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Timber structures in french caribbean seismic zone, from prescription to experimental validation for bracing systems

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Abstract.

Wooden house is a traditional mode of construction in the Caribbean Islands. The presence of a cyclonic risk and a seismic risk imposes detailing and design adapted to these two dynamic situations and this type of housing. For these two dynamic actions, the role of the mass is completely different and has to be taken into account in detailing and design. Simplified rules and multi-risk guidelines are adapted to the new standard panel of Eurocodes (NF EN 1995 and 1998-1) for French Caribbean Islands. Simplified earthquake rules for individual housing (CPMI Z5) is not yet published, but it has been tested on different projects by civil engineering design companies. Storm and earthquake design guide for wooden houses (maisons bois parasismiques et paracyclonique aux Antilles) was published few years ago, but it is not yet applied. This work present an experimental campaign performed in French Caribbean islands on traditional timber moment resisting frames. These bracing structures and light wooden frames are realized by students of a local technical school and by carpentry companies. These structural wall respect standard&guide requirements or local patterns and are full scale tested. Wall specimens, experimental setup, results and analysis are presented in this paper. A wide place is given to different detailing design and behavior. Anchoring to the basement is also discussed.

Keywords: Caribbean Islands wooden houses, traditional bracing systems, experimentation

1. Introduction

Timber houses are widely common in French Caribbean Islands; they represent the traditional housing. These structures have to support sever dynamic loadings, extreme wind loads and also earthquake actions. Local or national programs contributed and still contribute to reduce accidental risks with identification of hazard maps [1] or simplification of Eurocode rules (NF EN 1998) for usual building [2], [3] & [4]. These usual buildings are less complicated than complex ones, but much more representative in terms of number of floor built square meters [5]. So, prescription of hand book have been written (cyclonic and earthquake prescription for timber French Caribbean houses, CPMI application examples guide) [6], [7];. the present work focuses on experimentation of timber bracings validation (or not) of bracing design included or not guideline requirements.

This experimental study is conducted under the umbrella of Guadeloupe region administration and AFPS association (French association on earthquake design). This program integrates undergraduate students, architects, carpenters, factories, control companies and a civil engineering laboratory. In order to associate local carpenter companies, tests were performed directly in Guadeloupe. In order to implicate young students, tests are carried out in a professional school without any experimental equipment. Student of the masonry section fabricated the ground longitudinal beams. Metallurgical section provided safety equipment in order to assume the lateral stability of the experimental setup. The cyclic load was applied by a hydraulic jack located between the tested shear wall and a strong wall (support reaction) realized with large Angelim wood triangularly braced elements. Mechanical parameters are measured and recorded by load cells, LVDTs and inclinometers, connected to electronic and numerical equipments. Some of the shear walls are designed with hand book requirements, others correspond to local use. Part of these full scale bracings are realized by carpenters other are realized by carpenter section students. Different solutions of anchors have been also carried out.

Experimental setup, shear wall configurations (more specifically two shear wall configuration commonly used in French Caribbean islands and France), experimental results & observations, results analysis are successively presented in this paper Partial or global failure modes are discussed. Anchoring conditions and mechanical behavior are also discussed and compared to Eurocode approach and requirements (NF EN 1995-5 , 1998-1) [8], [9].

Guadeloupe regional administration, local carpentry companies, local carpenters students from Guadeloupe technical schools, ANCO control office, Polytech Clermont-Ferrand laboratory, Lamentin Bertène Juminer school administration, French association on earthquake design AFPS are involved in this work.

2. Experimentation

2.1. Overview

A set of full scale tests have been carried out at the beginning of 2013 in Bertène Juminer school (Lamentin-Guadeloupe) on timber resisting frames. These tests were performed by Anco Guadeloupe Company, Polytech Clermont-Ferrand laboratory and different local or national professional actors.

