Equaljoints Plus

Valorisation of knowledge for European pre-QUALified steel JOINTS

Research Fund for Coal & Steel

European Commission

European Qualification of Seismic Resistant Steel Beam-to-column Joints:

THE EQUALJOINTS PROJECT

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Equaljoints Plus

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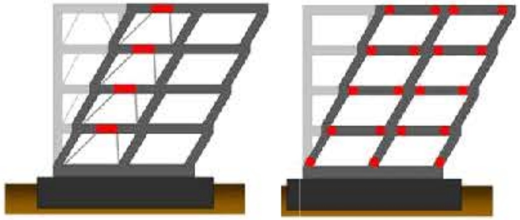
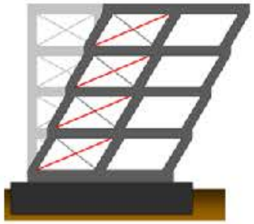
Joints in steel structures

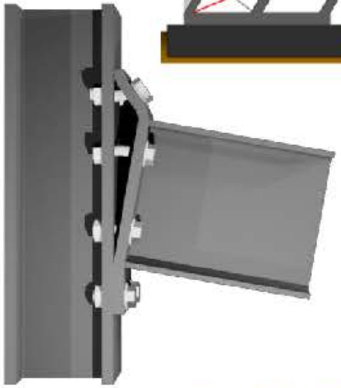
Steel joints in seismic application

Design of steel connections

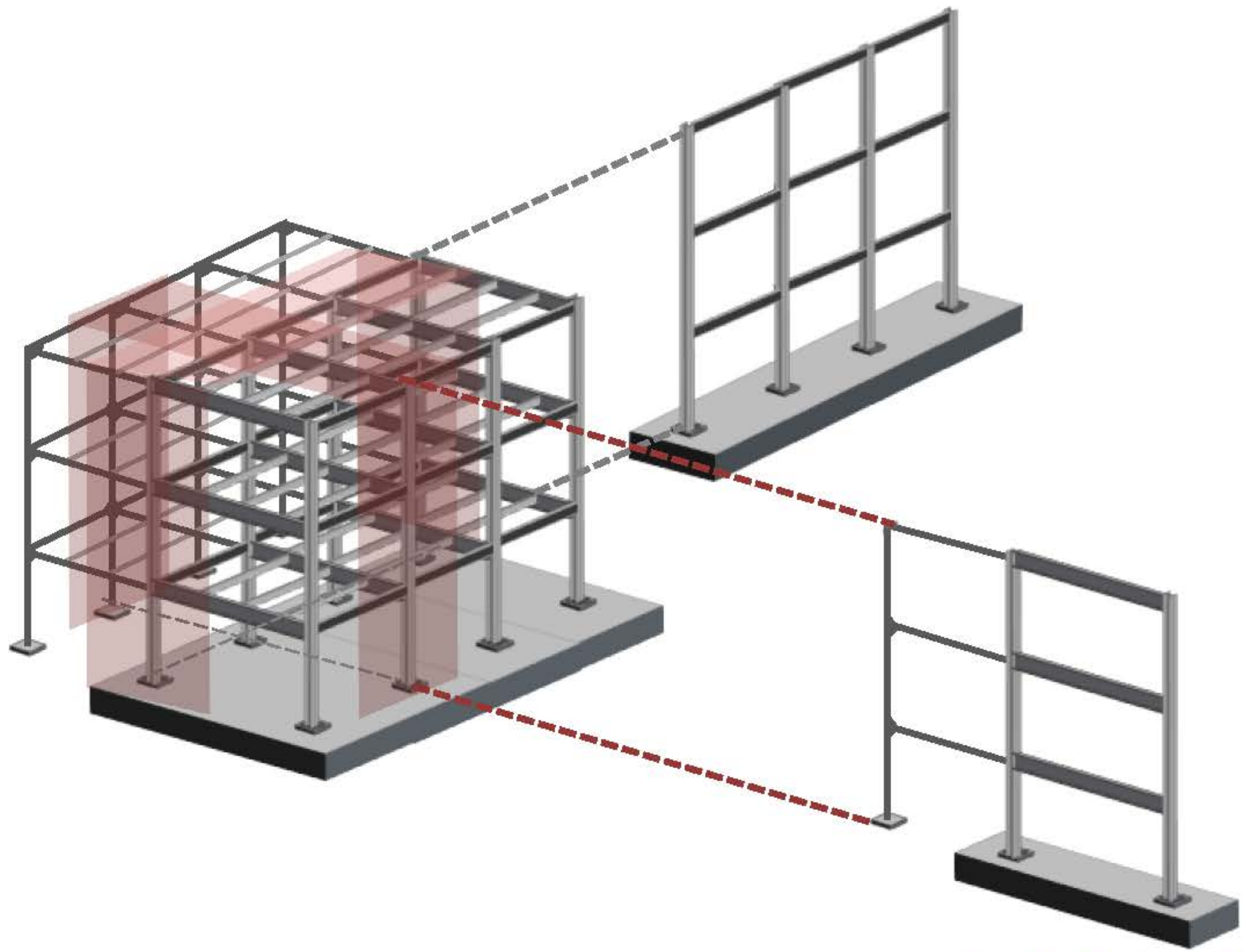
- The design of connection represent a key aspect in steel systems, especially in **seismic resistant structures** where effetive design rules are fundamental in order to assure a **global ductile failure mechanism** with plasticity restrained in selected zones.







Moment-Resisting Frames (MRF)



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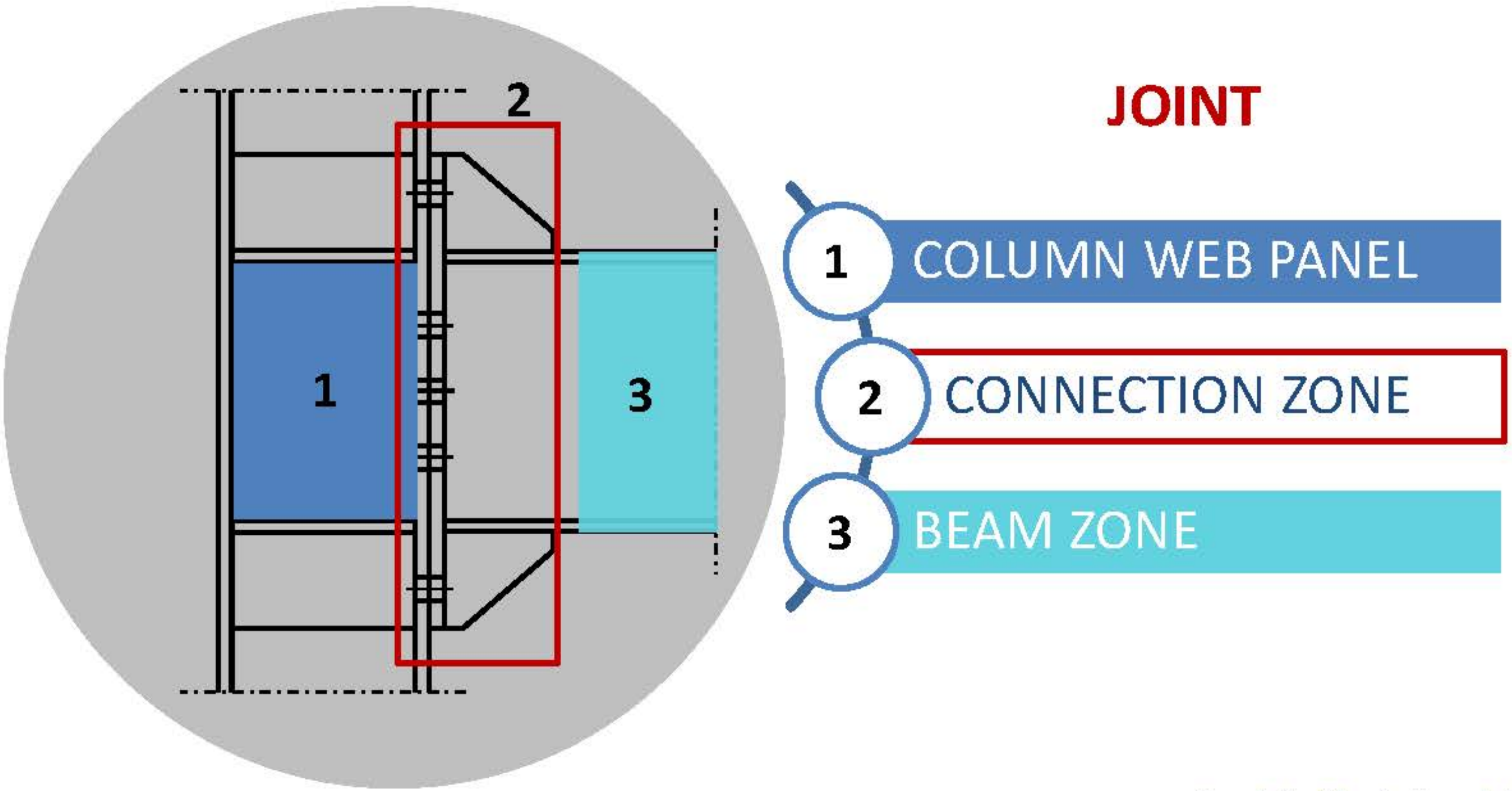
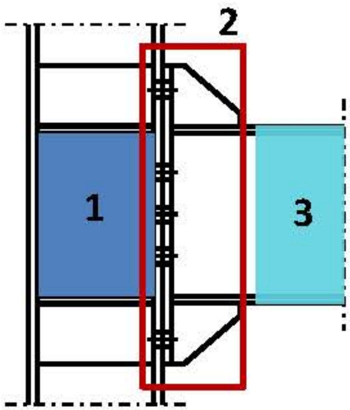
Beam-to-column joints

According to EN1993:1-8 the joint is made of 1) column web panel; 2) connection and 3) beam.
These three macro-components are mechanically coupled, but under some assumptions can be characterized separately.

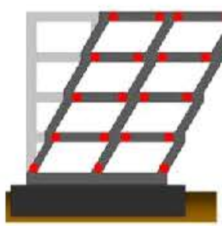


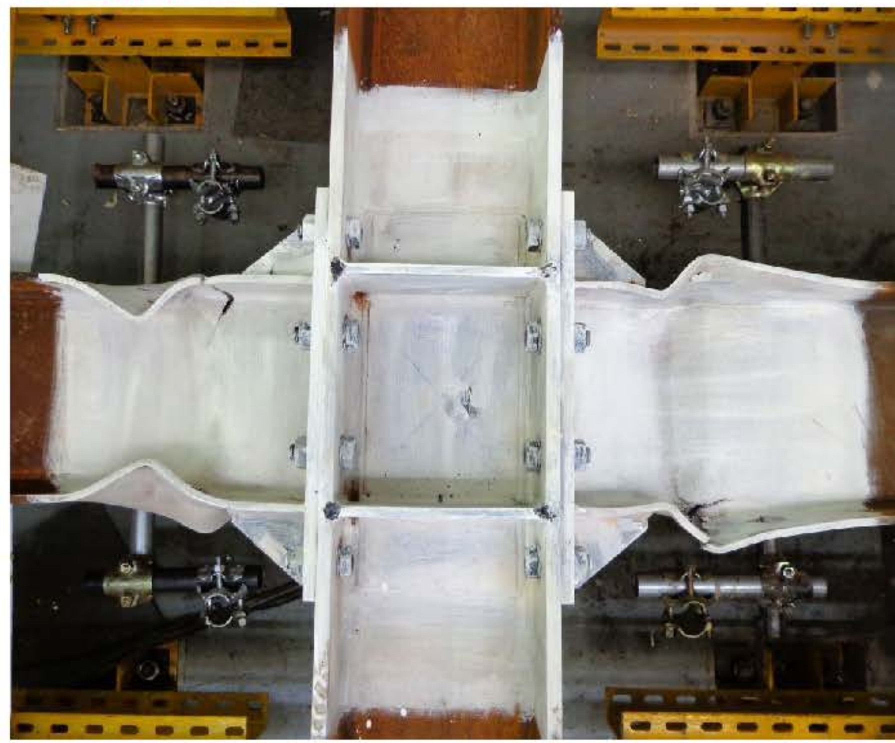
Beam-to-column joints



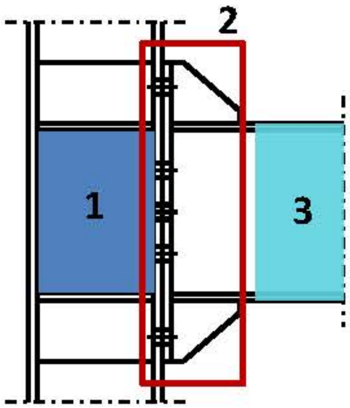
Which zones have to be selected to undergo plastic deformations and to dissipate seismic input energy?

a) **NON-DISSIPATIVE CONNECTIONS:** the connection zone does not experience any plasticity and the inealistic deformation is restrained into the connected members (rigid and semi-rigid, full strength joint)



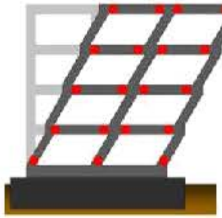


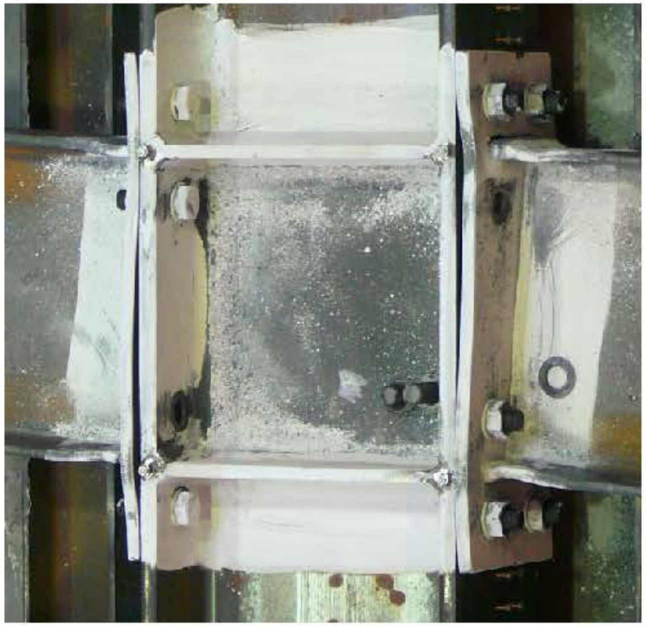
Beam-to-column joints



Which zones have to be selected to undergo plastic deformations and to dissipate seismic input energy?

b) DISSIPATIVE CONNECTIONS: the connection zone undergoes plastic deformations (semi-rigid, partial strength joint)





Non-dissipative connections: *current rules in EN-1998*

The **overstrength criterion** for non-dissipative connections:

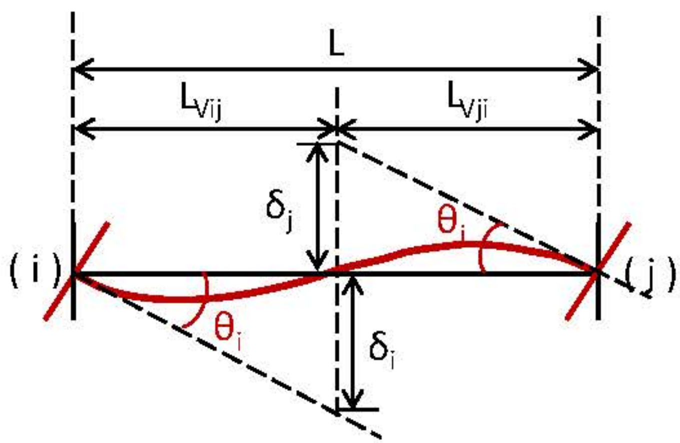
$$R_d \geq 1{,}1\ \gamma_{ov}\ R_{fy}$$

- R_d is the resistance of connection according to EN-1993
- R_{fy} is the plastic resistance of the connected dissipative member based on the yield stress of the material as defined in EN-1993
- γ_{ov} is the material overstrength factor

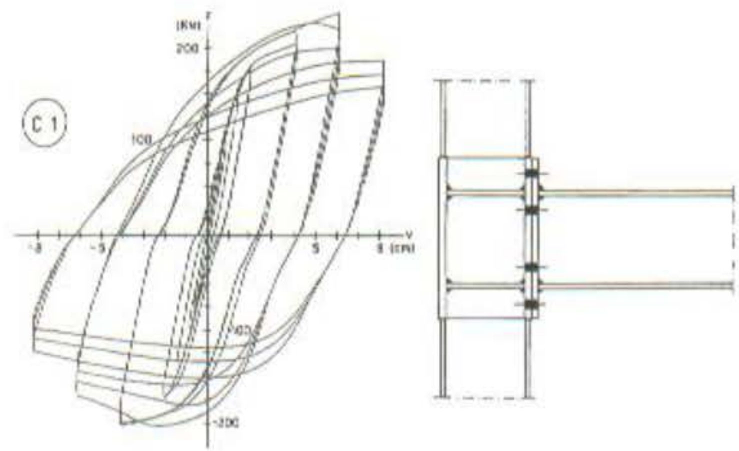
Dissipative connections: *current rules in EN-1998*

EN 1998 allows the formation of plastic hinges in the connections in case of partial-strength and/or semi-rigid joints, provided that :

Joint cyclic rotation capacity **in plastic range** should be at least **0.035 rad** in case of DCH or **0.025 rad** in case of DCM



Chord rotation



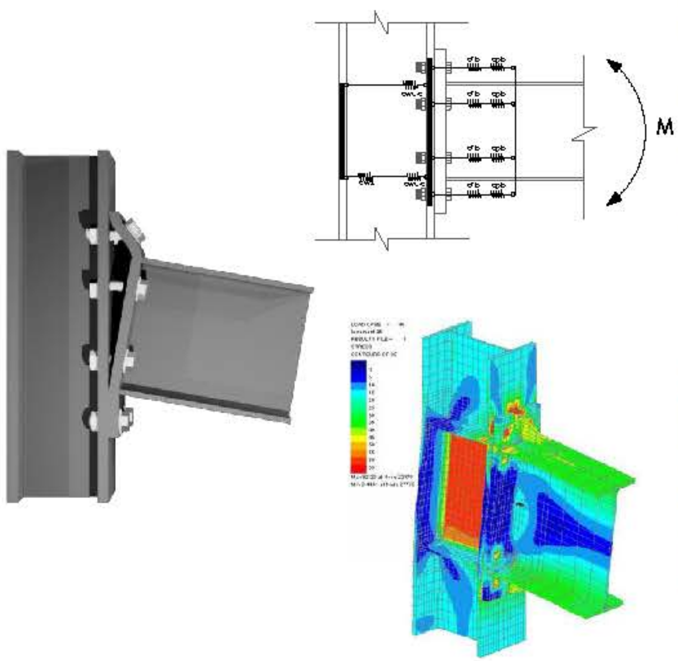
End plate joint

Dissipative connections: *criticisms*

How to assess the Joint cyclic rotation capacity?

