WP3 TR3.1.b
Structural Analysis
(TEST REPORTS)

CLT STRUCTURAL ANALYSIS REPORT OF IMIP PANELS, (TEST REPORTS) ACTIVITY 3.1.b (ED2310385)

IMIP-SOE3/P3/E0963

Project funded by the Interreg Sudoe programme through the European Regional Development Funds (ERDF)

PROJECT CONTEXT

Project acronym	IMIP
Project title	Innovative Eco-Construction System Based on Interlocking Modular Insulation Wood & Cork-Based Panels
Project code	SOE3/P3/E0963
Coordinator	Universitat Politècnica de València (UPV), Instituto ITACA
Duration	1 May 2020 – 31 January 2023 (33 months)
Working Package (WP)	WP5.TR5.1.1
Deliverable	TR5.1.1
Summary	The deliverable includes the structure, responsibilities and procedure of the different management bodies created, both for the correct technical, communication and financial monitoring.
Delivery date	05/2023
WP Leader	ISA
Activity coordinator	ISA
Payer Customer	INIA
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CONTENT

INTRODUCTION

This report describes the system that will be used for the evaluation of the results obtained with those programmed in the proposal. This system consists of a continuous evaluation to detect early deviations from the established plans to correct them with enough time.

Project monitoring and evaluation (M&E) will be carried out internally. Monitorization will be done once a month for ongoing activities. Instead, project progress will be evaluated every 6 months during the Steering Committee meetings. Any required action will be defined during these meetings.

The M&E goal is to ensure that project contributes to the **programme specific objective** by reducing any risk or deviation that may rise during project execution. IMIP project will contribute to this objective with the **project main objective** which will be pursuit by the **project specific objectives** and the related activities defined in the project proposal.

The **programme result indicator** will be employed to evaluate how well the programme specific objective has been achieved. **Project results**, and specially the three **main project products**, will be used to evaluate the success of the project main objective.

Objectives and results are defined in Table 1.

Table 1: Programme and Project objectives and results.

Programme specific objective	To improve energy efficiency policies in public buildings and homes through the implementation of networks and joint experimentation.
Project main objective	To support the change towards a low carbon economy using bioproducts (wood and cork) for smart, sustainable, and inclusive growth with a special focus on the public construction sector.
Project specific objectives	To design, validate and implement a new ecological construction system to improve energy efficiency in public buildings. Related activities are: - To design an ecological construction system based on innovative wood and cork products supporting a low carbon economy, - To test prototypes, - To develop an Information and Communication Technology for design, modelling, and evaluation of potential construction solutions, - To compare the modular and interconnected insulating panels designed with currently used insulating panels, - To disseminate results and to train prescribers.
Programme result indicator	Percentage of actors in the energy efficiency sector participating in transnational cooperation projects.
Project results	An interconnected modular system of insulating panels made of wood and cork to improve energy efficiency of buildings, including their entire life cycle. A BIM plug-in to analyse the environmental benefits of bioproducts used in construction (carbon storage and substitute effect).

OBJETIVES

The aim of the present technical report is to validate the load capacity for four different CLT panels due to flexion and compression.

In the previous report, WP3 TR3.1.1 a Structural Analysis CLT PANELS LOAD CAPACITY (ED2210276), are described the materials, the characteristics of the panels and the capacity of the panels. Three studies are carried out in this study:

1. Adaptation of sections and materials according to the suppliers
2. Validation of the results obtained through tests

Throughout the study, the panel materials have been adapted to the availability of the suppliers by adjusting some characteristics. In this study, the geometrical and mechanical characteristics of the panels used are reviewed.

Materials

The materials used for the construction of the beams and the 60mm CLT, which form the type A and C panels, are "Pinus uncinata" usually known as "Pino negro". In panels' type B and D, the "Pinus Pinaster" usually known as "Pino marítimo" has been used.

Usually the "Pinus Pinaster" is a lower quality pine and is usually classified as C16 and the "Pinus uncinata" has a better quality and can be compared to a C18 or C20. The panels finally constructed, with the data obtained from the visual classification and the tests, have been determined in both cases to have a C18 classification.

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Description of the test panels

Type A

- Type A: CLT of 60mm (3 layers of 20mm) + ribs of 80x200mm Total thickness of 260mm.
- Material "Pinus uncinata" C18.
- Test section

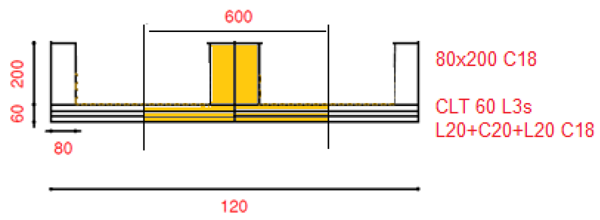

Figure 1: Panel A test section

The original definition had an OSB panel and an internal cork which are not structural and have therefore not been included in the tests. In the tests, no major differences have been found with respect to the results of the calculations carried out in previous report WP3 TR3.1.1.

In summary, in short spans of around 3 metres, it limits the shear stresses and for spans of around 6 metres it limits the deformations, the failure associated with the material appears with deformations of around L/100, well below the minimum normative criteria of L/300.

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Type B

- Type B: CLT of 45mm (2 layers of 18mm + oriented strand board layer of 9mm) + 100 and 150mm cork insulation + CLT of 45mm. Total thickness of 190 to 240mm.
- Material “Pinus Pinaster” C18, Cork (E=5MPa) and OSB
- Test section

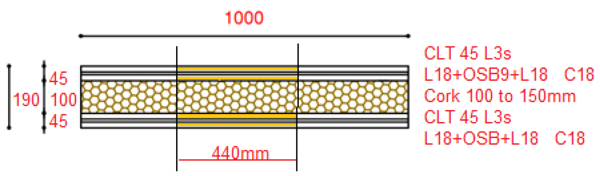

Figure 2: Panel B test section

The cork layer was not considered structural in previous report WP3 TR3.1.1. As was foreseeable after the tests, it can be confirmed that if cork is considered as a structural material, it will be possible to support larger spans than the initial ones, obtaining deformations 20 times smaller and stress states between 20% and 100% smaller than the uncoupled work.

Even being conservative, without further studies and disregarding the tensile improvement of the CLT layers, it would be possible to eliminate the deformation restriction and limit the capacity of the panel in its stress states.

However, it is observed that most of the cracks occur in the OSB layer. The characterisation of the OSB was carried out using the tables provided by the standards. Comparing it with tables from other suppliers, it can be seen that its resistance capacities are 10 times lower than those considered in the load study, and should therefore be re-studied.

At the time of writing this report, the technical data sheet for OSB is still awaited. It has already been indicated that there is no technical data sheet for cork at a resistance level.

With the results obtained from the tests, a detailed study should be made of both the mechanical characteristics of the cork and the mechanical characteristics of the OSB, determining not only the states of deformation but also the stress states through the placement of extensiometric bands. Cork loading and unloading and stiffening cycles should also be carried out over time.

In summary, to validate the composite behaviour, a detailed study should be carried out. Conservatively, it is proposed to revise the tables by including the real characteristics of OSB and disregarding the deformations.

Type C

- Type C: CLT of 60mm (3 layers of 20mm) + ribs of 80x200mm + CLT of 60mm. Total thickness of 320mm.
- Material “Pinus uncinata” C18
- Test section

The cork layer is not considered structural.

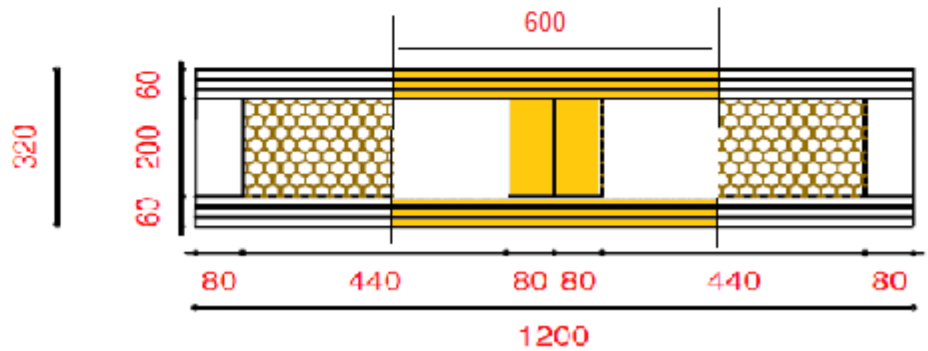

Figure 3: Panel C test section

Type D

- Type D: CLT of 100mm (5 layers of 20 mm) + 100mm cork insulation. Total thickness of 200mm.
- Material “Pinus Pinaster” C18

- Test section, (test results are pending)

The cork layer is not considered structural.

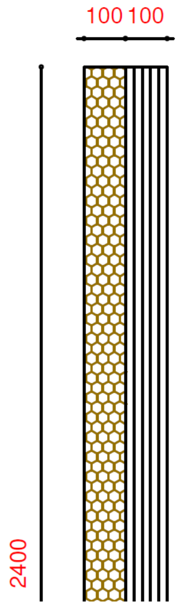

Figure 4: Panel D test section

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Basis of test

- Design code

For the tests in panels A, B and C, ETAG16 has been used.

Materials properties

The materials used to make the structural elements are detailed below.

