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Research Article

A Simplified Methodology of European Steel Characterization on Theoretic Structural Application with Buckling Restrained Braces

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The objective of this research is to provide simplified equations to fix the steel mechanical parameters when applied to all-steel buckling restrained braces (BRBs) whiting a whole theoretic structural calculation. These equations can be mainly useful in the predesign stage when the data of steel tests are still not available. A revision and search were carried out of available steel values from monotonic and cyclic uniaxial tests by different European steels. Curves of regression were fitted to find the necessary parameters for numeric models of BRBs with typical hysteretic dissipation. A comparison of results from applying three different groups of adopted steel values (nominal, regression or actual, and maximum) is done with a well-known and tested BRB. The high dispersion of results that arise is shown. The regression equations found demonstrate great usefulness. For an initial theoretic calculation, departing from most actual parameters of steel strongly decrease the uncertainty and it allows calculating structures with BRBs in a more realistic way.

1. Introduction

Currently, in seismically active zones, the application of elements to energy dissipation is becoming more frequent. Among the possible applied elements, buckling restrained braces (BRBs) are starting to have great implantation.

In general, when BRBs are incorporated in a preliminary design, theoretic values are used as parameters of calculation (especially on materials), and the problem arises because in the true work time, their functioning can be very different. Basically, this implies that BRBs will not behave as had been supposed. In the case of all-steel BRB, the behavior can be even more different than in the case of concrete-infilled BRB. As a consequence, the whole structure is strongly dependent on the behavior of the BRBs. An adequate calculation will be possible when the BRB behavior (by means of experimental tests) is well-known, as is its influence on the complete structure. This means that the structure will undoubtedly have to be recalculated to surrogate a reliable structural response. The importance of adequately assessing BRBs behavior is evident, and several important implications can be described for different aspects of behavior.

(i) First of all, the characterization of steel is often done with the known tensional test. This is a monoaxial and, generally, pseudostatic test. The most coherent test is a cyclic dynamic, although this is more complex to carry out. The true seismic behavior is due to reversible nonuniform load, and this is still different to cyclic uniform behavior [1]. The values of parameters that define the behavior of steel will be different in each case. Even using the actual values obtained from the monotonic test, the behavior of steel working on seismic actions cannot be guaranteed.

(ii) The manufacturers of steel elements provide some characteristics and properties according to the material but indicate that these are minimal or guaranteed values (p = 5%). This information is not completely useful since they are not actual values of the material. The experimental values (that are not known in the design phase) are the only ones that should be applied. Here, we must bear in mind that the BRBs have a specific function as the improvement of the structural behavior against seismic loads. However, in general, manufacturers do not test or give information in relation to the dynamic cyclic behavior.

(iii) In the habitual calculation method of limit states (EC3) [2], it is necessary that a BRB behaves as elastic stiffness (or very low inelasticity) in service limit state (SLS) and as an efficient dissipator in ultimate limit state (ULS). In both states, materials are affected by a safety factor ($g_m = 1$ and $g_m = 1.05$, respectively). The use of an applied partial factor for a material leads to a reduction in strength, and therefore, the BRB with its actual strength will act as a simple elastic stiffness when it is assumed that hysteretic dissipation must exist. Care should be taken with the use of this coefficient in this case, and it should always be proposed to increase the nominal yield stress (F_y). This is proposed in EC8 [3], as will be seen later. However, keep in mind that a proposed material overstrength factor is also a theoretical value.

(iv) When performance based earthquake engineering (PBEE) calculation is applied by the four typical FEMA levels (operational, OP; immediate occupancy, IO; life safety, LS; and collapse prevention, CP) [4, 5], the behavior of the BRB should be well controlled. For instance, in the OP level, the BRB should behave in an elastic way to provide a low interstory drift value. Here, it is also very important to know with precision F_y, e_y (yield strain), and E (elasticity modulus) of the dissipative BRB core. In the CP level, the BRB should behave with maximum possible dissipation (guaranteeing stability). Therefore, it is also important to know the buckling safety, F_u (ultimate stress), $e_{\max}$ (maximum strain), and ductility values on the BRB core.

(v) The different actual-theoretic behaviors of BRB in different PBEE levels will generate different behaviors in the other resistant elements of the mainframe, and therefore, it could be ill-designed if the theoretic (nonactual) values are applicable. Take into account that each PBEE level must be independently verified for the whole structure.

(vi) In all-steel BRB, the gap between the core and the restrainer allows both core lateral expansion in compression and core high mode buckling waving [6]. The latter would generate friction forces between the two members in compression. If this gap is insufficient, the core will be gripped within the restrainer. If the gap is excessive, the amplitude of the buckling waves will be higher, and thus the friction forces also increase [7]. Strength and axial stiffness of the steel core are a key factor in these behaviors.

Habitually, in the modeling of hysteretic cycles of dissipation, an inverse type of analysis is applied, finding parameters of adjustment for fitting the searched model. The authors believe that the first true adjustment is to ascertain the actual adopted material to use. To have reliable material parameters should be the first step. In this work, the study of the steel characterization to be applicable to a BRB is discussed. The goal is to provide simplified formulation for the preliminary design of BRB taking into account a more reliable material. This work combines a way to have a better definition of the theoretical properties for each steel with a reliable model (cyclic with hardening and asymmetric hysteretic plastic behavior with increase in compression). The objective is to have an "actual" reference of initial material properties parameters to be able to perform a calculation in the structural design phase. A cyclic model will be adjusted, and the behavior towards seismic loads will be analyzed by a well-studied and constructed BRB [8, 9]. Important conclusions will be found about the need to improve the characterization of the material, especially in preliminary numeric design.

2. Types of Adopted Steels, Methodology, and Elaboration of Curves of Regression

The objective has been to find European steels of normal strength and to create a database with the available values. Carbon steels, hot-rolled and with different carbon percentage are analyzed. These have different elastic value of yield that are indicated in their denomination (EN 10025) [10].

The considered steels are S185, S235, S250, S275, S300, S355, S400, S460, S500, and S690. Other steels with conditions such as large chemical aggregates or with specific behavior have not been taken into account. The environmental temperature was also considered. Observe that there are steels with less structural uses, but they have been taken into account equally. S400 and S500, mostly used in reinforced concrete structures, have also been incorporated. The S690 was assumed in this research as a superior limit with high strength. All specimens have a thickness less than or equal to 16 mm.

Few data have been found with cyclic tests and most of these are data from monotonic tests. Even so, cyclic data have been incorporated.

