COMPARISON OF SEISMIC DESIGN PROCEDURES FOR STRUCTURES EQUIPPED WITH HYSTERETIC DAMPERS

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Abstract

This paper describes and compares three procedures for the definition of a complete set of metallic hysteretic devices to be installed throughout the height of a building structure: (1) "direct" iterative method, (2) "reverse" or "fixed-force" iterative method,(3) displacement-based design method. All procedures can be applied manually or by means of specific software developed in Visual Basic thus automating each operational step. Procedures (1) and (2) are designed to be suitable for a specific hysteretic damper, i.e. the Shear Link Bozzo, supported by steel braced or r.c. uncoupled walls, whereas the (3) is feasible for a wide range of hysteretic devices. Commonly implemented in professional practice, the "direct" iterative procedure allows to select a proper set of devices so that the shear demand-to-capacity ratio, obtained by response spectrum analysis, is at most equal to a fixed value such as 1.5. The latter value considers cumulative factors that could be considered only by nonlinear analysis such as kinematic hardening of steel or its greater resistance to dynamic loads. In this case, time-history nonlinear analysis is recommended at the end of the process for assessment of results. Using this procedure and after each iteration the devices typically increase their dimensions and so does their supporting element (uncoupled concrete walls or steel chevron braces).The "fixed-force" or "reverse" iterative procedure is an alternative to the "direct" one to limit the thickness of the decoupled walls and the size of the devices that consecutively increase after each iteration. This time, the shear capacity of a reinforced-concrete wall is fixed (considering a certain value for compressive strength f'c, length and thickness of the wall) and consequently the maximum force that can be transmitted by the dampers is set. Differently, the displacement-based design method allows to design a dissipative system, i.e. hysteretic devices and their supports, according to the target top displacement of the rigid structure and the allowable damage of the bare frame. It is based on the Capacity Spectrum Method thus including nonlinear capacity curves of the bare structure, dissipative system and rigid structure. Through this procedure, it can be considered the equivalent damping ratio for the evaluation of the reduced seismic demand. Preliminary pushover analysis is necessary whereas time-history nonlinear analysis is recommended for outcomes assessment. A case-study of a real complex structure built in a high seismic area is provided to demonstrate the effectiveness of the procedures. Final results have been compared in terms of interstorey drift, story acceleration, seismic coefficient, quantity and cost of dissipators and of concrete walls. For the case-study in exam, among all procedures the "reverse" can be considered the most effective, ensuring a better structural behaviour, acceptable thicknesses for decoupled walls and a lower computational time which allows it to be implemented many times. On the other hand, the displacement-based procedure results in a more economical design solution.

Keywords: Design procedures, Displacement-based design; Hysteretic dampers; Shear Link Bozzo devices

1. Introduction

Nowadays, metallic hysteretic dampers, within the family of passive energy dissipation systems, represent a well-known solution for seismic hazard mitigation of both new and existing structures. Dissipative capacity of these devices is based upon a mechanism involving plastic deformation of their constitutive material, commonly consisting in mild steel. Major ductility demand and consequent damage is meant to be concentrated in these devices, thus reducing displacement

demand on elements belonging to the principal framing system. Differently from active or semi-active devices, their proper operating does not require for external power supply or control algorithm. Many devices have been proposed in literature by now[1], characterized by different shapes, constitutive material and energy dissipation principle. However, the idea of employing metallic hysteretic dampers to enhance seismic performance of new and existing structures is attributed to Kelly et al. [2]. Thereafter, Bergman and Goel [3] and Whittaker et al. [4]developed the Added Damping and Stiffness (ADAS) system, consisting in X-shaped metallic plates connected at the top and bottom end to a rigid element in order to avoid rotation. Dissipation capacity of the ADAS damper is based upon flexural deformation of the plates. Later on, Tsai et al. [5]proposed the Triangular-plate Added Damping and Stiffness (TADAS), made of triangular parallel metallic plates which, subjected to a lateral perpendicular force, undergo uniform yielding along their height. Kobori et al. [6] introduced a honeycomb steel damper (or "panel system"), consisting in a steel plate characterized by a honeycomb-shaped opening in the central part and subjected to loads acting in its own plane. Such device is commonly employed to increase energy absorption in high-rise buildings. Watanabe et al.[7]proposed the buckling-restrained brace (BRB), made of an unbounded thin steel core encased in a concrete-filled steel tube. According to BRBs, energy dissipation is provided by axial deformation of the internal steel core, meanwhile buckling is avoided by the external casing. Finally, at first investigated at University of Girona, in Spain, by Cahis et al. [8] and Bozzo et al. [9],[10] the Shear Link (SL) consists in a steel panel with variable thickness and width along its height, able to undergo significant inelastic shear deformations when subjected to lateral loading.