The objective of this experimentation is to determine the behavior, the strength and the failure mode(s) of traditional or innovative light wooden frames and timber bracing frames in order to be able to compare to the theory and guideline and code requirements. The load history is derived from NF—EN 12512 (for timber joints in seismic situation) [10] with increasing cyclic sequences.

2.2. Methodology and instrumentation

The tests are designed to be as representative as possible of the reality:

- realization of bracing by carpenters companies and carpenters students,
- realization of reinforced concrete ground beams by students of masonry section,
- utilization of industrial hole down and anchors in real configuration.

Figures 1 and 2 show the configuration (sketch and photos) of the testing of these bracing systems. A 5 meter high hall with an horizontal floor is required for the experimentation; masonry training building of Bertène Juminer vocational school offers us this equipment. Two ground beams were installed here in order to anchor the shear walls and the reactive wall. Building structure elements are used to stabilize the experimental equipment. The horizontal force is applied through a hydraulic jack with pin connection at these two extremities.

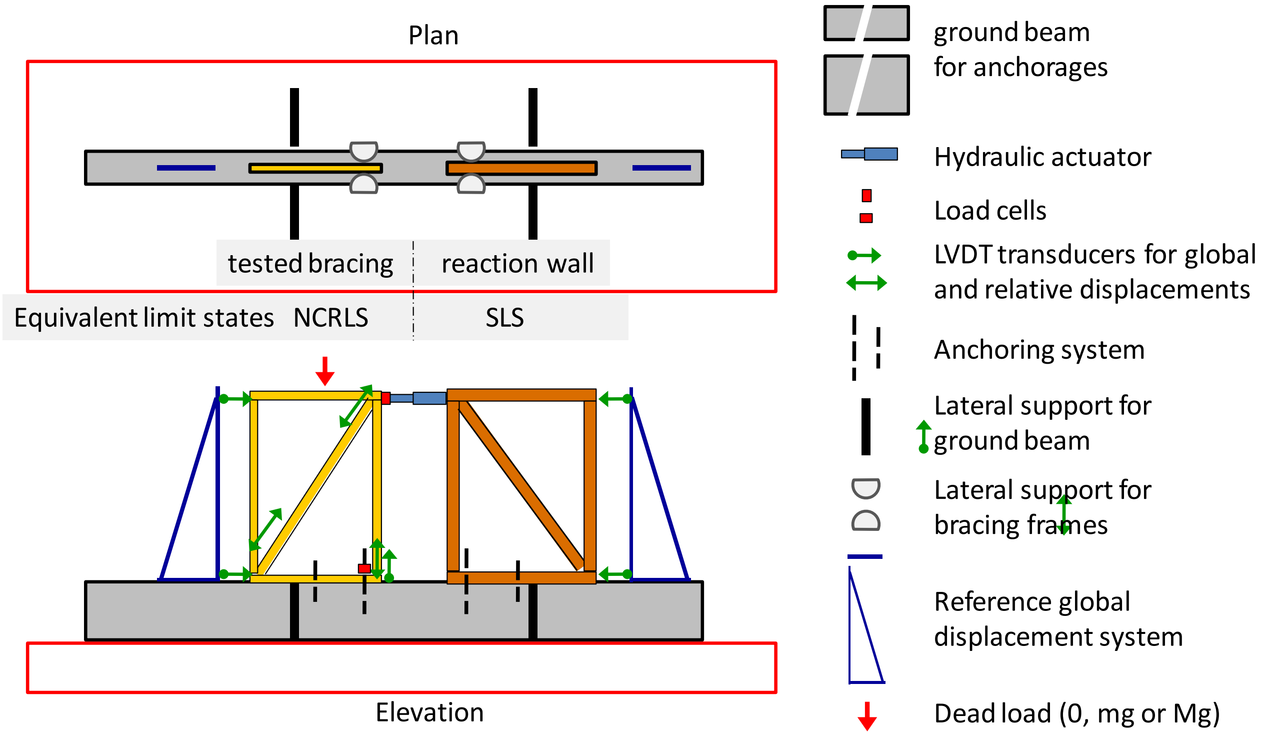
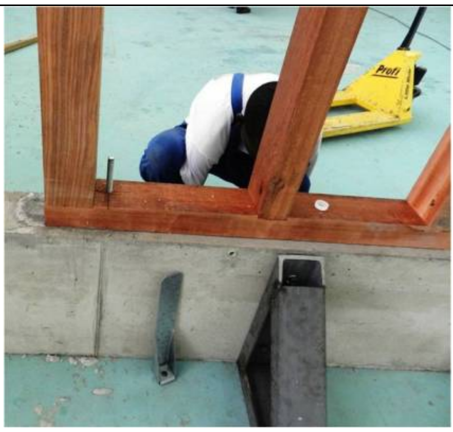


