European Commission
Research Programme of the Research Fund for Coal and Steel

INNOSEIS

Valorization of innovative anti-seismic devices

WORK PACAKGE 3 – DELIVERABLE 3.1

Borders between EN 15129 and EN 1998-1 on dissipative devices

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Grant Agreement Number: 709434

30/09/2016

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1 Introduction

Within the dissemination project INNOSEIS, 12 innovative dissipative elements which enlarge structural damping in case of seismic actions, are described in detail in design guidelines to facilitate their application in real structures. To be introduced in the marked it is crucial that they fulfill applicable technical requirements. The aim of WP 3 is to clarify which of the 12 anticipated INNOSEIS devices must be qualified in accordance with EN 15129 for anti-seismic devices. For devices that fall outside EN 15129, pre-normative design recommendations will be produced that may be incorporated in the next revision of EN 1998-1.

In this report the Standard EN 15129 is being explained as a harmonised product standard in the context of the structural Eurocodes. Afterwards a comparison of requirements for steel dissipative elements given in EN 15129 and EN 1998-1 is made. Based on this comparison the 12 anticipated devices of the INNOSEIS project are classified into anti-seismic devices acc. to EN 15129 and dissipative structural members acc. to EN 1998. At the end of the report a list of necessary requirements for structural dissipative members is given as basis for revising EN 1998-1.

2 Structural Eurocodes and harmonised Product Standards

2.1 General

In the European Union, the matter of construction products is regulated by Construction Products Regulation (CPR) N. 305/2011, which is much stricter than the former Directive on the Construction Products. “Construction product” means any product which is manufactured for incorporation in a permanent manner in construction works, including both buildings and civil engineering works. All construction products shall bear the CE marking, which signifies their compliance with a relevant European product standard or, where there is not one, with National standard (provided it has been published in the Official journal of the European Communities), or European Technical Approval (ETA).

Harmonized technical specifications for construction products and the technical rules for structures should be consistent. All relevant information for CE Marking of the construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters are affected.

2.2 EN 15129 as harmonised product Standard

In fact, the European Committee for Standardization (CEN) officially established the Technical Committee CEN-TC 340: Anti-seismic Devices in 1993 and the Norm EN 15129 came officially into force in the European Union on August 1st, 2011. The scope of this Technical Committee was to proceed with the standardization of the seismic hardware for use in structures erected in seismic areas and designed in accordance with EUROCODE 8: Design of Structures for Earthquake Resistance, with the aim of modifying their response to seismic action.

The EN 15129 is, effectively, a “product standard” that covers the design, manufacturing, testing and validation of the seismic hardware, i.e. the whole of the mechanical devices used in seismic engineering. It deals with the design of structural devices, which modify the structural response to seismic action. The modification of the seismic response of the structure may be obtained by increasing the fundamental period of the structure, by modifying the shape of the fundamental mode, by increasing the damping, by limiting the forces transmitted to the structure and/or introducing temporary connections that improve the overall seismic response of the structure. This European standard sets rules for the design of anti-seismic devices, specific to the seismic situation. These devices have in general to sustain non-seismic situations; in these situations, they are ruled by Eurocodes and other European Standards (e.g. EN 1337 for isolators used as bridge bearings).

2.3 Practical Application

2.3.1 Conventional Steel Construction

For conventional steel structures, it is sufficient to design them according to structural Eurocodes, using steel products, which comply with product standards like e.g. EN 10025-1, EN 10210, EN 13479, etc. and Construction Product Regulation (CPR), and fabrication according to EN 1090.

