UNIVERSITY OF PADUA

DEPARTEMENT OF INDUSTRIAL ENGINEERING

MASTER DEGREE IN MECHANICAL ENGINEERING

STRUCTURAL BEHAVIOR ANALYSIS OF ELASTIC COMPENSATION SUPERSTRUCTURE FOR INNOVATIVE SKI PRODUCTION

Supervisor: Prof. NICOLA PETRONE

Co-supervisor: Prof. VITTORIO QUAGGIOTTI

Student:

FEDERICO SIGNORETTO

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Professor Vittorio Quaggiotti is the second person that I would like to thank, because he transmitted me important comments and experiences on skies, skiing and on lecture of diagrams that we have developed together using the workbench.

Tests on slope would not have been made if there were not also Giuseppe and Stefano. The first help me and Stefano on analysis of data and plots. The second was the tester for my thesis, but also he used that time for performing test regarding his thesis.

It’s important remember that Nordica Group had given availability for tests on their laboratory and so thank to Michele, Stefano and Franco. Then I would like to thank Giorgio, laboratory technician, because his interest on ski and superstructure permits us to product the 3D model that was developed in this period of thesis.

In this period I known new friends here in laboratory and I would like thank each one of them for all moments we spend together here in Padua and in the period of Winter School and for advices and help that we exchange each other. So thank you Alberto P, Gianluca B., Francesco T., Enrico C., Matteo C., Matteo D., Andrea D., Paolo A., Valentina P. and Joseph.

I don’t want to forget to thank my parents Oriella and Paolo, my sister Elena, my brother-in-law Michele, my niece Elisabetta for everything they gave me in this last five and half years, and I will hope to reciprocate in future all these helps that they gave me. Also I would like to greet all my relatives from cousins to grandparents.

In the end, last but not least, I would like to hug all my friends that were near me in periods of free time during the weekend, in the evening spend in pool room or in some pub to watch football match and for the weekly soccer match that help me to distract from stress caused by study but also by my daily travel in bus for coming in Padua. So thank you Luca C., Marco B., Marco G., Luca S., Alberto G., Mirco C., Laura V., Elisa B., Annalisa T., Alessia T., Lorenzo B., Lorenzo V., Alessio T., Nicola T., Luca N., Daniel C., Natascia T., Stefania T., Martina M. A particular gratitude to Enrico V. because he helped me to update my pc for installing important software that I have used during this period to develop diagrams, 3D models and Finite Elements simulations.

INTRODUCTION

Alpine skiing is a discipline developed with the diffusion of new technologies for ski construction evolved after the second World War. Skiing enters in a modern phase and public most important diffusion was given by television in 1956, when Winter Olympic Game of Cortina d'Ampezzo were the first ski games transmitted. From this data since today a lot of technologies and materials were studied and developed for ski construction and for ski safety, because ski is a sport that is becoming a discipline very diffuse for all age people who want to enjoy holiday in mountain and want to discover new typology of skiing.

The aim of this thesis is based on development of a new innovative elastic compensation superstructure for alpine ski and then optimization of the same one for industrial production. The presence of a superstructure change ski properties in laboratory and in in-field tests: skiers that have try prototype version of this idea on slopes observed positive differences on ski deflection and on forces and moment on curve entering. In this thesis there is a first chapter who explain how to collect data like bending moment on ski shovel during skiing and the substantial differences on three typologies of carving style. This to observing if the subjective feelings of skiers have a confirm on forces and moments measured, that would be higher when superstructure is attach to ski.

Superstructure applied on ski provides differences with respect to the original configuration and then these configuration were reproduced in laboratory for studying their internal property. Workbenches developed for ski analysis are important instruments for comparison of different ski and different snow hardness. Values of bending moment coming from laboratory are compared with in-field values and some discussions and decisions were done for understanding which is the best way for future development of new superstructures.

In this thesis it was completed the study of existent wood and resin superstructure and wood was retained the best material for future prototypes.

Fig. 1: Wood superstructure – top and lateral view (length 300mm)

Other two new innovative structures were developed: for first an extension of Piston Marker ® plate with a superstructure named "unique piece" that have the same properties of stiffness and displacements of the existent wood structure. ANSYS® finite elements analysis software was used to verify the geometries of this new structure designed for two material: aluminum and polyamide resin (POM) which are diffuse in industrial ambient for injecting processes. Complete description in chapter 6.

Fig. 2: Resin superstructure – top and lateral view (length 300mm)

A second typology of superstructure regards an integral wood plate who couple plate and “arm structure”. Wood is used for production of preliminary structure. This integral plate was coupled in two ski and analyzed on Nordica Group laboratory test bench for flexional behavior of ski. This test was important to confirm the initial idea that each superstructure is adaptable at one ski. So a future optimization of this new idea is to make a structure adaptable at different size of ski, and this is very important for reducing costs of in series industrial production.

The last part of thesis shows different curves coming out from Padua and Chemnitz workbenches. Other diagrams, which are “footprint” of ski, are reported to identify families of ski brands and different behavior of ski on different snow conditions.

In the last appendix some views of the new unique piece superstructures are reported.

HYSTORY OF SUPERSTRUCTURES

Figure **1A** shows how a modern ski presents a longitudinal concave downward profile, so when it's not loaded and leaned on the horizontal plane, the ski is raised on the central zone **<1>** between heel **<T>** and tip **<P>** of binding. Tail **<2>** and showel **<3>** touch the plane on two point.

This shape of ski permits greater stability on straight sliding, but when the skier follows a curved trajectory, the centrifugal force, who it's originate from dynamic equilibrium, imposes an inclined position to the skier and the ski has to counter-flex to enter in this trajectory. In figure **3** the ski shovel loses the contact with the ground because of a great inclination of the skier.

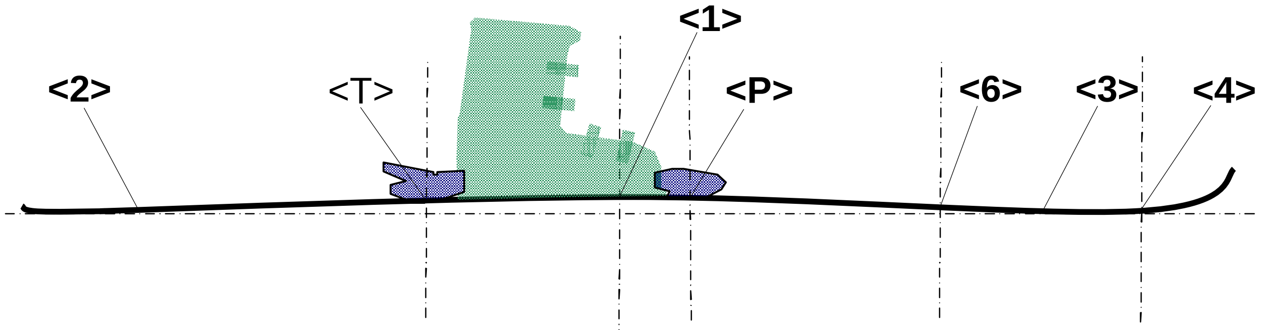


Fig.1A

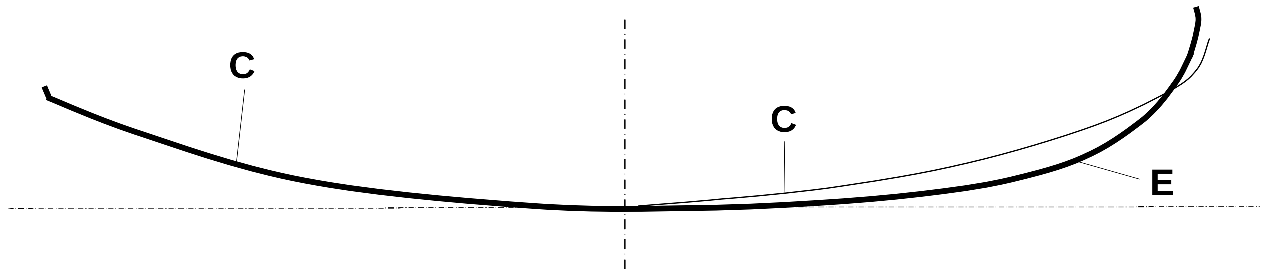


Fig.1B

In figure **1B** the deformation line who describe the counter-flexion it's similar to a circle arc. The idea is to sustain that from the initial access in the curve and in then into the curve, the adherence to the ground, lateral grip, stability and sliding of the ski would derive a significant benefit if the anterior part of the ski would be assimilated to an arc of ellipse (line E). Stiffness of anterior part of ski has to be increased in his initial part and then decreased on shovel, tapering thickness on a little zone between point **<6>** and **<3>**.

Fragility would came from this operation and torsion stiffness would be compromised. The use of complex structure and difficulty on repeatability of them for each ski comport inefficiency on productive processes and on industrial economy.

Fig. 3: particular of shovel that don't touch the ground and particular view of ski deflection.

Patent's object is an innovative plate (fig. 4) in which the base core is extended with an extension and the extremity of this produce a load (**Fspat**) on a point **<6>** in a central disposition between tip of binding **<P>** and ski tip **<4>** due to reaction at counter-inflexion of the ski during a turn. Also a preload could provides a load on this extremity.

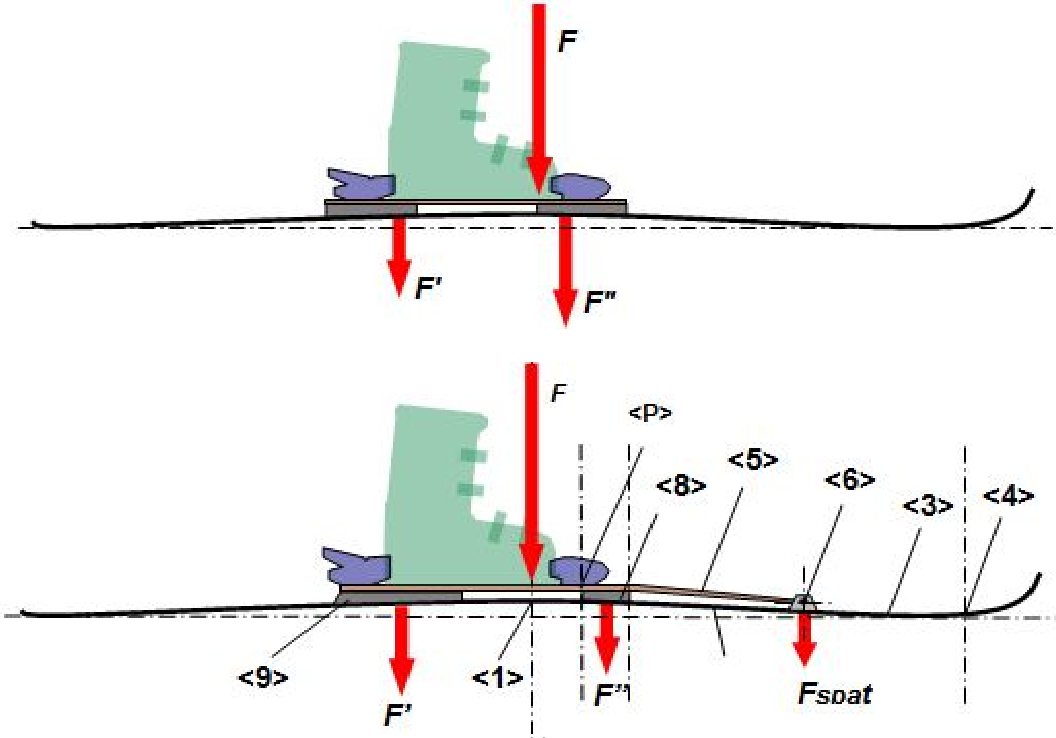


Fig. 4: Distribution of forces on the ski

This innovative superstructure, with respect to the traditional configuration, permits a better redistribution of skier forces on the ski, because the adding of **Fspat** would lightening the other two forces F' and F''. Ski would have greater flexibility and an efficient adherence to the ground. Ski becomes easy to use, continuous on trajectory and on sliding.

The superstructure provides a deformed line as line E in figure 1B such that pressure on the ground in correspondence of point **<6>** is higher than original configuration. Curve entrance is facilitated by higher pressure, and also the successive edge change.

Point **<6>** ha s to respect important boundary condition: vertical displacement of shovel would be avoided but has to permits the maximum flexibility, the horizontal displacements is permitted and also rotation on the same point: so the bound became a slotted hinge.

Thickness individuated with point <8> and <9> would be adaguated for each specifical base configuration and load that is desired on the system. So the extension wouldn't be rigidly matched on base plate, but, for example, with the variant of figure 4:

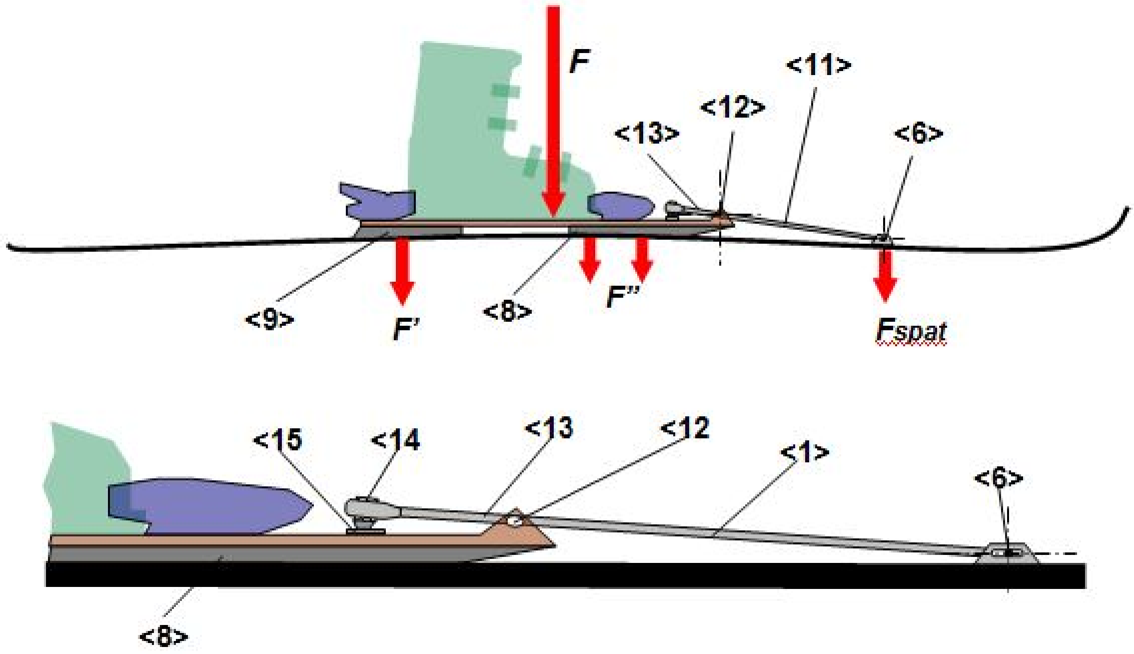


Fig. 5: first prototype of superstructure

An hinge on point **<12>** is the connection between base plate and superstructure. The same "arm" would be displaced in horizontal direction and fixed with a screw **<14>** on the base plate. The elastic element **<15>** connects screw and plate.

In-field test would be only objective if the same ski is given at different testers. In laboratory it's possible to find experimental anwers using a bench, who permits to shows the effect of superstructures on ski curve of pressure on the ground. This curve is named Edge Load Profile (ELP). The description of this bench and of hits output is given on chapter 3.

In the next page it's reported and example of ELP.