EN 1998-1 (2004) requires design supported by specific experimental testing, resulting in impractical solutions within the typical time and budget constraints of real-life projects.

- Joint modelling

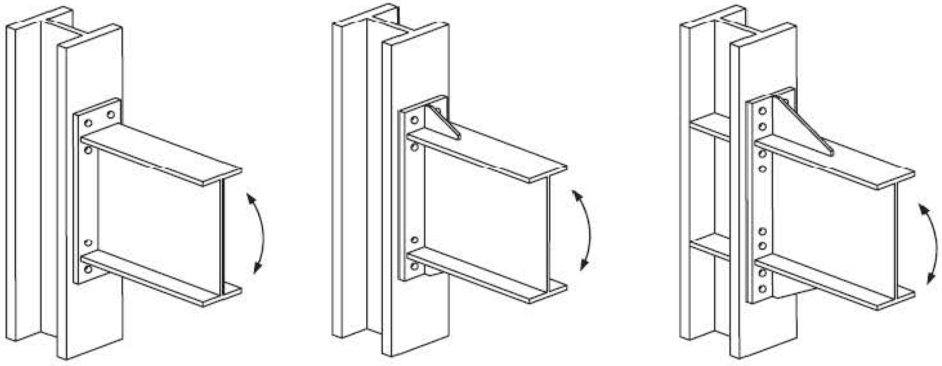


- Experimental tests

Dissipative connections: *potential upgrade*

Prequalification of beam-to-column connections

- In US and Japan this issue has been solved adopting **pre-qualified standard joints**.
- Within the FEMA/SAC program (1995), devoted to develop and evaluate guidelines for the inspection, evaluation, repair, rehabilitation, and construction of steel moment frame resisting structures.
- The US research effort was directed to feed into a specific standard (ANSI/AISC 358-05, 2005) **containing design, detailing, fabrication and quality criteria for a set of selected types of connections** including the most common used in US practice, that are prequalified for use in Special and Intermediate MRFs



(a) (b) (c)

Fig. 6.1. Extended end-plate configurations: (a) four-bolt unstiffened, 4E; (b) four-bolt stiffened, 4ES; (c) eight-bolt stiffened, 8ES.

Dissipative connections: *potential upgrade*

Limit of application of US prequalification procedure for EU practice

Joint type

Joint types different from the set prequalified within ANSI/AISC 358-16, 2016 are not allowed by US code.

TABLE 2.1.
Prequalified Moment Connections

Connection Type	Chapter	Systems
Reduced beam section (RBS)	5	SMF, IMF
Bolted unstiffened extended end plate (BUEEP)	6	SMF, IMF
Bolted stiffened extended end plate (BSEEP)	6	SMF, IMF
Bolted flange plate (BFP)	7	SMF, IMF
Welded unreinforced flange-welded web (WUF-W)	8	SMF, IMF
Kaiser bolted bracket (KBB)	9	SMF, IMF
ConXtech ConXL moment connection (ConXL)	10	SMF, IMF
SidePlate moment connection (SidePlate)	11	SMF, IMF
Simpson Strong-Tie Strong Frame moment connection	12	SMF, IMF
Double-tee moment connection	13	SMF, IMF

ANSI/AISC 358-16, 2016

Connected members

The prequalification is limited to a selected **range of cross sections** of the connected members, that are quite different from ones commonly used in EU practice.

TABLE 6.1
Parametric Limitations on Prequalification

	Four-Bolt Unstiffened (4E)		Four-Bolt Stiffened (4ES)		Eight-Bolt Stiffened (8ES)	
Parameter	Maximum in. (mm)	Minimum in. (mm)	Maximum in. (mm)	Minimum in. (mm)	Maximum in. (mm)	Minimum in. (mm)
t_{bf}	¾ (19)	⅜ (10)	¾ (19)	⅜ (10)	1 (25)	9/16 (14)
b_{bf}	9¼ (235)	6 (152)	9 (229)	6 (152)	12¼ (311)	7½ (190)
d	55 (1400)	13¾ (349)	24 (610)	13¾ (349)	36 (914)	18 (457)
t_p	2¼ (57)	½ (13)	1½ (38)	½ (13)	2½ (64)	¾ (19)
b_p	10¾ (273)	7 (178)	10¾ (273)	7 (178)	15 (381)	9 (229)
g	6 (152)	4 (102)	6 (152)	3¼ (83)	6 (152)	5 (127)
p_{fi}, p_{fo}	4½ (114)	1½ (38)	5½ (140)	1¾ (44)	2 (51)	1⅝ (41)
p_b	—	—	—	—	3¾ (95)	3½ (89)

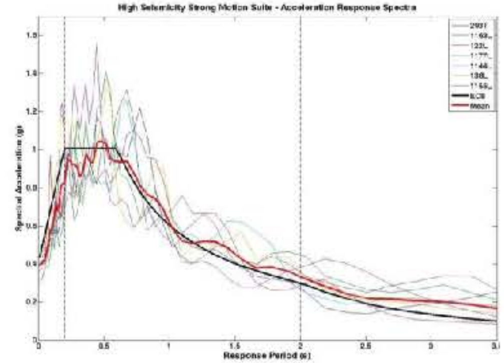
b_{bf} width of beam flange, in. (mm)
b_p width of end-plate, in. (mm)
d depth of connecting beam, in. (mm)
g – horizontal distance between bolts, in. (mm)
p_b vertical distance between the inner and outer row of bolts in an 8ES connection, in. (mm)
p_{fi} vertical distance from the inside of a beam tension flange to the nearest inside bolt row, in. (mm)
p_{fo} vertical distance from the outside of a beam tension flange to the nearest outside bolt row, in. (mm)
t_{bf} = thickness of beam flange, in. (mm)
t_p = thickness of end-plate, in. (mm)

Dissipative connections: *potential upgrade*

Limit of application of US prequalification procedure for EU practice

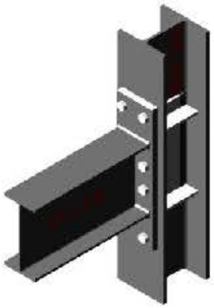
The type of seismic input, which affect the ductility demand on joints and connected members, differs between the different counties.

Seismic input



What about Europe?

In order to fill these gaps, the recently finished European research project "Equaljoints" was aimed at providing prequalification criteria of steel joints for the next version of EN 1998-1.



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EQUALJOINTS PROJECT (2014-2016)

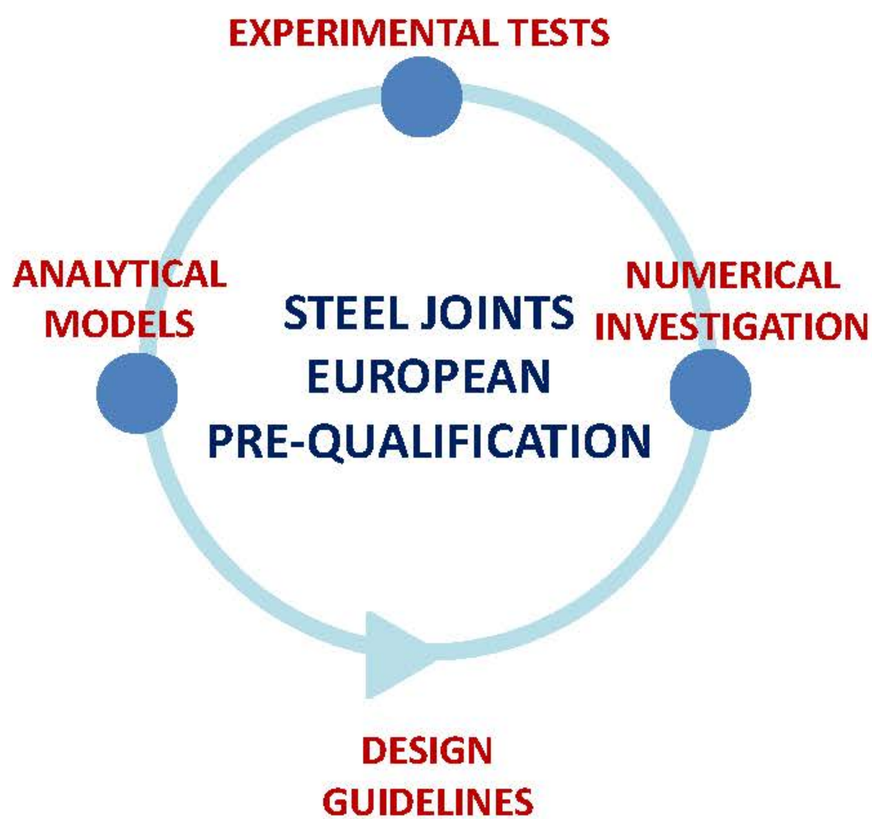
Research Fund for Coal & Steel

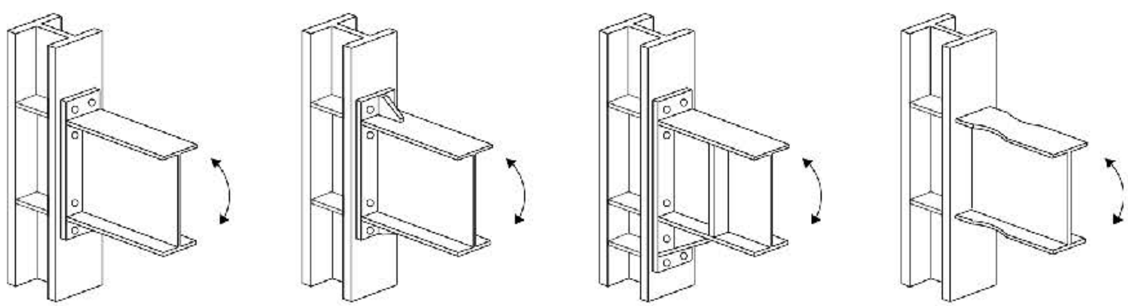
PARTNERS

- University of Naples Federico II - CO1 -Italy
- Arcelormittal Belval & Differdange SA- BEN2 - Luxembourg
- Universite de Liege- BEN3 – Belgium
- Universitatea Politehnica din Timisoara BEN4 – Romania
- Imperial College of Science, Technology and Medicine- BEN5 - UK
- Universidade de Coimbra- BEN6 - Portugal
- European Convention for Constructional Steelwork Vereniging-BEN7 - Belgium

Project Objectives

- The **EQUALJOINTS** research project was aimed at providing **pre-qualification procedure** for a set of selected seismic resistant steel beam-to-column joints, introducing a **codified practice currently missing in Europe.**
- A large **experimental** programme supported by **theoretical** and **numerical** analyses has been proposed.
- The pre-qualification criteria will refer to both **full-strength** and **partial-strength** joints for three types of bolted configurations and one welded dog-bone joint.





(a) (b) (c) (d)

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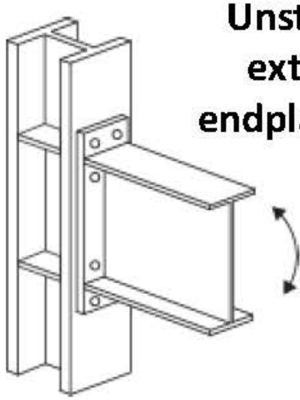
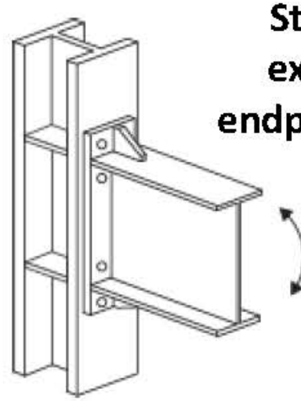
Prequalified joint typologies

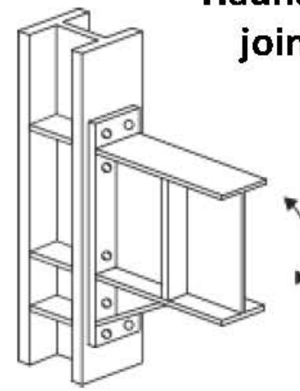
- Three bolted joint types:



Unstiffened extended endplate joints

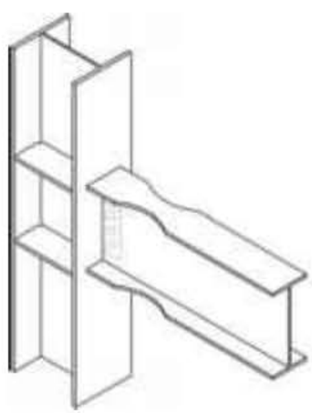


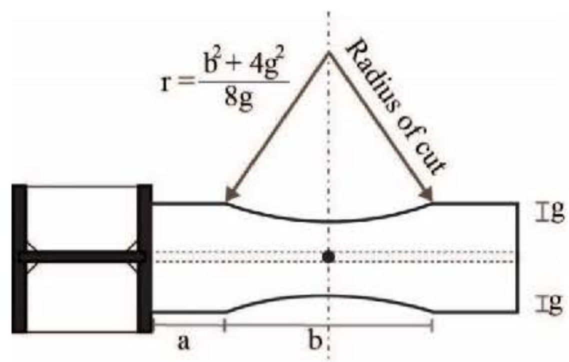
Stiffened extended endplate joints



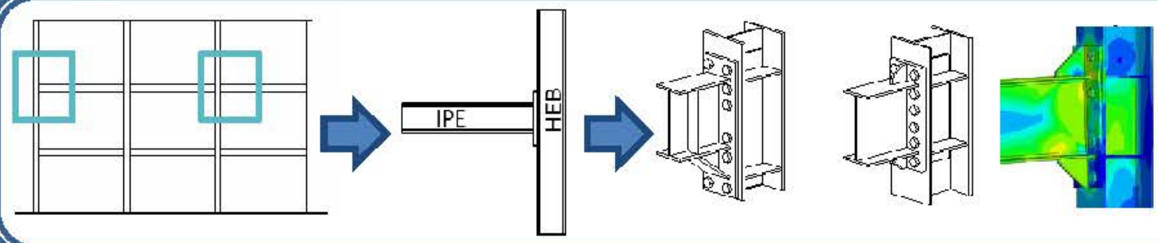
Haunched joints

- And welded **dog-bone** joints:

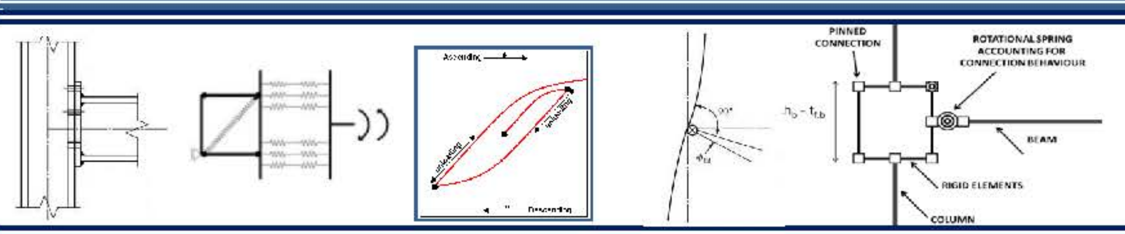




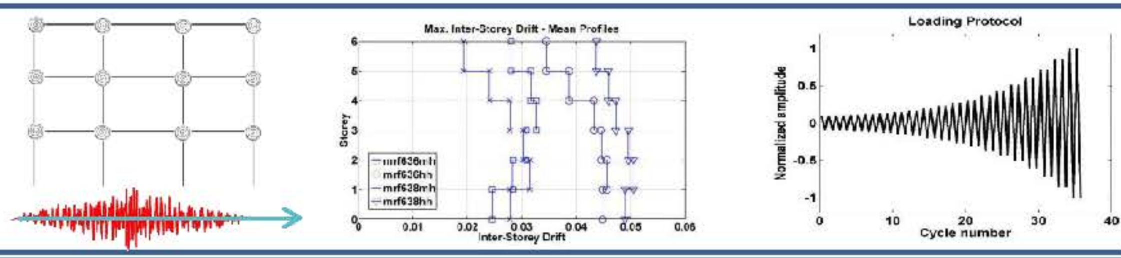
Project Flow Chart



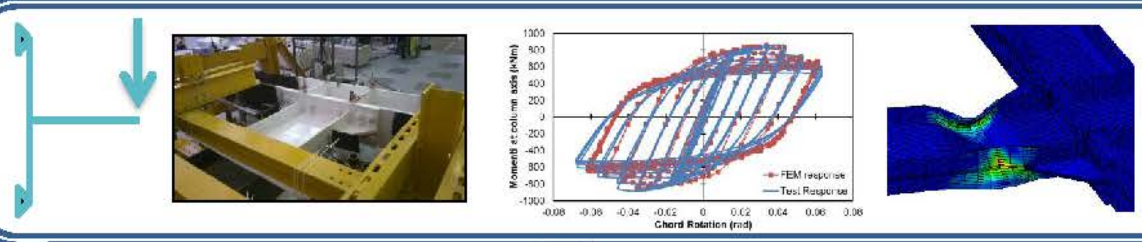
DESIGN OF REFERENCE STRUCTURES
SELECTION OF BEAM-TO-COLUMN ASSEMBLIES
DESIGN OF JOINTS



ANALYTICAL MODEL
DEFINITION OF HYSTERETIC JOINT BEHAVIOUR
CHARACTERISATION OF ROTATIONAL SPRINGS



EVALUATION OF SEISMIC DEMAND ON JOINTS
DEFINITION OF NEW EU LOADING PROTOCOL



EXPERIMENTAL PROGRAMME
CALIBRATION OF FEM MODELS
FEM PARAMETRIC ANALYSES

DESIGN GUIDELINES AND PREQUALIFICATION CHARTS

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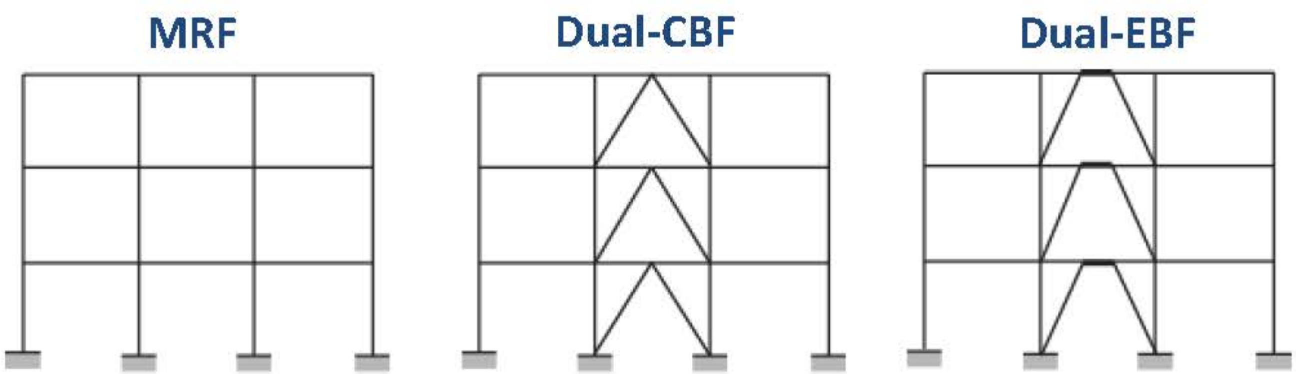
Building Archetypes:

Domain of application of prequalified joints

- In order to properly address the design of joints and to evaluate the seismic demand in both internal and external configurations, a set of **Building Archetypes** representative of different structural schemes (namely **MRF, Dual-CBF, Dual-EBF**) has been selected and **numerically investigated**.