Despite the wide range of devices, the use of metallic dampers as seismic protection system is yet not widely spread. Actually, the lack of prompt and straightforward design procedures able to consider elasto-plastic behaviour of these devices, thus considering the equivalent damping ratio they provide, is a discriminatory factor for practitioners willing to employ them. Nonlinear analysis is certainly suitable to predict inelastic structural behaviour, and, in this approach, various authors developed quite advanced hysteresis models (Vaiana et al. [11]). In addition, a wide range of performance-based design approaches based on static nonlinear analysis has been developed by now. Namely, Kim and Choi [12] proposed a methodology providing the required effective damping of BRBs at the target displacement. Bergami and Nuti [13] developed an iterative procedure where a target damping ratio is defined according to a fixed displacement demand. Mazza and Vulcano [14] introduced a method to size the dissipative system according to a target deformation. Finally, Nuzzo et al. [16] developed a displacement-based design approach able to deliver the capacity curve of the braced structure, i.e. the bare frame equipped with the dissipative system, according to a fixed performance level.

2. Shear Link Bozzo dampers

Widely spread in South America, especially in Perú, Mexico and Ecuador, Shear Link Bozzo (SLB) devices are often installed to provide seismic protection of both new and existing building structures. The SLB is a metallic damper able to dissipate seismic input energy by means of its hysteretic behaviour. Their major contribution is to reduce interstorey drifts ratios during an earthquake, thus providing important benefits for both structural and non-structural elements. In addition, the substitution of the devices after a high intensity seismic event is easy, cheap and minimally invasive. The device is manufactured from a hot laminated steel plate modelled in order to obtain a I-shape (Nuzzo et al.[17],[18]), shown in Figure 1. Top and bottom flanges represent the stiffer parts and are employed to provide the connection to other structural elements, i.e. upper

beam and supporting element. Differently, energy dissipation is concentrated in correspondence of the so-called dissipative windows, positioned in the web and manufactured with a reduced thickness through a milling process. Peculiarity of the SLB is the comb connection the device is provided of on its top flange. In this way, axial load transfer from the upper beam is avoided, hence the device is subjected only to lateral shear forces. Commonly, SLB dampers are installed throughout the height of the structure on chevron steel braces supports or, alternatively, on low-reinforced decoupled concrete walls characterized by 15-30cm thickness. In all cases, the devices are not required to be aligned vertically due to the comb connections, thus ensuring no axial load transfer from the upper beam to the damper.
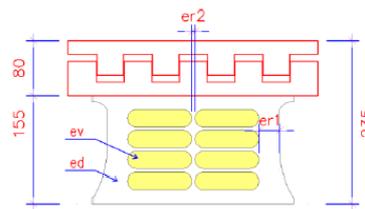

Figure 1Shear Link Bozzo (SLB) damper

Over the last decade, several generations of SLB dampers have been developed and numerous experimental programs have been carried out in order to investigate and validate their mechanical behaviour. At first, experimental campaigns were carried at ISMES S.p.A in Bergamo (Italy) [19]and later at University of Girona [21],[22],[23]. More recently, further tests were performed at the University of Naples [18], showing a quite stable hysteretic behaviour of the damper under cyclic loading (Figure 2). Finally, further tests have been performed at the Structures and Materials laboratory of the Institute of Engineering situated in Mexico [20].
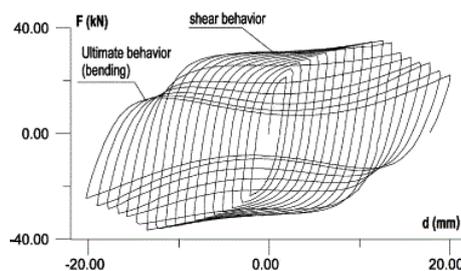

Figure 2 Force-displacement hysteretic behaviour of SLB dampers[18]

3. Design procedures for structures equipped with metallic hysteretic devices

Nowadays, various design procedures for building structures equipped with shear links dampers have been developed. Designers in professional practice often prefer prompt iterative approaches based on simplified linear elastic analysis. On the other hand, research communities constantly undertake special effort to develop displacement-based design approaches based upon more accurate static nonlinear analysis able to consider inelastic behaviour of dampers through simple analytical procedures.