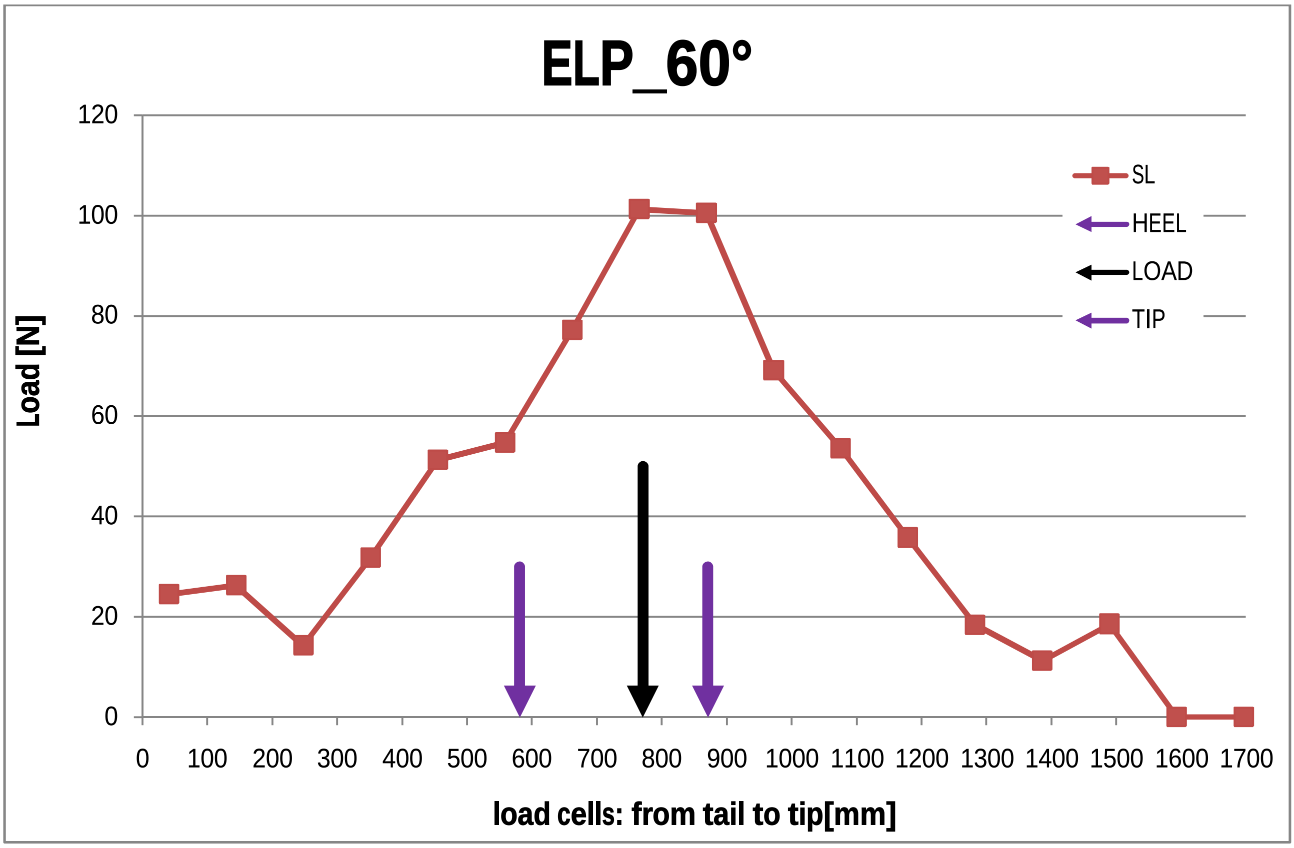
This figures shows a turning and it's possible to note the deflection of the external ski:

Fig. 6: effect of turning on ski deflection

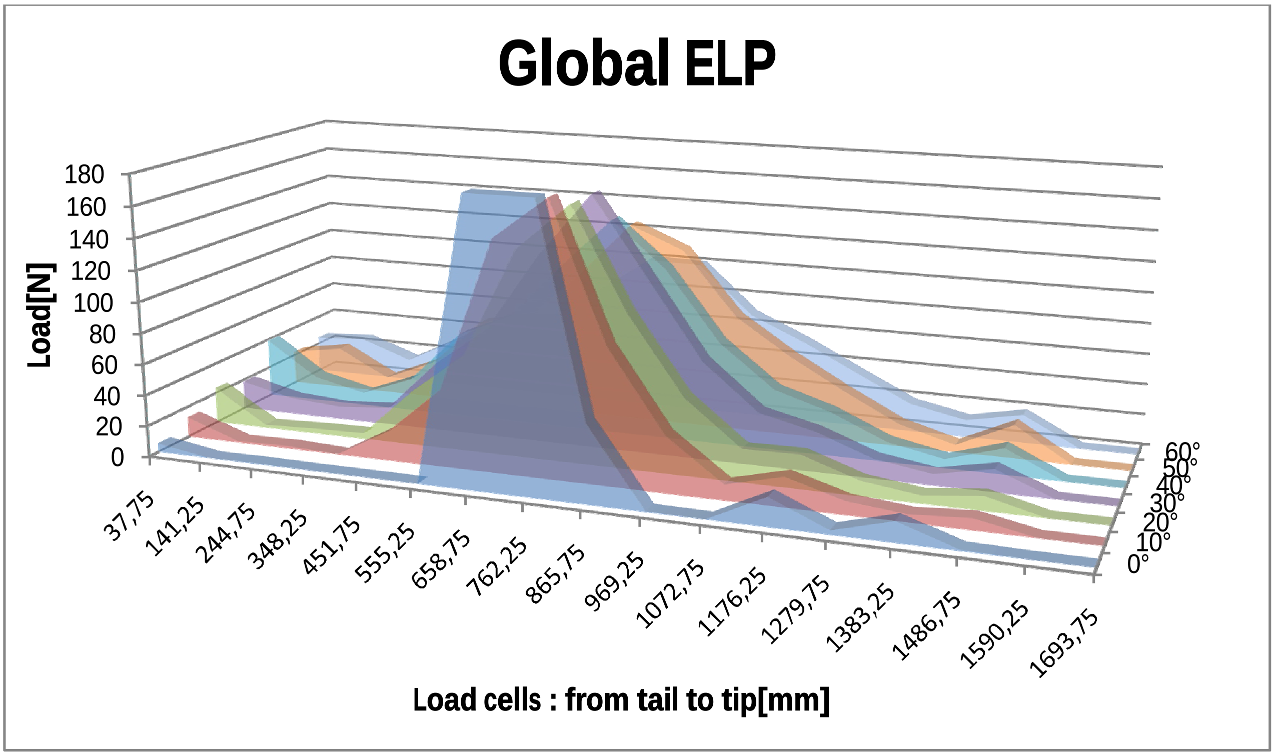
Edging bench reproduce this deflection applying a load at in a fixed angle.

Fig. 7: ski loaded on edging bench

The resulting profile is the diagram reported in the next page.



Another type is global diagram who shows the fitting of ELP on ski shovel at different angle.



Other descriptions and diagrams are reported in chapter 3.

Chapter 1: CHARACTERIZATION OF SKI SPITFIRE 168, WOOD AND RESIN ARM

1.1 INTRODUCTION

Tests of characterization are effectuated on arms and skies to obtain information about the material they are made. Stiffness is the most important output parameter of these tests. These experiences want to show the sum of the stiffness of arms and skies when they are coupled. A second part of characterization is based on the analysis of the effect of arm extension. For each type of arm an extension is applied from 10 to +50mm at step of 10mm. Characterization tests were effectuated repeating the same procedures of the previous test without extension.

During experiences did in the past, it was observed that constraint conditions of arm installed on ski influences the value of arm's stiffness. Arms are installed on ski with hypothesis of perfect fit: this is only an approximation because the bond is not fix during test, but it moves following the displacement of the ski. Usually a bond with this features is called soft joint and change his properties in time. Figures on the paragraph 1.1.1 shows how superstructures are matched with skies.

To obtain valid results it's important to respect the boundary conditions.

Tests are effectuated with arms alone fixed on a rigid support, then a ski is fixed on the bench with shovel lift up and arms are fixed on ski, so other test are made loading only arms. One test is reserved for ski in original configuration. Last tests are for ski and arms coupled.

Other similar test were done introducing the effect of length using a steel extension.

Load is made by four masses of different value, that are supported one above the other respecting an interval of 15 seconds. Masses are used following a load cycle that it's the same for all tests. Displacements are measured with a comparator of 26mm full scale.

Putting data on a Cartesian scheme with displacement on x axis and load on y axis, it's simple to draw the load line. The line's slope provides the value of stiffness. Stiffness values are calculated using a linear regression equation.

The last part of this chapter reports tables and diagram about the theoretical and experimental sum of stiffness with relatives percentual differences, and then percentual differences regarding the decreasing of stiffness when length is extended with respect to the original configuration without length.

1.1.1 SUPERSTRUCTURES INSTALLING

Wood and resin superstructures are installed on ski using these instruments: aluminum plate and screws. Superstructures are not directly fixed on the ski: the presence of an aluminum plate permits to distribute a fraction of bending moment on the base plate. Two of the four screws is those of the base plate. The follow picture shows superstructure matching:

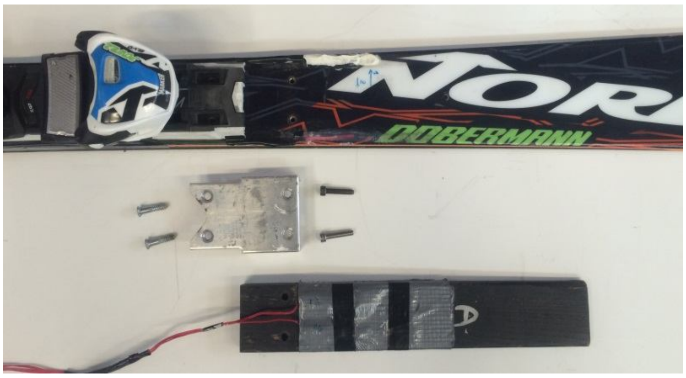


Fig. 8: Wood, aluminum plate and screws

Fig. 9: Resin, aluminum plate and screws

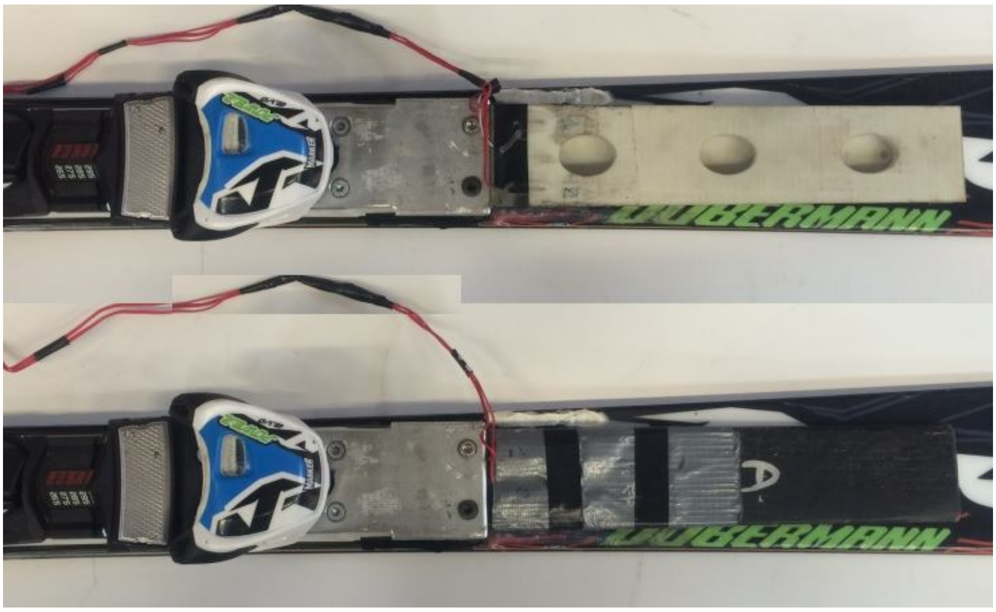


Fig. 10: Final matching

These are the final combination of ski and superstructure that are studied in characterization experiences. Wires on superstructure regard strain gauges measurements that are explained in chapter 2.

1.2 MATERIAL AND METHODS

These experiences want to compare resin and wood arm's stiffness. One resin and one wood arm are used. The following pictures shows of the two arms. Ski used is a Nordica Spitfire 168. Length arm's is 300mm. The effective flexible length is 250mm.

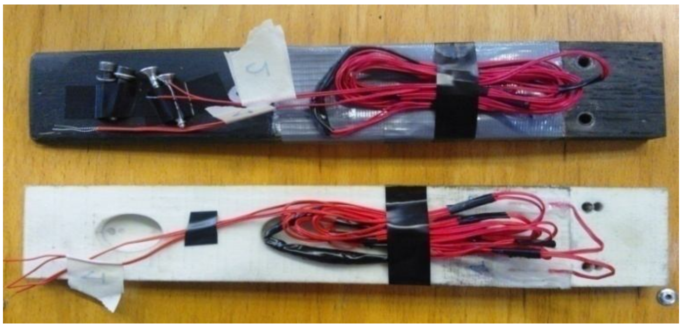


Fig. 11: wood arm (black) and resin arm(white)

	WOOD	RESIN
CROSS SECTION	53x16 mm^2	52x15 mm^2
$J_{on\ c.s.}$	18090 mm^4	14625 mm^4
Wf	2261,33 mm^3	1950 mm^3
E (literature)	9000 MPa	4200 MPa

Fig. 12: Nordica Spitfire Pro 168

Using classic mechanical formulas, once loads and displacements are known, stiffness are calculated with a regression line, and it's simple to obtain a n equivalent value of Young modulus:

$$f = \frac{FL^3}{3EJ} \quad \rightarrow \quad E = \frac{kL^3}{3J}$$

1.2.1 OBJECTIVES OF THE STUDY

The first objective of characterization test was researching the sum of arm and ski stiffness when they are coupled and then compare the results with theory sum.

When the extension is applied it's possible to study the effect of length on stiffness for different material. For theory there is an inverse cubic relation between stiffness and length. Also in this case it's possible to apply some sum comparison between theory and experimental.

1.3 LIST OF TESTS

Characterization tests effectuated are:

- Resin arm fixed on the rigid support
- Wood arm fixed on the rigid support
- Resin arm on the ski
- Resin arm and ski together
- Only ski
- Wood arm on the ski
- Wood arm and ski together

Load cycle are repeated two times for all test, displacements are read 5" after load application. Step between two masses is 15". Masses used: 1,585 kg ; 3,3 kg ; 3,85 kg ; 4,06 kg.

1.4 TESTS

1.4.1 RESIN ARM INSTALLED ON A RIGID SUPPORT

In this test it is assumed the presence of a perfect fit near the arm's anchorage screws. The arm is fixed on the support with a pack closure, because the test need for a constraint as much as possible rigid. Only the tip of the arm is stressed by the loads.

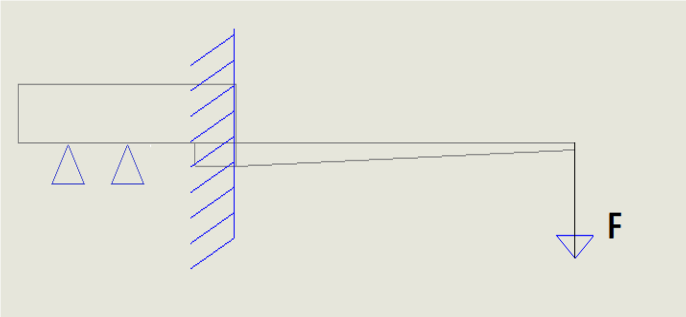
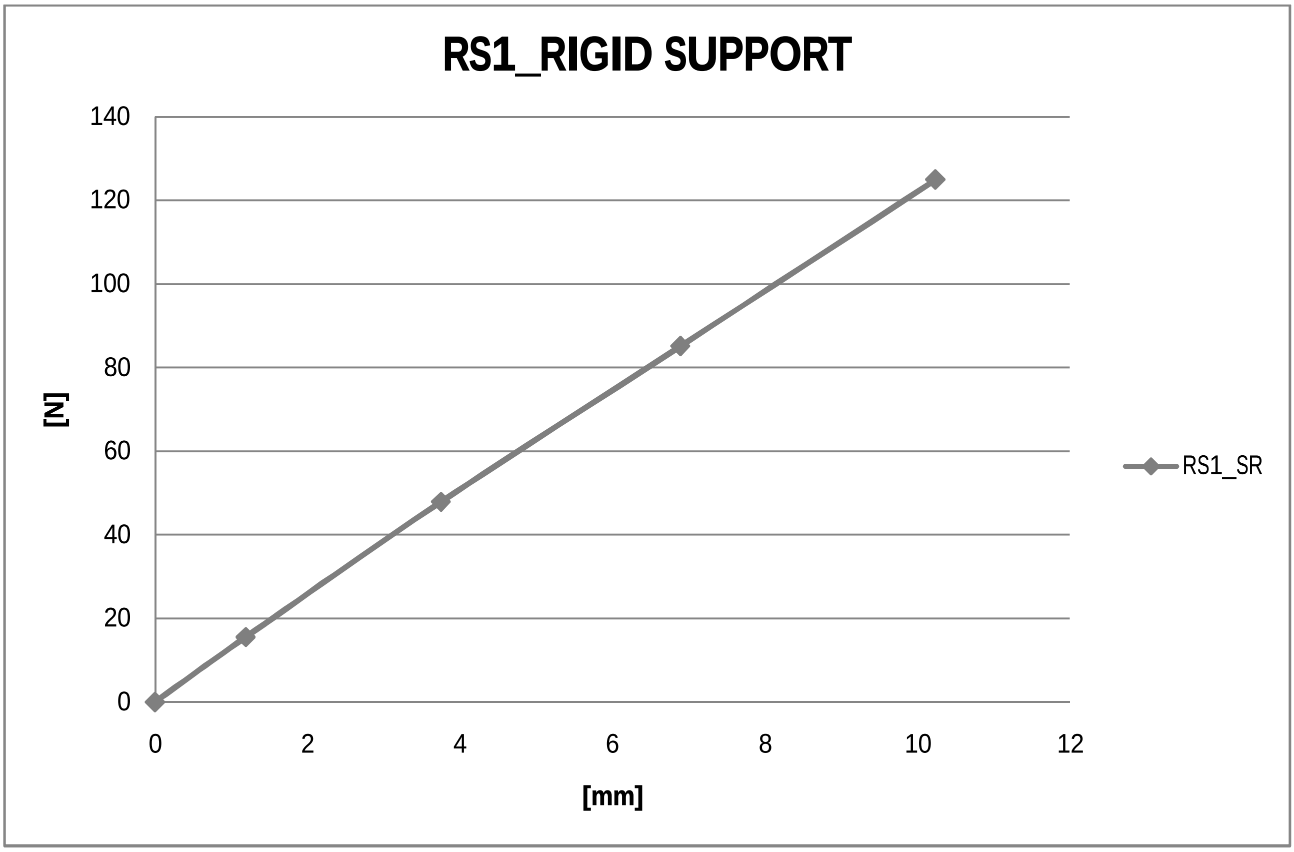


Fig. 13: static scheme (up) and real scheme (right)

Load line:



Stiffness has a linear increment. By the regression of data it is obtain the follow value of stiffness:

$$k_{RS1\_SR} = 12{,}19 \frac{N}{mm}$$

1.4.2 WOOD ARM INSTALLED ON A RIGID SUPPORT

It is repeated the procedure of the precedent test. In this test there is a perfect fit near the anchorage screws , and the pack closure is the same to obtain a constraint as much as possible rigid.

