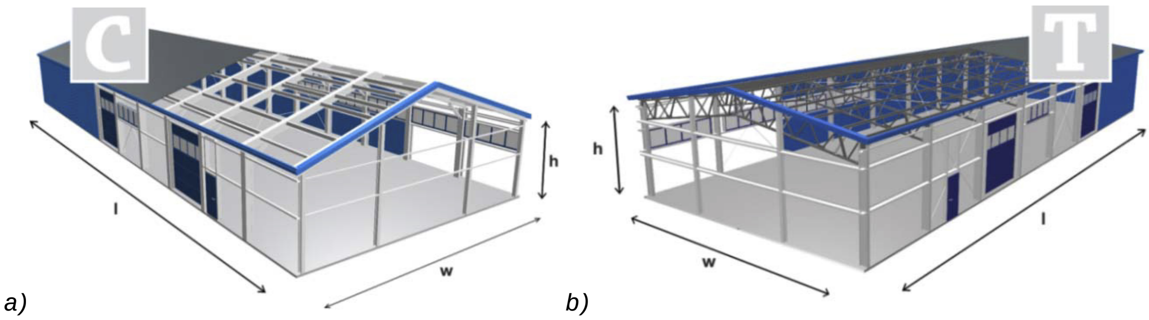


Figure 5: Overall view of industrial buildings made of LGS profiles by a) frame system and b) truss.

In the TS and in the corresponding WE an example of design of an industrial steel building with LGS profiles is presented, including both technical and economic aspects. The design process can be summarized in the following steps:

[1] *Determination of the main geometry of the building:* plan and elevation geometry, number of span, span length, height of the building.

[2] *Determination of design action and load combination*: evaluated according to Eurocode 1 [6] and Eurocode 8 [5].

[3] *Selection of elements section*: LGS profiles are selected for primary elements. Since effective LGS section calculation is not normally included in software and the adoption of the cross-section geometry leads to a global over-estimation of members' stiffness, LGS sections can be "manually" introduced for pre-calculated section properties.

[4] *Selection and design of secondary elements - claddings*: roof cladding shall be designed considering fundamental load combination, wall claddings have to face wind loads acting perpendicularly to their plane. Tables are used to estimate the ULS and SLS loads for the adopted cladding configuration; pull-out of connections shall be checked.

[5] *Selection and design of purlins and side rails:* profiles with galvanized cold-formed Z, C, Σ and Ω sections of Class 4 have been adopted according to EN 1993-1-3 [12], designed using tables provided by manufacturers.

[6] *Design of the bracing system:* since the introduction of braces considerably increases the complexity of the design, especially for what concerns connections, if possible, the use of diaphragm effect of the roof is strongly advisable.

[7] *Modelling and analysis*: preliminary linear analyses shall be executed on 3D FE models of the building, adopting a suggested behaviour factor equal to 1,50. The stiffness contribution of claddings shall be directly introduced in the modelling. Local buckling, distortion due to the stress concentration at the frames connections and imperfections are possible to predict, while plate buckling of the LGS members cannot be included in the model. Nonlinear analyses can be also carried out to confirm or, otherwise, to modify the preliminary design.

[8] *Design of connections and details:* foundation joints and gable frames are pinned: in-plane stability is provided by diaphragm effect of the wall sheeting. The global response of the building is ensured by exploiting roof and wall diaphragm effect.

Figure 6: Example of details and connections.

The proposed methodology and its application to a case study building can be found in TS and WE and in the corresponding deliverables D.1.1 and D.1.2.

1.1.3 Steel industrial building with WT sections

Welded-Tapered (WT) profiles for single and multi-span industrial buildings are currently used with the aim to optimize sections towards acting loads. WT members may be tailored for a specific application or pre-designed in producer catalogues (Figure 7).

Since sections are optimized, WT frames result in less material consumption if compared to similar frames with HR profiles; however, manufacturing is more challenging, especially due to the tendency of distortion of the long welded members. Moreover, due to the higher slenderness of WT frame members compared to HR ones, transport and lifting may also present additional problems: these aspects make the feasibility of WT frames a “balance” between material costs and labour.

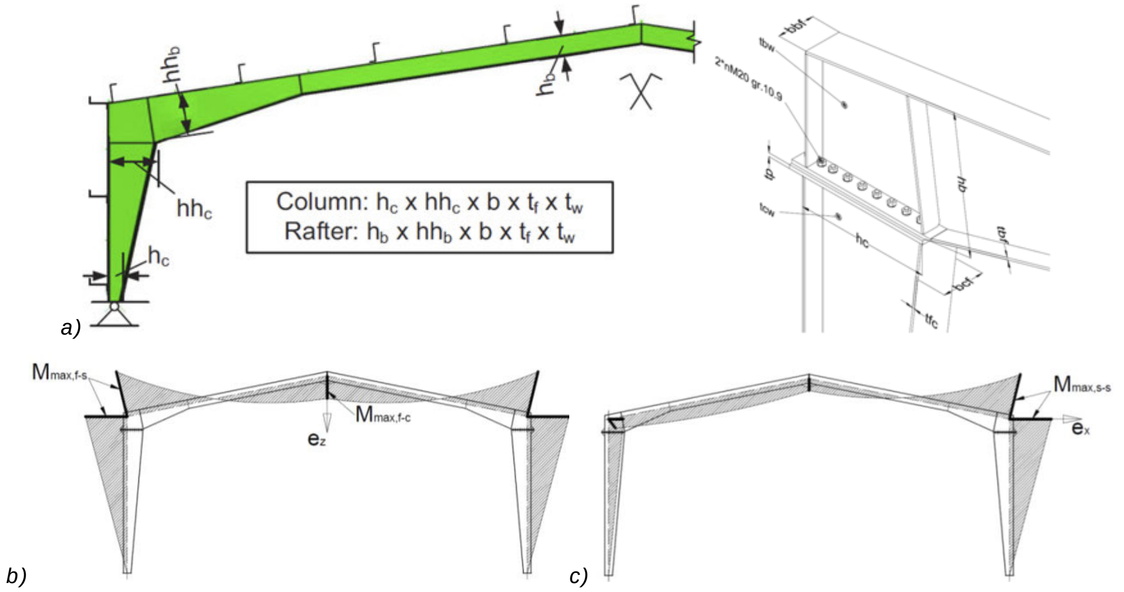


Figure 7: a) Welded-tapered frame configuration with height variation of both column and beam section bending moment diagram from vertical (b) and horizontal (c) loads.

Secondary elements of the structure are usually based on cold-formed purlins and side railing; claddings are mostly corrugated sheets, sandwich panels or cassettes. The introduction of bracing system is generally required only in the longitudinal direction, since frames themselves have enough strength and stiffness.

Supports of WT frames are usually pinned to minimize foundation sizes; fixed supports can be considered if the design is governed by limiting lateral deflection or buckling lengths of columns.

Depending on the climatic conditions, especially snow load, the primary objective of the design is to resist vertical action; in the case of high span length or very high frames the deflection and sway criteria may become dominant in the design. Seismic action shall be considered if needed and a low dissipative design concept (low q factor) can be used without increasing costs. The use of diaphragm action of the roof sheeting to homogenize the seismic response can eliminate the need of roof bracing.

In the TS and in the corresponding WE an example of design of an industrial steel building with WT profiles is presented, including both technical and economic aspects. In particular, the following aspects have been accurately taken into account.

[1] *Determination of the main geometry of the building:* plan and elevation geometry, number of span, span length, height of the building. Typical configurations has span length between 12 and 30 m and height between 6.0 and 8.0 m

[2] *Determination of design action and load combination*: evaluated according to Eurocode 1 [8] and Eurocode 8 [5].

[3] *Material choice*: the usual grades adopted are S235, S275, S355 and S450.

[4] *Selection of elements section*: primary elements with variable cross-section for structural design optimization.

[5] *Selection and design of secondary elements – claddings:* design of roof claddings executed considering fundamental load combination, wall claddings designed to face wind loads acting perpendicularly to the plane of the cladding. Tables are generally used to estimate the ULS and SLS loads for the adopted cladding configuration; pull-out of cladding connectors shall be checked.

[6] *Selection and design of secondary elements – purlins and side rails:* cold formed profiles with galvanized Z, C, Σ and Ω sections of Class 4 can be adopted according to EN 1993-1-3

[12]. The design of such elements is traditionally executed using design tables provided by manufacturers.

[7] *Modelling and analysis*: preliminary linear analyses shall be executed on 3D FE models of the building. Both in-plane and out-of-plane imperfections included in the FE model, as well as the stiffness contribution of claddings. Further investigations with nonlinear analyses can be executed with eventual following modifications to the initial design.

[8] *Design of elements, connections and details*: structural elements and connections shall satisfy the requirements of actual standards. The component method of Eurocode 3 shall be adopted for connections. The most common base fixing for a WT frame is nominally pinned; in order to limit the effect of strong outward push, the foundations of WT frames can be also tied. The eaves connection, generally fixed, shall be able to resist high bending moments (Figure 8). Purlins and side rails are typically connected to the main frame using short studs or cleats resulting in a pinned connection.

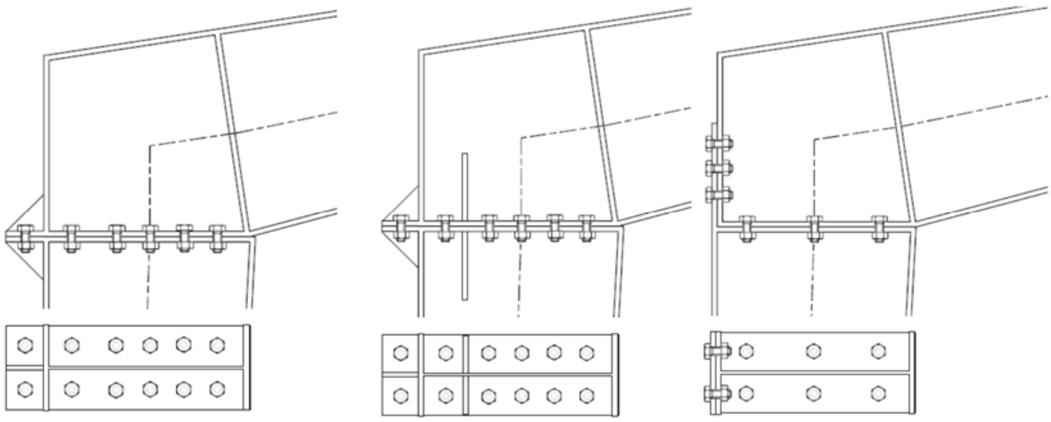


Figure 8: Connection typologies proposed in the PRECASTEEL [1] project for WT frames.

The proposed methodology and its application to a case study building can be found in TS and WE and in the corresponding deliverables D.1.1 and D.1.2.

1.1.4 Steel-concrete commercial buildings with different bracing systems

The design of structures for low-rise commercial buildings shall take into consideration functional, efficiency, safety, transportation aspects as well as the possibility to adopt prefabricated components.

The use of tables or tools for the quick pre-design of elements is possible only for regular and repetitive structural layouts: the adoption of usual dimensions and space organization is however often replaced by complex situations improving the aesthetical and functional values of the building.

In the cases analyzed in *Steel-Earth* project, the considered structure is regular and obtained by coupling a “gravity structure” with “lateral resisting elements”: the gravity structure shall withstand vertical actions whereas the lateral resisting elements have to resist horizontal forces (wind and earthquakes) and stabilize the whole system against geometrical effects due to vertical loads. The behaviour of the building is subordinated to the existence of in-plane stiff diaphragms connecting the gravity structure to the lateral resisting elements.

The *gravity structure* is constituted by beams hinged to continuous columns while the *seismic resistant structure* may be constituted by steel concentric or eccentric braces or by shear reinforced concrete walls (Figure 9). MRF have been not considered since characterised by high lateral deformability and high cost of beam-to-column connections. Flooring systems and columns have been designed to withstand gravity actions whereas the braces have been designed to resist the assigned base shear forces.

Composite beams have been adopted to directly include in the design the contribution of flooring systems. Different solutions have been evaluated, including composite elements HR profiles, cold formed beams (ZKU, ZKUG, rectangular), and trusses constructed with HR profiles and CF profiles. Primary and secondary elements of flooring systems are considered pinned at the two ends.

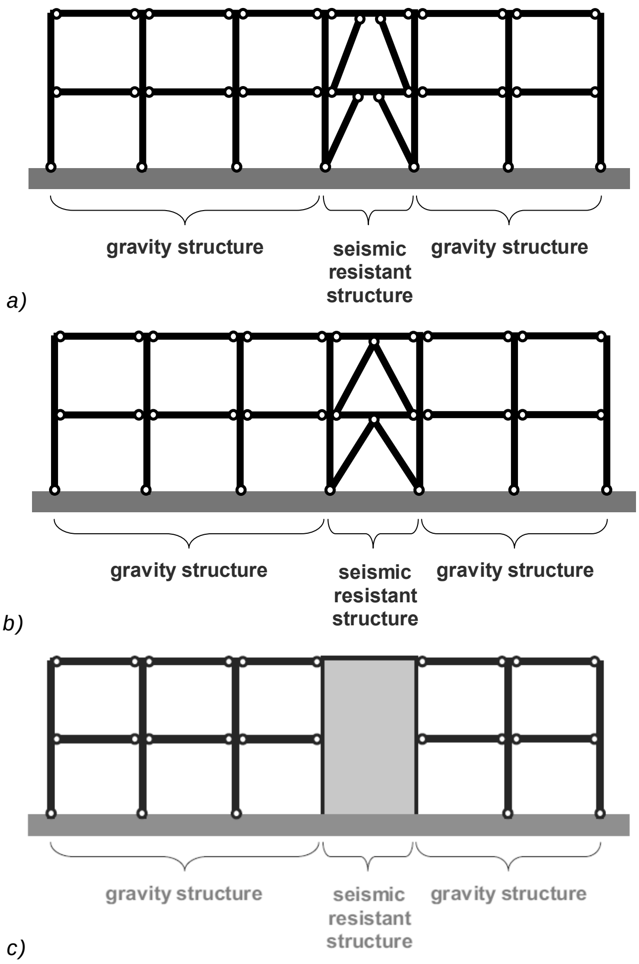


Figure 9: Structural scheme for commercial buildings: (a) eccentric braces; (b) concentric braces, (c) prefabricated shear walls.

The following design procedure has been adopted for the design of the composite steel/concrete commercial case studies presented in *Steel-Earth* . A steel bracing system and a r.c. precast shear wall as lateral resistant structure have been adopted.

[1] *Determination of the main geometry of the building:* plan and elevation geometry, number of span, span length, height of the building.

[2] *Determination of design action and load combination*: acting loads evaluated according to Eurocode 1 [6] and Eurocode 8 [5].

[3] *Material selection:* the characteristics of the structural materials are defined according to Eurocode 3 ([12]÷[14]) for the steel elements, Eurocode 2 [15] for concrete elements and Eurocode 8 [5] for specifications about seismic requirements.

[4] *Elements' sections*: for composite beam elements, in relation to the length of the element, simple profiles (IPE or HE) or truss beams have been selected. For columns, both hot rolled (HE) and circular hollow sections (CHS) have been considered for one-storey and two-storey buildings, including bare steel profiles, partially encased sections (PEHE) and concrete filled circular hollow sections (CFCHS).

[5] *Selection and design of the bracing system*: concentrically braced (CB), eccentrically braced (EB) structures and r.c. precast walls have been considered and compared; in the case of EB, the dissipative link elements can be used mainly in shear or in flexure in relation to the length (Figure 10).

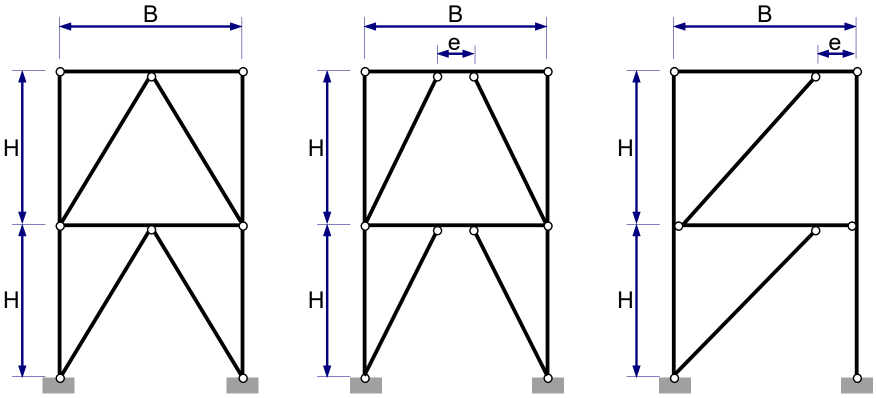


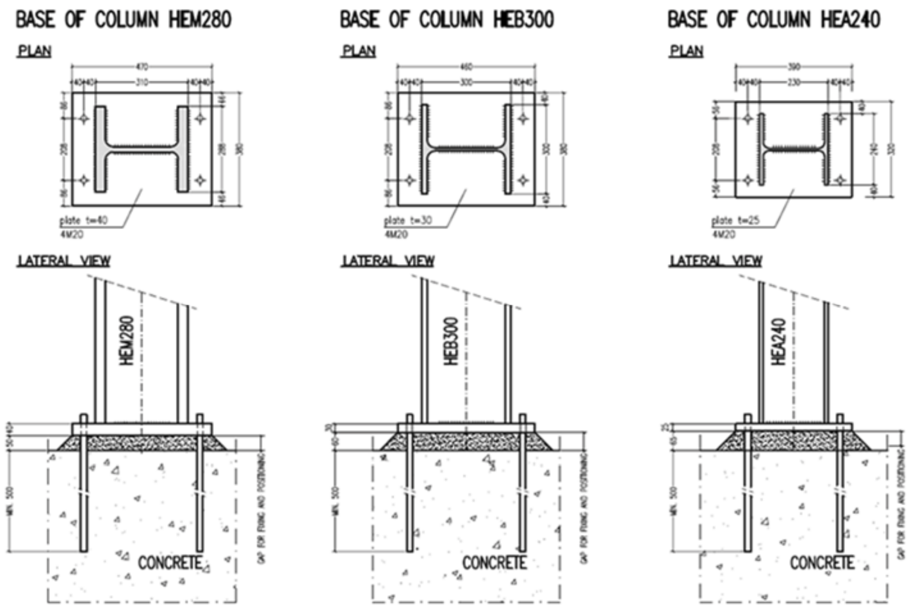
Figure 10: Possible braces configurations for the design.

[6] *Modelling and analysis*: for the design, linear analyses (static and/or dynamic) on three-dimensional model shall be adopted, beside the elaboration of simple structural schemes adopted for the pre-design of elements. In the FE model beams, columns and diagonal members shall be modelled with linear frame elements, with an ideal hinge at the base of each column. Connections between beams and columns are assumed to be pinned; in the case of EBF and CBF the diagonals of the bracing system are pinned too, but maintaining the continuity of the beam containing the link element. Beams are assumed to be composite: the contribution of the concrete slab to the stiffness is directly taken into account. The presence of rigid planes is introduced at each floor by assigning a rigid diaphragm constraint. In the case of r.c. wall bracing system, shear wall deformation is taken into account through a refined stiffness model (Timoshenko).

[7] *Structural design and safety checks of primary elements:* the capacity design approach has been adopted for seismic action. All the safety checks foreseen by EN1998-1:2005 [5] for ULS and SLS shall be executed, including strength, displacement, interstorey drift and buckling verifications. Sensitivity to second order effects (θ coefficient) shall be also checked. An accurate selection of the behaviour factor shall be executed.

[8] *Design of connections and details:* for the vertical resistant structure (MRF) opportune design of connections (i.e. beam to column, base column, beam to beam and connection in correspondence of sections' change) shall be executed. For the bracing system and for the shear r.c. walls attention shall be paid to the design and assembly of connections in correspondence of the dissipative link element and between the shear wall and composite beams.

The proposed methodology and its application to the case study buildings can be found in TS and WE and in the corresponding deliverables D.1.1 and D.1.2. Examples of executive drawings are presented in Figure 11 for the case study with EBF and in Figure 12 for the case study with r.c. precast shear wall.



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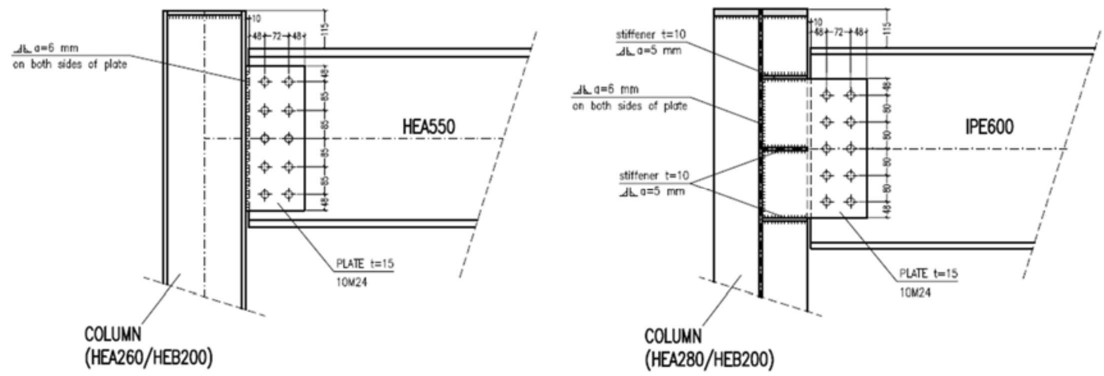

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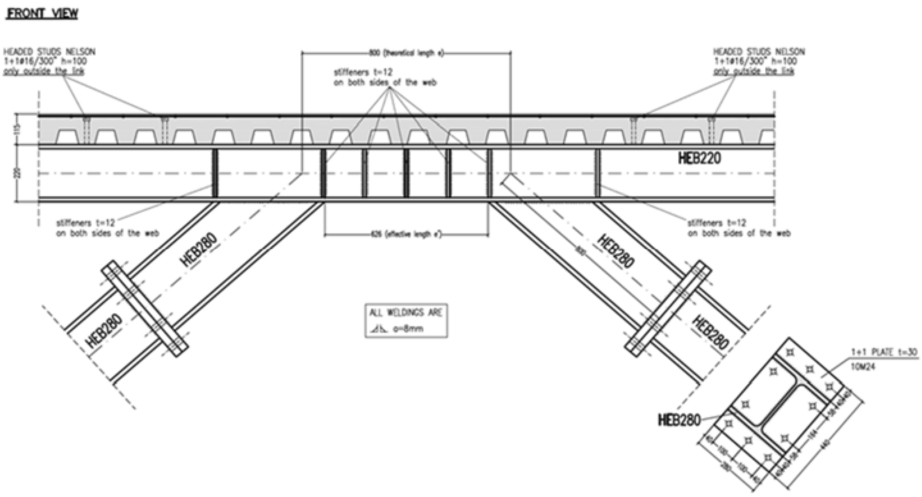

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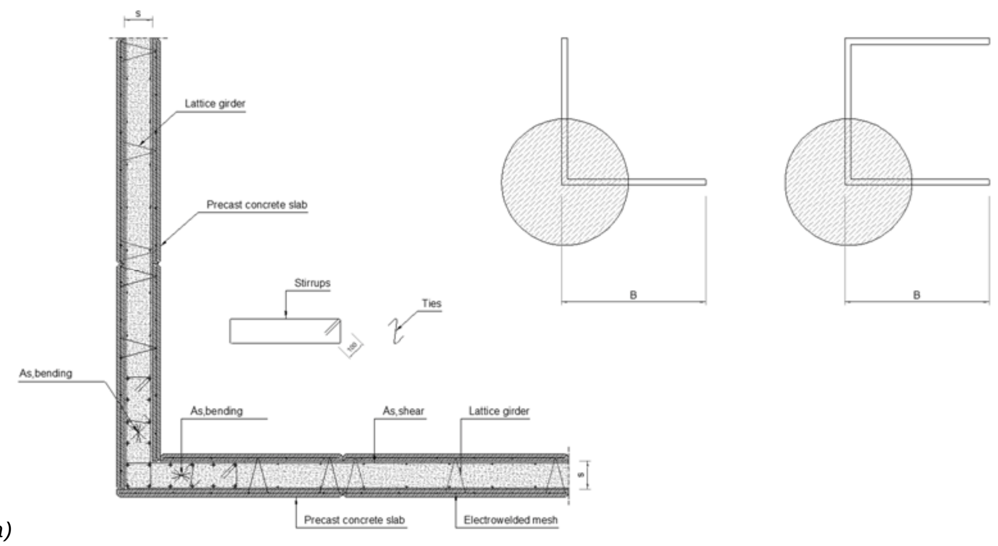
Figure 11: Example of details elaborated for the analyzed case study.



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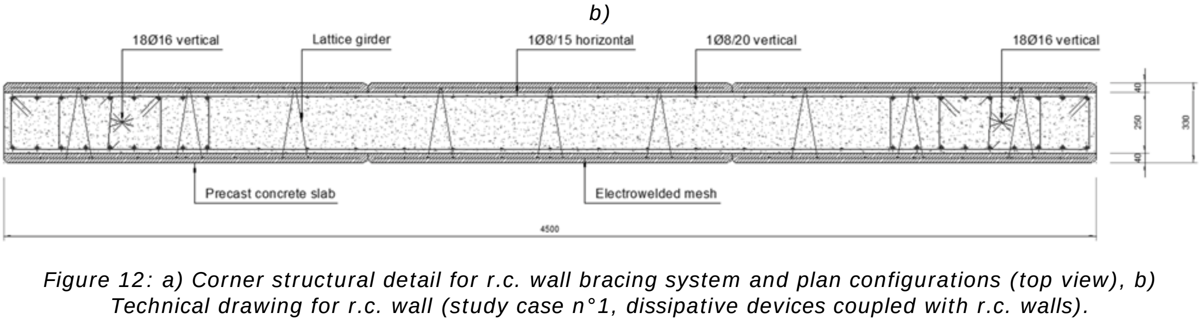


Figure 12: a) Corner structural detail for r.c. wall bracing system and plan configurations (top view), b) Technical drawing for r.c. wall (study case n°1, dissipative devices coupled with r.c. walls).

- ***Comparison of proposed bracing systems for composite commercial buildings***

A detailed comparison of the proposed solutions (steel braces vs. r.c. precast walls) from a technical and economic point of view has been executed, in terms of both influence area and total/unitary costs, varying geometrical parameters (span length, height, entity of seismic action) and ductility class selected for the design. Predalle floor systems, always resulting more convenient than steel sheeting floor, were assumed.

The cost model already elaborated in PrecaSteel project [1] has been updated to the current year considering both price analysis and official price lists of the public administrations (Table 1) coming from different countries (Italy - Southern Europe; Germany - Central Europe).

Table 1: Update of unit construction costs (Italy - Southern Europe; Germany - Central Europe).

ITEM	Unit. cost	U.M.	NOTE
Concrete for r.c. walls (without formwork)	322.22	€/m³	C25/30, XC2, S4
Concrete for r.c. slabs (without formwork)	222.22	€/m³	C25/30, XC2, S4
Steel for r.c. structures	1.90	€/kg	
Precast double plate r.c. walls	23.25	€/m²	Included cost of lattice girders, electro-welded meshes and assembling. Excluding fresh concrete cast in place
Precast r.c. floor (Predalle)	32.99	€/m²	Unpropped solution
Steel sheeting composite floor	54.57	€/m²	Unpropped solution
Steel for frame structures	2.74	€/kg	S355, included surface treatments, erection, bolted and welded joints

The wide dissertation regarding the comparison is presented in the TS and WE related to the commercial building with precast r.c. walls.

As a general remark, r.c. walls solutions are almost always (96%) competitive towards CBF systems for what concerns the dissipative capacity. This consideration is almost valid also comparing r.c. walls and EBF systems, characterized by a high capacity to dissipate seismic energy towards a more limited application. From a structural point of view, vertical loads can compromise the optimal dissipative behavior of link: to solve this problems, in EBF the decoupling of beams for gravitational loads and link is often executed. On the other hand, r.c. shear walls are able to sustain vertical load during the earthquake without compromising their dissipative capacity, resulting in a wider versatility application. An example of the executed comparisons is presented in Figure 13.

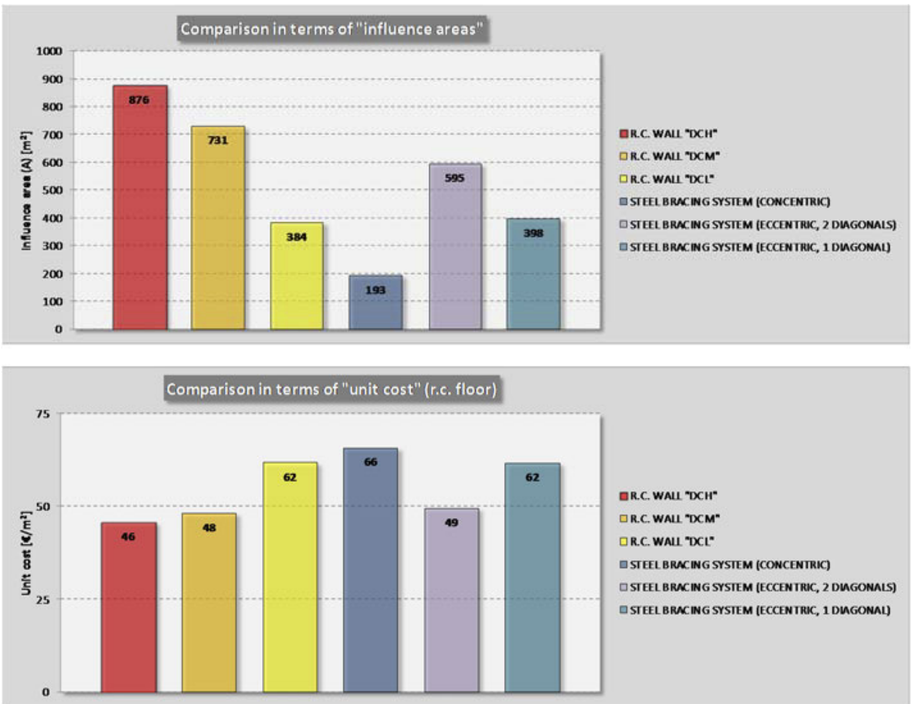


Figure 13: Comparison between r.c. wall and steel bracing systems (B=8.0 m, H=6.0 m, shear base 500 kN).

1.1.5 Steel-concrete commercial building with enhanced passive dissipative system

The design of a steel-concrete commercial building with the introduction of the steel self-centering device (SSCD) developed, realized and experimentally tested inside *PrecaSteel* [1] and *SteelRetro* [3] has been proposed inside Steel-Earth (Figure 14). The adoption of such systems allows to reduce the residual displacements affecting the building after a seismic/cyclic event, decreasing the damages to non-structural elements and the following interruption of ordinary activities. Respect to traditional dissipative systems, self-centering devices present lower energy dissipation but the recovering of displacements (Figure 15). In the SSCD system, the dissipative capacity is devoted to specific low-yielding strength elements while the re-centering behaviour is due to the presence of pre-tensioned cables; the behaviour of the proposed system has been deeply investigated (Braconi et al. 2012 [16]) also in relation to the results of experimental tests executed on real scale prototypes.

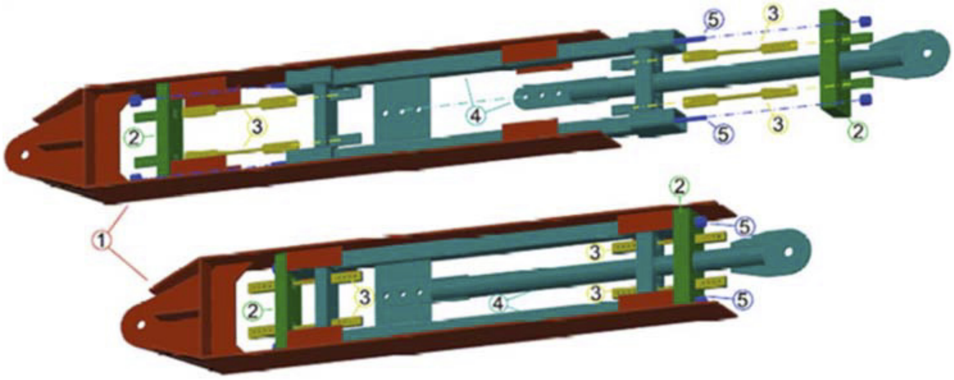


Figure 14: Main components of the proposed system.