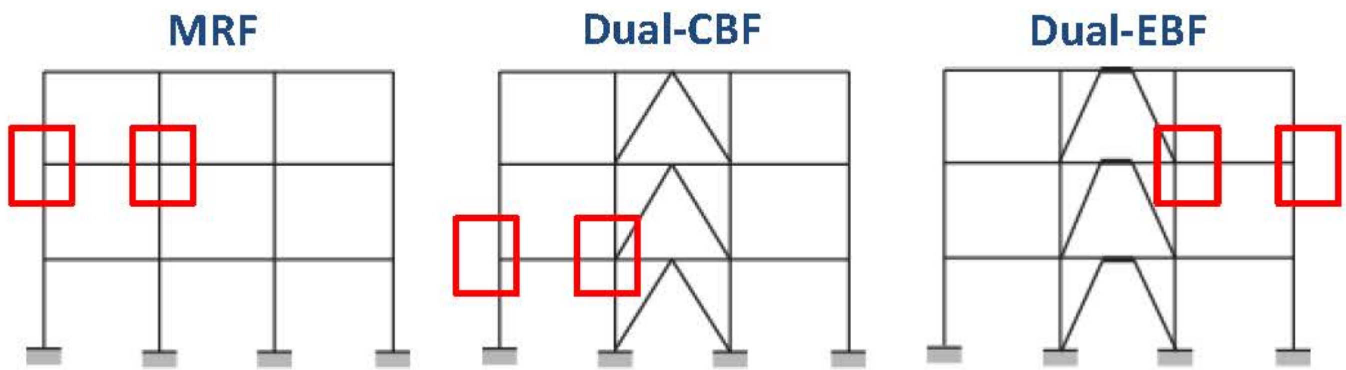
REFERENCE STRUCTURES PARAMETERS

Frame Type	No. of Storeys	No. of Spans	Span Length	Hazard Level (PGA/g)
MRF	3 or 6	3 or 5	6m or 8m	0.25 or 0.35
D-CBF	6 or 12	3 or 5	6m or 8m	0.25 or 0.35
D-EBF	6 or 12	3 or 5	6m or 8m	0.25 or 0.35

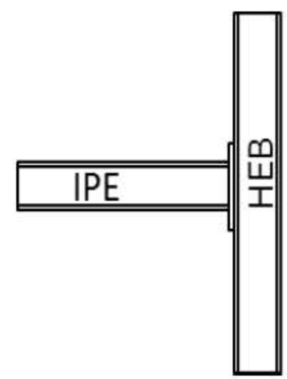
Building Archetypes:

Domain of application of prequalified joints

- A set of beam-to-column assemblies have been chosen in order to select the rational geometries for the joints for the prequalification procedure; all the relevant cases have been designed.



BEAM TO COLUMN ASSEMBLIES			
	1	2	3
Beam	IPE360	IPE450	IPE600
Column for exterior (T) joints	HEB280	HEB340	HEB500
Column for interior (X) joints	HEB340	HEB500	HEB650
Span in frame	6 m	6 m	8 m



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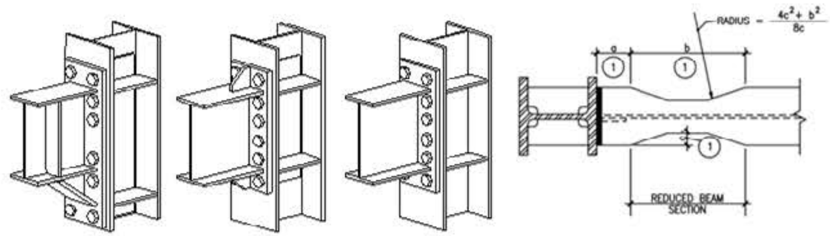
Design of Joints

JOINT TYPES



BEAM-TO-COLUMN ASSSEMBLIES

BEAM TO COLUMN ASSEMBLIES

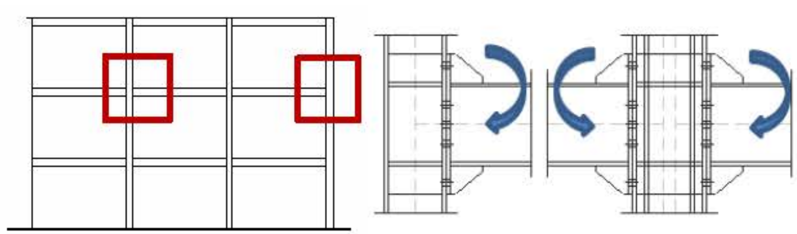
	1	2	3
Beam	IPE360	IPE450	IPE600
Column for exterior (T) joints	HEB280	HEB340	HEB500
Column for interior (X) joints	HEB340	HEB500	HEB650
Span in frame	6 m	6 m	8 m

- The **bolted joints** have been designed in compliance with **EN1993 1-8 and EN1998-1**
- **Dogbone** joints have been designed in compliance **with ASCE 7-10, AISC 341-10, AISC 358-10 and AISC 360-10.**
- Analytical and experimental-based formulations available in the literature, validated against numerical simulations, have been implemented in the assessment to cover issues not addressed in the codes.

76 JOINTS

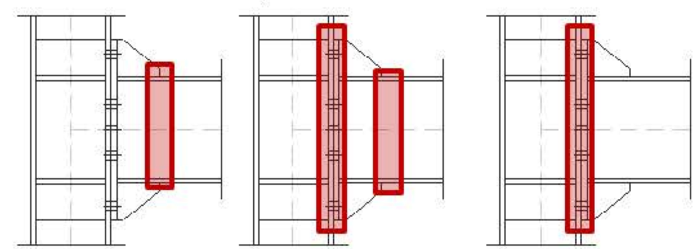
JOINT CONFIGURATION IN FRAME

INTERNAL JOINTS / EXTERNAL JOINTS



PERFORMANCE LEVELS

FULL-STRENGTH EQUAL-STRENGTH PARTIAL-STRENGTH

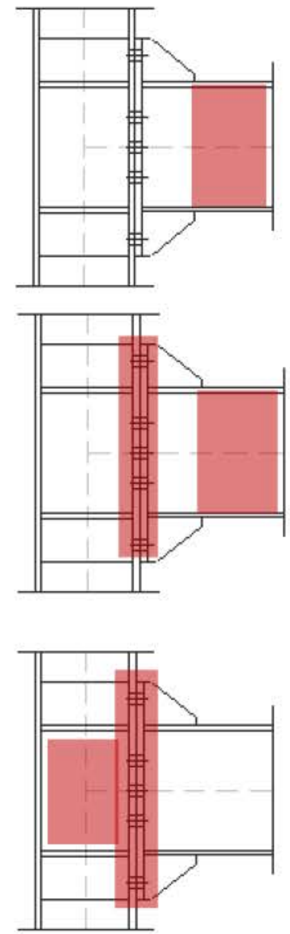


Performance objectives for EU prequalified joints

- **Full strength Joint**: plastic deformations should occur only in the beam, while the connection should behave elastically.
  Column web panel is full strength

- **Equal strength joint**: plastic deformations could simultaneously occur both in the connection zone and in the connected beam.
  Column web panel is either full strength

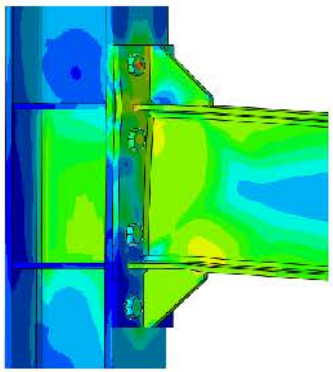
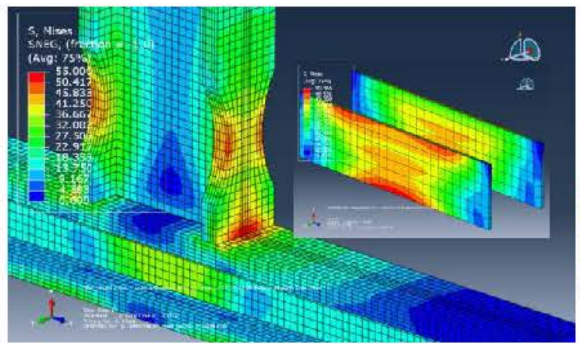
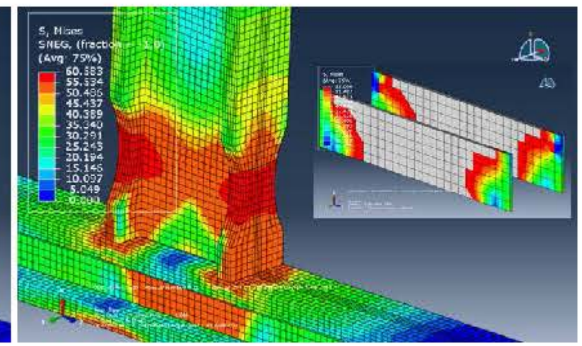
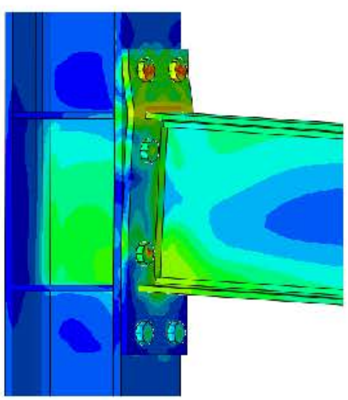
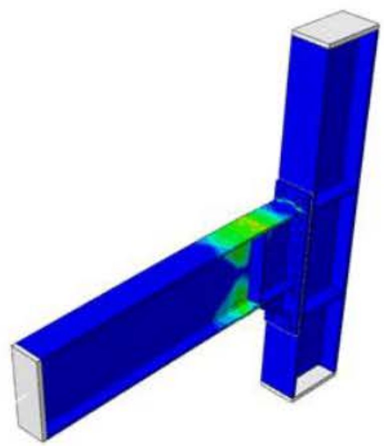
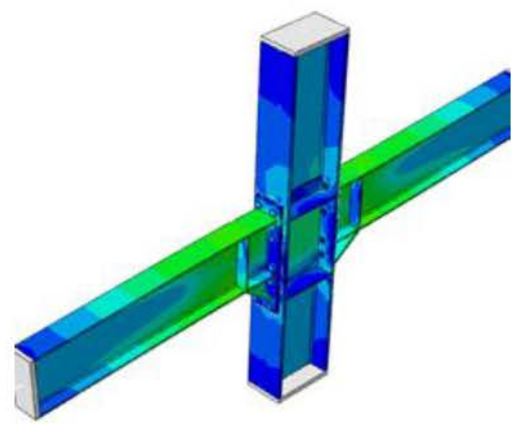
- **Partial strength joint**: plastic deformations occur both in the connection zone that is the weakest component.
  Column web panel is assumed balance strength



D'Aniello M., Tartaglia R., Costanzo S., Landolfo R. (2017). Seismic design of extended stiffened end-plate joints in the framework of Eurocodes. Journal of Constructional Steel Research, Volume 128, January 2017, Pages 512–527

FEM Numerical Investigations to Support the Design of Joint Specimens

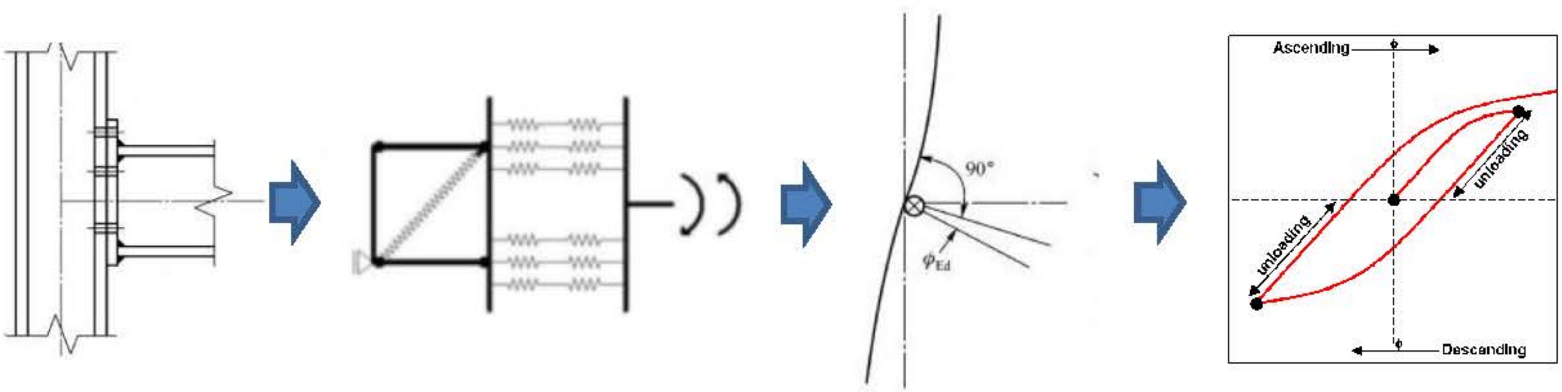
- The design of joint specimens was supported by numerical simulations aimed at validating the design assumptions.

Analytical Models

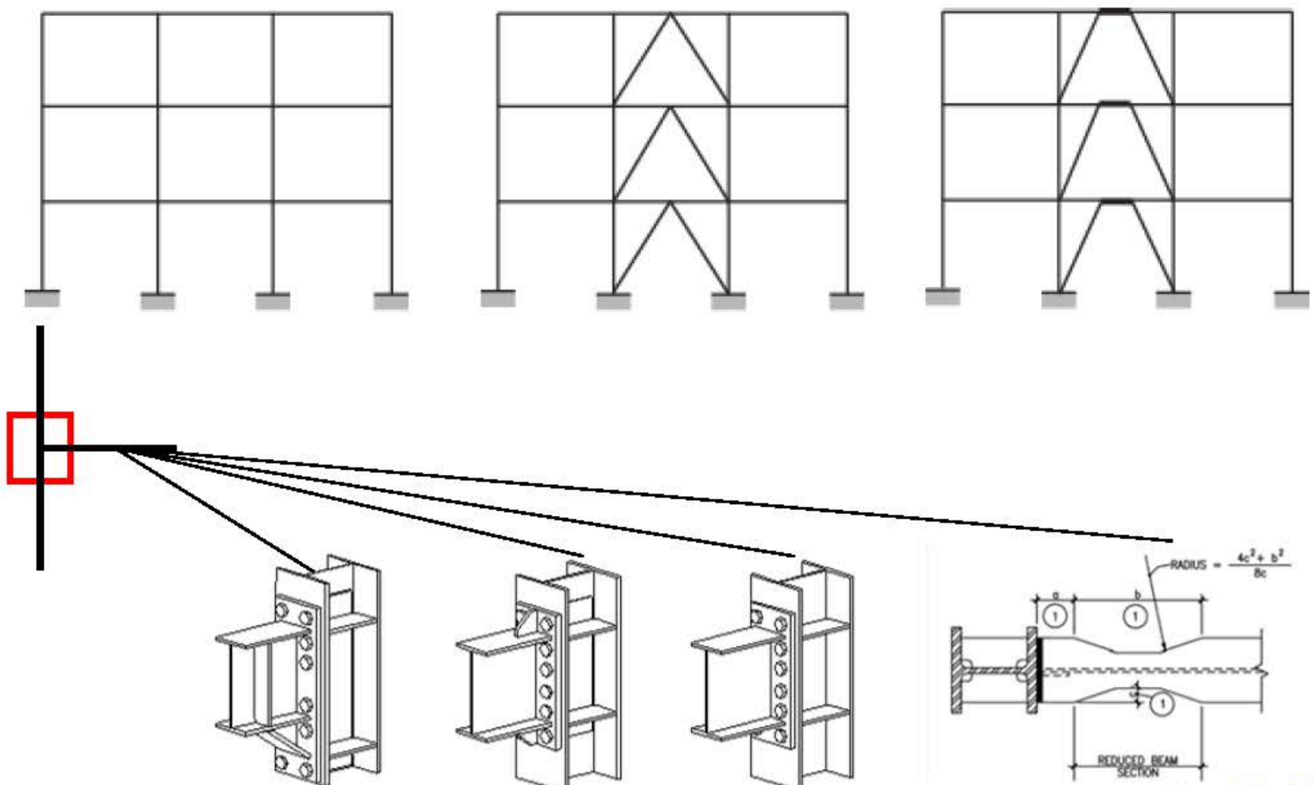
- An FE program is developed for nonlinear analysis of steel joints under cyclic loading. **This program extends the component-based method for steel joints under cyclic load and generates hysteretic behaviour of the joint and components**.
- A modelling strategy to develop **refined models** able to specifically account for the **moment-rotation characteristics of different types of joint in frames** has been defined and validated against experimental tests.

PREDICTION OF HYSTERETIC BEHAVIOUR



Characterisation of the Seismic Demand

- In order to address the design and the operating conditions of the joints, the seismic performance of the designed structures are evaluated on the basis of push-over and IDA analyses
- The set of numerical analyses on frames cover all the structural configurations MRF, D-CBF, D-EBF which have to be analysed by varying the joint types.