Wood from panels A, B, C and D

The type of wood used to validate the tests is a coniferous wood C18. Its most relevant characteristics, which have been considered in the calculation, are the following:

Definition and characteristics of coniferous sawn wood defined in the UNE-EN 338:

Properties	C16	C18
Charasteristic strenght N/mm^2		
Bending strength f_{mk}	16	18
Tensile strength along the grain $f_{t,0,k}$	10	11
Tensile strength perpendicular to the grain $f_{t,90,k}$	0.4	0.4
Compressive strength along the grain $f_{c,0,k}$	17	18
Compressive strength perpendicular to grain $f_{c,90,k}$	2.2	2.2
Shear strength $f_{v,k}$	3.2	3.4
Stiffness kN/mm^2		
Mean value of modulus of elasticity $E_{0,mean}$	8	9
Fifth percentile value of modulus of elasticity $E_{0.05,k}$	5.4	6.0
Mean value of modulus of elasticity perpendicular $E_{90,mean}$	0.27	0.30
Shear modulus G_{mean}	0.50	0.56
Density Kg/m^3		
Characteristic density ρ_k	310	320
Mean density ρ_{mean}	370	380

OSB panel from type B panel

The main characteristics of the OSB panel, which have been considered in the structural calculation, have been the ones defined in the UNE-EN 300:

Propiedades			OSB/2 y OSB/3 (UNE-EN 300:2007) Para su uso en ambiente seco y húmedo Espesor nominal, t_{nom}, en mm		
			$6 < t_{nom} \le 10$	$10 < t_{nom} \le 18$	$18 < t_{nom} \le 25$
Resistencia (característica), en N/mm²					
Flexión	paralela	$f_{m,p,0,k}$	18,0	16,4	14,8
	perpendicular	$f_{m,p,90,k}$	9,0	8,2	7,4
Tracción	paralela	$f_{t,p,0,k}$	9,9	9,4	9,0
	perpendicular	$f_{t,p,90,k}$	7,2	7,0	6,8
Compresión	paralela	$f_{c,p,0,k}$	15,9	15,4	14,8
	perpendicular	$f_{c,p,90,k}$	12,9	12,7	12,4
Cortante, en el grueso		$f_{v,p,k}$	6,8	6,8	6,8
Cortante, en el plano		$f_{r,p,k}$	1,0	1,0	1,0
Rigidez (media), en N/mm²					
A flexión	paralela	$E_{m,0,p}$	4930	4930	4930
	perpendicular	$E_{m,90,p}$	1980	1980	1980
A tracción	paralela	$E_{t,0,p}$	3800	3800	3800
	perpendicular	$E_{t,90,p}$	3000	3000	3000
A compresión	paralela	$E_{c,0,p}$	3800	3800	3800
	perpendicular	$E_{c,90,p}$	3000	3000	3000
A cortante, en el grueso		$G_{v,p}$	1080	1080	1080
A cortante, en el plano		$G_{r,p}$	50	50	50
Densidad, en kg/m³					
Característica		$\rho_{p,k}$	550	550	550

From the validation by means of tests, it is observed that in type B panels, systematic breakage is produced by the OSB panel. There is no specific technical data sheet for the OSB panel, so the data sheet of a local industrial supplier, "Maderas Alberch", was sought, which provided the following technical data sheet.

PROPIEDADES FISICO-MECÁNICAS

	Espesor (mm)			
	6 – 8 -10	10 – 12	18 – 22	REF.
Densidad (kg/m³)* - rango	620±40	600±40	580±40	EN 323
Humedad residual (%) - rango	9±3	9±3	9±3	EN 322
Flexión (MPa) – min.				
Módulo longitudinal	4600	4600	4600	EN 310
Módulo transversal	1900	1900	1900	EN 310
Resistencia flexión longitudinal	28	26	24	EN 310
Resistencia flexión transversal	14	13	12	EN 310
Resistencia flexión V313	12	11	10	EN 310
Tracción (MPa) – min.				
Resistencia tracción	0,50	0,45	0,40	EN 319
Resistencia tracción V313	0,18	0,15	0,13	EN 319
Resistencia tracción V100	0,15	0,13	0,12	EN 319
Hinchamiento (24h) (%) – max.	15	12	12	EN 317
Sin formaldeího añadido				

**dato orientativo*

It is important to highlight the significant difference in values between the two tables, especially in relation to the tensile strength of the panel, which goes from 9.9 N/mm2 to 0.45 N/mm2, a value that would justify the failures observed in the tests. We are currently awaiting the technical data sheet of the manufacturer who supplied the material.

Actions and environmental influences

For the test loads of panels A, B and C, ETAG16 was used. Up to the breakage of the panel. The results obtained are shown in the Annex.

Calculation methods

From the tests, the rupture modes, the applied load and the deformation obtained are provided. No stress data are available.

For type A and C panels. This is a widely studied typology, the stress state is determined from the load data by applying the following tests the basic postulates of the elasticity and resistance of materials have been used.

For the Type B panel, the test contemplates cork as a structural material, so the basic postulates of the elasticity and resistance of materials are not applicable, since the section does not remain flat. In order to determine the stress state of this panel, a finite element model is used which takes into account the shear deformation.

As there is no stress data in the tests, a rigorous analysis cannot be carried out, so a qualitative non-quantitative analysis is carried out, considering elastic and linear models.

A: Test results

The results of the panel tests are validated by means of tests, the modes of rupture of the tests are compared with finite element studies and a classical linear sectional calculation. As there are no detailed data of the intermediate phases of the tests or extensometer bands, the comparative study is done in the linear scope, considering the classical hypotheses of material resistance.

The results of the tests are obtained from an Excel file where geometric data, loads, deformations obtained and rupture nodes are indicated. For future studies, it would be necessary to obtain the load-deformation graphs, carry out loading and unloading cycles and use strain gages to validate the results. Partial information is available in pictures of the rupture modes obtained.

Panel Type A test results

Three videos of panel type A show the following breakage modes:

- Figure 7 and 9, flexural breakage at the bottom of the panel and the joint between panel and beam.
- Figure 8, breakage at the fingers

Figure 5: Failure at the interface between the flange and the web of the section

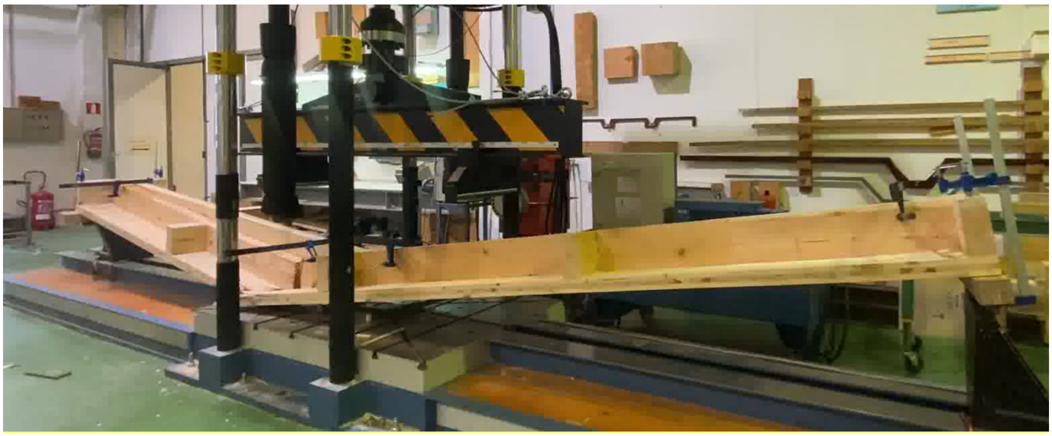


Figure 6: Failure by finger joint

Figure 7: Failure Panel A6-2 failure by flexure traction

Figure 8: Panel A failure detail

ANEX A of WP3 TR3.1.1 presents the results of the theoretical studies according to the standards. At this point, the study is carried out without considering the safety coefficients.

Table 1 shows the cross-sectional characteristics considered. Table 2 shows the modes determining the sizing from Annex A of WP3 TR3.1.1. Table 3 shows the deformations and stresses of the test results obtained.

Panel A	AreaTotal (cm2)	AreaNeta (cm2)	Inercia (cm4)	Dsup(cm)	Dinf(cm)	Wsup (cm3)	Winf (cm3)
L=6m	680.00	564.00	35 104.31	15.62	10.38	2 247.40	3 381.92
L=3	680.00	507.07	31 416.18	14.80	11.20	2 123.30	2 805.02

Table 1: Mechanical characteristics of the section

Longitud	AreaBruta cm(2)	AreaNeta(cm2)	Inercia cm(4)	Wsup (cm3)	ME(cm3)	us deformad	us moment	us tallant	US Resultant [kN/m]	
2.00	680.00	466.40	28 266.84	2 007.50	1 523.31	78.54	52.79	25.77	25.77	Limita Cortante
3.00	680.00	507.07	31 416.18	2 123.30	1 716.54	24.70	23.99	16.41	16.41	Limita Cortante
4.00	680.00	547.73	34 123.64	2 215.09	1 881.07	10.37	13.43	11.79	10.37	Limita deformacion
5.00	680.00	564.00	35 104.31	2 246.80	1 940.24	4.64	8.17	9.09	4.64	Limita deformacion
6.00	680.00	564.00	35 104.31	2 246.80	1 940.24	1.95	5.19	7.32	1.95	Limita deformacion
7.00	680.00	564.00	35 104.31	2 246.80	1 940.24	0.59	3.40	6.05	0.59	Limita deformacion

Table 2: Section analysis result Annex A

				mm				kN/mm2	kN/mm3		cm3	cm4	mkN	cm3	cm	kN	N/mm2	N/mm2	N/mm2
Tipo de panel	Código componente	Tipo de probeta	Fecha ensayo	DEF centro	L/	Fenómeno Fallo	Localización fallo	Inercia Ensayo	Inercia Teorica	Ie/It	W sup	Winf	M ensayo	ME	base alma	Vmax	fmd(sup)	fmd(inf)	fvd
A	A-2-1	1	26/01/2023	87.06	68.00	Cortante plano ala-alma	- Viga en extremo izquierdo entre apoyo y carga	37 794.39	35 104.00	1.08	2 246.80	3 381.92	82.51	1 940.24	16.00	37.85	36.72	24.40	1.31
A	A-3-1	1	27/01/2023	109.52	54.05	Flexotracción	Cara inferior, tercio central	31 709.02	35 104.00	0.90	2 246.80	3 381.92	87.09	1 940.24	16.00	39.95	38.76	25.75	1.38
A	A-4-1	1	27/01/2023	95.38	62.07	Flexotracción	Cara inferior, tercio central	38 367.74	35 104.00	1.09	2 246.80	3 381.92	91.78	1 940.24	16.00	42.10	40.85	27.14	1.45
A	A-4-2 / A-4-3	2	01/02/2023	103.49	57.21	Flexotracción	sta fingerjoint entre las dos cargas superiores. En	36 990.25	35 104.00	1.05	2 246.80	3 381.92	99.82	1 940.24	16.00	45.79	44.43	29.52	1.58
A	A-5-2 / A-5-3	2	30/01/2023	102.31	57.86	Flexotracción	LT inferior en zona de máximo momento flector	36 725.36	35 104.00	1.05	2 246.80	3 381.92	96.61	1 940.24	16.00	44.32	43.00	28.57	1.53
A	A-6-2 / A-6-3	2	31/01/2023	101.00	58.61	Flexotracción	as superiores. Trasera próximo al apoyo der. Del	36 464.24	35 104.00	1.04	2 246.80	3 381.92	93.40	1 940.24	16.00	42.84	41.57	27.62	1.48
A	A-1-2 / A-1-3	3	15/02/2023	101.52	58.32	Cortante plano ala-alma	- Viga en extremo derecho entre apoyo y carga	33 433.50	35 104.00	0.95	2 246.80	3 381.92	85.72	1 940.24	16.00	39.32	38.15	25.35	1.36
A	A-2-2 / A-2-3	3	13/02/2023	76.24	77.65	Cortante plano ala-alma	- Viga en extremo derecho entre apoyo y carga	36 374.21	35 104.00	1.04	2 246.80	3 381.92	68.72	1 940.24	16.00	31.53	30.59	20.32	1.09
A	A-3-2 / A-3-3	3	08/02/2023	100.81	58.72	Cortante plano ala-alma	pieza trasera zona central derecha, bajo apoyo	36 747.87	35 104.00	1.05	2 246.80	3 381.92	93.63	1 940.24	16.00	42.95	41.67	27.69	1.48
A	A-1-1	4	17/02/2023	31.29	94.93	Cortante plano ala-alma	LT - Viga en extremo izquierdo entre apoyo y carg	29 629.96	31 416.18	0.94	2 123.30	2 805.02	81.81	1 716.54	16.00	116.05	38.53	29.17	3.96
A	A-5-1	4	17/02/2023	27.01	109.96	Cortante plano ala-alma	- Viga en extremo izquierdo entre apoyo y carga	29 390.13	31 416.18	0.94	2 123.30	2 805.02	70.06	1 716.54	16.00	99.37	32.99	24.98	3.39
A	A-6-1	4	16/02/2023	32.65	90.96	Cortante plano ala-alma	CLT - Viga en extremo izquierdo bajo apoyo sup	26 173.78	31 416.18	0.83	2 123.30	2 805.02	75.42	1 716.54	16.00	106.98	35.52	26.89	3.65