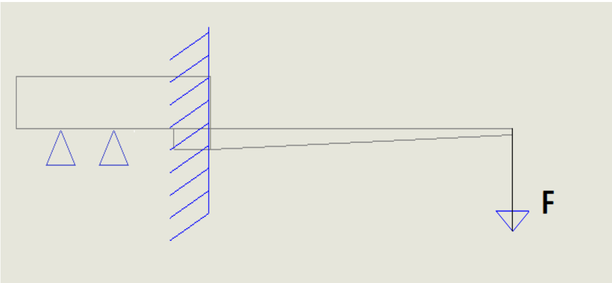
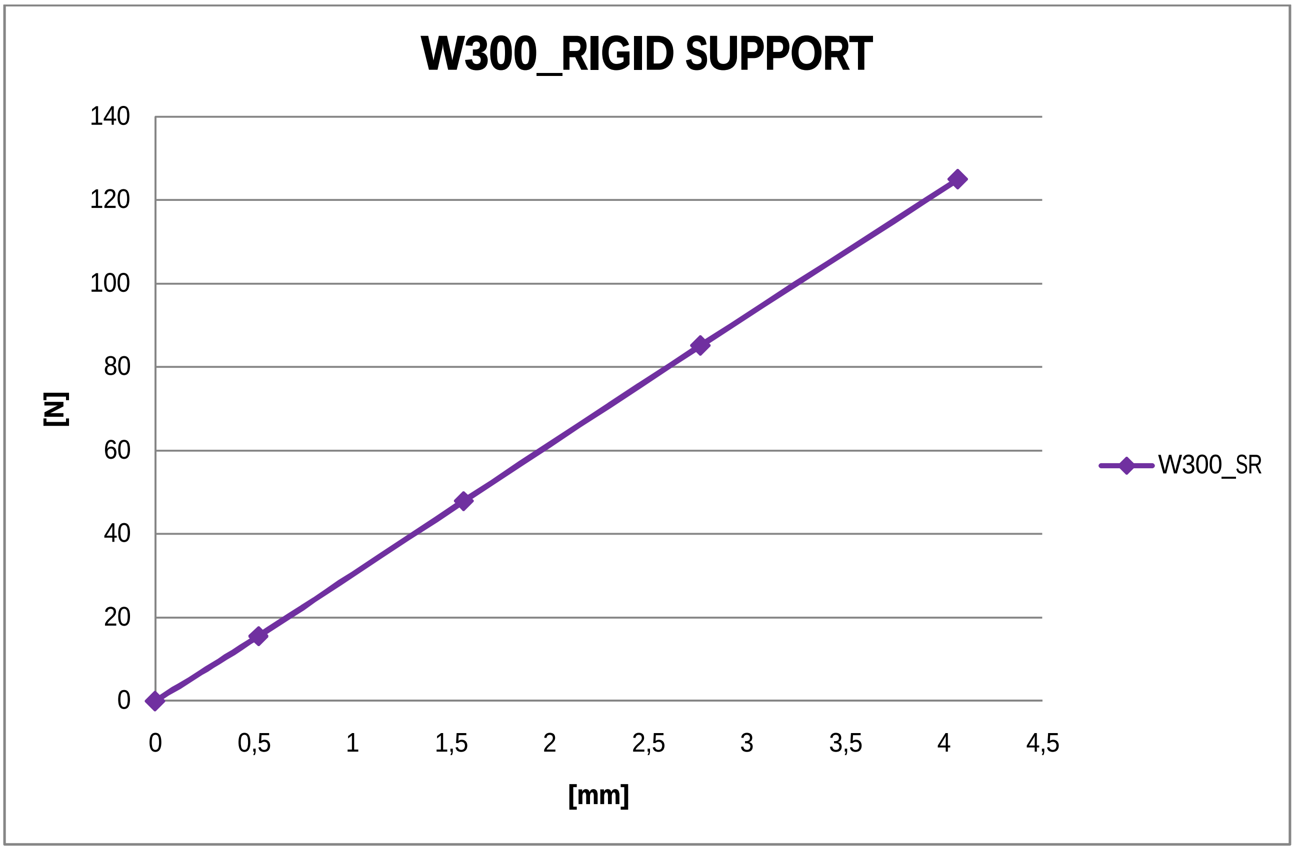


Fig. 14: static scheme (up) and real scheme (right)

Load line:

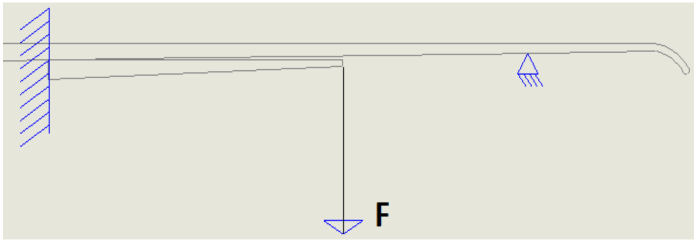


By the regression of data , the stiffness is :

$$k_{W300\_SR} = 30{,}82\ \frac{N}{mm}$$

1.4.3 RESIN ARM INSTALLED ON SKI

In this configuration ski is fixed using the aluminum boot and two clamps near bindings. Then the shovel is lift to avoid the contact between ski and arm. Arm is fixed at the ski using two screws. The hypothesis is that of reproducing a perfect constraint near the anchorage screws. It is added a clamp near the screws and a crick under the clamp to avoid vertical displacement of the clamp. Only the tip of the arm is loaded.



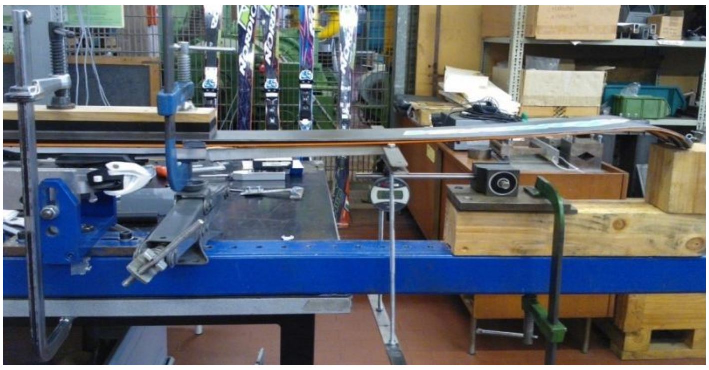
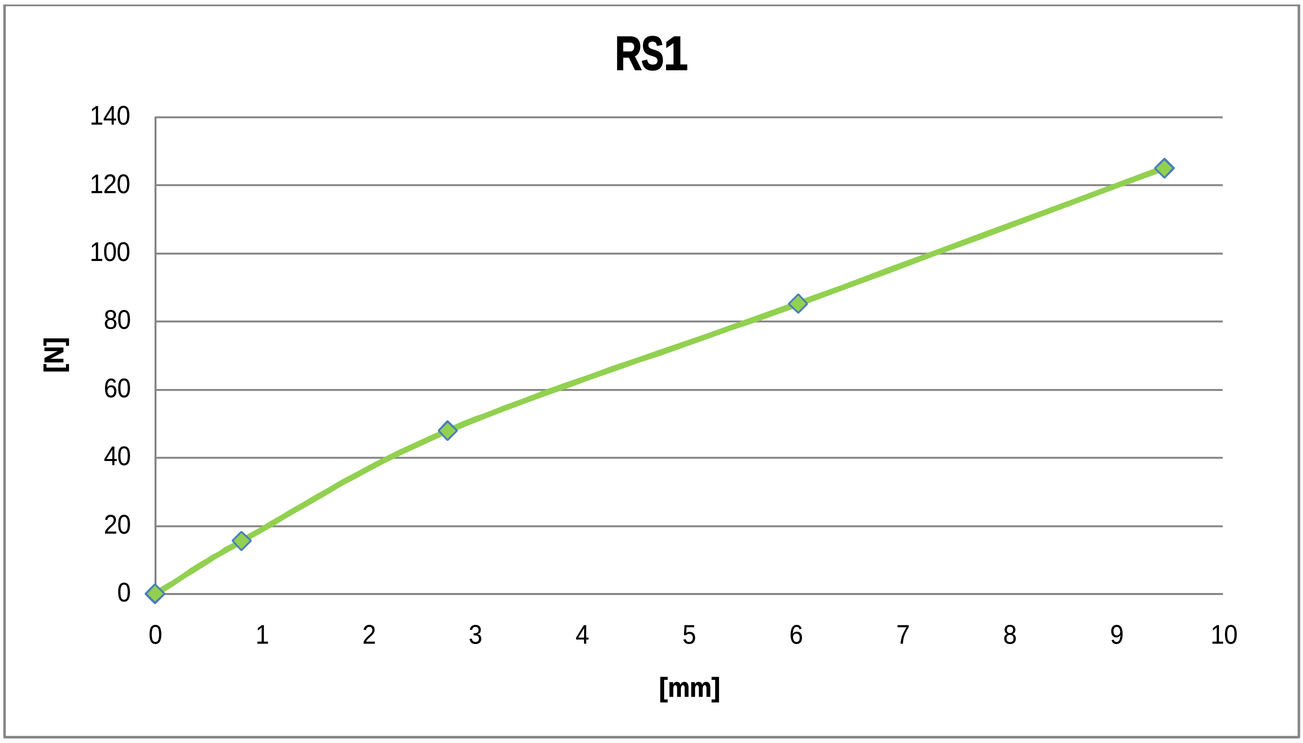


Fig. 15: static and real scheme

Load line:



Stiffness has not a linear increment. By the regression of data the value of stiffness is the follow:

$$k_{RS1\_S} = 12{,}99 \, \frac{N}{mm}$$

1.4.4 SKI LOADED IN PRESENCE OF RESIN ARM

In this configuration the ski is stressed by the loads near the point of contact with the arm. The aim is to test if the stiffness of the ski is cumulative with that of the arm.

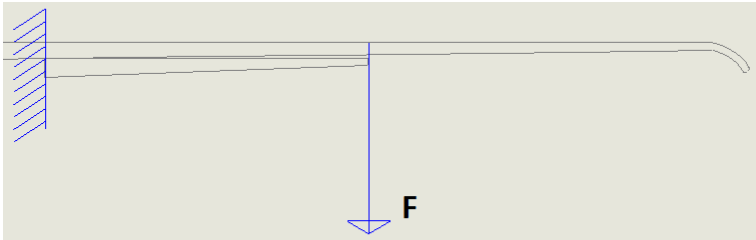
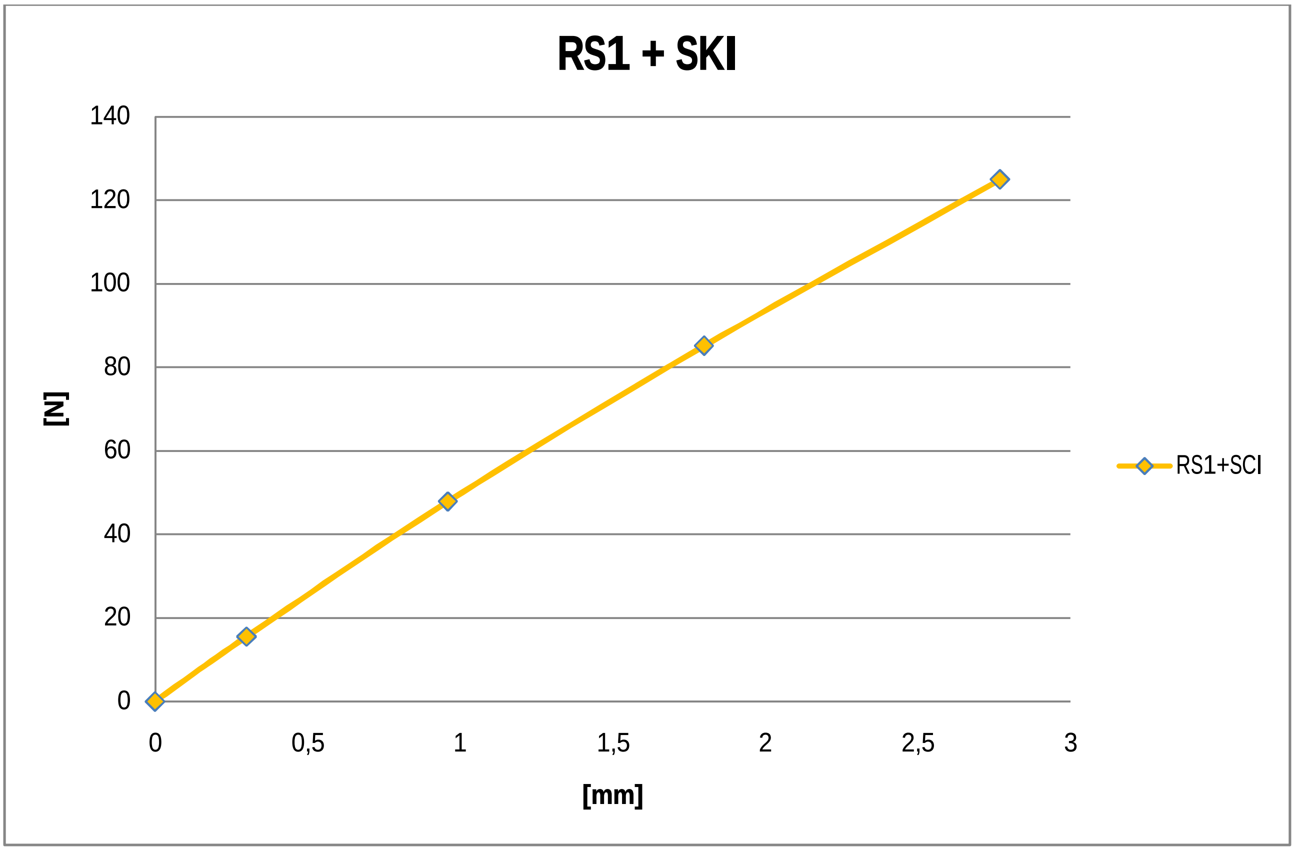


Fig. 16: static and real scheme

Load line:



By regression of data, the value is:

$$k_{RS1eS} = 45{,}10\ \frac{N}{mm}$$

1.4.5 ONLY SKI

In the same point of application of the precedent load , and without varying the load, arm is removed and it is repeated the load cycle. This test is important to understand how this ski is stiff in his original configuration.