3.1.Direct and "Fixed-force" iterative design procedures

Commonly implemented in professional practice applications, the direct iterative procedure [24] consists in quick and straightforward steps aimed at providing the designer of a complete set of shear link devices according to a target interstorey drift. To get started the dissipative system design, first trial dimensions of shear links devices have to be considered. Thereafter, the shear force acting on each damper has to be evaluated by means of simplified linear analysis and compared with its capacity, namely its yielding force ($F_{y,SL}$). In the perspective of ensuring proper inelastic behaviour of the device, $F_{y,SL}$ should be smaller than the shear force, thus allowing energy dissipation occur through yielding of the device. However, to avoid failure condition, an upper bound for the demand-to-yielding shear force has to be considered. Authors suggest such ratio to be within 1.1-1.5 range, thus considering cumulative factors such as kinematic hardening of steel or its greater resistance to dynamic loads. If such condition is not verified, the procedure has to be iterated. Hence, further devices will be selected so that their yielding force is lower than the shear on the previous ones, while guaranteeing satisfaction of the interstorey drift consistency check with the target. Analysis should be run again, strongly depending the shear force acting on the SLB on its stiffness. Usually, 3-4 iterations are necessary to achieve a convergence condition. Once devices' dimensions have been set, their supporting element can be designed accordingly. However, various case-studies have shown that the implementation of the direct procedure often delivers greater shear links at each iteration and, therefore, commonly lead to oversized supporting elements[25]. From authors' experience, according to both architectural and economical aspects, a maximum thickness equal to 25-30cmcan be set for uncoupled walls. Hence, in the perspective of avoiding oversized supporting elements, the "fixed-force" or reverse iterative procedure [24] has been developed as an alternative to the direct one. This time, the shear capacity of the supporting element (chevron steel braces or decoupled r.c. walls) is fixed at the beginning according to its geometrical and mechanical properties. In this way, in the perspective of not overcoming such capacity, the maximum shear force that the shear links may transfer to their support is automatically defined. After having fixed the upper bound of the devices' capacity, the reverse procedure recalls the same steps of the direct design method described above. Although, despite the little time-processing of these procedures, the simplified linear analyses they are based on do not allow to properly consider the effective elasto-plastic behaviour of the dampers. Moreover, being performed in the elastic range, response spectrum analyses commonly led to shear forces on the devices greater than the actual forces, which would be obtained considering their strong inelastic force-displacement behaviour.

3.2. Displacement-based design approach

Developed by Nuzzo et al.[16], the displacement-based design (DBD) approach allows to obtain a preliminary sizing of the dissipative system, i.e. metallic hysteretic devices and their supporting elements, according to the target top displacement of the rigid structure and the allowable damage of the bare frame. Suitable for both new and existing structures, the method takes into account additional damping provided by SLBs and their supporting element for the evaluation of the reduced seismic demand. Final objective of the method is to provide the designer with the desired force-displacement capacity curve of the equivalent braced frame (BF system), i.e. the structure equipped with shear link dampers, given in Figure 3, in order to achieve the desired performance level. Namely, the BF system is considered as the bare frame (F system) and the damped brace (DB system) working in parallel, whereas the equivalent DB system is considered as the damper (D) and its supporting element (B) working in series.
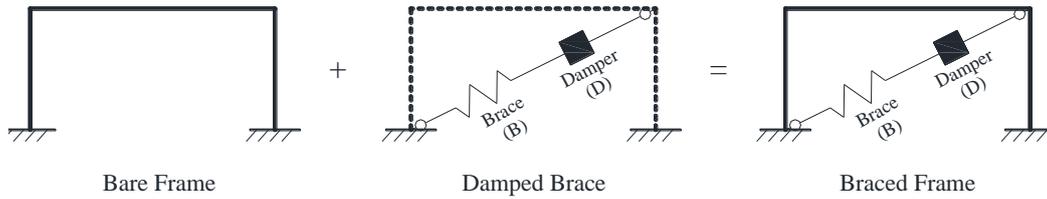
Figure 3Schematization of the bare frame (F), damped brace (DB) and braced frame (BF) systems