The experimental data that have been searched for are indicated in Table 1. Other types of steels have been discarded since they have little or incomplete data. However, even the steel data considered are not uniform or incomplete.

Table 1 lists the investigated mechanical properties that are the most important parameters for a dissipative model. For instance, to characterize a BRB, F_y, F_u (tension and compression), E, e_y, and $e_{\max}$ are fundamentals. Some parameters have a greater number of records than others, even so, they all have approximately 50 records. In many instances, F_u/F_y, E, and m values have been deducted from the experimental curves. Because this is a hot topic issue, several studies investigated this aspect; however, the most important references are listed in the reference section [11–20].

Table 1: Steel parameters are considered.

Parameters	Description
F_y	Yield strength
F_u	Ultimate tensile strength
F_u/F_y	Maximum strength/yield relation
E	Longitudinal modulus of elasticity
e_y	Yield strain
e_{max}	Maximum strain before final down branch
m	Ductility

Since the goal is to apply steels to the development of BRB, special care is taken in having sufficient and reliable data in relation to S185, S235, S250, and S275. These could be the very frequently used as core steels.

The experimental campaign provided the mean values of parameters listed in Table 1 to each steel considered. Results vary with a standard deviation less than 20%. Mean values were used to obtain an adjusted regression curve with an adequate correlation coefficient (R^2) (Figure 1). Analytical equations (equations (1)–(7)) are calibrated through the nominal steel value S_n in MPa. All curves of regression obtained are indicated in Figure 2. Table 2 summarizes all obtained mechanical parameters corresponding to the nominal steel values.

The equations obtained are as follows:

$$F_y = 0.0008S_n^2 + 0.4076S_n + 114.75\left(R^2 = 0.9972\right), \quad (1)$$

$$F_u = -0.0003S_n^2 + 1.3365S_n + 83.63\left(R^2 = 0.9996\right), \quad (2)$$

$$E = 9E - 05S_n^2 - 0.1139S_n + 237.96\left(R^2 = 0.9910\right), \quad (3)$$

$$\frac{F_u}{F_y} = 5E - 09S_n^3 - 8E - 06S_n^2 + 0.003S_n + 1.1616\left(R^2 = 0.9994\right), \quad (4)$$

$$e_y = 4E - 09S_n^2 - 2E - 06S_n + 0.0005\left(R^2 = 0.9968\right), \quad (5)$$

$$e_{\max} = 2E - 07S_n^2 - 0.0005S_n + 0.3503\left(R^2 = 0.9885\right), \quad (6)$$

$$m = -0.0506S_n + 52.195\left(R^2 = 0.9902\right). \quad (7)$$

3. BRB Application and Numerical Modeling

An all-steel BRB discussed in [8, 9] was assumed as case study in this research, and an overview is illustrated in Figure 3. A characterization of model behavior must be accomplished in order to use it later with a reliable numerical model. As it is shown in Figure 3, the BRB is composed of two parts: an elastic zone and an inelastic zone (core). The second one will have great inelastic dissipation by hysteretic cycles. The BRB is pinned, therefore, bending efforts from gusset plates of joints are not considered.

From a cyclic pseudostatic available test, a numerical adjust modeling has been carried out to cyclic loads with

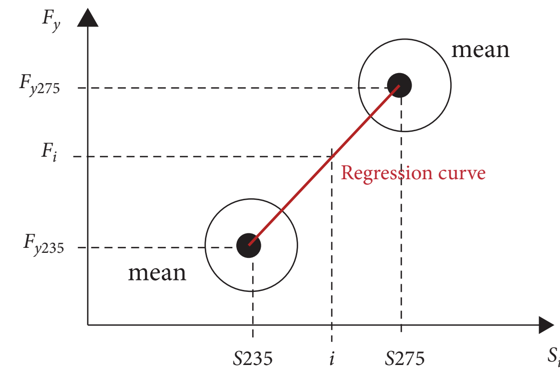


Figure 1: Mean and regression curves adjust applied.

OpenSees [21]. This software enables considering different models and adjusting the best suited. As it was expected, the cyclic hysteretic model curve has an hardening trend (kinematic and isotropic), a typical Bauschinger type behavior and different force and displacement levels in tension and compression (no symmetric behavior). A compression overstrength arises due to known friction that are caused between the core and the casing system. It is an external metallic tube restrained with elastic behavior. BRB modelled without external restraint or core is shown in Figure 3.

Different parts have different behaviors. The zone of the joint pinned connection and the transition zone (L_e) have been considered as a bilinear material (in the following steel01 model), and the dissipative zone (L_c) is considered nonlinear (in the following steel04 model) [12, 21, 22]. Still considering steel01 (bilinear), it is defined that this zone always behaves elastically, and the core zone assumes the high inelastic dissipation. It is important to mention that the steel04 model has been initially proposed to tube BRB infill (with concrete), and here we are working with an all-steel BRB. Even so, this model proves to be adequate due to the great configuration that it enables. It is a good model and very configurable. Each defined zone of the BRB has been divided into finite element method (FEM) segments. The number of considered nodes is larger in the core part than in the lateral zones. The variable sections in the lightened parts and the stabilizing bridges were also taken into account. This FEM modeling allows to adequately control the material behavior of every part. In zones 1 and 2, uniaxial materials named steel 01 and 16 nodes were used; in zone 3, that is the dissipative zone, uniaxial materials named steel 04 and 44 nodes were used (Figure 3).

The nominal steel of experimentally studied BRB is S235 and corresponding mechanical values estimated by tests are $F_y = 251$ MPa (yield stress in tension and compression,; $F_{uT} = 386$ MPa (maximum stress in tension,; $F_{uT}/F_y = 1.54$ (maximum/yield stress relation) $F_{uC} = b\ F_{uT} = 448.45$ MPa (experimental relation strength found $b = 1.16$, maximum in compression), $E_o = 206$ GPa (initial modulus of longitudinal elasticity), ratio_$E = E_o/E_i = 0.003$ (ratio of two E branches), and $e_y = 0.00122$.