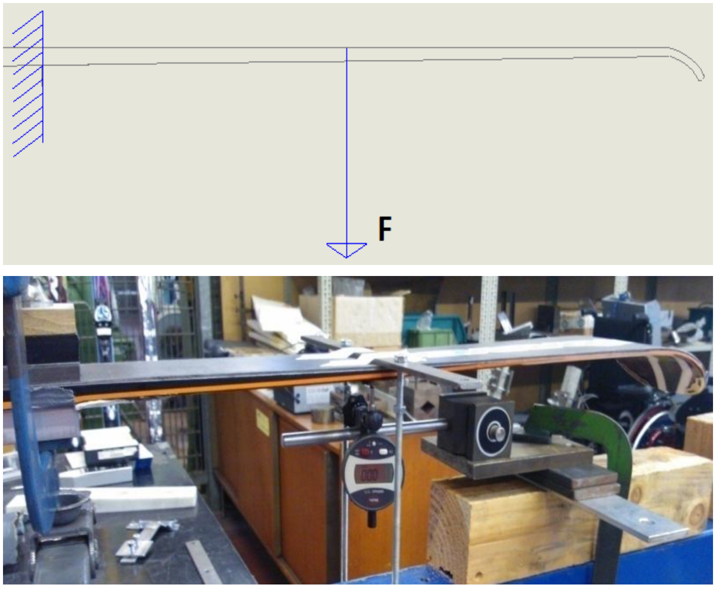
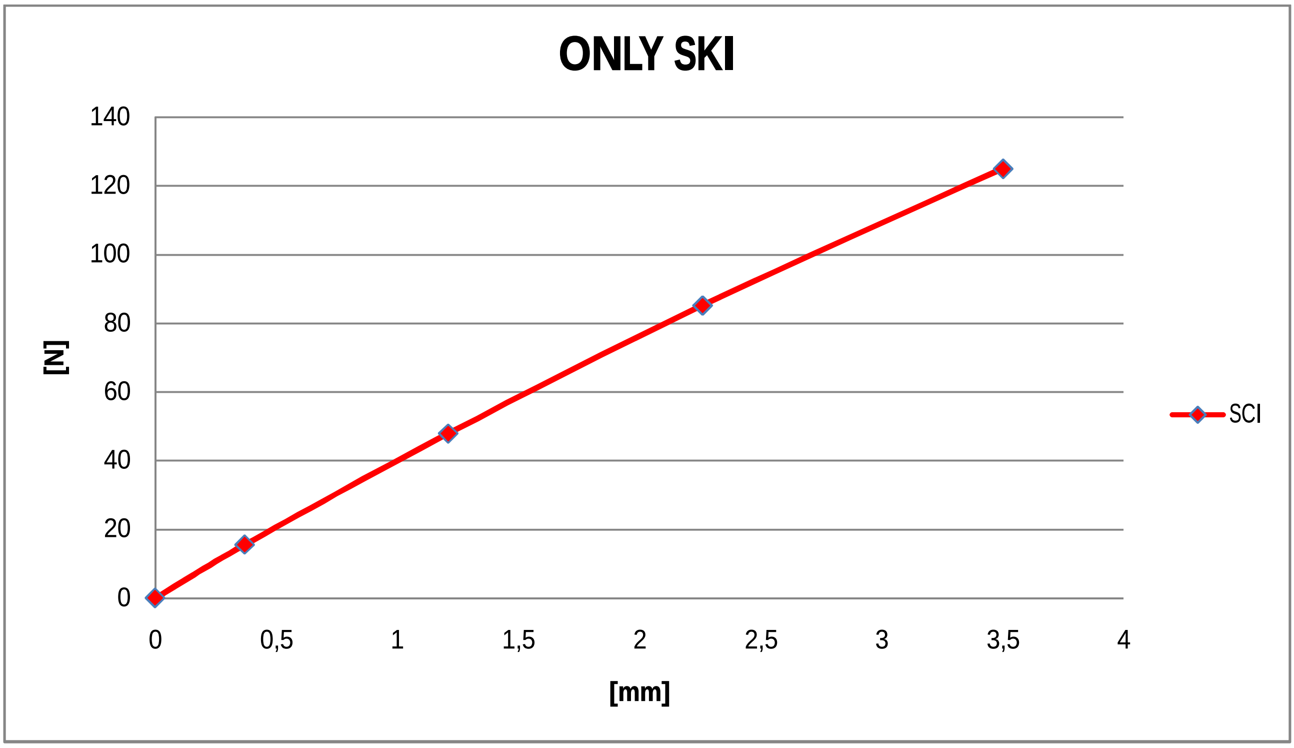


Fig. 17: static and real scheme

Load line:



By regression of data, the value of stiffness is :

$$k_S = 35{,}77 \frac{N}{mm}$$

1.4.6 WOOD ARM INSTALLED ON SKI

All the previous procedures are repeated with the wood arm. This is important to assess wood and resin and understand which of the two gives the best bending behavior.

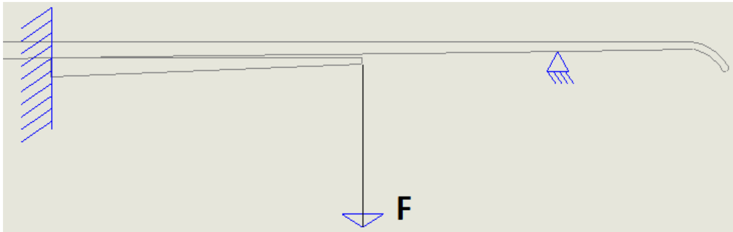
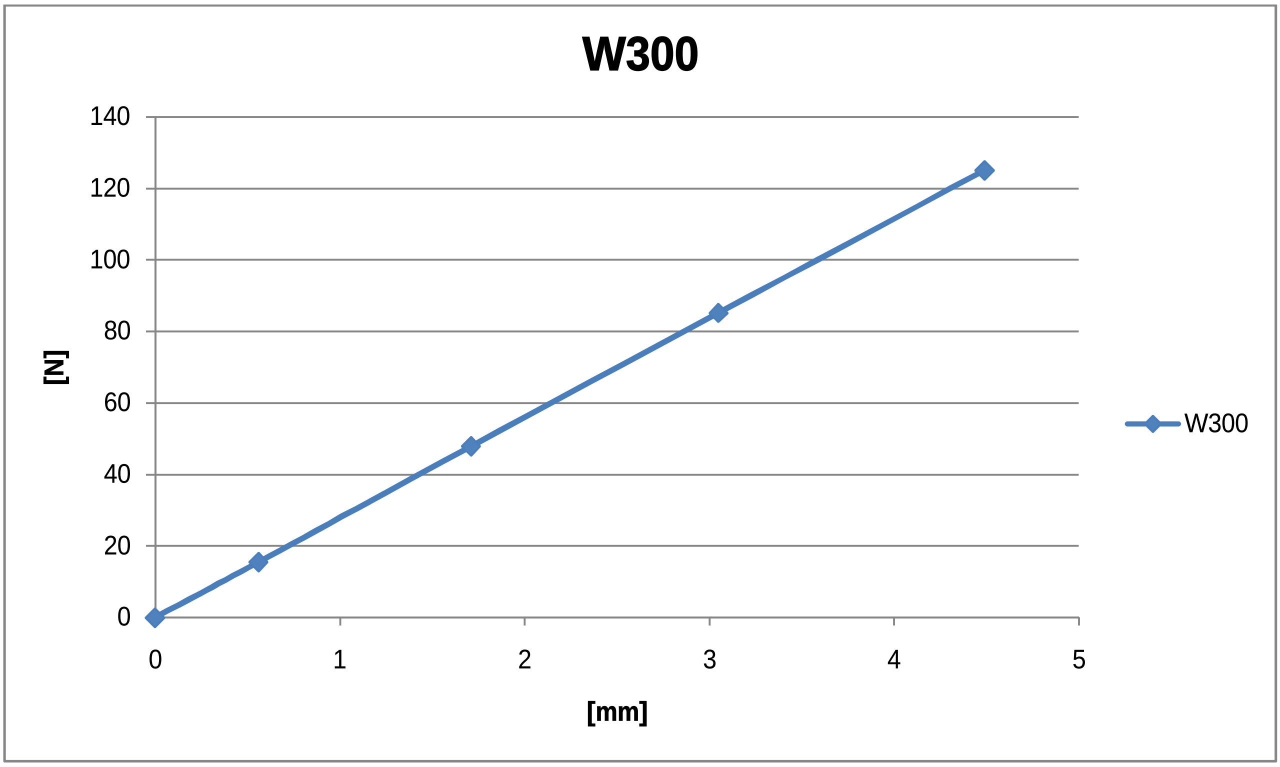


Fig. 18: static and real scheme

Load line:



Wood shows a linear increment. By regression of data the value of stiffness is:

$$k_{W\_S} = 27{,}87 \frac{N}{mm}$$

1.4.7 SKI LOADED IN PRESENCE OF WOOD ARM

The load F is applied in the same point of the fourth and the fifth test. From this test we expect a stiffness value that is comparable to the sum of the stiffness of the two individual cases.

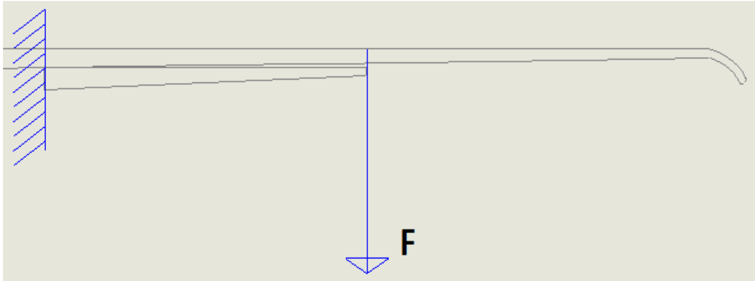
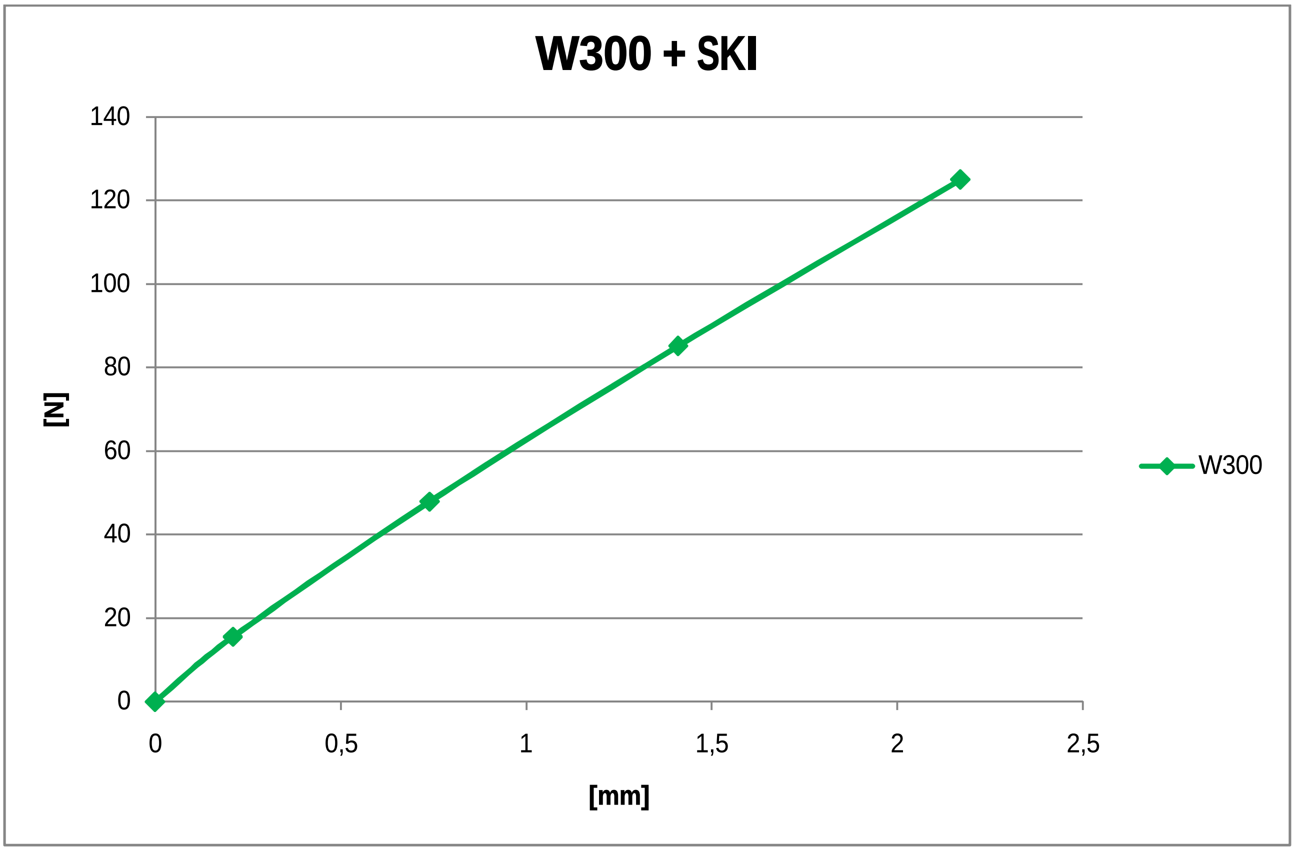


Fig. 19: static and real scheme

Load line:

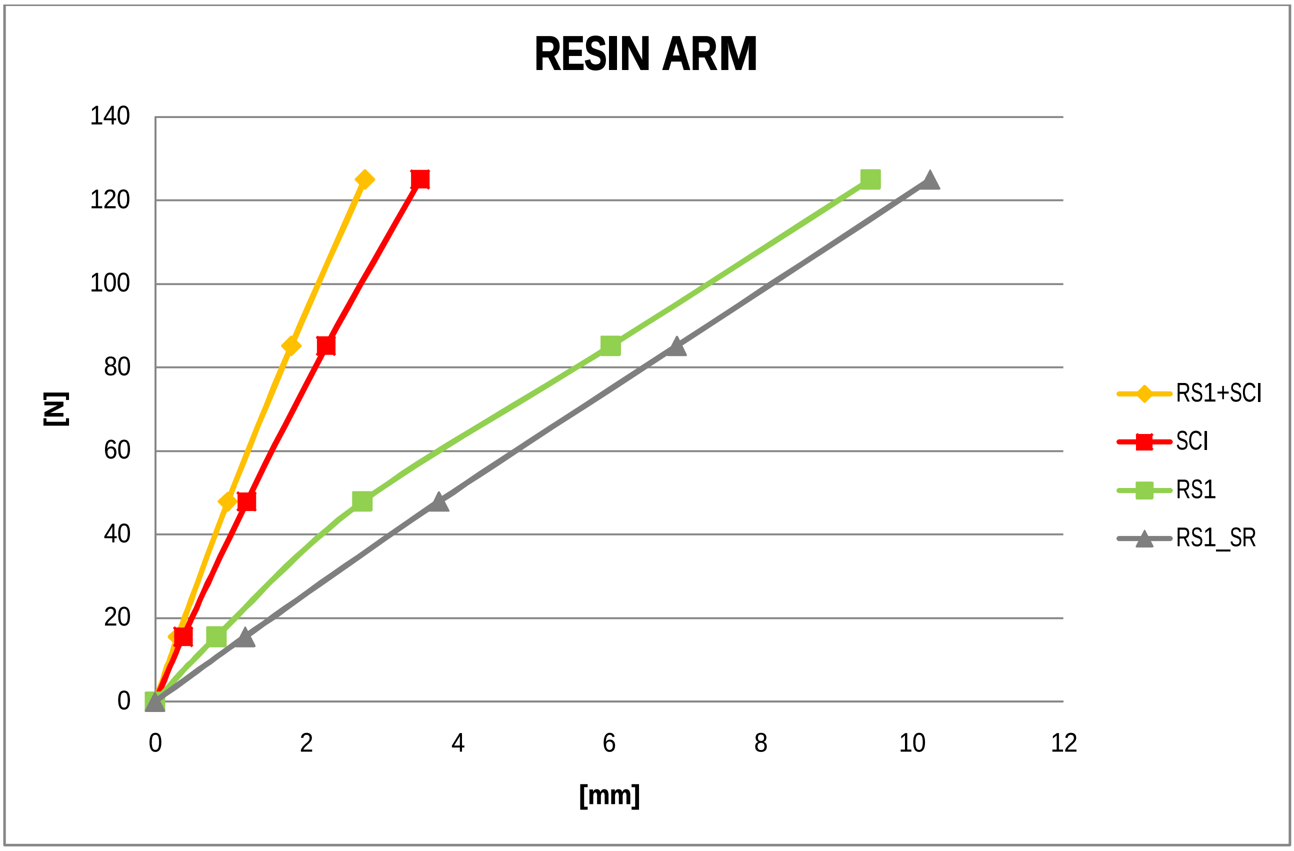


By regression of the data, stiffness is:

$$k_{Wes} = 57{,}33 \frac{N}{mm}$$

1.5 ANALYSIS AND COMMENTS

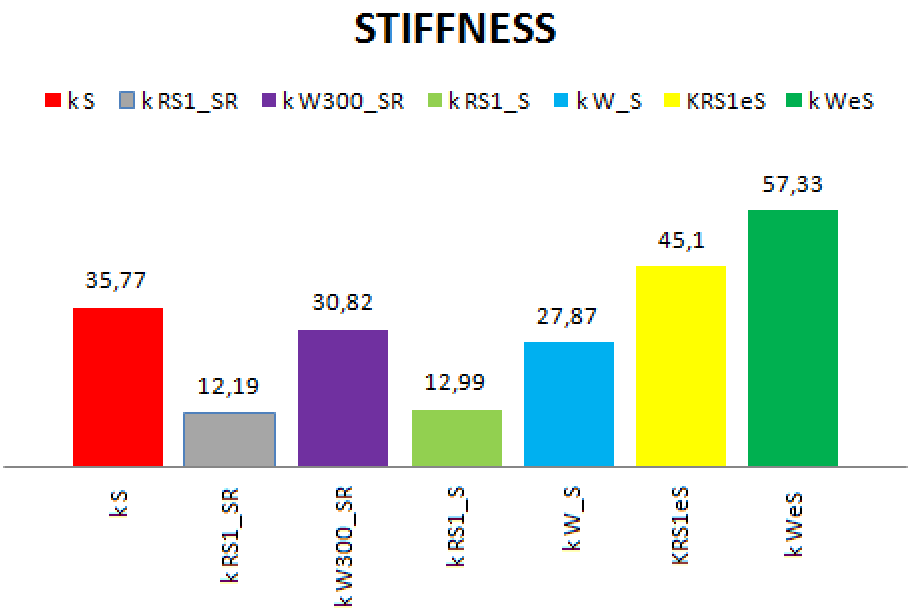
Summary diagrams



Observation:

- Ski stiffness (red line) increases with the resin arm , but the effect of the arm in the sum is less influent. Ski stiffness is preponderant and the value of increasing is linear with the load.
- Ski stiffness (red line) increases with the wood arm and his stiffness influences a lot the value of the sum (maybe the double).
- Resin arm installed in the rigid support and on the ski shows the same stiffness, and shows a linear increment only in the high loads .
- Wood arm shows a greater stiffness if installed in the rigid support.
- The bond system on the ski shows, less of a corrective factor, the additively of the single case of arm and ski.