In this approach, the performance point (PP) is evaluated according to the target displacement of the bare frame and defining the corresponding level of force, also considering the equivalent damping ratio provided by SLBs hysteretic force-displacement behaviour. Modal and pushover analysis of the bare frame are required at the beginning of the procedure, whereas further structural analyses are not necessary to achieve the final results. Despite it is still an iterative procedure, the overall dissipative system design procedure is based on simple and closed-form analytical relations, thus suitable to be implemented by means of a common spreadsheet. However, Nuzzo et al. [26] overtook a significant effort in order to develop *DIBRAST*– design of DIssipative BRAced STructures – a computer-aided tool in Visual Basic environment which finally provides the dissipative system' mechanical properties needed in order to achieve the desired structural performance (Figure 4).The software supports the designer in the fulfilment of the several phases the procedure is composed of. Moreover, it automates the required iterations, thus significantly reducing time-processing.

The displacement-based design method consists in six steps and is comprehensively described in Nuzzo et al. [16]. However, it will be shortly recalled in the following. At step 1, after choosing a dissipative, partially dissipative or elastic behaviour of the bare frame, the target performance displacement (d_{PP}) has to be defined. Namely, in case nonlinear configuration of F, a target interstorey drift (θ_d) can be set considering the maximum allowable plastic hinge rotation according to code provisions or reparability issues, respectively. Differently, for elastic behaviour, θ_d can be defined in order to limit damage to non-structural elements. Thereafter, a nonlinear static analysis of the bare frame is required in order to obtain F capacity curve. At step 2, the performance point can be detected according to d_{PP} and to the base shear of the equivalent braced frame ($V^*_{PP,BF}$) system. The latter strongly depends on the effective damping ratio $\xi_{eq,BF}$which can be computed through the Eq.1 suggested by Mazza and Vulcano (2015):

$$\xi_{eq,BF}=\xi_{v,F}+\frac{\xi_{h,F}\cdot V^*_{PP,F}+\xi_{h,DB}\cdot V^*_{PP,DB}}{V^*_{PP,F}+V^*_{PP,DB}}[1]$$

where $\xi_{v,F}$is the equivalent viscous damping ratio of the F system and$\xi_{h,F}$is the equivalent hysteretic damping ratio of the F system,$V^*_{PP,F}$is the equivalent F system base shear at performance point, determined at step 1 and $V^*_{PP,DB}$is the equivalent damped brace base shear at performance point determined as a difference between corresponding values for braced frame and bare frame systems (Eq. 2):

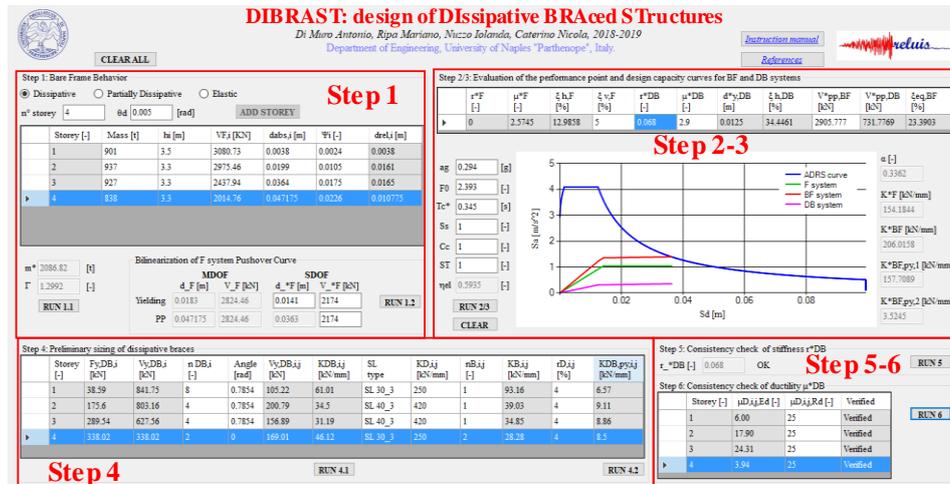$$V^*_{PP,DB}=V^*_{PP,BF}-V^*_{PP,F} \qquad [2]$$

