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IDRIZI Infill Wall System for Seismic Protection of Residential Buildings

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Abstract: It is widely acknowledged that masonry walls in RC (reinforced concrete) frame structures, although often omitted in the design process, contribute significantly on the seismic resistance of buildings. Their contribution toward seismic response improvement is proportional to their participation level on buildings. The more abundant they are on buildings, their lateral strength contribution gets more significant, especially for "frame systems" of both RC and steel structures. This paper presents an "innovative" solution which aims to provide a seismic protection to masonry walls and to improve the seismic performance of the entire building structure. These goals are achieved through use of so called "IDRIZI" seismic devices. These "box-like" devices are placed at characteristic locations between the masonry infill walls and the structural frame system of the building. They act as special link elements between the top of wall panels and the bottom of beams and/or slabs. The assemblage of a wall panel, IDRIZI seismic devices and other boundary structural elements forms an integral structural system that is shortly called "IDRIZI" wall system. In addition, as part of this paper is shown selected experimental investigations, which demonstrate that under "optimal design" of buildings integrated with IDRIZI wall system, up to 80% of earthquake energy input in the structure can be dissipated by the friction mechanism of the IDRIZI devices. This feature provides remarkable improvements on the seismic performance of residential buildings or any other type of building where masonry walls are abundantly present.

Key words: Structural control, friction control, IDRIZI wall system, earthquake protection.

1. Introduction

This paper presents an "innovative" solution which aims to provide a seismic protection to masonry walls and to improve the seismic performance of the entire building structure. These goals are achieved through use of so called "IDRIZI" seismic devices. They are placed at characteristic locations between the RC frame and the URM (unreinforced masonry wall) infill wall panels. These "innovative" devices facilitate the optimal utilization of strength and ductility of all constitutive structural units of a frame system, namely the RC frame system and the URM infill wall system.

The integration of IDRIZI devices between the infill wall panels and the surrounding structural frame greatly modifies the nonlinear behavior and the basic dynamic characteristics of the integrated structure. In other words, the infill wall panels integrated with IDRIZI devices on top of them, impose significant improvements to the dynamic response of the integrated structure. Besides the structural response improvements, the utilization of IDRIZI devices imposes significant modifications in the construction process of infill walls in buildings. Because of these reasons, these infill wall panels are no longer recognized as classical system of infill walls but rather as a new wall system named as "the IDRIZI wall system".

This newly proposed technical solution was greatly influenced by the extensive work of Dr. Uwe E. Dorka (professor in Kassel University, Germany) in passive control systems [1-5].

Besides special considerations on passive control systems, many studies related to various aspects of

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masonry wall behavior have greatly contributed to the development of the newly proposed technological solution, some of which are listed in the references section [6-7].

The function of the IDRIZI wall system and its advantage over the classical system is best explained by observing and comparing their lateral response. A comparative study, related to this matter, was done both analytically and experimentally. This paper, however, focuses mainly on illustrating the conceptual idea behind the IDRIZI wall system, describing its differences related to the classical wall system, and finally presenting the obtained experimental results which confirms the advantages of the IDRIZI wall system versus the classical walls in terms of performance and safety.

2. IDRIZI Wall System—The Concept

Fig. 1 illustrates the composition of a typical 2D classical frame system (top) and a so called IDRIZI wall system (bottom). Both wall systems, shown in Fig. 1, are decomposed to their constitutive structural units, namely the RC bare frame, the URM wall and the IDRIZI seismic device. In this figure, the classical system (2D frame with infill wall) is denoted with letter "A", while its constitutive units (RC bare frame and URM wall panel) are denoted with letters "A1" and "A2", respectively. In the same fashion, the IDRIZI wall system, denoted with letter "B" is constituted of RC bare frame (B1), wall panel (B2) and IDRIZI seismic device (ID).

2.1 Classical Wall System—General Characteristics

The characteristic mechanical behavior of structural Units "A1" and "A2", constituents of the classical wall system, are illustrated in Fig. 2.