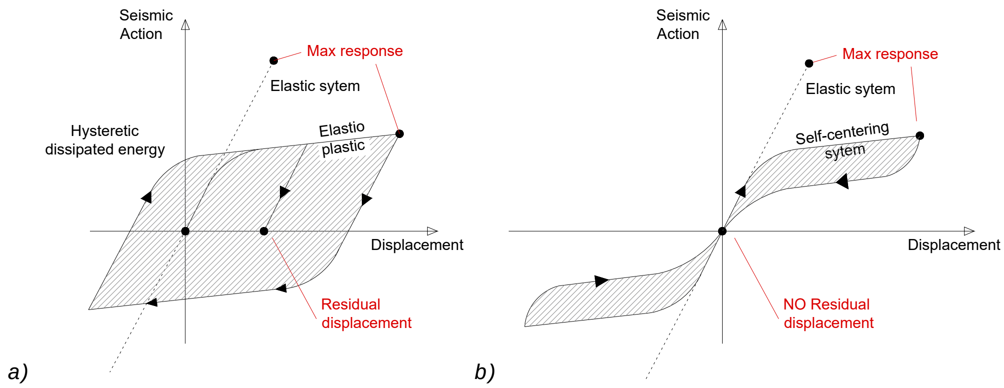


Figure 15: Ideal seismic response of a) an elasto-plastic dissipative system; b) self-centering device.

Since current standards do not provide specific indications for the design of such systems, in the TS/WE a procedure is proposed for the application of the SSCD to a commercial case study building, based on the adoption of nonlinear methodologies. Also in this case, the decoupling of the structural behaviour has been adopted (Figure 16): r.c. shear walls, positioned in correspondence of the four corners, are designed to face the horizontal seismic action while internal steel pinned frames have been sized to resist gravitational loads; the connection between the r.c. walls and the steel frames is executed through SSCDs, responsible for the re-centering and dissipative capability of the designed building.

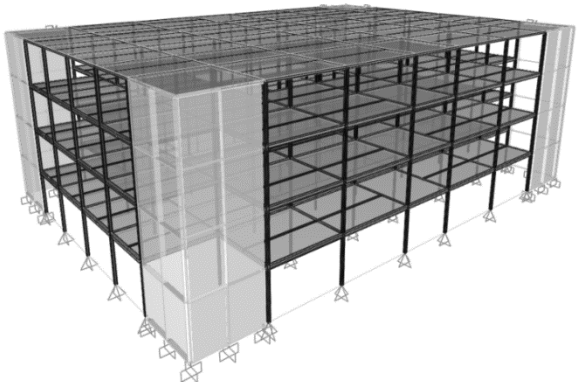


Figure 16: Three dimensional schematization of the case study building.

The design methodology to be adopted can be summarized as follows, with some steps that are common with the other design approaches.

[1] *Determination of the geometry of the building*: plan and elevation geometry, number of span, span length, height of the building.

[2] *Determination of design action and load combinations*: acting loads have been evaluated according to Eurocode 1([6]÷[11]) and Eurocode 8 [5].

[3] *Material selection*: steel grades and concrete class shall be selected in agreement with standards' prescriptions. The main remark is related to the material selected for the dissipative elements of the SSCD device (i.e. low yielding steel).

[4] *Pre-design of structural elements*: since no specific indications are given by technical standards, steel frames have been designed considering only vertical gravitational loads. The r.c. shear walls have been designed considering the horizontal seismic action adopting a behaviour factor q equal to 1.0: this means SSCDs behave as "rigid components" that do not dissipate the seismic action and transfer it as a whole directly to the walls.

[5] *Preliminary linear modelling and analysis*: linear static and dynamic analyses shall be executed on a 3D model of the building. To minimize lateral displacements, the parameters constituting the SSCD (i.e. length, dimensions of the dissipative elements, diameter of pre-tensioned cables, …) have been modified to obtain a specific "deformed-shape configuration", like the one presented in Figure 17: this allows to reduce relative displacements among different floors.

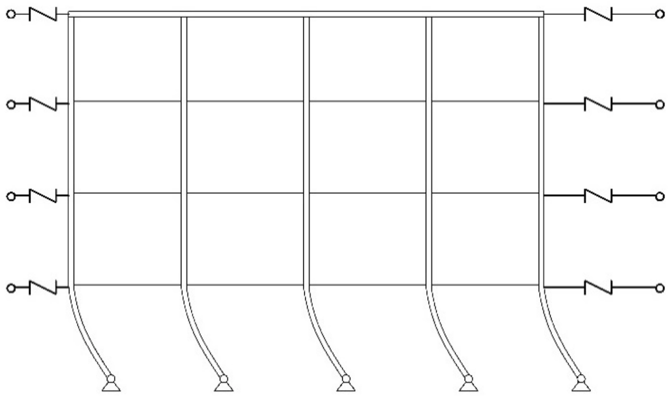
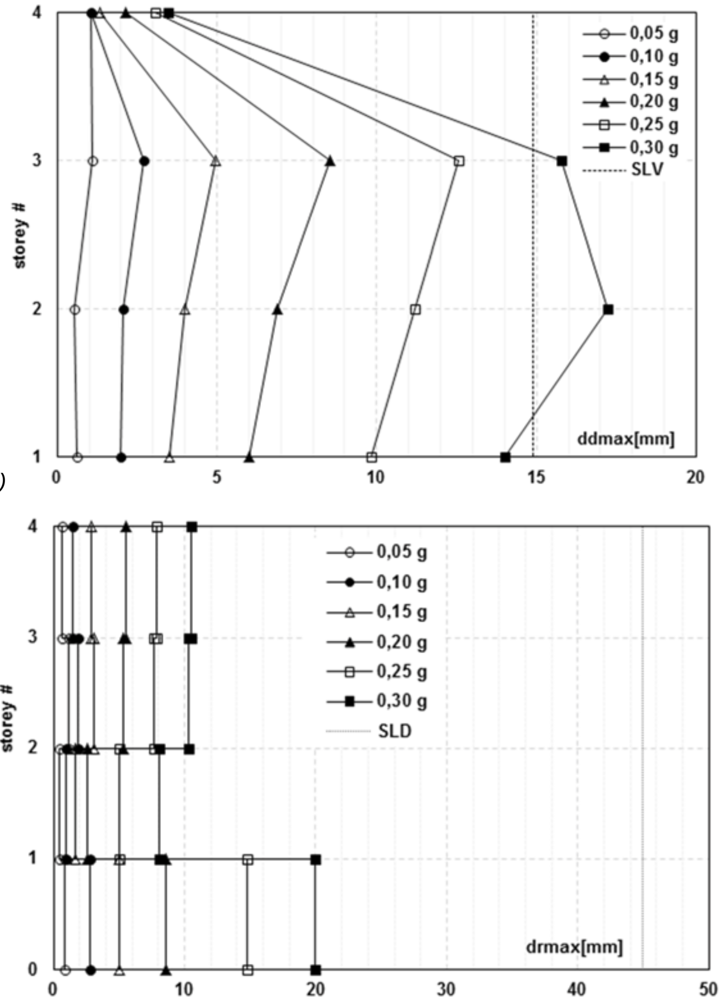


Figure 17: Desired modal deformation.

[6] *Determination of limit state conditions:* two performance levels have been established to describe the behaviour of a building with introduced SSCDs, in relation to the theoretical behaviour of the system (since no indications are provided by current standards). The ULS has been defined in relation to the axial deformation of the SSCD systems (higher than the maximum allowed elongation), corresponding to the yielding condition of pre-tensioned cables and the loss of re-centering capability; the SLS is associated to the achievement of the maximum interstorey drift able to guarantee the effective use of the building.

[7] *Nonlinear modelling and analysis:* non-linear dynamic analyses (Figure 18) have been executed on the developed model (with specific simplified relationship to simulate the dissipative/re-centering behaviour of the SSCD necessary to implement such devices in the model) in order to "optimize" the structural performance towards both ULS and SLS.

[8] *Evaluation of the parameters' influence:* the execution of IDA with different accelerograms has allowed to define the most influencing parameters affecting the behaviour of buildings with introduced SSCD. In particular, analyses evidenced the effect of the length of the system, of the diameter of pre-tensioned cables, of the size of dissipative members and of a combination of such parameters on both the dissipative and re-centering behaviour of the building.



a)

b)

Figure 18: IDA results: a) max displacement of SSCD (ULS) and b) max interstorey displacement (SLS).

1.2 Retrofit of existing buildings

In WP1 Technical Sheets (TS) and Working Examples (WE) dealing with retrofit approaches for existing r.c. and masonry buildings in seismic area, mainly adopting steel-based devices, have been developed.

The TS represent a useful tool for designers and engineers that are guided in the evaluation of the efficacy of the proposed techniques considering technical, economic and feasibility aspects. A general description of the proposed technique is provided in the introduction of each TS, explaining the main benefits in the adoption of the system, its disadvantages as well as a general overview of the actual diffusion/application inside and outside Europe. The corresponding WE provide fully developed practical applications to existing case study buildings, showing in details all the steps to be followed for the rehabilitation interventions.

The produced documentation, globally collected in deliverables D.1.1 and D.1.2 and in the proceedings of the final workshop of *Steel-Earth* project, constitutes a potential instrument for designers, engineers and design companies involved in the retrofit of existing buildings.

Indications for the retrofit of vertical elements, horizontal floors, roof systems and foundations in both r.c. and masonry buildings, adopting traditional approaches as well as introducing steel-based innovative systems (braces, steel shear walls and enhanced passive dissipation systems, BRB, etc.) in relation to the performance levels that want to be achieved as a function of the seismic hazard, of the intensity of horizontal action, of the accepted criteria for structural safety, etc. are provided.

All the TS (and the corresponding WE) follow the retrofit procedure elaborated inside *SteelRetro* project [3], that is a modification of the Performance Based Seismic Design (PBSD) for the application to existing buildings, briefly summarized in the steps below.

[1] Survey of existing constructions and determination of the structural vulnerabilities (at dot, local and global level), in line with what foreseen by current standards.

[2] Application of the PBEE methodology (i.e. Performance Based Earthquake Engineering), joining together design strategy, definition of the hazard model, modelling techniques, simulation method, definition acceptance criteria (i.e. FEMA 356 [17] and EN1998 [5]), analysis of technical and economic aspects.

[3] Pre-selection of the most common retrofit techniques (also not steel based) that can be adopted for the considered existing building; determination of those ones that are not convenient and consequently neglected (due to accessibility, difficulty level for applicability, manpower skill for in-field works, demolition, previous technical evidences…). This step can be executed in agreement with the definition of a matrix approach (Table 3, Table 4), as proposed in SteelRetro [3].

[4] Application of the selected rehabilitation technique(s) to the existing case study building: modelling and structural analysis of the existing retrofitted construction. The use of graphic methodologies, such as the N2 method ([18], [19]) or the Capacity Spectrum Method (ATC40 [20]), allow to directly evaluate the efficiency of proposed solutions and the design of eventual improvements.

[5] Analysis of the structural response of the retrofitted foundation system with evaluation of the required bearing capacity and executive design of the adopted system.

[6] Analysis of the structural response of the retrofitted superstructure (vertical and horizontal/floor systems) and eventual optimization of the retrofit approach.

[7] Design of connections and details, especially in the case of new resisting systems connected to the existing retrofitted structure.

The procedure above summarized is described as a general approach for all the considered applications in the TS, while its practical application is introduced inside the corresponding WE.

Table 2: Summary of possible vulnerabilities in existing buildings.

BUILDING SUMMARY: building type, location, age of construction					
Vulnerability Type	Description	Structural sub-system	Critical zones and elements involved	Limit state	D/C
DOT	e.g. shear failure in the wall near the openings	e.g. vertical resisting system (localization)	e.g. type "a" critical zone (openings), class "2" collecting element (wall)	e.g. Limit State of Damage Limitation	e.g. 1,5
LOCAL	e.g. out-of-plane failure of the wall with failure of the wall-to-wall connections	e.g. vertical resisting system (localization)	e.g. type "b" critical zone (wall connections), class "2" collecting element (wall), type "I" transferring zones (wall-to-wall connections)	e.g. Life Safety Limit State	e.g. 2,1

GLOBAL	e.g. failure of the corner between two orthogonal walls with following failure of the roof system	e.g. vertical resisting system and roof system (localization)	e.g. type "a" critical zone (openings), class "2" collecting element (wall), type "I" transferring zones (wall-to-wall and roof-to-wall connections)	e.g. Collapse Prevention Limit State	e.g. 1,3

Table 3: Decisional Matrix condensing all relevant aspects for a preliminary judgment of the structural intervention technique. Legend for scoring L = low, M = medium, H = high; Mark – L (5-6), M (7-8), H (9-10).

Structural aspects	LMH	Mark
Capability to achieve requested performance objective (after building evaluation!)		
Compatibility with the actual structural system (no need of complementary strengthening or confinement measures)		
Adaptability to change of actions seismic typology (near field, far field, T<>Tic, etc.)		
Adaptability to change of building typology		
Technical aspects	**LMH**	**Mark**
Reversibility of intervention		
Durability		
Operational		
Functionally and aesthetically compatible and complementary to the existing building		
Sustainability		
Technical capability		
Technical support (codification, recommendations, technical rules)		
Availability of material/device		
Quality control		
Economic aspects	**LMH**	**Mark**
Costs (material, fabrication, transportation, erection, installation, maintenance, preparatory works)		

Table 4: Typological form to be adopted with the decisional matrix in the preliminary selection of intervention technique – form filled for ring beam technique for roof in masonry building.

Typological analysis of intervention (horizontal and vertical)		
Technique classification		Non-structural properties
Stiffening	Yes/No	Amount of materials:-
Strength	Yes/No	Technological aspects: -
Ductility	Yes/No	Used space: -
Structural classification		Demolition: -
Masonry:		Accessibility: -
Reinforced concrete		Reversibility: -
		Maintenance: -

1.2.1 General indications for the retrofit of existing buildings

In the TS/WE *"General principles for seismic rehabilitation of masonry and r.c. buildings"* general indications for the retrofit of existing r.c. and masonry constructions are provided.

Current standards for constructions (D.M.14/01/2008 [21], EN1998-3:2005 [22], FEMA356 [17]) provide a codified procedure for the planning of readjustment/improvement operations for existing buildings. The adopted procedure is based on a deep investigation of the state of art the structure, achieved through structural and geometrical surveys, critical historical analyses and determination of the material mechanical properties. The PBEE approach foresees the execution of safety checks of the actual structural condition of the building, determining the dot/local/global vulnerabilities of the building in relation to whom the retrofit can be organized. Different solutions exist to reduce the seismic vulnerability of ancient constructions, in relation to structural typology, material, damage level and so on; the retrofit strategy can prescribe the increase of the strength, of the ductility, of the dissipative capacity or of a combination of them (Figure 19).

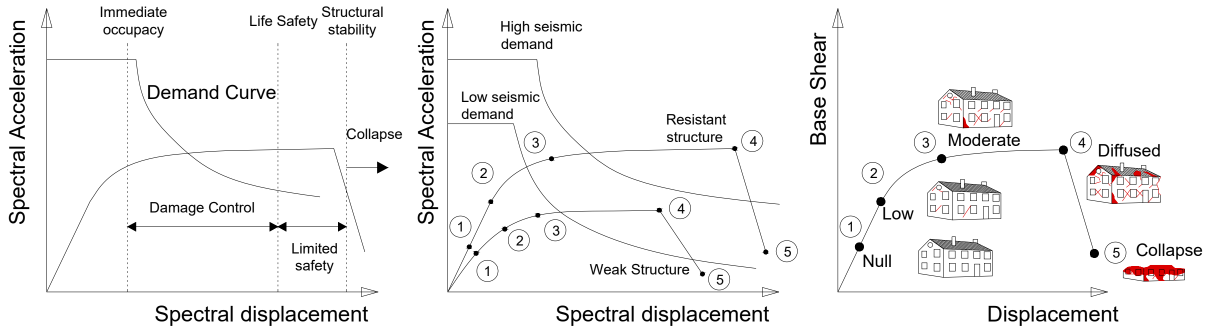


Figure 19: Structural performance: damage levels in relation to the force/displacement behaviour and in relation to seismic demand.

Retrofit mainly consists in modifying the demand/capacity ratio to make single elements and whole structure able to satisfy the required safety levels (i.e. D/C ≤ 1.0). Two main general approaches can be then used:

1. Retrofit interventions able to reduce the seismic demand.
2. Retrofit interventions able to increase the capacity of the building.

The reduction of the demand (D) can be obtained decreasing the mass/loads of the building or by the introduction of an isolation system. Such systems, applied between the superstructure and the foundation, increase of the vibration period of the building, with the following decrease of the related spectral acceleration and of design forces. The increase of the vibration period leads, at the same time, to the increase of the global displacement demand, that is anyway concentrated in correspondence of isolators, opportunely designed to face such displacements.

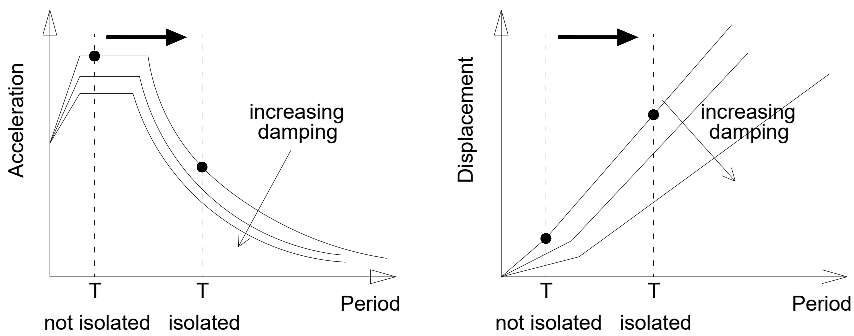


Figure 20: Response spectra in acceleration and displacement for buildings with/without isolation devices.

The increase of the capacity (C) can be exploited increasing the strength, the ductility or the dissipative capacity of the construction, referring to single structural elements or, otherwise, to the whole building.

The introduction of a new resisting system facing horizontal seismic actions can produce (if correctly designed) a significant increase of the structural capacity, in terms of strength, stiffness and ductility. The application of braces, for example, can lead to the global protection of the building, that remains in the elastic field for a fixed level of seismic intensity and/or is able to sustain a certain damage level if plastic deformations take place. Different bracing systems can be used: traditional passive braces, BRB, dissipative self-centering systems, steel shear walls and so on.

The application of all such typologies to existing r.c. and masonry constructions has been deeply explained, also with practical examples, in deliverables D.1.1 and D.1.2.

The above described retrofit techniques alter the “global” dynamic behaviour of the construction, due to the introduction of a new and different resisting structural system (isolators, bracings, r.c. walls, …); beside such modifications, local interventions of single elements (steel, r.c. or FRP jacketing, masonry injections,…) are frequently needed to reach D/C ≤ 1.0. Table 5 summarizes the possible dot/local vulnerabilities affecting r.c. and masonry buildings of horizontal floors and roof, vertical bearing system and foundation.

More details and information are presented in the TS/WE collected in deliverables D.1.1 and D.1.2.

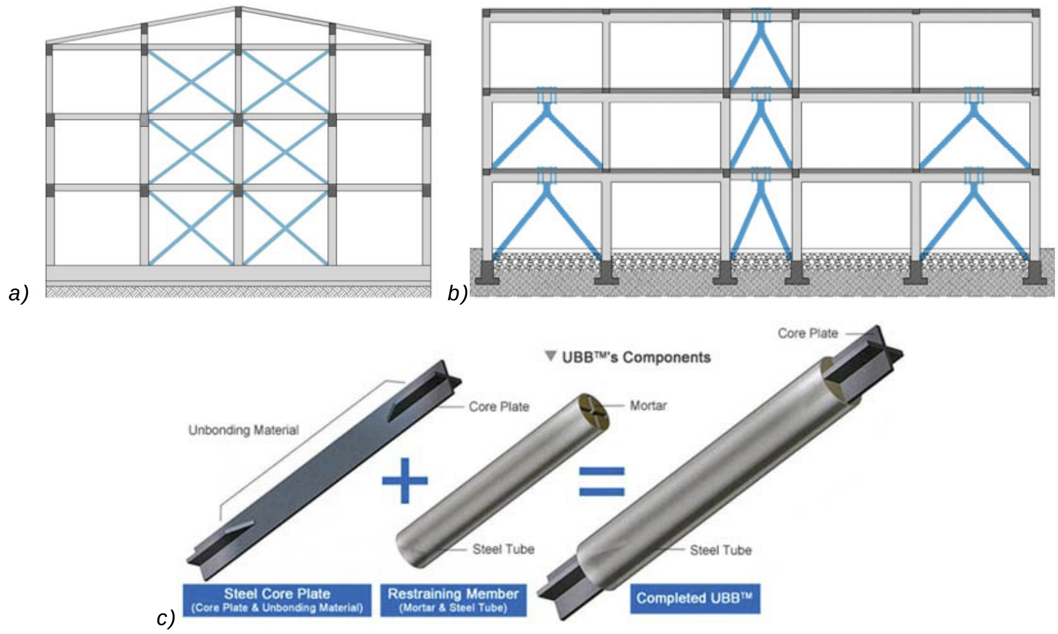


Figure 21: Example of bracing systems to increase the capacity of existing buildings: a) CBF, b) EBF, c) BRB.

Table 5: Typical vulnerabilities (local) for r.c. and masonry buildings.

Structural system		Vulnerabilities
Foundation	r.c./masonry	Insufficient flexural and shear strength of foundation elements, Insufficient axial strength (deep foundations), Inadequate size of foundation on poor soil with following subsidence and relative
Vertical resisting system (for gravitational loads)	Masonry	Poor quality of materials, Insufficient thickness of walls, Wide openings with irregular disposition, Inadequate connections between walls and storey slabs, Plan and elevation irregularities
	r.c.	Longitudinal reinforcements insufficient or with insufficient overlapping length, Too high stirrup spacing, Insufficient anchorage length, Not adequate connections between columns and beams, Plan and elevation irregularities
Horizontal floors and roof	r.c./masonry	High deformability, Absence of adequate connections, Presence of relevant openings (stairs…), Plan irregularities

1.2.2 Indications for the seismic rehabilitation of the foundation system

The weaknesses of the foundation system shall be deeply analyzed, since of fundamental importance in assessing the performance of the structure as a whole. The foundation system and the subsoil shall be able to withstand pressures due to seismic load combination, providing adequate stiffness without compromising the functionality and the safety of the superstructure.
The retrofit of existing foundations mainly consists in the increase of the strength and of the stiffness capacity, while no requirements are needed for the ductility capacity, designed to remain in elastic range. Different approaches exist for the retrofit of foundations, related to the improvement of the capacity of the system or, otherwise, to the decrease of the demand.

In agreement with §2, the general presented methodology is used to organize the retrofit of foundation systems. In particular, in the TS/WE *"Seismic rehabilitation of foundations of existing buildings"* the application of micropiles as retrofit technique for an existing building is proposed.

For the pre-selection of the appropriate retrofit technique, the matrix approach proposed in SteelRetro [3], basing on general qualitative-marking criteria, can be used (Table 6).

	Isolated spread footings	Strip footings	Foundation of new elements	Mat foundations	Pile foundations	Accessibility and height restrictions	Impose noise and vibration	Restrictions imposed by existing utilities (gas, water, supply systems)	Restrictions associated with on going operations
Spread footing enlargement or replacement	Yes	Yes	Yes	-	-	A	S	S	S
Addition of a strap beam	Yes	Yes	-	-	-	A	S	S	S
Addition of micropiles	Yes	Yes	Yes	Yes	Yes	NA	M	M	M
Addition of shallow elements to deep foundations	-	-	-	-	Yes	A	S	S	S
Addition of a driven Piles	Yes	Yes	Yes	Yes	Yes	NA	M	M	M
Overlaying mat foundations	-	-	-	Yes	-	A	S	S	S

Table 6: Suitability for foundation typologies in r.c. and main limitations for rehabilitation method; Yes – Possible to use method for strengthening; A – Applicable; NA – Not Applicable; SC – Special Car; M – Major; S – Small; - None

The analysis of ground-soil characteristics is necessary to evaluate the mechanical properties and the stratigraphic profile of the significant part of the soil interested by the applied intervention; the data regarding shear wave velocity (V_s), elastic shear modulus (G_0), bond strength (q_b) and undrained cohesion (c_u) are also needed to evaluate and, if necessary, to model the soil-structure-interaction.

In the case of the introduction of micropiles to increase the strength of the existing system, for example, a correct array of piles shall be analyzed and studied (number, typology and disposition of micro-piles). Preliminary checks shall be executed to assess strength and buckling problems; modelling, analysis and safety verifications of the adopted solution are finally required to evaluated the influence of the retrofit technique on the structural safety of the whole construction.

More details and information are presented in the TS/WE collected in deliverables D.1.1 and D.1.2.

1.2.3 Indications for the seismic rehabilitation of vertical systems

The rehabilitation of vertical systems (i.e. vertical walls in masonry buildings, beams and columns/frames in the case of r.c. buildings) shall be pursued both in terms of strength and lateral stiffness, in agreement with safety requirements foreseen for ULS and SLS.

In the case of ***masonry buildings,*** vertical walls are the structural elements responsible for the lateral resistance: their seismic performance consequently governs the overall behaviour of the construction. The low seismic performance of masonry buildings is generally associated to the lack of ductility due to brittle materials and to the absence of seismic detailing able to guarantee the "box" behaviour. The failure of masonry panels usually takes place at low deformation and is associated with a large and sudden drop in lateral load resistance. In addition, the lateral/shear strength of the walls tends to degrade faster than their flexural strength with cycling loading.

In the case of ***r.c. buildings*** columns and beams are responsible for the structural capacity of the whole construction; the adoption of MRF is usually associated to a high lateral deformability due to the reduced stiffness of the system. Existing r.c. buildings are often characterized by poor quality of concrete (lower than 150 kg/cm^2) and by the adoption of the scheme strong beam/weak column, opposite to the one actually foreseen by modern seismic design standards to allow the development of global collapse modalities. Poor details of reinforcements and the absence of connections between perpendicular frames generate the high vulnerability to horizontal seismic action.

As a general remark, after the determination of vulnerabilities coming from the detailed analysis of the state of art of the building and the adoption of the matrix approach (following for example Table 3 and Table 4) for the pre-selection of retrofit techniques, the ones considered "more efficient" (from a technical and economic point of view) have been applied to the structural model of the existing building to evaluate their contribution.

The application of a new resistant system, designed to face lateral horizontal actions and working in parallel with the existing structure, represents one of the best possibilities to improve the structural performance of the existing constructions. Figure 22 presents possible approaches for masonry buildings, consisting in the application of steel mesh able to increase the strength of the vertical walls, or in the introduction of additional resisting systems such as steel braces or an internal MRF frame. Figure 25 shows possible application of additional vertical steel bracing systems (including traditional passive braces and BRB) in r.c. existing frames.

Figure 22: Rehabilitation of masonry walls: with steel mesh and shotcrete, steel braces, MRF steel frame.

Figure 23: Example of retrofit of r.c. vertical structure with BRB and traditional bracing systems.

Numerical models of the existing case study buildings with application of the different analyzed retrofit techniques have been elaborated inside *Steel-Earth* to evaluate the efficacy of the proposed systems (Figure 24). Nonlinear analyses are suggested to compare the behaviour of the building before and rehabilitation: the *N2 method* ([18], [19]) allows to evaluate the structural efficiency of proposed techniques, comparing demand and capacity of the retrofitted structure and finally selecting the system that better satisfy the performance levels that want to be achieved (Figure 25). The analysis of the technical and economic feasibility is necessary to select the most appropriate retrofit approach, i.e. the evaluation of the benefits of application towards the intrinsic costs necessary for the installation. The final design of details and connections shall be accurately taken into consideration since the connection between the existing structure and the new resisting system cannot be easy to realize especially due to the poor quality of materials of the old construction.

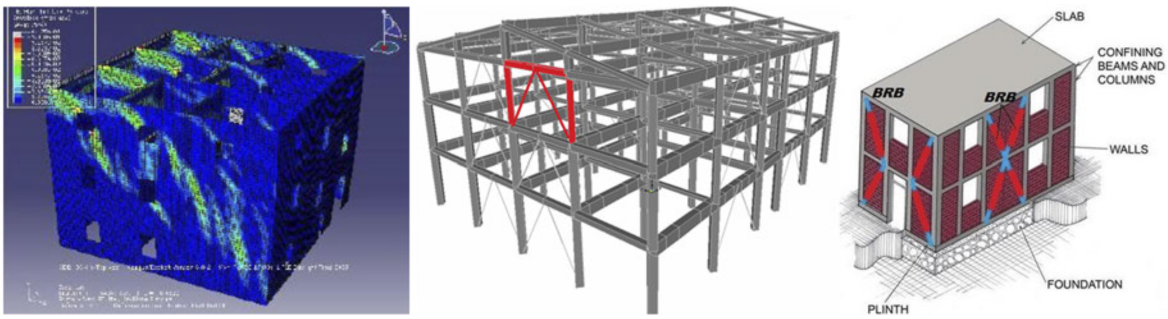


Figure 24: FEM models for a) masonry building and b-c) r.c. frames with bracing system for retrofit.

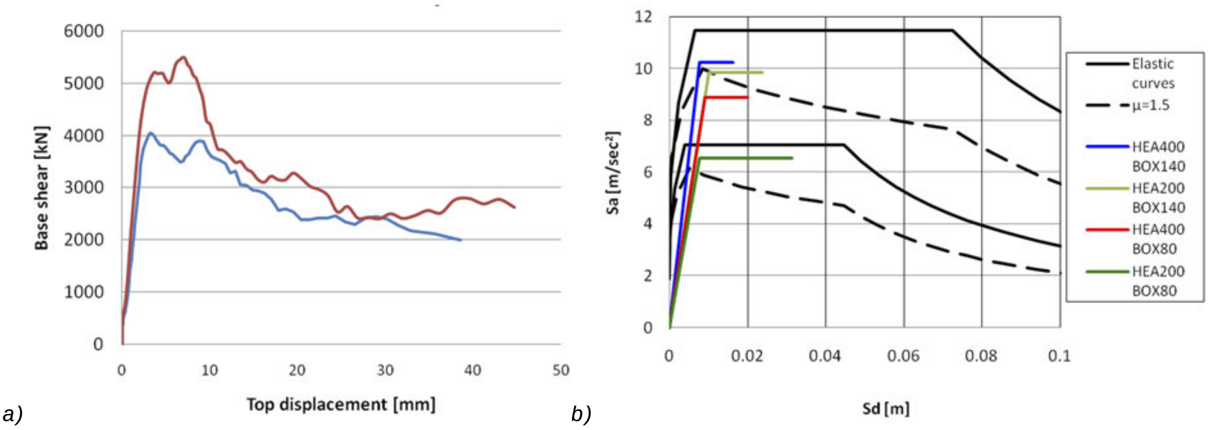


Figure 25: a) Capacity curve of the un-retrofitted structure, b) N2 method and comparison demand/capacity.

The methodology above briefly summarized has be practically applied to existing buildings as deeply presented in the following TS and WE:

- *"Seismic rehabilitation of vertical systems in masonry buildings".*
- *"Rehabilitation of r.c. and masonry existing buildings using traditional bracing systems"*
- *"Rehabilitation of r.c. existing building introducing BRB"*
- *"Rehabilitation of r.c. existing building introducing steel shear walls"*
- *"Rehabilitation of r.c. existing building introducing SSCD"*

- ***Indications for masonry buildings***

In a typical masonry building, three structural sub-systems can be recognised:

- *horizontal systems (i.e. structural elements of the building's roof and floors).*
- *vertical systems (i.e. structural elements supporting the building's roof and floors).*
- *foundation system (i.e. structural elements transferring loads to the ground and the ground itself).*

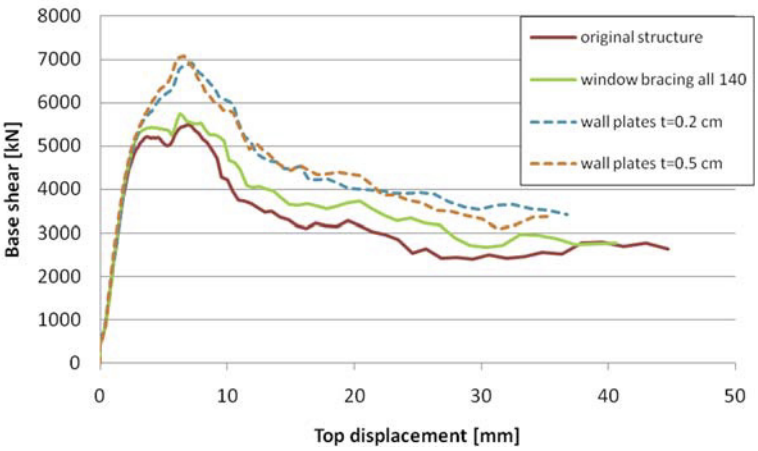
In the common practice of masonry buildings, floors and roofs are made of timber and have a very weak connection with their supporting walls. Masonry walls (vertical resisting systems) are most commonly made by stones, bricks, adobes or hollow concrete blocks and shall be able to sustain safely the transmitted weights by the roofs and floors.

For optimum seismic performance, the structure shall provide a "*box behaviour*": this means that the roof and the floors shall give diaphragmatic action, interconnecting with the building's structural members and distributing lateral forces to the vertical resisting, whose connection shall be guaranteed in and out of plane.