Figure 4 Screenshot of DIBRAST: computer-aided tool for preliminary sizing of dissipative braced structures

The equivalent braced frame base shear $V_{PP,BF}^*$ in correspondence of the performance point is initially unknown and has to be supposed greater than $V_{PP,F}^*$. Also, it depends on the spectral acceleration at performance point, as well unknown being a function of the equivalent damping ratio of the braced frame system $\xi_{eq,BF}$. Therefore, in order to solve Eq.1, the equivalent damping ratio of the damped brace can be defined according to trial values of the damped-brace equivalent ductility μ_{DB}^* and pre-to-yielding stiffness ratio r_{DB}^*. These parameters will be checked by the end of the procedure. Once $\xi_{eq,BF}$ is known, the equivalent braced frame base shear $V_{PP,BF}^*$ will be then computed from the reduced ADRS response spectrum in correspondence to performance point. Finally, the equivalent damped brace system's base shear can be evaluated as a difference between corresponding values of bare frame and braced frame systems. Once the performance point is identified, step 3 of the displacement-based design approach allows to define the desired capacity curve of the braced frame according to a fixed performance level through the analytical procedure described in [16]. Afterwards, the equivalent damped brace capacity curve can be obtained as a difference between BF and F capacity curves. At step 4 of the procedure, the desired mechanical properties of the dissipative system, in terms of elastic stiffness and yielding force, can be distributed along dissipative braces proportionally to modal properties of the bare frame. Subsequently, they can be converted into effective damper and supporting element mechanical properties. Finally, at steps 5 and 6, actual dissipative system's post-elastic-to-elastic stiffness ratio and ductility capacity are compared with values initially assumed. If the consistency check is not satisfied, the procedure shall be iterated from step 2. However, few iterations are generally enough to achieve convergence condition.

4. Case study: seismic upgrade of a RC structure by means of SLB hysteretic dampers

The proposed frameworks are applied to a case study of a new 9-storey RC frame structure situated in Puerto Vallarta (Mexico) to be equipped with supplemental energy dissipation devices for 8 stories, therefore excluding the first underground level destinated to car parking. The building occupancy is supposed to be residential and its structural plan and elevation views are given in Figure 5. The principal frame is designed according to Mexican (CFE-2015) and American (ACI 318-14) codes. As main performance objective, energy dissipation and damage are meant to be

concentrated mostly in shear links, thus ensuring low damage of the primary frame elements under extreme seismic events and no damage to nonstructural elements. Therefore, it has been assumed a serviceability target interstorey drift equal to 0.4% at ultimate limit state. The proposed dissipative system is composed of SLB devices supported by lightly-reinforced concrete walls uncoupled from adjacent columns. In this way, coupled effects between the primary structure and the latter during an earthquake are avoided. The number of dissipative systems at i-th storey has been chosen considering different factors, such as architectural design and torsional effects. Herein, 8 dissipative systems for each floor are designed: 5 along y direction and 3 rotated of a 37° angle in respect to the global reference system x axis (Figure 5). Such configuration resulted to be optimal in limiting torsional motion due to strong plan and elevation irregularities while meeting architectural needs.
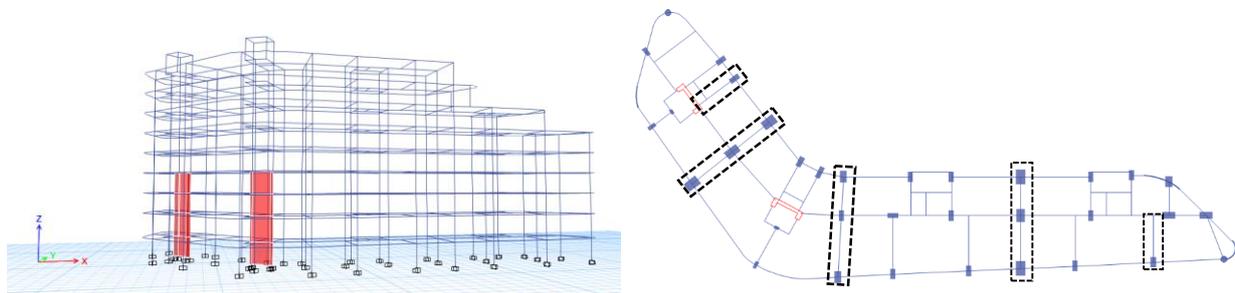