1.5.1 STIFFNESS' SUMMARY HISTOGRAM

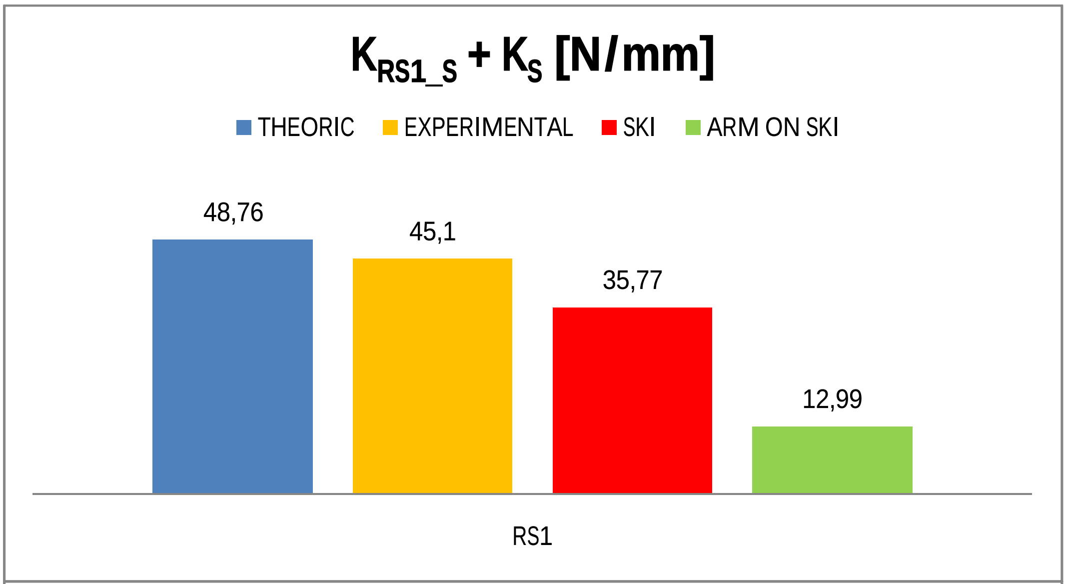


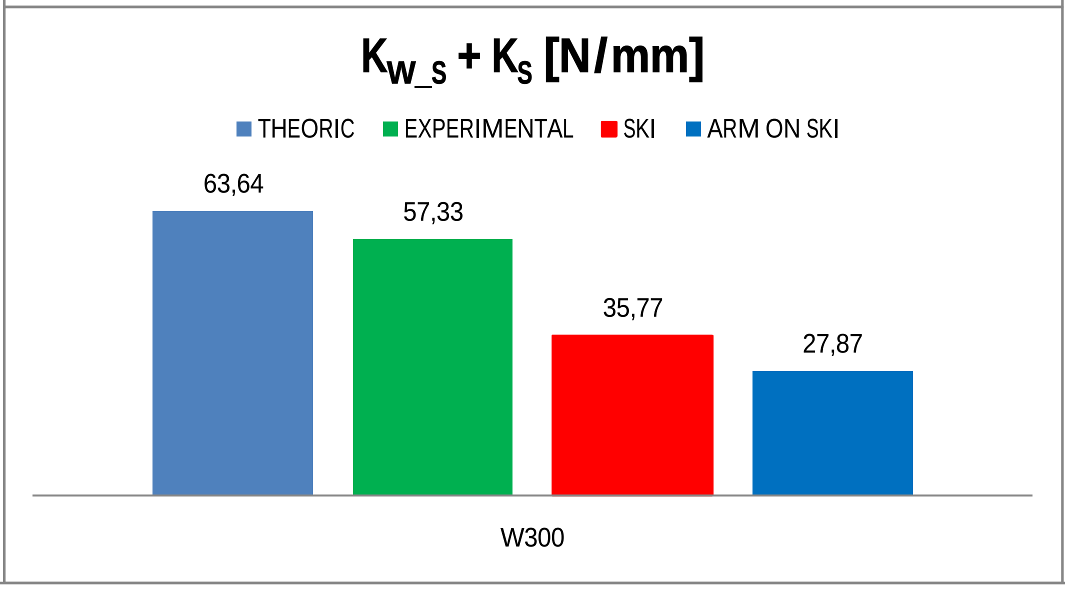
OBSERVATIONS :

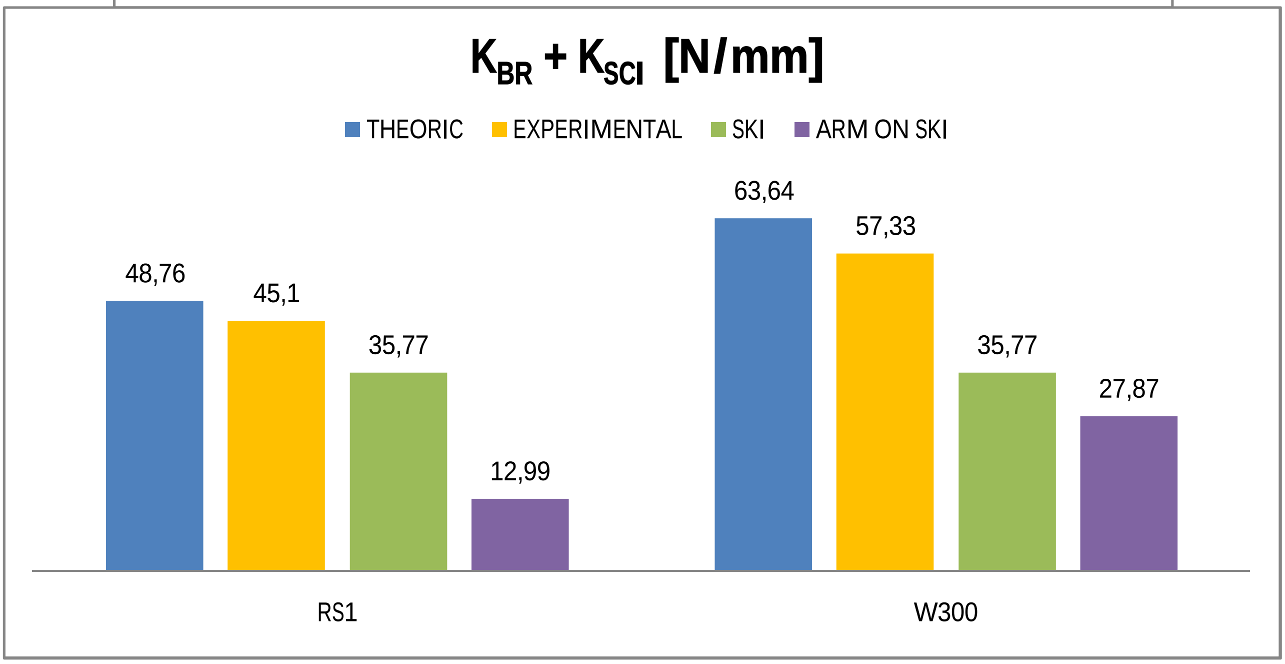
THEORETICAL SUM	EXPERIMENTAL SUM	DIFFERENCE : (EXP-TH/EXP)%
$K_{RS1\_S} + K_S$ = **48,76 N/mm**	K_{RS1eS} = **45,10 N/mm**	**-7,5 %**
$K_{W\_S} + K_S$ = **63,64 N/mm**	K_{WeS} = **57,33 N/mm**	**-9,92 %**

CONFIGURATION	STIFFNESS SIMBOL	STIFFNESS [N/mm]	DIFF % ARM-NOARM
SKI	**k_S**	35,77	-
SKI + RESIN	$k_{RS1}eS$	45,1	20,69%
SKI + WOOD	$k_{W}eS$	57,33	37,61%

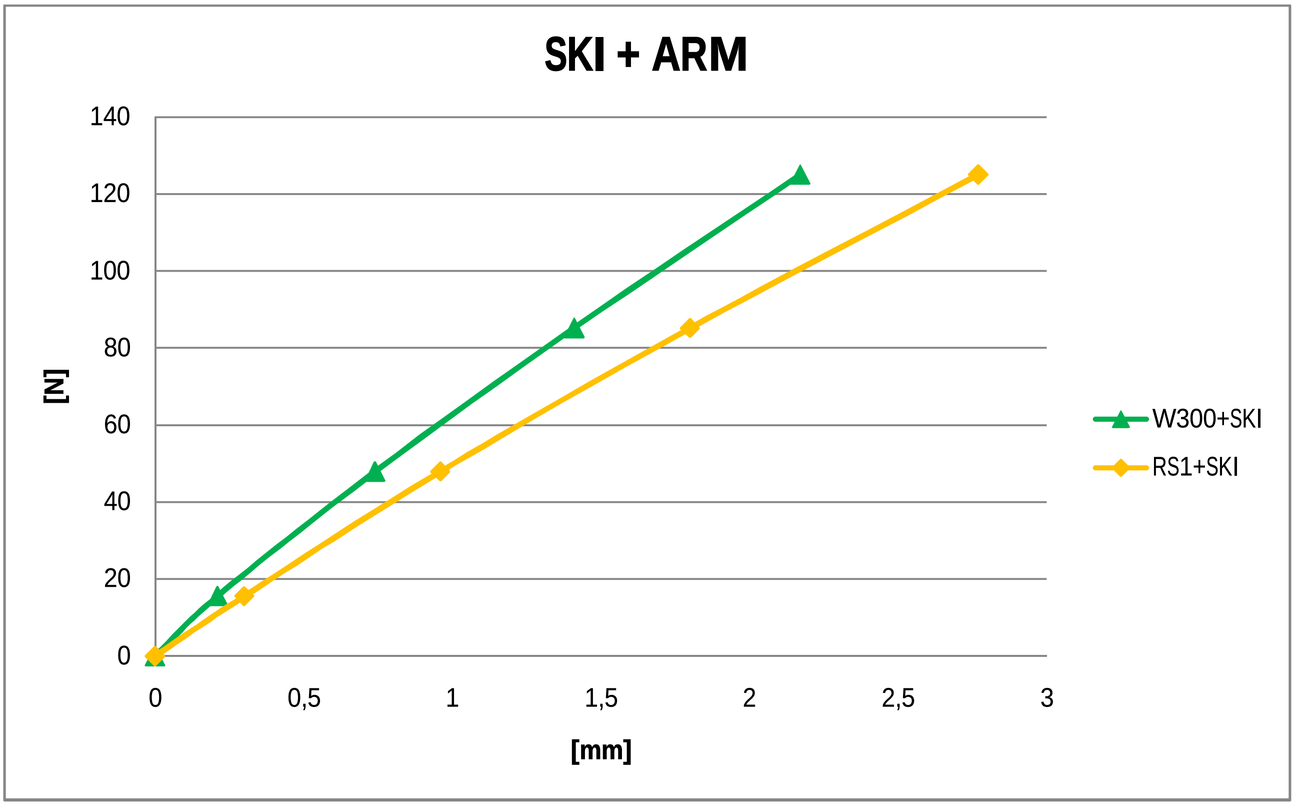
SUMMARY HISTOGRAM



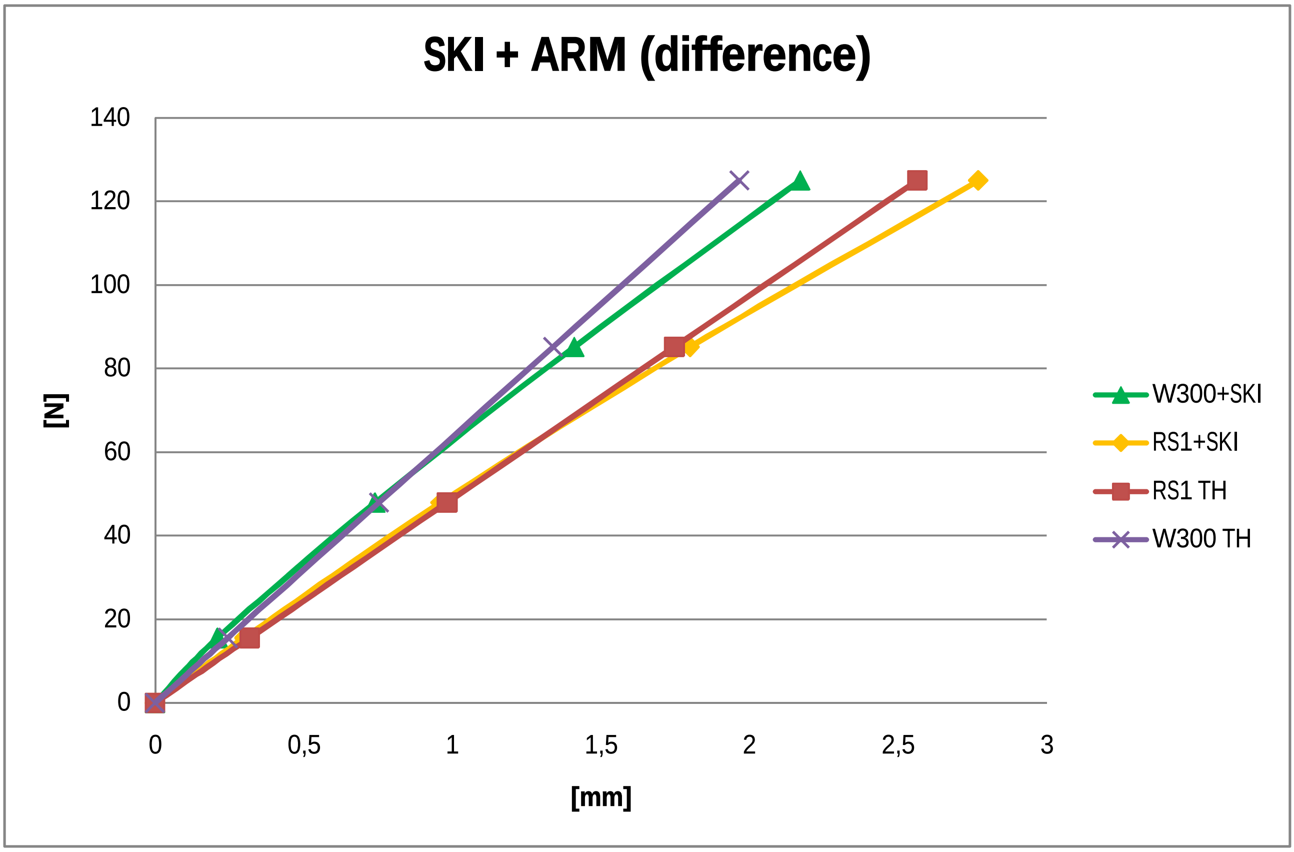




The following diagrams are shown ski + arm configuration.



In this diagram there are the effect of difference from experimental and theory sum. Difference effects are greater at high loads.



1.6 SUMMARY RESULTS

The following table reports the results of the previous analysis and shows the percentual differences between resin and wood stiffness in the first and in the fourth column. The third column resumes the percentual difference of arm stiffness fixed in rigid support and after on ski. The last two column report the percentual differences of ski stiffness in original and in coupled disposition, and between theoretical and experimental sum of stiffness (arm+ski).

STIFFNESS [N/mm]							
	$K_{R.S.}$	$K_{on\ ski}$	$\Delta\%_{on\ ski}$	K_{ski}	$K_{ski\ +arm}$	$\Delta\%_{ski\ ,\ ski+arm}$	$\Delta\%_{\Sigma EX-\Sigma TH}$
RESIN	12,19	12,99	6,16%	35,77	45,10	20,68%	6,34%
WOOD	30,82	27,87	-10,58%	35,77	57,33	37,6 %	16,15%
$\Delta\%_{RS-W}$	-60,45%				-21,33%		

From table it results that wood has a stiffness 60% greater than resin, but this effect is not reproduced in coupled configuration because the percentual difference decreases at 21 %.