According to Fig. 2, under monotonic increase of lateral force *F*, the gradual deformation of the structural Unit "A1" is parabolic, starting from characteristic Point 1 up to characteristic Point 3 (Fig. 2 (top)). Point 3 represents the maximum bearing capacity of structural Unit A1 (RC frame). Pass this point, with further lateral displacement increase Unit A1 gradually degrades and flexural cracks develop at critical regions (column degradation). Point 4 represents the loss of structural integrity of Unit A1 (column failure). Finally, it is observed that the mechanical behavior of A1 is characterized with a certain level of flexibility and ductility. A1 structural unit has tendency for a flexible and ductile behavior

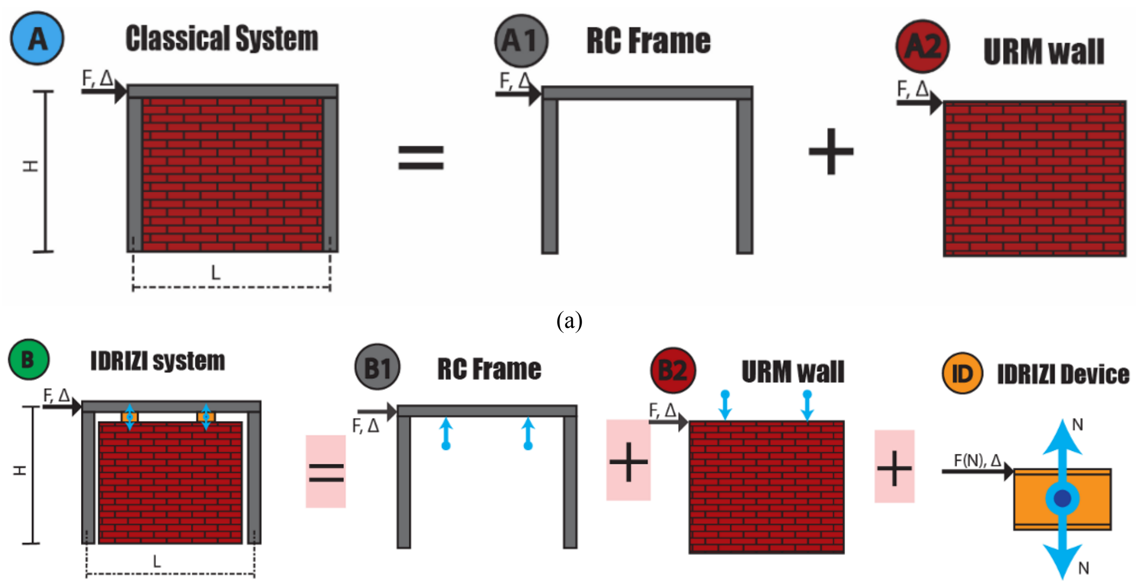


Fig. 1 Composition of: (a) a 2D frame classical system; (b) composition of a 2D frame IDRIZI wall system.

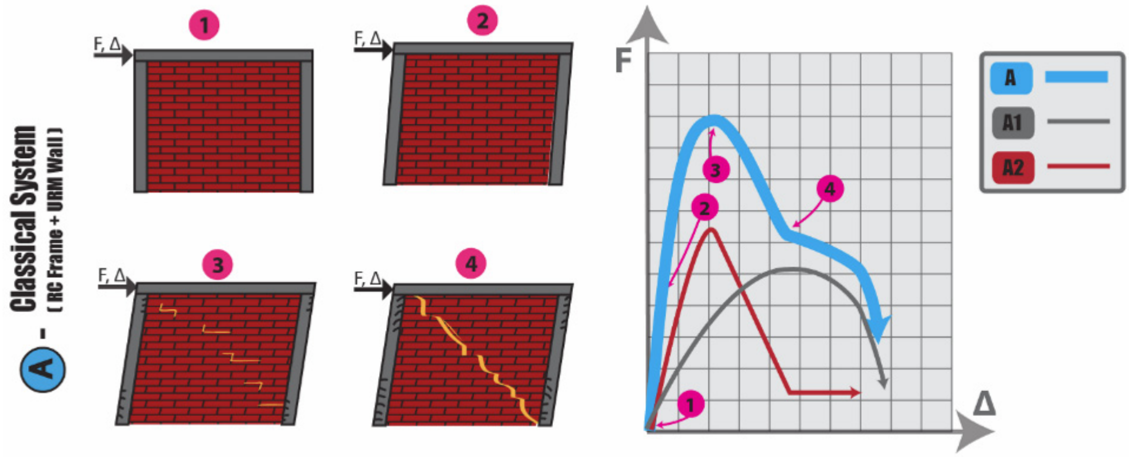


Fig. 2 Mechanical behavior of 2D frame classical system.

under lateral forces, respectively, it can withstand a certain level of nonlinear deformations without degradation of their lateral resistant capacity. Contrary to "A1", structural Unit "A2" (URM wall panel) is notably higher than "A1", consequently much stiffer in respect to A1. This means that the masonry wall A2 is more reluctant to deformations when subjected to lateral forces.