2.3.2 Building and Bridge Construction with anti-seismic Devices

When a structural engineer decides to apply anti-seismic devices in his structural model to prevent failure due to seismic actions, he derives the properties of the anti-seismic devices from nonlinear analyses of the entire structural system including devices and their nonlinear behaviour, under seismic actions. For steel dissipative devices the structural engineer defines the performance characteristics through the assignment of d_{bd}, K_{effb} and ξ_{effb}, besides K_1, K_2 as well as of the expected number of cycles, the displacement rate, the design temperature range, the environmental conditions for ageing. It is also crucial to define lower and upper bounds of these characteristics. Based on these characteristics the owner resp. construction company calls for tenders also with regard of geometrical installation condition, connections to the structure and prospected lifetime. The offered devices have to hold a CE-mark, therefore comply with EN 15129.

3 Dissipative Elements

In the codes, different terms for elements are used, which should reduce the seismic effects of the structure. In EN 15129 the expression “device” is used, while in EN 1998 the term “member” is used.

3.1 Structural dissipative Zones acc. to EN 1998-1

In EN 1998-1 a dissipative zone resp. dissipative element is a load carrying structural member with dissipative behavior during earthquakes

dissipative structure

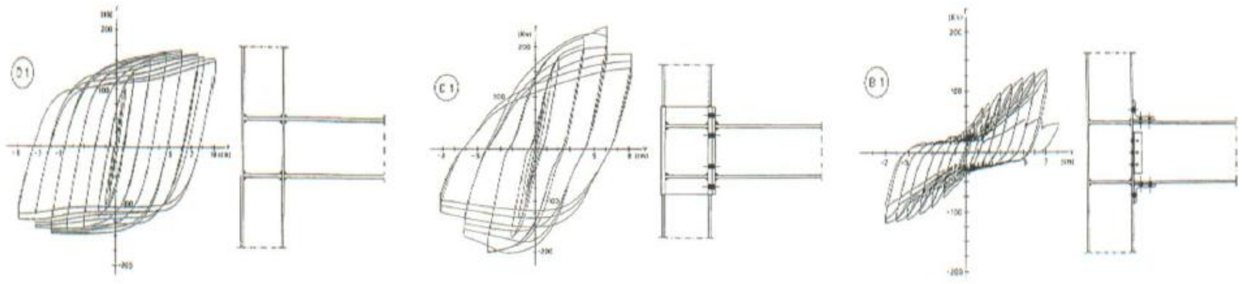
“structure which is able to dissipate energy by means of ductile hysteretic behavior and/or by other mechanisms

dissipative zones

“predetermined parts of a dissipative structure where the dissipative capabilities are mainly located”

primary seismic members

“members considered as part of the structural system that resists the seismic action, modelled in the analysis for the seismic design situation and fully designed and detailed for earthquake resistance in accordance with the rules of EN 1998”



Welded joint

End plate joint

Angle cleat joint

Figure 1: Dissipative connections [9]

3.2 Non-linear displacement dependent anti-seismic devices acc. to EN 15129

In EN 15129 anti-seismic devices based on steel hysteretic behaviour are named non-linear displacement dependent devices. It is stated that

- non linear anti-seismic devices do not carry vertical loads.
- behaviour is mainly dependent on displacement rather than on velocity,
- for use in structures erected in seismic areas in accordance with EN 1998.

Steel hysteretic energy dissipating devices are used as part of seismic isolation systems or as main components of energy dissipating bracing systems. Buckling restrained braces also belong to that category (see Annex D of [8]).

core element

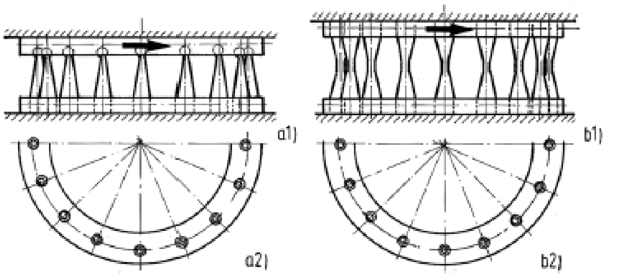
“component of a Linear Device (LD) or of a Non Linear Device (NLD) on which the mechanism characterising the device’s behaviour is based.