Figure 53D and plan view of the case study

4.1.Direct and inverse iterative design procedures application

The inverse iterative design procedure for shear link devices has been applied with the support of a Plugin for ETABS (Computers & Structures, Inc.)developed by Eng. Edinson Munoz. First trial SLB 15_3 set and 20cm thick uncoupled walls have been considered. A response spectrum analysis has been run and the shear force in each dissipator has been evaluated and compared with its yielding force. Given that the demand-to-capacity ratio resulted to be greater than the maximum allowable value, an iterative procedure has been implemented. Therefore, a new SLB set has been chosen so that the yielding force of each dissipator was smaller than the shear force read on the dissipator belonging to the previous set. After having chosen and implemented on the numerical model of the structure the II trial SLB set, a response spectrum analysis has been repeated and the check on the shear of the dissipator as well.

4.2. Displacement-based design method application

The displacement-based design method has been implemented with the support of DIBRAST software and, namely, the application of the framework in y direction is herein described. For the case study, it has been considered a design response spectrum with 0.15g PGA. As part of a damage-controlled design strategy, the bare frame is supposed to behave elastically, so no plastic hinge has to form in primary structural elements. Consequently, shear links are designed in order to develop strong inelastic behaviour within their ultimate displacement capacity. Downstream of a pushover analysis with distribution of forces proportional to masses, F properties in correspondence of the target displacement are input at step 1 of the procedure. Modal participation factor (Γ=1.52) and equivalent mass (m*=5569.39t) are obtained as output, allowing to determine the F SDOF system capacity curve. Thereafter, according to step 2 of the design framework, first trial ductility and elastic-to-post yielding stiffness ratio of the dissipative system are considered equal to 3 and

0.4respectively, allowing to determine the performance point. Once the capacity curve of the DB system is known from step 3 of the procedure, mechanical properties in correspondence of each story are determined at step 4. Therefore, given the optimal stiffness ($K_{DB,i,j}$) and yielding force ($V_{y,DB,i,j}$) of the j-th dissipative system at i-th storey from DIBRAST, SL geometry is chosen in order to match the design yielding force.

4.3. Outcomes comparison

The application of the design methods herein introduced led to the definition of various SLB sets, mainly differing in dimensions. Among all procedures, the displacement-based design approach delivered devices characterized by reduced width and thickness in respect to the ones obtained by means of the inverse and direct iterative procedure, respectively. The dimensions of the chosen SLB dampers type have had a direct consequence on the design of the supporting wall, being the latter designed by capacity, thus considering the maximum shear force transmittable by the supported devices. Therefore, devices' yielding force has been considered when sizing of the supporting element.

In order to assess effectiveness of the design results, nonlinear dynamic analyses are performed using ETABS software. In the 3D numerical model, SL dampers are modelled as nonlinear link elements through the plastic Wen model by defining force and stiffness properties. Input time-history functions are represented by 11 artificial records spectrum compatible with the elastic spectrum (Figure 6), generated by means of the dedicated commercial software SeismoMatch (2016) and according to American ASCE/SEI 7-6 code provisions from a set of natural records selected from a Mexican strong motion database.
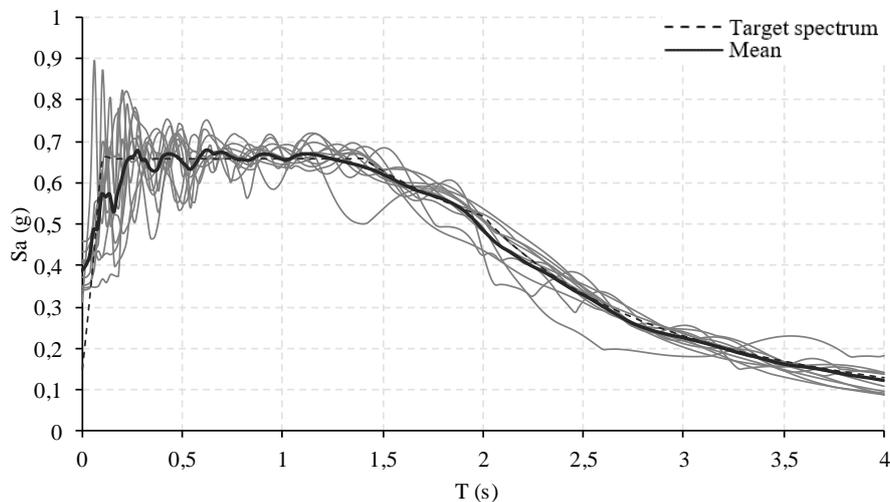