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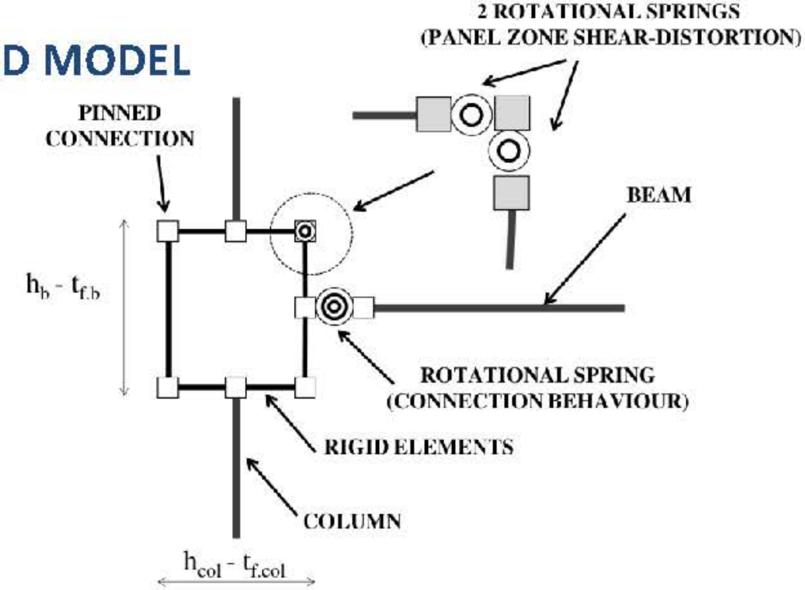
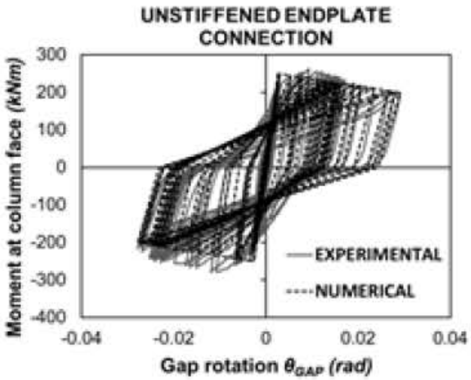
Characterisation of the Seismic Demand

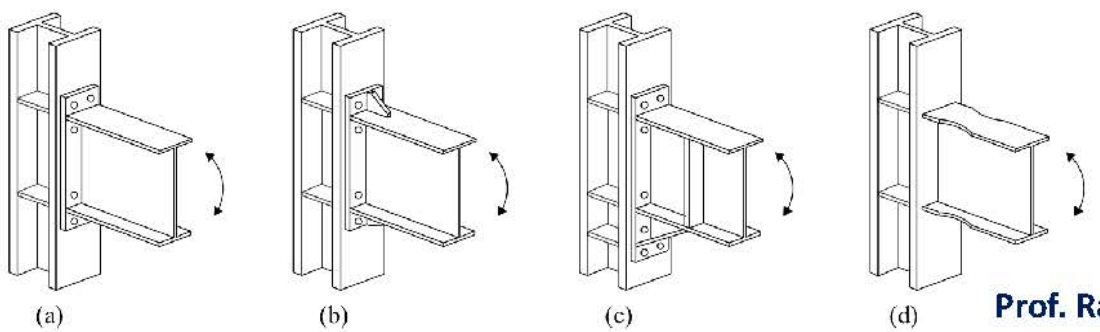
- In order to assess the seismic demand of different joint typologies, the numerical analyses on frames must be necessarily performed by using **refined models** in which the joint moment-rotation properties are specifically accounted for.

REFINED MODEL



CALIBRATION OF SPRINGS





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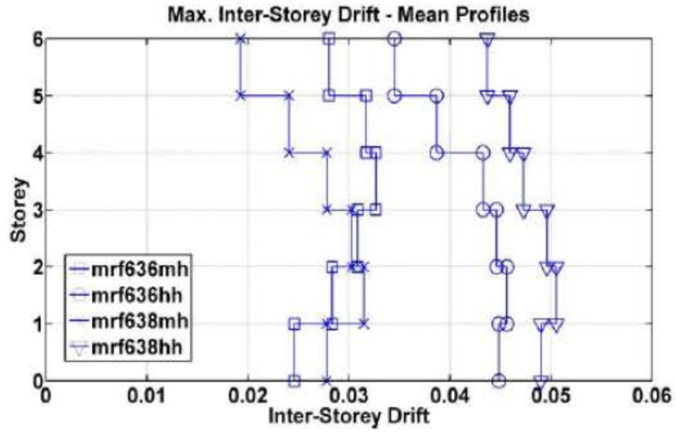
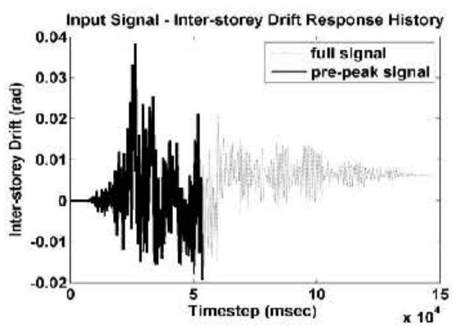
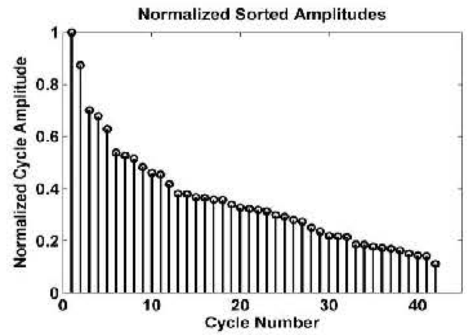
Characterisation of the Seismic Demand

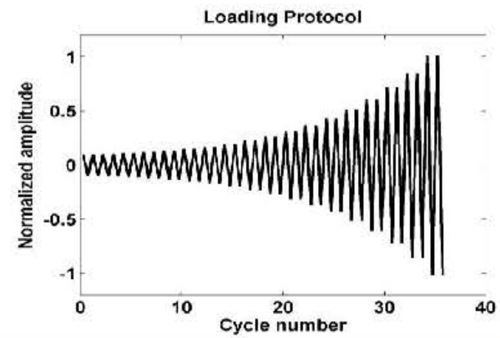


- **Two sets of 7 natural records** have been used to characterised the seismic demand for High Hazard (HH) and Medium Hazard (MH).
- A **new European loading protocol** has been defined, based on the results of a representative set of non-linear time-history analyses performed on the reference buildings
- The proposed loading protocol will be **applied during the experimental** tests and compared with AISC loading protocol.

Definition of the Loading Protocol



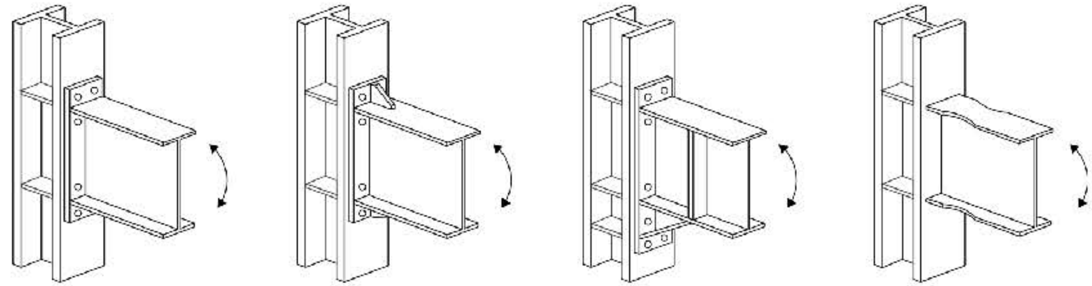




NUMERICAL INVESTIGATION → EVALUATION OF SEISMIC DEMAND → DEVELOPMENT OF METHODOLOGY TO DEFINE A NEW EUROPEAN LOADING PROTOCOL → THE NEW LOADING PROTOCOL WILL BE APPLIED DURING THE EXPERIMENTAL TESTS

Experimental Investigation

- Tests on base material
- Characterisation of bolts
- Cyclic characterisation of mild carbon steel
- 76 joint specimens



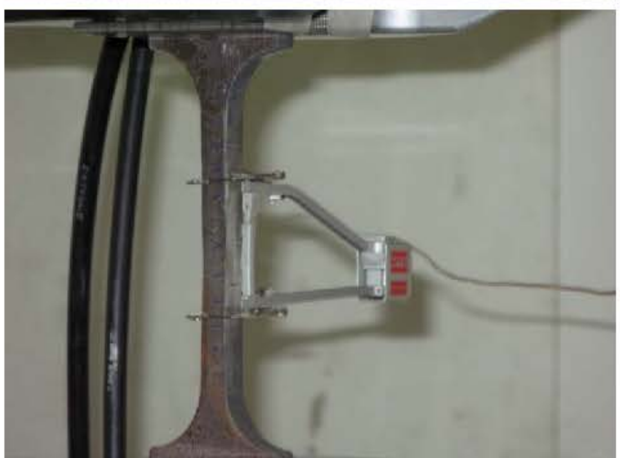
24 Tests — 24 Tests — 24 Tests — 4 Tests

EXPERIMENTAL PROGRAMME – 76 JOINT SPECIMENS	
BEAM TO COLUMN ASSEMBLIES	SMALL BEAM (IPE 360) – MEDIUM BEAM (IPE450) – DEEP BEAM (IPE600) *DOGBONE CONNECTION DISEGNED FOR W-TYPE US PROFILES.
JOINT TYPE	HAUNCHED – EXTENDED STIFFENED ENDPLATE – UNSTIFFENED ENDPLATE - DOGBONE
JOINT CONFIGURATION	INTERNAL AND EXTERNAL
PERFORMANCE OBJECTIVES	FULL STRENGTH – EQUAL STRENGTH – PARTIAL STRENGTH
LOADING PROTOCOL	MONOTONIC – CYCLIC AISC – CYCLIC PROPOSED
SHOOT PEENING	YES/NO

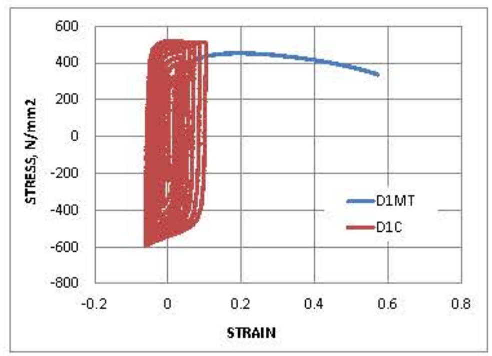
Characterisation of materials and bolts

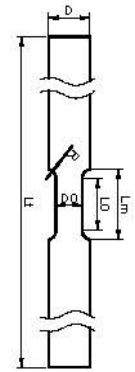
- The tests on base material are completed
- The tests aimed at bolts characterisation are completed
- Tests aimed at the cyclic characterisation of European mild carbon steel have been carried out

TESTS ON BASE MATERIAL



CYCLIC CHARACTERISATION OF EUROPEAN MILD CARBON STEEL





TESTS ON BOLTS

Prof. Raffaele Landolfo

Cyclic characterisation of European mild carbon steel

Steel grade:

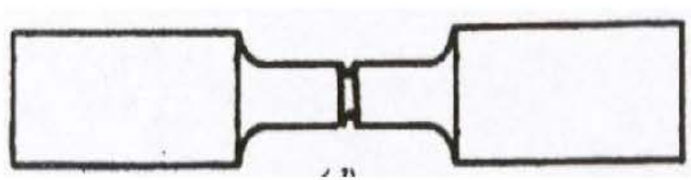
- S275, S355, S355 HISTAR, S460

Repetitions: 3

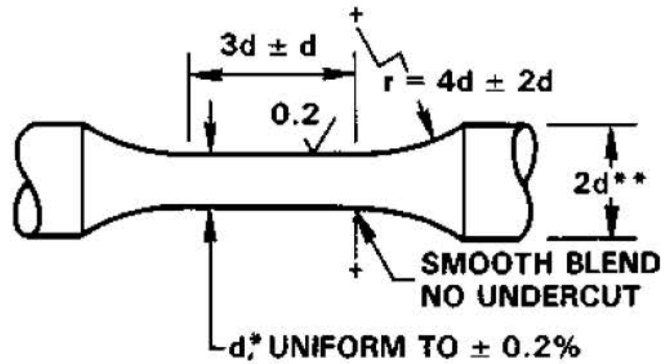
Loading protocol:

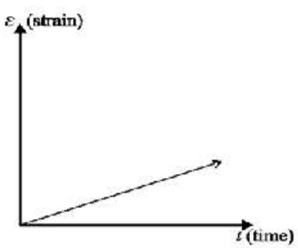
- Tensile tests
- Variable amplitude tests (2x1%, 2x3%, 2x5%, 2x7%, etc.)
- "Near field" loading protocol
- Constant amplitude tests, symmetric strain profile: 1%, 3%, 5%, 7%

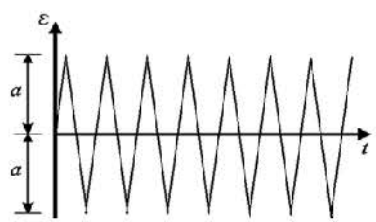
- **Notched specimen**

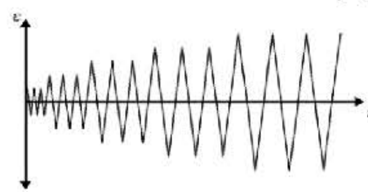


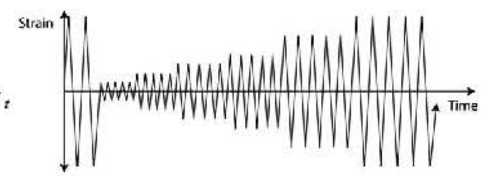
- **Smooth specimen**











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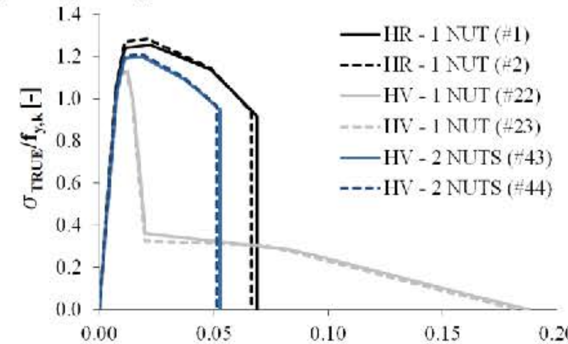
Characterisation OF EU High Strength Preloadable Bolts

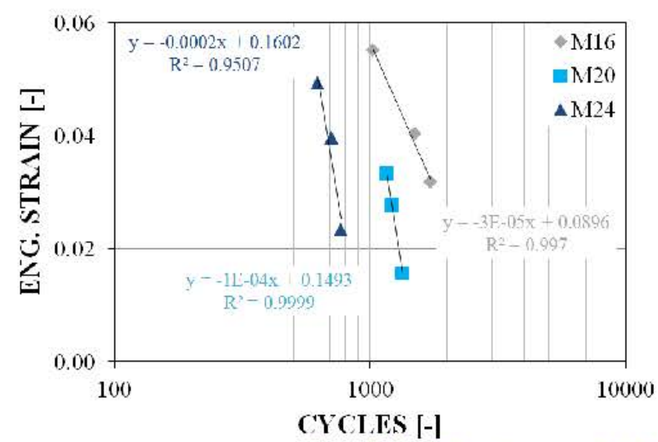
Bolt type: HR, HV, HV with 2 nuts
Repetitions: 3
Loading protocol:

- Tensile tests
- Variable amplitude tests
- Constant amplitude tests, zero to peak strain: 2%, 3%, 4%, 5%

HV Bolt failure

HR Bolt failure





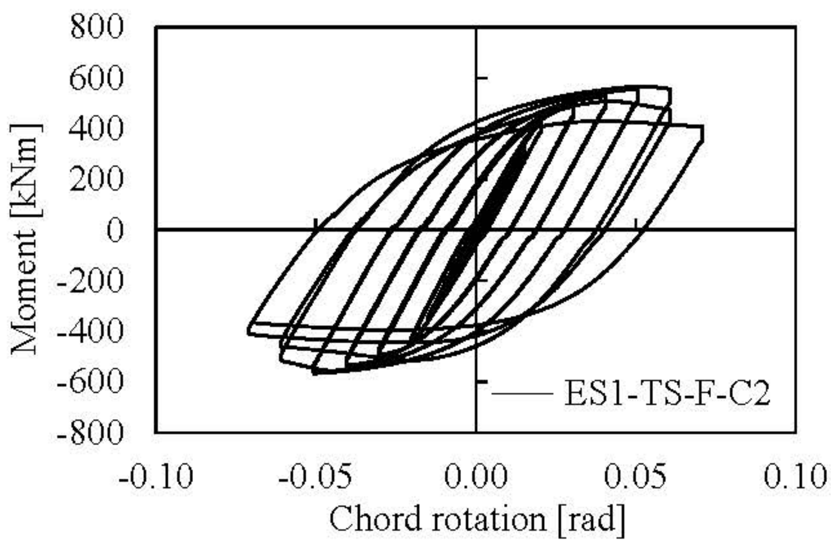
D'Aniello M., Cassiano D., Landolfo R., (2016) Monotonic and cyclic inelastic tensile response of European preloadable GR10.9 bolt assemblies. Journal of Constructional Steel Research, 124: 77–90

Tests on Joints

- Tests on Haunched joints (UPT)
- Tests on Extended Stiffened joints (UNINA)
- Tests on Extended Unstiffened joints (Ulg)
- Tests on Dog-bone (AM)

Tests on Extended Stiffnened Joints

- The **failure modes** of extended stiffened joints depend on the design performance level.
- Specimens **designed as full strength joints** exhibit **plastic hinge of the beam with progressive deterioration due to local buckling and fracture** of the beam due to low cycle fatigue)

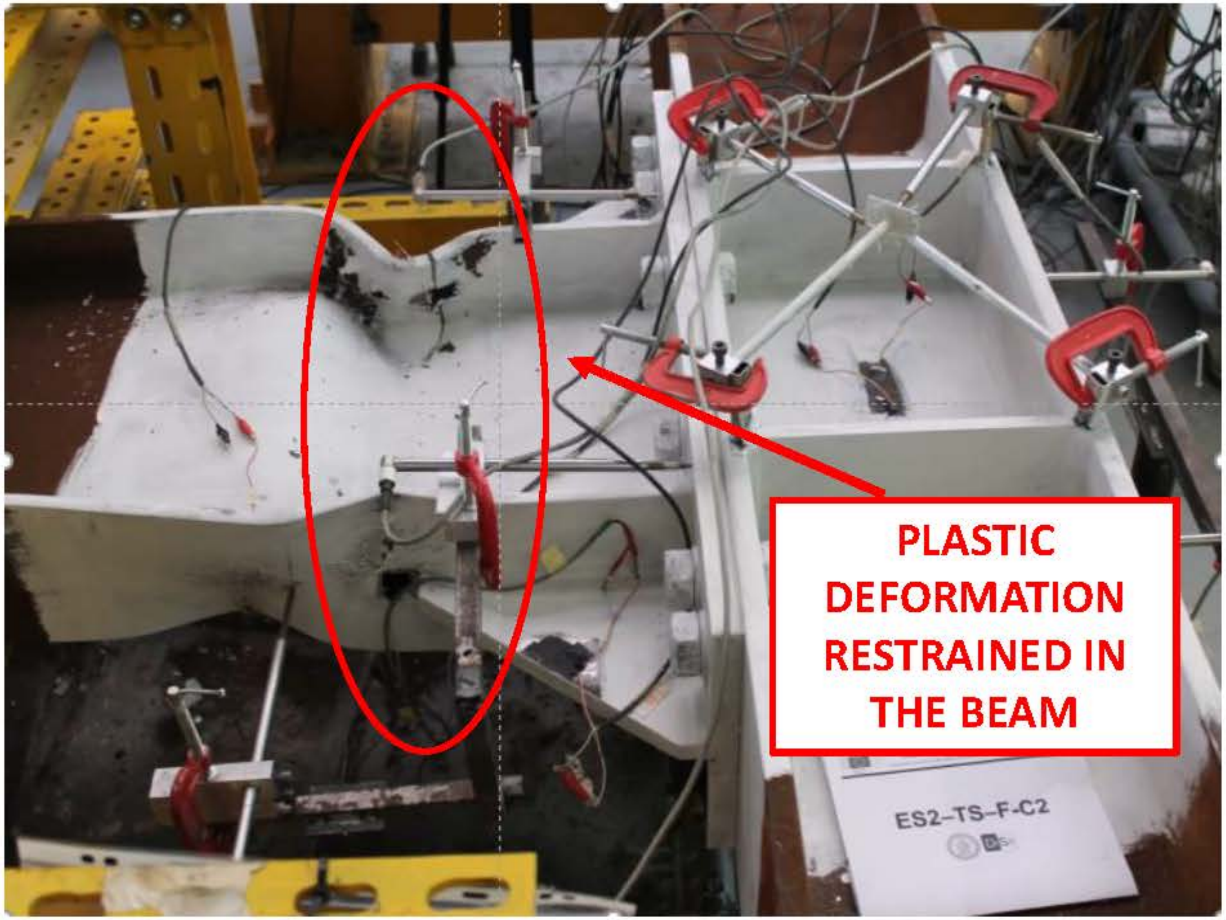


- This type of joints behave as **full-strength rigid** or **full-strength semi-rigid** (depending on the beam depth)
- This type of joints **satisfies both EC8 (for DCH and DCM) and AISC341 acceptance criteria**

