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CYCLIC TESTS ON AN INNOVATIVE FRICTION DISSIPATIVE DEVICE FOR SEISMIC RETROFIT WITH CLT PANELS

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ABSTRACT: Seismic renovation is a topic of crucial importance for many countries in the southern part of Europe, where the high levels of seismic hazard, combined with the presence of old RC frame structures, poses a severe risk to the lives of many. The e-CLT system, part of the European project e-Safe, proposes a seismic retrofit system for existing RC frame buildings by attaching CLT panels to the facade and connecting them to the existing structure with innovative friction dissipative devices. The authors conducted an experimental campaign at component level for this novel connector, with two different setups, with and without a CLT panel. This paper presents the cyclic test results on these friction devices, with particular attention to the influence of the timber connection on friction behaviour.

KEYWORDS: seismic renovation, Friction connector, experimental test, energy dissipation

1 INTRODUCTION

Up to 60% of residential buildings in Italy were built between 1946 and 1990, and 25% before 1946 [1], when proper seismic building codes were not available (the first codes were presented in the 1980s), and are therefore in great need of retrofitting. Many retrofit systems are available, directed either at reinforcing the existing structure, or providing extra energy dissipation Some systems can offer both. Traditional systems include steel jacketing, FRP, but are often cumbersome and expensive. The dissipation approach uses three different types of dissipation devices: active, semi-active and passive [2]. This paper will focus on friction dampers, a particular type of passive dissipation device that is becoming more studied in recent years for application in buildings. In its simplest form, a friction device is composed of three plates clamped together by preloaded bolts [3]. The middle plate has an elongated bolt, the outer plates have round holes, so there can be relative slip between the plates when the applied force reaches the friction limit. The system proposed by the authors is called e-CLT (Fig.1)[4], [5]: CLT panels are attached from the outside of existing buildings without disturbing the users' lives during renovation work. The main novelty of the system lies in the connection between the timber panel and the existing building: a Friction Connection, capable of offering a stiff joint for low levels of horizontal actions whilst sliding and dissipating energy via friction when subjected to higher loads like earthquakes. This paper presents an experimental study on a prototype of this novel connection, following the first phase presented in [5]. In the first phase, the friction connection was tested by itself, focusing solely on the friction behaviour, while the novelty of this paper is a new testing setup that includes a CLT panel. The goal is to study the performance of the interaction between friction connection and timber connection.

2 E-CLT

The system tested in this paper is part of an ongoing European project called e-SAFE (Energy and Seismic AFfordable rEnovation solutions) [5]. The project was financed in the Horizon 2020 framework of "decarbonizing the EU building stock", and proposes a multi-faceted approach to building renovation [4]. Different disciplines are involved, with to obtain better performances both regarding energy efficiency and structural behaviour. One of the systems proposed for seismic retrofit of existing RC frame buildings with masonry infill is called e-CLT, shortly illustrated in Figure 1.

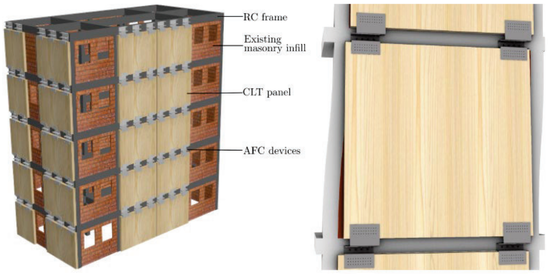

Figure 1: *e-CLT seismic retrofit system* [5].

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The renovation system e-CLT entails the application of a CLT panel from the outside of a building, on the bays without any openings, thus without disturbance for the residents. The main novelty lies in the connection system between the CLT panel and the existing structures: friction connections link the CLT panel to the beams of every floor. The friction connection is composed of two steel plates: the anchor profile is rigidly connected to the RC beam of a floor and the CLT panel of the floor above, while the free profile is connected to the CLT panel of the floor below and the anchor profile via preloaded bolts that can slide in an elongated hole. In this way, by setting the desired preload in the bolts, it is possible to choose the activation force of the sliding mechanism. For lateral force levels below the activation threshold the connection will behave as stiff. In contrast, for higher load levels, such as in the event of an earthquake, the system will start to slide and dissipate energy via friction. This paper will describe of one of the prototypes of this novel friction connection and the results from some cyclic tests.