In addition, specific values for the steel04 model, -kin, -iso, -asym, -init, and -mem, are adopted. A new and useful

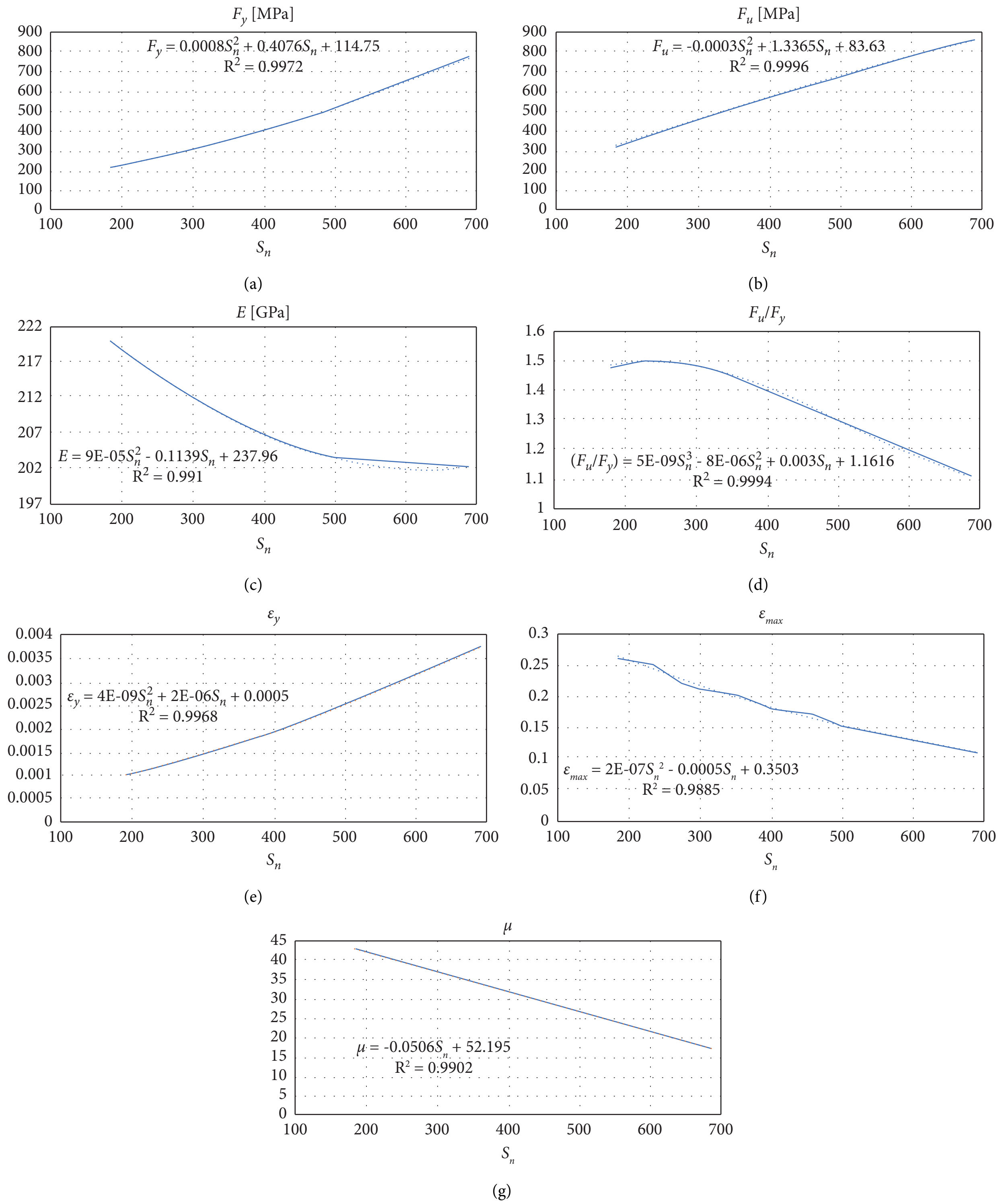


Figure 2: Regression curves based on equations (1)–(7).

tool to find the coefficients that characterize the searched numerical model has recently been published [23]. The investigated BRB has been submitted to numerical uniaxial test cycles of reversible loads controlled for displacements. In Figure 4, the applied load pattern test AISC341-16 [24] is applied, and the found model with the cycles to each level of test is shown. The adjustment is very good in each behavioral window. Also, a modeling with progressive displacement

Table 2: Regression values obtained for the steel used for specimens.

S_n	F_y (MPa)	F_u (MPa)	F_u/F_y	E (GPa)	e_y	e_{max}	m
185	217.5360	320.6150	1.4745	219.9688	0.0010	0.2646	42.83
235	254.7160	381.1400	1.4897	216.1638	0.0012	0.2438	40.30
250	266.6500	399.0050	1.4897	215.1100	0.0013	0.2378	39.55
275	287.3400	428.4800	1.4856	213.4438	0.0014	0.2279	38.28
300	309.0300	457.5800	1.4766	211.8900	0.0015	0.2183	37.02
355	360.2680	520.2800	1.4421	208.8678	0.0017	0.1980	34.23
400	405.7900	570.2300	1.4016	206.8000	0.0019	0.1823	31.96
460	471.5260	634.9400	1.3355	204.6100	0.0023	0.1626	28.92
500	518.5500	676.8800	1.2866	203.5100	0.0025	0.1503	26.90
690	776.8740	862.9850	1.0653	202.2180	0.0038	0.1105	17.28

*rows shaded indicate steels typically used mostly in Europe.

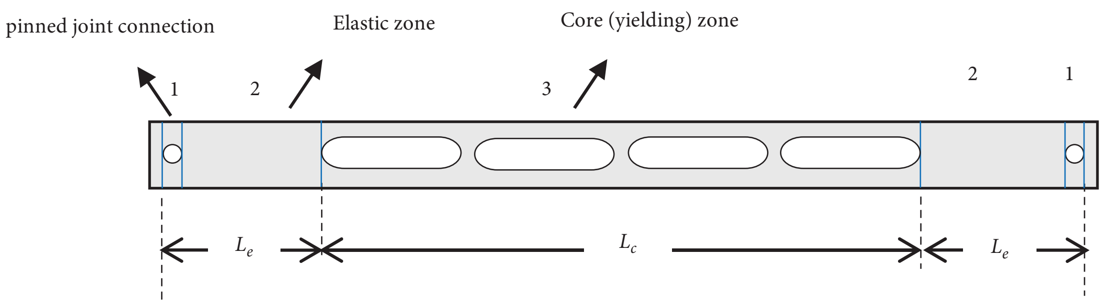


Figure 3: Schematic representation of core BRB.

allows showing the whole behavior of force-displacement range (Figure 5).