According to this figure, the lateral drift of the classical wall panel is roughly linear up to Point 2 while just before characteristic Point 3 is evidenced the onset of cracking. Right pass characteristic Point 3, with slight increase of the shear force a sudden crack line is developed along the diagonal of the masonry wall panel. This is followed with instantaneous reduction in the shear force. This phenomenon of instantaneous stress release by ways of diagonal cracking of the wall panel is also known as a "brittle" failure of masonry wall.

While A1 is more prone to lateral deformation due to its flexibility and possesses ductile characteristics, the A2 structural unit is stiffer and more reluctant to lateral deformations up to the level of their lateral strength resistance, after which follows a brittle failure with a rapid degradation and structural disintegration of the wall panel.

The mechanical behavior of the classical frame system "A", is derived as a superposition of the mechanical behavior of its constitutive structural Units A1 and A2 (Figs. 2 and 3). This law of superposition holds true especially for the linear stage of response of the classical frame system "A". However, this superposition is not always true for the nonlinear response stage of frame systems. The nonlinear response of the frame system "A" greatly depends on the relative strength characteristics between Units "A1" and "A2".

Thus, when structural Unit "A2" is with similar strength or even weaker in comparison to Unit "A1", (which is usually the case for infill URM walls consisted of hollow blocks) the response of frame system "A" is according to Fig. 2.

However, when structural Unit "A2" (URM wall panel) is notably stronger than Unit "A1" (which is the case for URM walls consisted of solid clay bricks), the response of frame system "A" is more similar with the behavior of Unit "A2". For the latter case, the potential energy accumulated on the classical frame system, close to the onset of cracking and brittle failure of URM wall panels, gets sufficiently high so it would damage the "A1" structural unit as well. Consequently, after degradation of relatively strong "A2" units, a brittle failure of the entire frame system "A" follows.

In relation to the behavior of classical frame systems, several conclusive remarks can be outlined, as follows:

- URM wall panel is notably stiffer than the bare frame, thus the major portion of lateral forces acting on the classical frame system is mainly resisted from the URM wall panel. This answers the question why URM walls usually precede the failure of structures subjected to earthquakes;

- Right up to the point of failure of URM walls, their contribution to the lateral resistance of classical frame systems is always positive and proportional to their lateral strength capacity;
- After the onset of cracks and strength degradation of URM walls, their contribution to the lateral resistance of classical frame systems is more complex. It is mainly dependent on the brittleness of URM walls and their lateral strength level in relation to the lateral strength of bare frames.

Additionally, in reference to existing engineering literatures concerning the effect of URM walls on buildings, it is necessary to outline two more conclusive remarks, respectively:

- Due to the highly brittle, orthotropic and unpredictable mechanical characteristics of URM walls, it is difficult to consider their contribution on the lateral strength resistance of buildings. Therefore, it is a common practice that in numerical analysis procedures, the strength capacity of URM walls is completely ignored;
- On many cases, participation of URM walls infilled on frame systems may exceed 70% of the total wall areas within buildings. This vast participation of URM walls on buildings greatly affects the lateral building strength. The effect of URM walls on lateral strength capacity of buildings is particularly beneficial for buildings subjected to low to medium level of earthquakes.

2.2 IDRIZI Wall System—General Characteristics

In the following is demonstrated the mechanical response of the previous frame system "upgraded" with IDRIZI seismic devices, which are placed between the top of wall panel and the bottom of the RC frame (Fig. 1b). This type of frame system composition is called the "IDRIZI" frame system.

The essential pre-requisites for achieving IDRIZI wall systems are the following:

- A structural gap should be accommodated between the perimeter of URM infill walls and the surrounding structural frame;
- IDRIZI seismic brake devices should be installed at characteristic locations between the top of URM walls and the beam/slab of the structural frame;
- The structural gap between the URM walls and the structural frame should be finally filled with a soft material, so that it would not interfere in the systems mechanical response.