3 MATERIALS AND METHODS

3.1 SPECIMEN

Different shapes and configurations of the specimen were modelled and tested in various phases, as seen in Figure 3. In the first testing phase, presented in [5], the research focused on two main designs: STD (standard) and ALT (alternative), seen in Figures 3 and 4. STD is composed of two steel plates: the anchor profile is rigidly connected to the beam of a floor and the CLT panel above, while the free profile has an elongated hole and is connected to the anchor profile and to the CLT panel below. In this case the screw connection the CLT panel is on the front of the system, offering easy access and inspection. Initial modelling and tests highlighted weaknesses in the 3-bend shape and high eccentricity between friction bolts and free profile, as seen in Fig.4, which brought to the conceiving of the ALT profile [6]. In this case, both CLT-to-steel screw connections are moved to the back, which means simpler L shapes for the plates and reduced eccentricity. This brought better mechanical performances at the expense of reduced accessibility of the screw connection. A further elaboration of the ALT is the ALT-AS, seen in Fig.5. In this prototype the free profile is composed of two separate pieces, connected by lateral bolts in elongated holes, which offer the additional benefit of vertical adjustability in the mounting phase [6], [7]. The third phase of testing, addressed in this paper, used a design called HYB (hybrid), which attempts to keep the positive aspects of STD and ALT: front mounting possibility and more straightforward L shape [8].

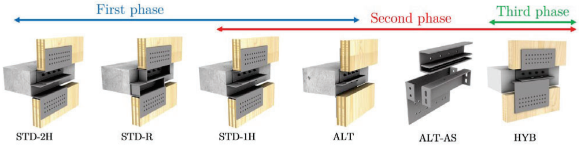

Figure 2: *Evolution of the dissipator shape.*

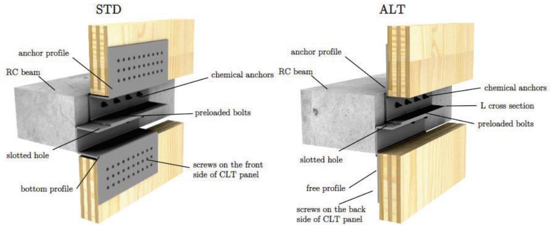

Figure 3: *Main features of the initial STD and ALT shapes* [5].

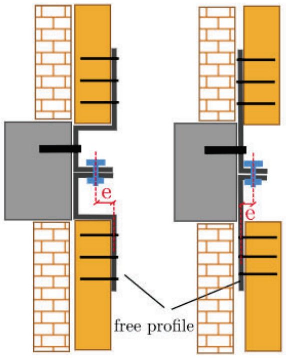

Figure 4: *Section illustration of STD and ALT shapes* [5].

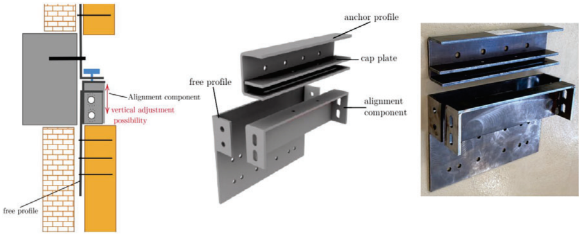

Figure 5: *Illustration of the ALT-AS shape* [7].

The HYB specimen, seen in Fig.6, is composed of two 8mm thick cold bent steel plates: the anchor profile is attached to the beam of the existing building and the CLT panel of the upper floor, while the free profile is attached to the CLT panel of the lower floor and the anchor profile with two high strength M16 bolts. The connection to the CLT panel is made with 33 10x80 screws. The free profile presents an elongated hole, which permits relative sliding, with a clearance of movement of 100mm in both directions. The friction connection is completed by a cap plate and two aluminium shim layers, which improve the friction behaviour. Four specimens were tested, as seen in Tab. 1. HYB 2 and HYB 3 were identical, HYB_e had a slightly reduced eccentricity, HYB_s was tested on a different steel setup. Multiple repetitions were performed on each specimen, with different preloads according to Tab.1.

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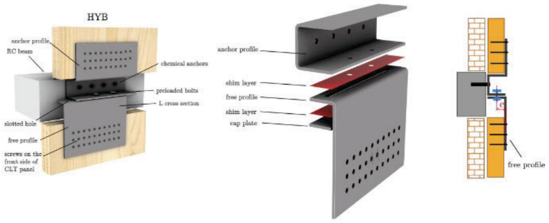

Figure 6: *Illustration of the HYB specimen* [8].