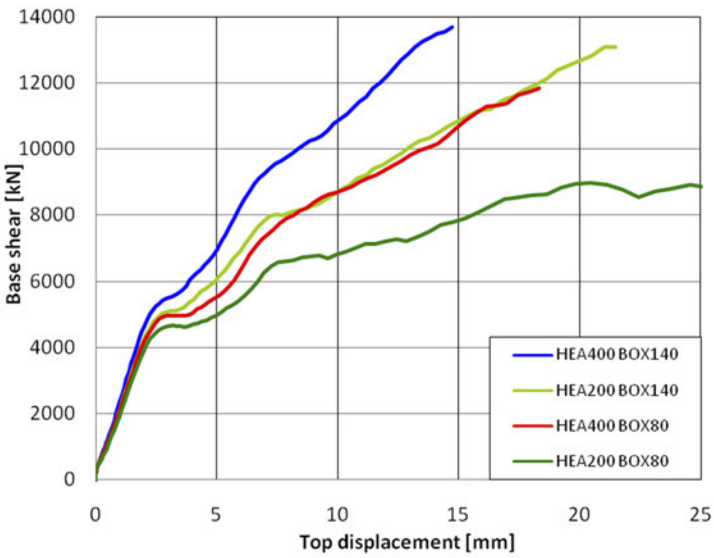
In the TS the general description of actual retrofit techniques for masonry constructions (i.e. tying of the upper part of the walls, using tension only ties, introduction of rigid diaphragm at the top of the walls, introduction of rigid diaphragm at roof level – eventually coupled with reinforcement of external ground floor walls by horizontal LGS strips, introduction of rigid diaphragm at each floor level – eventually coupled with reinforcement of external ground floor walls by horizontal LGS strips, introduction of steel frames with existing masonry walls) is provided. The corresponding WE shows the application of the above mentioned retrofit systems to a masonry benchmark building, representative of the constructions designed at the beginning of the XX century without "diaphragmatic" action at the floor and the roof levels, with absence of the global behaviour of the building as a whole.

The general approach described for the evaluation of the efficiency of proposed techniques presented in §2 has been applied, including the comparison of the demand/capacity curves before and after the different retrofit interventions, as simply summarized in Figure 26.

More details and information related to the application of the different techniques, including modelling, analysis and practical aspects, are presented in the TS/WE collected respectively in deliverables D.1.1 and D.1.2.



a)



b)

Figure 26: a) Capacity curves before and after the introduction of steel plates to strengthen masonry, b) comparison of capacity curves of the retrofitted system introducing different bracing systems.

- ***Indications for r.c. frames with introduction of bracing systems***

  ★ ***Procedure for the optimal location of braces in r.c. frames***

According to what specified in the general introduction of the present chapter, one of the most efficient techniques to increase the structural capacity of r.c. existing frames towards horizontal seismic action consists in the introduction of a new resisting system (i.e. braces of different typologies). The first step for the correct design of the retrofit solution consists in the choice of the system to be applied and in its optimal location inside the existing building, selected in order to achieve the most performing structural response minimizing irregularities and torsional modes, consequently reducing forces acting on elements.

In the TS *"Optimal location of enhanced dissipating systems in r.c. buildings"* the procedure to determine the most efficient configuration of bracing systems in retrofitted r.c. constructions is described. In the corresponding WE, the methodology adopted is applied to a case study building having the typical characteristics of a 1950/1970 construction designed according to the R.D. 2229/1939 [23] Italian code requirements, representative of common existing r.c. buildings in Italy (Figure 27).

In the first part of the WE, the traditional approach for the vulnerability analysis of the existing building, including evaluation of design actions, load combinations, analysis of mechanical properties of materials, execution of preliminary linear analyses and safety checks and further application of the N2 method for the determination of the achievement of different limit states (Figure 28), has been applied. Looking at the demand/capacity curves of Figure 28, it is possible to observe the behaviour of the existing building for different levels of seismic action/different limit states (DL, LS and CP), allowing to determine the performance points that want to be achieved.

The optimal location of braces (among the possible configurations, Figure 29) shall be determined through the optimization procedure summarized in Figure 30. The final assessment of retrofit intervention effectiveness shall be performed. Through push-over analyses on the retrofitted solutions, the achieving of desired performance levels can be verified: the results of push-over analysis are, for example, shown in Figure 31 in the ADSR plane (demand vs. capacity curves).

The optimization procedure deeply described in the TS/WE can be applied independently from the type of bracing system adopted. More details and information are presented in the TS/WE collected respectively in deliverables D.1.1 and D.1.2.

In the following pages, a brief summary of the procedures presented in deliverables D.1.1 and D.1.2 for the design of different bracing systems is presented.

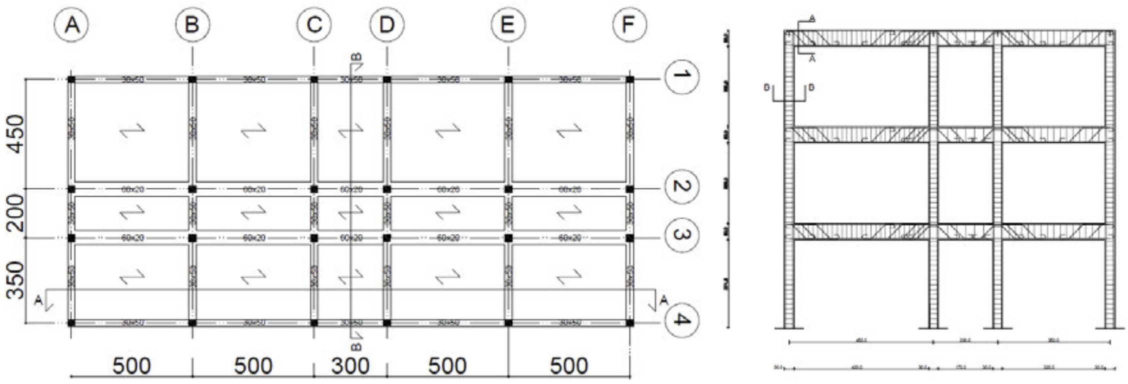


Figure 27: Plan view of the selected structure floor type, transversal section and reinforcements' details.

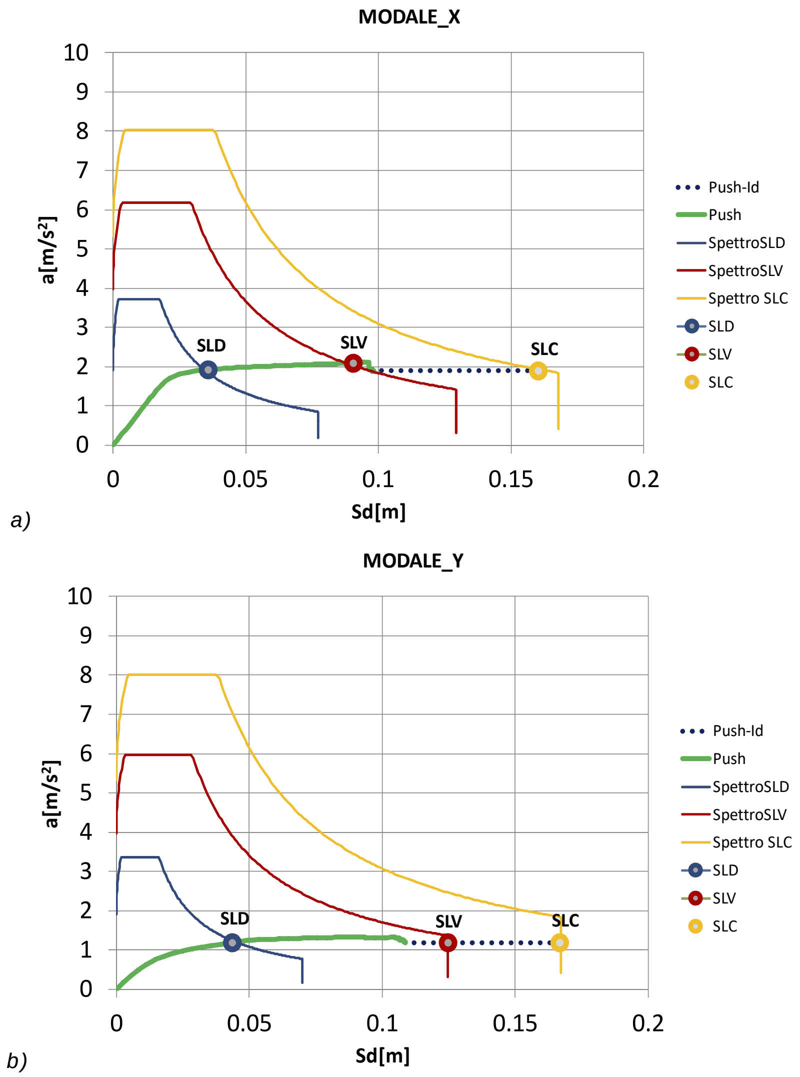


Figure 28: Push-over curves and performance points for different limit states of ESDOF system represented in ADRS plane: a) X-directions and b) Y-direction, Modal pattern of forces.

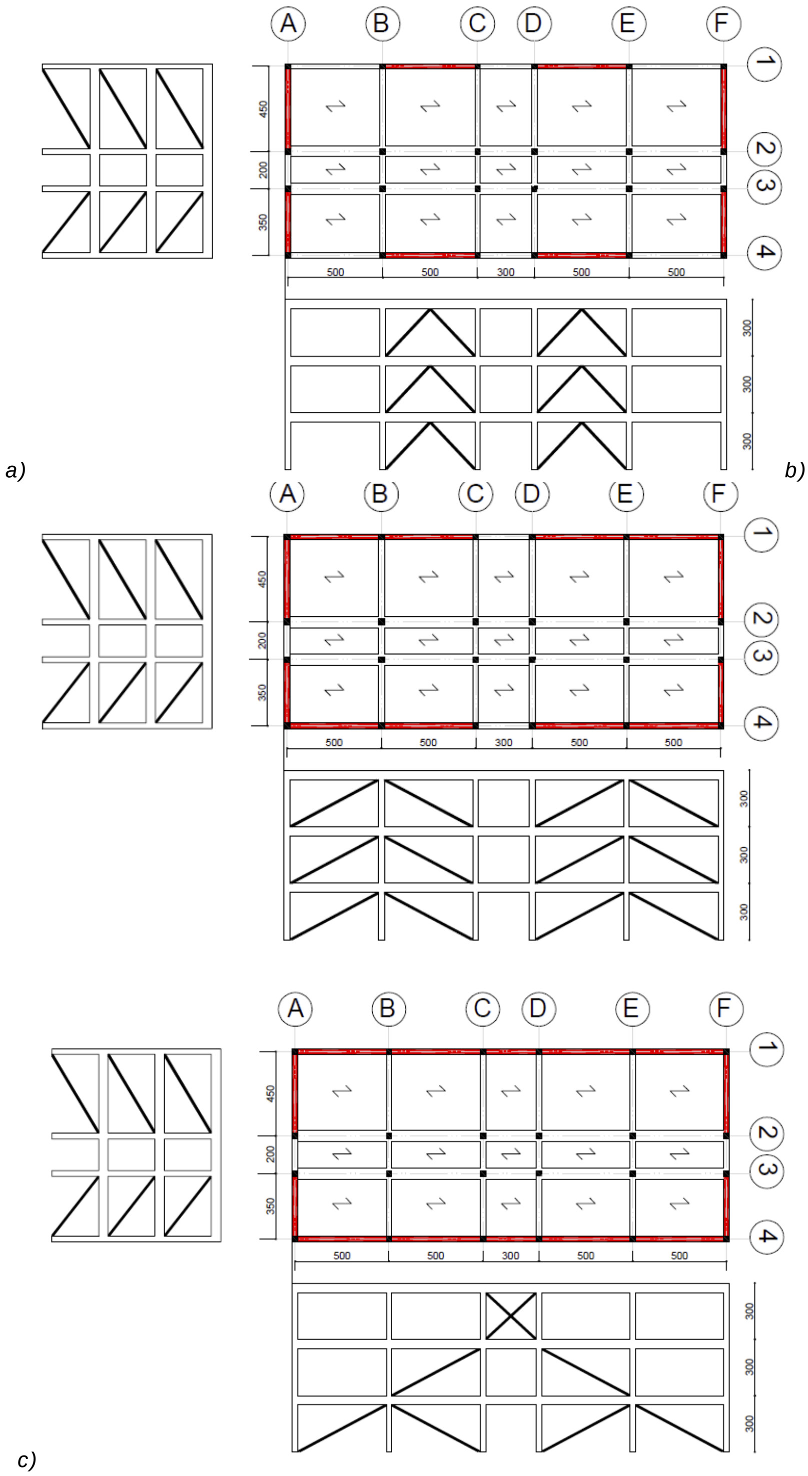


Figure 29: Analyzed configurations for bracings location: a) Chevron Brace layout, b) and c) Diagonal Brace layout

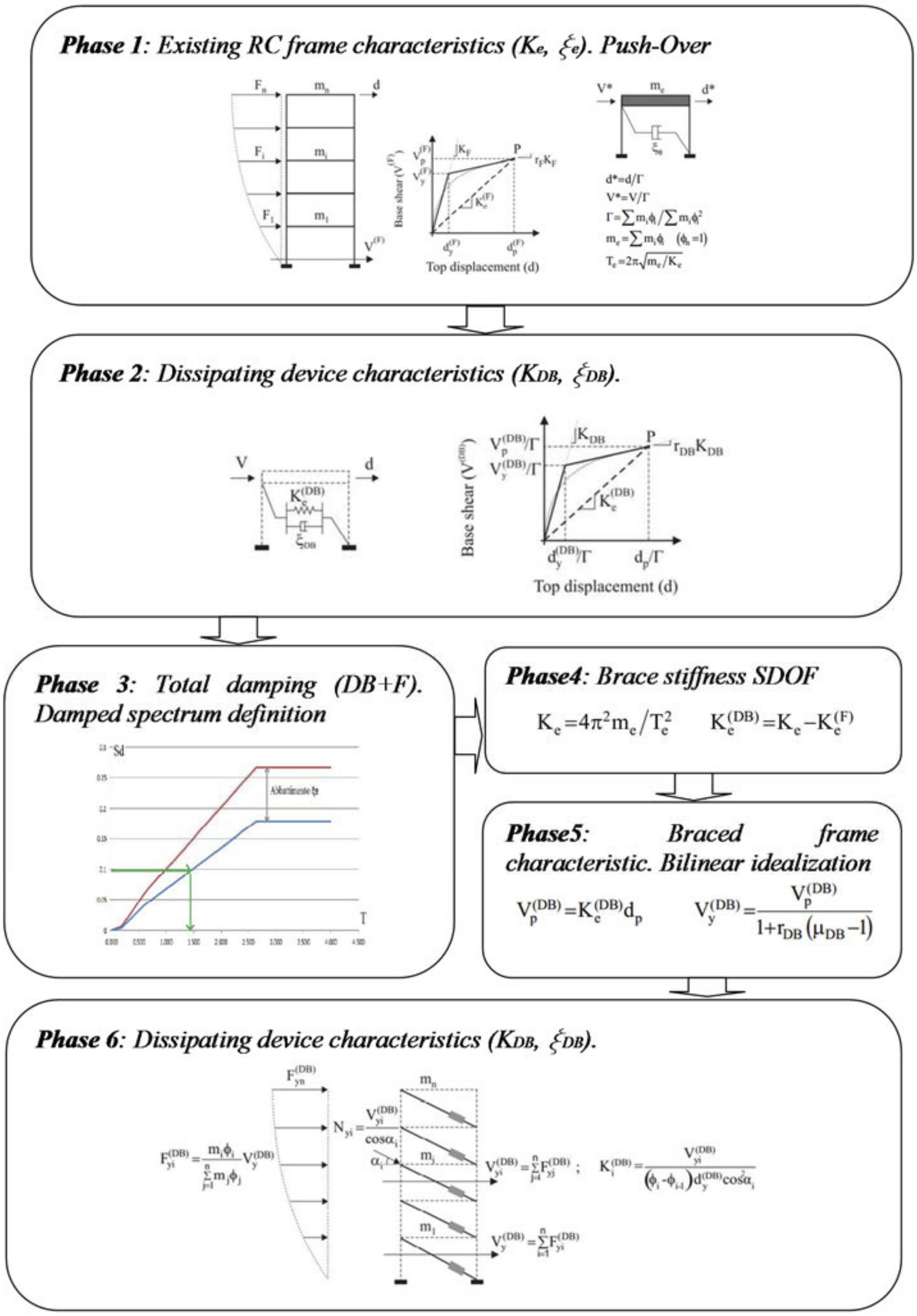


Figure 30: Schematization of the proposed simplified methodology for optimal location of dissipative system.

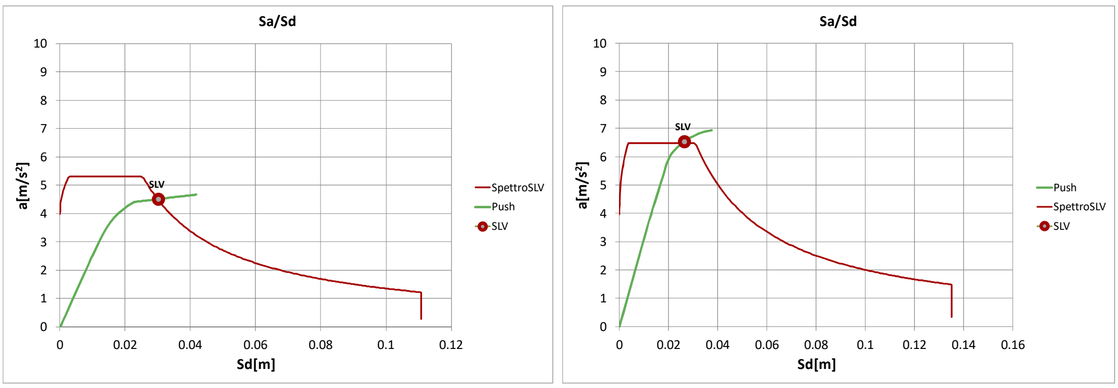


Figure 31: Push-over curve and performance points for different limit states of ESDOF system represented in ADRS plane for braced structure: a) X-direction, Modal pattern of forces, b) Y-direction, Modal pattern of forces.

★ ***Retrofit with application of BRB***

BRBs are widely used in retrofitting projects (Japan, USA, Taiwan, etc.) as bracing systems or to be incorporated into “outrigger” truss systems. The conceptual design of a BRB consists of a steel core introduced into a buckling restraining mechanism (Figure 32); an un-bonding interface (material or a small gap) is provided around the core to decouple the axial load transfer from the core to the buckling restraining mechanism, allowing the core to deform under compression. All the plastic deformations take place in the dissipative (yielding) zone.

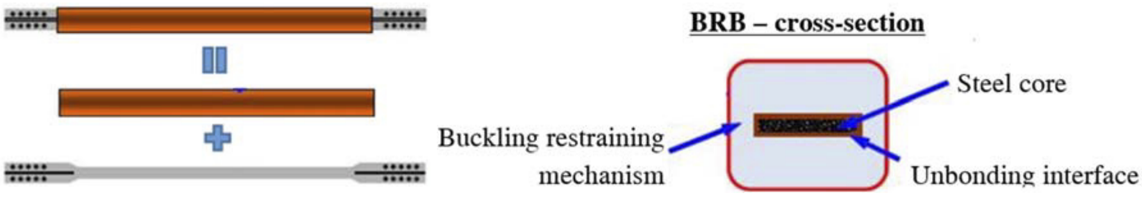


Figure 32: Conceptual scheme of a BRB.

In the technical sheet elaborated in WP1 *“Seismic rehabilitation of vertical systems in concrete buildings by bracing systems”* detailed indications are provided concerning the modelling of the BRB system in the case of linear and nonlinear (including both static and dynamic) analyses, with specific information regarding material, element and connections modelling to the existing building, mainly with reference to actual standards (such as P100-1/2013 [24], AISC 2010 [25], FEMA 2003 [26] and – for some aspects – ASCE and AISC provisions).

In the corresponding WE the application of BRB for the retrofit of the existing r.c. case study building presented in Figure 33, with a detailed description of the modelling technique adopted for the implementation of BRB inside the r.c. frame and of the nonlinear pushover analyses executed, allowing to compare the performance of the retrofit technique through the application of the N2 method (Figure 34, Figure 35). The general procedure described in §2 has been followed.

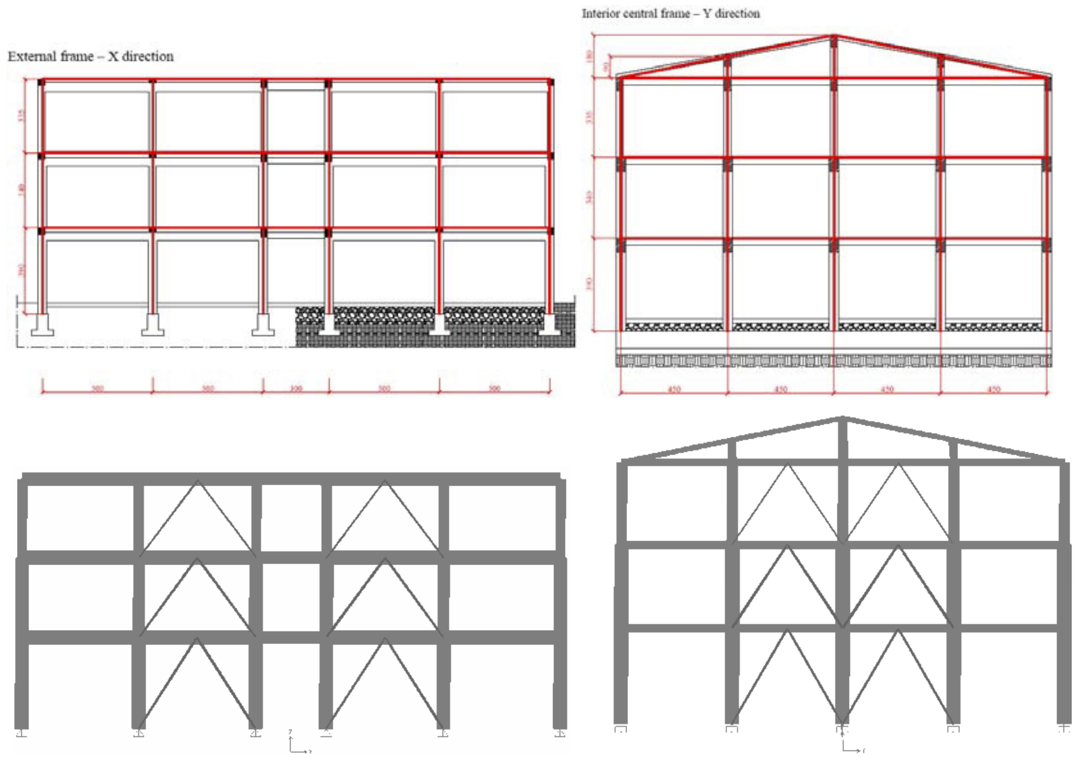
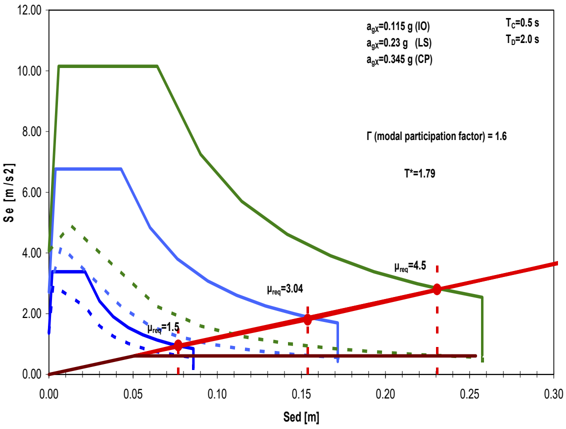
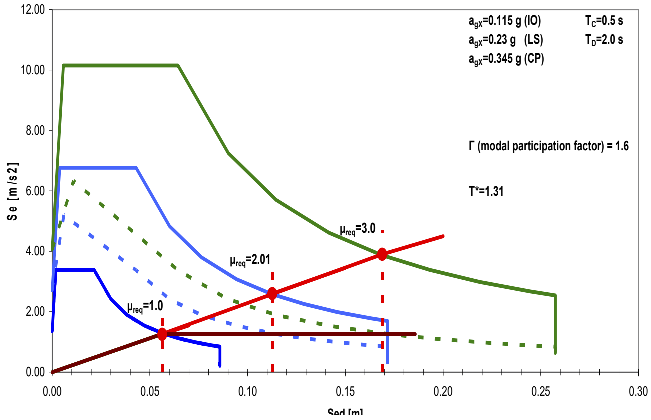


Figure 33: External frame in X direction and interior central frame in Y direction: a) existing MRF configuration, b) retrofitted condition (MRF+BRB).





inelastic spectra for a constant ductility of qu = Rμ = 1.16 — Elastic Spectrum in AD format
limit — Equivalent elasto-plastic displacement rel. from PO curves

Figure 34: Demand and capacity diagram of the equivalent SDOF system MRF - Y direction.

Figure 35 Demand and capacity diagram of the equivalent SDOF system MRF+BRB - Y direction

★ ***Retrofit with application of steel shear walls (SSW)***

In the TS/WE *"Rehabilitation of vertical systems in concrete buildings by steel wall systems"* the procedure for the location and retrofit intervention on existing r.c. buildings with SSW systems is proposed.

Steel Shear Walls (SSW) can be integrated in existing r.c. frames increasing strength and stiffness. SSW consist of thin steel shear panels framed by beams and columns made of steel profiles (Figure 36): the infill plates dissipate energy during the seismic event mainly by yielding in tension field action, while the frame creates boundaries of a shear panel and transmits the forces to the plate. To control the behaviour, the frame shall be designed to stay in the elastic range during cyclic loading. Additional stiffeners may be used to subdivide the SSW leading to more favorable (L/h) ratios (Figure 36), reducing bending forces in the steel boundary elements. Due to the fact that the retrofitted frame is stiffer if compared to the existing condition, the retrofit shall be accurately designed also in relation to the possible increase of resulting seismic actions.

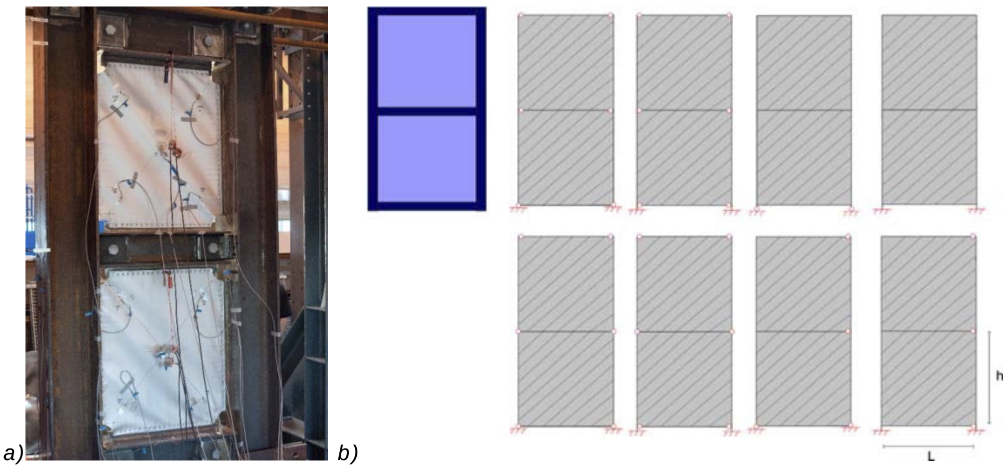


Figure 36: a) SSW tested in the laboratory of RWTH Aachen University, b) scheme of possible connections to existing structure.

Since actual standards do not provide indications for the application of such systems for the retrofit of existing constructions, the TS and the corresponding WE elaborated in WP1 give useful indications for designers and a methodology to be followed in order to evaluate the efficiency of SSW application.

The proposed methodology is aligned with the general procedure presented inside *SteelRetro* project [3] for what concerns the preliminary vulnerability analysis of the state of art of the existing building and the following selection of retrofit approach.

The pre-design of the SSW includes the determination of the SSW systems' location and of the main dimensions in relation to the r.c. frame in which the devices are introduced. The general overview of the design process is presented in Figure 37.

In the WE (deliverable D.1.2) the procedure adopted for the execution of retrofit on the existing r.c. case study building (Figure 38) is deeply presented, paying lot of attention to the connections with existing construction. The assessment of the building after the introduction of the SSW can be executed (Figure 39), in agreement with what foreseen inside *SteelRetro* project [3] adopting the N2 method, comparing the capacity curves of the building before and after retrofit.

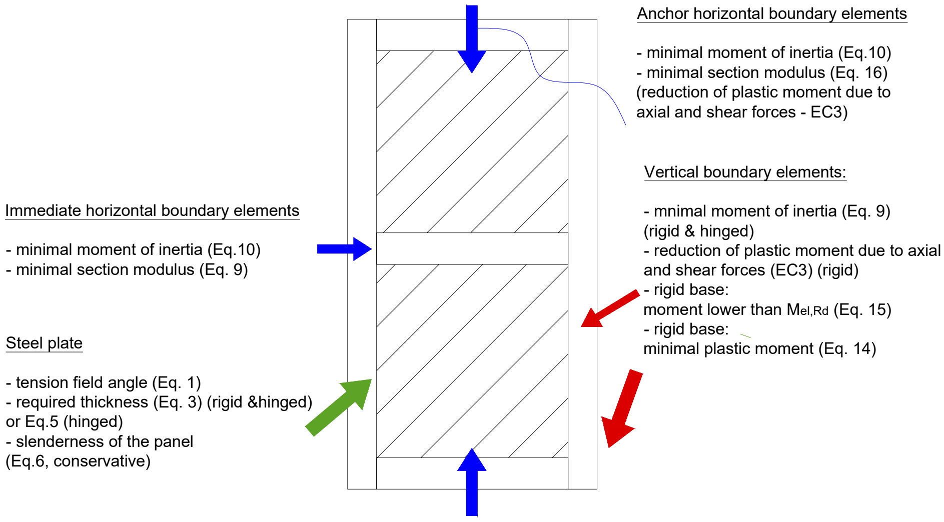


Figure 37: Overview SSW design.

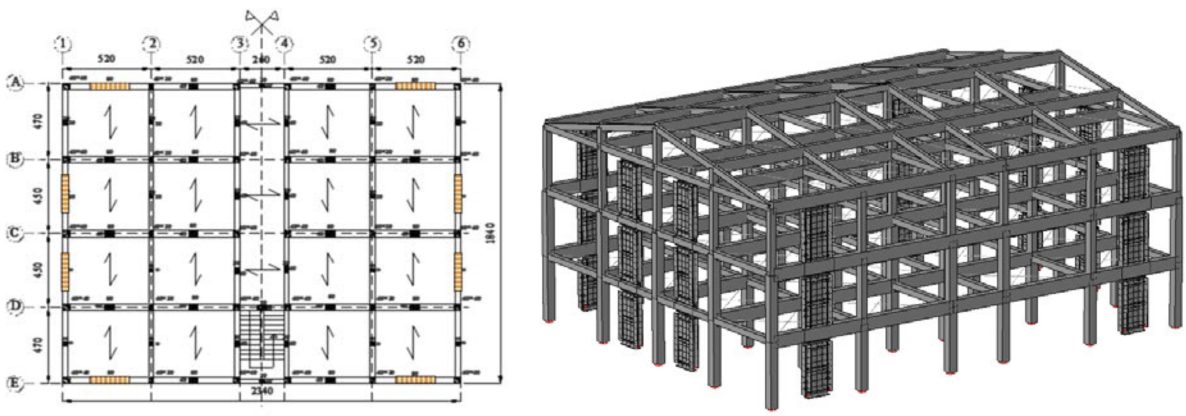


Figure 38: Existing r.c. case study building with location of SSW.

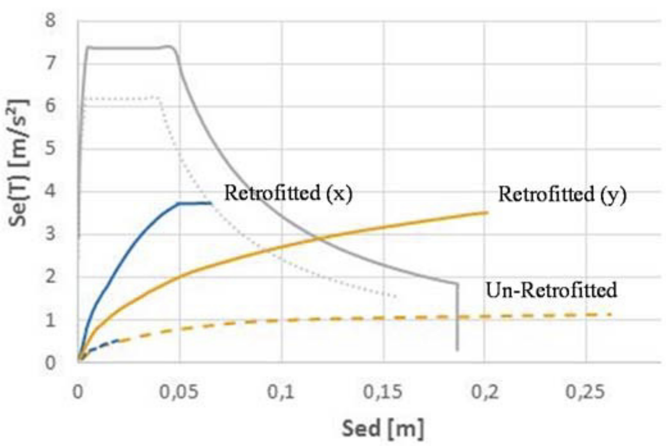


Figure 39: Demand and capacity curves in the ADRS plane before and after retrofit with SSW.