Fig 1 . Experimental configuration and instrumentation



Reinforced concrete ground beam, steel bracket for lateral stability and holdown for reaction wall

Between reaction wall and tested shear wall, double pined hydraulic jack with load cell in preparatory phase

Fig 2. Illustrations of experimental setup

The actuator is manually controlled; the applied load is composed by successive compressive cyclic sequences, the amplitude increases sequence by sequence. This load history corresponds to the loading of the greatest part of tested shear walls which are designed in order to be coupled in a primary wall and to work successively under repeated and non alternate loading. The reaction wall itself is a hardwood bracing wall designed for a greater horizontal force. The reaction wall is also instrumented and is integrated in the experimental campaign.

The loading is a quasi-static load, it consists of cyclic sequences. Each sequence of the quasi-static cyclic loading is composed of 3 complete cycles. The figure 3 illustrates the load history.

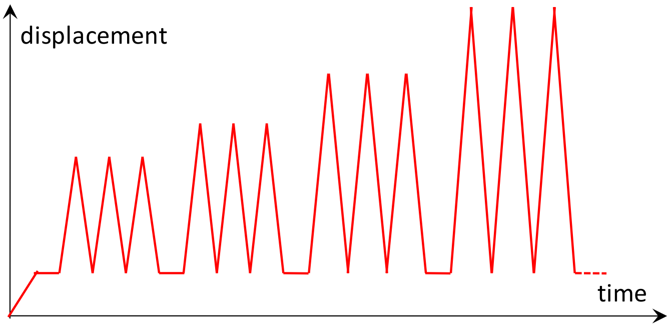


Fig **3 –** load history

The instrumentation is composed by load cells, LVDTs, and inclinometers. The objective of the instrumentation is to control the load history and the global behavior of the whole experimental system, to obtain the global behavior of the shear walls and the reaction wall, to obtain local information on the behavior of most important joints inside the walls. Figure 4 illustrates some of these equipments. The instrumentation equipment is composed by:
- two200 kN ring load cells
- one 200 kN compression load cell
- one 50 kN traction load cell
- eight LDVTs from 50 mm to 200 mm
- two +/- 15 degree inclinometers.

These equipments are directly fixed on the wall components for relative measurements or between shear walls and specific steel support for global displacement, cf. figure 1.

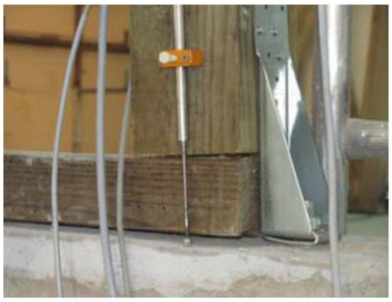
	Measurement of the rotation of the base of reaction wall (+/1 15° inclinometer)		Measurement of the relative displacement between diagonal & shear wall bottom plate (50 mm LVDT)
	Measurement of the horizontal global displacement of the shear wall (200 mm LVDT)		Measurement of vertical displacement in anchoring zone (50 mm LVDT)
	Measurement of anchorage force of the reaction wall (200kN ring load cell)		Measurement of anchorage force of the shear wall (200kN ring load cell)