The characteristic mechanical behavior of structural Units "B1", "B2", and "ID" constituents of the IDRIZI wall system (structural system "B"), are schematically illustrated in Fig. 3.

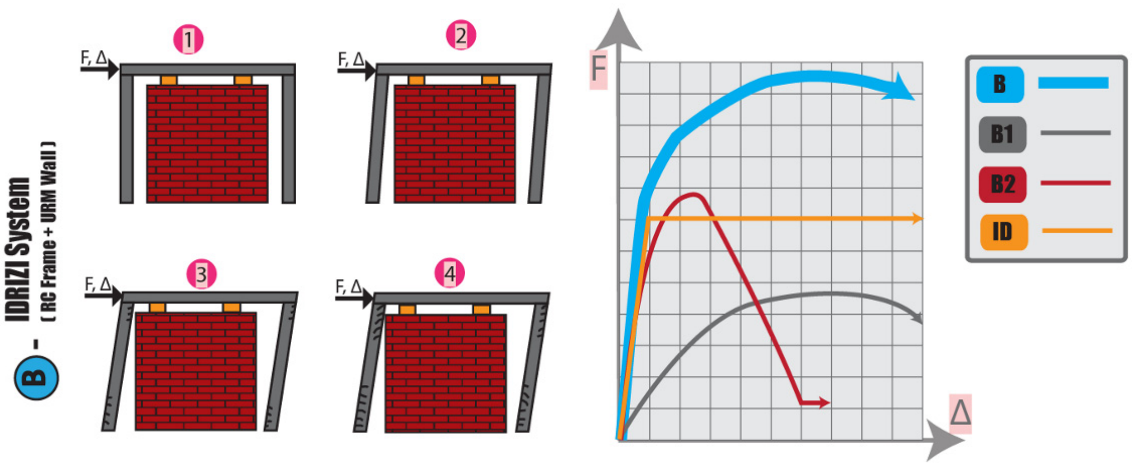


Fig. 3 Capacity curve of the IDRIZI frame system.

According to Fig. 3, the capacity curve of the "IDRIZI" frame system (Curve B), is derived as a linear superposition of the capacity curves representing the structural bare frame (Curve B1) and "friction pad" of the IDRIZI seismic brake device (Curve ID). The law of superposition for "IDRIZI" frame system holds true throughout the entire response stages, under the "strict" condition that the friction force is lower than the strength of the infill wall (maximum force attained in Curve "ID" must be lower than in Curve "B2").

The best way to demonstrate the beneficial effects of the "IDRIZI" frame system over the "classical" system, is by comparing both systems in a single graph, such as shown in Figs. 4a and 4b.

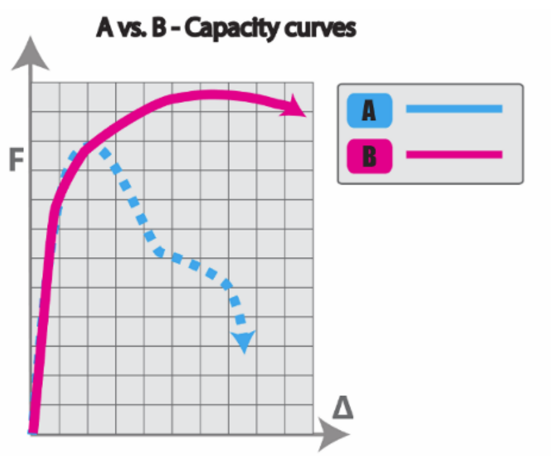
Fig. 4a shows the "capacity curves", and Fig. 4b the "hysteretic response" for both the classical wall system (Curve A, blue color) and the IDRIZI wall system (Curve B, magenta color).

According to Fig. 4a, the "IDRIZI" system shows about 2-3 times larger ductility in respect to the classical frame system and higher shear strength compared to the classical frame system. In addition, the superior performance of IDRIZI system over the classical one is best demonstrated in terms of seismic energy dissipation capacities. The IDRIZI system shows 3 to 4 times higher energy dissipation capabilities comparing to the classical frame system, Fig. 4b. Perhaps, Fig. 4b is the most suitable graph that explains both quantitatively and qualitatively the gained advantages of the IDRIZI wall system when subjected to seismic dynamic actions.