★ ***Retrofit with application of SSCD systems***

The system proposed by Braconi et al. [16] inside *PrecaSteel* project [1] and already briefly presented in §1.1.5 for the application on new buildings can be also used for the retrofit of existing r.c. structures, allowing, also in this case to minimize displacements induced by cyclic action (i.e. after the earthquake) and to consequently reduce damages to non-structural elements.

The procedure proposed in the TS/WE *"Seismic rehabilitation of reinforced concrete buildings with enhanced steel-based dissipative systems"* follows the general methodology previously described, with one modification related to the execution of nonlinear pushover analysis, since, due to the re-centering capacity of the SSCD system the N2 method shall be replaced by the Capacity Spectrum Method [19] with the procedure presented in ATC40 [20].

The procedure is applied to an existing r.c. one-storey/one-bay industrial r.c. building in Italy, damaged after the 2012 earthquake. Evaluation of design actions (with adequate behaviour factor) and load combinations, analysis of mechanical properties of materials, execution of preliminary linear analyses and safety checks (i.e. shear and flexural mechanisms) and application of the CSM method for the determination of the achievement of different limit states evidenced the main structural problems of the existing building (Figure 40), located in correspondence of foundations and ground soil.

Different configurations for the SSDC (varying number of dissipative devices and main characteristics – dissipation and re-centering capability, Figure 41) were analyzed and compared in order to determine the better solution for the existing building (Figure 42), able to minimize the impact and to reduce costs related to application.

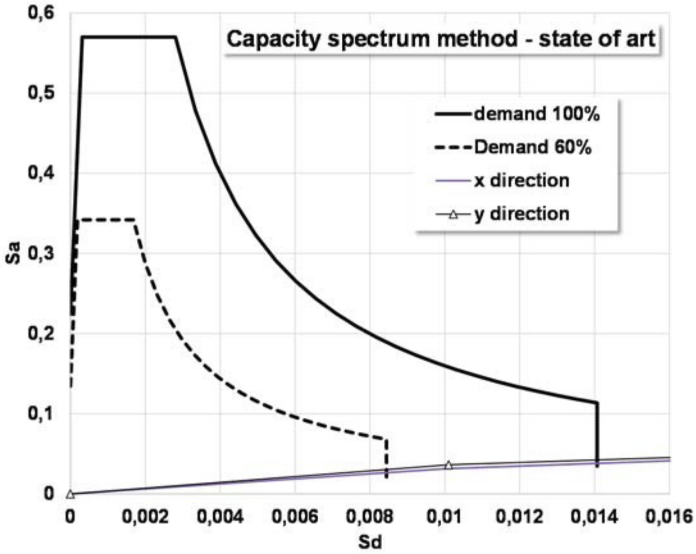


Figure 40: Capacity spectrum method applied for the state of art condition (x and y direction).

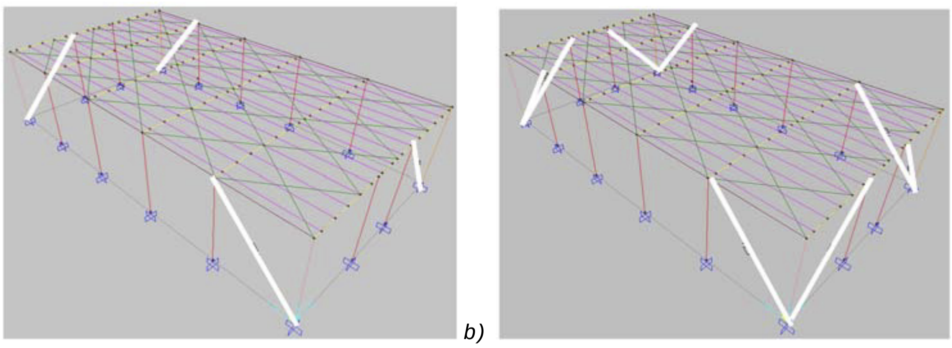
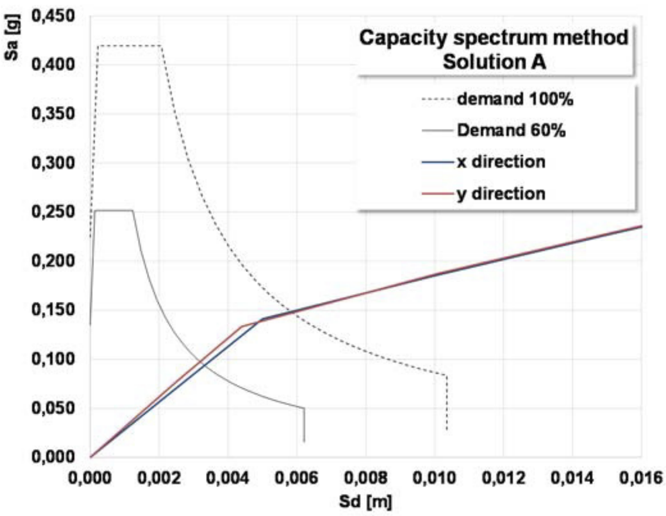


Figure 41: Different configurations of SSCD studied for the analyzed building: a) solution A, b) solution B.



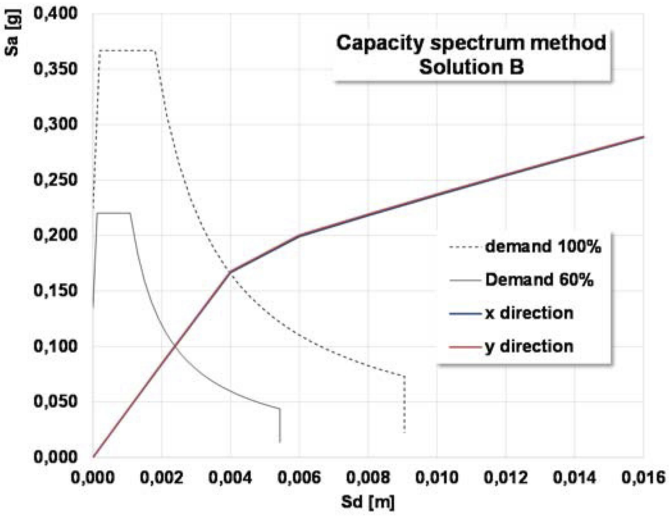


Figure 42: Capacity Spectrum Method applied to the retrofitted solutions (A) and (B)

The application of the dissipative devices strongly conditions the structural behaviour of the existing building. Safety checks according to the prescriptions of actual standards were executed on the updated model of the building, evidencing the higher capability of structural systems, with satisfaction of standards' requirements for columns and, globally, also for isolated foundations and ground soil. Localized problems still remain in correspondence of few foundations, for which a specific intervention shall be adopted.

What is evident, moreover, in the application of considered retrofit intervention is the necessity to locally executed strengthening of the elements characterized by the introduction of SSCD: the connections between the re-centering system and the structural elements shall be deeply analyzed as well as the joint at foundation level.

2. WP2: arrangements of pre-normative background documents

Basing on the results of *Opus* [2], *PrecaSteel* [1] and *SteelRetro* [3] and, moreover, on the practical applications developed inside *Steel-Earth* dissemination project (WP1), contributions and pre-normative background documents, useful for the possible implementation of Eurocodes, regarding the design of new buildings and the rehabilitation of existing constructions have been prepared (WP2). In particular, the following contributions have been prepared:

- A pre-normative document for the harmonization between design and production standard (Eurocodes and Euronorms), basing on the investigations and on the results coming from *Opus* [2] and concerning different structural typologies (MRF, CBF and EBF with steel and composite structure).
- Background contributions regarding the retrofit of existing buildings, including:
    - ❖ Procedure for the application of the Performance Based Seismic Design (PBSD) to existing building, based on *SteelRetro* [3] results.
    - ❖ General rules for the rehabilitation of existing constructions (based on *SteelRetro* [3]).
    - ❖ General rules for the seismic rehabilitation of industrial and/or commercial buildings with r.c. precast structure (based on *PrecaSteel* [1] and *SteelRetro* [3]).

2.1 Pre-normative document for standards' harmonization

2.1.1 General presentation of the problems

Actual design codes for constructions in seismic areas foresee the adoption of the capacity design principles: the "protection" of structural elements adjacent to dissipative zones - in which plastic hinges are expected - is obtained by providing these elements with a resistance higher than the one of the dissipative zone.

Eurocode 8 [5] imposes to take into account the uncertainty on the actual yield strength of the dissipative zone by considering an increased yield strength with respect to the nominal value, through the adoption of an "overstrength coefficient" γ_{OV}. The recommended default value of this coefficient is 1.25 but this remains open to national decisions, γ_{OV} being on the list of the nationally determined parameters. For instance, France recommends values ranging from 1.05 for S460 to 1.20 for S235, while Italy recommends values from 1.10 to 1.20, also in this case in relation to the steel grade.

In this general framework, the research project *Opus* [2] has implemented a number of tasks with the double objective of mainly clarifying the two following aspects:

- What would be the benefit of introducing an upper yield stress limitation on the final performances of steel and steel-concrete structures in seismic areas?
- What are the appropriate values of the overstrength factor γ_{OV} to be applied in the capacity design procedure?

A probabilistic procedure was applied to a set of 40 structural models including MRFs, CBFs and EBFs steel and steel-concrete composite structures (Figure 43), covering industrial as well as office buildings and based on comprehensive statistical data on mechanical properties of steel obtained from two major producers involved in the research project.

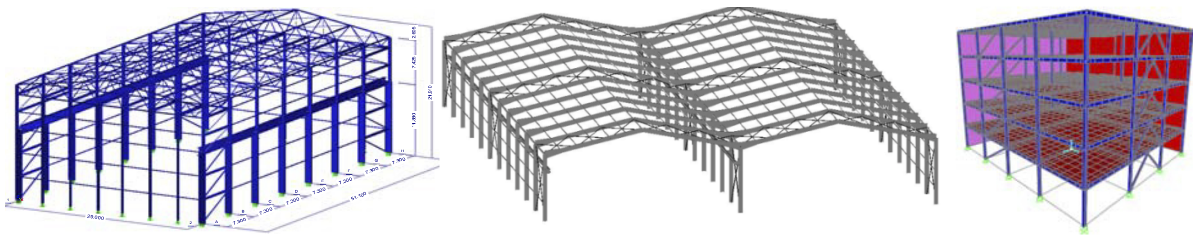


Figure 43: Example of buildings analysed inside Opus research project..

The probabilistic procedure took into account material properties' variability adopting 500 different "samples" (in terms of f_y, f_u and ε_u), generated on the base of the probabilistic model generated inside *Opus* adopting the data provided by the main European steel producers. Incremental Dynamic Analyses (IDAs) were executed using 7 accelerograms spectrum-compatible in order to limit the influence of seismic input. Results were analyzed in terms of fragility curves and failure probabilities.

The main conclusions coming obtained from analyses executed in *Opus* [2] can be summarized as follows:

- Seismic performance of steel and composite structures designed considering $_{OV}$ equal to 1.25 are not degraded by the material properties scattering or by the seismic input variability (limited influence). According to all numerical results, it has been clearly demonstrated that the variability of steel mechanical properties is mitigated by the capacity design approach and by the application of the design procedure of EN1998 taken as a whole.

- The annual probability of failure P_f estimated for all relevant collapse modes (selected in relation to the considered structural typology) is always lower than an acceptance limit fixed equal to 10^{-4}[46] (i.e. on the safe side because many authors proposed also 10^{-3} as acceptable limit).
- The full set of analysed buildings was designed considering steel qualities S235, S275 and S355 with flange thickness higher than 16 mm. The corresponding ranges of material overstrength values obtained from the monitoring of the production are respectively equal to [1.45-1.52], [1.32-1.35] and [1.20-1.34]. The seismic design of all the case studies was however carried out assuming systematically a γ_{OV} equal to 1.25, in agreement with [2]. All case studies showed an acceptable safety level. This suggests that the material over-strength coefficient γ_{OV} works at a global structural level and not at material level and that it would be too restrictive and demanding for a steel structure to identify the γ_{OV} defined in Eurocode 8 with the γ_{OV} coefficient statistically examined and assessed from the material data.
- Imposing an arbitrary upper limitation on the yield stress does not significantly affect the resulting P_f (variation in average of 5%). Only some very few cases are found to exhibit a variation of up to 30% at the very maximum, for a limitation of the yield strength to 1.25 times its nominal value (in case of structures designed in purpose with a very low overstrength). This observation must be considered as indicative because focused only on a set of structures characterized by plan and elevation regularity and designed by experts and so classified as engineered structures. Anyway, this assessment confirms that the definition of an upper limit on the yield stress at the production plant does not bring a decisively higher safety level of steel and composite structures if compared with the level reached considering production requirements imposed by EN10025.
- Imposing an upper limitation on the yield stress in dissipative zones results indeed in a decreasing P_f for the protected capacity-designed members but simultaneously induces an increasing probability of failure associated to the ductile collapse modes. This leads to consider that the definition of upper limitation on the yield stress would have to be defined trying to optimize the effects on both ductile and non-ductile failure modes. A good balance seems to be reached for an upper limit of about 1.3 to 1.375 $f_{y,nom}$.

The full discussion of the results obtained inside *Opus*, in relation to the different considered structural typologies, are summarized in several publications [47], [48], [49].

In the framework of *Steel-Earth* project, in order to further investigate the practical consequences of the *Opus* findings and to go deeper in the analysis of the overstrength issue, some complementary study have been carried out on 3 types of structures selected from the Opus database (one steel EBF, one steel-concrete CBF/EBF and one composite MRF). For each typology, the following questions are addressed:

A. What is the practical impact of on the final design of a modification of the value of the overstrength factor γ_{OV}?

B. What is the actual behaviour of a structure designed referring to the nominal values of the material properties if the real values are considered?

C. Knowing that the behaviour of the connections and foundations was completely disregarded in the original OPUS studies (i.e. connections were assumed as pinned or fully rigid and never likely to fail), what are the consequences of a change in the way to handle the variability of the material properties on the final design of the connections, including accounting for capacity design rules at local level?

In order to fulfil the “A” objective, that is to investigate the influence of adopting specific overstrength factors in the design procedure basing on the actual data coming from producers, selected buildings (Figure 44, Figure 45 and Figure 46) were “re-designed” adopting different values of γ_{OV} in relation to the steel grades adopted for structural elements, selected in relation to the result of statistical investigations based on production data and on further elaborations according to what simply summarized in Table 7.

Table 7: γov values adopted in different countries and evaluated according to the statistical analyses executed inside Opus.

Overstrength factors adopted/suggested				
	S235	S275	S355	S460
France	1,20	-	1,15	1,05
Italy	1,20	1,15	1,10	1,10
(Japan)	1,50	1,40	1,40	
(US)	1,50	1,30	1.10 - 1.20	1,10
Opus (Log Normal)	1,40	1,34	1,17	1,09
Opus (Normal)	1,39	1,33	1,16	1,09
Gündel (Log-Normal)	1,44	1,34	1,21	1,10
Gündel (Normal)	1,43	1,33	1,20	1,10
Suggested values	1,45	1,35	1,20	1,10

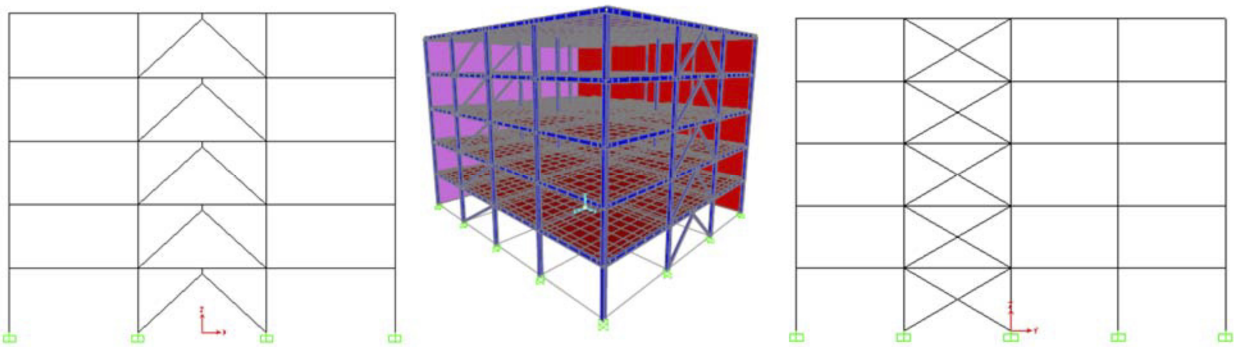


Figure 44: Braced frame (composite) case-study: CBF in one direction, EBF with vertical link in the other direction.

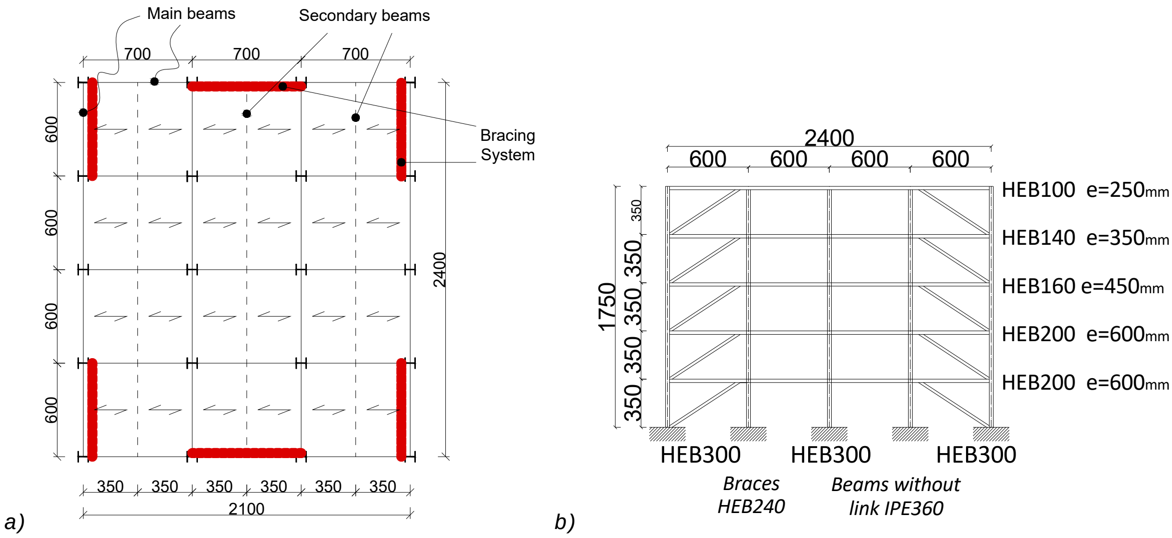


Figure 45: General plan of EBF steel building a) 5 storey buildings (3 and 4 in [2]), b) scheme of elevation.

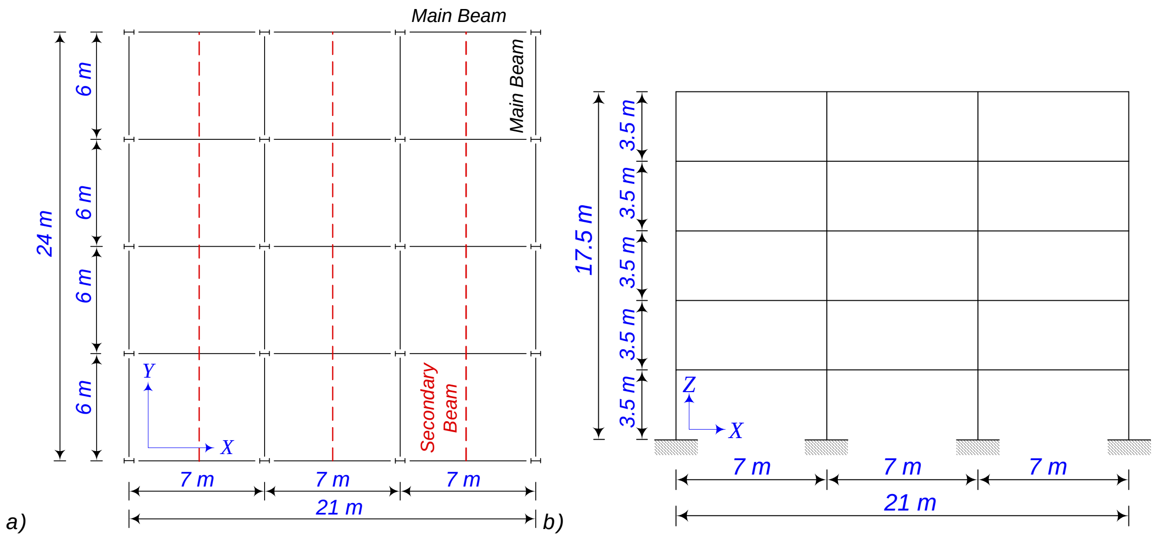


Figure 46: a) MRF Plane view of the composite frames, b) Elevation of the composite frame.

In order to pursue objective "B", static pushover and dynamic nonlinear analyses (IDAs) were executed on the models elaborated inside *Opus* [2] of considered buildings using two groups of variables for the material properties:

- nominal design values of $f_{y,nom}$, $f_{u,nom}$ and ε_u already adopted for the design according to Eurocode 8 [5] in relation to the selected steel grade;
- mean values of the "real" mechanical properties obtained from the probabilistic model elaborated inside *Opus*. This means, for example:
  - For S355: $f_{y,nom}$= 355 MPa, $f_{u,nom}$= 510 MPa, $f_{y,real}$= 415 MPa, $f_{u,nom}$= 565 MPa, ε_u=24%
  - For S275: $f_{y,nom}$= 275 MPa, $f_{u,nom}$= 430 MPa, $f_{y,real}$= 350 MPa, $f_{u,nom}$= 460 MPa, ε_u=24%

Results of nonlinear analyses were compared in terms of activation of significant collapse modalities for each considered structural typology; this allowed to assess the "effective" structural performance of buildings designed using nominal values but realized with steel grades having different "real" mechanical properties, and, at the same time, to evaluate the efficacy of actual overstrength coefficient in the protection of non-dissipative elements.

The third objective "C" has been introduced in Steel-Earth due to the complete neglecting of the analysis of connections at both beam-to-column and foundation level. Obviously, this aspect mainly refers to the case of MRF frames.

2.1.2 Results of further investigations basing on Opus results

- ***Objective A***

The design of steel structures following what foreseen by actual design standards often leads to buildings that are not optimized for what concerns the sections of non-dissipative members (i.e. braces, columns and beams without links in EBF), due to the necessity of fulfilling limitations that are related not only to the capacity design approach but also to:

- gravity loading;
- drift overcoming;
- second order effects (that shall be lower than 0.20 to have the possibility to execute linear analysis for the design);
- buckling of members in compression.

The design of non-dissipative members (such as columns, braces and beams without links) is executed adopting an overstrength factor globally equal to $1{,}1 \cdot \gamma_{ov} \cdot \Omega_{\min}$, being $\Omega_{\min} = \min\left(\frac{M_{Sd,i}}{M_{Rd,i}}\right)$ in the case of MRF, $\Omega_{\min} = 1{,}5 \cdot \min\left(\frac{M_{link,Sd,i}}{M_{link,Rd,i}}\right)$ or $\Omega_{\min} = 1{,}5 \cdot \min\left(\frac{V_{link,Sd,i}}{V_{link,Rd,i}}\right)$ respectively for bending and shear links in EBF and $\Omega_{\min} = \min\left(\frac{N_{Sd,i}}{N_{Rd,i}}\right)$ for CBF buildings.

The design of EBF buildings in *Opus* [2], for example, has been strongly influenced by second order effects (i.e. control of θ coefficient) and by the control drift limitation, leading to an additional oversizing of non-dissipative elements respect to the one necessarily due to $1{,}1 \cdot \gamma_{ov} \cdot \Omega_{min}$.

As a general comment (the detailed description of the topic can be found in deliverable D.2.1), results of additional investigations executed inside *Steel-Earth* evidenced that the adoption of reduced values of the material overstrength factors (equal for instance to 1.20 and 1.15) is then not really useful to optimize protected elements, since the capacity design approach is not always the most significant requirement.

The situation is even more clear regarding MRF: the γ_{ov} factor has no single effect on the design of the members; for example, the design of the column members is actually governed by the deflection conditions and the weak beam-strong column condition. On the other hand, although the actual material overstrength factors observed from real production tends to be higher than the recommended value of 1.25, structures designed on the basis of this value seems to present a sufficient reliability level.

- ***Objective B***

The scattering of mechanical material properties according to what is observed from statistical analyses of data coming from the actual European production of steel profiles alters only in a *limited way* the effective seismic behaviour of structures (Figure 47 for MRF, Table 8 for EBF).
As observed comparing results of IDA and pushover analyses carried out with nominal and actual values of the mechanical properties of steel, the levels of PGA triggering a collapse remain higher that the ones adopted in the design, confirming thus the general oversizing of the building, with a difference of only ±0.05g between nominal and actual values and without visible consequence on the failure mechanisms, that remain the ones conditioning the design rules of Eurocode 8 [5]. This limited influence is by far lower than the uncertainty on the reliability of structural modelling and analysis or on the deformation capacity of the dissipative elements.

Table 8: EBF Building with short shear links: PGA activating collapse criteria with nominal and actual values of materials.

Building 3	3EBFX Link		3EBFX Drift		3EBFY Link		3EBFY Drift		3EBFY Brace	
	nom.	real	nom.	real	nom.	real	nom.	real	nom.	real
PGA [g]	0,51	0,51	0,50	0,57	0,49	0,49	0,52	0,51	0,69	0,78

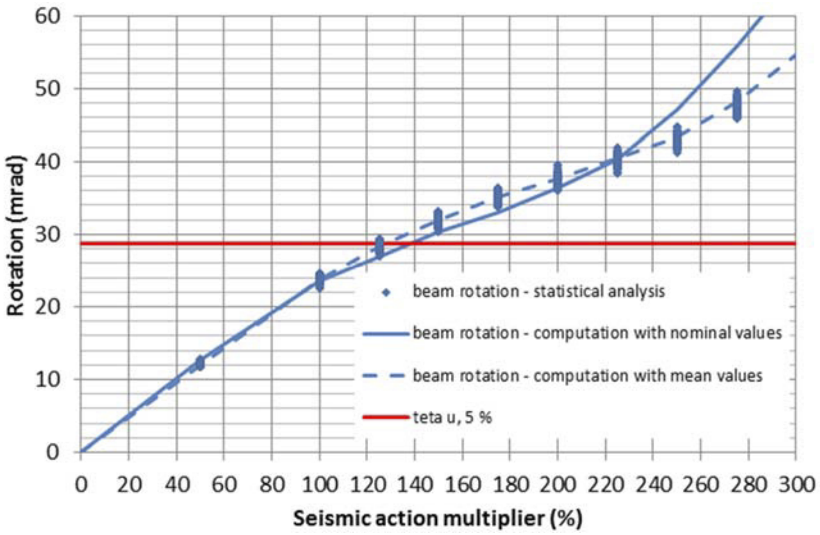


Figure 47: Comparison of the evolution of the rotation in the plastic hinges of the beams in the case of MRF composite buildings.

- ***Objective C***

Several investigations were executed considering beam-to-column joints and foundation of EBF and MRF buildings.
In the case of EBF, the design actions adopted for the sizing of foundations are given by the expression $E_{F,G} + 1.1\gamma_{Rd} \cdot \Omega_{min} \cdot E_{F,E}$ where $E_{F,G}$ and $E_{F,E}$ are respectively the values of the axial force coming from gravitational and seismic loads and γ_{Rd} is the overstrength factor assumed equal to 1.20, not dependent on material: this means that the adoption of different γ_{ov}, in this case, does not directly influence the sizing of foundation. If a limited optimization of profiles can be executed varying the γ_{ov} since the design was mainly influenced by second order effects and drift limitations

respect to capacity design, no significant modifications of actions on columns' base can be revealed (Table 9).

In the case of MRF composite buildings, values of actions on foundations obtained from elastic design are far under 95% fractiles of nonlinear dynamic analyses, as can be observed from Table 10. Forces demands on bases deduced from nonlinear dynamic analysis appear higher than what can be found from the design analysis and the overstrength factors and method proposed in EN 1998 [5]. Column feet are submitted to an imposed rotation, and the large over resistance of the steel leads to an over-resistance in plastic normal force, that increases dramatically the plastic moment, and thus the moment exerted on the bases.

No definitive conclusion can however be taken from this observation, because this study is only made on forces demand, and does not take into account the design of the base. It is obvious this design presents large safety coefficients, representing the large dispersion that exist in the resistance of soils, and in the knowledge of true characteristics and response of soils.

Table 9: Design of non-dissipative members considering the adoption of different material overstrength factors (building 3).

γ_{ov}	Ω	$N_{col\ Ed(Max)}$	$N_{col\ Ed(min)}$	$N_{braces\ Ed}$	$N_{col.Fd\ (Max)}$	$N_{col.Fd\ (min)}$
	$\Omega_i = 1{,}5 \cdot \min\left(\frac{V_{p,link,i}}{V_{Ed,i}}\right)$	$N_{Ed,G} + 1{,}1 \cdot \gamma_{ov} \cdot \Omega_{\min} \cdot N_{Ed,E}$			$E_{F,G} + 1.1\gamma_{Rd} \cdot \Omega_{\min} \cdot E_{F,E}$	
		HE280B	HE280B	HE240A		
1,25	1,53	811,8 kN	-2362,8 kN	965,6 kN	595,6 kN	-2137,2 kN
		HE280B	HE280B	HE240B	γ_{Rd}=1.20	γ_{Rd}=1.20
1,25	1,506	782,5 kN	-2344,2 kN	951,2 kN	584,4 kN	-2146,2 kN
1,20	1,506	722,1 kN	-2283,8 kN	914,3 kN	584,4 kN	-2146,2 kN
1,15	1,506	658,0 kN	-2219,7 kN	875,1 kN	584,4 kN	-2146,2 kN

Table 10: Forces on bases: MRF composite building.

Comparison of actions on foundation	Elastic design	Nonlinear analyses
	EN 1998 (γov = 1.25, γ_{Rd} = 1.2)	*95% - fractiles (500 values)*
M_{max} - bases - external columns	674 kNm	925 kNm
M_{max} - bases - internal columns	696 kNm	879 kNm
V_{max} - bases - external columns	266 kN	335 kN
V_{max} - bases - internal columns	294 kN	364 kN

Similar considerations can be executed in the case of beam-to column joints for MRF composite buildings and are deeply described in the corresponding deliverable D.2.1. Anyway, based on the few case-studies considered in the present document, it appears that the demand on joints and foundations obtained from the overstrength values recommended by Eurocode 8 [5] are lower than the one evaluated by a direct analysis using actual values of the material properties of the structural elements. It is however not possible at this point to conclude on the reliability of the Eurocode 8 [5] recommendations since the actual distribution of the resistance of connections and bases has not been specifically investigated. Complementary statistical studies dealing with the demand-resistance relation for connections and bases are still required to draw definitive conclusions on the overstrength factors to be recommended for their design.

2.2 Background documents with indications for the retrofit of existing constructions

2.2.1 Performance Based Seismic Design - PBSD

One of the main objectives achieved inside *SteelRetro* project was the modification of the Performance Based Seismic Design (PBSD) to be applied to existing constructions.

New standards for seismic design ([5], [17], [20], etc.) introduce a clear method to predict the behaviour of the buildings subjected to earthquake motions. This procedure, with opportune modifications, can be adopted also to pursue rehabilitation objectives in the case of existing structures: by understanding of Performance Objectives, the engineer can design the Damage Levels of structural and non-structural members at a certain intensity of seismic action and consequently organize the retrofit interventions at dot/local/global level.

This approach, globally known as "Performance-Based Earthquake Engineering" (PBEE), is able to provide methods for designing, constructing, evaluating and maintaining buildings, making them able to guarantee predictable structural performance under seismic action. Performance is measured in terms of the amount of damage sustained by the building under seismic action: multiple target performance levels are expected to be achieved - or not exceeded – under earthquakes of specified intensity.

Structures shall be able to meet specific *Performance Objectives*, facing moderate earthquakes with limited structural and non-structural damages and major earthquakes with significant damage to structural and non-structural elements but with limited risk to life safety. In the case of existing buildings, *Rehabilitation Objectives* [45] – i.e. one or more retrofit goals relating a target Building Performance Level to an Earthquake Hazard Level (the association of a damage state to a hazard level) - shall be selected based on building's occupancy, importance of the functions occurring inside, economic considerations including costs related to damage repair and business interruption and, moreover, the potential importance of the building as a historical or cultural resource. Current national codes establish various Rehabilitation Objectives.

The PBSD procedure for the rehabilitation of existing building has been widely explained, with reference to its main components (i.e. the determination of Building Performance Objectives, hazard level, Performance Levels for both structural and non-structural elements) in the specific background document contained in deliverable D.2.2.

For sake of clarity and to make an example, Table 12 shows the correlation between different components of the considered procedure for the case of a "fictitious case study" in order to attain a given rehabilitation objective. The general flow-chart of the procedure presented in Figure 48 can be adopted as accepted methodology.