Resin superstructure shows lower percentual differences from theoretical and experimental sum of stiffness, but the best grow of stiffness is given by wood superstructure, who improves shovel stiffness of 37% .

1.7 EFFECT OF LENGTH

A stainless steel extension is added at the two arms (called w300 and RS1). Now it is possible to extend the length of the arm in step of 10mm, from 300mm to 350mm. Skiers are free to choose their subjective best configuration. The presence of the extension change the flexibility of the ski and then the stiffness.

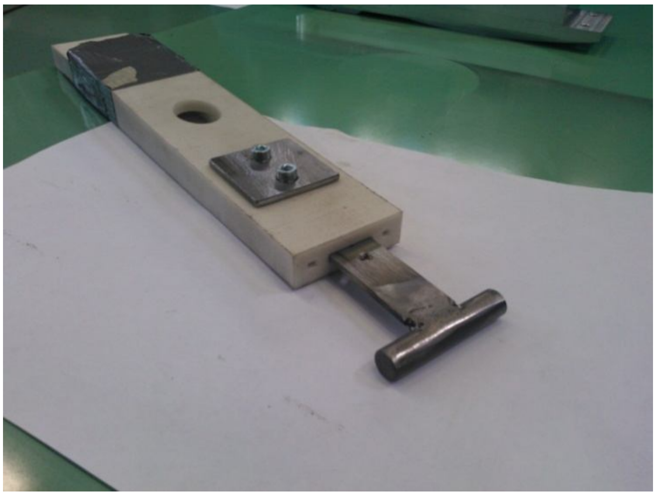


Fig. 20: extension installed on resin arm

The aim of this analysis is observing if stiffness follow an inverse cubic law in function of length:

$$f = \frac{Pl^3}{3EJ} \quad \rightarrow \quad k = \frac{P}{f} = \frac{3EJ}{l^3}$$

where f is the displacement, and k the stiffness.

Tests are effectuated with arm extended of 30mm and 50mm, which are considered significant. The others (10, 20 e 40mm) where interpolated. In every test two load cycle where effectuated putting masses in step of 15”. Displacement value are read 5” after the application of a mass.

Fig. 21 and 37 bis: extension installed on wood (up) and on resin arm (right) coupled on spitfire

1.7.1 TEST PERFORMED WITH ARM INSTALLED ON SKI:

1. W300+30

$$k_{w300+30} = 11{,}67 \frac{N}{mm}$$

2. W300+50

$$k_{w300+50} = 8{,}15 \frac{N}{mm}$$

Fig. 22: Wood arm loaded on ski

3. RS1+30

$$k_{RS1+30} = 7{,}04 \frac{N}{mm}$$

4. RS1+50

$$k_{RS1+50} = 5{,}47 \frac{N}{mm}$$

Fig. 23:Resin arm loaded on ski

Fig. 24: Particular of resin arm deformation

1.7.2 TEST PERFORMED WITH SKI AND ARM TOGETHER

1. W300+30+SCI

$$k_{w300+30\_sci} = 28{,}35\ \frac{N}{mm}$$

2. W300+50+SCI

$$k_{w300+50\_sci} = 25{,}09\ \frac{N}{mm}$$

Fig. 25: Ski and wood arm loaded

3. RS1+30+SCI

$$k_{RS1+30\_sci} = 34{,}08\ \frac{N}{mm}$$

4. RS1+50+SCI

$$k_{RS1+50\_sci} = 24{,}97\ \frac{N}{mm}$$

Fig. 26: Ski and resin arm loaded

1.7.3 TEST ON THE RIGID SUPPORT

1. W300+30_SR

$$k_{w300+30\_SR} = 13{,}49\ \frac{N}{mm}$$

Fig. 27: Wood arm on rigid support

2. W300+50_SR

$$k_{w300+50\_SR} = 8{,}83\ \frac{N}{mm}$$

3. RS1+30_SR

$$k_{RS1+30\_SR} = 7{,}20\ \frac{N}{mm}$$

Fig. 28: Resin arm on rigid support

4. RS1+50_SR

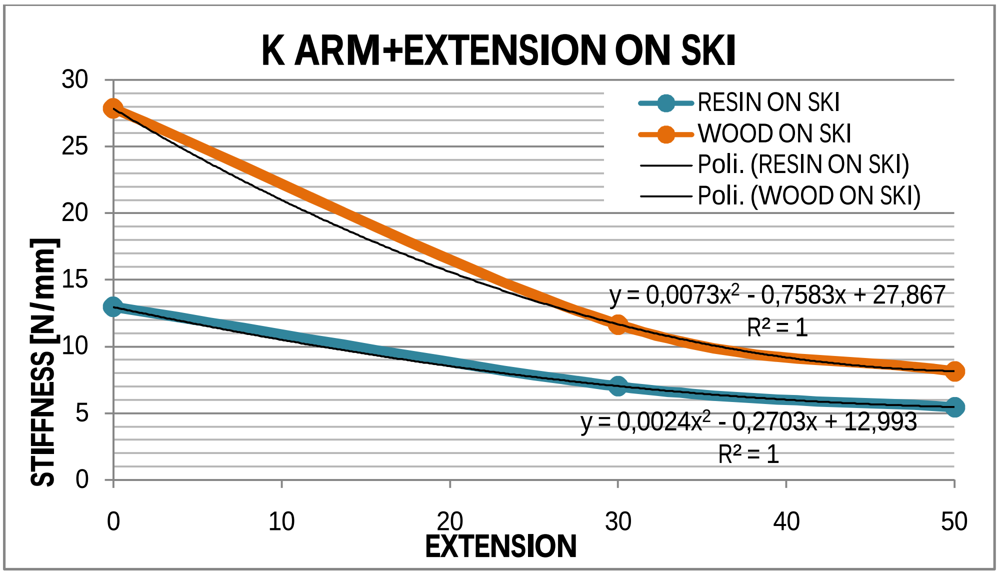
$$k_{RS1+50\_SR} = 5{,}93\ \frac{N}{mm}$$

1.8 ANALYSIS AND COMMENTS

1.8.1 SUMMARY HISTOGRAMS (_0, _+30, _+50 mm)

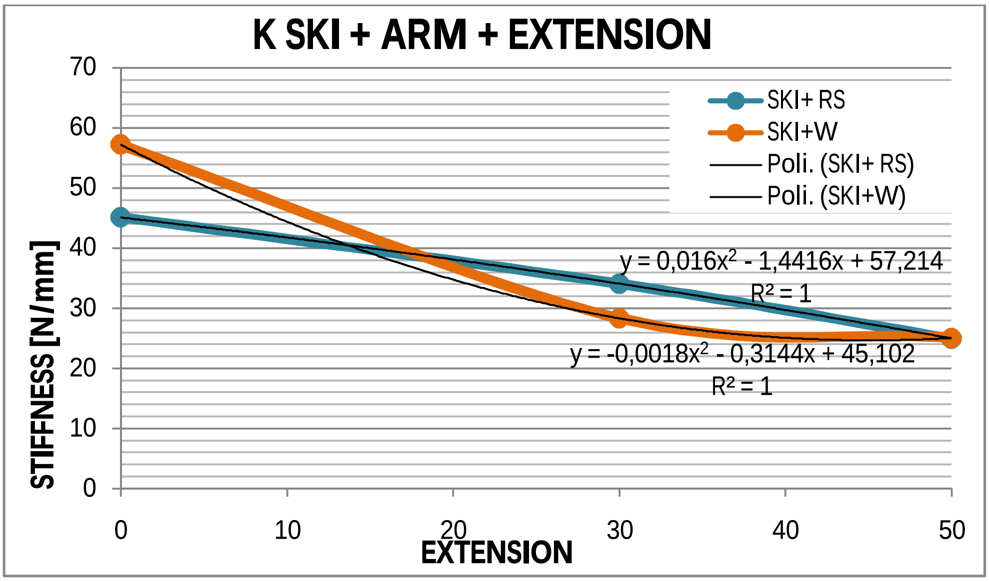
ARM + EXTENSION ON SKI:

	[N/mm]	Δ%		[N/mm]	Δ%
k_{w300}	27,87		k_{RS1}	12,99	
$k_{w300+30}$	11,67	-58,13%	k_{RS1+30}	7,04	-45,80%
$k_{w300+50}$	8,15	-70,76%	k_{RS1+50}	5,47	-57,89%



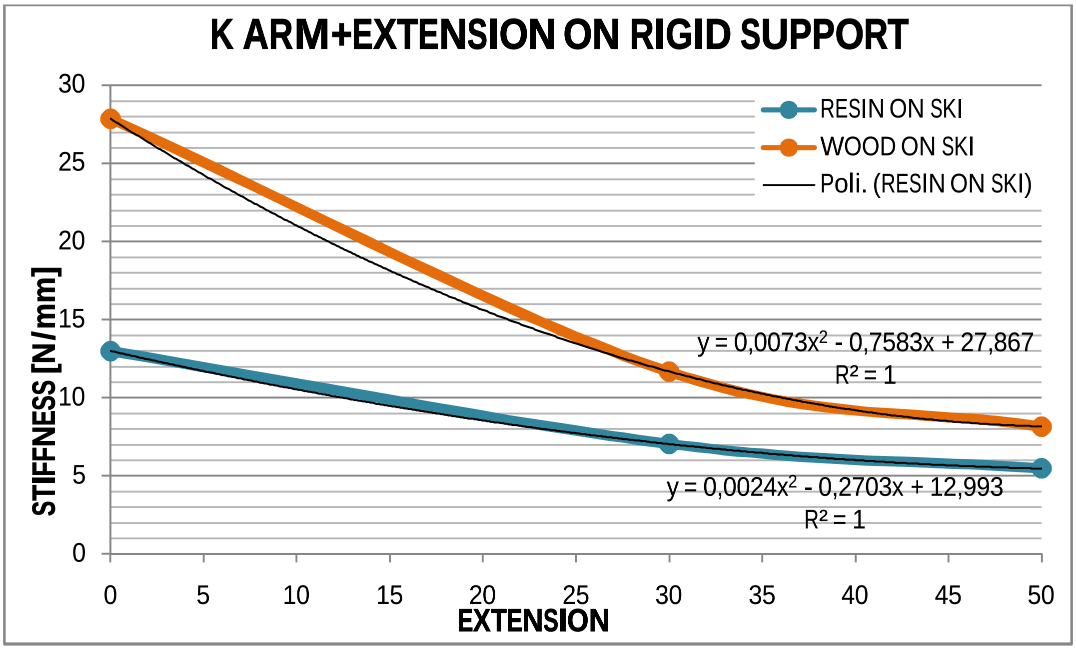
SKI + ARM + EXTENSION:

	[N/mm]	Δ%		[N/mm]	Δ%
k_{w300}	57,21		k_{RS1}	45,1	
$k_{w300+30+sci}$	28,35	-50,45%	$k_{RS1+30+sci}$	34,08	-24,43%
$k_{w300+50+sci}$	25,09	-56,14%	$k_{RS1+50+sci}$	24,97	-44,63%



ARM + EXTENSION ON THE RIGID SUPPORT

	[N/mm]	Δ%		[N/mm]	Δ%
k_{w300_SR}	30,81		k_{RS1_SR}	12,18	
$k_{w300+30\_SR}$	13,49	-56,22%	k_{RS1+30_SR}	7,2	-40,89%
$k_{w300+50\_SR}$	8,83	-71,34%	k_{RS1+50_SR}	5,93	-51,31%



Stiffness, as expected, decreases when the length of the arm is extended. This fall don't follow the theoretical law, because there isn't inverse proportionality with the cube of the length. Percentages of stiffness decreasing with respect to the length 300mm are reported near the stiffness value.

In this case the law is not respected not because the boundary condition, because it's the same for all tests, but because of the change of the cross section from the arm and the extension. Also the changing of the material influence the tests.

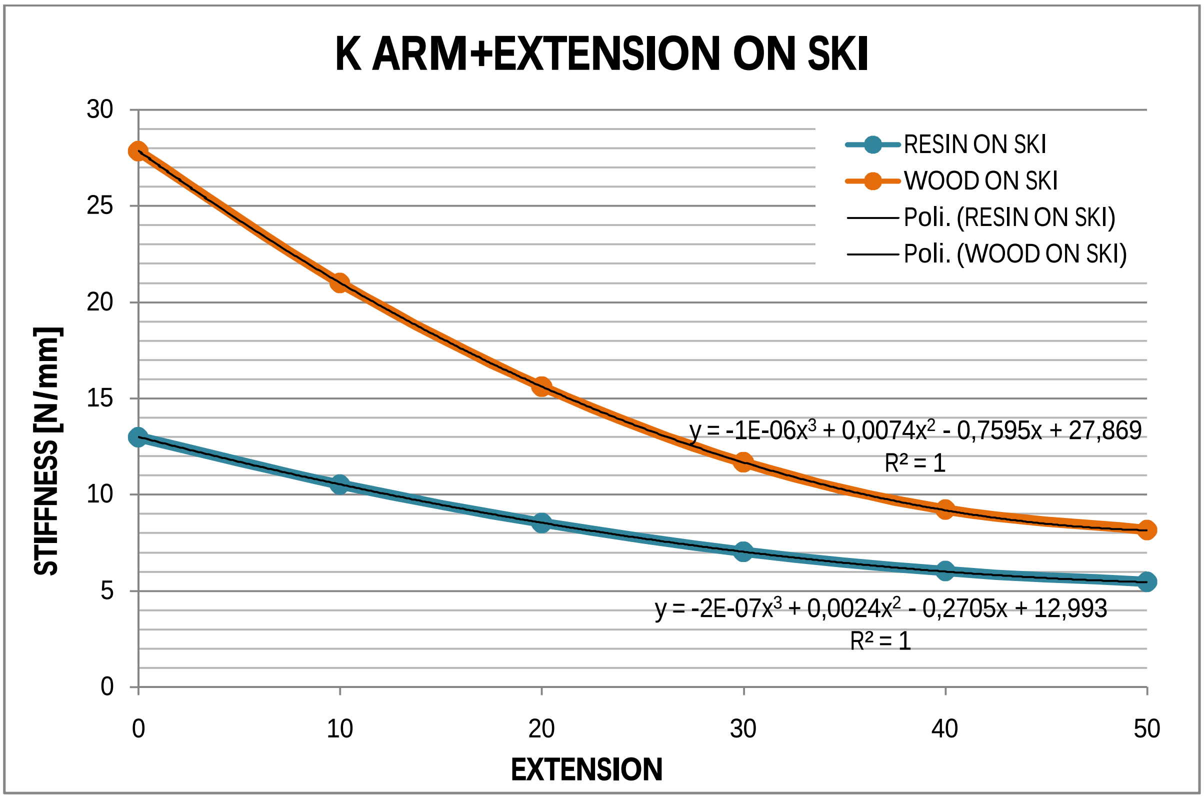
The interpolation law of the previous data where found by an Microsoft Office Excel's sheet. This curves, less than an approximation of the order of tenth of N/mm, could give values of stiffness for arm extended of 10, 20 and 40 mm.

To facilitate the lecture, red values are the experimental, the black one are interpolated. Stiffness decreasing percentages are reported also in the following tables.