Table 3: Summary results of tests and deformation and stress analysis

Panel A deformations

To validate the deformations, two studies are carried out, one at sectional level and a finite element study of the section.

- Test result A-2-1: 87mm
- Finite elements result A-2-1: 82mm
- Sectional result A-2-1: 98mm

As can be seen in table 3, the deformation results obtained with respect to the theoretical studies vary between 0.83 and 1.05.

This variation is considered low, local plasticisation start to occur in the tests before breakage. No intermediate information is available for the load steps, but in general the sectional study is consistent with the results obtained considering a wood quality of C18.

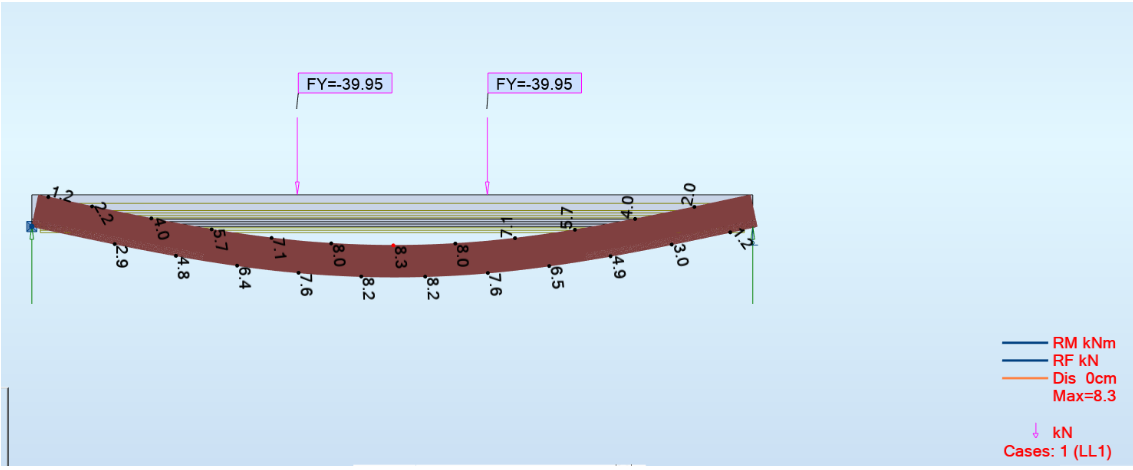


Figure 9: Finite element model deformations

As it can be seen in table 2, the theoretical model studied in short beams limits the shear while in long beams it limits the deformation. In the tests carried out, it can be observed that in the long beams the limitation in rupture occurs with deformations with edge/span ratios around L/60 and in the short beams with a ratio of L/100. Considering that the admissible deformations will be at ratios L/300. These values coincide with the criteria of the previous study where the dimensioning limitation is located in the SLS with the exception of the short beams that with the application of the safety coefficients limit the ULS for shear stresses.

Panel A stresses

Strain gauges are not available in the tests to validate the stress states. The finite element model is used to validate the stress states. The comparison is qualitative not quantitative because no validated stress values are being used with the tests. The modes of rupture compared to the theoretical stress state values can help us to understand how the section works.

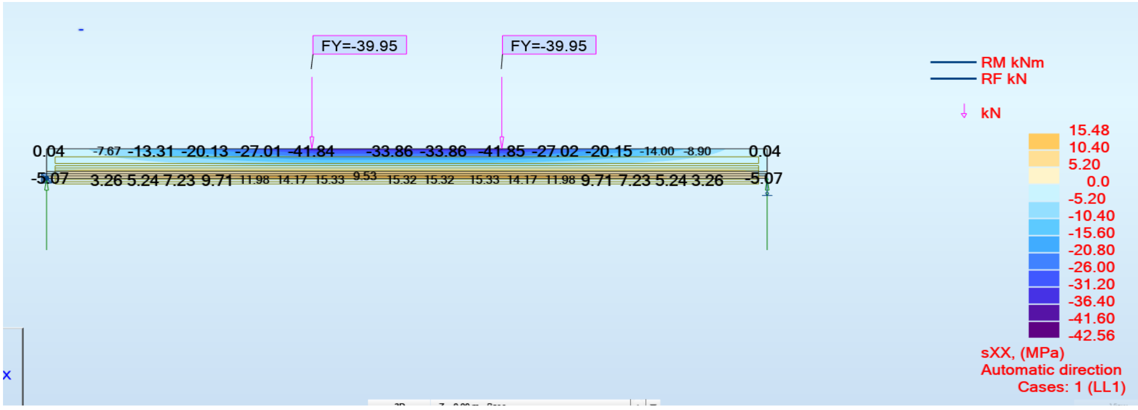


Figure 10: Panel A finite element model normal stresses

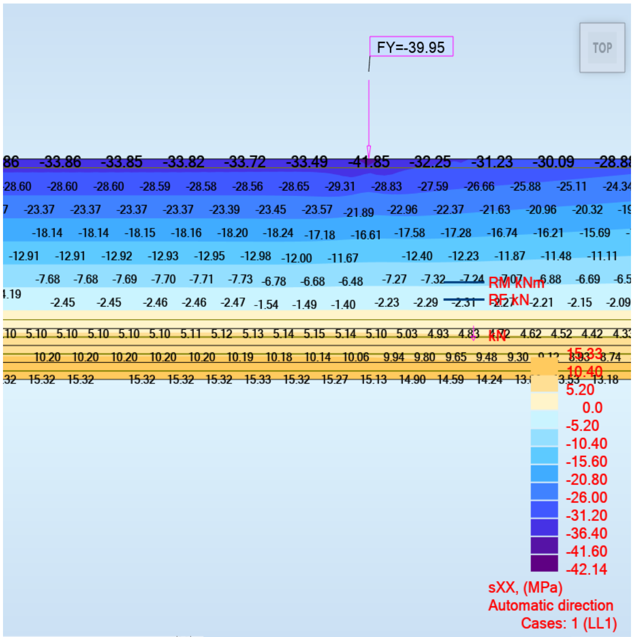


Figure 11: Panel A normal stresses detail in the centre

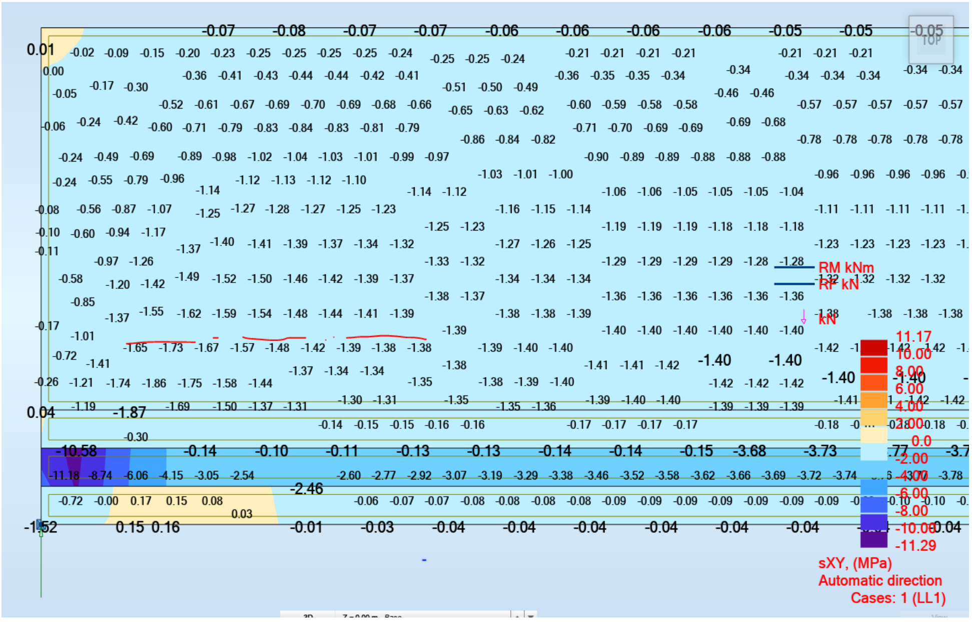


Figure 12: Panel A normal stresses detail in the support

First, the finite element model result (FEM) is compared with the sectional result, and the following results are obtained:

	FEM	Sectional	Difference
Upper stress (N/mm2)	33.8	36.72	1.08
Lower stress (N/mm2)	15.32	24.40	1.6
Shear stress (N/mm2)	1.40	1.31	0.93

Table 4: Results comparison

Comparing the stresses obtained from the sectional element model with the theoretical allowable values, they are in the range for the upper stresses while the lower stresses differ due to the 90° layer considerations.

If we compare qualitatively the results obtained in, most of the breaks should occur in the compressed block under a higher stress state. At this point, it is very likely that the compressed block has plasticised and it is a cause that cannot be validated with the data provided by transferring the failure to the lower tensile part.

We consider that it is reasonable that the breakage occurs in the lower section, with a value between 1.12 and 1.7 of the theoretical value. Remember that the load safety coefficient has an average of 1.45 and the material safety coefficient is 1.8, so the overall coefficient is around 2.61.

With regard to the shear stress, it can be observed that in the short beams they are clearly determined by the tangential tensions, exceeding the theoretical value with a range between 1.37 and 1.42.