The building performance objectives (BPO) for a residential non-seismic r.c. frame structure shall be established by the owner together with the designer: this means, in the common practice, to select if the building shall provide the "traditional" level of safety (i.e. Basic Safety Objective: little damage from relatively frequent, moderate earthquakes, but significant damage and potential economic loss from the most severe and infrequent earthquakes) or, otherwise, if limited or enhanced rehabilitation levels (in relation to different intensities of hazard) are required.

Considering the selected case study building and the desired performance objectives (as a function of expected damage for a specific level of seismic intensity), the two situations (*k+p*) presented in Table 11 for the Building Performance Levels (BPL) shall be checked:

- for a rare earthquake (475 years) the BPL shall be in the Life Safety range;
- for a very rare earthquake (2475 years) the BPL shall be in the Collapse Prevention range.

Once fixed BPL, the damages for structural and non-structural members shall be assessed (according to general tables presented in D.2.2, summarized in Table 12).

For the considered case study, *"k"* verification is associated to Life Safety Level for both structural and non-structural elements. On the other hand, *"p"* verification corresponds to Collapse Prevention Level imposed for structural elements and Hazards Reduced Level imposed for non-structural elements, in order to avoid risks to users due to the falling of parapets, cladding panels, heavy plaster ceilings.

Table 11: Rehabilitation Objectives.

		Target Building Performance Levels			
		Operational Performance	Immediate Occupancy Performance	Life Safety Performance	Collapse Prevention Performance
Earthquake Hazard Level	50%/50 year	a	b	c	d
	20%/50 year	e	f	g	h
	10%/50 year	i	j	k	l
	2%/50 year	m	n	o	p

Table 12: PBE application example.

Objective	Verification	Earthquake hazard (MRI years)	Building Performance Level	Structural Performance Level	Non-structural Performance Level
Basic Safety Objective	k	474	Life Safety (3-C)	Life Safety (S-3)	Life Safety (N-C)
	p	2 475	Collapse Prevention (5-D)	Collapse Prevention (S-5)	Hazards Reduced (N-4)

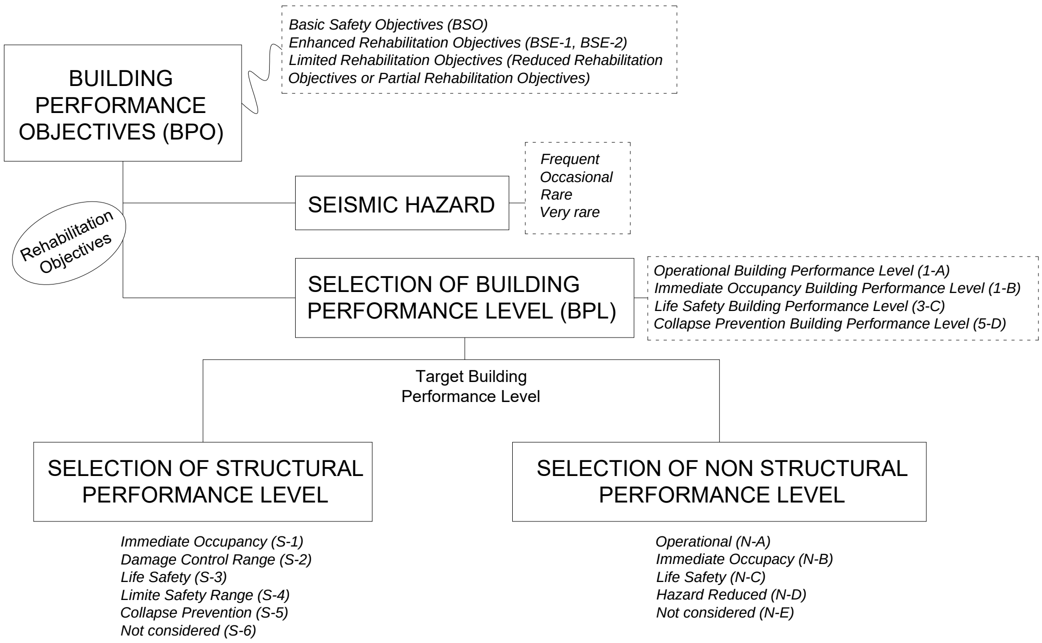


Figure 48: Selection of seismic hazard and performance levels for structural and non-structural members.

2.2.2 Rules for rehabilitation of existing constructions

In order to attain the desired building rehabilitation objectives, as a function of the building's typology, hazard level/intensity of seismic action and structural performance, several retrofit techniques can be adopted for existing buildings that, in their current state, are not able to provide a sufficient margin of safety towards earthquake motions.
The document presenting general rules for rehabilitation has been prepared by CERI collecting the results obtained from *SteelRetro* [3] and from the applications and procedures developed in WP1 of *Steel-Earth* project, with the aim of providing indications that can be used as guidelines for the enhancement of future Eurocodes on existing buildings which are currently under development.

The contents of the contribution regard the use of different steel-based intervention techniques for the retrofit of existing concrete or masonry buildings, defining specific rules for rehabilitation of vertical elements, horizontal floors, roof and foundation systems. In the case of vertical elements of r.c. buildings, the attention was focused on "innovative" solutions such as BRB and SSW respect to "traditional" CBF or EBF and providing simple rules for the design and the application of such systems, actually not introduced in current European standards (even if present in several national and international standards).

The document is divided into four sections:

1. Rehabilitation of vertical systems in r.c. existing frames.
2. Rehabilitation of vertical systems in masonry existing buildings.
3. Retrofit of floors and roof systems.
4. Retrofit of foundation system.

For each investigated intervention technique, general design rules, tips for a proper modeling of the new added elements and, if available, a design methodology of such elements are provided. In the case of introduction of a new resisting system towards horizontal actions a strategy for the optimal placement of the additional bracing system to achieve the desired structural performance with the minimum economic effort has been elaborated and are presented in the corresponding deliverables. Just to give an example, the guidelines for the design of BRB and SSW as bracing members are briefly presented hereafter.

More details can be found in deliverable D.2.2/D.2.3.

- ***Guidelines for the design of retrofit with SSW***

Modelling indications. The steel plate introduced as bracing system can be described using a strip model [29] with a series of pinned, tension only stripes. The cross-sectional area of each stripe equals the stripe's width times the plate's thickness. To evaluate the distributions of moments, axial and shear forces in the boundary elements, the system can be divided into two sub systems: the steel frame without the steel panel under sway action and the steel frame under panel forces from the tension field action (Figure 49). The panel forces can be further divided into vertical and horizontal components (Figure 50).

After the pre-design, the SSW can be modeled by nonlinear beam elements using the strip model with a number of strips at least equal to 10. A member ductility μ equal to 4.0 can be assumed for ordinary steel grades if the SSW panel is welded to the frame or if connections by fasteners are used; low yielding steel grades for the panel can increase the member ductility up to 8.0.

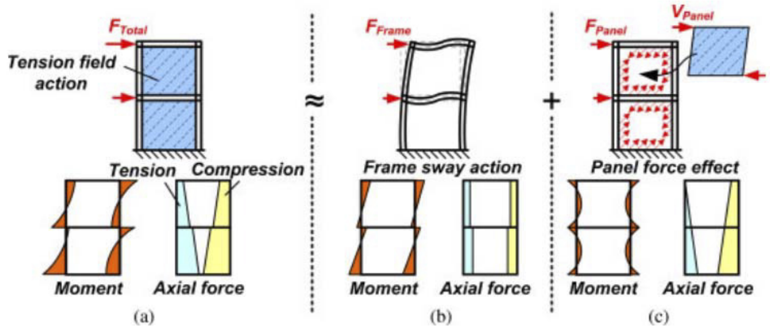


Figure 49: Moments and axial forces from (a) substitution of (b) sway action and (c) the panel force effect by Li et al. [30]

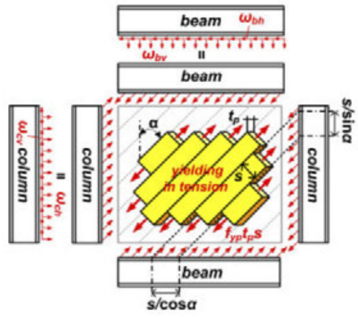


Figure 50: Fully yielding panel forces acting on the boundary elements (Li et al. [30]).

Pre-design methodology. The pre-design of the SSW can be executed considering the following steps, better detailed in deliverable D.2.2 and, for the numerical application, in deliverable D.1.2.

[1] Selection of an adequate aspect ratio (suggested between 0.8 < L/h < 2.5).

[2] Determination of the inclination angle α of the tension field that is formed by the infill plates to resist lateral loads, defined according to Bruneau et al. [31]:

$$\alpha = tan^{-1}\sqrt[4]{\frac{1+\frac{t_w \cdot L}{2A_c}}{1+t_w \cdot h \cdot \left(\frac{1}{A_b}+\frac{h^3}{360 \cdot I_c \cdot L}\right)}}$$

α angle of the tension field measured relative to the vertical

t_w thickness of shear panel

h storey height

L distance between vertical boundary element centerlines

I_c moment of inertia of vertical boundary element

A_c cross-sectional area of vertical boundary element

A_b cross-sectional area of horizontal boundary element

[3] Evaluation of the maximum base shear force capacity of a SSW with hinged connected boundary elements can be calculated using the following equation (Bruneau [31] and AISC 341-10 [25]), being fy the yield strength of the shear panel:

$$V = \frac{1}{2} \cdot f_y \cdot t_w \cdot L \cdot \sin(2\alpha)$$

[4] Evaluation of the shear panel thickness knowing the required base shear force:

$$t_w = \frac{2V}{f_y \cdot L \cdot \sin(2\alpha)}$$

[5] Evaluation of the stiffness of the SSW through the equation:

$$K = \frac{1}{4} \cdot \frac{E \cdot t_w \cdot L}{h} \cdot \sin^2(2\alpha)$$

[6] The slenderness of the panel should comply the following restriction as a conservative recommendation:

$$\frac{\min(L,h)}{t_w} \le 25 \cdot \sqrt{\frac{E}{f_y}}$$

[7] For the design of the column, flexibility parameter should be:

$$\omega_h = \sin\alpha \cdot h \cdot \sqrt[4]{\frac{t_w}{2 \cdot L \cdot I_c}} \leq 2{,}5$$

$$I_c \geq \frac{0{,}00307 \cdot t_w \cdot h^4}{L}$$

[8] The upper bound for the top horizontal element as well for the bottom element is given by Dastfan et al. [32] (the web thickness of the boundary elements shall be higher than the thickness of the shear panel):

$$\omega_L = 0{,}7 \cdot \sqrt[4]{\left(\frac{h^4}{I_c} + \frac{L^4}{I_b}\right) \cdot \frac{t_w}{4L}} \begin{cases} \leq 2{,}5 & \text{for the top horizontal boundary element} \\ \leq 2{,}0 & \text{for the bottom horizontal boundary element} \end{cases}$$

[9] The other parameters of the elements are:

$$\omega_{cv} = \omega_{bh} = f_{y,w} \cdot t_w \cdot \cos\alpha \cdot \sin\alpha = \frac{1}{2} \cdot f_{y,w} \cdot t_w \cdot \sin 2\alpha$$

$$\omega_{ch} = f_{y,w} \cdot t_w \cdot \sin^2\alpha$$

$$\omega_{bv} = f_{y,w} \cdot t_w \cdot \cos^2\alpha$$

[10] The plastic moment M_p of the column under compression at the base can be expressed as:

$$M_p \geq 0{,}4 \cdot \omega_{ch} \cdot h^2$$

[11] The moment M_t at first storey of the SSW is given by:

$$M_t = \frac{M_p}{\lambda} + \left(1 + \frac{1}{\lambda}\right) \cdot \left(\frac{\omega_{ch} \cdot h^2}{12}\right)$$

Where factor λ describes the relation between the base and the first-storey moment before plastic hinges develop (as shown in Figure 51). Note that this procedure is only necessary for the compressed column.

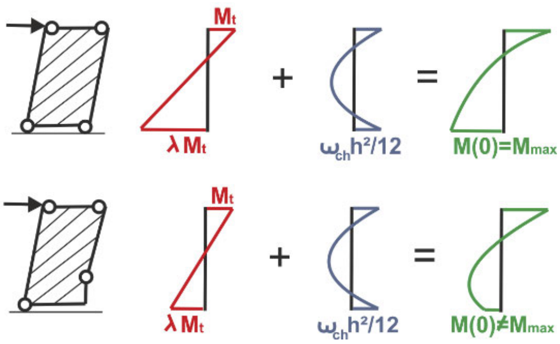


Figure 51: Plastic hinge locations and moment diagrams for compressed columns: a) proper and b) improper design.

[12] The section modulus W_b of an anchor horizontal boundary elements has to fulfil the following restriction (Vian and Bruneau [33]):

$$W_b \geq \frac{L^2 \cdot t \cdot \cos^2\alpha}{4} \cdot \frac{f_{y,w}}{f_{y,b}} \cdot \left[\frac{1}{1 + \sqrt{1 - \beta^2}}\right]$$

$$\beta = \frac{M_{pl,Rd}^{RBS}}{M_{pl,Rd}}$$

In the case of perforated panels:

Strength formula for plates with circular perforations (Purba and Bruneau [34]):

$$V_{y,perf} = \left(1 - 0{,}7\frac{D}{S_{diag}}\right) \cdot V_y$$

$V_{y,perf}$ *strength of the shear wall with perforations*

D *diameter of the perforations*

S_{diag} *distance between the centers of the holes*

V_y *strength of the shear wall without perforations*

Methodology of connection design. Yield strength for welded connections can be evaluated with EN1998-1:2005 [5], eq. 6.2(3)a.

Connection to reinforced concrete frame. The capacity of the anchors (connecting the transfer beams and the transfer plate) can be evaluated as defined in SteelRetro [3] project (§10.2.2.3.1, eq. 10.15):

$$V_{Rk,d} = k \cdot \alpha \cdot A_s \cdot f_{u,k} / \gamma_M$$

k *0.8 for group behaviour*

α *0.4 for concrete strength ≤ C20/25*

A_S *section area of anchor*

f_u *tensile strength of anchor*

More indications can be found in the corresponding background document (deliverable D.2.2).

- ***Guidelines for the design of retrofit with BRB***

Modelling and Analysis indications. The steel core of BRB is composed of three segments ([35],[36]):

1. Restrained yielding segment, L_c: most of the elastic and all plastic deformations take place here.
2. Restrained non-yielding segment, L_t: an extension of the yielding segment with enlarged area to ensure elastic response.
3. Unrestrained non-yielding segment, L_j: used to connect the BRB to other structural elements.

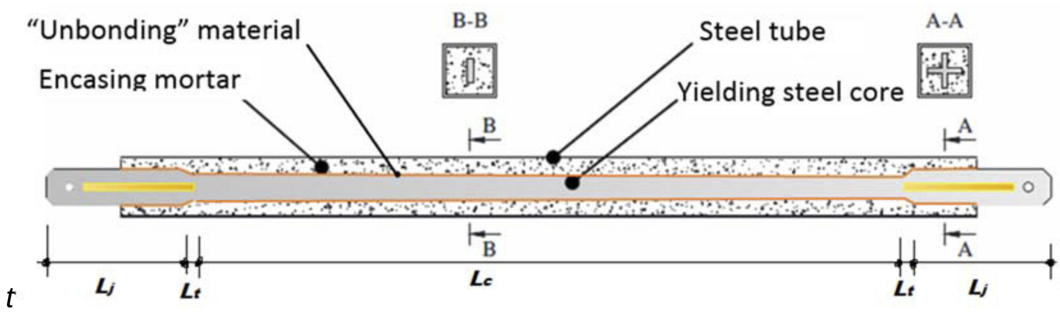


Figure 52: Details of a typical BRB ((a) P100-1/2013 [24]).

The strength, stiffness and ductility of a BRB can be easily adjusted:

- The strength (N_{Rd}) can be determined as the area of the core corresponding to the dissipative segment, A, multiplied by the nominal yield strength (f_y) and divided by a safety factor:

$$N_{Rd} = \frac{A \cdot f_y}{\gamma_{M0}}$$

- The stiffness K_{eff} can be determined based on the geometrical aspects (L_c, A_c, L_t, A_t, L_j, A_j, - length and area of the dissipative yielding segment, transition segment, and connection segment respectively) and the Young's modulus of the steel-core, E. By varying one of the geometrical aspect a new stiffness can be obtained with the formula (Tsai [37]):

$$K_{eff} = \frac{1}{\frac{L_c}{EA_c} + \frac{2L_t}{EA_t} + \frac{2L_j}{EA_j}} = \frac{E \cdot A_j \cdot A_c \cdot A_t}{A_j \cdot A_t \cdot L_c + 2A_c \cdot A_t \cdot L_j + 2A_c \cdot A_j \cdot L_t}$$

- Ductility μ_{max} can be adjusted by varying the type of steel used for the core (material ductility), and the level of strain in the dissipative segment ε_c (varying the ratio $\alpha = L_c / L$,).

$$\mu_{\max} = \frac{\Delta_{\max}}{\Delta_{by}} \geq 20 \text{ recommended} \leftarrow \varepsilon_c = \frac{\Delta_{\max} \cdot \cos\theta}{\alpha \cdot L} \text{ (Razavi et al.[41])}$$

Δ_{max} *the maximum relative story displacement corresponding to twice the elastic design story drift, but not less than 2 % of the story high. If dynamic nonlinear analysis is performed, then the maximum displacement will be taken directly from the analysis;*

Δ_{max} *the yield displacement.*

ε_c *the maximum plastic core strain.*

θ *the slope.*

L *work point to work point length of the BRB.*

The most appropriate model should be chosen on the basis of the type of analysis:

If *linear analyses* are adopted, BRBs can be modeled using elastic truss elements (when a pinned connection is used, or when stiffness of a rigid connection is neglected in analysis) or frame elements. Some authors suggested approximating brace stiffness to the one of the yielding segment alone, as most of the elastic deformations and all of the plastic ones are concentrated here (Clark et al.[38]). More recent studies (Saxey et al. [39]; Robinson [40]) suggest using a stiffness factor, K_f, which amplifies the stiffness of the core, $K = A_cE / L_{wp\text{-}wp}$, when modeled with a constant area, A_c, from work-point to work-point, $L_{wp\text{-}wp}$ (Figure 53). For the same frame geometry different types of connections will introduce different K_f values (Figure 54).Also, the stiffness of the brace varies depending on the elastic of plastic domain of reference (Figure 55).

$$K_{BRB} = K_f \cdot \frac{EA_c}{L_{wp-wp}} \quad \textit{where } K_f = 1{,}2...2{,}0$$

The design axial strength of a BRB can be determined as previously defined.

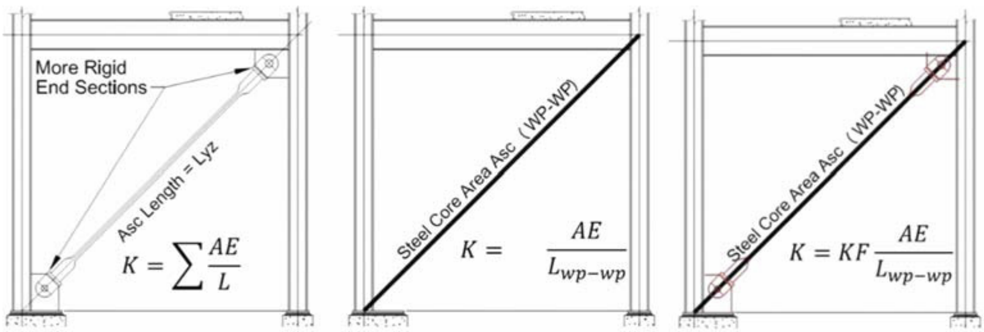


Figure 53: Modelling the stiffness factor, K_f (Saxey et al., [39])

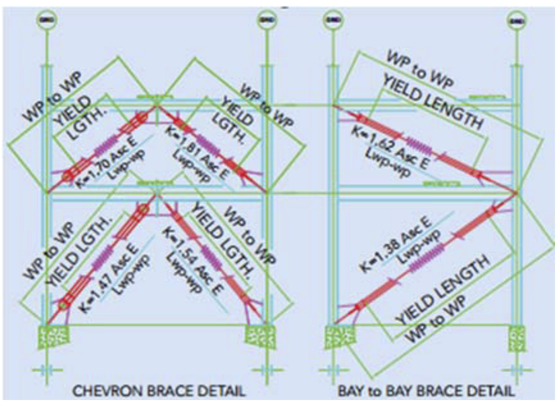


Figure 54: The variation of the stiffness factor, K_f, due to frame geometry and type of connection (pinned versus welded) (Robinson, [42]).

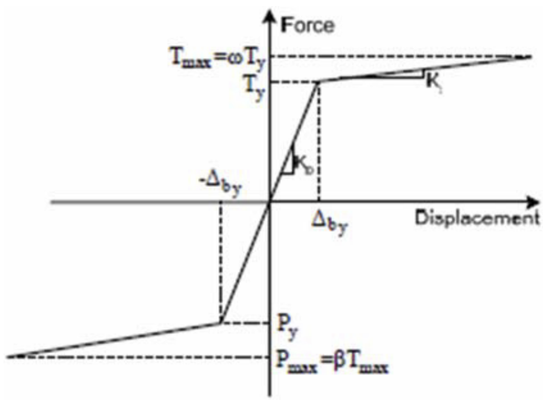


Figure 55: The variation of the BRB stiffness depending on the behavior domain (n.d.).

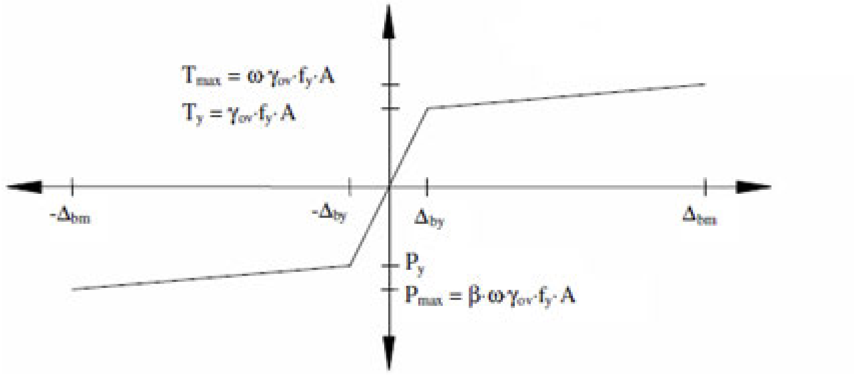


Figure 56: Bilinear modelling (P100-1/2013 [24])

If *nonlinear static analysis* shall be executed, Two factors are to be accounted for in addition to the initial stiffness. The first one is the compression-strength adjustment factor, β, reflecting higher strength in compression in comparison with the strength in tension. The second one is the tension strength adjustment factor, ω. A simple bilinear model based on the above consideration is shown in Figure 56. This force-displacement relationship can be incorporated in a nonlinear truss element in order to obtain a complete model of a BRB for a pushover analysis.

The adjusted tension and compression strength can be written as:

- Tension $T_{\max} = \omega \cdot \gamma_{ov} \cdot f_y \cdot A = \omega \cdot T_y$
- Compression $P_{\max} = \beta \cdot \omega \cdot \gamma_{ov} \cdot f_y \cdot A = \beta \cdot \omega \cdot T_y$

The overstrength factors can be written as:

$$\omega = T_{\max} \Big/ A \cdot f_{y,m} = \frac{\text{maximum tensile force}}{\text{yield force}} \geq 1.0$$

$$\beta = P_{\max} \Big/ T_{\max} = \frac{\text{maximum compression force}}{\text{maximum tensile force}} \geq 1.0$$

But $1.0 \leq \beta \leq 1{,}3$

If *nonlinear dynamic analysis* shall be executed BRBs can be modelled using a simple hysteretic model with hardening, based on the bilinear model from Figure 56.

Design methodology. Procedures suitable for static equivalent global analysis of BRB frames, using strength reduction factors, are available in the following codes: P100-1/2013 [24], AISC 2010 [25] and FEMA 2003 [26]. However, equivalent static procedure is believed to be suitable for new steel BRB frames. Application of this procedure for strengthening of existing structures may be inappropriate, therefore pushover and nonlinear time-history analyses are believed to be better suited for this case.

Modeling the BRB parameters for seismic evaluation and retrofit of existing building projects is given in ASCE 41-13 [27], Chapter 9.5.4.

Due to the facts that BRBs are mostly proprietary and manufactured by a specialty manufacturer, rather than built by a contractor or steel fabricator, performance criteria for BRBs are generally difficult to be defined. Then, assuming a brace ductility capacity in the range of $\mu = \varepsilon_{\max} \big/ \varepsilon_y = 4 \div 8$

BRBs should be designed as to yield for an interstorey-drift of 0.25 %.

- ***Guidelines for the retrofit of existing precast buildings***

Recent seismic events evidenced the high vulnerability of r.c. precast buildings used for industrial and commercial activities, designed without specific attention to seismic details, with significant economic and human losses that shall be prevented through the application of specific retrofit interventions, including local and global rehabilitation. The main structural deficiencies of precast buildings are related to the lack of connections between structural/non-structural elements: from the resistance point of view, in general, r.c. precast beams and columns present good performance and high quality of materials, being consequently able to avoid failures due to the overcoming of flexural or shear strength. At the same time, the insufficiency of connections (between beams and columns, between roof panels and beams, between columns and beams and infill panels) can lead to significant damages with human and economic losses.

The global structural response of the precast building is strongly influenced by the typologies of connections and by the interaction between structural and non-structural elements composing the construction. The general scheme of a precast r.c. building for industrial activities is presented in Figure 57.

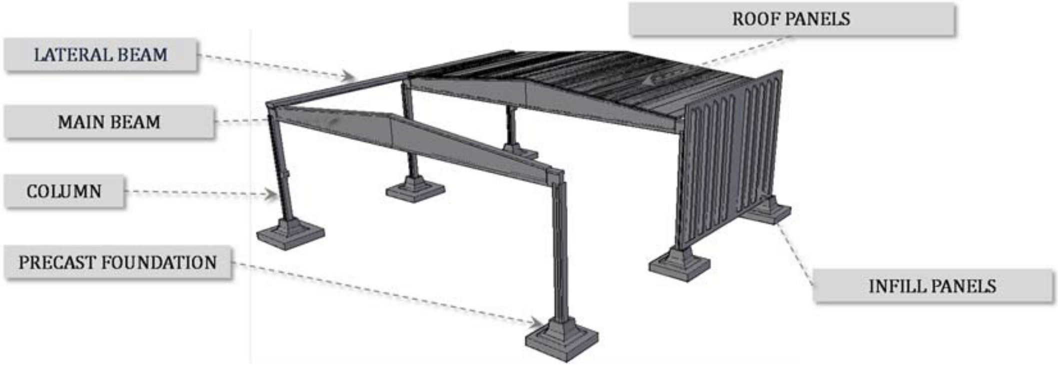


Figure 57: General scheme of r.c. precast building with indication of structural and non-structural elements.

Figure 58 summarizes the main problems regarding the traditional structural scheme for r.c. precast buildings, usually concentrated in:

- *Connection between columns and main beams*: absence of adequate support length in the case of friction connections (actually not foreseen by standards for the design of new buildings), insufficient size of pinned or fork connections, not designed for seismic actions.
- *Connection between columns and foundation*: as shown by seismic damages, the insufficient details in correspondence of column-foundation joint can lead to significant structural damages.
- *Connection between column and cladding panel:* if the infill panels are not correctly anchored to the structural elements of the r.c. frame, the overturning of the non-structural element becomes possible.
- *Connection between main beam and roof panels:* if there is no adequate support length or if there are no specific connections, the sliding of the roof panel, with possible collapse of the non-structural element.

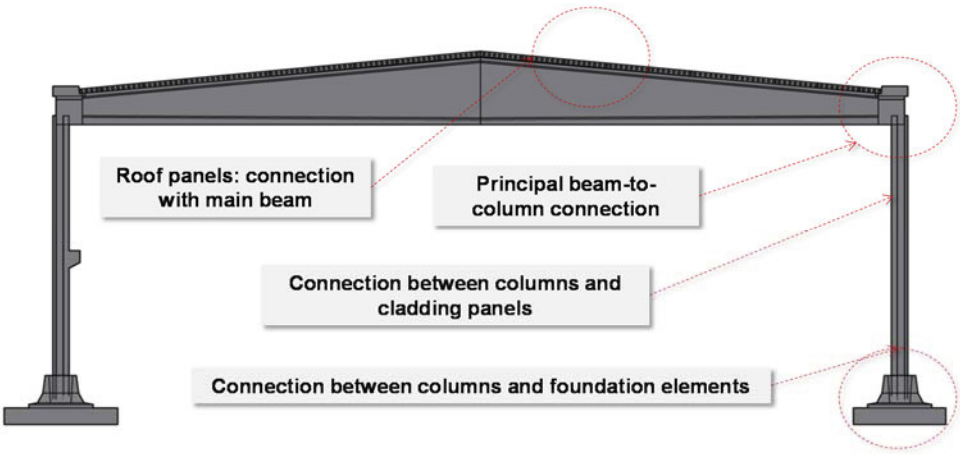
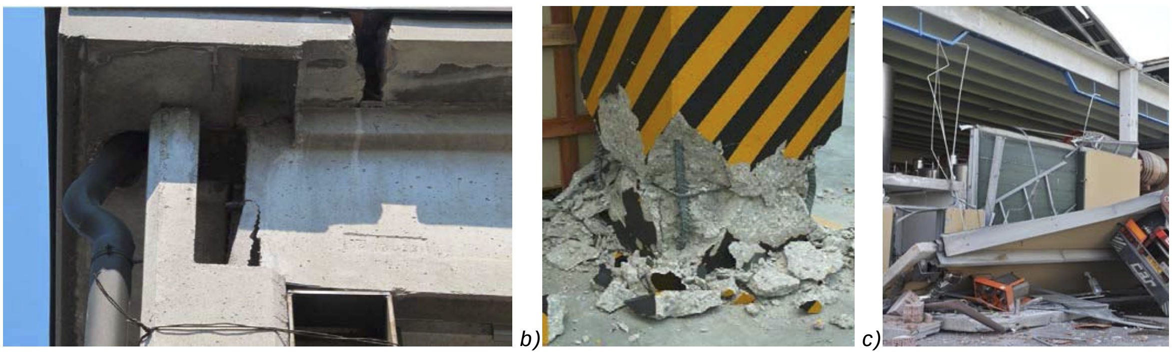


Figure 58: Summarizing scheme of structural problems in r.c. precast traditional buildings.



a) *b)* *c)*

Figure 59: Collapse due to: a) insufficient support length between beam and column, b) collapse in correspondence of the column-to-foundation joint, c) collapse of the cladding panels.

The retrofit of existing r.c. precast buildings shall mainly follow the "traditional" methodology proposed for existing buildings, already presented inside *SteelRetro* project and hereafter summarized. Some additional indications can be provided in relation to the typology of the retrofit system to be applied, especially for what concerns the modelling, analysis and evaluation of the efficacy aspects.

Survey and determination of vulnerabilities. The first step consists in the determination of vulnerabilities affecting the existing precast building, after a detailed structural survey of the construction. Since r.c. precast buildings have been often realized by design companies adopting standardized elements, the executive drawings of the existing buildings can be available. As mentioned in the previous paragraph, many of the problems are related to connections and can be consequently evidenced through a detailed survey of the building.

*Modelling, analysis and structural assessment of the existing building***.** The model of the building, necessary for the execution of the analysis and of the following structural assessment of the elements, shall be representative of the actual configuration of the construction. If connections are missing the model shall be able to represent this situation. In the case of structural deficiencies effectively revealed in the building coming not directly from the design but from an incorrect realization of the building, preliminary urgent interventions shall be executed on the existing building in order to perform the structural safety checks in the effective "design condition". As an example, in the case presented in Figure 60, the model adopted for structural analysis (c) corresponds to the design foreseen situation, obtained after the re-introduction of specific connections (a, b).

a) b) c)

Figure 60: a) Details of connections between structural elements and structural/non-structural elements.

Different typologies of structural analysis can be adopted, including linear and nonlinear analyses. In general, linear static/dynamic analyses are used as "standard method" for the evaluation of the structural safety of the building, for the execution of checks towards ductile and brittle mechanisms of beams, columns, foundation system and connections. More refined nonlinear analyses (preferring, in general static pushover respect to dynamic time histories due to the higher simplicity of execution) are suggested, especially if information regarding structural details and mechanical properties of materials are known, allowing to validate the results coming from linear analyses and assessing the structural performance of the building for increasing levels of horizontal action.

*Pre-selection of the retrofit technique***.** The pre-selection of the most common retrofit techniques shall be executed basing on surveyed vulnerabilities and on the results of structural assessment. Moreover, in the case of industrial/commercial precast building, another important aspect that shall be taken into consideration is the need not to interrupt developed activities for a very long time, since in such case, further economic losses will be produced. Techniques with problems related to accessibility, difficult applicability to the existing r.c. precast buildings, interruption of developed activities for long periods, etc. (i.e. all the techniques that have no sufficient feasibility for the application to the considered building) shall be neglected.