NOTE Core elements of a LD or of a NLD are the device’s components that provide it with the flexibility and, eventually, with the energy dissipation and/or re-centring capacity or any other mechanical characteristic compatible with the requirements of a LD or of a NLD. Examples of core elements are steel plates or bars, shape memory alloy wires or bars, rubber elements.”

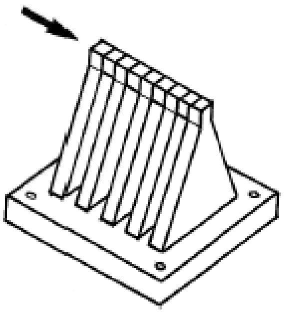
Non Linear Device (NLD)

“anti-seismic device which is characterised by a non-linear load-displacement relationship, with a stable behaviour under the required number of cycles and substantial independence from velocity. A device is classified as non-linear if either ξ_{effb} is greater than 15 % or the ratio $|K_{effb} - K1| / K_1$ is greater than 20 %.

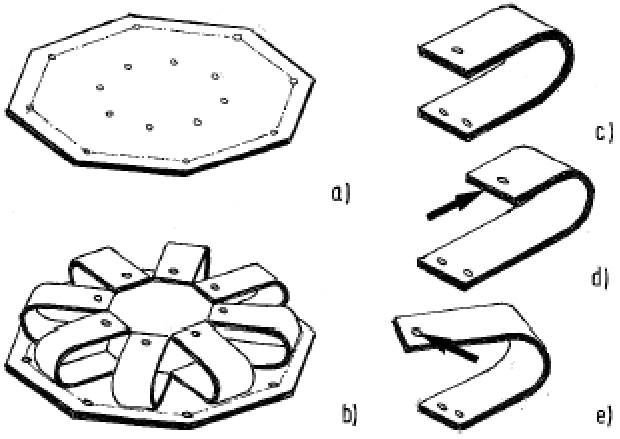
ξ_{effb} and K_{effb} are evaluated at the 3rd cycle with maximum displacement equal to d_{bd}.



a) Pin Shape Steel Hysteretic Elements



b) Triangular Shape Steel Hysteretic Elements



c) U Shape Steel Hysteretic Elements

Figure 2: Non-linear displacement dependent anti-seismic devices [10]

3.3 Classification of INNOSEIS-Elements

Load carrying member is a rather general definition, while the definition of EN 15129 is more precise. According to the definition of EN 15129 structural members that carry vertical forces are not covered by this Standard, while structural braces loaded in tension and compression are within the scope of EN 15129. All INNOSEIS devices, dissipative connections/links/elements provide seismic resistance. However, some contribute also to gravity loading resistance, while other do not as listed in the following Table.

Table 1: Classification of 12 INNOSEIS-devices

Steel-hysteretic Element with contribution to gravity loading resistance	Steel-hysteretic Element with no contribution to gravity loading resistance
Replaceable shear links (DUAREM)	Dissipative pin and U-plate brace connections (INERD)
Dissipative beam bolted and welded splices (FUSEIS)	Dissipative beam and pin links (FUSEIS)
	Modified braces for CBF
Replaceable shear panels (SPSW)	
	SSCD device
	TRSH device
	MSSH device

Dissipative elements or links listed above to get the status of anti-seismic devices must undergo the tests and procedures as described in EN 15129.