4. Study Cases. Structural Behavior of the BRB System with Different Material Parameters and Different Applied Seismic Records

4.1. Materials. The S235 steel was assumed in this calculation, and mechanical parameters were estimated through: (i) the nominal or minimum values from EN 10025 and EC3, (ii) the actual values obtained by regression analysis in this work, and (iii) the maximum possible values as they are defined in EC8-1 (point 6.2 materials) [3]. The parameters to consider in the model are F_y, F_{uT}, F_{uC}, E, and ratio_E. On the other hand, P_{ycore} (yield force) and y F_{uC}, are deduced. All three sets are listed in Table 3. In EC8-1, it is recommended the actual F_y to use as $F_{yA} = 1.1\ Y_{ov} F_y$, where F_y is the nominal yield strength specified for the steel grade, F_{yA} is the actual value, and g_{ov} is the overstrength factor used in design. For S235, F_{ymax} is equal to 323.12 MPa (with recommended value g_{ov} = 1.25).

4.2. Applied Actual Seismic Records and Calculation Process. In order to analyze the influence of the different adopted material parameters in the behavior of BRB, a dynamic study with actual records is carried out. To that end, several records will be axially applied at one end of the complete BRB. Considering the inherent randomness of the used records (of different conditions), it will be statistically possible to assess the behavior of the BRB and to obtain some conclusions. The BRB is the same defined and characterized in the previous point.

The city of Granada (Granada, Spain), a global low-to-moderate seismicity zone, is chosen, with acceleration $a_b = 0.23$ g, importance factor $r = 1$, and soil between type II and type III (medium-soft soil) $C = 1.50$. The elastic response spectrum (5%) to level PBEE-LS (Life Safety) (FEMA) or NCSE-02 standard [25] is found. This level is defined as 10/50/475 that respectively are the percentage of exceedance/years/return period.

From the PEER seismic database [26], 5 records are sought, conveniently scaled (maximum allowed scale factor SF = 1.5), and downloaded (Table 4). The final individual scaled spectra, mean spectrum, and design spectrum are indicated in Figure 6. Then, each record is applied, and results are extracted. Figures 7–11 illustrate displacements and hysteretic cycles for each record, and Table 5 summarized mean values for all three investigated materials.

For each parameter analyzed, mean values of results from 5 records are estimated and compared according to the material type (nominal values). In Table 5 the variation in % relative to the smallest or reference value (nom) is given. It was observed that significant differences are found. It was observed that significant differences are found and some unrealistic values was also estimated.

5. Analysis of Results

As an additional check, in all cases P_y is found. Obviously P_y always depends on the F_y used, and it is seen that the model

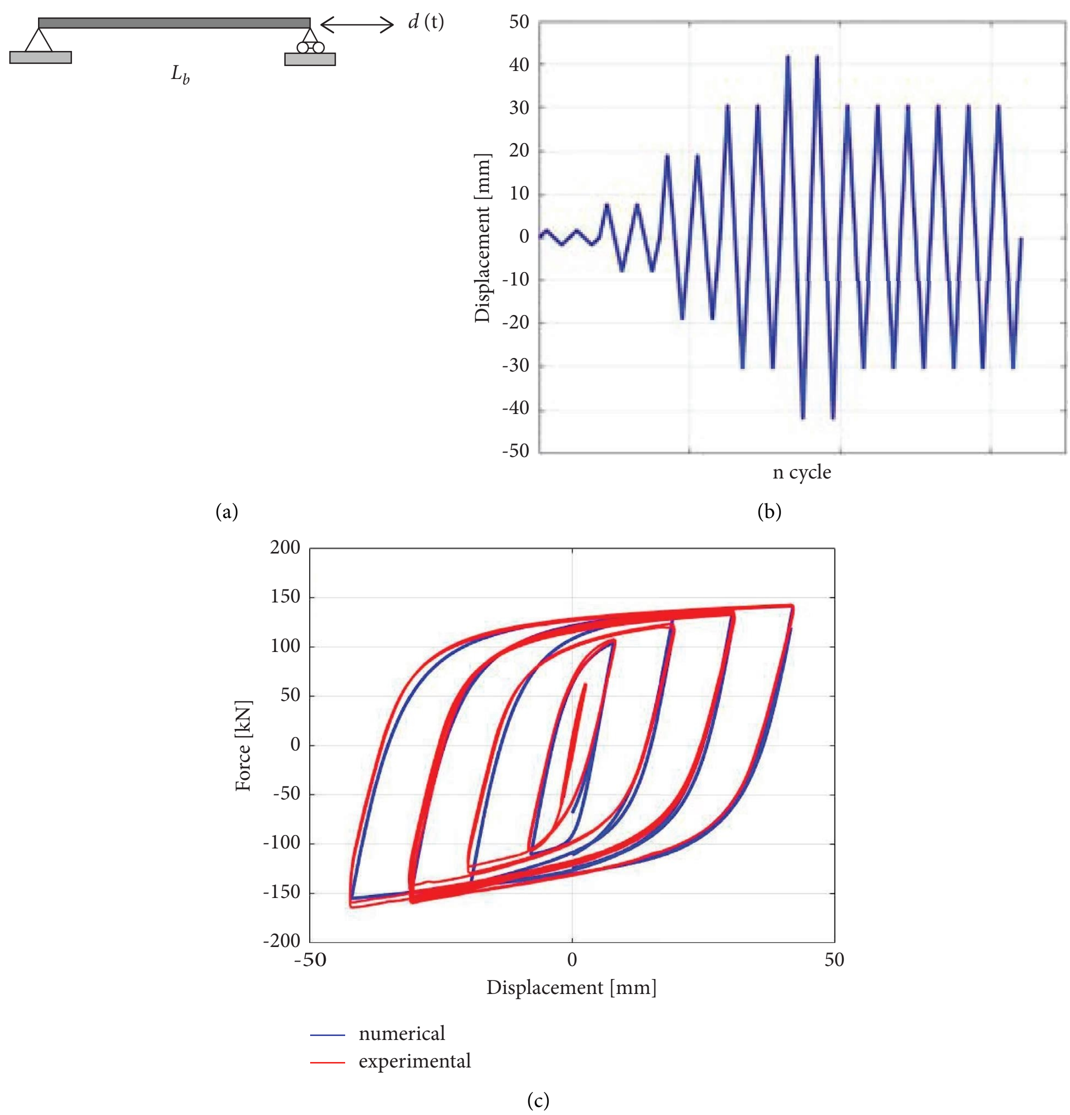


Figure 4: AISC test: numerical model (a), applied displacement load (b), and experimental and numerical load-deformation hysteretic curves (c).

correctly predicts its value. In addition, it is evident that the applicable range of values has a very high amplitude of 37.50%. The comparison between the value of regression and nominal (minimum) is 8.40%. This can be unaffordable in a PBEE calculation where the beginning of core plasticization is a fundamental issue. It should be considered that for PBEE operational level, ideally the whole structure should behave elastically, that is, the BRB must work as stiffness. But over this point, it is necessary that the inelastic dissipation begins. If F_y value is not suitable, the dissipation may occur earlier (nominal case) or much later than necessary (maximum case).