Regarding the shear ruptures in the 6-metre beams, more data should be provided on the modes of rupture and the characteristics of the section because there are shear failures with values lower than the theoretical values with ruptures between 0.32 and 0.7 of the shear that the section should be able to withstand. We do not find a logical reason but we do not have images of these shear failures either.

In figures 7 and 8 it can be seen a failure of the fingers, this is a problem that should be discussed with the industrial supplier who has manufactured the panels. The fingers should not be aligned in a section.

Panel Type B test results

As expected, the result obtained is much better than the previous studies carried out in annex A of the WP3 TR3.1.1 report. In the previous theoretical study, as there were no reliable data on the characteristics of the cork layers, it was decided to conservatively consider the work of the panels independently.

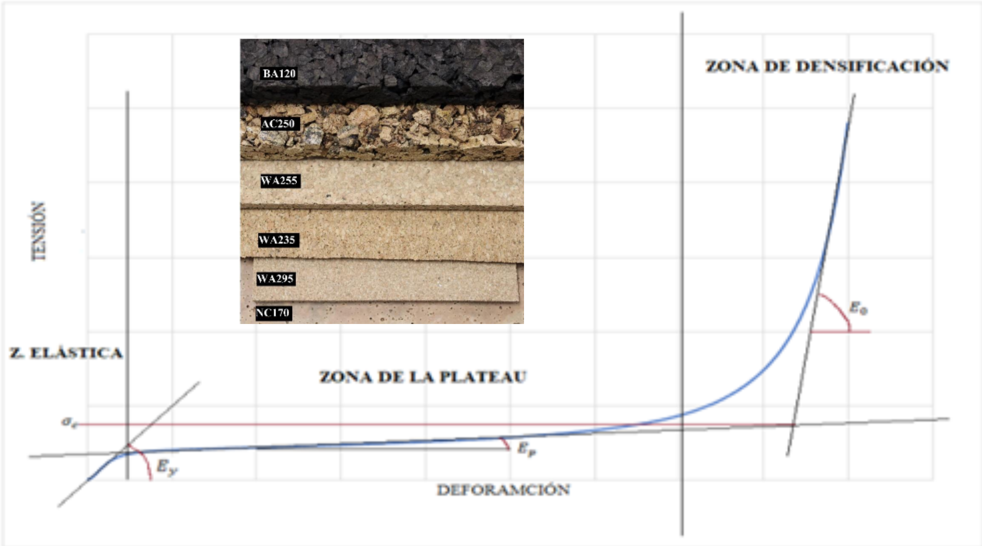
On the other hand, the study has served to question the values assigned to the OSB panel by the regulations, since most of the breakages have occurred in the thickness of the OSB. Technical data sheets of commercial OSB panels were searched and it was observed that the tensile strength of the panel shows variations in the order of 10 units, which would justify this breakage.

Given the lack of information on the characteristics of the cork panel, it has been characterized by adjusting the modulus of elasticity of the material so that the finite element model matches the deformations obtained in the tests. Finally, considering the following characteristics:

Modulus of elasticity 5MPa

Poison Coefficient 0.3

Comparing the value with the study by Manuel Rafael Bello Legua, “Study of the mechanical properties of natural cork and its agglomerates” (2020), it can be seen that the value obtained is in the range of the values of the study tests.



. Parámetros característicos calculados sobre la curva tensión-deformación

. Valores obtenidos en el ensayo de caracterización al 90% de deformación.

	WA290	WA235	WA255	NC170	AC250	BA110	EPS75	Unidades
E_y	6,4	13,0	9,2	19,8	3,3	2,0	21,4	MPa
E_p	3,52	2,37	3,07	2,21	2,10	0,622	0,772	MPa
σ_y	0,3-0,38	0,57-0,63	0,42-0,47	0,4-0,44	0,43-0,46	0,09-0,1	0,53-0,6	MPa
ε_o	5-7 %	5-7 %	5-6 %	2-3 %	14-15 %	3-6 %	3-4 %	-
σ_p	3,00	2,46	2,43	2,47	1,81	0,54	1,43	MPa
ε_o	53%	55%	55%	63%	61%	57%	64%	-

Figure 13: Characteristics of cork study by Manuel Rafael Bello Legua

For panel B, detailed information is available on the intermediate results obtained and graphs of the behaviour of the element. There are also images that allow to understand the modes of rupture and the deformations obtained.

Videos of panels B1-1, B1-9_1, B2-1, B2-6, B3-1, B3-6 and the impact test.

Graphs:

IMIP B1-10_Graficas.xls
IMIP B1-11_Graficas.xls
IMIP B1-12_Graficas.xls
IMIP B1-1_bis_Graficas.xls
IMIP B1-1_Graficas.xls
IMIP B1-3_Graficas.xls
IMIP B1-4 TRIAPOYADO_Graficas.xls
IMIP B1-5 TRIAPOYADO_Graficas.xls
IMIP B1-6- TRIAPOYADO_Graficas.xls
IMIP B1-7_Graficas.xls
IMIP B1-8 (A)_Graficas.xls
IMIP B1-9_Graficas.xls
IMIP B2-1_Graficas.xls
IMIP B2-2_Graficas.xls
IMIP B2-3_Graficas.xls
IMIP B2-4 TRIAPOYADO_Graficas.xls
IMIP B2-5 TRIAPOYADO_Graficas.xls
IMIP B2-6 TRIAPOYADO_Graficas.xls
IMIP B3-1_Graficas.xls
IMIP B3-2_Graficas.xls
IMIP B3-3_Graficas.xls
IMIP B3-4 TRIAPOYADO_Graficas.xls
IMIP B3-5 TRIAPOYADO_Graficas.xls
IMIP B3-6 TRIAPOYADO TRIS_Graficas.xls

In the figures of the attached videos, it can be seen that most of the breaks are produced by the cork and OSB section. This makes the values considered in the previous analyses to be revised, it would be necessary to obtain the technical data sheets of both the OSB and the type of cork used.