Equaljoints Plus

INTRODUCTION
EJ PROJECT OVERVIEW
DESIGN OF JOINTS
ANALYTICAL MODELS
NUMERICAL ANALYSES
EXPERIMENTAL TESTS
FINITE ELEMENT ANALYSES
DESIGN GUIDELINES
EJ PLUS OVERVIEW
CONCLUSIVE REMARKS

Experimental tests: video

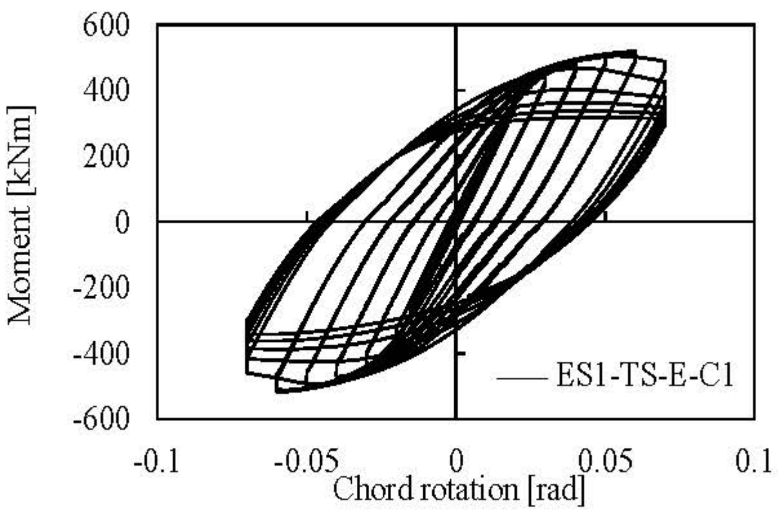


Joint type: Extended stiffened bolted joint
Assembly: IPE 450 – HEB340
Performance objective: FULL STRENGTH

Prof. Raffaele Landolfo

Tests on Extended Stiffned Joints

- The **failure modes** of extended stiffened joints depend on the design performance level.
- Specimens **designed as equal strength** with full strength web panel show a more complex **failure mechanism with the plastic deformations in both beam** (i.e. local buckling of the flanges) **and connection** (i.e. end-plate in bending)



- This type of joints behave as **equal-strength semi-rigid**
- This type of joint **satisfies both EC8 (for DCH and DCM) and AISC341 acceptance criteria**

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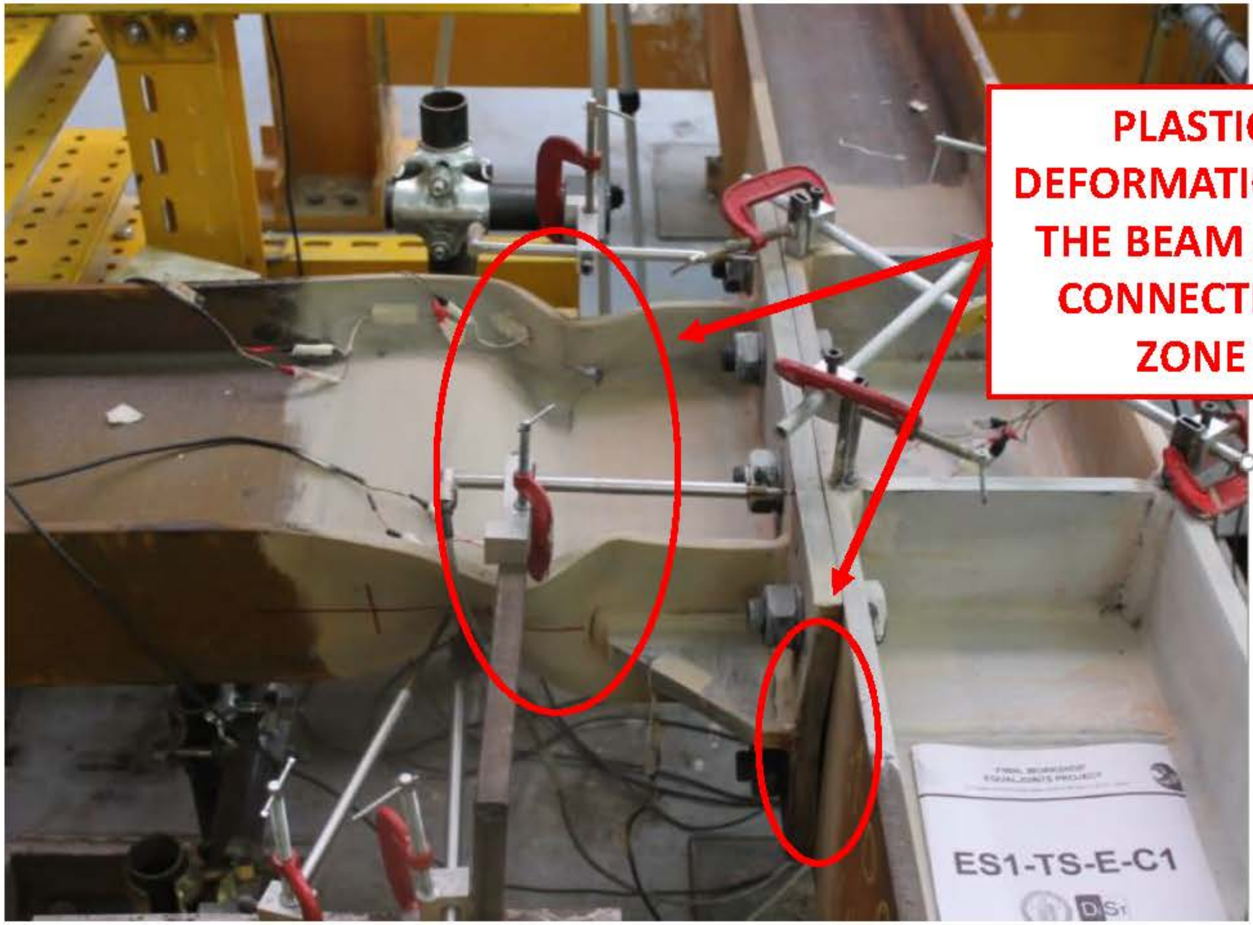
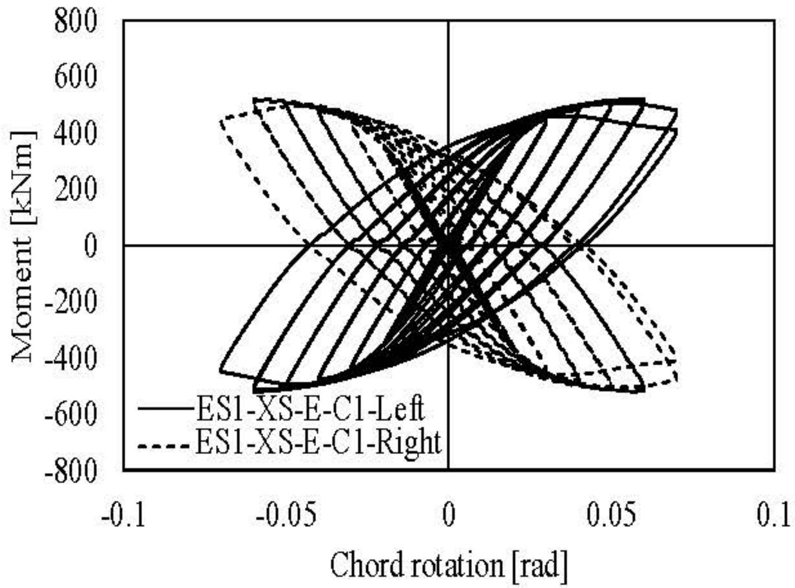
Experimental tests: video

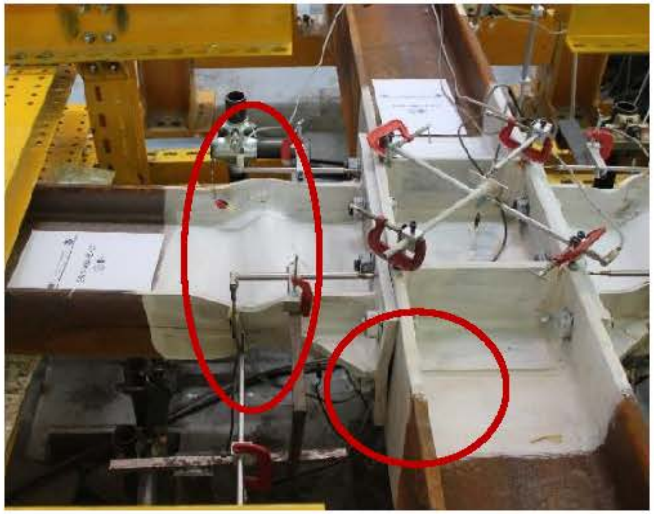


Joint type: Extended stiffened bolted joint
Assembly: IPE 360 – HEB280
Performance objective: EQUAL STRENGTH

Tests on Extended Stiffened Joints

- All tested **double-sided** (or internal) joints were **designed as equal strength** connection with strong web panel and their relevant experimental failure mode is fully consistent with the design criteria and in line with the corresponding external joints.



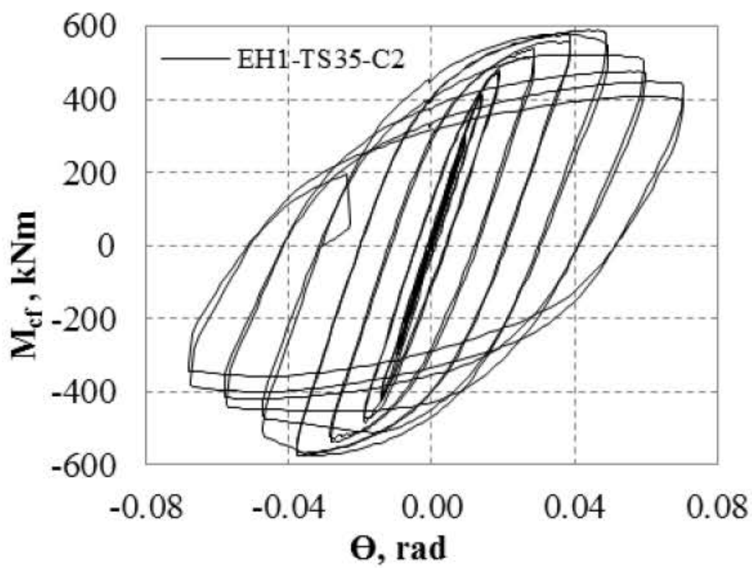


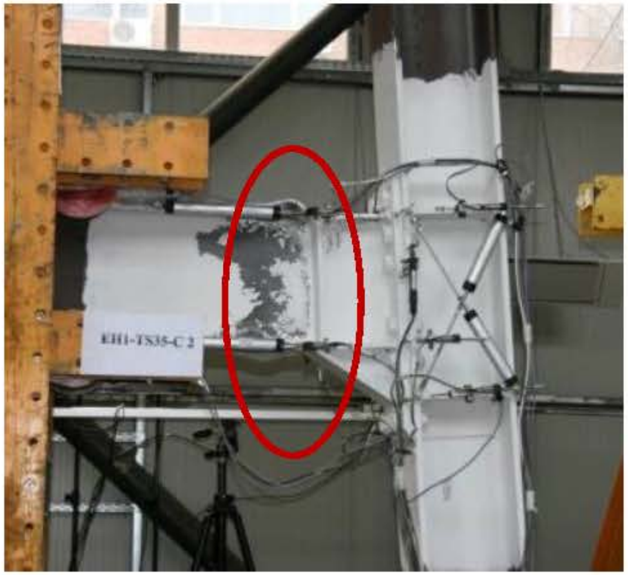
- This type of joints behave as **equal-strength semi-rigid**
- This type of joints satisfies both **EC8 (for DCH and DCM) and AISC341 acceptance criteria**

Tests on Haunched Joints

- All tested specimen showed a stable hysteretic response, with **plastic deformation concentrated in the beam** next to the haunch.

- **The failure** of these joints occurs either into the beam flange of the plastic hinge due to low-cycle fatigue cracking, or in the heat-affected zone (HAZ) of the weld between haunch and beam flanges, or at the interface between beam web and flange.

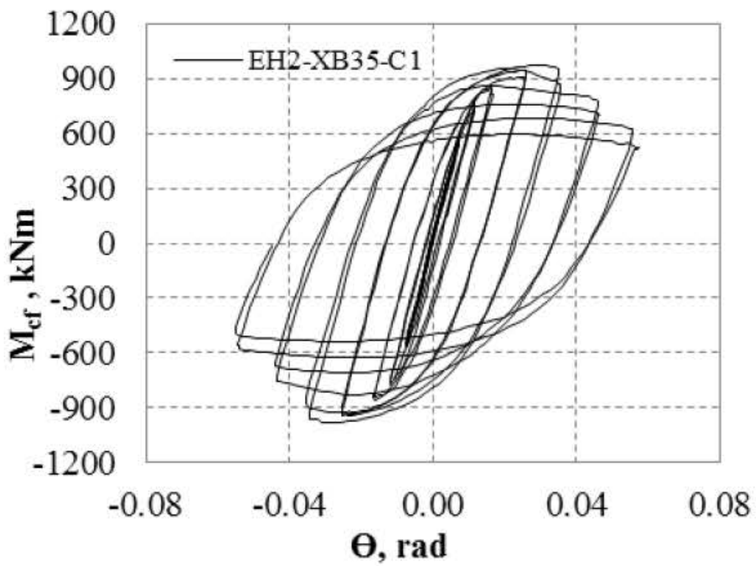




- This type of joints behave as **full-strength full rigid**

Tests on Haunched Joints

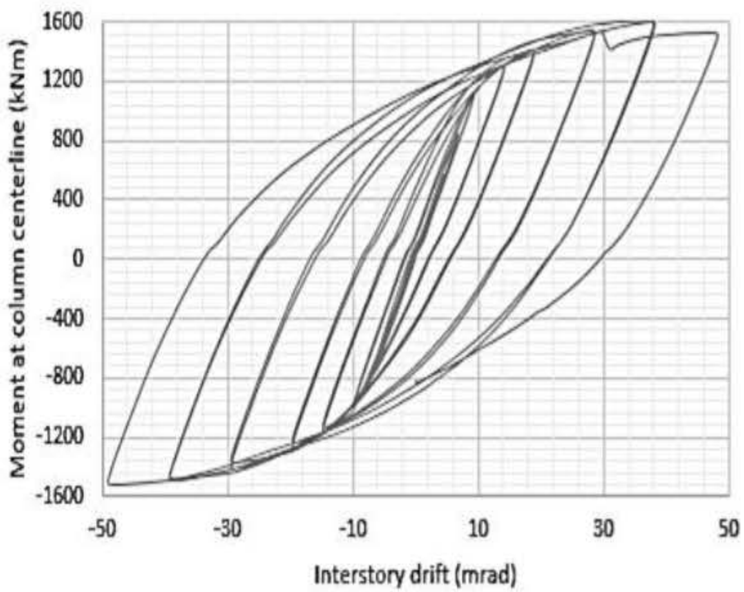
- All tested specimen showed a stable hysteretic response, with **plastic deformation concentrated in the beam** next to the haunch.
- **The failure** of these joints occurs either into the beam flange of the plastic hinge due to low-cycle fatigue cracking, or in the heat-affected zone (HAZ) of the weld between haunch and beam flanges, or at the interface between beam web and flange.