The $P_{\max}$ (tension or compression) follows a similar law. Values are given for the assumed method and the displacements (loads) applied to the BRB. The greater the F_u, the greater the $P_{\max}$. The found variability is excessive and inadmissible. A mean of the 5 records (with differences in parentheses) is $P_{\mathrm{maxNom}} = 158.37\,(5.37)$ KN (reference), $P_{\mathrm{maxRegre}} = 168.28\,(3.95)$ KN (+6.25%), and $P_{\mathrm{maxMax}} = 209.58\,(16.94)$ KN (+32.33%). Although these results seem foreseeable, taking into account that a difference of over 30% in max/nom and 24.54% in max/regre, it may occur that the same structure behaves in a totally different way.

The $P_{\max}/P_y$ relation for these examples varies approximately 1.60–1.75. All are higher than the generally proposed 1.40 value. Also, ratios are greater than the initial stress ratios of materials (EC3 proposes to use 1.10). A mean of the 5 records (with differences in parentheses) is $P_{\max}/P_{yNom} = 1.72\,(0.05)$ (reference), $P_{\max}/P_{y\mathrm{Regre}} = 1.69\,(0.04)$ (−1.75%), and $P_{\max}/P_{y\,\mathrm{Max}} = 1.66\,(0.12)$ (−3.49%). Like stress, the relation decreases as an increase of force (or stress) are considered. This is according to the regression curves F_u/F_y previously found. For hysteretic energy dissipated (E_{diss}), with mean of the 5 records for nom, regre, and max cases are

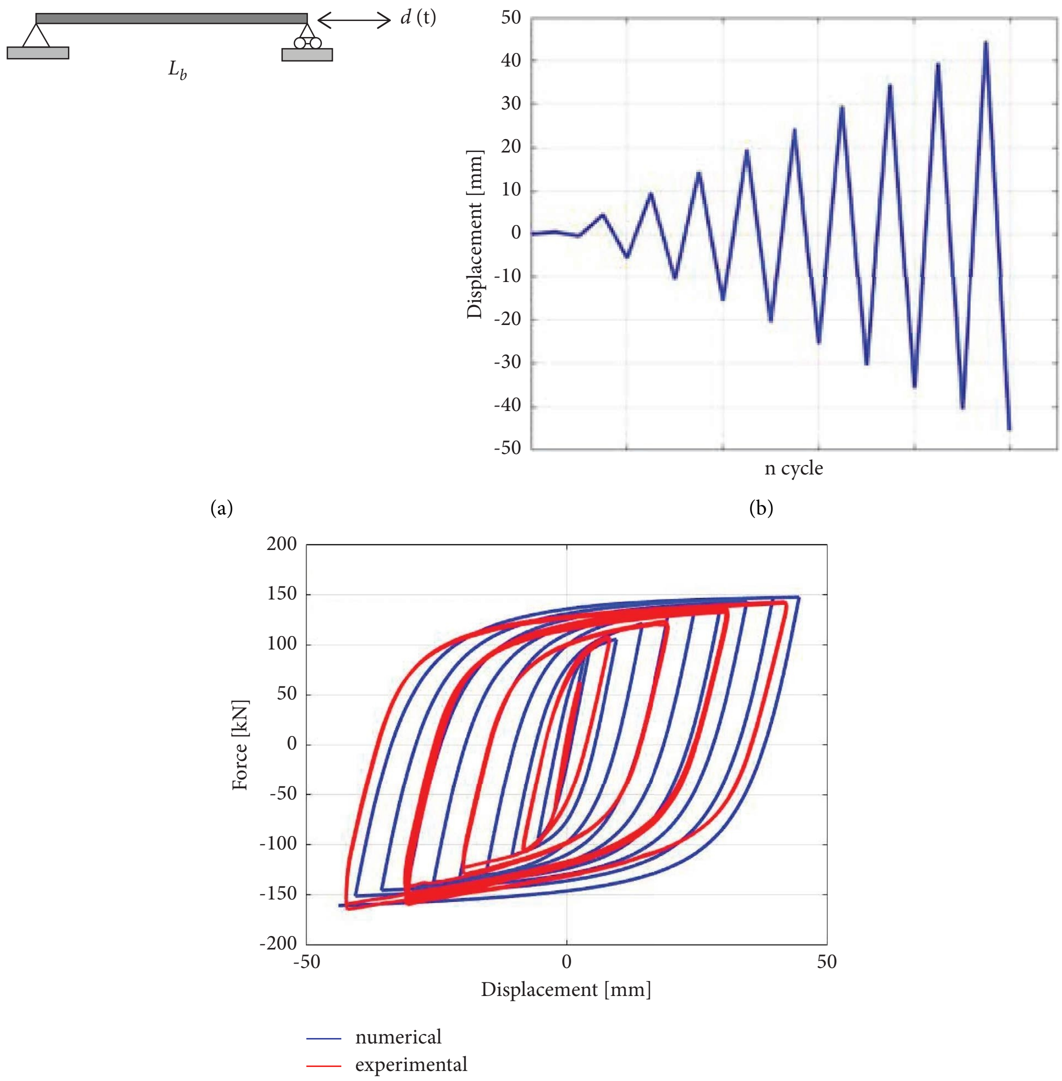


Figure 5: Progressive test: numerical model (a), applied displacement load of progressive test (b), and experimental and numerical load-deformation hysteretic curves (c).

Table 3: Adopted steel core parameters.

Parameters	Case 1. nominal (EC3-EN 10025-2)	Case 2. regression (this work)	Case 3. maximum (EC8-1 6.2 materials)
F_y (MPa)	235	254.71	323.12
F_{uT} (MPa)	360^{*}	381.14	510^{**}
$F_{uC} = b * F_{uT}$ (with $b = 1.16$)	417.60	442.12	591.60
F_{uT}/F_y	1.53	1.496	1.578
E (GPa)	210^{+}	216.16	210^{+}
Ratio_$E = E_I/E^{++}$	0.003	0.003	0.003
e_y^{***}	0.00112	0.0012	0.00154
A_{core} $(mm^2)^{++}$	392	392	392
P_{ycore} $(KN)^{***}$	92.12	99.84	126.66

*minimum nominal value of EC3, **maximum nominal value of EC3, $^{+}$nominal recommended value, $^{++}$data, and ***deduced. b value is the experimentally found relation between maxima tensile and compressive forces.