Fig 4 Illustrations of the setup of the instrumentation

The value of the vertical dead load varies with the implantation of the shear wall in the building (orientation of beam floors parallel or perpendicular to the shear wall, façade or inside wall, number of storey 1 or 2...) and also with the action, earthquake or storm. Three configurations have been expected (cf. figure 1), without dead load, with a minimum value of dead load (xx kN), or with a maximum value (yy kN); these values are determined with standards requirements and traditional local building techniques. In order to test the shear wall in the worse situation it has been decided to not applied dead loads. This situation correspond to a single story building with beam floors parallel to the shear wall, or shear wall with a vertical wind action equal to dead loads. Upper plate joints and anchors are so tested under severe conditions.

2.3. Tested panels

The assumption for the tests is a service class 2 in terms of Eurocode 5 criteria (a measure of on-site wood moisture content was performed giving dune wood humidity of around 16%) Two of the shear walls are realized with Wooden panels, one is European OSB and the other is a north American plywood, T111 usually used for horizontal or roof diaphragm in Caribbean islands. Excepted for reaction wall made in Anglim hardwood, the other shear wall beam elements are realized with European soft wood, qualified as C24 (24 MPA as characteristic value for MOR). Six different types of shear walls have been realized. For each type, one shear wall is realized by a company, one is realized by vocational students. The 8 shear walls tested during this experimentation are named:

- VT-T111-C24 for shear wall with T111 panel,
- VT-OSB- C24 for shear wall with OSB panel,
- PST K-C24_S for double K bracing wall,
- PST1-C24_Cap for X bracing wall,
- PST1-C24_G idem,
- PST4-C24_G for single diagonal bracing wall,
- PST4-C24_Cap idem,
- PST4-D40 for the reaction wall,

Only VT-T111-C24, VT-OSB- C24, PST K-C24_S and PST1-C24_Cap are illustrated in Figure 5.

Test: PST1-C24_Cap	test 8: PSTK-C24_S	test 2: VT-OSB-C24	test 1: VT-T111-C24

Fig 5 Few illustrations of tested shear walls

2.4. Anchoring systems

Anchoring to the ground beam of reaction wall and shear walls are realized by HTT5 Simpson tension tie and different mechanical and chemical holdowns:

- wedge-type expansion anchor Strong-Bolt,
- threaded rod with nut and washer cast in a reservation,
- threaded rod with resin chemical seals.

These elements are illustrated on figure 6.

 tension ties, strong-bolt and threaded rod used during the tests	 joint between stud and top plate with HHT5 tie, screws and threaded rod + dovetail for reinforced PST4_G
 joint between stud and bottom plate and ground beam, HTT5 tie+16 4x50mm nails, 16mmf threaded rod: $F_{V, anc,Rk}$ = 24,70 kN)	 relative position of the threaded rod (220mm length) before anchoring

Fig 6 Illustration of anchoring systems

3. Experimental results

Only VT-OSB-C24 panel and PST4_C24 are presented here.

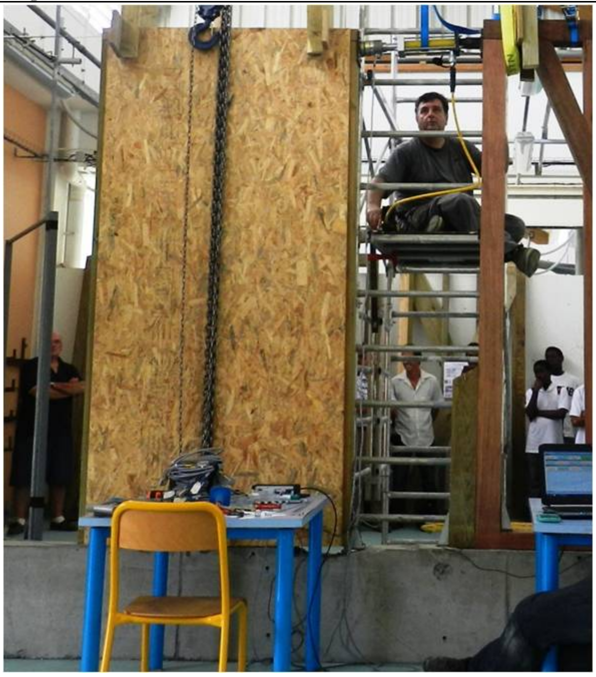
3.1. Observed damage and mechanical behavior