Figure 14: B1-1 Failure due to OSB central part

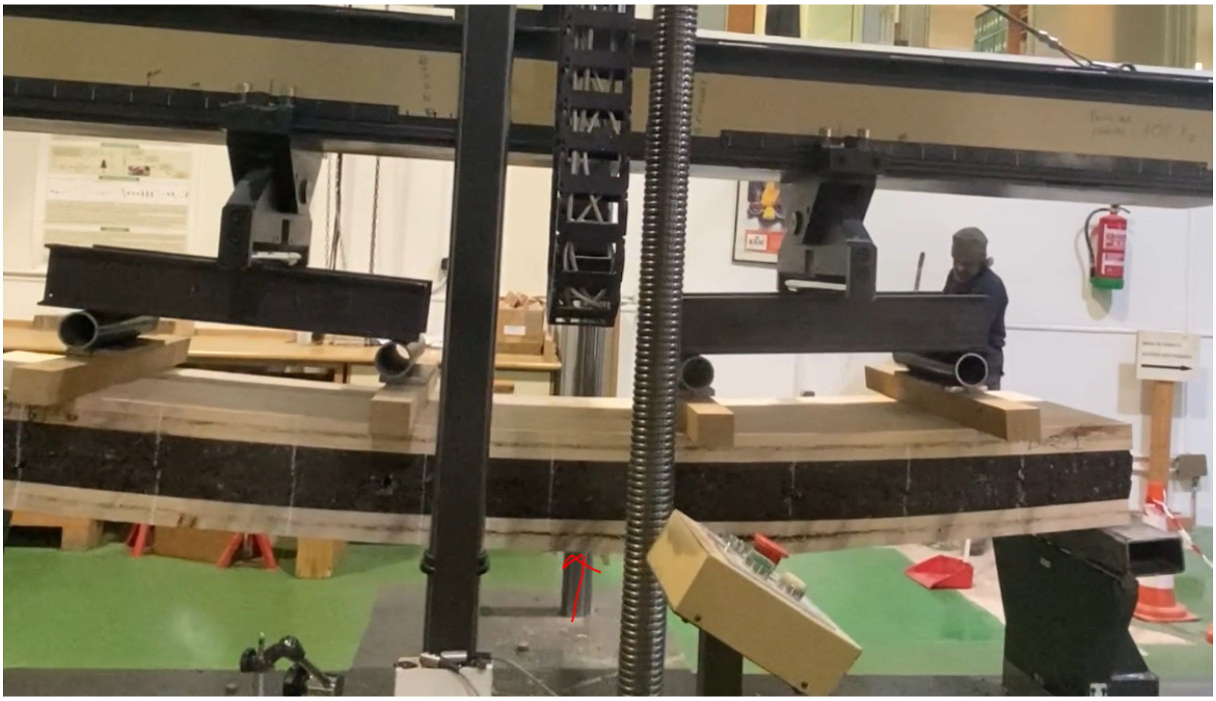


Figure 15: B2-1 Failure due to OSB central part

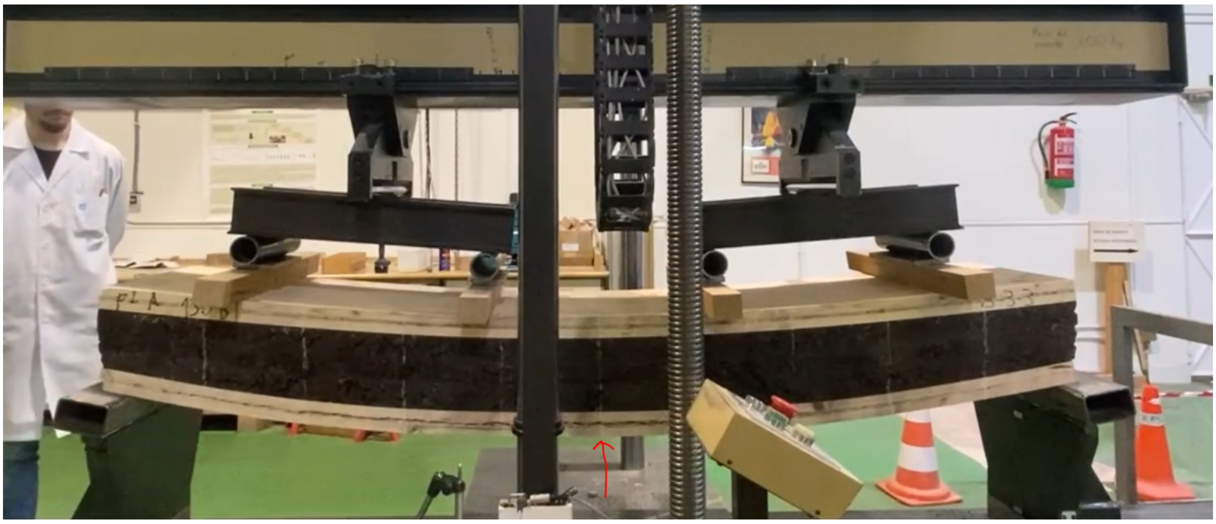


Figure 16: B3-3 Failure due to OSB central part

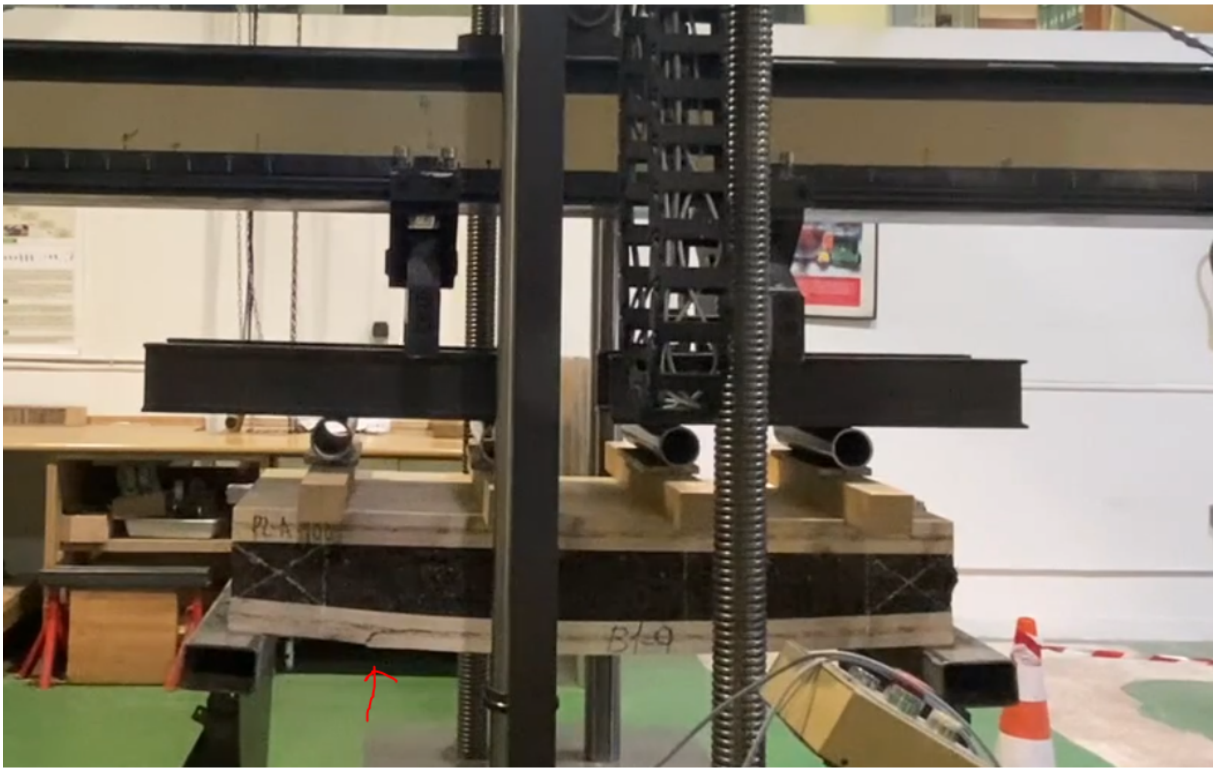


Figure 17: B1-9 Tensile failure bottom panel

Figure 18: B2-6 tri-supported panel OSB failure

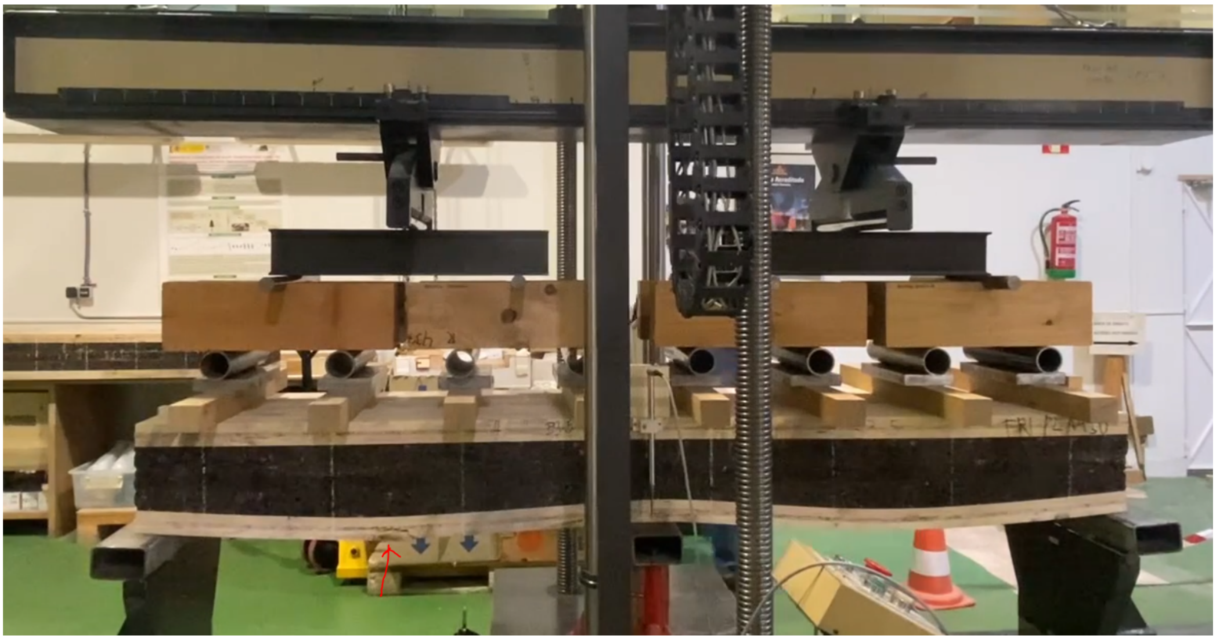


Figure 19: B3-6 Failure due to bending of lower left panel

Figure 20: Panel B Cork panel breakage detail

Annex A of the WP3 TR3.1.1 report presents the results of the theoretical studies according to the standards with the panels working independently. It is not comparable with the results obtained in this test because it is considered the collaboration of the cork at a resistance level. At this point, a finite element study is carried out to validate the tests, adjusting the modulus of elasticity to the test results, without considering any safety coefficient.

Table 5 shows the difference between the values obtained in the characteristics of the OSB panel. In table 6 and 7 the modes determining the sizing of Annex 2 are always produced by deformation. Table 7 analyses deformations and stresses of the test results obtained.

Material	fm,k(N/mm2)	ft,0,k(N/mm2)	ft,90,k(N/mm2	fc,0,k(N/mm2)	fc,90,k(N/mm2	fv,k(N/mm2)	fr,k min(N/mm2	E0,mean(N/mm2)	E90,mean(N/m	Gmean(N/mm2)
C16 conifera	16.00	10.00	0.40	17.00	2.20	3.20	0.80	8 000.00	270.00	500
C18 conifera	18.00	11.00	0.40	18.00	2.20	3.40	0.80	9 000.00	300.00	560
OSB CTE	16.40	9.40	7.00	15.40	12.70	1.00	1.00	4 930.00	50.00	
OSB Alberch	10.00	0.40	0.40				0.80	4 600.00		1900

Table 5: Mechanical characteristics Panel B

Panle B	AreaTotal (cm2)	AreaNeta (cm2)	nercia (cm4)	Dsup(cm)	Dinf(cm)	Wsup (cm3)	Winf (cm3)
L=2.00m	460.00	319.60	773.23	2.30	2.30	336.18	336.18

Table 6: Panel type B sectional characteristics Annex A

Longitud	AreaBruta cm(2)	AreaNeta(cm2)	Inercia cm(4)	Wsup (cm3)	Winf(cm3)	ME(cm3)	us deformad	us moment	us tallant	US Resultant [kN/m]	
1	920	639.2	1546.46	672.36	672.36	465.82	20.37	43.05	61.51	20.37	Limita deformación
1.5	920	639.2	1546.46	672.36	672.36	465.82	5.54	18.78	40.79	5.54	Limita deformación
2	920	639.2	1546.46	672.36	672.36	465.82	1.93	10.28	30.43	1.93	Limita deformación
2.5	920	639.2	1546.46	672.36	672.36	465.82	0.64	6.35	24.22	0.64	Limita deformación

Table 7: Sectional analysis results Annex A

ENSAYOS SEGÚN ETAG16																	Teorico			Modelo numérico			
								cm4	cm4		cm3	cm4	mkN	cm3	cm	kN	N/mm2	N/mm2	N/mm2				
Tipo de panel	Código componentes	Espesor del alma	Luz ensayo (mm)	def	L/?	Fenómeno Fallo inicial	Fenómeno Fallo final	Inercia Ensayo	Inercia Teorica	Ie/It	W sup	Wosb	M ensayo	ME	base alma	Vmax	fmd(inf)	fmd(osb)	fvd	fmd(inf)	fmd(osb)		
B1	B1-1	100	2000	14.84	134.80	Cortante alma	Flexotracción panel inferior OSB	15 191.59	680.44	22.33	295.84	332.66	4.75	204.96	44.00	9.50	16.06	7.93	0.65	7.20	1.20	2.02	6.61
B1	B1-2	100	2000	10.16	196.94	Cortante alma	Cortante OSB panel inferior	22 194.78	680.44	32.62	295.84	332.66	4.75	204.96	45.00	9.50	16.06	7.93	0.64				
B1	B1-3	100	2000	13.76	145.39	Cortante alma	Flexotracción panel inferior	23 283.83	680.44	34.22	295.84	332.66	6.75	204.96	46.00	13.50	22.82	11.27	0.88				
B2	B2-1	100	2000	14.93	133.94	Cortante alma	Flexotracción panel inferior OSB	21 928.12	680.44	32.23	295.84	332.66	6.90	204.96	47.00	13.80	23.32	11.52	0.88				
B2	B2-2	100	2000	14.30	139.87	Cortante alma	Flexotracción panel inferior	19 081.73	680.44	28.04	295.84	332.66	5.75	204.96	48.00	11.50	19.44	9.60	0.72				
B2	B2-3	100	2000	13.88	144.07	Cortante alma	Flexotracción panel inferior	21 363.43	680.44	31.40	295.84	332.66	6.25	204.96	49.00	12.50	21.13	10.44	0.77				
B3	B3-1	150	2000	18.70	106.93	Cortante alma	Cortante OSB panel inferior	14 550.61	680.44	21.38	295.84	332.66	5.74	204.96	50.00	11.47	19.39	9.58	0.69				
B3	B3-2	150	2000	18.22	109.75	Cortante alma	Flexotracción panel inferior por nudos	15 024.20	680.44	22.08	295.84	332.66	5.77	204.96	51.00	11.54	19.50	9.64	0.68				
B3	B3-3	150	2000	17.56	113.92	Cortante alma	Flexotracción panel inferior OSB	20 103.56	680.44	29.54	295.84	332.66	7.44	204.96	52.00	14.88	25.14	12.42	0.86				
B1	B1-7	100	1000	5.13	195.07	Aplastamiento alma	Flexotracción panel inferior	8 041.70	680.44	11.82	295.84	332.66	3.48	204.96	53.00	13.90	11.75	5.80	0.79				
B1	B1-8	100	1000	7.14	140.06	Aplastamiento alma	Flexotracción panel inferior	6 230.63	680.44	9.16	295.84	332.66	3.75	204.96	54.00	15.00	12.68	6.26	0.84				
B1	B1-9	100	1000	7.03	142.23	Aplastamiento alma	otracción panel inferior desplaado izqui	5 694.66	680.44	8.37	295.84	332.66	3.38	204.96	55.00	13.50	11.41	5.64	0.74				
B1	B1-10	100	1500	6.82	219.89	Aplastamiento alma	Flexotracción panel inferior	15 142.97	680.44	22.25	295.84	332.66	3.87	204.96	56.00	10.32	13.08	6.46	0.56				
B1	B1-11	100	1500	10.59	141.69	Cortante alma	Cortante OSB panel inferior	11 742.73	680.44	17.26	295.84	332.66	4.66	204.96	57.00	12.42	15.74	7.78	0.66				
B1	B1-12	100	1500	8.60	174.45	Cortante + Aplastamie	Flexotracción panel inferior por nudos	12 868.99	680.44	18.91	295.84	332.66	4.15	204.96	58.00	11.06	14.01	6.92	0.57				