$E_{dissNom} = 172.49$ (97.54) KJ (reference), $E_{dissRegre} = 181.96$ (102.38) KJ (+5.50%), and $E_{dissMax} = 208.68$ (118.53) KJ (+20.98%).

Again, the variation between the means is shown. The generated variability max/nom (and max/regre = 14.70%) is excessive for a theoretic calculation with a reasonable

Table 4: Applied records.

Name	ID	Station	Magnitude	Rjb (km)	Scale factor
Imperial Valley (1979)	ID0169	Delta	6.53	22.03	0.6037
Northridge (1994)	ID1057	Playa del Rey	6.69	24.42	1.502
Kobe (1995)	ID1100	Abeno	6.90	24.85	1.0768
Chuestsu-Oki (2007)	ID4840	Joetsu Kita	6.80	28.97	1.2565
Iwate (2008)	ID5779	Sanbongi	6.90	36.33	1.4393

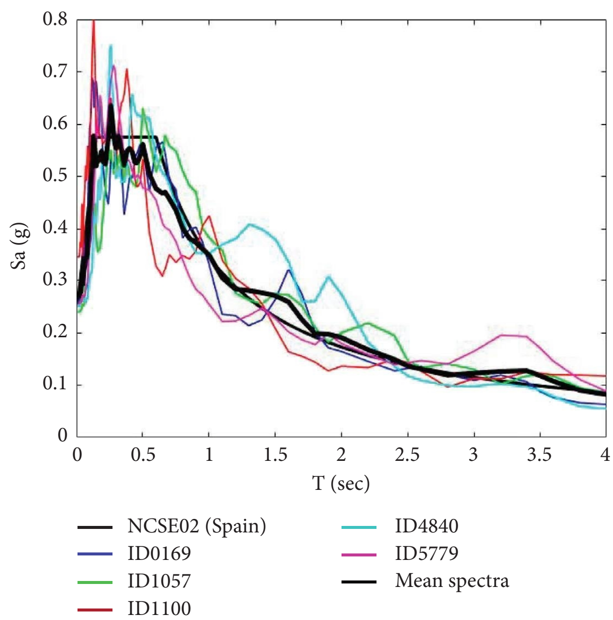


Figure 6: Scaled spectra, mean spectrum, and design spectrum.

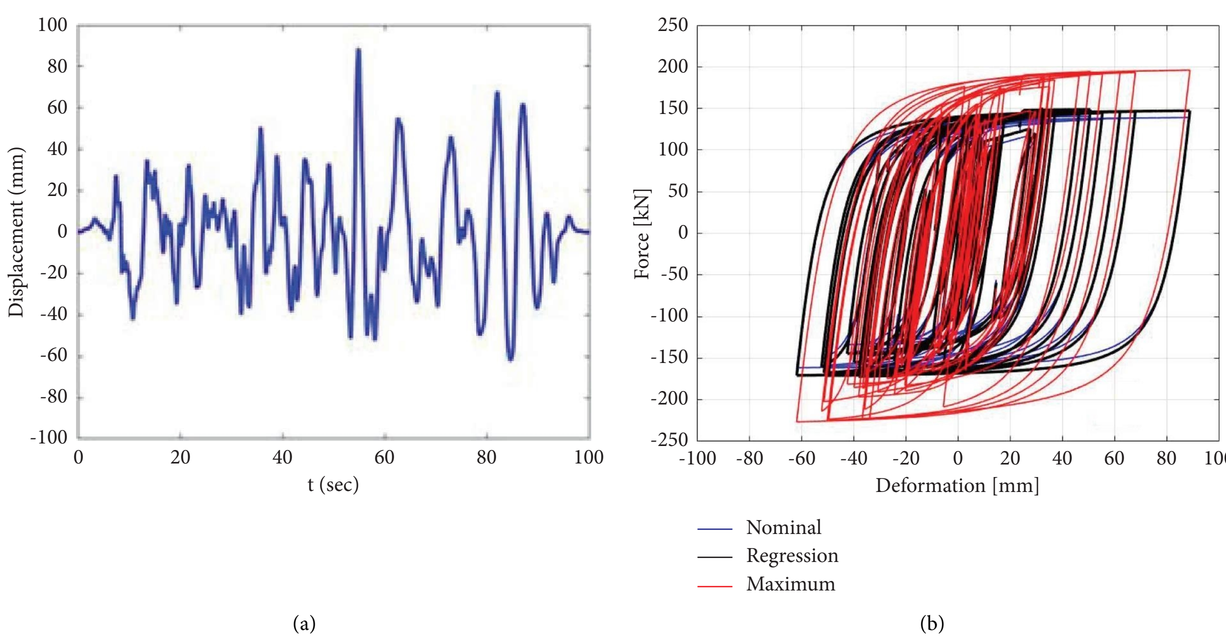
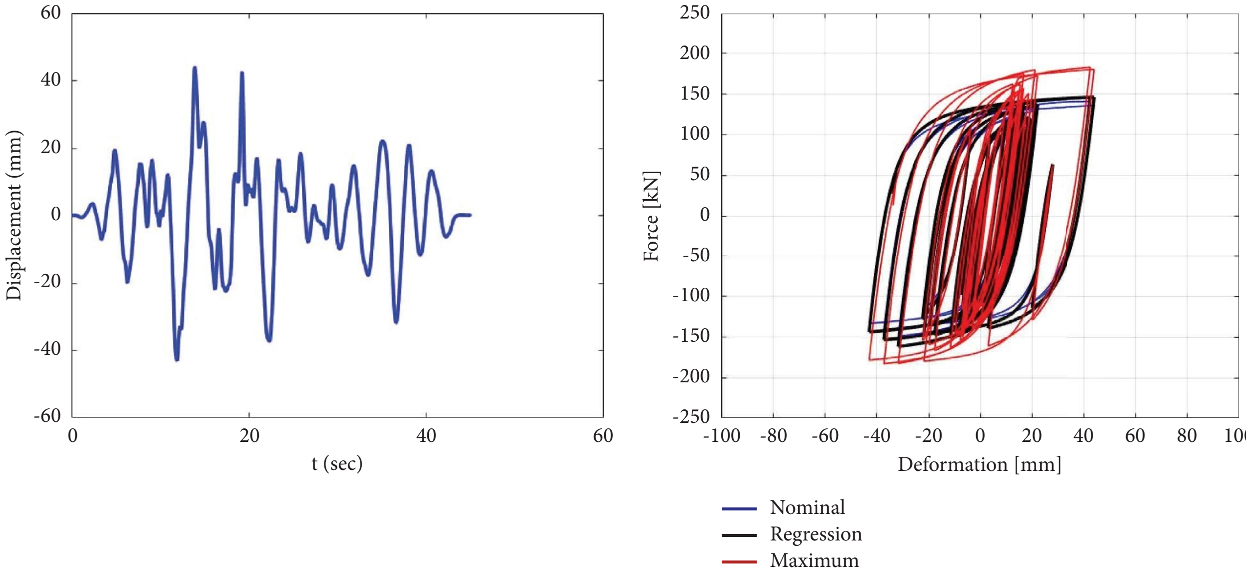