3.2 SETUP AND LOAD PROTOCOL

Two different setups were used for testing. The main setup is seen in Fig.3, where the free profile is connected with screws to a 100mm thick CLT panel. The anchor profile, simplified to a C shape for testing purposes, was connected to the actuator of the press, which simulated the movement of beam in a real building by moving up and down. One specimen was tested on a different setup, without the CLT panel, seen in Fig.8, to study the influence of the screw connection on friction behaviour. All the tests were carried out in displacement control with a speed of 2mm/s and the same cyclic protocol: 1x5-10mm+3x20-40-60-80-100mm.

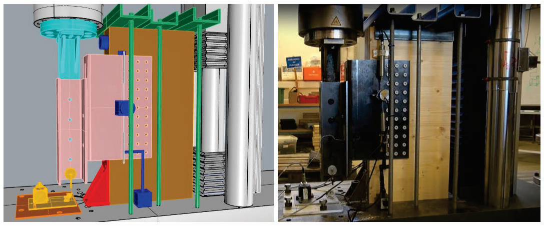

Figure 7: *Setup with CLT panel* [8].

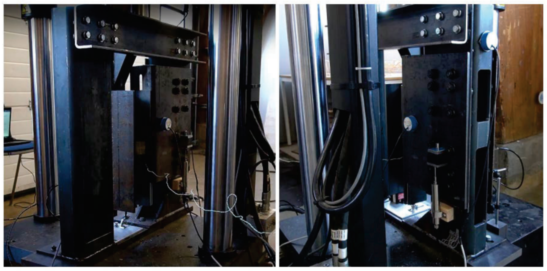

Figure 8: *Setup without CLT panel* [8].

Tab.1 shows the list of the specimen that were tested, and the repetition performed on each specimen.

Table 1: *Test list.*

Specimen	Rep.	Preload kN	Setup
HYB-2	1	25	CLT
	2	25	
	3	25	
	4	25	
HYB-3	1	25	CLT
	2	25	
	3	25	
	4	25	
HYB_e-1	1	25	CLT
	2	25	
	3	37.5	
	4	37.5	
	5	37.5	
HYB_s-1	1	25	no CLT
	2	25	
	3	37.5	
	4	37.5	
	5	37.5	

4 RESULTS AND DISCUSSION

This section will give a brief overview of the experimental results; the complete outcome is presented in [8]. Figures 9 to 12 show results of the tests in term of force-displacement graphs. The first three pictures refer to the specimens tested on the main setup, with the CLT panel. The shape of the hysteresis loops closely resembles that of a rectangle, which is the ideal shape for a rigid-plastic system. The shape is not precisely a rectangle since the system is not a pure friction connection, but it's influenced by the deformability of the steel plates and of the timber screw connection. The influence of the screw timber connection on the friction system is primarily visible in the initial cycles and at the change of directions: the graphs present a slight S shape, typical of the pinching phenomena of timber connections, which causes a loss in energy dissipation. In all the tests, the force value reaches peaks at initial cycles and then stabilizes to lower constant values, this was also observed in the previous campaign and is due to both the static vs dynamic friction behaviour and to wear degradation phenomena of the friction surfaces.

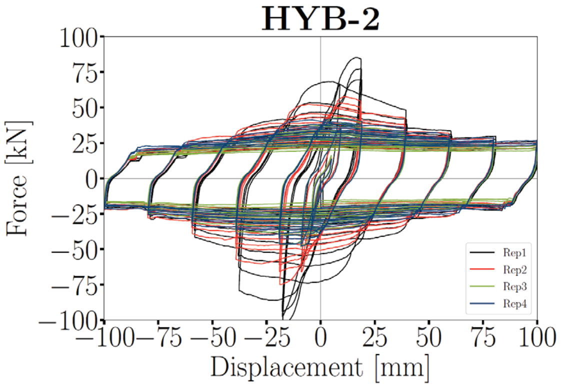

Figure 9: *Results of specimen HYB-2.*

Specimen HYB_e doesn`t present a drastically different behaviour from specimens HYB-2 and HYB-3, suggesting that the reduced eccentricity doesn`t play a key role in the stable friction behaviour. Figure 12 presents the results from the specimen that was tested on the second setup, which was made only of steel and used a bolted connection instead of a screw connection. The immediate difference in the graphs is that the shape is more

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rectangular, and the load inversion branches are more vertical, given the higher stiffness of the bolted connection. Additionally, the steel setup offers a more stable friction behaviour, with minor fluctuations in the slip force value, suggesting that a stiffer connection system is preferable to exploit the full potential of the friction connection.