Table 8: Summary results of tests for bi-supported beams

ENSAYOS SEGÚN ETAG16														Teorico		Modelo numérico			
							cm4	cm4		cm3	cm4	mkN	cm3	N/mm2	N/mm2	N/mm2	N/mm2		
Tipo de panel	Código componentes	Espesor del alma	Luz ensayo (mm)	def	L/	Fenómeno Fallo final	Inercia Ensayo	Inercia Teorica	Ie/It	W sup	Wosb	M- ensayo	M+ ensayo	fmd(inf) M-	fmd(inf) M+	fmd(inf) M-	fmd(inf) M+		
B1	B1-4	100	1000	9.55	104.67	CORTANTE OSB INFERIOR	8 469.28	680.44	12.45	295.84	332.66	8.68	5.21	29.34	17.61	26.14	12.31	1.122431	1.430623
B1	B1-5	100	1000	7.46	134.10	CORTANTE OSB INFERIOR	9 581.11	681.44	14.06	295.84	332.66	8.59	5.15	29.02	17.42	25.86	12.18		
B1	B1-6	100	1000	5.22	191.42	CORTANTE OSB INFERIOR IZQUIERDA	11 523.78	682.44	16.89	295.84	332.66	7.93	4.76	26.79	16.08	23.87	11.24		
B2	B2-4	100	1000	8.30	120.42	CORTANTE OSB INFERIOR	10 148.98	683.44	14.85	295.84	332.66	10.37	6.23	35.07	21.05	31.24	14.71		
B2	B2-5	100	1000	7.09	140.99	CORTANTE OSB INFERIOR	9 727.65	684.44	14.21	295.84	332.66	9.06	5.44	30.61	18.38	27.28	12.84		
B2	B2-6	100	1000	8.91	112.18	CORTANTE OSB INFERIOR	8 827.54	685.44	12.88	295.84	332.66	9.24	5.55	31.24	18.75	27.83	13.11		
B3	B3-4	150	1000	11.41	87.61	CORTANTE OSB INFERIOR													
B3	B3-5	150	1000	9.52	105.03	FLEXOTRACCIÓN PARAMENTO INFERIOR													
B3	B3-6	150	1000	9.25	108.09	Flexo traccion panel inferior izquierdo													

Table 9: Summary results of tests for tri-supported beams

In order to validate the test results, a linear finite element model is calibrated by matching the deformations of the tests with the deformations of the model, fixing the modulus of elasticity of the wood and OSB panels and varying the modulus of the cork panel. As can be seen in the detail of the support, it is not possible to make a classical sectional study as the sections do not remain flat (see Figure 22).

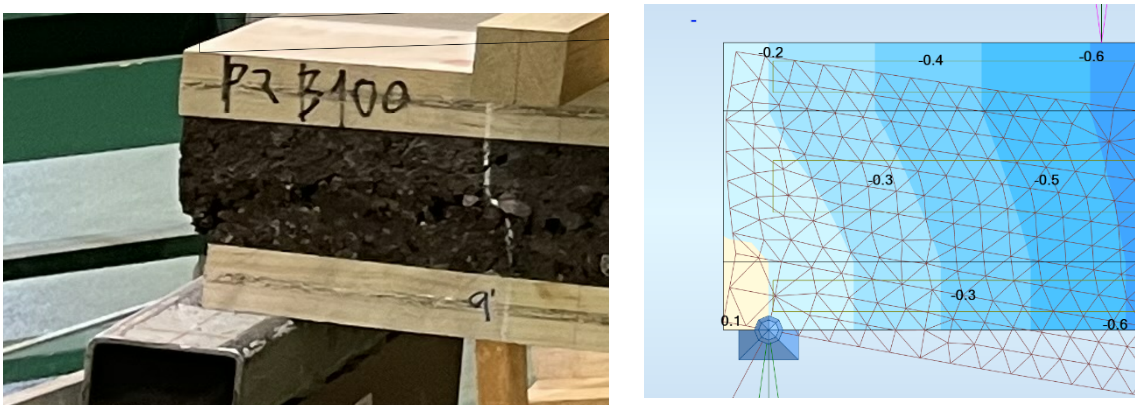


Figure 21: Shear deformation in the support section of panel type B

Panel B deformations

As the sections do not remain flat, a finite element study of the section of a dual and triple supported panel is carried out. As mentioned above, in order to obtain the stress results, the dual supported model is calibrated with the deformations obtained by adjusting the modulus of elasticity to 5MPa in the cork panel.

As can be seen in Figure 24 of the main stress diagram, the panels work quite uncoupled, but the deformation improves by 220 times with respect to the independent work of each panel. Also, the normal stresses are reduced by 20% to 50%.

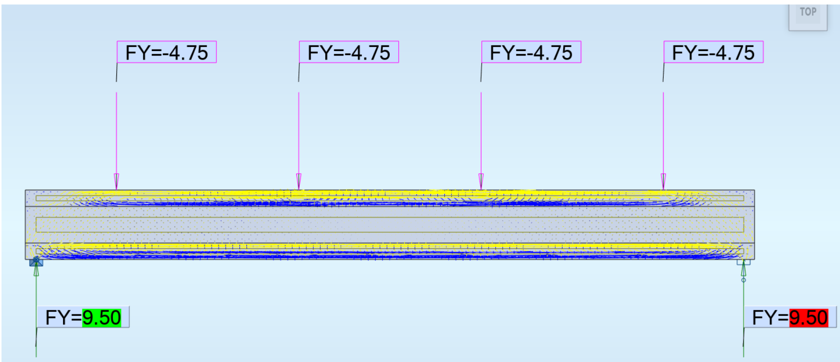


Figure: 22 Panel type B main stresses

Project funded by the Interreg Sudoe programme through the European Regional Development Funds (ERDF)