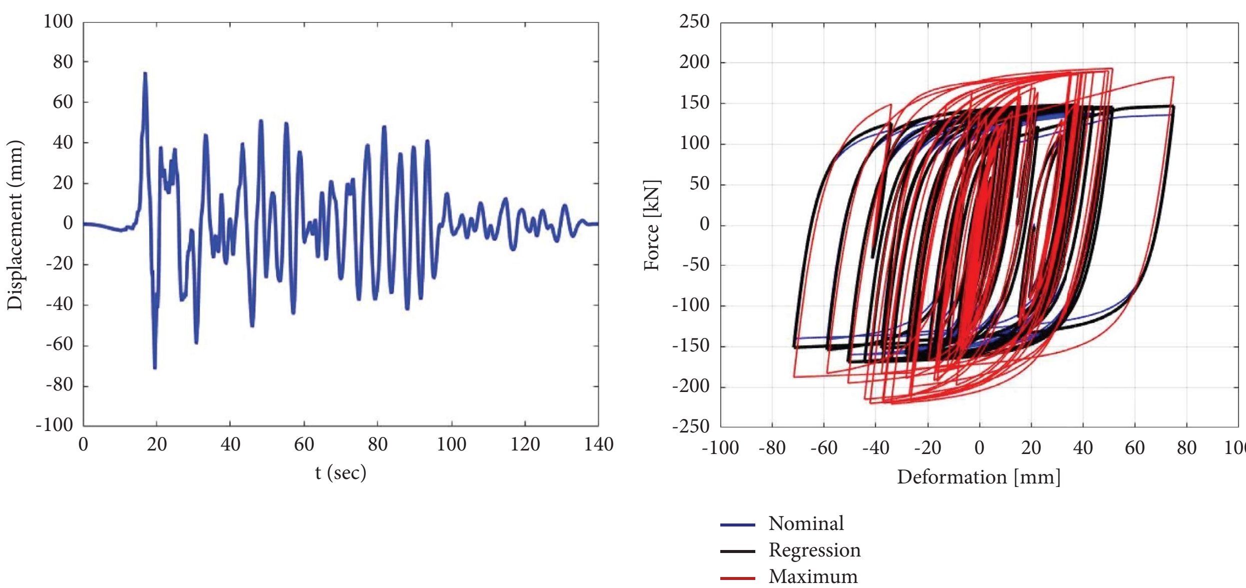
Figure 7: ID0169: applied displacements (a) and hysteresis curves (b).

adjustment. However, variability regre/nom (5.5%) could be assumable, given these examples. Observe that the same displacements have been applied as loads, so the difference of dissipated energies depends only on the forces generated at each time. Really, if these possible options to one BRB placed in a structure are considered, Case 1 will begin to inelastically



(a) (b)

Figure 8: ID1057: applied displacements (a) and hysteresis curves (b).

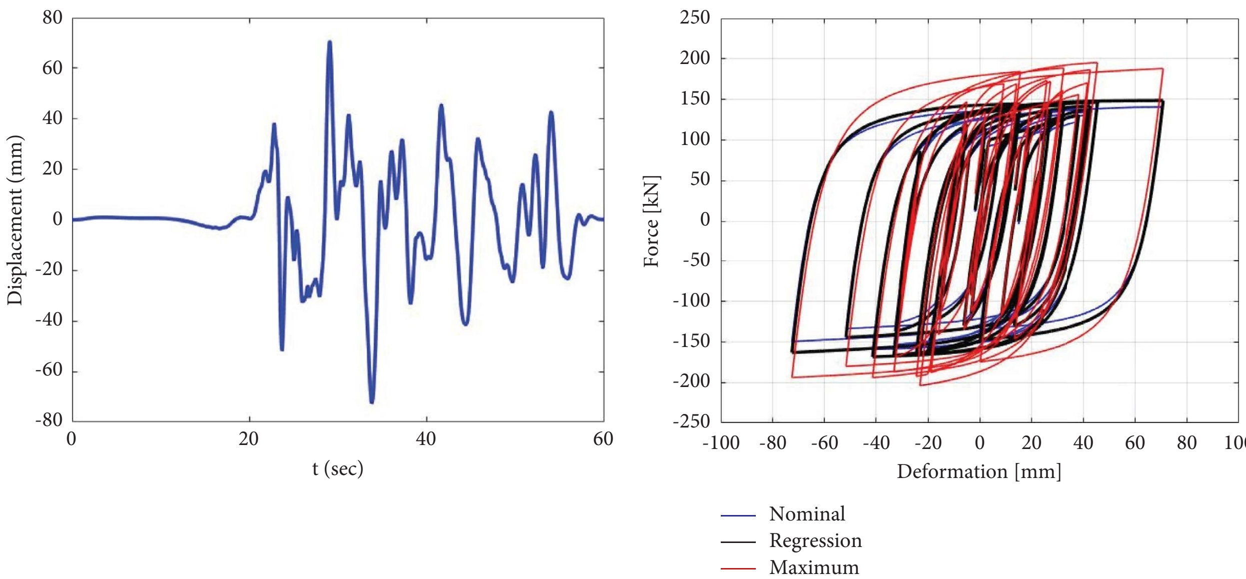


(a) (b)

Figure 9: ID1100: applied displacements (a) and hysteresis curves (b).