- This type of joints behave as **full-strength full rigid**

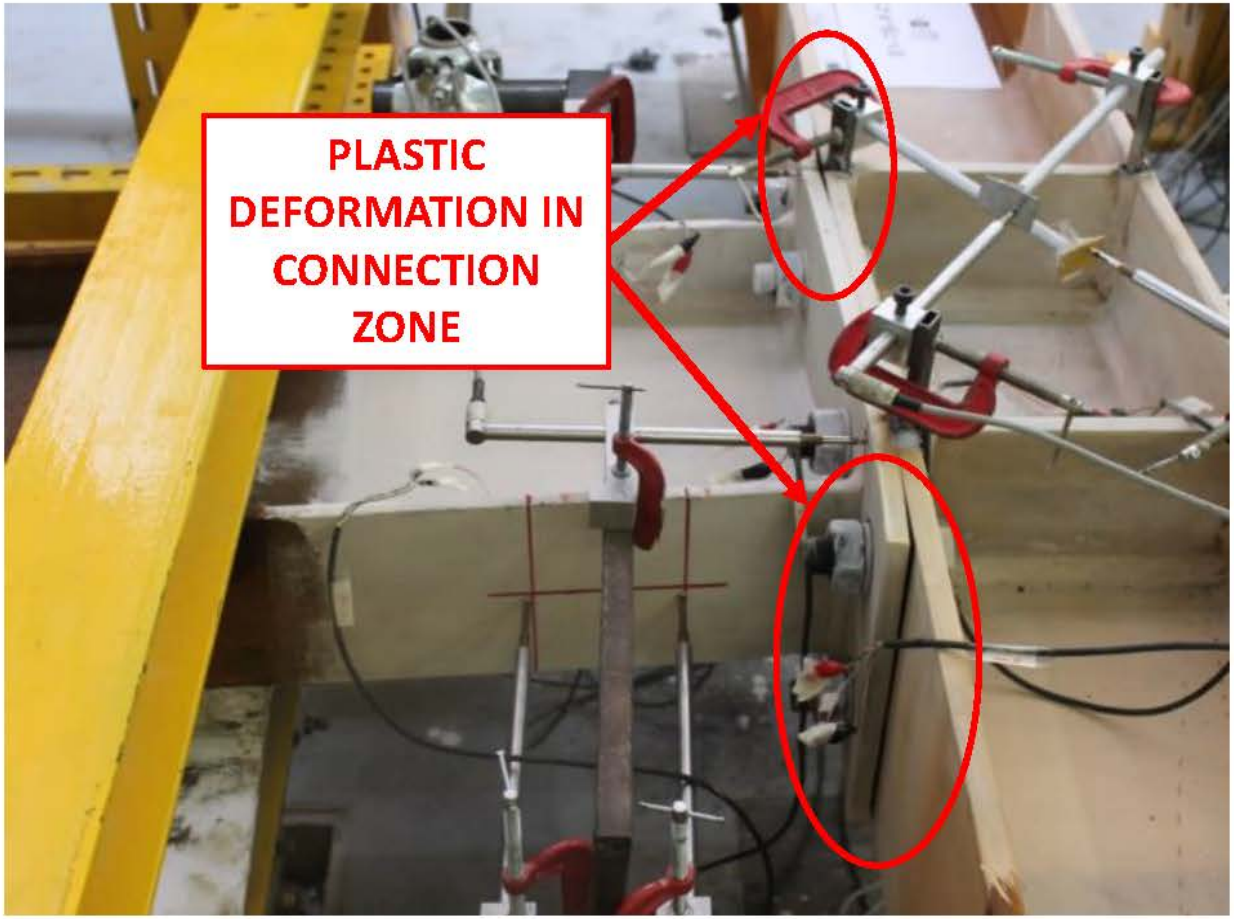
Tests on Unstiffened Endplate Joints

- The **failure modes** of extended unstiffened joints are mostly characterized by **plastic deformation of the connection** (i.e. end-plate in bending) **and column web panel.**



- This type of joints behave as **equal/partial-strength and semi-rigid.**

Experimental tests: video



Joint type: Extended unstiffened bolted joint
Assembly: IPE 360 – HEB280
Performance objective: PARTIAL STRENGTH

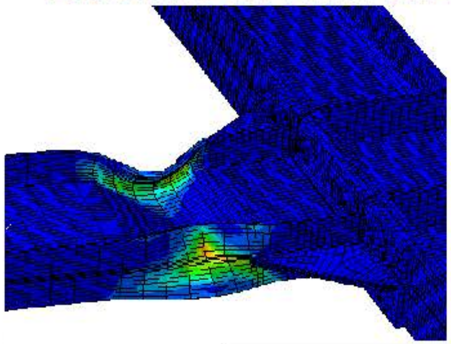
Effectiveness and domain of application

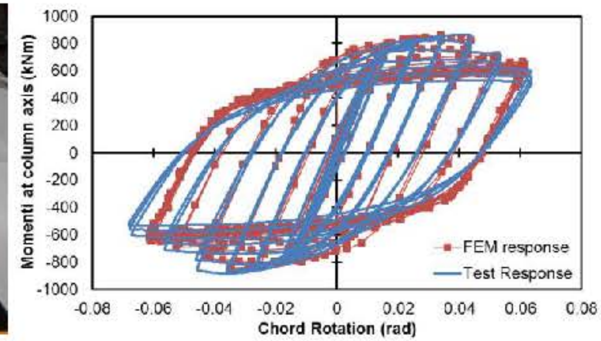
- **Haunched joints** are full strength and full rigid.
- **Extended stiffened joints** are either full strength or equal strength. In addition, depending on the beam depth, these joints can be rigid or semi-rigid.
- Both haunched and extended stiffened can be used for MRFs and Dual frames without any limitation on seismicity level.
- **Extended unstiffened joints** are equal or partial strength and semi-rigid. Hence, these joints are effective in stiff frames.
- Extended unstiffened joints are recommended for Dual frames without any limitation on seismicity level or for MRFs in low seismicity areas.

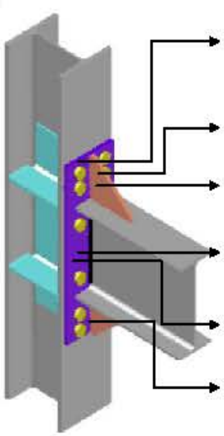
Calibration of FEMs and Parametric Analyses

- The numerical finite elements models have been calibrated on the basis of experimental results found in literature and carried out within the project.
- The calibrated models have been used to perform a FEM parametric analyses performed in order to extend **test outcomes** and to deepen the knowledge of the behaviour of semi-rigid steel joints

Extended stiffened end-plate joints







Design Approach Investigation – two sets of joints (IPE360, IPE450 and IPE600 Full, Partial and Equal strength joints) have been designed according to two design approaches (EN1993:1-8 and Alternative)

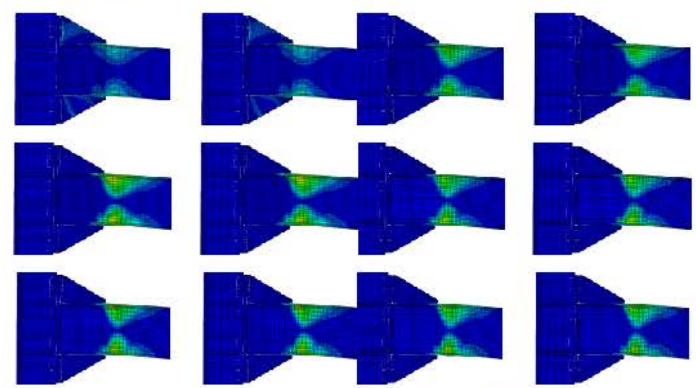
Joint overstrength Investigation – Full strength joints designed according to Alternative approach but considering different overstrength for joints (1.375 and

Rib Investigation – For joints designed with the Alternative approach, the rib thickness varies within [5 to 30 mm] and the rib aspect ratio varies within [30° - 40°]

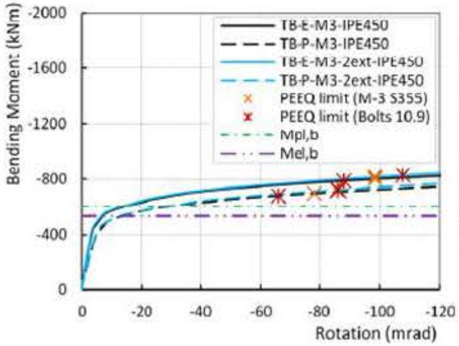
Middle bolt row Investigation – Two joint sets with or without a bolt row in symmetry axis of the connection

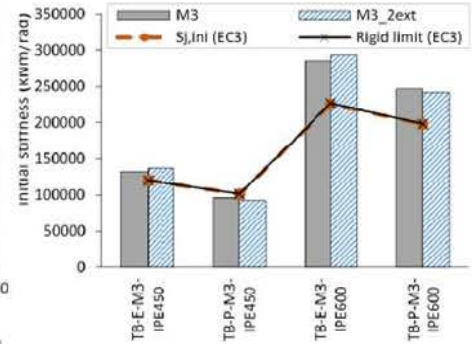
End Plate Material Investigation – The yield strength of end plate material is varied within (EP to M – 4)

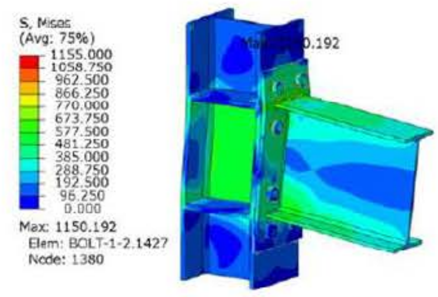
Compression centre Investigation – For the joints designed in the alternative approach the position of the compression centre is evaluated.



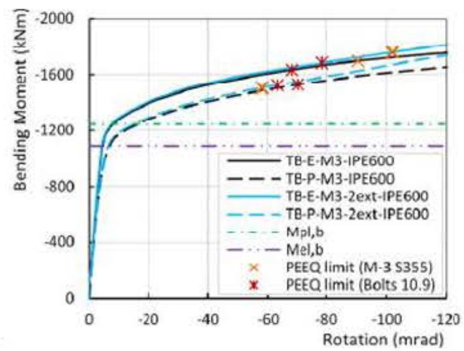
Unstiffened endplate joints

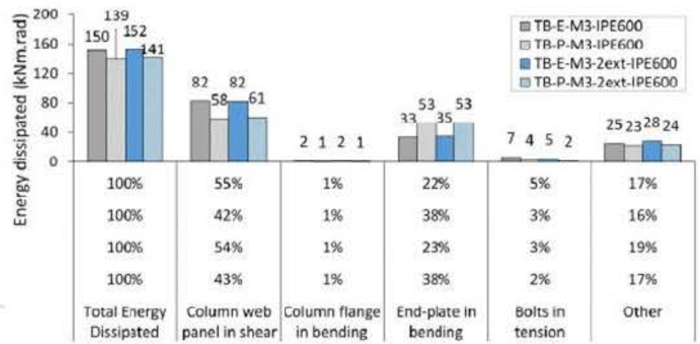


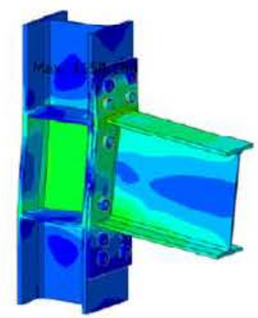


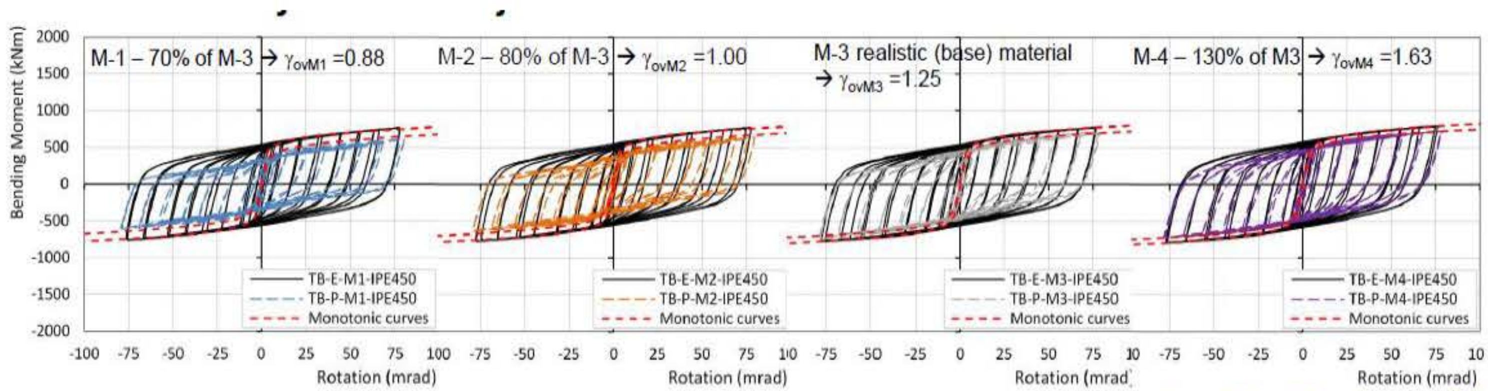


TB-P-IPE450

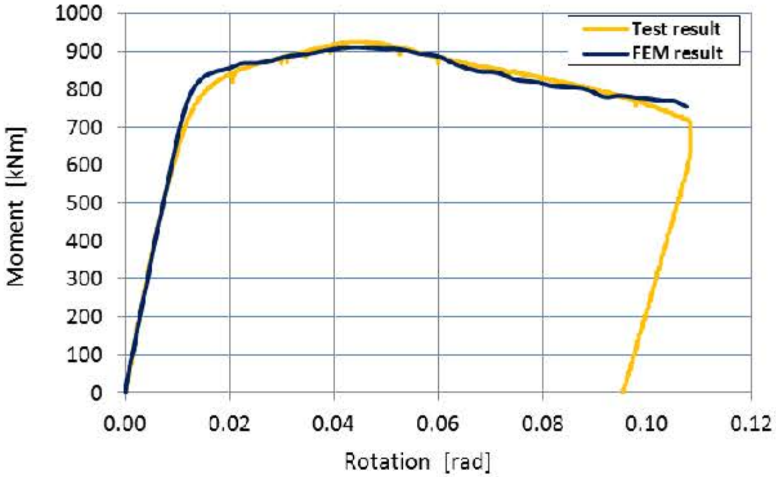


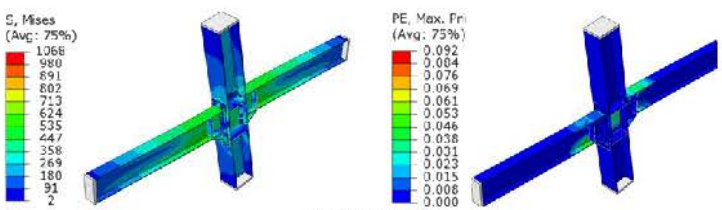






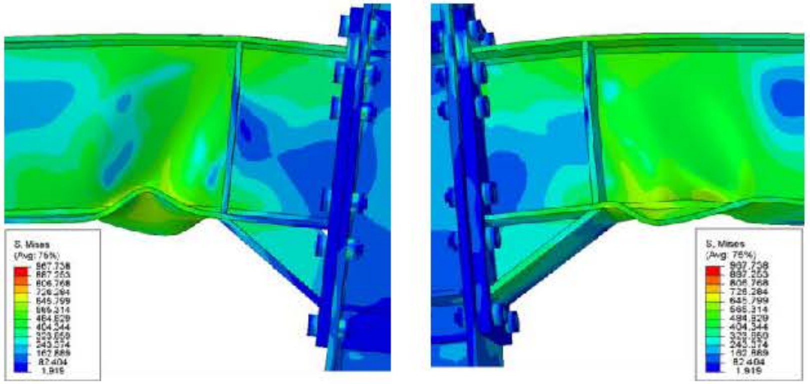
Haunched endplate joints





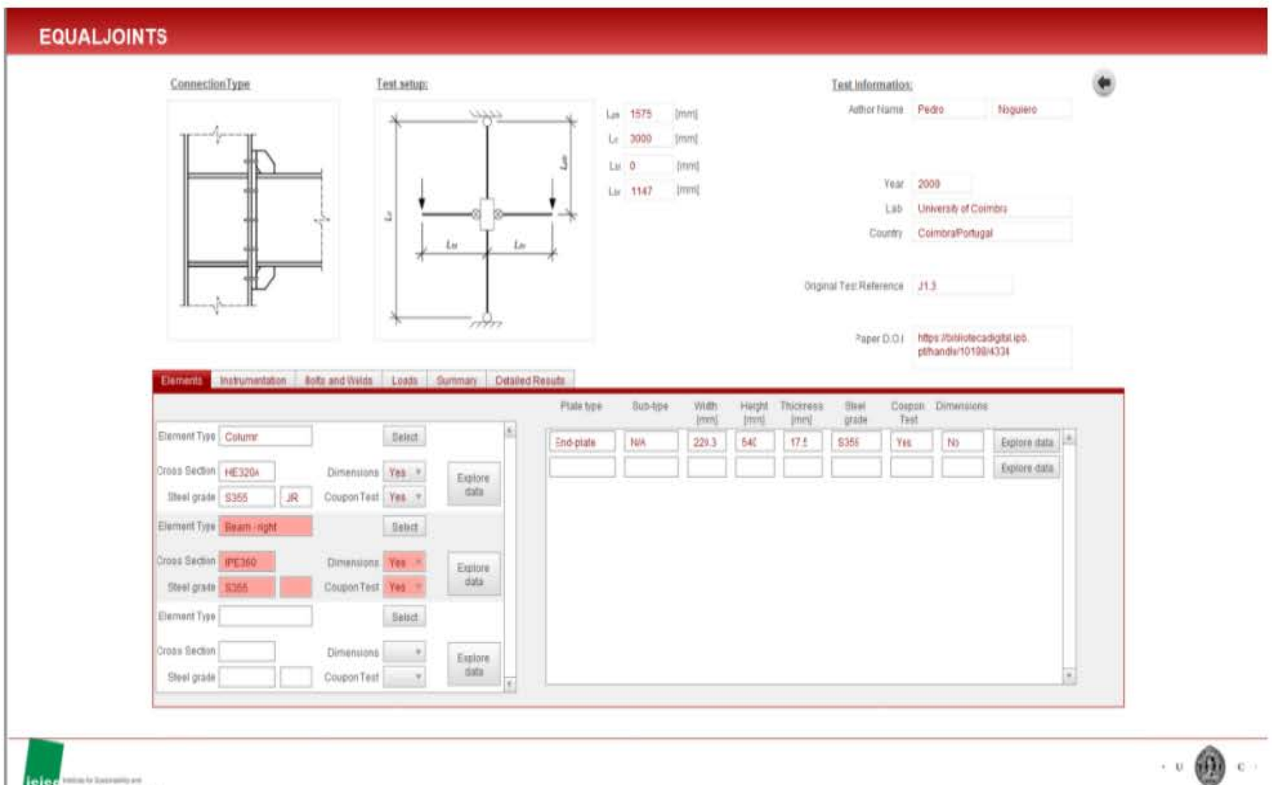
EH1-XB-35

EH2-XB-35

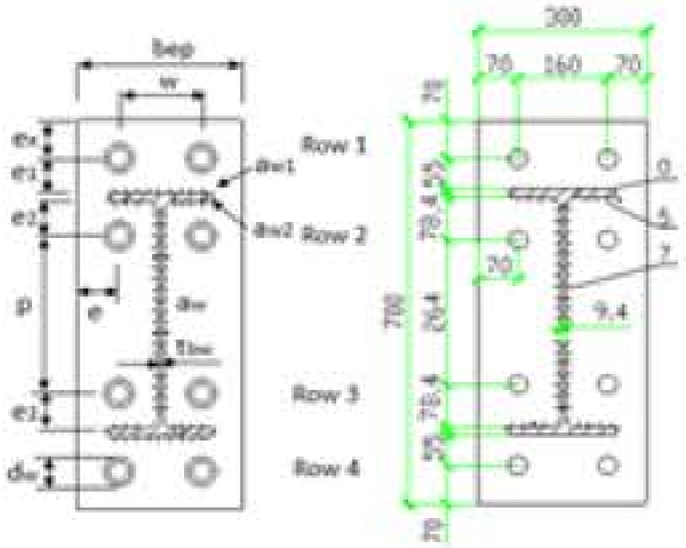


Experimental Database

- Experimental and numerical data are collected to develop prequalified charts.
- In this database all the available recorded data including the organisation and source of the data, geometric properties of each element, material properties of each element, geometrical imperfection if available, loading protocols, hysteretic behaviour of joint, failure mode and etc. were collected.