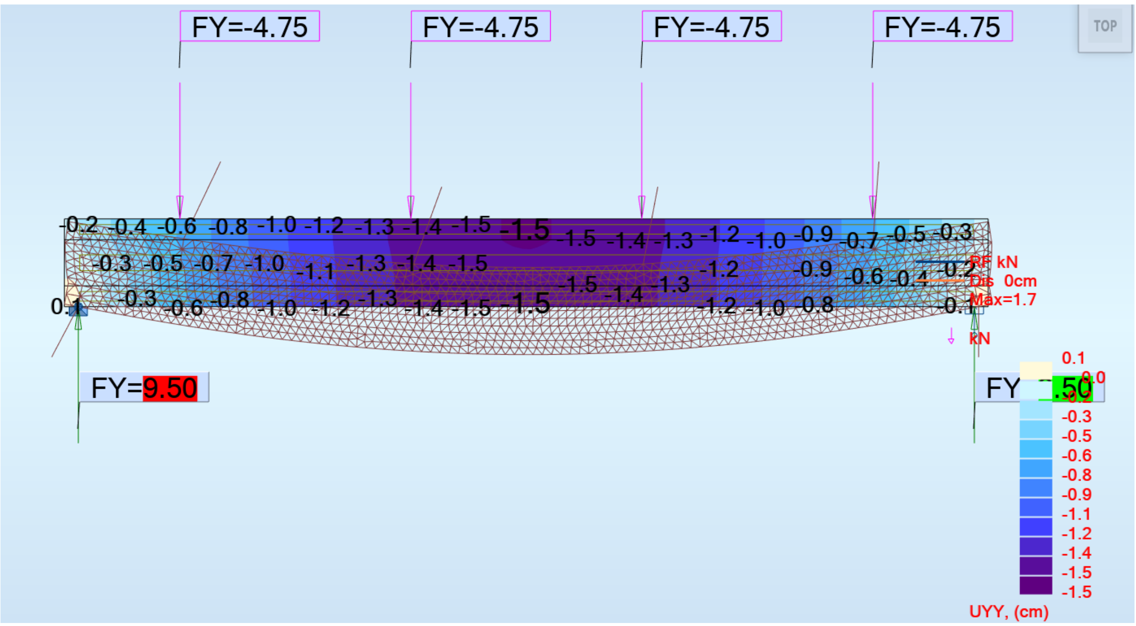


Figure 23: Panel B1-1 bi-supported FEM deformations

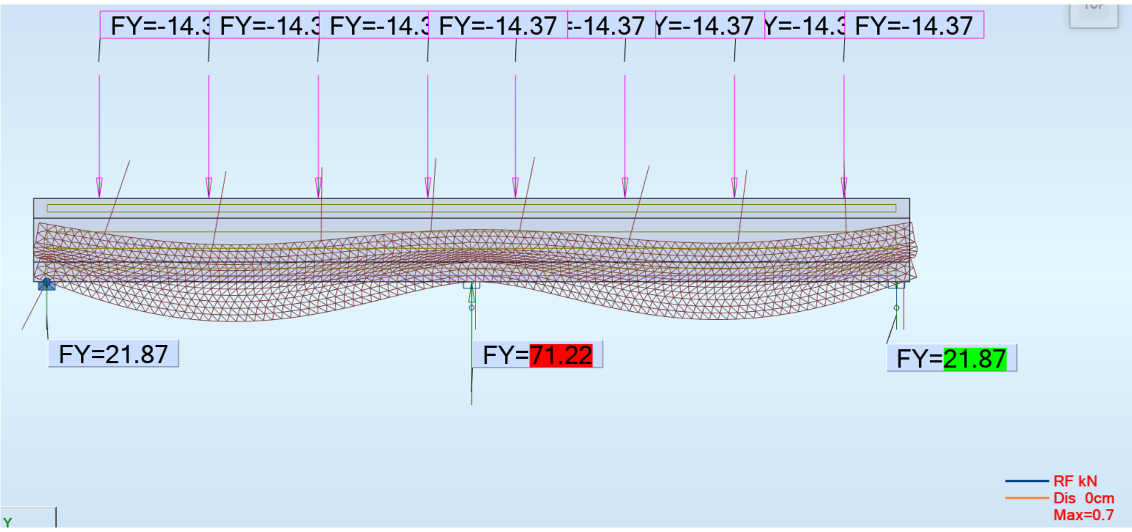


Figure 24: Panel B1-4 tri-supported FEM deformation

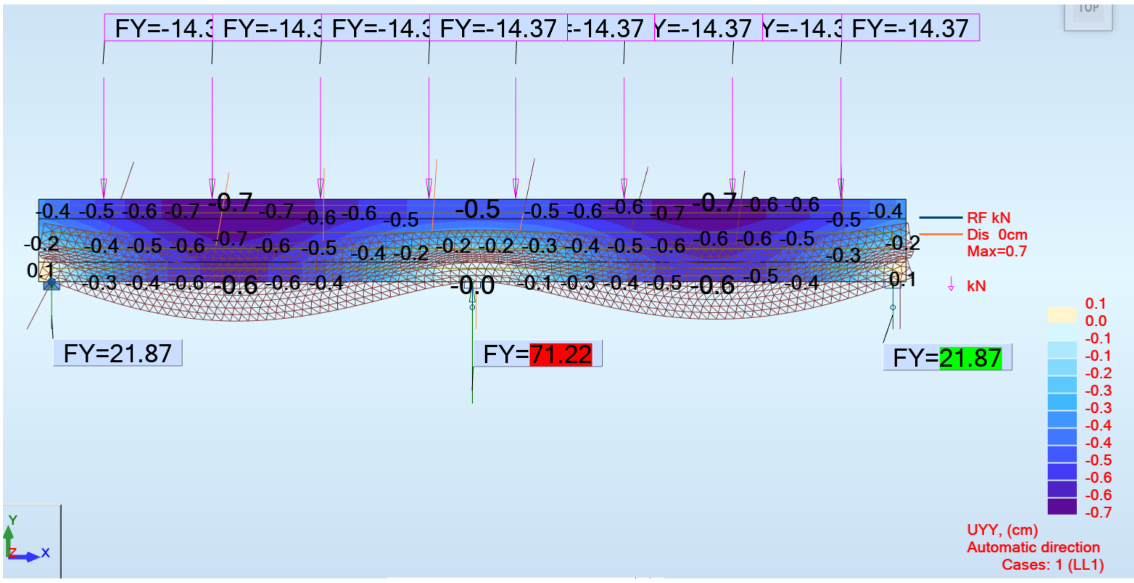


Figure 25: Panel B1-4 tri-supported deformation

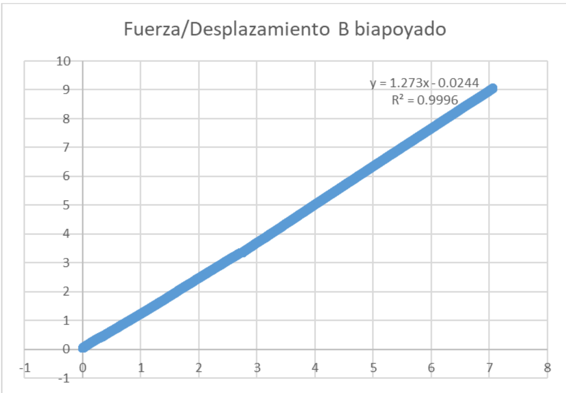


Figure 26: Panel type B force-displacement graph bi-supported

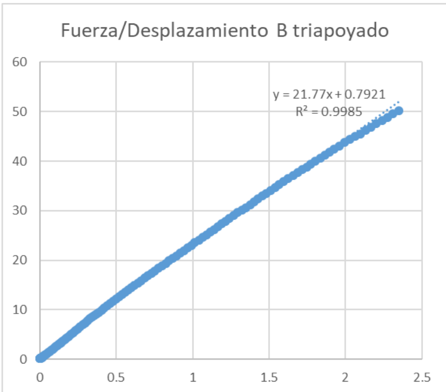


Figure 27: Panel type B force-displacement graph tri-supported

Maintaining the modulus of elasticity of the cork, the behaviour of the tri-supported panel is simulated, obtaining deformations compatible with the test results. It must be taken into account that a linear calculation is being made and the plastic behaviour of the materials is not being considered.

The phenomenon of cork crushing in the supports should be studied in detail, especially in the tri-supported panel, as it produces a redistribution of deformations and stresses, overloading the lower panel.

Panel B stresses

Strain gauges are not available in the tests to validate the stress states. The finite element model is used to validate the stress states. The comparison is qualitative not quantitative because non validated stress values are being used with the tests. The modes of rupture compared to the theoretical stress state values can help to understand how the section works.

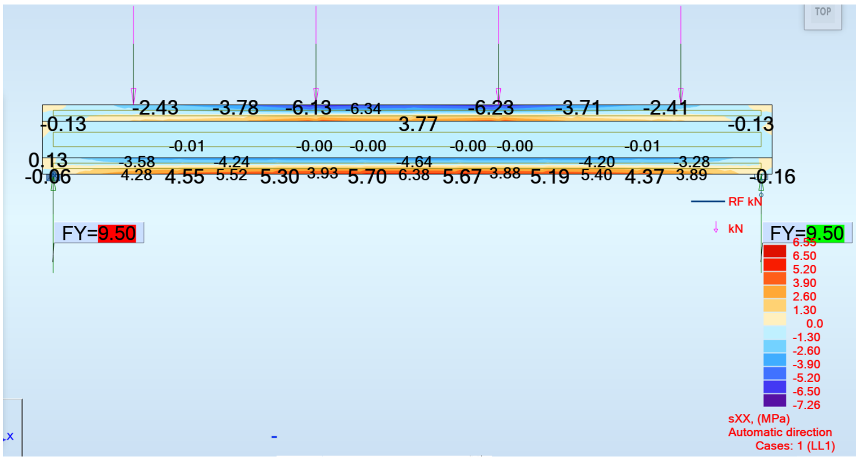


Figure 28: Normal stresses FEM Panel B bi-supported

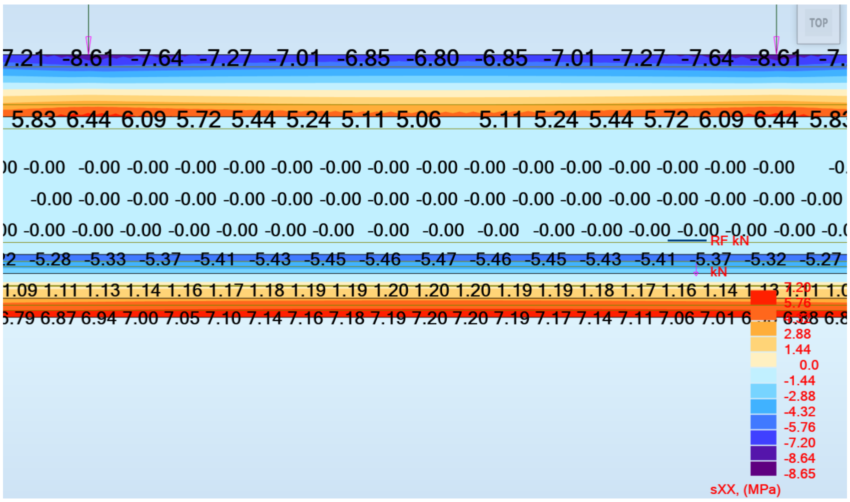


Figure 29: Detail normal stresses FEM Panel B bi-supported

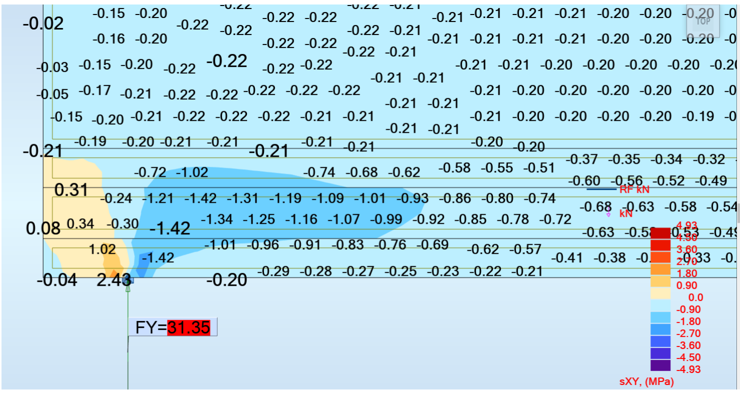


Figure 30: Detail of tangential stresses in the support of Panel B

Figure 31: Detail of stresses on cork Panel B

As it can be seen in table 8 and 9, the semi-coupled behaviour caused by the cork panel is reducing the stress on the panel by 1.2 to 2 times.

As it has been previously mentioned, in the tri-supported model, there is an effect that should be studied in detail, which is the crushing of the cork in the support areas. This effect causes the lower panel to be overloaded. In the test, values of the order of double the stress in the positive areas are being obtained and of the order of 4 times in the normal stresses of the central support section (see figure 34).