3.1.1. VT-OSB-C24 panel

The specimen - The VT-OSB-C24 panel is made of a solid wood frame: softwood C24 (1,27m long, 2,49 m high, section 6,6 x 11,8 cm²) and OSB3 wood-based panels jointed together by 2,8mm x 70 mm nails with a spacing of 100 mm. The actuator force is applied at the height of the top plate.

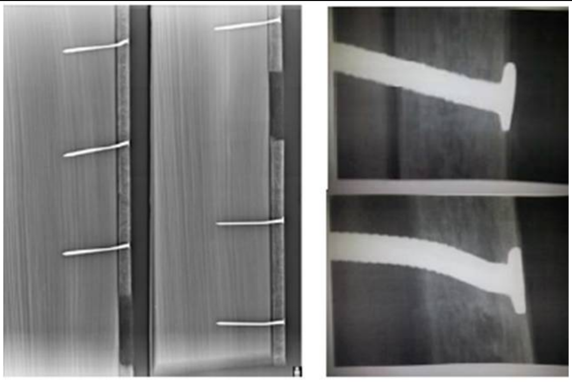
Final displacement, strength and damage - At the end of the test, the residual horizontal displacement of the VT-OSB-C24 shear wall is approximately 1,2 cm. The stop of the test is due to a failure of the anchorage; the holdown slept for a horizontal load of 1750 daN. This failure is due a non-sufficient length of tensile anchorage in the ground beam to a too low position of the steel bars of the reinforced concrete in the ground beam. The maximum horizontal displacement of the top plate of the shear wall reached 37,8 mm.

After the test radiographies have been performed in order to analyze the deformation of the nail between the frame and the panel. These experimental results are illustrated in figure 7. The deformation of the nails are in a good accuracy with Johansen model integrated in NF EN1995-1.1 [8].



VT-OSB-C24 panel: at the end of the test

VT-OSB-C24 panel: anchor residual slip of the tensile threaded (≈8mm) rod and concrete cracks



VT-OSB-C24 panel: frame-panel displacement and deformation of the nails

VT-OSB-C24 panel: Uprising of the bottom plate and concrete cracks around the anchorage

Fig 7 Illustration of the behavior of VT-OSB-C24

Mechanical behavior – The load-displacement curves of VT-OSB-C24 panel are presented in figure 9 and compared with PST4-C24 ones. These curves show non linear behavior of the shear wall. The global behavior horizontal displacement of the top plate versus actuator force is not complete due the lack of anchoring. The non elastic behavior of the nailed joint between frame and panel clearly appears on relative displacement curves.

3.1.2. Bracing wall PST4_C24-G and PST4-C24-Cap

The specimens - The two bracing walls PST4 present the same external dimensions. They differ by the kind of joints between peripheral members. The length and the height of the walls are respectively 1,49 m and 2,69 m. The section of external studs and top plate is 12x12 cm². Intermediate stud and bottom plate one is