*Selection of the retrofit technique and assessment of the retrofitted condition***.** The modelling and structural analysis of the existing construction with applied retrofit techniques shall be executed to have the possibility to compare pre-selected retrofit techniques and to determine the ones that are more performing for the considered case study building. Also in this case, linear and nonlinear approaches can be adopted (as well as for the un-retrofitted condition), but the use of graphic methodologies, such as the N2 method ([18], [19]) or the Capacity Spectrum Method (ATC40 [20]), allow to directly evaluate the efficiency of proposed solution and the design of eventual improvements.

As a general remark, as well as for ordinary r.c. buildings, retrofit can be executed adopting local and global systems. If new resisting systems, opportunely designed to face horizontal seismic actions, are introduced, the global performance of the retrofitted structure is modified both in terms of strength and stiffness; the impact on the existing building is higher but, at the same time, the number of elements still requiring local retrofit interventions is reduced.

2.2.3 Rules for the design of systems with SSCD

Modelling indications. The mechanical behaviour of the proposed SSCD system (Braconi et al.[16], Figure 61) has been widely presented in D.1.1 and D.1.2, in the case of application to both design and rehabilitation of r.c. buildings.

Actually, no specific standards exist for the sizing of self-centering devices: the only way to design such systems and to evaluate their influence on the global structural behaviour of buildings consists in the execution of nonlinear analyses, including both static and dynamic procedures, in which the model of the SSCD is based on the results of experimental tests executed on real-scale prototypes [16]. A very detailed semi-analytic model of the adopted SSCD was proposed by Banushi [43]; simplified versions shall be then provided for the application to the common practice.

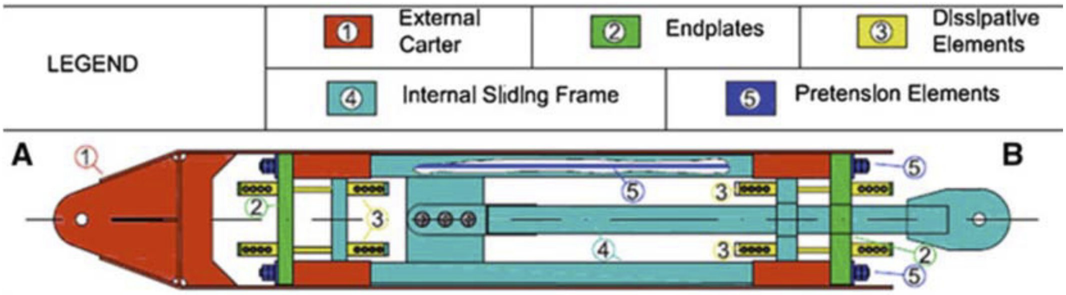


Figure 61: Main components of the proposed system.

The main elements of the SSCD are schematized such as *springs* with specific stiffness and constitutive relationship; the stiffness k_i of each single component can be evaluated as:

$$k_i = \frac{EA_i}{L_i}$$

being E the elastic modulus of the material, A_i the transversal section and L_i the length of the considered elements. Table 13 presents the summary of the main components of the SSCD system with the corresponding assumed constitutive relationships.

Table 13: Main components of the SSCD and constitutive relationship.

Element		Constitutive law
Carter 1	C1	Linear Elastic
Carter 2	C2	Linear Elastic (no tension)
Sliding frame	TM	Linear Elastic
Piston	P	Linear Elastic
Endplate (left)	CT_{SX}	$k=\infty$ (no tension)
Endplate (right)	CT_{DX}	$k=\infty$ (no tension)
Pre-tensioned cables	PT	Bilinear Elastic
Dissipative element (left)	DE_{SX}	Elastic perfectly plastic
Dissipative element (right)	DE_{DX}	Elastic perfectly plastic

The simplified model of the SSCD (Figure 62) has been elaborated taking into consideration equivalent stiffness of involved elements. For the determination of the F/d simplified curve, the pre-sizing of the significant components of the system is necessary.

The transversal sections of the carter, of the internal sliding frame and of the piston shall be evaluated in order to avoid buckling phenomena under seismic action, while pre-tensioned cables and dissipative elements are designed in order to satisfy the seismic demand.

The initial dimensions of elements shall be designed in relation to the definition of parameters k_{el}, k_{pe}, F_y, F_u, d_y, d_u, α and β, determining the characteristic flag-shaped curve:

- k_{el} *Elastic stiffness*
- k_{pe} *Post elastic stiffness*
- F_y *Yielding force of the system*
- F_u *Max force allowed by the system*
- d_y *Yielding displacement*
- d_u *Ultimate displacement*
- α *Post-elastic stiffness coefficient*
- β *Energy dissipation coefficient*

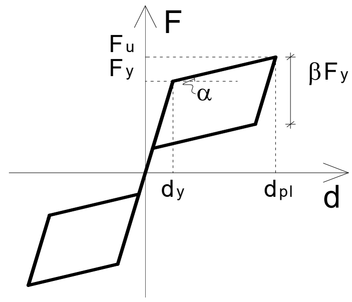
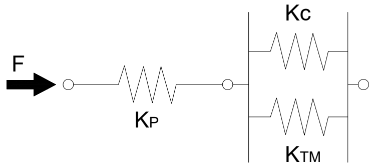


Figure 62: Ideal F-d relationship for a hysteretic self-centering system.

The first branch of the curve is characterized by stiffness equal to k_{el}, determined considering the spring associated to the piston (k_p) connected in parallel to the ones of the carter (k_c) and of the sliding frame (k_{TM}) according to the equation:

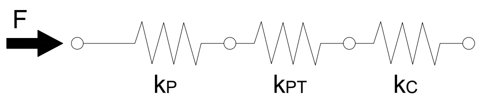
$$k_{el} = \frac{k_P\left(k_c + k_{TM}\right)}{k_P + k_C + k_{TM}}$$



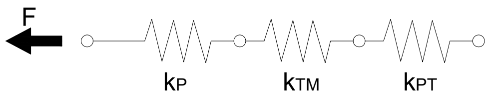
The post-elastic branch of the force/displacement curve, starting from the yielding point of the system, presents stiffness equal to k_{pe}; two different schemes shall be adopted to determine this value in relation to the compression or tension behaviour of the system. In both the two cases the contribution of the dissipative elements, yielded after the first loading, is neglected.

- Compression (k_{pec}): springs associate to the piston (k_p), pre-tensioned cables (k_{PT}) and carter (k_C) in series.
- Tension (k_{pet}): springs associated to the piston (k_p), the sliding frame (k_{TM}) and the cables (k_{PT}) in series.

$$k_{pec} = \frac{k_P \cdot k_{PT} \cdot k_C}{k_P k_{PT} + k_P k_C + k_{PT} k_C}$$



$$k_{pet} = \frac{k_P \cdot k_{TM} \cdot k_{PT}}{k_P k_{TM} + k_P k_{PT} + k_{PT} k_{TM}}$$



Assuming that the behaviour of the SSCD system is exactly the same under tension and compression according to what previously discussed, the stiffness of the post-elastic branch can be adopted as the average between the two values obtained: $k_{pe} = \frac{k_{pet} + k_{pec}}{2}$, where k_{pec} and k_{pet} only depends from the stiffness of the components of the system that always remain in the elastic field under seismic action.

The shape of the hysteretic curve is determined by two parameters, α and β, where α is the ratio between the hardening and the initial stiffness, while β reflects the energy dissipation and the system's re-centering capacity (Christopoulos and Filiatrault [44]), which, as mentioned, can be assumed equal to the ratio between the yield strength of the Dissipative Elements and the initial pretension force.

The two parameters α and β can be defined as:

$$\alpha = \frac{k_{pe}}{k_{el}}$$ *post yielding stiffness coefficient*

and

$$\beta = \frac{F_{yDE}}{F_{PTE}}$$ *energy dissipation coefficient*

In which F_{yDE} is the yielding force associated to dissipative elements and F_{PTE} the force of pre-tensioned elements. β can be also expressed by:

$$\beta = \frac{F_{yDE}}{F_{PTE}} = \frac{A_{DE}\, f_{yDE}}{A_{PTE}\,\rho_{PTE}\, f_{yPTE}}$$

Being A_{PTE} and A_{DE} respectively the transversal sections of pre-tensioned elements and dissipative elements, f_{yPTE} and f_{yDE} the yielding strength of pre-tensioned elements and dissipative elements and ρ_{PTE} the pre-tension percentage. β is consequently dependent on the variation of the section, of the pre-tension of cables and on the transversal section of dissipative components.

If $\beta=0$ the system coincides with a bilinear elastic system without dissipative capacity; on the other hand, $\beta=1$ represents the limit condition to provide re-centering characteristics. A specific combination of the two parameters α and β shall be provided for each designed system.

The yielding of the system, representing the limit in correspondence of which the stiffness shifts from the elastic to the post-elastic value, due to the overcoming of the pre-tensioning force of the cables. This force can be assumed consequently equal to:

$$F_y = F_{PTE} = A_{PTE} \cdot \rho_{PTE} \cdot f_{yPTE}\ .$$

The displacement d_y in correspondence of F_y can be determined as:

$$d_y = \frac{F_y}{k_{el}}$$

The ultimate (maximum) displacement of the system d_u, assumed equal to the maximum deformation of pre-tensioned cables, is defined as:

$$d_u = d_{PTE} = \frac{F_{yPTE} \cdot (1-\rho_{PTE})}{E_{PTE}} L_{PTE}$$

being d_{PTE} the deformation of pre-tensioned cables, L_{PTE} and E_{PTE} respectively their length and elastic modulus.
The maximum force of the system F_u can be finally expressed according to:

$$F_u = F_y + (d_u - d_y) \cdot k_{pe}$$

In the proposed design procedure, the transversal sections of the carter, sliding frame, piston and the global dimensions of the endplates have been kept constant. The number of parameters that shall be determined for the sizing of the SSCD system can be reduced according to what summarized in Table 15. Specific indications can be provided for the selection of the materials to be adopted for the realization of the dissipative SSCD device. The results obtained in the pre-design analyses showed that low yielding strength values of the dissipative elements provided a good global ductility and, at the same time, an effective re-centering capacity of the system once the external force drops to zero.

Table 14: Fixed values for the design of the SSCD system.

Parameter	Value	
A_{c1}	11088	mm^2
A_{TM}	1539	mm^2
A_P	862	mm^2
A_{CT}	66538	mm^2
E	210000	N/mm^2
f_{yPTE}	1670	N/mm^2
E_{PTE}	196000	N/mm^2
f_{yDE}	240	N/mm^2
L_{DE}	170	mm

Table 15: Parameters modified during the design and influence on the parameters describing the F/d curve.

Input parameter	Dependent parameters
L_{C1}	k_{el}, d_y
L_{TM}	k_{el}, d_y
L_P	k_{el}, d_y
L_{PTE}	k_{pe}, α, d_u, F_u
ϕ	k_{el}, k_{pe}, α, d_u, F_u
ρ	F_u, d_y
A_{DE}	β

Analysis and design indications. Once defined the simplified mechanical model of the system, the performance of the SSCD shall be calibrated in relation to the specific case study to which the system shall be applied. It's necessary to highlight that actually no specific standards are present with indication on the methodologies to be followed for the design of structures with passive protection systems, resulting, for example, in the absence of indications regarding *behaviour factor q* to be adopted for the pre-sizing of the element and so on. The execution of nonlinear static and dynamic analyses can be, as a consequence, the only way to determine the structural properties of the system in order to achieve specific performance levels.

In the case of *design of new buildings* with introduced SSCD, the execution of nonlinear dynamic analyses (time histories and IDA) is suggested.

The definition of limit states corresponding to Life Safety (coinciding with the achievement of the maximum elongation of pre-tensioned cables) and Damage Limitation (coinciding with the achievement of the maximum interstorey drift) conditions is necessary to determine the performance objectives of the building and to consequently calibrate the mechanical parameters of the different components (i.e. diameter of cables, dimensions of the dissipative elements, length of the SSCD and combination of them)

3. WP3: translation of documents and website for dissemination

In order to better disseminate the activities developed inside *Steel-Earth* and to distribute the knowledge and obtained results, documents produced in WP1 and WP2 were translated into several languages. Moreover, a website has been organized and translated into several language according to what foreseen in Work Package 3 (WP3). A Facebook and a LinkedIn profiles have been furthermore created in order to be adopted as mean of communication able to attract young engineers, students, etc.

3.1 Translation of documents

The technical sheets and working examples developed in WP1 (in English language) have been translated into the following languages.

- French.
- German.
- Italian.
- Greek.
- Romanian.

The background/pre-normative documents developed in WP2 (in English language) have been translated into French, German and Italian in order to be presented at National and International levels.

3.2 Organization of the STEEL-EARTH website

ECCS has organized a website for *Steel-Earth* project, permanently available (this means also at the end of the project) at the following link: https://www.steelconstruct.com/site/. The whole and complete description of the website and of its organization can be found in the deliverable D.3.2.

The website has been organized in order to constitute a sort of binder for all the documents elaborated inside the dissemination project, including technical sheets (TS), working examples (WE), background documents, list of the dissemination events organized and corresponding distributed material, that can be directly downloaded by users for design and rehabilitation of buildings.

All the documents are available free of charge, in order to spread as much as possible the knowledge among technicians, engineers, design companies, standardization bodies.

The website of the project is actually available into several languages, including French, Italian, German, Romanian and Greek (Figure 64). The website is organized into 7 different sections:

[1] *Mission*: presents the main objectives of the dissemination project, explaining its main aims and its origin in relation to the three research projects *SteelRetro* [3], *PrecaSteel* [1] and *Opus* [2]. In this section the general brochure of the project, distributed during the dissemination activities around Europe, is available into the different languages.

[2] *Seismic design*: the second section includes the results obtained concerning the seismic design of new buildings with steel or composite steel/concrete structure, with technical sheets and working examples available in the different foreseen languages free be downloaded.

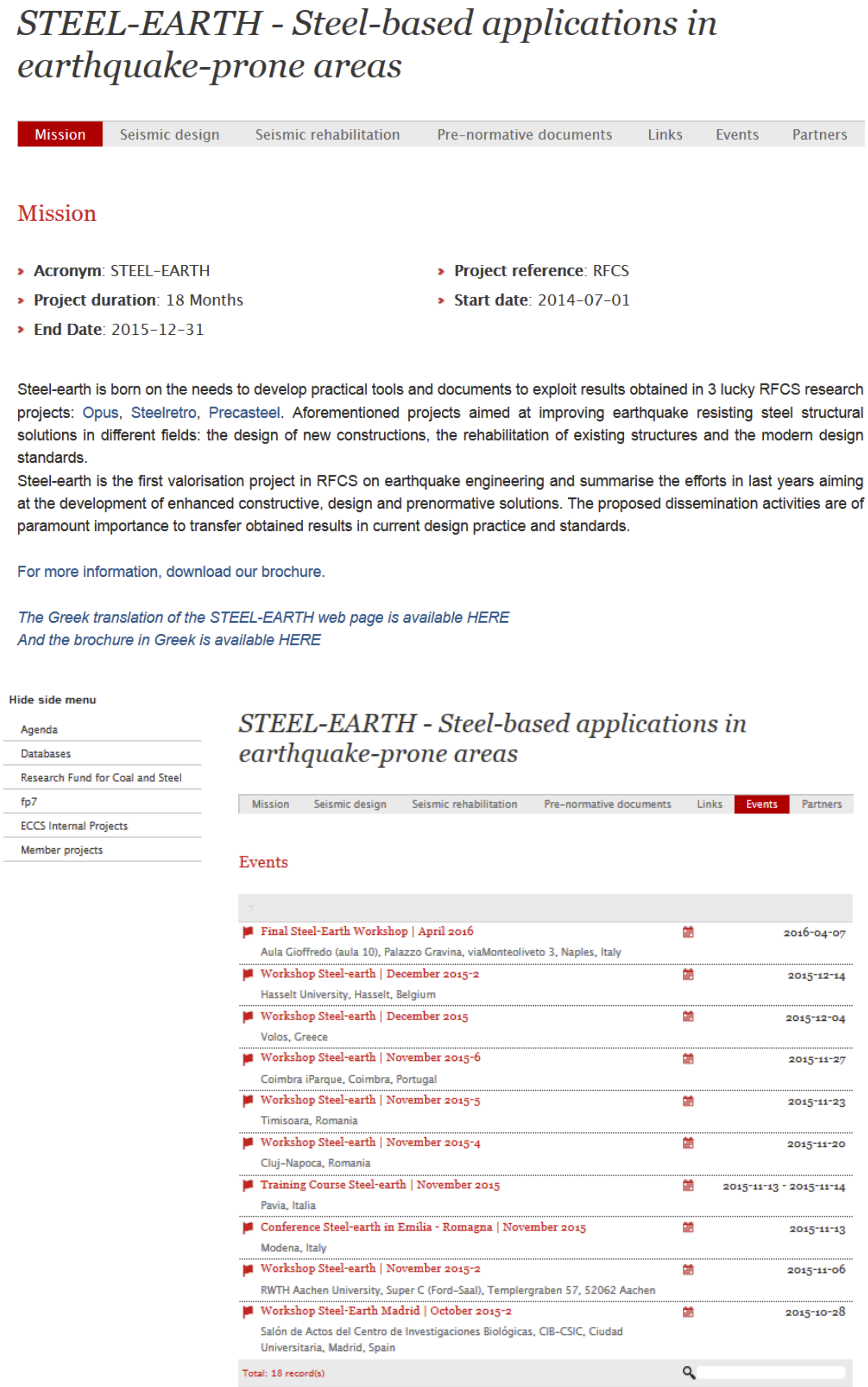
[3] *Seismic rehabilitation*: the third section includes the results obtained concerning the seismic rehabilitation of existing r.c. and masonry buildings adopting traditional and innovative steel-based systems, with technical sheets and working examples (developed in WP1 and translated in WP3) free available to be downloaded.

[4] *Pre-normative documents*: the fourth section includes the pre-normative documents elaborated in WP2, also in this case available into several languages according to the translations executed in WP3. This section contains both documents for the harmonization of design and production standards and contributions and pre-normative document for Eurocodes

[5] *Links*: in this section, links connecting to the main webpages of associations involved in the dissemination activities of *Steel-Earth* project can be found (such as: link to *Software PRECASTEEL, Federacciai, Fondazione Promozione acciaio, Buildup, Eurofer, World Steel Association, Steeluniversity, AIST - Association for Iron and Steel Technology*).

[6] *Events*: in the sixth section all the dissemination activities organized inside the project are presented and sponsored. For each of the workshops/conferences/training courses the programme, the pdf files of the presentations executed by speakers, videos and photos of the events as well as other material (brochure for example) are available to be free downloaded.

[7] *Partners*: in the last section of the website, the presentation of each of the involved partners of Steel-Earth project is provided.



STEEL-EARTH - Steel-based applications in earthquake-prone areas

Mission | Seismic design | Seismic rehabilitation | Pre-normative documents | Links | Events | Partners

Mission

- **Acronym**: STEEL-EARTH
- **Project reference**: RFCS
- **Project duration**: 18 Months
- **Start date**: 2014-07-01
- **End Date**: 2015-12-31

Steel-earth is born on the needs to develop practical tools and documents to exploit results obtained in 3 lucky RFCS research projects: Opus, Steelretro, Precasteel. Aforementioned projects aimed at improving earthquake resisting steel structural solutions in different fields: the design of new constructions, the rehabilitation of existing structures and the modern design standards.
Steel-earth is the first valorisation project in RFCS on earthquake engineering and summarise the efforts in last years aiming at the development of enhanced constructive, design and prenormative solutions. The proposed dissemination activities are of paramount importance to transfer obtained results in current design practice and standards.

For more information, download our brochure.

The Greek translation of the STEEL-EARTH web page is available HERE
And the brochure in Greek is available HERE

Hide side menu

- Agenda
- Databases
- Research Fund for Coal and Steel
- fp7
- ECCS Internal Projects
- Member projects

STEEL-EARTH - Steel-based applications in earthquake-prone areas

Mission | Seismic design | Seismic rehabilitation | Pre-normative documents | Links | Events | Partners

Events

Final Steel-Earth Workshop | April 2016 Aula Gioffredo (aula 10), Palazzo Gravina, viaMonteoliveto 3, Naples, Italy	2016-04-07
Workshop Steel-earth | December 2015-2 Hasselt University, Hasselt, Belgium	2015-12-14
Workshop Steel-earth | December 2015 Volos, Greece	2015-12-04
Workshop Steel-earth | November 2015-6 Coimbra iParque, Coimbra, Portugal	2015-11-27
Workshop Steel-earth | November 2015-5 Timisoara, Romania	2015-11-23
Workshop Steel-earth | November 2015-4 Cluj-Napoca, Romania	2015-11-20
Training Course Steel-earth | November 2015 Pavia, Italia	2015-11-13 - 2015-11-14
Conference Steel-earth in Emilia - Romagna | November 2015 Modena, Italy	2015-11-13
Workshop Steel-earth | November 2015-2 RWTH Aachen University, Super C (Ford-Saal), Templergraben 57, 52062 Aachen	2015-11-06
Workshop Steel-Earth Madrid | October 2015-2 Salón de Actos del Centro de Investigaciones Biológicas, CIB-CSIC, Ciudad Universitaria, Madrid, Spain	2015-10-28

Total: 18 record(s)

Figure 63: Website of Steel-Earth dissemination project for what concerns the "mission" and the "events" sections.

Figure 64: Screen-shots of the website of the project in French, German and Greek.

3.3 Dissemination through Facebook and LinkedIn profiles

In the *Facebook* profile (free without restrictions at https://www.facebook.com/ECCS-CECM-EKS-European-Convention-for-Constructional-Steelwork-118940171523522/?ref=aymt_homepage_panel) of the "*ECCS-CECM-EKS - European Convention for Constructional Steelwork*" all the information regarding dissemination activities (including conferences, workshops and training courses) have been uploaded, as well as photos and videos executed during the event. The ECCS Facebook page (Figure 65) has been used to disseminate all the information (publications, events, brochures).

A LinkedIn profile (https://www.linkedin.com/company/steel-earth-project) with actually several followers has been activated, promoting the dissemination activities developed inside the project (Figure 66).

Figure 65: Dissemination of STEEL-EARTH project information on Facebook.

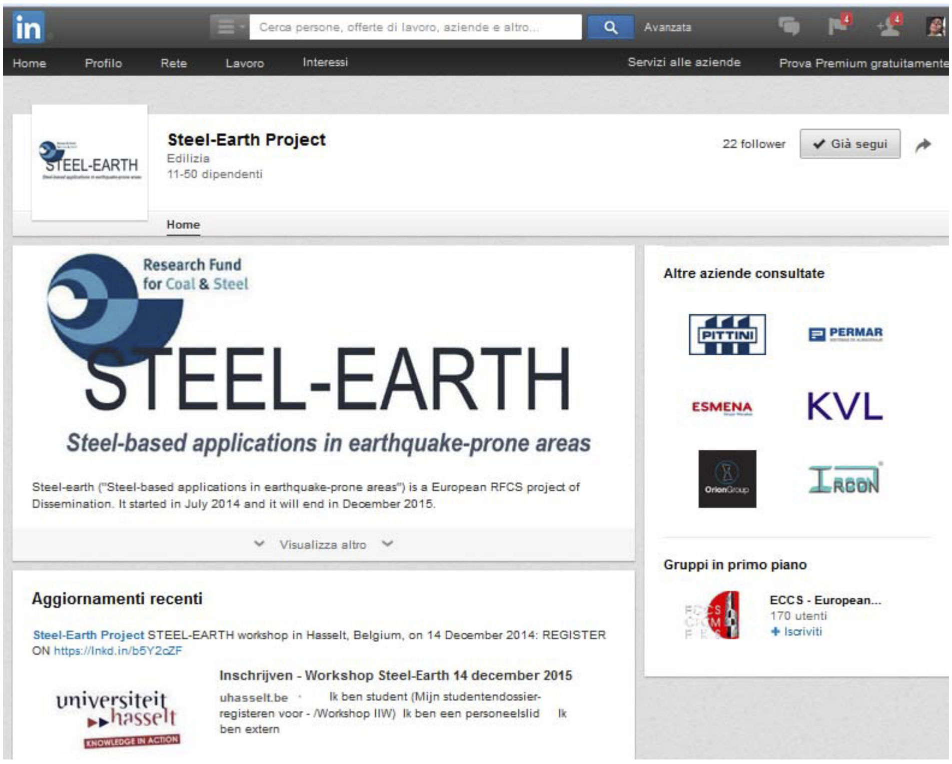


Figure 66: Dissemination of STEEL-EARTH project information on LinkedIn.

4. WP5: Organization of workshops and dissemination activities

11 International workshops in Italy, Germany, Greece, Belgium, Spain, Portugal, Finland and Romania, 5 conferences in Emilia – Romagna (Italy) and two training courses at EUCENTRE have been organized inside Steel-Earth project to disseminate the obtained results among engineers, technicians, academic people and design companies.
The main topics addressed in the dissemination activities are related to the results obtained inside *SteelRetro* [3] (rehabilitation of r.c. and masonry buildings with steel based systems), *PrecaSteel* [1] (design of steel and composite structures) and *Opus* [2] (influence of material properties' variability on the ductile behaviour of steel and steel/concrete composite structures with reference to actual standard problems). All the dissemination activities are presented with programme and all information required in website of the project and in deliverable D.5.1; hereafter a brief description of each event is provided.

4.1 International workshops

Table 16 presents a simple scheme of the workshops organized inside *Steel-Earth* project in the period within September 2015 and December 2015 (date of the end of the project). The workshop were located all around Europe mainly following the indications given in the project proposal; some modifications were needed to introduce the events in the main framework of national and international conferences, such as:

- The Italian National Conference on Earthquake Engineering (*ANIDIS – Associazione Italiana di Ingegneria Sismica*, http://www.anidis.it/), for the workshop organized by CERI in L'Aquila (Italy).
- The 13th Nordic Steel Construction Conference (http://www.tut.fi/en/nordic-steel-construction-conference-2015/) for the workshop organized in Tampere (Finland) by VTT.
- The National Romanian Conference on Metallic Constructions (http://www.cluj2015.eu/events/537-a-xiv-a-conferinta-nationala-de-constructii-metalice.html) for the workshop organized in Cluj-Napoca (Romania) by ECCS together with PUT. This event has replaced the one foreseen in Bulgaria, due to the possibility to highly diffuse results and to the relative proximity.
- The 10th Conference on Steel and Composite Structures (http://www.apcmc.pt/x-congresso-de-construcao-metalica-e-mista/) for the workshop in Coimbra (Portugal), organized by ECCS.

In addition to what initially planned, a final workshop has been also organized to disseminate the results of the project: the final *Steel-Earth* workshop has been held in Naples (Italy), the 07.04.2016 concurrently with the WG2 (*CEN/TC 250/SC 8/WG 2 "Steel and Composite Structures")* meeting (07 and 08.04.2016).

Table 16: Summary of workshops organized inside Steel-Earth project.

Date	Location/Organizer/people			Title	Language	Notes
16.09.2015	L'Aquila (I)	CERI	50	Steel-Earth: Steel based applications in earthquake prone areas	Italian English	Organized inside the Italian National Conference on Seismic Engineering ANIDIS 2016
25.09.2015	Tampere (Fin)	VTT	50	Steel for industrial and commercial buildings in earthquake prone areas	English	Organized inside the Nordic Steel Construction Conference
15.10.2015	Ljubljana (SLO)	FENO	69	Steel for industrial and commercial buildings in earthquake prone areas	Slovenian English	Organized in collaboration with the Institute of Civil Engineering Slovenia (ZAG)
28.10.2015	Madrid (E)	ECCS	53	Aplicaciones basadas en acero para zonas con riesgo sísmico - Steel based applications for seismic areas	English Spanish	Organized in collaboration with PLATEA (Plataforma Tecnologica Espanola del Acero), ASCEM (Asociaciòn para la construcciòn de estructuras metalicas) and CENIM (Centro Nacional de Investigaciones Metalurgicas)

06.11.2015	Aachen (DE)	RWTH	20	Building in earthquake prone areas	English German	-
20.11.2015	Cluj-Napoca (ROM)	ECCS PUT	75	Steel-based applications in earthquake prone areas	Romanian English	Organized inside the Romanian National Conference on Steel Structures
23.11.2015	Timisoara (ROM)	PUT	80	Seismic retrofitting of existing structures using steel-based solutions	Romanian English	-
27.11.2015	Coimbra (P)	ECCS	45	Steel-based applications in earthquake prone areas	English	Organized inside the X Conference on Steel and Composite constructions
04.12.2015	Volos (GR)	UTH SHELTER	40	Structural steel solutions in earthquake-prone areas: design and retrofitting	English	-
14.12.2015	Hasselt (BE)	UHasselt	35	Steel-Earth	English	-
07.04.2016	Naples (I)	UniPI	150	Steel-Earth final workshop	Italian English	In collaboration with University of Naples Federico II, in the framework of the WG2 meeting

During the workshops, presentations regarding the main aspects of the project (i.e. rehabilitation and design of buildings in seismic areas, with connected problems) have been executed by experts directly involved in *Steel-Earth* and/or in the previous *SteelRetro* [3], *PrecaSteel* [1] and *Opus* projects [2], such as: Prof. Dr.-Ing. Benno Hoffmeister, Dr.-Ing. Max Gündel, Dipl.-Ing. Hetty Bigelow (RWTH), Prof. S.A. Karamanos, Dr. Eng. Charis Papatheocharis, Dr. Eng. George Varelis (UTH), Prof. Herve Degee (ULG/UHasselt), Prof. Walter Salvatore, Dr. Eng. Silvia Caprili, Dr. Eng. Francesco Morelli, Eng. Nicola Mussini (UniPI), Prof. Dan Dubina, Dr. Eng. Aurel Stratan, Dr. Eng. Adrian Dogariu (PUT), Prof. Franco Braga, Dr. Eng. Rosario Gigliotti (CERI), Prof. Andrea Dall'Asta, Prof. Alessandro Zona (UniCAM), Dr. Eng. Ludovic Fulop (VTT), Eng. Roberta Mallardo (FENO), Veronique Dehan, Eng. Cecile Haremza (ECCS), Dr. Eng. Mario D'Aniello (University of Naples Federico II).

Other local experts have been opportunely invited to provide their useful contributions, often related the different organizations/associations supporting the events, such as:

- PLATEA (*Plataforma Tecnologica Espanola del Acero)*.
- ASCEM *(Asociaciòn para la construcciòn de estructuras metalicas).*
- CENIM *(Centro Nacional de Investigaciones Metalurgicas)*.
- Tecnalia Corporation Tecnologica (http://www.tecnalia.es/).
- National Technical University of Athens, Greece.

For the final workshop, the presence of prof. Raffaele Landolfo (University of Naples Federico II), chairman of the *CEN/TC 250/SC 8/WG 2 "Steel and Composite Structures"* has been also scheduled.

For each of the foreseen events, specific posters, such as the ones presented in the following pages, have been realized; the brochures of *Steel-Earth* produced by ECCS and translated into different languages by partners have been distributed to the attending people together with USB flash drives with uploaded TS, WE, background documents and pdf of the presentations executed during the events. All the proceeding and the presentations executed during the workshops can be downloaded at: https://www.steelconstruct.com/site/.

More information related to the different workshops, with photos, pictures of the event, list of the speakers, number of attending people, presentations and so on are deeply presented in deliverable D.5.1.

4.1.1 Workshop in L'Aquila, Italy

The workshop has been organized by CERI in the main framework of the 16th Italian Conference on Earthquake Engineering (ANIDIS 2016), held in L'Aquila, strongly damaged by the 2009 earthquake, the 13-17.09.2016.

Figure 68 shows the programme of the organized event, mainly dealing with retrofit of existing constructions and modern design techniques (base on *SteelRetro* [3] and *PrecaSteel* [1] results), with the interventions of ***Prof. Franco Braga*** (University of Rome La Sapienza – CERI), member of the Italian Committee for the arrangement of new standards on Structural Design of High Council of Public Works of Ministry of Infrastructures and Italian representative in TC250/SC8 for the development of Eurocode 8 for the seismic design of structures, and of ***Prof. Walter Salvatore*** (University of Pisa – UniPI), member of the Italian Committee for the arrangement of new standards on Structural Design of High Council of Public Works of Ministry of Infrastructures, member of the CEN/TC 250/WG2 for the development of new Eurocode on existing buildings and Italian representative in ECISS/TC 103 on qualification of structural steels.