Figure 6 Spectral matching

Three structures have been analyzed: (I) bare frame, (II) structure equipped with SLB devices designed according to the displacement-based design procedure, (III) structure equipped with SLB devices designed according to the inverse iterative procedure.Mean values over all records have been considered for the chosen control parameters, i.e. interstorey drifts and storey accelerations in Y direction As shown in Figure 7, interstorey drift (ID) ratios resulted significantly reduced due to the installation of the dissipative system. Among all, structure III exhibited ID ratios totally contained within the 0.4% target, whereas structure II seismic behaviour exceeded the target value of approximately 20% at some floors. However, a significant reduction of the drifts in respect to the

bare frame has been observed. Regarding story accelerations, both structures II and III presented better behaviour in respect to the bare frame. Specifically, the structure designed with the displacement-based design procedure presented lower story accelerations in Y direction. Base shear and seismic coefficient, i.e. the ratio between base shear and overall seismic weight, has been computed, mainly resulting in similar values for both structures equipped with dissipators. Namely, 5% reduction of this parameter has been recorded for the structure designed by means of the displacement-based procedure. Important differences in the results have been recorded for maximum deformations of the single SLB device. Particularly, shear links designed according to the displacement-based design procedure turned out to work for a maximum displacement 90% and 162% greater respect to the ones designed with the inverse iterative procedure, in x and y direction respectively.
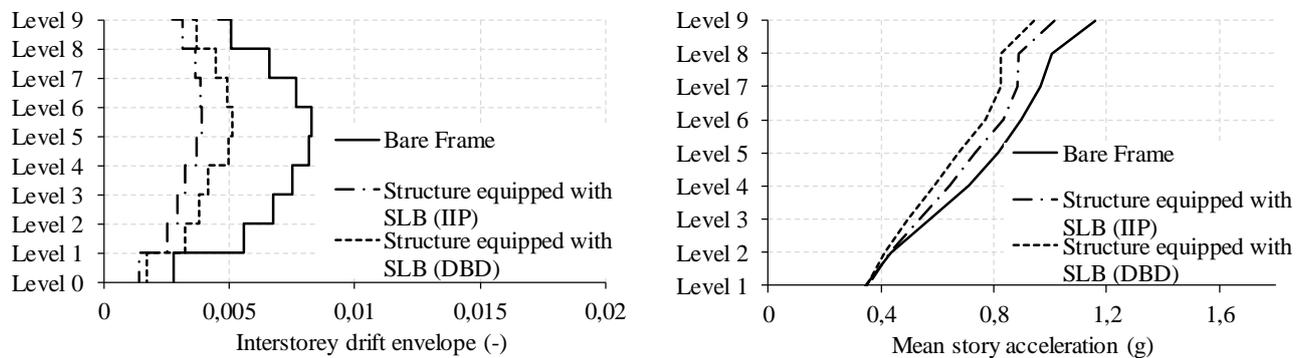

Figure 7 Interstorey drift and mean storey acceleration envelopes

Finally, an estimation of the quantity of SLB devices per story and the quantity of concrete for the uncoupled supporting walls has been performed for both design solutions, provided by the application of the inverse iterative procedure and the displacement-based design procedure. Namely, 212 devices have been designed with the fixed-force procedure, whereas 140 devices have been designed according to the displacement-based procedure. Also, the cost of the SLBs and of the concrete for the walls has been evaluated according to their unit cost. As a result, the displacement-based design method results in a more economical design solution from both SLB devices and concrete for the supporting walls points of view, resulting in 64% and 23% cost saving, respectively.