1.8.2 COMPLETE HISTOGRAM WITH LENGTH 310,320,340mm

ARM + EXTENSION ON SKI

	[N/mm]	Δ%		[N/mm]	Δ%
k_{w300}	27,87		k_{RS1}	12,99	
$k_{w300+10}$	21,01	-24,61%	k_{RS1+10}	10,53	-18,94%
$k_{w300+20}$	15,62	-43,95%	k_{RS1+20}	8,55	-34,18%
$k_{w300+30}$	11,67	-58,13%	k_{RS1+30}	7,04	-45,80%
$k_{w300+40}$	9,22	-66,92%	k_{RS1+40}	6,02	-53,66%
$k_{w300+50}$	8,15	-70,76%	k_{RS1+50}	5,47	-57,89%



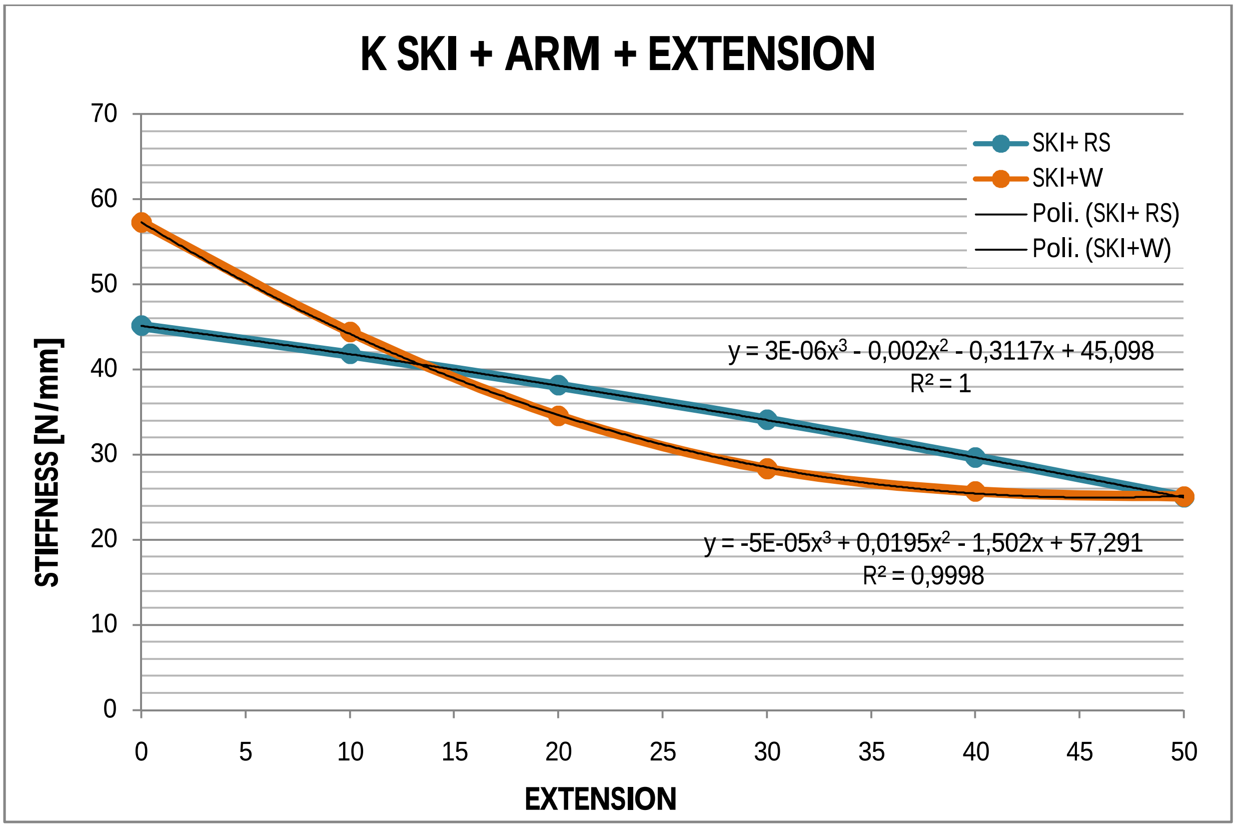
Inverse cubic interpolation:

WOOD ON SKI: $y= -1E\text{-}06x^3 + 0{,}0074x^2 - 0{,}7595x + 27{,}869$

RESIN ON SKI: $y = -2E\text{-}07x^3 + 0{,}0024x^2 - 0{,}2705x + 12{,}993$

SKI + ARM + EXTENSION

	[N/mm]	Δ%		[N/mm]	Δ%
$k_{w300+sci}$	57,21		$k_{RS1+sci}$	45,1	
$k_{w300+10+sci}$	44,39	-22,41%	$k_{RS1+10+sci}$	41,77	-7,38%
$k_{w300+20+sci}$	34,52	-39,66%	$k_{RS1+20+sci}$	38,09	-15,54%
$k_{w300+30+sci}$	28,35	-50,45%	$k_{RS1+30+sci}$	34,08	-24,43%
$k_{w300+40+sci}$	25,68	-55,11%	$k_{RS1+40+sci}$	29,65	-34,26%
$k_{w300+50+sci}$	25,09	-56,14%	$k_{RS1+50+sci}$	24,97	-44,63%



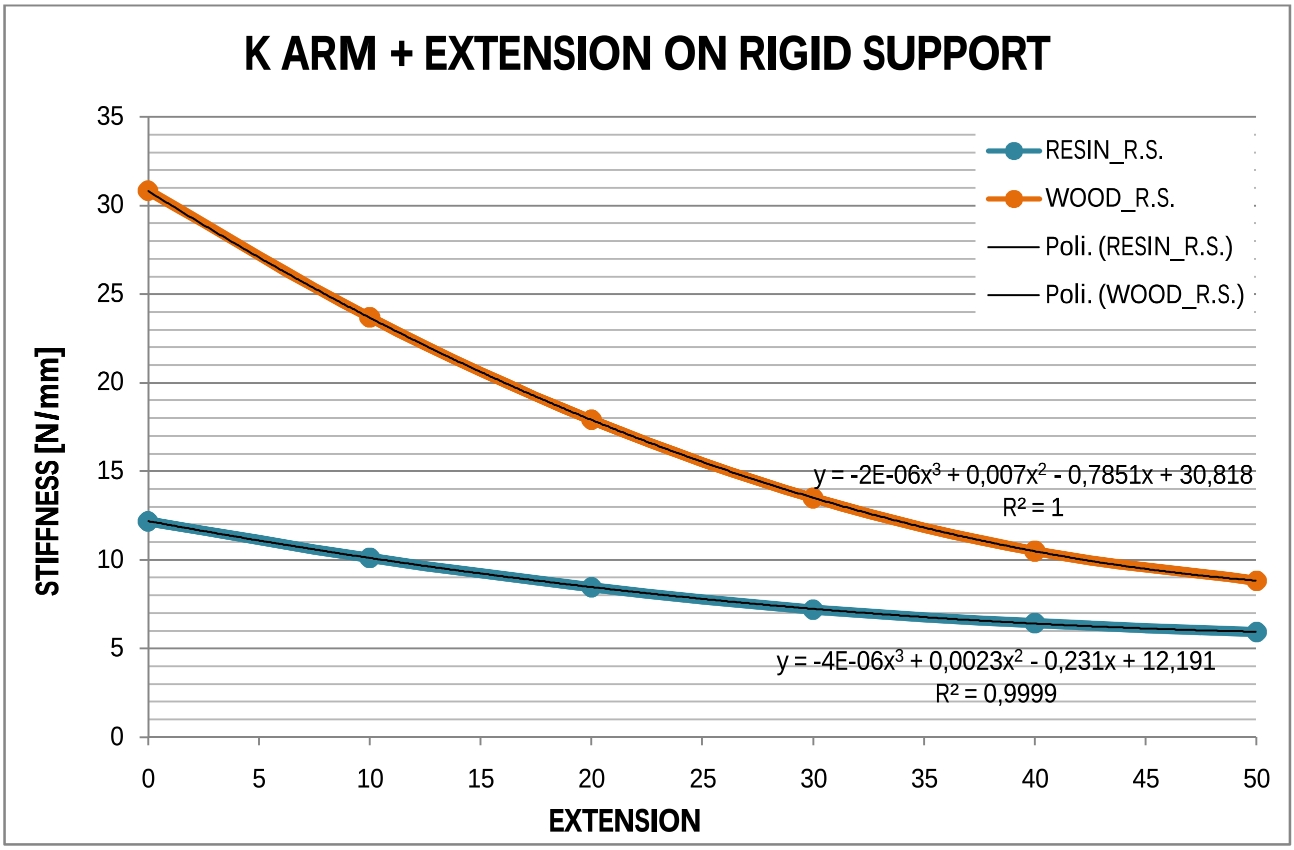
Inverse cubic interpolation:

SKI+WOOD: $y = -5E\text{-}05x^3 + 0,0195x^2 - 1,502x + 57,291$

SKI+RESIN: $y = 3E\text{-}06x^3 - 0,002x^2 - 0,3117x + 45,098$

ARM + EXTENSION ON RIGID SUPPORT

	[N/mm]	Δ%		[N/mm]	Δ%
k_{w300_SR}	30,81		k_{RS1_SR}	12,18	
$k_{w300+10\_SR}$	23,67	-23,17%	k_{RS1+10_SR}	10,12	-16,91%
$k_{w300+20\_SR}$	17,9	-41,90%	k_{RS1+20_SR}	8,47	-30,46%
$k_{w300+30\_SR}$	13,49	-56,22%	k_{RS1+30_SR}	7,2	-40,89%
$k_{w300+40\_SR}$	10,5	-65,92%	k_{RS1+40_SR}	6,43	-47,21%
$k_{w300+50\_SR}$	8,83	-71,34%	k_{RS1+50_SR}	5,93	-51,31%



Inverse cubic interpolation:

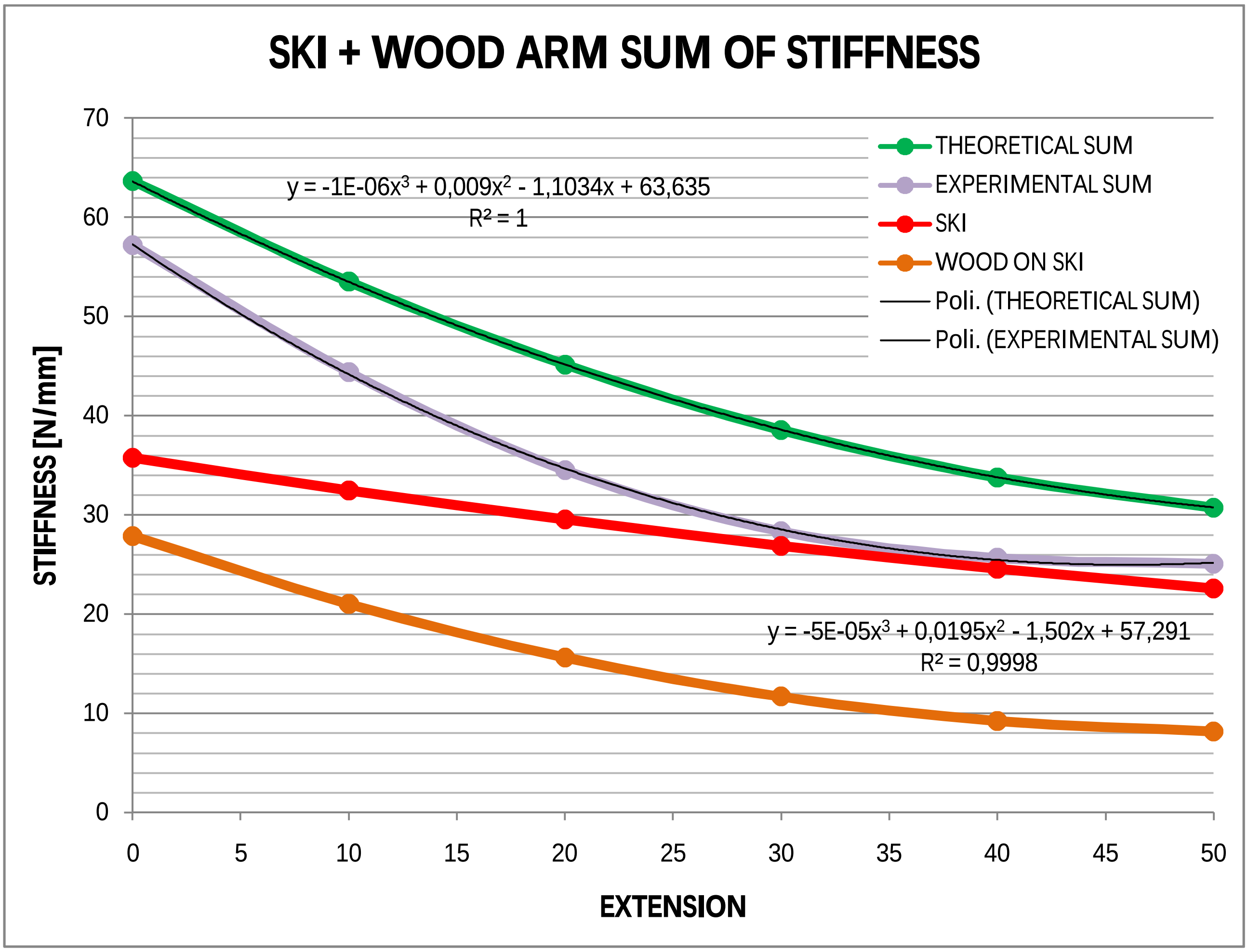
WOOD_R.S.: $y = -2E\text{-}06x^3 + 0{,}007x^2 - 0{,}7851x + 30{,}818$

RESIN_R.S.: $y = -4E\text{-}06x^3 + 0{,}0023x^2 - 0{,}231x + 12{,}191$

1.8.3 SUMMARY HISTOGRAM FOR EXPERIMENTAL AND THEORICAL SUM

WOOD ARM, W300

x [mm]	k_{ski+x} [N/mm]	k_{w300+x} [N/mm]	$k_{experimental}$ [N/mm]	Δ% EXP DECR.	$k_{theorical}$ [N/mm]	Δ% TH-EX
0	35,77	27,87	57,33		63,64	-9,92%
10	32,49	21,01	44,39	-22,57%	53,5	-17,03%
20	29,53	15,62	34,52	-39,79%	45,15	-23,54%
30	26,89	11,67	28,35	-50,55%	38,56	-26,48%
40	24,57	9,22	25,68	-55,21%	33,79	-24,00%
50	22,57	8,15	25,09	-56,24%	30,72	-18,33%



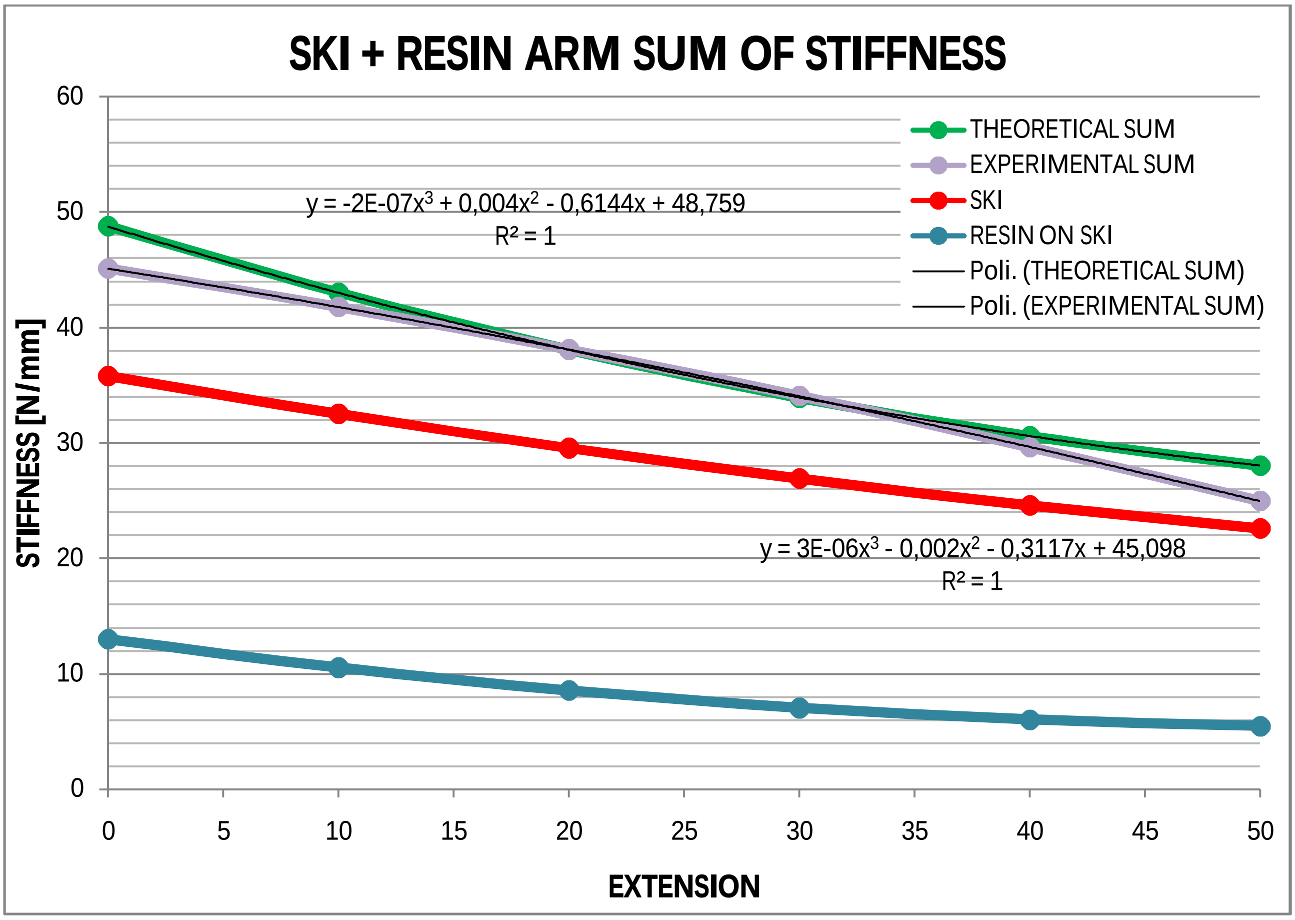
Inverse cubic interpolation:

Theoretical sum: $y = -1E\text{-}06x^3 + 0{,}009x^2 - 1{,}1034x + 63{,}635$

Experimental sum: $y = -5E\text{-}05x^3 + 0{,}0195x^2 - 1{,}502x + 57{,}291$

RESIN ARM, RS1

x [mm]	k_{ski+x} [N/mm]	k_{RS1+x} [N/mm]	$k_{experimental}$ [N/mm]	Δ% EXP DECR.	$k_{theorical}$ [N/mm]	Δ% TH-EX
0	35,77	12,99	45,1		48,76	-7,51%
10	32,49	10,53	41,77	-7,38%	43,02	-2,91%
20	29,53	8,55	38,09	-15,54%	38,08	0,03%
30	26,89	7,04	34,08	-24,43%	33,93	0,44%
40	24,57	6,02	29,65	-34,26%	30,59	-3,07%
50	22,57	5,47	24,97	-44,63%	28,04	-10,95%



Inverse cubic interpolation:

Theoretical sum: $y = -2E-07x^3 + 0,004x^2 - 0,6144x + 48,759$

Experimental sum: $y = 3E-06x^3 - 0,002x^2 - 0,3117x + 45,098$

1.9 RESULTS

These tables resume the effect of superstructure on shovel stiffness:

STIFFNESS [N/mm]			
EXTENSION	ONLY SKI	SKI + RESIN	DIFF % ARM-NO ARM
0	35,766	45,10196	20,70%
+10	32,487	41,778	22,24%
+20	29,528	38,094	22,49%
+30	26,889	34,08306	21,11%
+40	24,57	29,646	17,12%
+50	22,571	24,97433	9,62%

STIFFNESS [N/mm]			
EXTENSION	ONLY SKI	SKI + WOOD	DIFF % ARM-NO ARM
0	35,766	57,21417	37,49%
+10	32,487	44,398	26,83%
+20	29,528	34,528	14,48%
+30	26,889	28,35152	5,16%
+40	24,57	25,682	4,33%
+50	22,571	25,09259	10,05%

1.10 CONCLUSIONS

Characterization of a material is important to know Young modulus and stiffness of the same one. The ratio of the applied load and the respective displacement provides stiffness. The comparison of wood and resin shows that wood is more rigid (double) in rigid support , than the differences decreases when superstructure are applied and loaded on ski. Their real effect is evident in the coupled configuration.