Figure 67 presents some examples of the presentations held during the workshop.

a) 

b) 

c) 

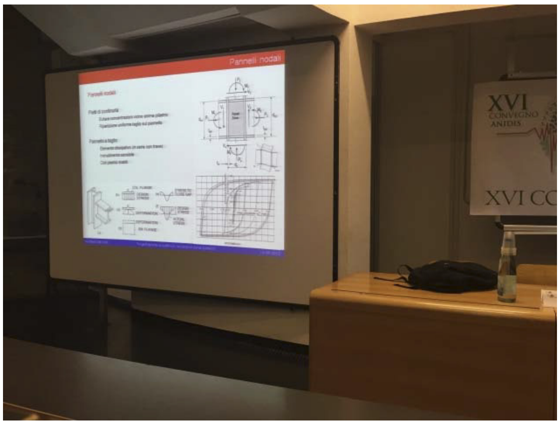
d) 

Figure 67: Presentation of a) Prof. Franco Braga and b) Prof. Andrea Dall'Asta during the conference in L'Aquila, c) people attending the conference and d) some examples of the presentations.

4.1.2 Workshop in Tampere, Finland

The workshop has been organized by VTT in the main framework of the Nordic Steel Conference (NSCC), held in Tampere, the 23-25.09.2015. Figure 69 shows the programme of the organized event.

The main aim of the workshop was to explore the roles of material choices and structural solutions on the seismic behaviour of steel and composite structures, mainly in relation to *Opus* [2] and *PrecaSteel* [1] results. The adoption of traditional structural solutions and advanced configurations with integrated response modification devices have been also discussed, in agreement with the results of *SteelRetro* project [3].

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.


RFCS: Research Fund for Coal and Steel L'Aquila 13-17 Settembre 2015

STEEL-EARTH: Steel-based applications in earthquake-prone area

Research Fund for Coal & Steel

L'Aquila, 16 Settembre 2015
Università degli studi dell'Aquila - Polo Ingegneria Roio
Piazzale E. Pontieri - Monteluco di Roio, 67100 L'Aquila.

Mercoledì, 16 Settembre 2015

Aula Magna

Programma dei lavori:

09:50-9:55 Introduzione

09:55-10:20 Rischio sismico e Nuove Norme Tecniche per le Costruzioni
(**Franco Braga**, *Università di Roma La Sapienza*)

10:20-10:45 Progettazione di edifici in acciaio ad uso commerciale e industriale
(**Andrea Dall'Asta**, *Università di Camerino*)

10:45-11:10 Criteri di intervento su edifici esistenti con sistemi in acciaio
(**Walter Salvatore**, *Università di Pisa*)

11:10-11:30 Pausa Caffè

11:30-12:00 Sistemi di protezione passiva
(**Rosario Gigliotti**, *Università di Roma La Sapienza*)

12:00-12:25 Interventi di miglioramento su edifici esistenti con sistemi in acciaio
(**Silvia Caprili**, *Università di Pisa*)

12:25-12:50 Interventi di miglioramento su edifici industriali con sistemi in acciaio
(**Francesco Morelli**, *Università di Pisa*)

Durante il convegno verrà distribuito il materiale didattico relativo al seminario.

Il seminario è organizzato nell'ambito del progetto finanziato dal Research Fund for Coal and Steel STEEL EARTH – Steel-based application in earthquake-prone areas.

Partners del progetto STEEL-EARTH

UNIVERSITÀ DI PISA
Coordinatore

XVI Convegno ANIDIS L'AQUILA 13-17 SETTEMBRE 2015

Università degli studi dell'Aquila - Polo Ingegneria Roio (facoltà di Ingegneria)Piazzale E. Pontieri - Monteluco di Roio, 67100 L'Aquila.

ANIDIS 2015 XVI CONVEGNO-SESSIONE SPECIALE (A)

Figure 68: Poster prepared for the workshop in L'Aquila, Italy (16.09.2015), in Italian (also available in English).

The Technical Research Center of Finland (VTT)
cordially invites you to the workshop on

Steel for industrial and commercial buildings in earthquake prone regions

When: 25th September 2015, 9.00-12.30
Where: Room Aaria, Tampere Hall, Yliopistonkatu 55, Tampere

Background

The aim of the workshop is to explore material choices and structural solutions when dealing with seismic loads. The building typologies are mainly industrial and commercial buildings, with some escapades to office structures. Traditional structural solutions based on judicious material choices and advanced configurations with integrated response modification devices are discussed.

Workshop program

9.00 – 10.00: Steel grades tomorrow's earthquake resistant buildings

Steel grades on the European market and ways forward with steel as a competitive material in seismic regions (*Benno Hoffmeister, RWTH Aachen / Max Gündel, Wölfel Group*)

The design/cost consequences of material quality in seismic applications (*Spyros Karamanos / Charis Papatheocharis, University of Thessaly*)

10.00 – 10.30 Coffee break

10.30 – 11.15 Advanced response modification (RM) devices

Design principles of response modification (RM) and steel based RM devices (*Walter Salvatore, University of Pisa*)

Capacity, stiffness and ductility demands of BRB's in relation with the target application (Aurel Stratan, Florin Vioca, Ciprian Zub / *Politehnica Uni. of Timisoara*)

Case study related to application of BRB's for a r.c framed structure (*Dan Dubina, Florea Dinu, Adrian Dogariu / Politehnica University of Timisoara*)

11.15 – 12.00: Industrial and commercial buildings for earthquake areas

Competing on a market with standardized building typologies (*Zsolt Nagy Gordias LTD / Ludovic Fülöp, VTT*)

Steel solutions for industrial applications (*Ludovic Fülöp, VTT*)

Steel solutions for commercial applications (*Silvia Caprili, University of Pisa*)

12.00-12.30 Conclusions and reflections (*Heikki Holopainen, Amec Foster Wheeler*)

Welcome!

The workshop material is based on the results of three projects:
- Optimizing the seismic performance of steel and steel-concrete structures by standardizing material quality control (OPUS),
- Prefabricated steel structures for low-rise buildings in seismic areas (PRECASTEEL)
- Steel solutions for seismic retrofit and upgrade of existing constructions (STEELRETRO)

Technical content
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Local organizer
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Organizer:
VTT

Project partners:
ECCS CECM EKS
University of Thessaly
EUCENTRE
INSA
Università di Pisa
RWTH
UNICAM
Università degli Studi di Parma
Sapienza Università di Roma
Regione Toscana
Universitatea Politehnica Timişoara
Université de Liège
RIVA ACCIAIO
FERRIERE NORD
SHELTER

Supported by:
Research Fund for Coal & Steel

Figure 69: Poster prepared for the workshop in Tampere, Finland (25.09.2015).

4.1.3 Workshop in Ljubljana, Slovenia

Figure 71 shows the programme of the workshop organized in Ljubljana (Slovenia) by FENO in collaboration with the national Slovenian Institute of Civil Engineering Slovenia (ZAG), the 15.10.2015.

The main topics of the workshops were the design of new steel and composite steel/concrete buildings and the application of retrofit techniques to existing constructions (i.e. *SteelRetro* [3] and *PrecaSteel* [1] results). The attending people was mainly made up by technicians, engineers, design companies, etc. The workshop was recognized as an instrument of valorisation and improvement of the knowledge of the attending people by ZAG, that consequently provided professional credits, in agreement with what actually foreseen by national associations of engineers.

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

4.1.4 Workshop in Madrid, Spain

Figure 72 presents the general programme of the event organized by ECCS in Madrid (Spain), the 28.10.2015. The workshop was organized with the direct participation of PLATEA (*Plataforma Tecnologica Espanola del Acero*), ASCEM (*Asociaciòn para la construcciòn de estructuras metalicas*) and CENIM (*Centro Nacional de Investigaciones Metalurgicas*). Figure 70 shows some moments of the conference.

The support of the three above mentioned associations included the execution of presentations by Jordi Romanyà (ASCEM) titled "*Economic assessment of the effects of the earthquake in the metal structure*", by José Antonio Chica (PLATEA) for the presentation of Technical Construction Committee PLATEA and by Iñigo Calderóny Amaia Aramburu (Tecnalia) and by José Luis Suárez (AST Ingeniería) for the presentations of the work executed inside two EU research projects related to the steel constructions. Presentations directly related to Steel-Earth and base projects were executed by Prof. Herve Degee (ULG/UHasselt), Dr. Eng. Francesco Morelli (UniPI) and by Veronique Dehan and Cecile Haremza (ECCS).

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Figure 70: Attending people and presentations during the workshop in Madrid.

4.1.5 Workshop in Aachen, Germany

Figure 73 shows the general programme of the workshop organized in Aachen, Germany by RWTH the 06.11.2015. As visible from the programme, presentations regarding PrecaSteel [1], SteelRetro [3] and Opus [2] results (i.e. design and verifications of buildings, retrofit techniques and influence of materials on the seismic design of ductile structures), were executed.

Prof. Benno Hoffmeister, organizer of the event and speaker, is member of DIN-Committee NA 005-51-06 AA, Special Issues (Sp CEN/TC 250/SC 8) and of ECCS TC13 related to seismic design. His involvement in such technical groups allowed the dissemination of the results among technical and scientific groups.

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Ferriere Nord (Pittini Group) v sodelovanju z Zavodom za gradbeništvo Slovenije (ZAG) organizira delavnico na temo:

JEKLA ZA INDUSTRIJSKE IN POSLOVNE STAVBE V POTRESNO OBČUTLJIVIH REGIJAH

ČETRTEK, 15. OKTOBER 2015, 9^{00}-13^{00}
ZAG - dvorana
Dimičeva ulica 12, 1000 Ljubljana, Slovenija

Namen delavnice je predstaviti raziskave jekla ter kompozitov jekla in betona ter konstrukcijske rešitve pri projektiranju potresno odpornih novogradenj, predvsem nizkih industrijskih in poslovnih stavb, ter rekonstrukcij obstoječih.
Razprava bo tekla o tradicionalnih konstrukcijskih rešitvah, ki temeljijo na ustrezni izbiri materialov.

Delavnica temelji predvsem na rešitvah, ki so rezultat dveh evropskih raziskav:
PRECASTEEL - Montažne jeklene konstrukcije za nizke zgradbe na potresnih območjih
STEELRETRO - Jeklene rešitve za potresno obnovo in nadgradnjo obstoječih konstrukcij

PROGRAM:

$9.^{00}$ – $9.^{15}$ Registracija

$9.^{15}$ – $9.^{30}$ Presentation of the workshop (delavnica bo potekala v angleškem jeziku)

$9.^{30}$ – $10.^{10}$ Prefabricated steel or steel-concrete solutions for industrial single-storey and commercial low-rise buildings in earthquake-prone areas
Ing. Davide Quattrini, University of Camerino, Massa Carrara - Italy

$10.^{10}$ – $10.^{50}$ Steel solution for a commercial building: Case-study
Ing. Davide Quattrini, University of Camerino, Massa Carrara - Italy

$10.^{50}$ – $11.^{30}$ Precast slabs and double slabs solutions for floor and bracing system in composite steel-concrete structure in earthquake prone areas
Ing. Roberta Mallardo, Ferriere Nord, Udine - Italy

$11.^{30}$ – $12.^{10}$ Dissipative devices for existing buildings retrofit
Prof. Walter Salvatore, University of Pisa, Pisa - Italy

$12.^{10}$ – $12.^{50}$ Steel system for existing building retrofit: Case-study
Ing. Silvia Caprili, University of Pisa, Pisa - Italy

$12.^{50}$ - $13.^{00}$ Conclusions

Udeležba na delavnici je ob predhodni prijavi brezplačna, prijave sprejemamo do torka, 6. oktobra 2015, po e-pošti na naslov ema.kemperle@zag.si. V prijavi navedite: ime in priimek, organizacijo, telefon in E - naslov. V primeru prevelikega števila prijav, bo upoštevan vrstni red njihovega prejema

Organizer:
FERRIERE NORD

Supported by:
ZAG
IZS

Project partners:

Figure 71: Poster prepared for the workshop in Ljubljana, Slovenia (15.10.2015).

Figure 72: Poster prepared for the workshop in Madrid, Spain (28.10.2015) – in Spanish (also available in English).

Tagungsprogramm

Hintergrund/Zielgruppe:

Der Workshop richtet sich an Tragwerksplaner und Prüfingenieure im Bereich Hochbau/Industriebau/ Stahlbau. Thematisiert werden dabei sowohl Neubauten als auch Möglichkeiten der nachträglichen Verstärkung von Bestandsbauwerken in Erdbebengebieten. Dabei wird auf Anwendungsbereiche in Gebieten mit geringer bis mittlerer Seismizität (z.B. in Deutschland) und auf Gebiete mit höherer Seismizität eingegangen (z.B. in Südeuropa).

Veranstalter:
Lehrstuhl für Stahlbau und Leichtmetallbau
RWTH Aachen University
Mies-van-der-Rohe-Str. 1, 52074 Aachen
Tel.: 0241/8025177

mit freundlicher Unterstützung durch
RFCS (Research Fund for Coal and Steel)

Research Fund for Coal & Steel

Das Programm beinhaltet 8 Fortbildungszeiteinheiten entsprechend der Regelungen der Ingenieurkammer-Bau NRW und ist als Fortbildungsveranstaltung für Ingenieure unter der **Reg.-Nr. 32765** genehmigt.

Das Seminar ist anerkannt gemäß FuWO für: Beratende Ingenieure, Ingenieure, staatl. anerk. Sachverständige Prüfung der Standsicherheit, öffentl. best. u. vereid. Sachverständige ÖbuvSV in diesem Sachgebiet, Bauvorlageberechtigung

Anmeldung

Anmeldung im Internet:
http://www.stb.rwth-aachen.de/erdbeben2015/anmeldung.php

oder schriftlich an:
Lehrstuhl für Stahlbau und Leichtmetallbau
Mies-van-der-Rohe-Str. 1
52074 Aachen
oder
per Fax: 0241/8022140

Titel: ____________________

Name: ____________________

Firma/Hochschule: ____________________

Abteilung/Institut: ____________________

Straße: ____________________

PLZ/Ort: ____________________

Land: ____________________

E-Mail: ____________________

Telefon: ____________________

Datum/Unterschrift: ____________________

Anmeldung bitte bis zum 15. Oktober 2015

Tagungsort
RWTH Aachen, SuperC
Templergraben 57
52062 Aachen

Teilnahmegebühr
Die Teilnahmegebühr in Höhe von 50 € (inkl. Vortragsband und Mittagessen) ist bis zum 20. Oktober 2015 auf folgendes Konto zu überweisen:
FFBMS e.V.
IBAN: DE 62 390500 00 0000006064
Swift-BIC: AACSDE33XXX
Vwz.: Bauen in Erdbebengebieten 2015, Name, Vorname.

Kontakt
Dipl.-Ing. Hetty Bigelow
Lehrstuhl für Stahlbau und Leichtmetallbau
RWTH Aachen University
Tel.: 0241/8025275
E-Mail: seminar@stb.rwth-aachen.de

EINLADUNG & PROGRAMM

Workshop zum Bauen in Erdbebengebieten

06. November 2015
09:00 - 17:00 Uhr

RWTH Aachen, SuperC
Templergraben 57
52062 Aachen
Ford Saal

Tagungsprogramm

Freitag, 06. November 2015

9:00 - 9:15 Uhr Begrüßung

Prof. Dr.-Ing. Benno Hoffmeister
RWTH Aachen University, Institut für Stahlbau

9:15 - 9:35 Uhr
Bemessung und Nachweisführung für Erdbeben - neue und bestehende Bauwerke

Prof. Dr.-Ing. Benno Hoffmeister
RWTH Aachen University, Institut für Stahlbau

9:35 - 10:20 Uhr
Precast slabs and double slabs solutions for floor and bracing system in steel structures

(Vortragssprache: Englisch)

Use of lattice girder slabs and double slabs in steel structures as alternative solutions to steel sheeting/ steel bracing systems for seismic actions in low-rise commercial buildings/ Working examples applying simplified design procedures using Eurocode standards

Eng. Roberta Mallardo
Technical Office - Ferriere Nord S.p.A.- Pittini Group

10:20 - 10:35 Uhr Kaffeepause

Tagungsprogramm

10:35 - 11:20 Uhr
Einsatz von Stahl-Schubwänden bei der nachträglichen Verstärkung von seismisch beanspruchten Bestandsbauten

Nachträgliche Verstärkung vertikaler Lastabtragungssysteme aus Stahlbeton (Stützen, Rahmenkonstruktionen) in Gewerbe- und Industriebauten mit Stahl-Schubwänden (SSW).

Dipl.-Ing. Hetty Bigelow
RWTH Aachen University, Institut für Stahlbau

Dr.-Ing. Max Gündel
Wölfel Beratende Ingenieure GmbH + Co. KG

11:30 - 12:30 Uhr
Design and detailing of composite structures in seismic regions

(Vortragssprache: Englisch)

Comparison to design of steel structures

Prof. Dr. Herve Degee
Universiteit Hasselt

12:30 - 13:15 Uhr Mittagspause

13:15 - 14:15 Uhr
Bemessung nach Eurocode 8: Berücksichtigung von Überfestigkeiten dissipativer Bauteile

Erdbebenbemessung unter Berücksichtigung von Überfestigkeitsbeiwerten für Werkstoffe (Kapazitätsbemessung)

Prof. Dr.-Ing. Benno Hoffmeister
RWTH Aachen University, Institut für Stahlbau

Dr.-Ing. Max Gündel
Wölfel Beratende Ingenieure GmbH + Co. KG

Tagungsprogramm

14:15 - 15:45 Uhr
Anwendungssoftware **Precasteel Web 2.0**

Vorstellung des Freeware Anwendungsprogramms Precasteel Web 2.0 zur Bemessung von Industrie- und Gewerbebauten in Stahlbauweise.

Dipl.-Ing. Hetty Bigelow
RWTH Aachen University, Institut für Stahlbau

15:45 - 16:00 Uhr Kaffeepause

16:00 - 16:45 Uhr
Bemessung von schlanken Stahlträgern in Gebieten mit geringer Seismizität

Vorstellung neuer Entwicklungen bei Verwendung schlanker Bauteile in Erdbebengebieten

Dipl.-Ing. (FH) Matthias Wieschollek
RWTH Aachen University, Institut für Stahlbau

16:45 - 17:00 Uhr Schlussworte

Prof. Dr.-Ing. Benno Hoffmeister
RWTH Aachen University, Institut für Stahlbau

Figure 73: Flyer prepared for the workshop in Aachen, Germany (06.11.2015) – in German (also available in English).

4.1.6 Workshop in Cluj-Napoca, Romania

Figure 77 shows the general programme of the workshop organized by ECCS and PUT in Cluj-Napoca, Romania, the 20.11.2015. The event has been introduced in the main framework of the National Romanian Conference on Metallic Constructions.

The aim of the workshop is to explore the influence of material choices and structural solutions for the ductile behaviour of buildings in seismic areas (i.e. *Opus [2]*), to analyze cost-effectiveness and safe design solutions (i.e. *PrecaSteel [1]*) and to present steel based techniques for the rehabilitation of existing constructions (i.e. *SteelRetro [3]*). The interventions were executed by Prof. Mohammed Hjiaj (INSA de Rennes, Figure 74), by Dr. Eng. Zsolt Nagy and Dr. Eng. Adrian Dogariu (PUT) and by Dr. Eng. Rosario Gigliotti and Eng. Armando Lanzi (CERI). All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Figure 74: Attending people and presentation of Prof. Hjiaj during the workshop in Cluj-Napoca.

4.1.7 Workshop in Timisoara, Romania

Figure 78 shows the general programme of the workshop organized by PUT in Timisoara, Romania, the 23.11.2015. The seminar presented several solutions for the seismic rehabilitation of existing buildings with steel-based devices, including technology interventions, design and evaluation methods and specific tools for the sizing of connections, according to the main results of SteelRetro project [3]. The presentations were executed by Prof. Dan Dubina, by Dr. Eng. Aurel Strata and Dr. Eng. Adrian Dogariu (PUT) and by Dr. Eng. Rosario Gigliotti and Eng. Francesca Mattei (CERI).

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

4.1.8 Workshop in Coimbra, Portugal

Figure 79 shows the general programme of the workshop organized by ECCS in Coimbra, Portugal. The event was introduced in the main framework of the 10th Conference on Steel and Composite constructions (*X Congreso de Construçao Metalica e Mista*), the 27.11.2015.

The aim of the event was to evaluate the influence of material choices on the design of different structural solutions for buildings in seismic areas (*Opus [2]*), to analyze problems connected to the seismic design of steel and steel/concrete composite structures (*PrecaSteel [1]*) and to proposed several steel-based techniques for the retrofit of existing constructions (*SteelRetro [3]*).
The presentations were mainly executed by academic people, including Steel-Earth participants (i.e. Veronique Dehan and Cecile Haremza – ECCS, José Henriques – University of Hasselt) and other external contributions, such as the ones of Prof. José Miguel Castro (University of Porto), Dr. Eng. Mario D'Aniello (University of Naples Federico II) and Prof. Hugo Augusto (University of Coimbra).
Figure 75 shows some moments of the event.
All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Figure 75: Attending people and presentation of Mario D'Aniello during the workshop in Coimbra.

4.1.9 Workshop in Volos, Greece

Figure 80 shows the general programme of the workshop organized in Volos (Greece) by University of Thessaly (UTH) and SHELTER S.A., the 04.12.2015. This workshop was addressed to engineers, interested in state-of-the-art applications of structural steel solutions in seismic-prone regions. Cost-effective and safe design solutions for industrial, commercial and office buildings, as well as steel-based solutions for the rehabilitation of existing structures were presented and discussed.

Interventions were executed mainly by academic people, both involved in *Steel-Earth* dissemination activities, such as for example Prof. Benno Hoffmeister (RWTH), Prof. S.A. Karamanos and Charis Papatheocharis (UTH), Dr. Eng. Francesco Morelli (UniPI), Dr. Eng. Ludovic Fulop (VTT), Dr. Eng. Adrian Dogariu (PUT), and by other invited lecturers, for example Prof. Ioannis Vayas (National Technical University of Athens).

Figure 76 shows some moments of the event. All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Figure 76: Presentations of prof. Hoffmeister (RWTH) and Karamanos (UTH) during the workshop in Volos.

4.1.10 Workshop in Hasselt, Belgium

Figure 81 shows the general programme of the workshop in Hasselt (Belgium), the 14.12.2015. As visible, the event was mainly divided into two sections, the first one directly related to Steel-Earth activities (mainly Opus [2] and SteelRetro [3] projects), with presentations of academic people such as Prof. Hervé Degee and Prof. José Henriques (UHasselt) and Prof. Benno Hoffmeister (RWTH), the second one with applications also executed by non-academic people and opportunely invited for the workshop.

All the presentations executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/.

Figure 77: Poster prepared for the workshop in Cluj-Napoca, Romania (20.11.2015).

Figure 78: Poster prepared for the workshop in Timisoara, Romania (23.11.2015) – in Romanian (also available in English).

Figure 79: Poster prepared for the workshop in Coimbra, Portugal (27.11.2015).

The University of Thessaly and Shelter SA cordially invite you to the workshop on

SHELTER

Research Fund for Coal & Steel

Structural steel solutions in earthquake-prone areas; Design & Retrofitting

Friday, December 04, 2015, 09:00-15:30

Tsalapatas Complex, Volos, Greece

This international workshop is addressed to engineers, interested in state-of-the-art applications of structural steel solutions in seismic-prone regions. Cost- effective and safe design solutions for industrial, commercial and office buildings, as well as steel based solutions for rehabilitation of existing structures will be presented and discussed.

Workshop program

- 09:00-10:30: **Part A**

09:00-09:10	Arrival of participants
09:10-09:15	Welcome and Introduction to the Workshop **Spyros A. Karamanos,** *University of Thessaly*
09:15-10:00	Structural systems and devices for seismic resistant buildings **Ioannis Vayas,** *National Technical University, Athens*
10:00-10:30	Earthquake performance of light gauge steel (LGS) structural members and systems **Ludovic Fulop,** *VTT, Finland*

- 10:30-11:00 Coffee break
- 11:00-12:30: **Part B**

11:00-11:30	Effect of steel grade and quality on structural steel design in seismic regions **Benno Hoffmeister**, *RWTH Aachen, Germany*
11:30-12:00	Design requirements for buckling restrained braces for different target applications **Aurel Stratan, Dan Dubina, Florin Voica, Adrian Dogariu, Ciprian Zub,** *Politechnica University of Timisoara, Romania*
12:00-12:30	Steel-based dissipative system for the retrofit of existing R.C. buildings **Francesco Morelli, Silvia Caprili, Walter Salvatore,** *University of Pisa, Italy*

- 12:30-13:30 Lunch break
- 13:30-15:00: **Part C**

13:30-14:00	Steel solutions for the seismic rehabilitation of masonry buildings **George E. Varelis[1], Daniel Vasilikis[2], Theocharis Papatheocharis[2], Spyros A. Karamanos[2],** *[1]PDL Solutions Ltd, U.K.; [2]University of Thessaly*
14:00-14:30	Theoretical - experimental investigation and optimization of the seismic strengthening of existing R.C. buildings with pilotis via steel concentric X-braces **Dimitrios Sophianopoulos, Konstantinos Papachristou, Theocharis Papatheocharis,** **Panos Tsopelas, Philip Perdikaris,** *University of Thessaly*
14:30-15:00	Application of dissipative steel links for seismic strengthening of existing structures with soft storey **Kyriaki Georgiadi-Stefanidi[1], Euripidis Mistakidis[1], Kosmas Stylianidis[2], Evangelos Barlas[1],** *[1]University of Thessaly, [2]Aristotle University of Thessaloniki*

- 15:00-15:30 Discussion and Closure: **Anthony S. Karamanos**, RFCS TGS8 committee member.

Based on the results of European RFCS Projects: OPUS, PRECASTEEL, STEELRETRO

Contact:	*Theocharis Papatheocharis* *Mob.: +30 6944745334* *e-mail: th_papath@yahoo.gr*	*Spyros A. Karamanos* *Mob.: +30 6944262967* *e-mail: skara@mie.uth.gr*

Figure 80: Poster prepared for the workshop in Volos, Greece (04.12.2015).

universiteit hasselt
KNOWLEDGE IN ACTION

WORKSHOP STEEL-EARTH
Monday 14th december 2015

Program

9:00 Welcome of participants

PART 1 – GENERAL ISSUES AND SEISMIC ACTION

9:20 – 9:25 Welcome address – Bram Vandoren (UHasselt)

9:25 – 9:55 Overview of Eurocode 8 – André Plumier (ULg)

9:55 – 10:40 Development of seismic hazard maps for Belgium – Thierry Camelbeeck (ORB/KSB)

10:40 – 11:00 Coffee break

PART 2 – SPECIFIC STEEL-EARTH PRESENTATIONS

11:00 – 11:30 Selection of the appropriate steel quality for efficient earthquake resistant structures – Jose Gouveia Henriques (UHasselt)

11:30 – 12:15 Seismic assessment of existing buildings and steel-based rehabilitation solutions – Benno Hoffmeister (RWTH Aachen)

12:15 – 13:00 Optimizing the seismic performances of steel and steel-concrete structures in low and moderate seismic zones – Hervé Degée (UHasselt)

13:00 – 14:00 Lunch break

PART 3 – LINKING WITH THE PRACTICE

14:00 – 16:00 Presentations of practical seismic design examples

Steven Ooms (SECO), Vincent de Ville & Yves Duchêne (Bureau GREISCH), Tom MOLKENS (Stubeco), Pierre Mengeot (BESIX)

16:00 16:30 Discussion

Figure 81: Poster prepared for the workshop in Hasselt, Belgium (14.12.2015).

4.1.11 Final STEEL-EARTH workshop

The final workshop of the dissemination project has been organized in Naples (Italy), the 07.04.2016, by University of Pisa (coordinator) with the collaboration of University of Naples Federico II. The event has been organized with the support of the Engineering Association of Naples, also providing professional credits to the attending people.

The choice of the date and of the location was related to the possibility to directly disseminate the results obtained inside Steel-Earth to the members of CEN present in Naples for the meeting of CEN/TC 250/WG2 related to steel and steel concrete composite structures.

The general programme of the final workshop is presented in Figure 83. As visible from the programme, after the general introduction of Steel-Earth project executed by Dr. Eng. Silvia Caprili (University of Pisa, coordinator), presentations mainly related to the results obtained inside *SteelRetro* [3] *("Retrofit of framed buildings with buckling restrained braces"*- Dr. Eng. Aurel Stratan, PUT and *"Retrofit of existing r.c. structures with steel based innovative systems"* – Dr. Eng. Silvia Caprili, UniPI), *PrecaSteel* [1] (*"Design of steel and composite steel-concrete structures in seismic zone according to EC8"* – Prof. Andrea Dall'Asta, UniCAM) and *Opus* [2] (*"Material-related issues in the seismic design of composite structure"* – Prof. Hervé Degee, UHasselt, *"Influence of material quality variation on seismic performance of steel structures"* – Prof. Benno Hoffmeister, RWTH) have been organized.

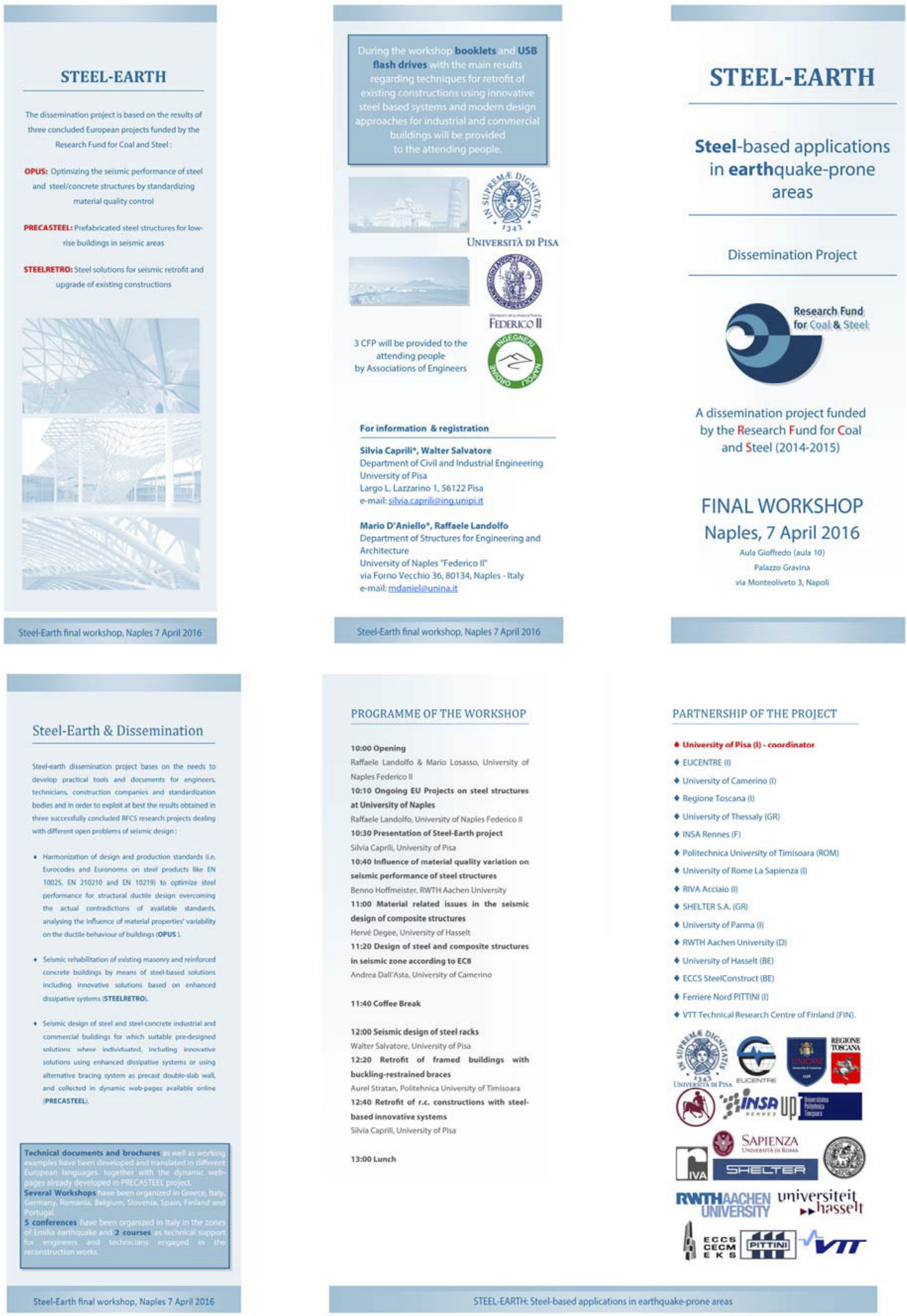
Beside, two interventions have been executed by Prof. Walter Salvatore (UniPI) and by Prof. Raffaele Landolfo and Prof. Mario Losasso (University of Naples Federico II).

Brochures (half in English and half in Italian for a total number of 250, Figure 84) related to the event and, more in general, to the Steel-Earth dissemination project have been prepared and distributed to the attending people, as well as volumes (n°250) containing the technical sheets (TS) and working examples (WE) developed in WP1 and background and pre-normative documents elaborated inside WP2 (Figure 85).

USB flash drives containing the pdf version of the documents have been prepared and distributed.

Figure 82: Example of the USB flash drives distributed to the attending people to the conferences.

Figure 83: Programme of the final workshop of the dissemination project.