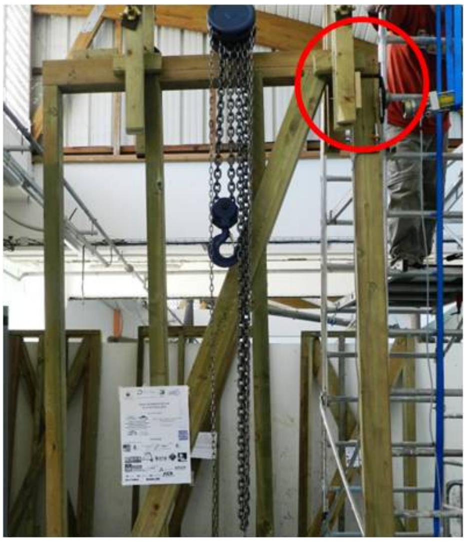
7x12 cm².The section of the diagonal member is 12x12 cm². All these members are made of C24 soft wood. The joints between diagonal and plates are rafter-tie beam joints in order to work in compression with two inclined screws to assume the relative position of the members after alternate loading.

For PST4-C24_G, the joints between peripheral members are dovetail ones, locally usual but not integrated in guides or requirements.

For PST4-C24_Cap, joints between peripheral members integrate 6 mm x 120 mm screws and tension tie brackets (Simpson HTT5).

Final displacement, strength and damage – The end of the PST4-C24_G is due to the failure of the dovetail joint between the top plate and the tensile stud for a maximum load of 902 daN while the horizontal displacement reaches 76 mm.

The maximum of load applied to PST4-C24_Cap reached 1 536 daN for a horizontal displacement of 122 mm. The final failure is due to the tensile rupture of the joint between the stud opposite to the applied load and the top plate.



PST4-C24_G bracing frame at the end of the test

PST4-C24_G bracing frame: failure of the dovetail joint

PST4C24_Cap bracing frame: bending of the top plate and failure of top plate – stud opposite to the load

PST4C24_Cap bracing frame: relative displacement close to the applied load and the diagonal between top plate and stud, joint with HTTR reinforcement

Fig 8 Illustration of PST4-C24 bracing frames

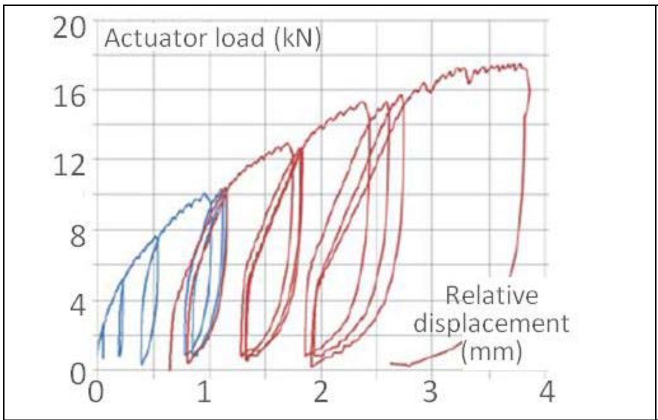
Mechanical behavior – The load-displacement curves of PST4-C24_Cap are shown on figure 9. The behavior PST4-C24_G is not reported in this paper, it is close to PST4-C24_Cap with an earlier failure. The local behavior is clearly non linear, but the global behavior is not so non linear.

3.2. Comparative analysis of the experimental results

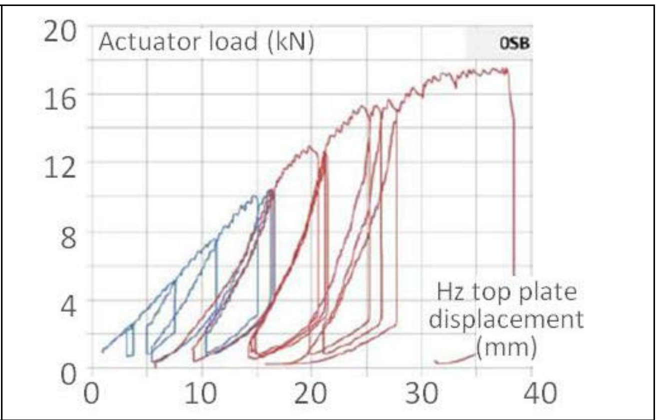
A comparison of the resistances indicated in the guides with those obtained is shown in Table 1 below. Local and global curves (force-displacement) are shown in Figure 9.