4 Requirements according to EN 1998-1 and EN 15129

4.1 Tabular Comparison

	EN 1998-1	EN 15129
Fundamental Requirements (Limit States)	Damage Limitation State (Frequent Earthquake) • no damage • Avoid limitations of use and high repair costs Ultimate Limit State (Design Earthquake) • no local or global collapse • Retain structural integrity and residual load bearing capacity after the event	Damage limitation requirement (Frequent Earthquake) • no or very minor damage of the device • no replacement necessary. Ultimate limit state (Design Earthquake) • without local or global failure • residual mechanical resistance including a residual load bearing capacity • damage which may necessitate repair or replacement.
Increased Reliability	importance factor γ_x	importance factor $\gamma_x \geq 1$ for devices and their connections
Functional requirements	So far applicable, serviceability requirements of structural Eurocodes for “ordinary loads” need to be considered	• function according to the design requirements and tolerances throughout the service life • design, construction and installation so that routine inspection and replacement are possible
Structural and mechanical requirements	Design criteria for seismic ULS • Yielding or local buckling do not affect the overall stability of the structure • Dissipative zones with enough ductility and resistance • Yield strength $f_{y,max} \leq 1{,}1\ \gamma_{OV}\ f_y$ ($1{,}1 \cdot 1{,}25 \cdot 235 = 323$N/mm^2 for S235) • Toughness acc. to EN1993-1-10 for quasi-permanent value of the service temperature • Cross sectional class 1 acc. to EN1993-1-1 for local ductility • Rotation capacity ≥ 0,035 rad for DCH and ≥ 0,025 rad for DCM	Requirements at Design Seismic Action • appropriate strength and ductility • damage but no failure. • Replacement possible without resorting to major intervention. • residual capacity equal to the permanent actions or to design situations (including eventually a seismic situation) that may occur after the earthquake. Requirements at frequent Seismic Action • remain in a serviceable state • very minor or superficial damage • no interruption of use • no immediate repair required.

	EN 1998-1	EN 15129
Reliability of the device behaviour		- good reproducibility of the mechanical behaviour - description of the mechanical behaviour based on modelling and tests - Assessment of mechanical and physical properties by tests. - no immediate risk of catastrophic failure of the device if the seismic action is beyond the design seismic action
Capacity Design	Adjacent parts and connections of dissipative zones shall have sufficient overstrength, global overstrength to be considered for overall stability verification	- over-strength factor γ_{Rd} = 1,1 for the actions transmitted by the device. - transmitted actions are based on Upper Boundary Design Properties.
Maintenance		- accessible for inspection and maintenance. - periodic inspection and maintenance program.
Modificaton and replacement		- Conformity with EN 15129
Device documentation	Documentation according to EN 1090	- type of the device, its performance and the range of temperature and other environmental conditions. - details, sizes and tolerances related to installation of the devices and their connections to the structure - design checks and results of the relevant type tests and factory production control tests - aspects of particular importance for the installation of the devices. - description of inspection and maintenance procedures - description of replacement procedures for the device.
Material properties	Steel used in devices shall conform to the requirements given in EN 10025, EN 10083, EN 10088, etc. Minimum toughness requirements for dissipative zones (T_{27J}) Steel to be used in dissipative zones shall have a maximum permissible yield stress $f_{y,mac}$ indicated in the drawings During construction it should be ensured that the yield stress of the actual steel used does not exceed $f_{y,mac}$ indicated in the drawings by more than 10%	Steel used in devices shall conform to the requirements given in EN 10025, EN 10083, and EN 10088. Consideration of - strain and strain rate during the design seismic situation. - environmental (physical, biological, chemical and nuclear) conditions - effects of temperature variation and ageing phenomena - loading history and the accumulated strain cycles. - potential deformation and deformation rate. - Design (mean) properties (DP) shall be derived from type tests. - Consideration of Upper bound design properties (UBDP) and Lower bound design properties (LBDP).