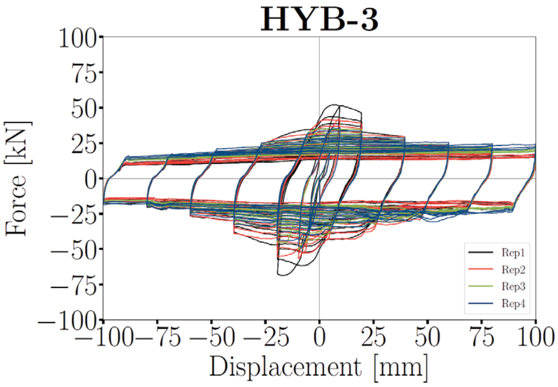

Figure 10: *Results of specimen HYB-3.*

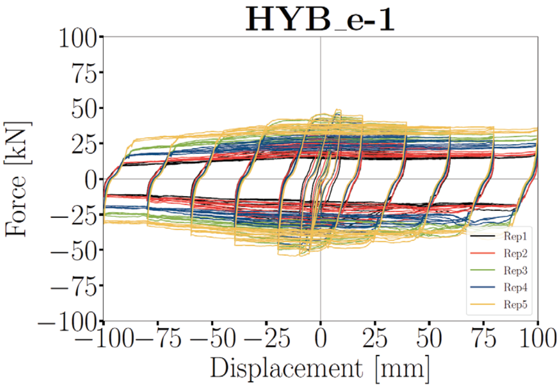

Figure 11: *Results of specimen HYB_e-1.*

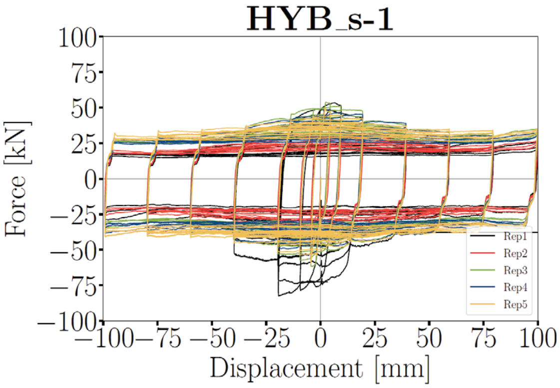

Figure 12: *Results of specimen HYB_s-1.*

Results in terms of slip force and friction coefficient are presented in Table 2. The definition of the slip force from the experimental data is not immediate, as the value fluctuates throughout the test, changes sign and is influenced by the initial phenomenon of changing from static to dynamic friction. The authors decided, therefore, to use the same approach adopted by [9]. The definition of slip force is based on the total dissipated energy and the cumulated displacements, both values are positive and strictly increasing functions. The dissipated hysteretic energy is defined by the following:

$$E = \sum_{i=0}^{n} E_i = \sum_{i=0}^{n} \left|\frac{F_{i+1}+F_i}{2}\cdot(\delta_{i+1}-\delta_i)\right| \qquad (1)$$

where E is the dissipated energy, E_i the dissipated energy at the i −th time step, F_i and δ_i are the force and displacement at the same time step, respectively.

The cumulative distance of travel D is the sum of the displacement time steps:

$$D = \sum_{i=0}^{n} |\delta_{i+1}-\delta_i| \qquad (2)$$

The slip force is thus calculated as the energy per unit of length:

$$F_{\text{slip}} = \frac{E}{D} \qquad (3)$$

The experimental friction coefficient μ is calculated as

$$\mu = \frac{F_{\text{slip}}}{n_s n_b F_P} \qquad (4)$$

where F_{slip} is the slip force calculated in Eq.((4)), n_s is the number of shear surfaces equal to 2, n_b is the number of the preloaded bolts equal to 2, and F_P is the preload force from Tab.1.