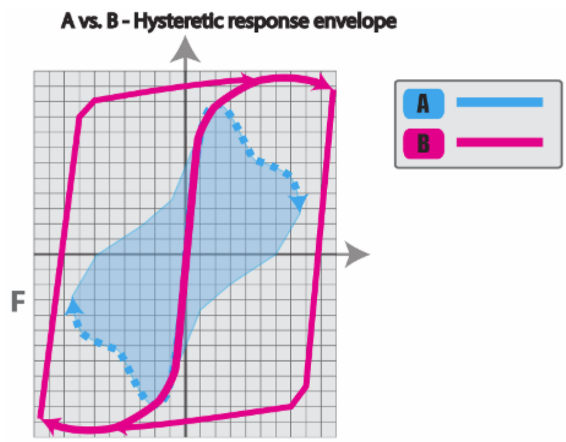
3. Experimental Verification

So far, theoretically were elaborated the advantages of the IDRIZI wall system over the classical type of walls. Obviously, this theory has to be ultimately verified experimentally, before further steps toward the practical implementation of this innovative wall system are taken.

For this purpose, many half-scaled wall physical models were prepared and subjected to various combinations of in-plane vertical and lateral quasi-static forces. Specifically, all wall panels were subjected to a certain intensity of compressive stress which was kept steady while a quasi-static cyclic horizontal forces were acting laterally in order to inflict controlled lateral deformations in the wall panels. On the case of classical wall panels, the deformation cycles imposed on wall panels followed a gradually increasing pattern up to a magnitude of 35 mm (Fig. 5a). As shown in Fig. 6, this deformation pattern succeeds into imposing a full collapse of the classical walls. On the other hand, the cyclic deformations imposed on the IDRIZI wall panels followed a pattern of cyclic deformations with constant



(a)



(b)

Fig. 4 Classical vs. IDRIZI system: (a) capacity curves); (b) hysteretic behavior.

magnitude (Fig. 5b). As shown in Fig. 6, IDRIZI wall panels will perform reliably under five cycles of lateral quasi-static forces.

It is crucially important to understand that the horizontal quasi-static forces, acting laterally on the plane of the wall panels, were deformation-controlled, i.e., their intensity was a function of the desired lateral displacements. Specifically, the quasi-static horizontal forces acting on the classical type of wall panels were generated based on a time-history function of cyclic displacements (Fig. 5a).

Fig. 6 is, perhaps, the most representative figure which demonstrates the superior performance of the IDRIZI wall over the classical one. As can be observed from this figure, the classical type of wall (Fig. 6a) is fully damaged with severe cracks along the two diagonals of the wall panel, while IDRIZI wall panel (Fig. 6b) remained completely intact. In addition, the graphical charts shown to the right side of Fig. 6 present the hysteretic "shear-force vs. latter top displacement" response for both types of wall systems. According to these graphs, it can be observed that the shear-forces attained by the wall panel are ranging from 6 t up to 8 t, while the lateral displacement are significantly larger on the case of the IDRIZI wall panels. In other words, IDRIZI wall panels demonstrate notably larger lateral displacement abilities in respect to the classical wall panels without manifestation of any cracks along the panel. The energy absorbed by the IDRIZI wall panels is significantly larger than that in the case of a classical wall panel although it attains smaller shear-forces.