	EN 1998-1	EN 15129
Recentring Capability		$E_s \geq 0{,}25\ E_h$ E_s: reversibly stored Energy E_h: dissipated Energy The offset displacement (i.e. the residual displacement at zero force at the end of earthquake) produced by the SLS design seismic action shall not exceed the value d^* where d^* is a NDP (5 % of d_{bd} but not less than 10 mm).
Constitutive laws for analysis	a) Generally bi-linear stress-strain material law for steel with strain hardening b) Provision of non-linear constitutive laws for dissipative elements c) Provision of non-linear cyclic laws for dissipative elements	Appropriate constitutive laws shall be established by tests and account for e.g. non-linear effects.
Design Analysis	a) Modal response spectrum analysis using behaviour Factors Requirements that plastic zones appear at similar levels of loading/displacement. b) Non-linear static (pushover) analysis c) Non-linear time-history analysis	It is strongly recommended that a time-history analysis is performed when the equivalent damping ratio related to hysteretic energy dissipation is higher than 15 %.

	EN 1998-1	EN 15129
Performance Requirements	Only a limited number of structural types is covered by the Code for which sufficient experience on their performance to seismic loading exists from past earthquakes. Structural and mechanical properties (e.g. b/t-ratio, toughness) are deemed to satisfy the condition for sufficient rotational capacity as well as for sufficient cyclic resistance, based on results of specific or generic tests and simulations.	• $\gamma_b \geq 1{,}1$ • compliance of the requirements for non-seismic conditions • evaluation of parameters using the 3rd test cycle • upper and lower bound values of the behavioral parameters based on experiments. • tolerance limits for stiffness parameters are applied to forces and displacements • maximum differences of the experimental values within the tolerance limits • Evaluation of maximum differences due to statistical variations with respect to the design value. • Evaluation of maximum differences due to ageing, temperature and strain rate with respect to the normal condition value at (23 ± 5) °C (testing temperature). • Evaluation of differences due to temperature with reference to the upper and lower design temperature values. • stable behaviour under cyclic loading by limiting variations in a series of load cycles to $(K_{2,i} - K_{2,3}) / K_{2,3} \leq 0{,}10$ for NLD $(\xi_{effb,i} - \xi_{effb,3}) / \xi_{effb,3} \leq 0{,}10$ for NLD subscript 3 is the 3rd load cycle and subscript i ($i \geq 2$) is the ith load cycle • The ratio between upper bound and lower bound characteristic values of any performance related material properties shall not exceed 1,4 for metallic components • The overall variation, to be considered when evaluating the upper and lower bound of the design values as specified in EN 1998, is a linear combination of the single differences, where the combination coefficients shall take account of the probability of simultaneous occurrence of such differences.

	EN 1998-1	EN 15129
Testing	Design supported by specific experimental testing Testing is required if partial strength connections are used. Tests shall show that: a) The connections have a rotation capacity consistent with global deformations. b) Members framing into the connections are demonstrated to be stable at ULS c) The effect of connection deformation on global drift is taken into account by non-linear analysis methods.	Type Test of Materials • Needs for relating the measured material behaviour to its behaviour in the device; evaluating the variation of material behaviour with respect to changes of environmental conditions, material temperature, ageing, strain rate; evaluating the interactions between material behaviour and device performance. • For Steel Certifications based on existing standards are required. Other tests may be specified as appropriate. Factory Production Test of the Materials • For Steel Certifications based on existing standards are required. Other tests may be specified as appropriate. Type Test of the Device • Devices shall be qualified together with their connection system. • Testing procedures shall be such that the working conditions and fixings of the device are reproduced. • full-scale specimen • same stresses and strains as induced by the design earthquake. • dynamic tests to reproduce the actual working conditions • quasi-static tests if velocity has negligible influence • evaluation of the force-displacement cycle. Increasing amplitude cycles at 5x 25 %, 5x 50 % and 10x 100 % of the maximum displacement ($\geq \pm d_{bd}$) →No break and keep its characteristics unchanged • static evaluation of the failure displacement with a displacement $\geq \gamma_b \gamma_x d_{bd}$ or a force $\geq \gamma_b \gamma_x V_{Ebd}$, →No decrease of force with increasing displacement. Factory Production Control Test of the Device • Identification of each device and association with the production lot • evaluation of the force-displacement cycle on at least 2% of the supply, with a minimum number of one device.