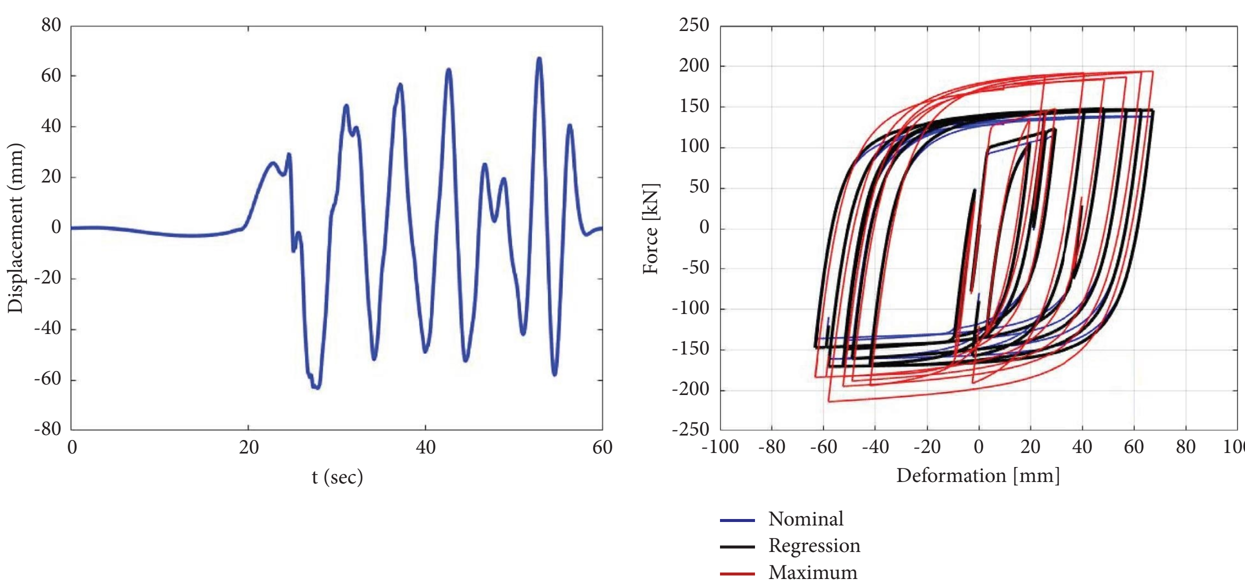
dissipate before Case 2 and Case 3. In fact, there could be a great inelastic dissipation for nom case, regre case could have low dissipation, and max case could show elastic behavior and act only as stiffener. The dissipation under an extreme condition is inelastic. This parameter is a good indicator of the expected behavior of BRB, but it is always necessary to consider the trigger time when the inelastic dissipation really starts. Other studies should be carried out, but dissipated energy variability may be very large.

In relation to $e_{\max}$ (%) with mean value of 1.93 (0.46), fewer conclusions can be drawn since the values of $d_{\max}$ and $e_{\max}$ depend on the corresponding applied displacement to each record. Nevertheless, considering $e_{\max}$ is a value to complete BRB (i.e., including core and elastic zones), to PBEE-LS, IDR (interstory drift ratio) will be between 1–2%, according to the control of accepted damage. This implies that for a typical diagonal pinned BRB, $e_{\max}$ could be between 0.8–1.50%. Then, a value of 2–3% for the core could be considered [27]. Logically, this parameter is strongly affected by the BRB length, core length, and angle of diagonal in addition to the material. If the material is strongly stressed (with low ductility), it may not reach the required $e_{\max}$ by a real case.



(a) (b)

Figure 10: ID4840: applied displacements (a) and hysteresis curves (b).



(a) (b)

Figure 11: ID5779: applied displacements (a) and hysteresis curves (b).

Table 5: Results of mean of values obtained.

	Nom.	Regres.	Maxim.	Max. range (max/nom) (%)	Med. range (regre/nom) (%)
			ID0169		
P_y (KN)	92.12	99.84	126.66	37.50	8.40
P_{max} (KN)	162.49	171.98	226.40	39.33	5.85
P_{max}/P_y	1.76	1.72	1.79	1.70	2.30
E_{diss} (KJ)	274.21	288.30	331.94	21.10	5.14
d_{max} (mm)				88.66	

Table 5: Continued.

	Nom.	Regres.	Maxim.	Max. range (max/nom) (%)	Med. range (regre/nom) (%)
e_{max} (%)				2.50	
			ID1057		
P_y (KN)	92.12	99.84	126.66	37.50	8.40
P_{max} (KN)	149.03	161.69	183.16	22.90	8.50
P_{max}/P_y	1.62	1.62	1.46	10.95	0
E_{diss} (KJ)	42.40	44.88	49.92	17.74	5.85
d_{max} (mm)				44.08	
e_{max} (%)				1.25	
			ID1100		
P_y (KN)	92.12	99.84	126.66	37.50	8.40
P_{max} (KN)	159.80	168.90	220.42	37.94	5.70
P_{max}/P_y	1.73	1.69	1.74	0.60	2.35
E_{diss} (KJ)	265.43	279.54	321.10	20.98	5.32
d_{max} (mm)				74.94	
e_{max} (%)				2.12	
			ID4840		
P_y (KN)	92.12	99.84	126.66	37.50	8.40
P_{max} (KN)	159.30	168.35	203.95	28.05	5.70
P_{max}/P_y	1.72	1.70	1.61	6.83	1.18
E_{diss} (KJ)	134.39	142.10	160.15	19.17	5.74
d_{max} (mm)				72.40	
e_{max} (%)				2.00	
			ID5779		
P_y (KN)	92.12	99.84	126.66	37.50	8.40
P_{max} (KN)	161.25	170.50	213.93	32.67	5.74
P_{max}/P_y	1.75	1.71	1.69	3.55	2.34
E_{diss} (KJ)	146.03	155.06	180.25	23.43	6.18
d_{max} (mm)				67.32	
e_{max} (%)				1.78	

6. Conclusions

Curves of regression were fitted to find the basic mechanical steel parameters to compute a theoretic numeric model of BRB. A comparison of results from applying three possible groups of different values (i.e., nominal, values given by the regression line and maxima) is carried out and it showed a high dispersion rate. This demonstrates the great importance of correctly assessing the characteristic parameters of materials, especially when in a predesign stage. The regression equations found show great usefulness. The equations found allow obtaining more realistic values of steel parameters, and thus being able to do a more realistic preliminary theoretical calculation of the BRB application. From its initial design (or theoretic stage), where all the structural behavior will be influenced by the BRB characterization, more accurate structures can be obtained. Then, specific tests must be available both for the dynamic characterization of steel, and for the complete behavior of the BRB. However, starting from a more reliable first step, this second step (in recalculation) can be easier and more successful.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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