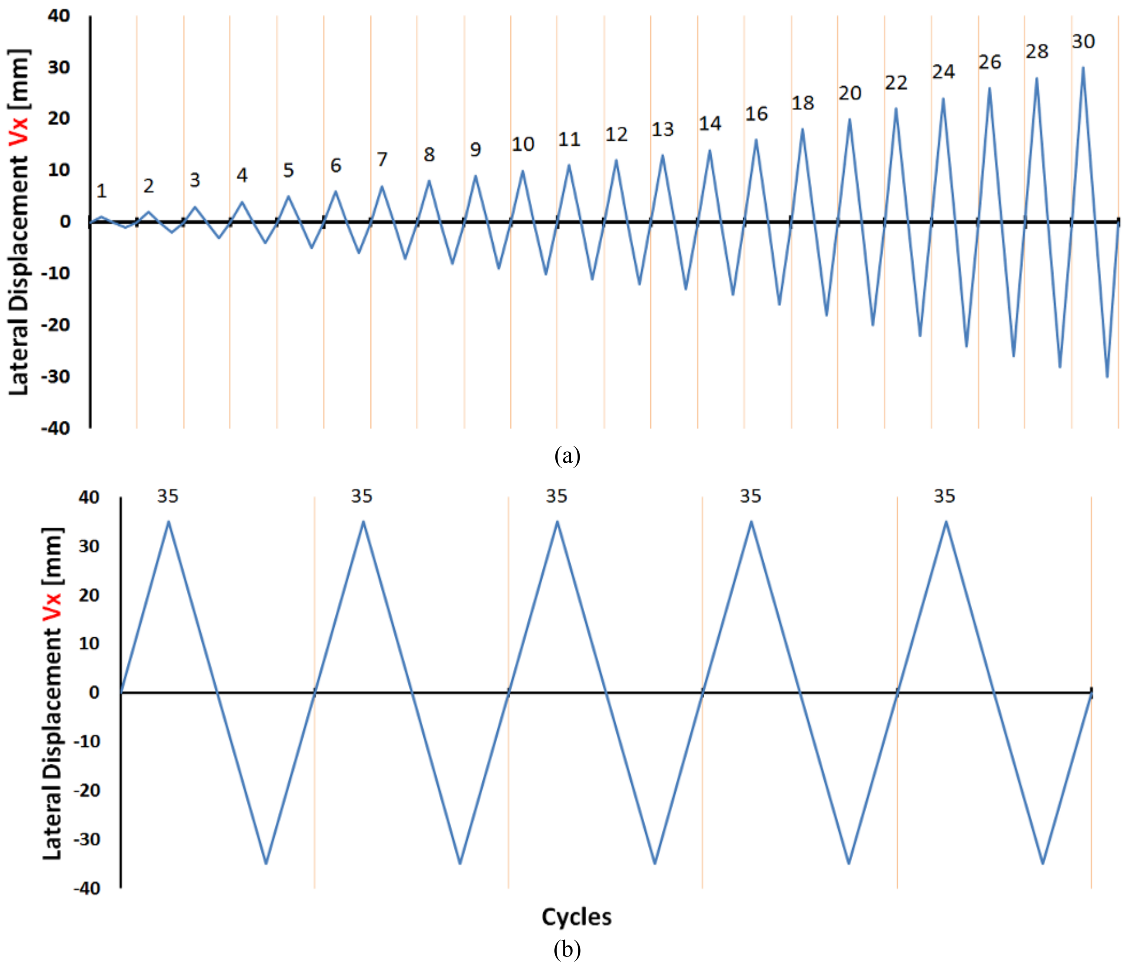


Fig. 5 Time history cyclic function of the horizontal displacement acted on top of: (a) classical wall models; (b) IDRIZI wall physical models..