	EN 1998-1	EN 15129
Documentation		• type of the device, its performance and the range of temperature and other environmental conditions. • details, sizes and tolerances related to installation of the devices and their connections to the structure • design checks and results of the relevant type tests and factory production control tests • aspects of particular importance for the installation • description of inspection and maintenance procedures • description of replacement procedures.
Validation procedure		• proof for remaining operational within its domain of use, including the seismic situation, over its service life. • ranges of parameters relevant for the type of device • a method to estimate the expected service life; • proof of the ability to function in a reliable and stable way during its service life; • values of the mechanical properties of the device • range of acceptable environmental conditions; • description of the behaviour beyond design seismic action • description of constitutive laws for analysis; • a constitutive model describing the behaviour of the device under different conditions of use; • Consideration of interaction with adjacent structural elements • Report on type tests

4.2 Conclusion based on anti-seismic device design philosophy

If a structure is designed to allow yielding in zones to reduce the forces in adjacent members and to reduce the stiffness of the overall structure, while considering only the standard structural damping of e.g. 5%, design and construction can be performed according to EN1998 and EN1090. But if the resistance of a structure exposed to earthquakes relies on distinct elements producing hysteretic damping, the operational reliability of these elements have to be checked with different requirements than steel structures based on capacity design.

The most important requirements are

- Prevention of subsequent yielding of elements, as it affects the equivalent structural damping.
- Lower and upper bound of properties of the steel dissipative zones has to be considered in the design calculations of the structure. The sensitiveness of the structure due to varying properties is an important issue for their overall reliability.
- Experimental verification of the elements’ properties and production control.
- Inspection and possible remedial measures
- Check of remaining load bearing capacity (e.g. after shocks)
- Check of low cycle fatigue check
- recentring ability if dissipative zones becomes active for seismic action below the design seismic event.
- Inspection of the dissipative zones after earthquakes is necessary to check operational reliability.

It is therefore recommended that, whenever a higher damping due to the dissipative behaviour of distinct elements is crucial for the overall structural safety when subjected to the design seismic action, adequate and reliable dissipative behaviour of these elements should be proven by requirements given in EN15129 or equivalent methods such as~~.~~ assignment of higher execution class for this element/part, testing of this element/part according to EN 15129, improved quality assurance and quality control for the material of this element/part by more precise rules to be developed~~.~~.

4.3 Conclusion based on structural design philosophy

The comparison shows that the procedures and requirements of EN 15129 provide more detailed and precise provisions. As consequence, anti-seismic devices acc. to EN 15129 provide a high reliability regarding their performance and reduce uncertainties in prediction of the expected response and performance by providing precise values for boundary conditions and hysteretic characteristics, while the rest of the structure (except the devices) still remains a civil engineering work with all imperfections and uncertainties.

The aim of using dissipative zones according to EN 1998-1 is to absorb a major part of energy introduced into the structure by seismic excitation, by means of cyclic plastic deformations, instead of conserving the introduced energy by elastic response with continuously increasing deformations and internal forces. Yielding in the dissipative zones leads to plastic zones or plastic hinges that:

- limit forces in adjacent members and subsequently in the entire laterally resisting structure,
- temporarily reduce the overall stiffness of the structure and change the modal shapes, which lowers the susceptibility to harmonic excitation and resonance effects by increasing the fundamental period and by interruption of the potential harmonic response.
- dissipate energy.

The given design rules and requirements for dissipative zones cover a limited number of conventional structural typologies with well-known seismic behaviour from past experience. The efficiency of these systems strongly depends on the actual material properties in dissipative zones, on appropriate detailing taking into consideration local effects (e.g. strain concentration) and on quality and control of realisation. Not all of these criteria are explicitly defined in EC 8, expecting the structural designer to take responsibility for them. Requirements and criteria for development of new systems are missing or incomplete.

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