Prequalification charts and design guidelines

Component	Detail calculations	References
	Geometries $a_{w,1}$=0 mm $a_{w,2}$=5 mm a_w=7 mm b_{ep}=300 mm d_w=56 mm e=70 mm e_1=55 mm e_2=78.4 mm e_x=70 mm t_{wb}=9.4 mm w=160 mm  *"T-Stub" parameters* e_w=0.25*56=14 mm m, n and α parameters for the different bolt rows: *Row 1* $m = e_1 - 0.8a_{w,1}\sqrt{2}$ =55.0-0.0=55.0 mm $n = \min[e_x, 1.25m]$ =min(70,1.25*55)=68.75 mm *Rows 2 and 3* $m = 0.5(b_{ep} - 2e - t_{bw} - 1.6a_w\sqrt{2})$ =0.5*(300-2*70-9.4-1.6*7*1.414)=67.38 mm $n = \min[e, 1.25m]$ =min(70,1.25*67.38)=70 mm $m_2 = e_2 - 0.8a_{w,2}\sqrt{2}$ = 78.4 -0.8*5*1.414 =72.74 mm $\lambda_1 = \frac{m}{m+e}$ =0.49 $\lambda_2 = \frac{m_2}{m+e}$ =0.53 →α =5.70 *Effective lengths* Bolt row 1 (individual) $l_{eff,1} = \min\begin{cases} 2\pi m, \ \pi m + w, \ \pi m + 2e \\ 4m + 1.25e_x, \ e + 2m + 0.625e_x, \ 0.5b_{ep}, \ 0.5w + 2m + 0.625e_x \end{cases}$ $= \min\begin{cases} 2*3.14*55, \ 3.14*55+160, \ 3.14*55+2*70 \\ 4*55+1.25*70, \ 70+2*55+0.625*70, \ 0.5*300, \ 0.5*160+2*55+0.625*70 \end{cases}$ = 150 mm $l_{eff,2} = \min[4m + 1.25e_x, \ e + 2m + 0.625e_x, \ 0.5b_{ep}, \ 0.5w + 2m + 0.625e_x]$ =min(4*55+1.25*70, 70+2*55+0.625*70, 0.5*300, 0.5*160+2*55+0.625*70) = 150 mm	EC3-1-8 6.2.6.5

Component	Detail calculations	References
Beam flanges and web in compression	$F_{fb,Rd} = M_{c,Rd}/(h - t_{fb})$ =604210000/(450-14.5)*10⁻³=1387.4 kN	EC3-1-8
Column web and continuity plates in compression	$b_{eff,c,wc} = t_{fb} + \sqrt{2}(a_{w} + a_{w,1}) + 5(t_{fc} + r_c) + 2t_p$ = 14.6+1.414*(0+5)+5*(21.5+27)+2*18=300.17 mm A_{vc}=18*(300-12)=5184 mm² $\omega = \frac{1}{\sqrt{1+1.3(b_{eff,c,wc}t_{wc}/A_{vc})^2}}$ =1/((1+1.3*(300.17*12/3609)²)^0.5)=0.807 k_{wc}=1.0 (supposing $\sigma_{com,Ed} < f_{y,wc}$) $F_{wc,Rd} = \frac{\omega k_{wc} b_{eff,c,wc} t_{wc} f_{y,wc}}{\gamma_{M0}} + \frac{A_s f_{y,s}}{\gamma_{M0}}$ =(0.807*300.17*12*355/1+5184*355/1)*10⁻³=2872.3 kN	
Beam web in tension	Bolt row 2 (individual): $F_{t,wb,Rd,r2} = b_{eff,t,wb} t_{wb} f_{y,wb} / \gamma_{M0}$=584.07*9.4*355*10⁻³/1=1281.64 kN Bolt row 3 (individual): $F_{t,wb,Rd,r3} = F_{t,wb,Rd,r2}$= 1281.64 kN Group 1 (rows 2 +3): $F_{t,wb,Rd,g1} = b_{eff,t,wb} t_{wb} f_{y,wb} / \gamma_{M0}$ =(324.05+324.05)*9.4*355*10⁻³/1=2162.58 kN	EC3-1-8 6.2.6.8

Prof. Raffaele Landolfo

EJ-PLUS PROJECT (2017-2019)

Coordinator		Università degli Studi di Napoli Federico II (UNINA)
Beneficiaries	Former EJ project	Arcelormittal Belval & Differdange SA (AM)
	Former EJ project	Universite de Liege (Ulg)
	Former EJ project	Universitatea Politehnica Timisoara (UPT)
	Former EJ project	Universidade de Coimbra (UC)
	Former EJ project	Convention Europeenne de la Construction Metallique (ECCS)
	Former EJ project	Universita degli Studi di Salerno (UNISA)
	Former EJ project	Imperial College of Science Technology and Medicine (IC)
		Centre Technique Industriel de la Construction Metallique (CTICM)
		National Technical University of Athens (NTUA)
		Ceske Vysoke Uceni Technicke V Praze (CVUT)
		Technische Universiteit Delft (TUD)
		Univerza V Ljubljani (UL)
		Universitet Po Architektura Stroitelstvo I Geodezija (UASG)
		Universitat Politecnica de Catalunya (UPC)
		Rheinisch-Westfaelische Technische Hochschule Aachen (RWTHA)

EJ-PLUS overview

Research Fund for Coal & Steel

- **Equaljoint-PLUS** is a **24 month** RFCS project devoted to disseminate the knowledge achieved within the previous RCFS 36 months-project EQUALJOINTS
- Within the former RFCS project EQUALJOINTS (RFSR-CT-2013-00021), European seismic prequalification criteria of steel joints have been developed.
- **Equaljoint-PLUS** aims at the **valorisation**, the **dissemination** and the **extension** of the developed prequalification criteria **for practical applications to a wide audience** (i.e. academic institutions, Engineers and architects, construction companies, steel producers, etc.)

Sector (Coal /Steel):	Steel2 RTD
Technical Group:	TG S8
Grant Agreement No.:	RFSR-CT-2013-00021
Title:	Valorisation of knowledge for European pre-QUALified steel JOINTS
Acronym:	EQUALJOINTS-PLUS
Start Date:	1ST July 2017
End Date:	30st June 2019

EJ PLUS PROJECT OBJECTIVES

- To **collect and organize informative material** concerning the prequalified joint typologies: informative documents will be prepared in 12 languages
- To develop **pre-normative design recommendations** of seismically qualified joints on the basis of results from Equaljoints project.
- To develop **design guidelines in order to design steel structures accounting for the type of joints**.

UCyclic Objectives

- Development of a component based software that provides the analytical prediction of the cyclic response of joints
- Development of a user interface in the software in order to allow an easy application by users in practice.
- To prepare a user manual for the EQUALJOINTS-tool

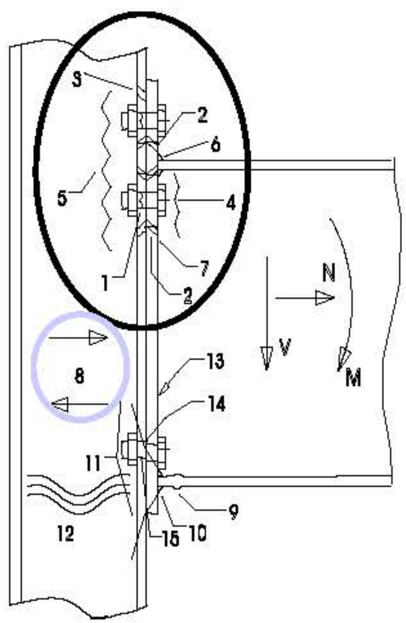
Mobile App Objectives

- Provide users with a simple tool (App) to design seismic pre-qualified beam-to-column connections
- Integrate the tool with other available tools provided by ECCS (e.g. ECCS EC3 Steel Member Calculator)

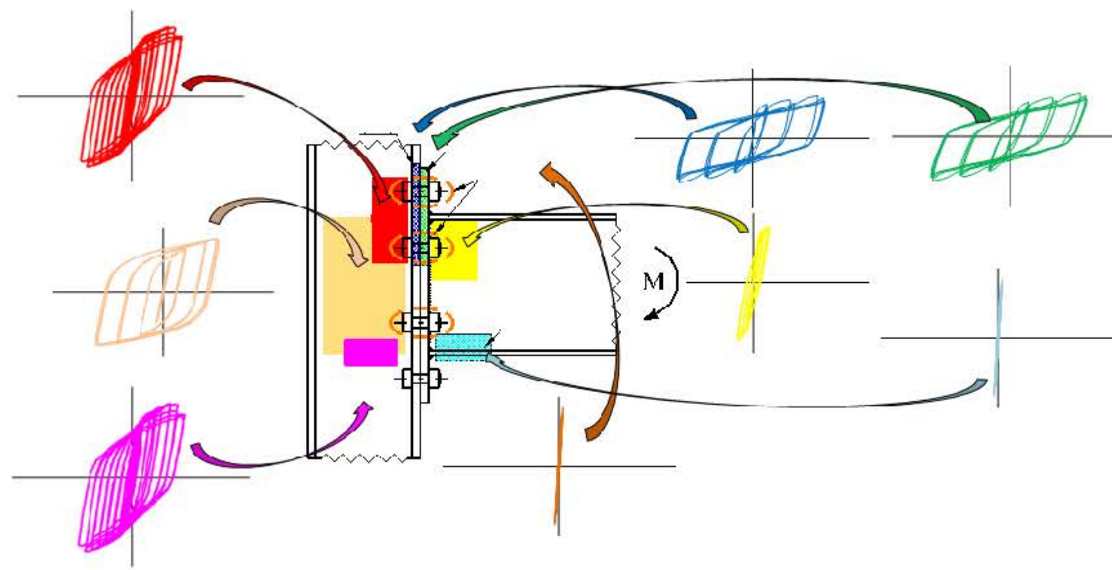
EQUALJOINTS MATLAB TOOL

- A FE program has been developed for nonlinear analysis of steel joints under cyclic loading
- **This program extends component-based method for steel joints under cyclic load and generates hysteretic behaviour of the joint and components.**
- A modelling strategy to develop **refined models** able to specifically account for the **moment-rotation charachteristics of different types of joint in frames**, has been defined and validated against experimental tests.

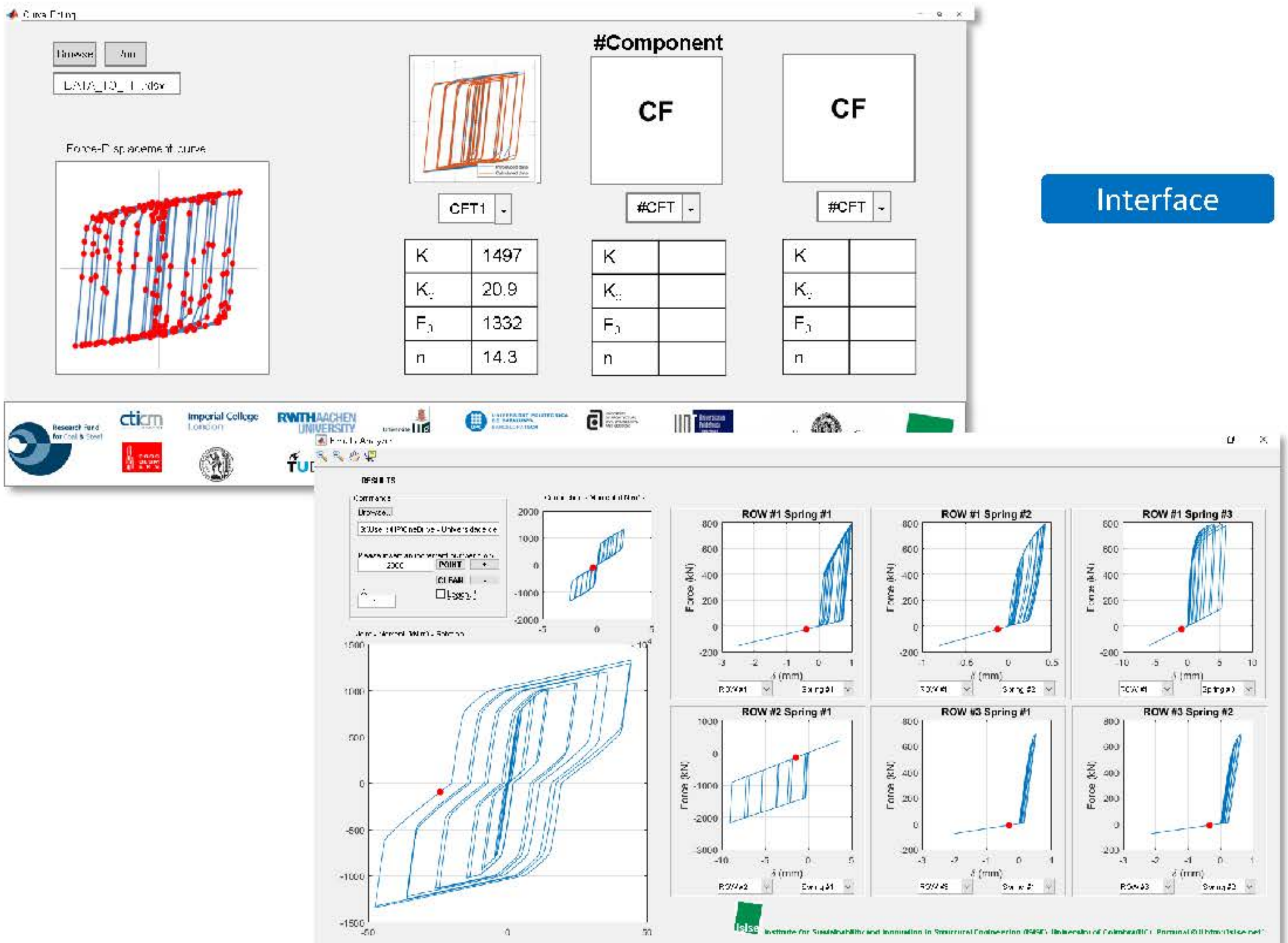
Component identification



Model and typical component behaviour



- **User-friendly interface** has been implemented.



Interface

EQUALJOINTS APP

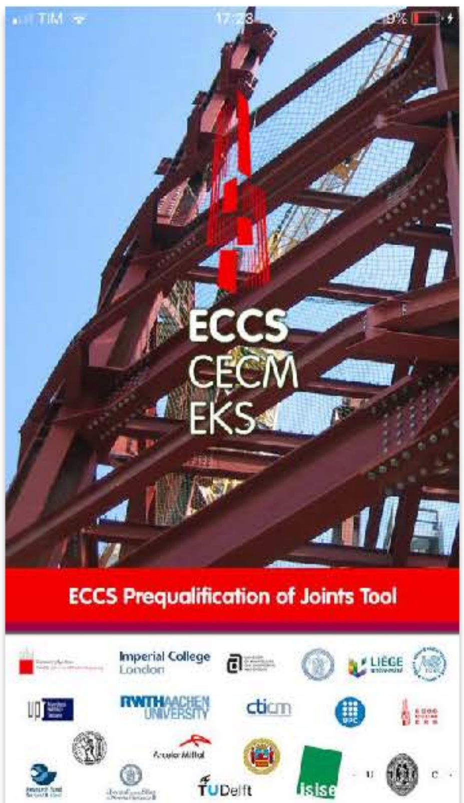
- iOS (AppStore) and Android (Google Play) versions (search for EqualJoints)

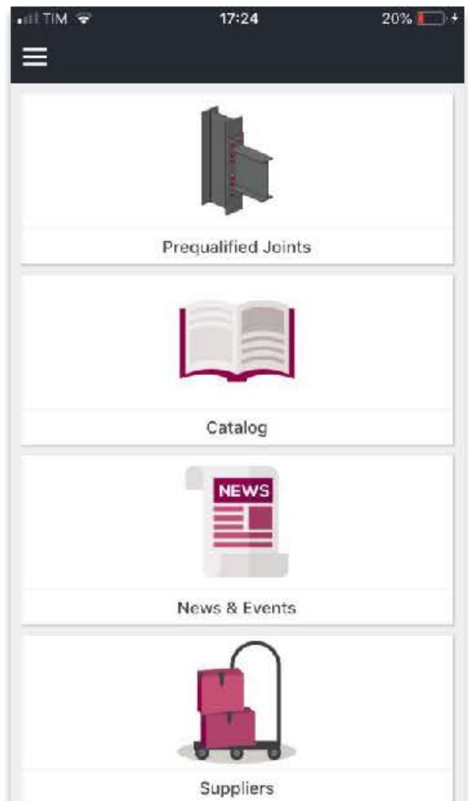
EQUALJOINTS TOOLS

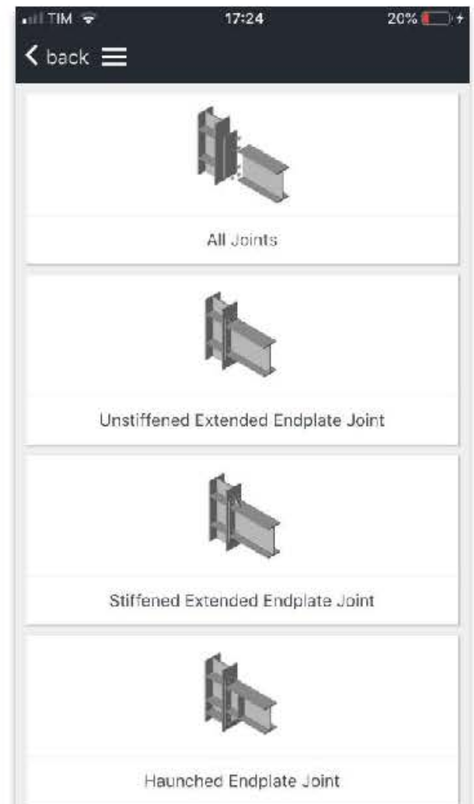
- To develop a **software and an app for mobile to predict the inelastic response of joints.**