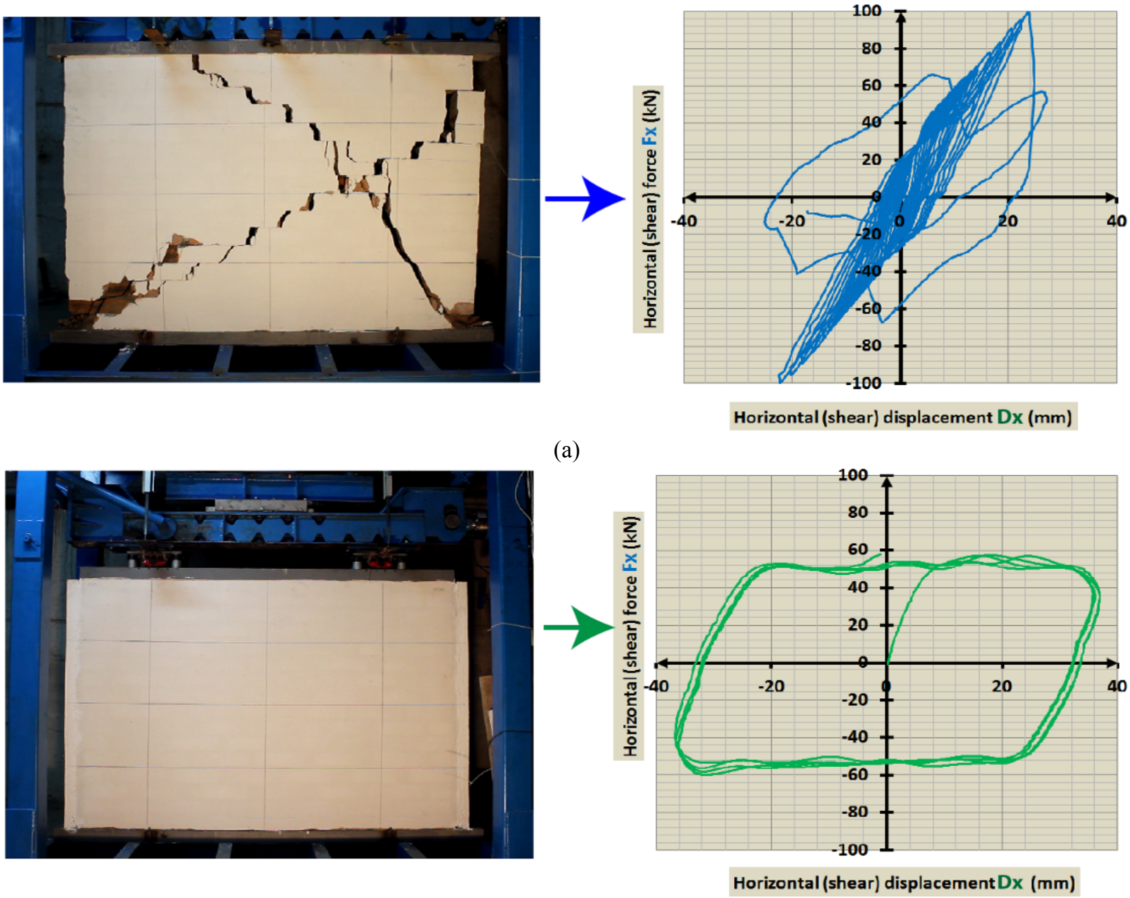


Fig. 6 Hysteretic behavior representative for: (a) Test 1 of model "WALL FP_CL"; and (b) Test 8 of model "WALL FP_ID.

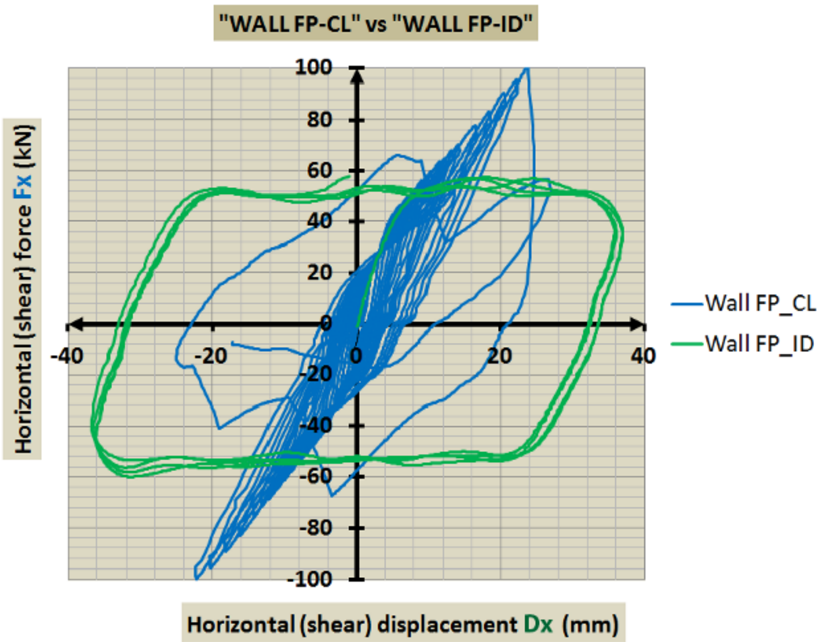


Fig. 7 Comparative survey between hysteretic behaviors representative for Test 1 of model "WALL FP_CL" and Test 8 of model "WALL FP_ID.

Thanks to the IDRIZI seismic brakes, the bean over the IDRIZI wall panels starts to slide before maximum shear-capacity of wall panel is developed.

A better visual representation of the superiority of IDRIZI wall panels over the classical wall panels is best demonstrated by the historic curves given by Fig. 7. Having into consideration that the area enclosed by the historic curves represents the accumulate energy, it is remarkable how this energy level is significantly larger for the IDRIZI wall system (4 to 5 times larger). In other words, IDRIZI wall system is capable of absorbing 4 to 5 times larger seismic energy in respect to the classical walls systems.

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