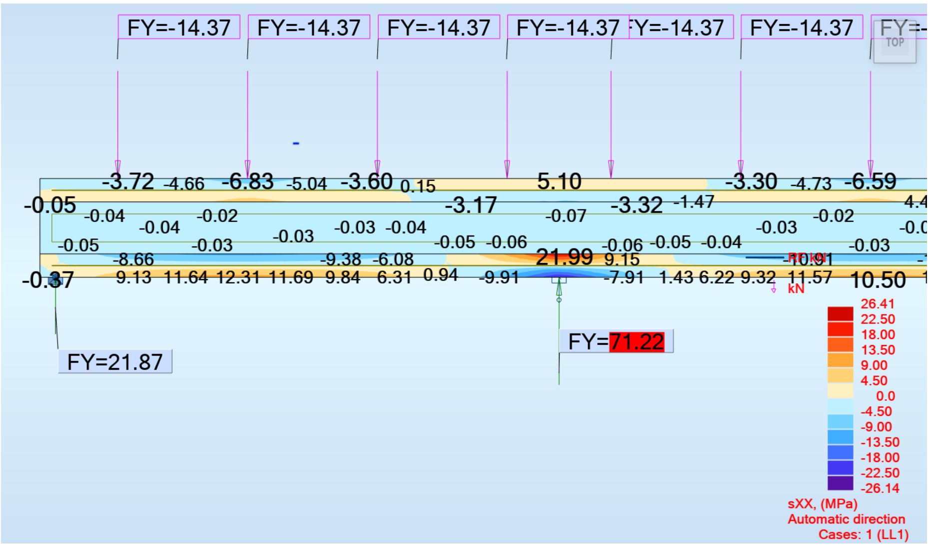


Figure 32: Stresses in Panel B tri-supported

In the detail of the stresses in both the OSB (considering values from Alberch's data sheet) and the cork, the admissible stresses of the material are being exceeded. This matches with the breaks observed in the tests.

Panel Type C test results

Three videos of panel type C show the following breakage modes:

- Figure 35 and 36, shear rupture of the panel at the support for the glued joint.
- Figure 37, shear fracture of the panel in the web.

Figure 33: Panel C4-1 Failure in the connection between the beam and the panel on the right side of the support

Figure 34: Panel C4-2 Failure in the connection between the beam and the panel on the right side of the support

Figure 35: Panel C5-2 Shear fracture in the web of the beam

Figure 36: Panel C detail of shear fracture coinciding with knots

Figure 37: Panel C6-1 failure flush start

Annex A of WP3 TR3.1.1 presents the results of the theoretical studies according to the standards. At this point, the study is carried out without considering the safety coefficients.

Table 10 shows the cross-sectional characteristics considered. Table 11 shows the modes determining the sizing from Annex A of WP3 TR3.1.1. Table 12 shows the deformations and stresses of the test results obtained.

Panel C	AreaTotal (cm2)	AreaNeta (cm2)	Inercia (cm4)	Dsup(cm)	Dinf(cm)	Wsup (cm3)	Winf (cm3)
L=6m	1 040.00	808.00	95 221.33	16.00	16.00	5 951.33	5 951.33
L=4	1 040.00	694.13	75 491.91	16.00	16.00	4 718.24	4 718.24

Table 10: Mechanical characteristics of the section

Longitud	AreaBruta cm(2)	AreaNeta(cm2)	Inercia cm(4)	Wsup (cm3)	Winf(cm3)	ME(cm3)	us deformad	us moment	us tallant	US Resultant [kN/m]	
2.00	1 040.00	612.80	61 399.47	3 837.47	3 837.47	2 703.20	172.35	102.07	31.62	31.62	Limita cortante
3.00	1 040.00	694.13	75 491.91	4 718.24	4 718.24	3 231.87	61.49	54.94	21.10	21.10	Limita cortante
4.00	1 040.00	775.47	89 584.36	5 599.02	5 599.02	3 760.53	29.77	36.07	15.71	15.71	Limita cortante
5.00	1 040.00	808.00	95 221.33	5 951.33	5 951.33	3 972.00	15.27	23.95	12.29	12.29	Limita cortante
6.00	1 040.00	808.00	95 221.33	5 951.33	5 951.33	3 972.00	7.98	16.07	9.93	7.98	Limita deformación
7.00	1 040.00	808.00	95 221.33	5 951.33	5 951.33	3 972.00	4.27	11.32	8.25	4.27	Limita deformación
8.00	1 040.00	808.00	95 221.33	5 951.33	5 951.33	3 972.00	2.19	8.24	6.99	2.19	Limita deformación
9.00	1 040.00	808.00	95 221.33	5 951.33	5 951.33	3 972.00	0.93	6.12	6.01	0.93	Limita deformación

Table 11: Sectional analysis results Annex A

				mm				kN/mm2	kN/mm3		cm3	cm4	mkN	cm3	cm	kN	N/mm2	N/mm2	N/mm2
Tipo de pane	Código componente	Tipo de probe	Fecha ensayo	DEF centro	L/	Fenómeno Fallo	Localización fallo	Inercia Ensayo	Inercia Teorica	Ie/It	W sup	Winf	M ensayo	ME	base alma	Vmax	fmd(sup)	fmd(inf)	fvd
C	C-4-1	1	03/02/2023	54.62	108.38	Cortante plano ala-alma	Deslizamiento CLT - Viga entre apoyo y carga sup	103 506.77	95 221.33	1.09	5 951.33	5 951.33	137.00	3 972.00	16.00	68.50	23.02	23.02	1.79
C	C-5-1	1	01/02/2023	74.08	79.92	Flexotracción	CLT inferior entre las dos cargas superiores.	103 819.24	95 221.33	1.09	5 951.33	5 951.33	186.36	3 972.00	16.00	93.18	31.31	31.31	2.43
C	C-6-1	1	02/02/2023	66.73	88.72	Cortante plano ala-alma	Adhesivo CLT - Viga en extremo izquierdo entre	109 068.81	95 221.33	1.15	5 951.33	5 951.33	176.35	3 972.00	16.00	88.18	29.63	29.63	2.30
C	C-4-2 / C-4-3	2	06/02/2023	70.21	84.32	Cortante plano ala-alma	Rot. Madera CLT superior - Viga trasera en extre	103 002.99	95 221.33	1.08	5 951.33	5 951.33	171.95	3 972.00	16.00	85.98	28.89	28.89	2.24
C	C-5-2 / C-5-3	2	06/02/2023	47.45	124.77	Cortante plano ala-alma	Adhesivo CLT superior - Viga frontal en extremo	105 074.85	95 221.33	1.10	5 951.33	5 951.33	122.00	3 972.00	16.00	61.00	20.50	20.50	1.59
C	C-6-2 / C-6-3	2	06/02/2023	41.92	141.23	Cortante plano ala-alma	Rot. Madera CLT superior - Viga trasera en extre	107 876.48	95 221.33	1.13	5 951.33	5 951.33	110.08	3 972.00	16.00	55.04	18.50	18.50	1.43
C	C-1-2 / C-1-3	3	13/02/2023	63.05	93.89	Cortante plano ala-alma	Cortante pieza trasera zona extremo izquierdo, e	105 720.89	95 221.33	1.11	5 951.33	5 951.33	160.40	3 972.00	16.00	80.20	26.95	26.95	2.09
C	C-2-2 / C-2-3	3	10/02/2023	67.93	87.14	Cortante plano ala-alma	Adhesivo CLT inferior - Viga en extremo izquierd	112 126.47	95 221.33	1.18	5 951.33	5 951.33	184.40	3 972.00	16.00	92.20	30.98	30.98	2.40
C	C-3-2 / C-3-3	3	09/02/2023	70.55	83.91	Flexotracción	Rotura por CLT inferior hasta fingerjoint nervio d	108 786.47	95 221.33	1.14	5 951.33	5 951.33	189.00	3 972.00	16.00	94.50	31.76	31.76	2.46
C	C-1-1	4	20/02/2023	14.44	205.71	Cortante plano ala-alma	Desplazamiento CLT - Viga en extremo derecho e	74 714.39	75 491.91	0.99	4 718.24	4 718.24	91.88	3 231.87	16.00	175.00	19.47	19.47	4.68
C	C-2-1	4	20/02/2023	16.25	182.80	Cortante plano ala-alma	Desplazamiento CLT - Viga en extremo derecho e	73 032.43	75 491.91	0.97	4 718.24	4 718.24	101.06	3 231.87	16.00	192.50	21.42	21.42	5.15
C	C-3-1	4	17/02/2023	14.76	201.15	Cortante plano ala-alma	Rot. Madera CLT - Viga en extremo izquierdo ent	75 353.76	75 491.91	1.00	4 718.24	4 718.24	94.76	3 231.87	16.00	180.50	20.08	20.08	4.83

Table 12: Summary results of tests and deformation and stress analysis

Panel C deformations

In order to validate the deformations, given that this is a common case of analysis, the study is carried out at a sectional level.

As can be seen in table 12, the deformation results obtained with respect to the theoretical studies vary from 0.97 to 1.18.

This variation is considered low, in the tests before rupture, local plasticisation begins to occur. There is no intermediate information on the load steps, but in general, the sectional study is coherent with the results obtained considering a wood quality of C18.

In the tests carried out, it can be observed that in the long beams the limitation in breakage occurs with deformations with edge/light ratios of around L/100 and in the short beams with a ratio of L/200.

Panel C stresses

In the tests, strain gauges are not available to validate the stress states. The sectional model is used considering that the sections remain flat. The comparison is qualitative not quantitative because stress values not validated with the tests are being used.

As it can be seen in table 11 in the previous study, it can be observed that in this type of panel the tangential stresses are the limiting factor, and only from spans of about 7 metres does it begin to limit the deformations. All the breaks observed occur in the web, see figures 29 to 35. Coinciding with the most stressed areas. The shear in this type of section is distributed uniformly throughout the web, so the crack occurs where there is a construction fault, either at knots or in the gluing area, which is decisive.

B Conclusions

The results of the IMIP panel tests, both in terms of deformation and breakage, are similar to those established in the calculation hypotheses of the WP3 TR 3.1.a report for the cases of type A, C panels. For type B, the have produced some variations in terms of deformation that have made the behavior at break improve with respect to the initial calculation hypothesis.

It should be noted that the comparison table has been carried out qualitatively because the tests did not include the calibrated measurements of the deformation of the piece at the time prior to breakage.

Panel B has been discretized in finite elements to determine stresses that, by comparison to the deformation, are similar to those established by calculation, slightly improving the breaking stress by calculation to the initial ones.

The breaks in panels A and C have occurred mainly in the gluing and finger joints, which could be explained by incorrect gluing of the pieces.

Due to this circumstance repeated in the tests, it can be assumed that if this industrial process had better quality control, it could improve the performance of the tested systems. Even with these circumstances, the resistances derived from the mechanical tests have been in accordance with those established by the initial theoretical calculation.

For all of the above, the IMIP construction systems based on pine wood as well as natural cork respond in a very solvent way to meet the requirements of construction standards set by European and national regulations and make them optimal for implementation both in building of new construction as in rehabilitation.