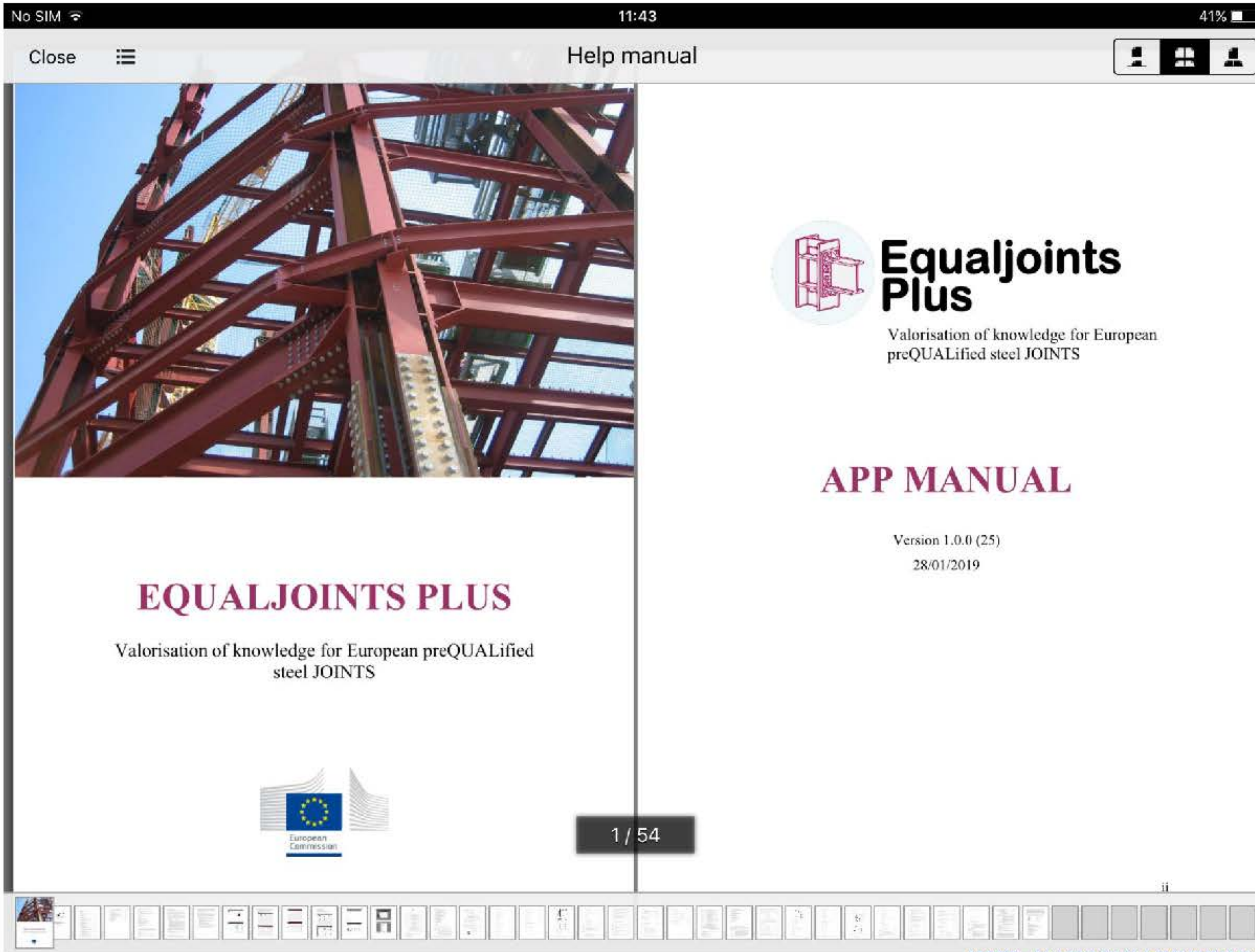
Equal Joints

Utility





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EQUALJOINTS PLUS
Valorisation of knowledge for European preQUALified steel JOINTS
European Commission
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Equaljoints Plus
Valorisation of knowledge for European preQUALified steel JOINTS
APP MANUAL
Version 1.0.0 (25)
28/01/2019
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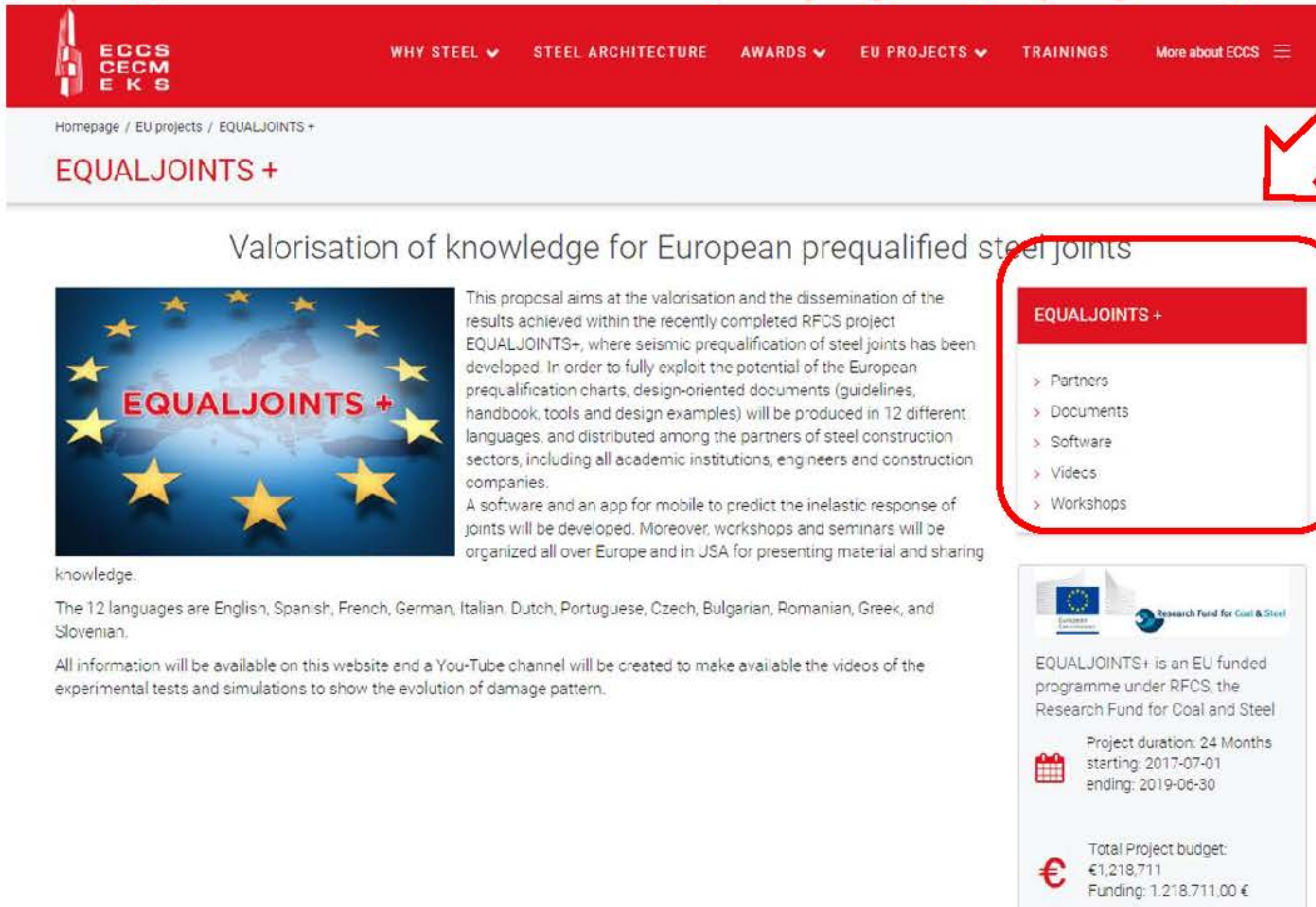
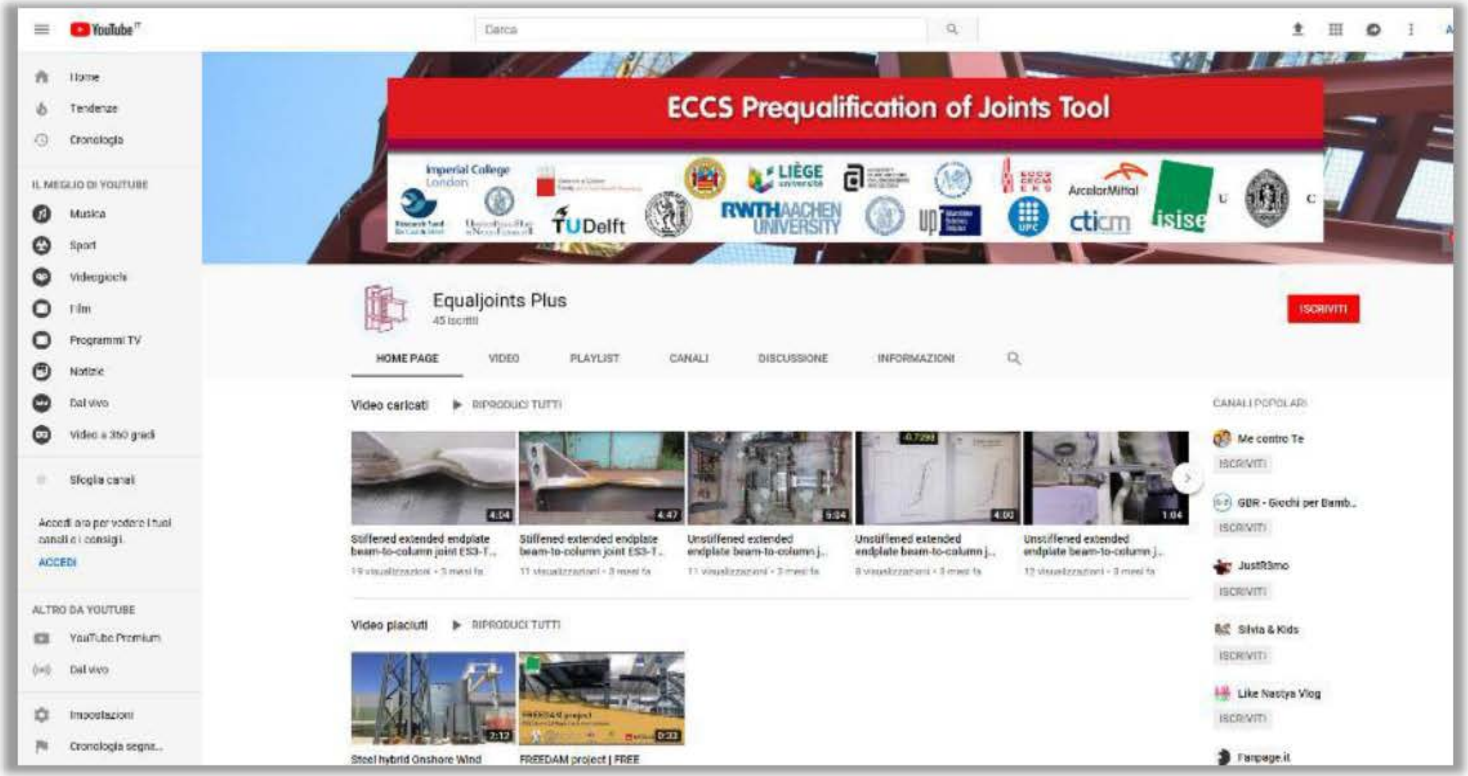
- **The dissemination material is available on the web site with free access** to the users in order to promote the obtained results:

https://www.steelconstruct.com/eu-projects/equaljoints/

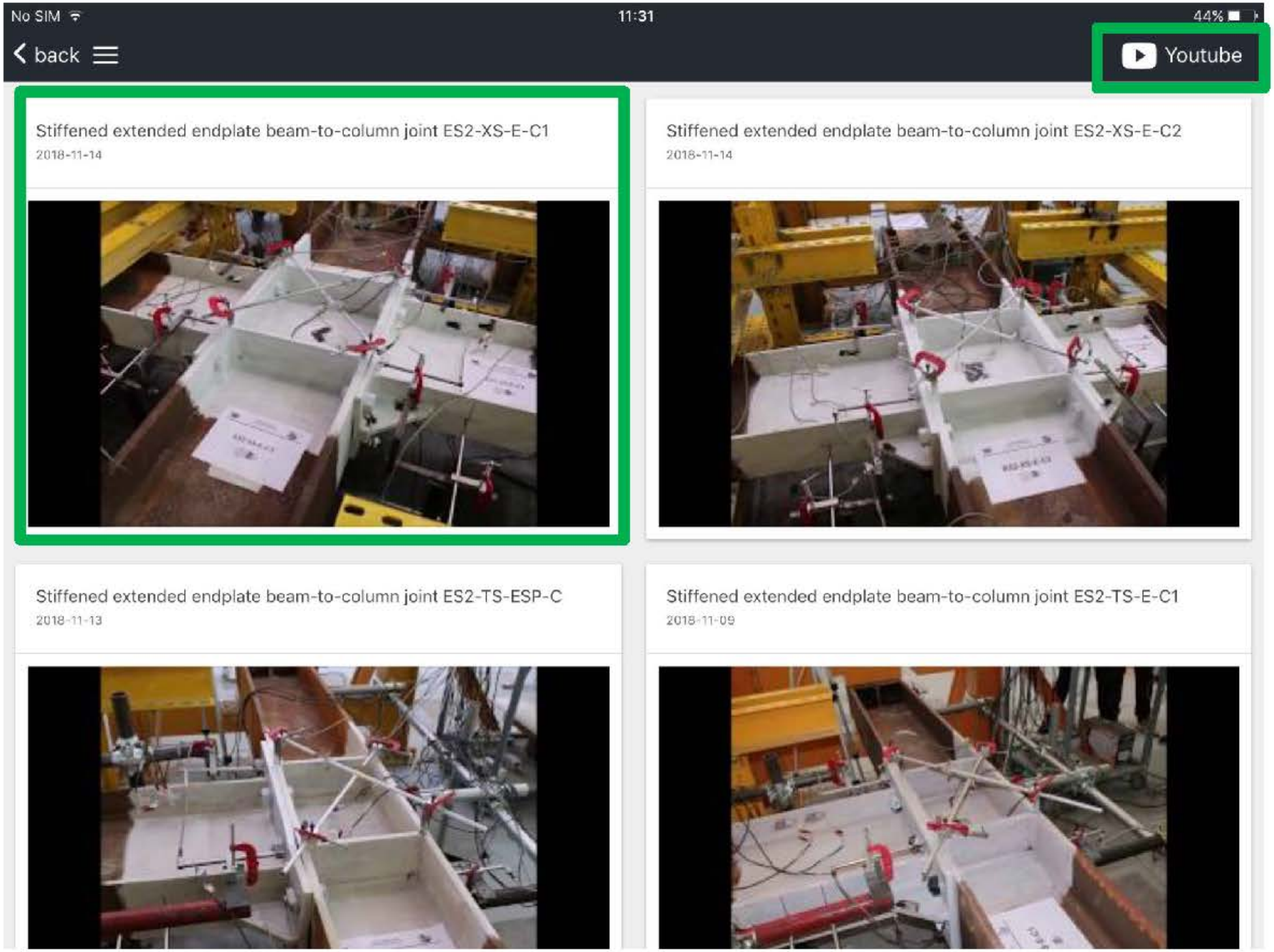


- **You-Tube channel to make available the videos of the experimental tests** and simulations to show the evolution of damage pattern.

https://www.youtube.com/channel/UCYkMWYk2Co3827gn3xYpsbA



- INTRODUCTION
- EJ PROJECT OVERVIEW
- DESIGN OF JOINTS
- ANALYTICAL MODELS
- NUMERICAL ANALYSES
- EXPERIMENTAL TESTS
- FINITE ELEMENT ANALYSES
- DESIGN GUIDELINES
- **EJ PLUS OVERVIEW**
- CONCLUSIVE REMARKS



EJ PLUS WORKSHOPS

- To organize **seminars and workshops** for disseminating the gained knowledge over EU and internationally. Workshops and seminars will be organized in the own-countries of partners involved in the project

Organized by	Country
UNINA, UNISA	Italy
ULG	Belgium
UPT	Romania
UC	Portugal
UNINA, UNISA	Italy
IC	UK
CTICM	France
NTUA	Greece
CVUT	Czech Republic
TU Delft	Netherlands
UL	Slovenia
UASG	Bulgaria
UPC	Spain
RWTH AACHEN	Germany

Equaljoints Plus

- INTRODUCTION
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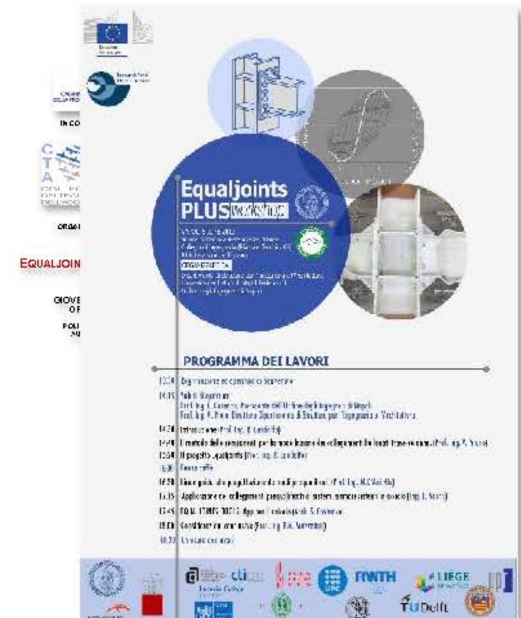
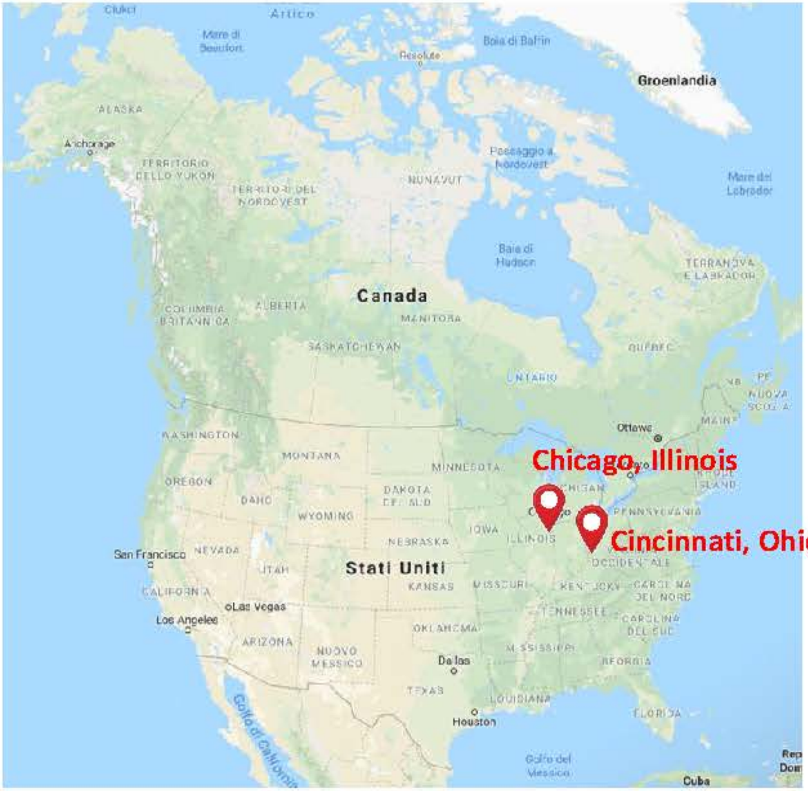
EJ PLUS WORKSHOPS



Landolfo

EJ PLUS WORKSHOPS

- Two seminars will take please in the USA (Chicago and Cincinnati)



EJ PLUS WORKSHOPS

- Two seminars will take please in the USA (Chicago and Cincinnati)

AISC Annual convention
"Connection Prequalification Review Panel (CPRP)"
Chair: Mike Engelhardt

Chicago, Illinois
11 June 2019

CONCLUSIVE REMARKS

- An overview of the recently completed European research project "Equaljoints (European pre-QUALified steel JOINTS, RFSR-CT-2013-00021) has been provided.

- On the basis of an extensive experimental campaign and comprehensive numerical and analytical analyses, the project was devoted **to introduce in European practice a pre-qualification procedure for the design of moment resisting connection in seismic resistant steel frames**, in compliance with EN1998-1 requirements.

- Equaljoints PLUS is aimed at the **valorisation**, the **dissemination** and the **extension** of the developed prequalification criteria **for practical applications to a wide audience.**

- The prequalification procedure developed within Equaljoints project is thus intended as contribution to the wider activity of the **CEN/TC250/SC8-PT2** committee in charge of amend the material dependent parts of EN 1998-1.

I would like to express my deepest gratitude to all the partners involved in both Equaljoints and Equaljoints PLUS projects that always provide their enthusiastic, and precious contribution.
I am sincerely honored to coordinate such a motivated and valuable group of experts on seismic design of steel structures.

Prof. Raffaele Landolfo

Equaljoints Plus

Thank You !