Tab. 2 shows the friction coefficient values as an average for the repetitions on every specimen with the same preload force. The global average of the testing campaign is 0.21, which aligns with literature values for friction coefficients of aluminium vs steel. [10]. Aluminium is also a good choice for the friction system for its ease of sourcing, manufacturing, and price, when compared to other possible materials for the shim layers of the friction connection.

Table 2: *Test results: slip force and friction coefficient.*

Tests	Preload [kN]	F_{slip} [kN]	μ
HYB-2(r1234)	25	25.9	0.26
HYB-3(r1234)	25	20.5	0.21
HYB_e-1(r12)	25	18.2	0.18
HYB_s-1(r12)	25	21.2	0.21
HYB_e-1(r345)	37.5	29.9	0.20
HYB_s-1(r345)	37.5	32.2	0.22
mean			0.21

Tab. 3 attempts to clarify the most critical aspect of the difference between the two setups: energy dissipation. When testing a simple friction connection, composed of a basic system of 3 plates with relative sliding, the expected mechanical behaviour is a perfectly plastic system, producing rectangular hysteresis loops, as seen in Fig.13a. The friction device tested in this campaign is more complex than a basic friction connection, it has a complex

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shape and it`s asymmetric, thus introducing additional deformational contribution to the system. These components then reduce the energy dissipation compared to the ideal rectangular behaviour, see Fig.13b. Moreover, if a connection with screws is added to the system, then it acts as an additional deformation component, which also causes a loss of energy dissipation and a more unstable friction behaviour, see Fig.13c. This concept is summarised in Tab. 3 where some values of dissipated energy are presented. In the first part of the table, the dissipated energy is the average as the tests on the CLT setup vs the test on the steel setup for a preload of 25kN, while in the second part, the same dissipated energy value is presented but referred to the tests with 37.5kN preload. The percentage of difference in dissipated energy summarises the contribution of the screw connection to the friction system. On average it causes a 12% energy loss when compared to a system without the CLT connection.

Table 3: *Test results: dissipated energy.*

Test	F_{slip} [kN]	Energy [MJ]µ
HYB-2; HYB-3; HYB_e-1 (r12)	21.8	78.5
HYB_s-1(r12)	21.2	89.4
Diff %		12.2
HYB_e-1(r345)	29.9	100.5
HYB_s-1(r345)	32.2	118.6
Diff.%		11.4

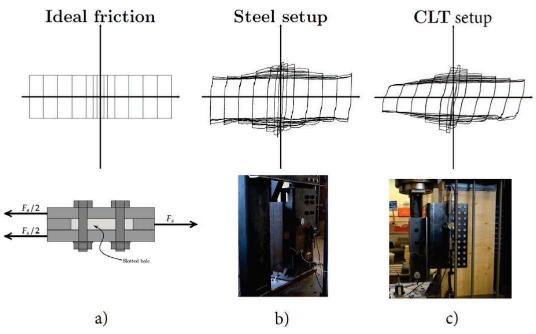

Figure 13: *Scheme illustrating how the addition of more components to the friction connection influences the behaviour: a)single ideal friction connection; b)specimens tested on the steel setup in* [5], [8]*; c) specimens tested on the CLT setup in* [8].

5 CONCLUSIONS

This paper presents the results of an experimental campaign on a novel friction connection for seismic retrofit purposes. The retrofit system, part of the European project e-Safe, is called e-CLT and consists of applying a CLT panel to the outside of existing RC-framed buildings by using a special connector that acts as a friction damper. The experimental campaign presented in this paper, following the first phase presented in [11], aims at studying the interaction between the friction behaviour and the presence of a screw connection between the steel plate and a CLT panel. Four different specimens were tested on two setups: one with a CLT panel and one without a CLT panel, and the main conclusions are:

- The system works and dissipates energy with a rectangular-like shaped hysteresis loop, while not being a perfect rigid-plastic system because of the many components of the system;
- Aluminium represents a good choice for the shim layers, and the friction coefficient values that were obtained are in line with literature values;
- The main effect of adding a steel-to-timber screw connection to the system is a loss of dissipation capacity due to the added deformability component: on average the system with CLT connection dissipates 12% less energy.

Following the promising results of the testing campaign at component level, a new series of tests at frame level is being planned. A 3x4 m RC frame with masonry infill will be tested with and without the e-CLT retrofit system.

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