STEEL-EARTH

The dissemination project is based on the results of three concluded European projects funded by the Research Fund for Coal and Steel:

OPUS: Optimizing the seismic performance of steel and steel/concrete structures by standardizing material quality control

PRECASTEEL: Prefabricated steel structures for low-rise buildings in seismic areas

STEELRETRO: Steel solutions for seismic retrofit and upgrade of existing constructions

Steel-Earth final workshop, Naples 7 April 2016

During the workshop **booklets** and **USB flash drives** with the main results regarding techniques for retrofit of existing constructions using innovative steel based systems and modern design approaches for industrial and commercial buildings will be provided to the attending people.

3 CFP will be provided to the attending people by Associations of Engineers

For information & registration

Silvia Caprili*, Walter Salvatore
Department of Civil and Industrial Engineering
University of Pisa
Largo L. Lazzarino 1, 56122 Pisa
e-mail: silvia.caprili@ing.unipi.it

Mario D'Aniello*, Raffaele Landolfo
Department of Structures for Engineering and Architecture
University of Naples "Federico II"
via Forno Vecchio 36, 80134, Naples - Italy
e-mail: mdaniel@unina.it

Steel-Earth final workshop, Naples 7 April 2016

STEEL-EARTH

Steel-based applications in **earth**quake-prone areas

Dissemination Project

A dissemination project funded by the Research Fund for Coal and Steel (2014-2015)

FINAL WORKSHOP
Naples, 7 April 2016
Aula Gioffredo (aula 10)
Palazzo Gravina
via Monteoliveto 3, Napoli

Steel-Earth & Dissemination

Steel-earth dissemination project bases on the needs to develop practical tools and documents for engineers, technicians, construction companies and standardization bodies and in order to exploit at best the results obtained in three successfully concluded RFCS research projects dealing with different open problems of seismic design:

- Harmonization of design and production standards (i.e. Eurocodes and Euronorms on steel products like EN 10025, EN 210210 and EN 10219) to optimize steel performance for structural ductile design overcoming the actual contradictions of available standards, analysing the influence of material properties' variability on the ductile behaviour of buildings (**OPUS**).
- Seismic rehabilitation of existing masonry and reinforced concrete buildings by means of steel-based solutions including innovative solutions based on enhanced dissipative systems (**STEELRETRO**).
- Seismic design of steel and steel-concrete industrial and commercial buildings for which suitable pre-designed solutions where individuated, including innovative solutions using enhanced dissipative systems or using alternative bracing system as precast double-slab wall, and collected in dynamic web-pages available online (**PRECASTEEL**).

Technical documents and brochures as well as working examples have been developed and translated in different European languages, together with the dynamic web-pages already developed in PRECASTEEL project.
Several Workshops have been organized in Greece, Italy, Germany, Romania, Belgium, Slovenia, Spain, Finland and Portugal.
5 conferences have been organized in Italy in the zones of Emilia earthquake and **2 courses** as technical support for engineers and technicians engaged in the reconstruction works.

Steel-Earth final workshop, Naples 7 April 2016

PROGRAMME OF THE WORKSHOP

10:00 Opening
Raffaele Landolfo & Mario Losasso, University of Naples Federico II
10:10 Ongoing EU Projects on steel structures at University of Naples
Raffaele Landolfo, University of Naples Federico II
10:30 Presentation of Steel-Earth project
Silvia Caprili, University of Pisa
10:40 Influence of material quality variation on seismic performance of steel structures
Benno Hoffmeister, RWTH Aachen University
11:00 Material related issues in the seismic design of composite structures
Hervé Degee, University of Hasselt
11:20 Design of steel and composite structures in seismic zone according to EC8
Andrea Dall'Asta, University of Camerino

11:40 Coffee Break

12:00 Seismic design of steel racks
Walter Salvatore, University of Pisa
12:20 Retrofit of framed buildings with buckling-restrained braces
Aurel Stratan, Politehnica University of Timisoara
12:40 Retrofit of r.c. constructions with steel-based innovative systems
Silvia Caprili, University of Pisa

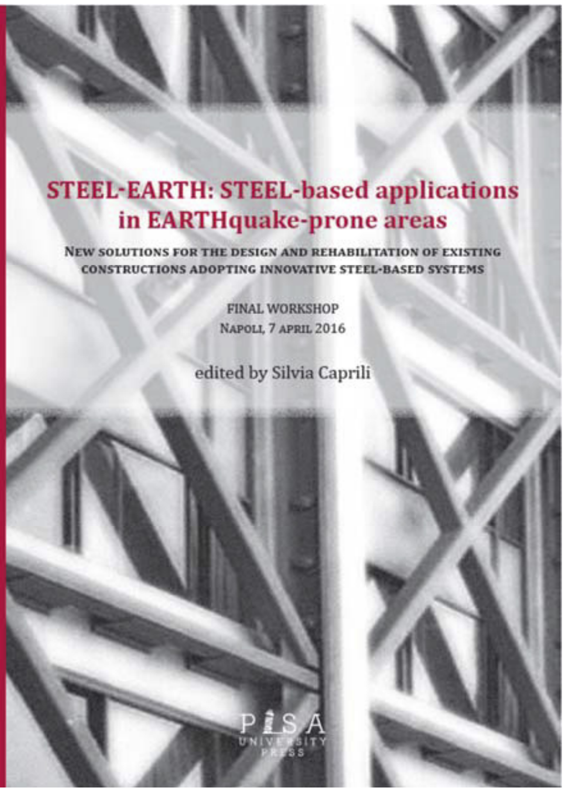
13:00 Lunch

PARTNERSHIP OF THE PROJECT

- **University of Pisa (I) - coordinator**
- EUCENTRE (I)
- University of Camerino (I)
- Regione Toscana (I)
- University of Thessaly (GR)
- INSA Rennes (F)
- Politechnica University of Timisoara (ROM)
- University of Rome La Sapienza (I)
- RIVA Acciaio (I)
- SHELTER S.A. (GR)
- University of Parma (I)
- RWTH Aachen University (D)
- University of Hasselt (BE)
- ECCS SteelConstruct (BE)
- Ferriere Nord PITTINI (I)
- VTT Technical Research Centre of Finland (FIN).

STEEL-EARTH: Steel-based applications in earthquake-prone areas

Figure 84: Brochure prepared for the final workshop of Steel-Earth (in English and in Italian).



Il presente volume raccoglie alcuni documenti tecnici ed esempi applicativi relativi alle moderne tecniche di progettazione di edifici con struttura in acciaio e composta acciaio/calcestruzzo in zona sismica ed alle metodologie di adeguamento, miglioramento sismico e di intervento locale su edifici esistenti in cemento armato e in muratura impiegando sia sistemi di tipo tradizionale sia sistemi innovativi. I diversi contributi sono stati sviluppati nell'ambito del progetto Europeo "Steel-Earth: *Steel-based applications in earthquake-prone areas*", finalizzato alla disseminazione dei risultati ottenuti nell'ambito dei tre precedenti progetti di ricerca finanziati dal Research Fund for Coal and Steel (RFCS) "*SteelRetro*" – riguardante l'applicazione di moderne tecniche di adeguamento sismico per costruzioni esistenti basati sull'impiego dell'acciaio, "*PrecaSteel*" – riguardante la progettazione di edifici industriali/commerciali con struttura in acciaio o composta considerando gli aspetti economici oltre a quelli strettamente tecnici e di dettaglio, e "*Opus*" – riguardante l'analisi dell'influenza della variabilità delle caratteristiche meccaniche del materiale acciaio sul comportamento duttile di strutture in acciaio di diverse tipologie progettate in zona sismica.

Silvia Caprili: è dottore di ricerca in Scienze e Tecniche dell' Ingegneria Civile – curriculum strutture. È titolare di un assegno di ricerca presso il Dipartimento di Ingegneria Civile e Industriale dell'Università di Pisa dove svolge attività di ricerca nel campo dell'ingegneria strutturale sulla progettazione antisismica di nuove costruzioni e sull'adeguamento di edifici esistenti. È autrice di pubblicazioni a livello nazionale ed internazionale.

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S. Caprili (ed.) STEEL-EARTH: STEEL-based applications in EARTHquake-prone areas

STEEL-EARTH: STEEL-based applications in EARTHquake-prone areas

NEW SOLUTIONS FOR THE DESIGN AND REHABILITATION OF EXISTING CONSTRUCTIONS ADOPTING INNOVATIVE STEEL-BASED SYSTEMS

FINAL WORKSHOP
NAPOLI, 7 APRIL 2016

edited by Silvia Caprili

PISA UNIVERSITY PRESS

STEEL-EARTH: STEEL-based applications in EARTHquake-prone areas

NEW SOLUTIONS FOR THE DESIGN AND REHABILITATION OF EXISTING CONSTRUCTIONS ADOPTING INNOVATIVE STEEL-BASED SYSTEMS

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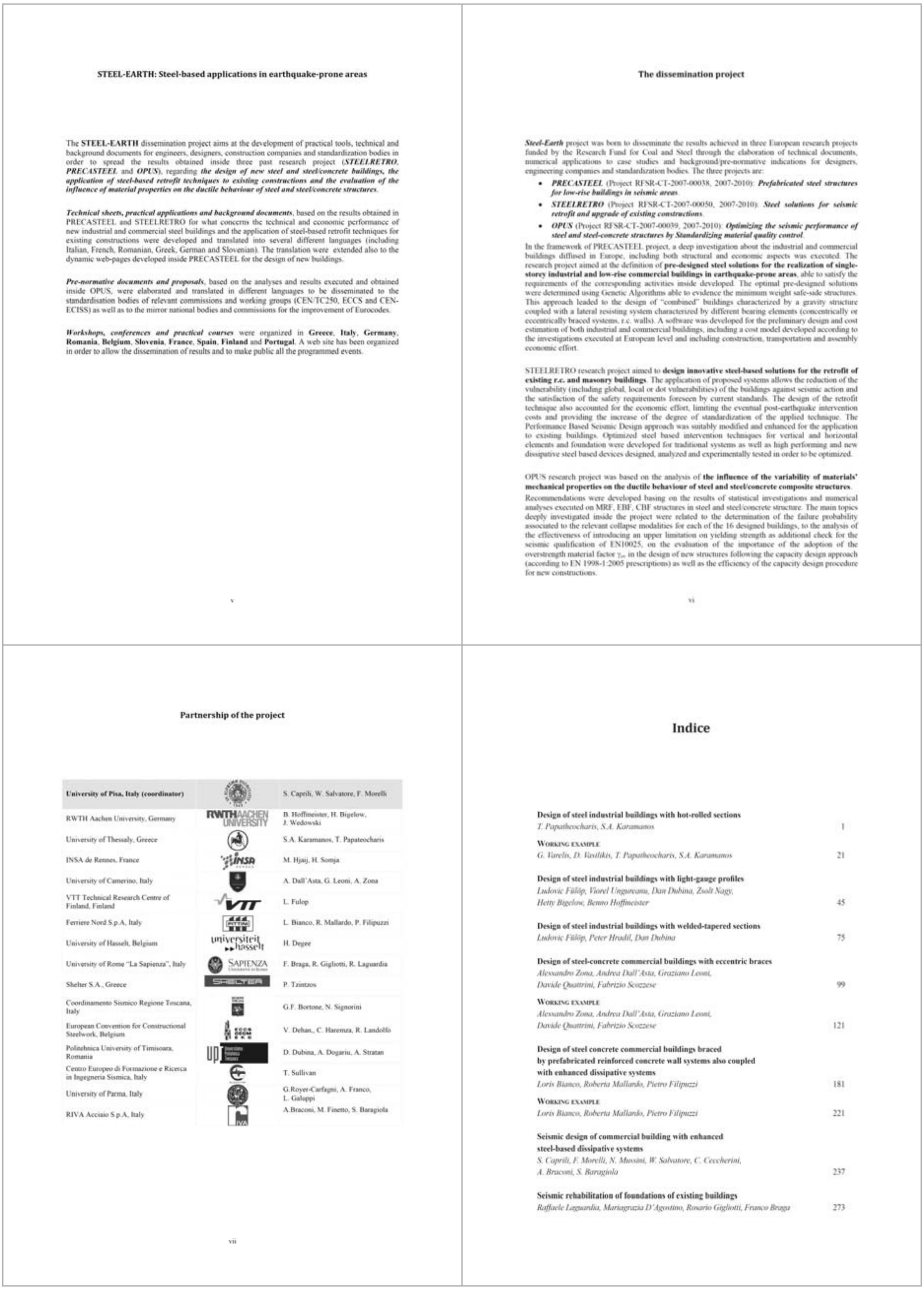

STEEL-EARTH: Steel-based applications in earthquake-prone areas

The **STEEL-EARTH** dissemination project aims at the development of practical tools, technical and background documents for engineers, designers, construction companies and standardization bodies in order to spread the results obtained inside three past research project (***STEELRETRO***, ***PRECASTEEL*** and ***OPUS***), regarding ***the design of new steel and steel/concrete buildings, the application of steel-based retrofit techniques to existing constructions and the evaluation of the influence of material properties on the ductile behaviour of steel and steel/concrete structures***.

Technical sheets, practical applications and background documents, based on the results obtained in PRECASTEEL and STEELRETRO for what concerns the technical and economic performance of new industrial and commercial steel buildings and the application of steel-based retrofit techniques for existing constructions were developed and translated into several different languages (including Italian, French, Romanian, Greek, German and Slovenian). The translation were extended also to the dynamic web-pages developed inside PRECASTEEL for the design of new buildings.

Pre-normative documents and proposals, based on the analyses and results executed and obtained inside OPUS, were elaborated and translated in different languages to be disseminated to the standardisation bodies of relevant commissions and working groups (CEN/TC250, ECCS and CEN-ECISS) as well as to the mirror national bodies and commissions for the improvement of Eurocodes.

Workshops, conferences and practical courses were organized in **Greece**, **Italy**, **Germany**, **Romania**, **Belgium**, **Slovenia**, **France**, **Spain**, **Finland** and **Portugal**. A web site has been organized in order to allow the dissemination of results and to make public all the programmed events.

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The dissemination project

Steel-Earth project was born to disseminate the results achieved in three European research projects funded by the Research Fund for Coal and Steel through the elaboration of technical documents, numerical applications to case studies and background/pre-normative indications for designers, engineering companies and standardization bodies. The three projects are:

- ***PRECASTEEL*** (Project RFSR-CT-2007-00038, 2007-2010): ***Prefabricated steel structures for low-rise buildings in seismic areas***.
- ***STEELRETRO*** (Project RFSR-CT-2007-00050, 2007-2010): ***Steel solutions for seismic retrofit and upgrade of existing constructions***.
- ***OPUS*** (Project RFSR-CT-2007-00039, 2007-2010): ***Optimizing the seismic performance of steel and steel-concrete structures by Standardizing material quality control***.

In the framework of PRECASTEEL project, a deep investigation about the industrial and commercial buildings diffused in Europe, including both structural and economic aspects was executed. The research project aimed at the definition of **pre-designed steel solutions for the realization of single-storey industrial and low-rise commercial buildings in earthquake-prone areas**, able to satisfy the requirements of the corresponding activities inside developed. The optimal pre-designed solutions were determined using Genetic Algorithms able to evidence the minimum weight safe-side structures. This approach leaded to the design of "combined" buildings characterized by a gravity structure coupled with a lateral resisting system characterized by different bearing elements (concentrically or eccentrically braced systems, r.c. walls). A software was developed for the preliminary design and cost estimation of both industrial and commercial buildings, including a cost model developed according to the investigations executed at European level and including construction, transportation and assembly economic effort.

STEELRETRO research project aimed to **design innovative steel-based solutions for the retrofit of existing r.c. and masonry buildings**. The application of proposed systems allows the reduction of the vulnerability (including global, local or dot vulnerabilities) of the buildings against seismic action and the satisfaction of the safety requirements foreseen by current standards. The design of the retrofit technique also accounted for the economic effort, limiting the eventual post-earthquake intervention costs and providing the increase of the degree of standardization of the applied technique. The Performance Based Seismic Design approach was suitably modified and enhanced for the application to existing buildings. Optimized steel based intervention techniques for vertical and horizontal elements and foundation were developed for traditional systems as well as high performing and new dissipative steel based devices designed, analyzed and experimentally tested in order to be optimized.

OPUS research project was based on the analysis of **the influence of the variability of materials' mechanical properties on the ductile behaviour of steel and steel/concrete composite structures**.

Recommendations were developed basing on the results of statistical investigations and numerical analyses executed on MRF, EBF, CBF structures in steel and steel/concrete structure. The main topics deeply investigated inside the project were related to the determination of the failure probability associated to the relevant collapse modalities for each of the 16 designed buildings, to the analysis of the effectiveness of introducing an upper limitation on yielding strength as additional check for the seismic qualification of EN10025, on the evaluation of the importance of the adoption of the overstrength material factor γ_{ov} in the design of new structures following the capacity design approach (according to EN 1998-1:2005 prescriptions) as well as the efficiency of the capacity design procedure for new constructions.

vi

Partnership of the project

University of Pisa, Italy (coordinator)	S. Caprili, W. Salvatore, F. Morelli
RWTH Aachen University, Germany	B. Hoffmeister, H. Bigelow, J. Wedowski
University of Thessaly, Greece	S.A. Karamanos, T. Papateocharis
INSA de Rennes, France	M. Hjaij, H. Somja
University of Camerino, Italy	A. Dall'Asta, G. Leoni, A. Zona
VTT Technical Research Centre of Finland, Finland	L. Fulop
Ferriere Nord S.p.A, Italy	L. Bianco, R. Mallardo, P. Filipuzzi
University of Hasselt, Belgium	H. Degee
University of Rome "La Sapienza", Italy	F. Braga, R. Gigliotti, R. Laguardia
Shelter S.A., Greece	P. Tzintzos
Coordinamento Sismico Regione Toscana, Italy	G.F. Bortone, N. Signorini
European Convention for Constructional Steelwork, Belgium	V. Dehan,, C. Haremza, R. Landolfo
Polinehnica University of Timisoara, Romania	D. Dubina, A. Dogariu, A. Stratan
Centro Europeo di Formazione e Ricerca in Ingegneria Sismica, Italy	T. Sullivan
University of Parma, Italy	G.Royer-Carfagni, A. Franco, L. Galuppi
RIVA Acciaio S.p.A, Italy	A.Braconi, M. Finetto, S. Baragiola

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Indice

Figure 85: Booklets distributed during the final workshop in Naples.

4.2 Conferences in Emilia-Romagna

Five conferences have been organized by University of Parma (UniPR) in Emilia-Romagna (Italy), region strongly damaged by the 2012 earthquake, causing significant economic losses due to the interruption of industrial and commercial activities developed inside r.c. and precast existing buildings that were not able to correctly sustain seismic action. Seminars organized in the framework of Steel-Earth project had the main aim to provide to engineers, design companies, architects and technicians involved in constructions useful information for the retrofit of existing buildings (basing on *SteelRetro* [3] results) and for the design of new constructions according to actual seismic design codes (basing on *PrecaSteel* [1] results).

The conferences were organized with the support of the Universities of Bologna, Modena and Reggio Emilia, Milano (for the seminar in Mantova) and Ferrara, as well as with the collaboration of the local Engineering Associations. Except for the introduction intervention, different in relation to the location, the general programme of the conferences is presented in Figure 91 and Figure 92.

Table 17: Conferences in Emilia-Romagna organized inside Steel-Earth.

n°	Date	Location	n° attending people	Notes
1	03.07.2015	Parma	100	
2	18.09.2015	Mantova	170	The seminar has been organized in collaboration with prof. Luigi Biolzi (Politecnico di Milano)
3	09.10.2015	Ferrara	100	The seminar has been organized in collaboration with prof. Antonio Tralli (University of Ferrara)
4	22.10.2015	Bologna	110	The seminar has been organized in collaboration with prof. Marco Savoia (University of Bologna)
5	13.11.2015	Modena	180	The seminar has been organized in collaboration with prof. Angelo Marcello Tarantino (University of Modena e Reggio Emilia)

Technical Italian associations and design companies, such as:

- *FPA - Fondazione Promozione Acciaio* (http://www.promozioneacciaio.it/)
- *INGENIO – informazione tecnica e progettuale* (http://www.ingenio-web.it/)
- *Stalbau Pichler* (http://www.stahlbaupichler.com/it)

also provided their contribution to the organization and development of the workshops, providing useful material such as depliants, documents, technical publications, etc. to the attending people, as deeply described in deliverable D.5.1.

USB flash drives (in number corresponding about to the number of foreseen participants) with the pdf of presentations and of documents elaborated inside Steel-Earth (i.e. TS and WE of WP1) were distributed to the attending people. All the presentations and videos executed during the workshops can be downloaded from the website of the project at the following link: https://www.steelconstruct.com/site/. Figure 86÷Figure 90 shows some moments of the seminars.

Figure 86: Attending people and presentation during the seminar in Parma.

Figure 87: Attending people and presentation during the seminar in Mantova.

Figure 88: Attending people and presentation during the seminar in Ferrara.

Figure 89: Attending people and presentation during the seminar in Bologna.

Figure 90: Attending people and presentation during the seminar in Modena.

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Ordine degli Ingegneri Della Provincia di Bologna

Research Fund for Coal & Steel

A 3 anni dal terremoto in Emilia: progettazione ed adeguamento di strutture in zona sismica

22 Ottobre 2015
Università degli Studi di Bologna
Aula Magna – viale del Risorgimento 2 - Bologna

Programma

9,00 – 9,30	Registrazione partecipanti
9:30 – 10:00	Saluti – Introduzione a cura dell'Università di Bologna e dell'ordine degli ingegneri di Bologna
10:00 – 10:45	Terremoto in Emilia: aspetti tecnici e socio-economici (***Marco Savoia,*** *Università di Bologna*)
10:45 – 11:15	*Pausa Caffè*
11:15 – 12:15	Sistemi di protezione passiva per il miglioramento di edifici esistenti (***Walter Salvatore,*** *Università di Pisa*)
12:15 – 13:00	Caso studio: miglioramento di edifici esistenti con sistemi in acciaio (***Silvia Caprili***, *Università di Pisa*)
14:00 – 15:30	Progettazione di strutture in acciaio e composte acciaio-cls in zona sismica secondo EC8 (***Andrea Dall'Asta,*** *Università di Camerino)*
15:30 – 16:00	*Pausa Caffè*
16:00 – 16:45	Soluzioni progettuali per edifici industriali in zona sismica: esempi ed applicazioni (***Rosario Gigliotti,*** *Università di Roma*)
16:45 – 17:30	Caso studio: Soluzioni con pannelli prefabbricati in calcestruzzo in strutture in acciaio (***Roberta Mallardo,*** *Ferrerie Nord*)
17:30 – 18:00	Costruzioni in acciaio nell'Emilia post-Sisma: esempi di realizzazioni (***Luca Benetti***, *Stahlbau Pichler*)
18:00 – 18:30	Discussione

- **Durante il corso verrà distribuito il materiale didattico relativo alla conferenza.**
- **Ai partecipanti sarà rilasciata, se richiesta, una dichiarazione di frequenza.**
- **La partecipazione all'evento rilascia agli Ingegneri n. 6 CFP, ai fini dell'aggiornamento delle competenze professionali ex DPR 137/2012 e successivo regolamento approvato dal Ministero della Giustizia. I CFP saranno riconosciuti unicamente con la partecipazione all'intera durata dell'evento, attestata mediante la registrazione con firma in ingresso ed in uscita sia per la sessione della mattina che per quella del pomeriggio.**
- **È prevista la partecipazione di un massimo di 150 persone. È pertanto obbligatoria l'iscrizione online tramite la piattaforma www.iscrizioneformazione.it**

Il seminario è organizzato nell'ambito del progetto finanziato dal Research Fund for Coal and Steel
STEEL EARTH – Steel-based application in earthquake-prone areas.

Project partners:

Universitatea Politehnica Timişoara
SAPIENZA Università di Roma
SHELTER
FERRIERE NORD
Università degli Studi di Parma
RWTH Aachen
INSA Rennes
Regione Toscana
VTT
Université de Liège
ECCS CECM EKS
UNICAM
Università di Pisa
EUCENTRE
RIVA ACCIAIO
University of Thessaly

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PRECASTEEL – Prefabricated steel structures for low-rise buildings in seismic areas
STEELRETRO – Steel solutions for seismic retrofit and upgrade of existing constructions
STEEL-EARTH – Steel-based applications in earthquake-prone areas

Figure 91: General programme of the seminars in Emilia-Romagna (specific for Bologna).

Figure 92: General programme of the seminars in Emilia-Romagna (Parma, Mantova, Ferrara and Modena).

4.3 Training courses at EUCENTRE, Pavia (Italy)

Two training courses (with the same programme) were organized by EUCENTRE, Pavia, in October 16-17, 2015 and in November 15-16, 2015. Figure 93 shows the general programme of the two courses; as visible the main topic of the first day course was the design of new steel and steel/concrete structures including passive protection devices (with lessons executed by Prof. Raffaele Landolfo – University of Naples Federico II, Prof. Alessandro Zona and Prof. Andrea Dall'Asta – University of Camerino and Dr. Eng. Francesco Morelli – University of Pisa). The second day was mainly focused on the rehabilitation of existing constructions (with lessons of Prof. Gaetano Della Corte and Dr. Eng. Mario D'Aniello – University of Naples Federico II).

Also in this case, contributions by partners directly involved in Steel-Earth and by additional experts in the field of both design and retrofit of constructions were introduced in the training courses.

Printed copies of presentations and of related documents were distributed to the attending people.

Figure 93: Programme of the training courses at EUCENTRE, Pavia (Italy).

5. Conclusions

The dissemination project *Steel-Earth* “Steel-based applications in earthquake prone areas” (RFS2-CT-2014-00022) allowed the elaboration of practical tools for the design and the rehabilitation of existing buildings adopting steel-based techniques. The spreading of the results coming from the three past RFCS projects *PrecaSteel* [1], *SteelRetro* [3] and *Opus* [2] has been guaranteed by the preparation of technical documents, practical applications to case study buildings and pre-normative guidelines useful for technicians, designers, construction companies and standardization bodies.

Technical Sheets (TS) and Working Examples (WE) have been prepared concerning innovative solutions for the seismic design of steel and composite steel-concrete buildings and the rehabilitation of existing masonry and r.c. buildings by adopting enhanced steel-based techniques; in WE the numerical applications to case studies of the simple procedures presented in the corresponding TS for design and retrofit are proposed.

In particular, the following documents have been prepared:

- TS+WE on the design of steel industrial buildings with HR sections.
- TS+WE on the design of steel industrial buildings with LGS profiles.
- TS+WE on the design of steel industrial buildings with WT profiles.
- TS+WE on the design of composite commercial buildings with steel bracing systems.
- TS+WE on the design of composite commercial buildings with r.c. shear walls.
- TS+WE on the design of composite commercial buildings with SSCD.
- TS on general principles for seismic rehabilitation of masonry and r.c. buildings.
- TS+WE on the seismic rehabilitation of foundations of existing buildings.
- TS+WE on the seismic rehabilitation of vertical systems in masonry buildings.
- TS+WE on the seismic rehabilitation of vertical systems in r.c. buildings by bracing systems.
- TS+WE on the rehabilitation of vertical systems in r.c. buildings by SSW.
- TS+WE on seismic rehabilitation of r.c. buildings with SSCD.
- TS+WE on the optimal location of bracing systems in r.c. buildings.

Background documents and pre-normative guidelines have been prepared concerning design, rehabilitation and problems related to inconsistencies between design and production standards (i.e. Eurocodes and Euronorms for steel products), mainly coming from the results obtained inside *Opus* [2] and from the further investigations developed in *Steel-Earth*. In this case, in particular, a pre-normative document related to the efficacy of adopting different γ_{ov} for different steel grades and of the capacity design approach in protecting non-dissipative members, considering the actual difference between nominal and real material mechanical properties, has been prepared and distributed to the members of WG2 of Eurocode (CEN/TC 250/SC 8/WG 2 *"Steel and Composite Structures"*) during the final workshop of the project for the possible implementation of Eurocode.

Design guidelines for the rehabilitation techniques adopting BRB, SSW and SSCD – actually not implemented in standards at European level – have been provided, basing on the modified Performance Based Seismic Design (PBSD) procedure, developed and opportunely adapted for the application to existing constructions.

The global dissemination of the results was achieved through several instruments: TS, WE and background/pre-normative documents were translated into several languages and are actually free available to be downloaded from the project website:

(https://www.steelconstruct.com/site/→Projects RFCS →STEEL-EARTH)

in English, Italian, French, German, Greek and Romanian (only English, French and Italian for background documents), constituting a useful tool for designers.

The obtained results concerning design and rehabilitation of constructions have been moreover diffused among engineers, academic people, etc. through workshops, conferences/seminars and training courses held all around Europe, during which pen-drives and/or DVDs containing the documents and examples elaborated within Steel-Earth have been distributed to the attending people.

6. Exploitation and impact of the research results

The exploitation of results obtained inside *Steel-Earth* dissemination project has been widely presented in the previous paragraphs for what concerns:

- Elaboration of technical documents concerning design of steel and composite steel-concrete buildings and practical applications.
- Elaboration of technical documents concerning rehabilitation of existing r.c. and masonry buildings with innovative steel-based systems and practical applications.
- Preparation of background documents regarding design and rehabilitation techniques.
- Preparation of pre-normative documents concerning the influence of material properties' variability on the ductile behaviour of steel and steel-concrete composite buildings.
- Translations of all the documents in several languages.

A website, a Facebook profile and a LinkedIn profile have been organized in order to freely distribute the documents among technicians, engineers, design and standardization bodies, etc. as well as to sponsor and make public all the dissemination activities (including workshops, conferences and training courses) organized within *Steel-Earth* project.

During dissemination evens, proceedings – mainly including presentations, technical sheets and working examples elaborated in WP1 and WP2 - have been distributed through pen-drives, DVDs and/or printed paper copies.

A final volume has been prepared and printed in 250 copies distributed to the attending people and to members of technical committees during the final workshop of the dissemination project (Naples, 07 April 2016). During the WG2 meeting (CEN/TC 250/SC 8/WG 2 *"Steel and Composite Structures"*) held in Naples the background and pre-normative documents elaborated have been distributed to the Committee's members.

More details about all the dissemination activities can be found in the previous paragraphs and in the corresponding deliverables.

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List of Acronyms and Abbreviations

–	ADRS	Acceleration – Displacement Response Spectrum
–	BRB	Buckling Restrained Braces
–	CBF	Concentrically Braced Frames
–	CHS	Circular Hollow Sections
–	CF	Cold Formed
–	CP	Collapse Prevention
–	CSM	Capacity Spectrum Method
–	DCH	High Ductility Class
–	DLS	Damage Limit State
–	EBF	Eccentrically Braced Frames
–	FC	Confidence Factor
–	HR	Hot-Rolled (sections)
–	IDA	Incremental Dynamic Analysis
–	IO	Immediate Occupancy
–	LGS	Light Gauge Steel
–	LS	Life Safety
–	MRF	Moment Resisting Frames
–	PBEE	Performance Based Earthquake Engineering
–	PEHE	Partially Encased Sections
–	PGA	Peak Ground Acceleration
–	PTE	Pre-Tension Elements
–	RC	Reinforced Concrete
–	SDOF	Single Degree Of Freedom
–	SINLDA	Statistical Incremental Nonlinear Dynamic Analysis
–	SLS	Serviceability Limit State
–	SSCD	Steel Self-Centering Device
–	SSW	Steel Shear Walls
–	TS	Technical Sheet
–	ULS	Ultimate Limit State
–	WE	Working Example
–	WT	Weld-Tapered

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Steel-Earth project aims at distributing among technicians, engineers, design companies and standardization bodies the results of three past RFCS projects (*Steel-Retro* [3], *Opus* [2] and *PrecaSteel* [1]), providing useful tools for the design and for the retrofit of existing buildings.

Technical documents and practical applications to case studies, regarding design of steel and composite steel/concrete buildings and innovative steel-based techniques for the retrofit of existing r.c. and masonry constructions, have been elaborated and collected into a volume distributed during the final workshop of the dissemination project.

Pre-normative and background documents concerning the design of steel and composite structures and the rehabilitation of existing constructions have been prepared. A lot of attention has been paid to the analysis of the influence of overstrength factors on the seismic design of steel and composite structures. The prepared documents have been distributed to the attending people and to the members of WG 2 *(CEN/TC 250/SC 8/WG 2 "Steel and Composite Structures")* during the final workshop of the project.

Technical sheets, working examples and background documents have been translated into several languages (German, French, Italian, Romanian and Greek) and are free available on the website of the project (https://www.steelconstruct.com/site/), where information regarding Steel-Earth are also presented.

11 Workshops in Italy, Greece, Germany, Belgium, Portugal, Spain and Romania and 5 conferences in Emilia-Romagna have been organized, as well as 2 practical courses for engineers and academic people in Pavia (Italy). Flash-drives with the technical documents and applications elaborated in Steel-Earth have been distributed to the attending people.

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