Table 1 Failure mode and strength comparison of shear walls

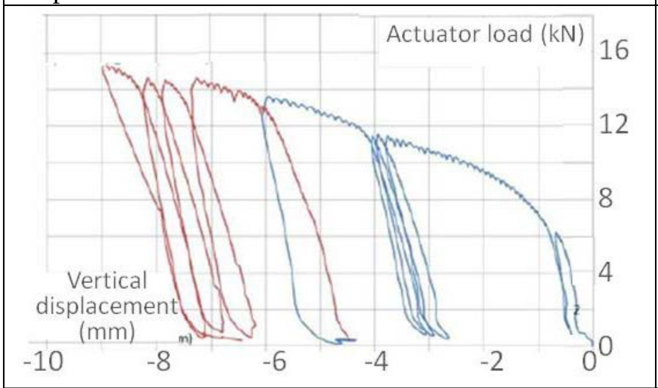
Test	Panel	Configuration	Experimental strength F (daN)	Strength value in CPMI-Z5* and Timber guide** FRd Sis (daN)	Comments
No. 2	VT-OSB-C24	OSB nailed panel on Light C24 frame	1 750	* 750 - (2,8mm nail) ** 850 - (3,1mm nail)	Experimental results are above guide values
No. 6	PST4-C24_G	Single diagonal and screws+HTT5 tension ties	1 286	* 3 440 ** 5 280	Guide strength value is defined by buckling strength of the diagonal member and not the strength of joints
No. 7	PST4-C24_Cap	Single diagonal and dovetail joints	1 536	* 3 440 ** 5 280	



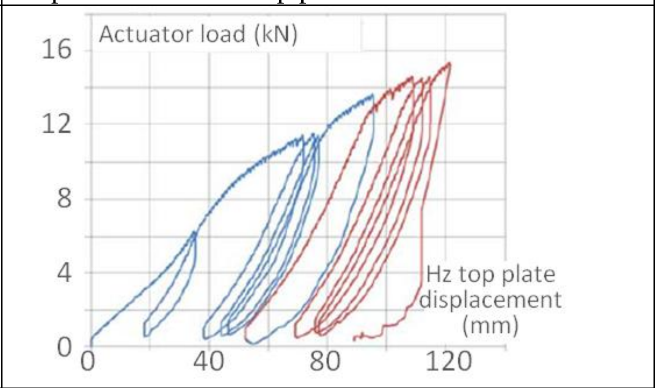
VT-OSB-C24 actuator load – relative stud-panel displacement



VT-OSB-C24 actuator load – horizontal displacement of the top plate



PST4-C24_G actuator load – vertical displacement of the tensile stud



PST4-C24_G actuator load – horizontal displacement of the top plate

Fig 9 – Comparison of mechanical behavior of shear walls

4. Conclusion

This unique project for the carpentry industry in the French Caribbean islands has been performed in partnership with many professional players in the construction of Guadeloupe, Martinique, France with Guadeloupe vocational schools (High Schools B. Juminer Lamentin, P. LACAVE Capesterre Belle Eau, C. Nicolo Basse Terre). During the 8 days of the experimentation in Bertène Juminer school conferences on the

Eurocodes (including Eurocode 1998-1) on experimentation instrumentation, and educational activities have been carried out. More than a hundred students moved to saw experimentation or to participate to the test of the bracing wall they realized.

A lot of information has been extract from these height tests, on strength, rigidity, ductility and failure mode. Failure modes have been analyzed compared with requirement values and modifications or reinforcement of shear wall have been proposed. Elements of requirement guides have been modified in order to reach the expected ductile behavior. These tests show the impact of the semi-rigid behavior of the different joints on the rigidity of the shear wall, but also on the failure mode. Anchors can also be integrated in this remark. These results are actually complete by material experimentation on material of component in order to integrate these tests in an experimental by design approach proposed by Eurocode standard.

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