In conclusion, the application of the design procedures on the case-study highlighted that the fixed-force iterative procedure delivers both SLBs and the walls of greater dimensions, guaranteeing full respect of the target interstorey drift. On the other hand, the added ductility contribution is minimal, allowing the devices to work for 7mm and 4mm (respectively in x and y direction) displacements against 30mm of capable displacement. The displacement-based design method, instead, is a more complex procedure that requires a greater number of approximations, also given the strong plan and elevation irregularity of the case-study. It leads to a result that, although acceptable (interstorey drift ratio equal to 0.5%), does not respect the target value. However, it guarantees a greater control over the work, in terms of displacement, to which the SLBs are called and, therefore, over the ductility demand of the devices.

5. Conclusions

This paper provides an overview on three practical design procedures for structures equipped with hysteretic dampers. Despite continuous advancements in the state-of-the-art of design procedures based nonlinear analysis, practitioners often prefer to implement linear elastic analyses, simpler to be managed and with a reduced time-processing. This is particularly true for early stages in the design process where most important decisions are taken, and full nonlinear analysis is time consuming. Three design procedures employing a particular damper - the Shear Link Bozzo (SLB) - are presented: (1) direct procedure, (2) "reverse" or fixed-force procedure, (3) displacement-based design method. Namely, the displacement-based framework is based upon static nonlinear analysis of the bare frame and allows obtaining the desired mechanical properties of the dissipative system, in terms of yielding force and elastic stiffness, according to a fixed performance level. Differently, the direct and fixed-force iterative procedures are based upon simple linear elastic modal analysis. It is relevant to specify that the aforementioned (1) and (2) procedures are for a fast-preliminary selection of devices, nevertheless a nonlinear step by step verification is recommended.

The herein introduced procedure have been employed to design an optimal SLB set for a complex case-study situated in Puerto Vallarta (Mexico) and, as a result, the (1) delivered devices of great width and thickness as well as the (2), meanwhile the (3) delivered smaller devices. The dimensions of the dampers have a direct consequence on the design of the supporting wall, being the latter designed by capacity considering the maximum shear force transmittable by the supported SLB, i.e. their yielding force which increases with their dimensions. Therefore, the (1) has been discarded being a procedure that delivers bigger dampers at each iteration and, therefore, eventually unacceptable thick supporting wall. Namely, 25-30cm can be considered a maximum thickness from both architectonical and economical points of view. Structural behavior of the bare frame and of the structures equipped SLB devices designed according to the reverse iterative procedure and according to the displacement-based design procedure have been analyzed by performing dynamic nonlinear analysis in y direction. Mean values for the chosen control parameters have been considered. In particular, the interstorey drift of the bare frame resulted drastically reduced by the installation of the dissipative system and, particularly, the structure equipped with SLBs designed with the reverse iterative procedure exhibited interstorey drifts fully contained within the target (0.4% in order to avoid damage to nonstructural elements, CFE 15) whereas structure designed with the displacement-based design procedure presented interstorey drifts not always respecting the target which turned out to be exceeded of 20%. However, a significant reduction of the drift in respect to the bare frame has been observed in all cases. Regarding story accelerations, both structures presented better behavior in respect to the bare frame, particularly the one equipped with devices designed according to the displacement-based design procedure. Moreover, it has been observed a reduction in the seismic coefficient for the latter structure. Important differences in the results have been recorded when considering the mean maximum SLB devices' deformation for both structures. Particularly, shear links designed according to the displacement-based design procedure turned out to work for a maximum displacement 162% higher in respect to the ones designed with the reverse iterative procedure in y direction. Finally, economic considerations have been carried out by evaluating, for both structures, the number and cost of shear links per story and the quantity and cost of concrete of the supporting walls. As a result, the displacement-based design method turned out in a more economical design solution. Also, the number of dampers per story is strongly reduced when applying such design procedure. However, if the final objective is the reduction of the interstorey drift, the reverse or direct procedures result more effective. Anyway, besides their inherent simplicity, their iterative nature can lead them to be quite time-consuming.

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