The comparison of total stiffness measured in the configuration ski+arm and the theoretical value (sum of only shovel stiffness and only arm stiffness) shows that there are no coincidence on values. That because of the boundary condition: screws where arms are attached are not a fixed bond because they move with ski deflection. For resin arm differences on values are in the order of 10% and this is acceptable. In presence of extension at different elongation the percentage change and could arrive at 25% for wood arm: the hypothesis is that the extension has a different section respect to the two type of arm. The assessment of the two materials shows that the resin has lesser values on the percentage difference between experimental and theory, instead wood has greater value. Resin works better with the extension, maybe because the extension is better bounded on the arm.

In the last comparison the presence o wood arm and extension until +30mm configuration shows that the difference is in order of 20% and then decreases, instead for resin there is an initial decreasing, beu for +50mm there is a new growing of percentage difference. These differences are also evident in the edge load profile which are reported in the third chapter.

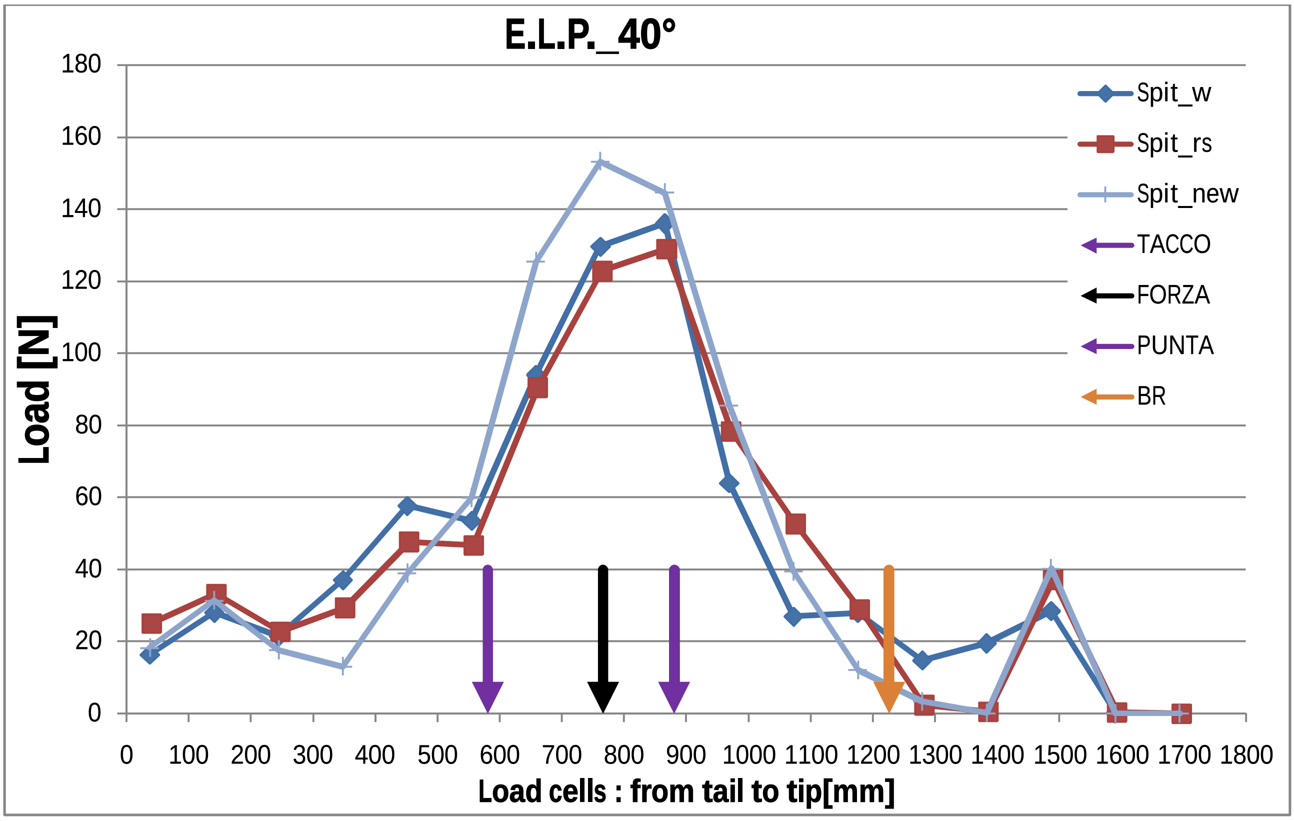
Chapter 2: USE OF STRAIN GAUGE ON SKI AND ARMS FOR BENDING MOMENT MEASUREMENTS

2.1 INTRODUCTION

Wood and resin existent superstructure were tried in the slopes. The testers reported that the presence of a superstructure on the top of the ski permits to have different feelings and sensations during skiing. The analysis of this chapter is developed to find the forces and the moments that act on arm and ski when the ski shovel is loaded in presence of a superstructure and in original configuration.

The analysis proceeded putting the ski on benches for bending moment, torque and for finding edge profile diagrams, from which was possible to calculate which are the significant value of strength for future comparisons from laboratory to in-field tests. This experiences permits to shows differences in stiffness when ski is coupled with a stiffness compensation superstructure of wood material and when ski is in his original configuration.

Thanks to this assessment skiers can know how much the stiffness of their skies grows when they are matched with a wood arm. Different values of ski stiffness have important effect during the skiing, expecially during the entrance into curve.



This effect is clearly visible on the diagrams of Slytech Bench. In the previous diagram (example of a Nordica Spitfire 168 Edge Load Profile at 40°) it's possible to note how in the shovel of the ski the diagram changes with different materials. The peak of force in the top is higher for ski+resin arm, but this configuration shows a valley in the middle of the shovel. Ski+wood arm , instead, with a lower top peak shows a better increment of load in the middle of shovel. For this reason in this chapter is analyzed only the configuration ski + wood arm.

The better profile load is given by wood thanks his stiffness, because for ski is more difficult bending the shovel with a harder superstructure, so load is better distribute. A stiffness so much hard is not a good device for skiers, because ski became much hard to bend , and superstructure improvement effects could fall down.
In the reality, so in a real downhill, an expert skier can give a mark about the quality of skiing with or without arms. So in the end of the skiing marks given by skiers could be compared with the values of stiffness. Skier have to be the same during the test , also the weather and the snow condition have to be the same for all the test, otherwise, during the analysis phase, the comparisons will not give a good correlation with results.

2.2 THEORIC MODEL AND REFERENCES

Ideally, the shovel of the ski, could be studied like a beam fixed on a side and loaded in the opposite one. In this case the bond is on the section where starts the binding's plate. Later the study continues setting the bond in the section where there are the two screws who match arm and ski. The opposite side of the beam is loaded with masses during the calibration tests and then ski is loaded by the actuator of the Slytech bench. Masses and loads impose a deformation measured by strain gauges. Strain gauges are connected with a software (SOMAT) that provides a electric tension value as output.

2.2.1 About strain gauges

In case of bending solicitation of a fixed beam, the deformation that are created interest the external surface of the beam. It is possible to exploit this phenomena to execute strain measurements using instruments based on the deformation surface analysis. Measurement is easy because the state of stress is two-dimensional.
The system able to measure that deformation is named strain gauge, which is made of different typology: mechanical, optical, acoustic, pneumatic, photo-elastic. Another family is the electric strain gauges, that are of three different typology: capacitive, inductive and resistive.
The most utilized is the electric metallic resistor strain gauge. It convert an input signal of mechanical nature (strain) in an output signal of electrical nature (resistance, or voltage).
It's functioning is based on piezo-resistance, and is characterized by the electric property of a conductor material, or semiconductor, where the resistance of the material oppose the passing of electricity as a result of a variation of electric resistivity due to a deformation inducted on the material by an external load, so, a deformation of the strain gauge means a variation of its length, varying its resistance and so, varying the intensity of electricity in the circuit. The variation of electricity or of tension is measured by a Wheatstone bridge, finding the deformation using appropriate mathematical equations.

The fundamental parameter of a strain gauge is its grid length because local deformation are measured as a result of concentration of strength, and so it is necessary that the base of the strain gauge is the smallest as possible. One strain gauge is used for measuring deformation due to strength along one direction (mono-axial) ; it's necessary use more strain gauge if the state of deformation is composed by different direction, or use strain gauge rosettes composed by two or three strain gauges mounted on the same support.

This typology of instruments are usually built with a grid, where electricity passes, a support with bigger dimensions than the grid, an adhesive for gluing the strain gauge to the object and a protection for the sensible part of it.
The characteristic of the electric resistance is given by:

$$R = \rho\frac{L}{A} \qquad (1)$$

where :

- ρ is the resistivity of the material of strain gauge
- **L** is the length of the base
- **A** is the section of the grid

The sensitivity at deformation is defined by "gauge factor" expressed by the ratio between the variation of resistivity of the grid and the initial value and the deformation in the axial direction of the strain gauge:

$$K = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} = \frac{\frac{\Delta \mathrm{R}}{R}}{\varepsilon} \qquad (2)$$

Differentiating (1) it results:

$$R = d\rho\frac{L}{A} + dL\frac{\rho}{A} - dA\frac{\rho L}{A^2}$$

Passing to finite difference:

$$\Delta R = \Delta\rho\frac{L}{A} + \Delta L\frac{\rho}{A} - \Delta A\frac{\rho L}{A^2}$$

Divide by R:

$$\frac{\Delta R}{R} = \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L} - \frac{dA}{A} = \frac{\Delta\rho}{\rho} + \frac{\Delta L}{L} - 2\frac{dD}{D}$$

where D is the diameter of grid section.
Gauge factor is obtained with another expression:

$$K = 1 + 2\upsilon + \frac{\frac{\Delta\rho}{\rho}}{\varepsilon}$$

where it could be noted that K depends by a geometric part and by a resistivity part.

The value of K is given by the constructor and determined by a statistic way extracting a sample of strain gauges from the total industrial production. Normally gauge factor is near to 2, and the tolerance is 1%.
The sensitivity at temperature is given by α factor:

$$\alpha = \frac{\frac{\Delta R}{R}}{\Delta T}$$

This parameter is typical of the material used to create the grid of the strain gauges. Usually constructor use constantan to eliminate effect of temperature into measurements ($\alpha=10^{-6}$ppm/K).

Auto-compensate strain gauges could be used to eliminate temperature effects in respect of the thermal deformation of the object, or it's possible to built an half bridge connection with two strain gauges glued on opposite surface of material. In this case it is used a quarter bridge because is not possible gluing on the sliding part of the ski.

The grid is designed to have the most possible sensible section at deformations of the material.
The scope of a strain gauge varies between 0 and 3000 ppm.

The input tension given by SOMAT is 2,11 V. Less value of tension don't cause Joule effects on the grid and on the elastic element.
An electric strain gauge is show in this figure:

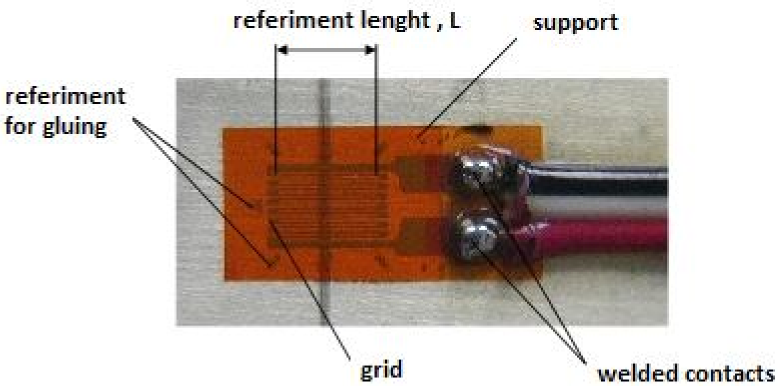


Fig. 29:Example of strain gauge

Parameters by constructor (T=23°C)

- gage factor: K = 2,06 ± 0,5 %
- resistance: R = 120 Ω ± 0,6 %

2.2.2 Wheatstone bridge circuits

Strain gauge, after gluing procedure, is connected with cables on a Wheatstone bridge unit that amplifies the weak output signal caused by weak resistance variations.
The Wheatstone bridge is composed by a tension generator who feeds two branch of resistors in parallel disposition. The resistors into the bridge are the strain gauges. The circuit change name and function in base of the number of strain gauges: one strain gauge means quarter bridge; two strain gauges means half bridge; four strain gauges means full bridge.
In this experience is used four strain gauges, each one connected at quarter bridge.
An example of quarter bridge is the follow:

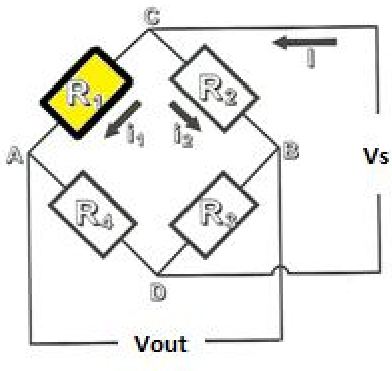


Fig. 30: scheme of Wheatstone bridge

where :

- $\mathbf{V_S}$ is the supply tension (input)
- $\mathbf{R_1}$ is the resistance of strain gauge
- $\mathbf{R_2}$, $\mathbf{R_3}$, $\mathbf{R_4}$ are compensation resistances
- $\mathbf{V_{OUT}}$ is the output tension

The equilibrium condition of the bridge is:

$$\mathbf{R_1 * R_3 = R_2 * R_4}$$

Intensities of electricity are:

$$i_1 = \frac{V_S}{R_1 + R_4} \quad ; \quad i_2 = \frac{V_S}{R_2 + R_3}$$

Variation between A and C nodes :

$$V_A - V_C = i_1 R_1$$

Substituting i_1:

$$V_A - V_C = E\frac{R_1}{R_1 + R_4}$$

For the other branch:

$$V_B - V_C = E\frac{R_2}{R_2 + R_3}$$

V_{OUT} results:

$$V_{out} = (V_A - V_C) - (V_B - V_C) = (V_A - V_B) = E(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3})$$

So:

$$\frac{V_{out}}{E} = \left(\frac{R_1}{R_1 + R_4} - \frac{R_2}{R_2 + R_3}\right) = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_4)(R_2 + R_3)}$$

The bridge will be unbalance,

$$\frac{V_{out} + \Delta V_{out}}{E} = \frac{(R_1 + \Delta R_1)R_3 - R_2 R_4}{(R_1 + \Delta R_1 + R_4)(R_2 + R_3)}$$

V_{out} is zero when the bridge is equilibrated ($R_1 * R_3 = R_2 * R_4$), so :

$$\frac{V_{out}}{E} = \frac{\Delta R_1 R_3}{(R_1 + \Delta R_1 + R_4)(R_2 + R_3)}$$

All the resistances are equal so simplifying:

$$\frac{\Delta V_{out}}{E} = \frac{\Delta R_1}{4R}$$

For the other 4 resistor the precedent equation is valid, so adding the four contributes:

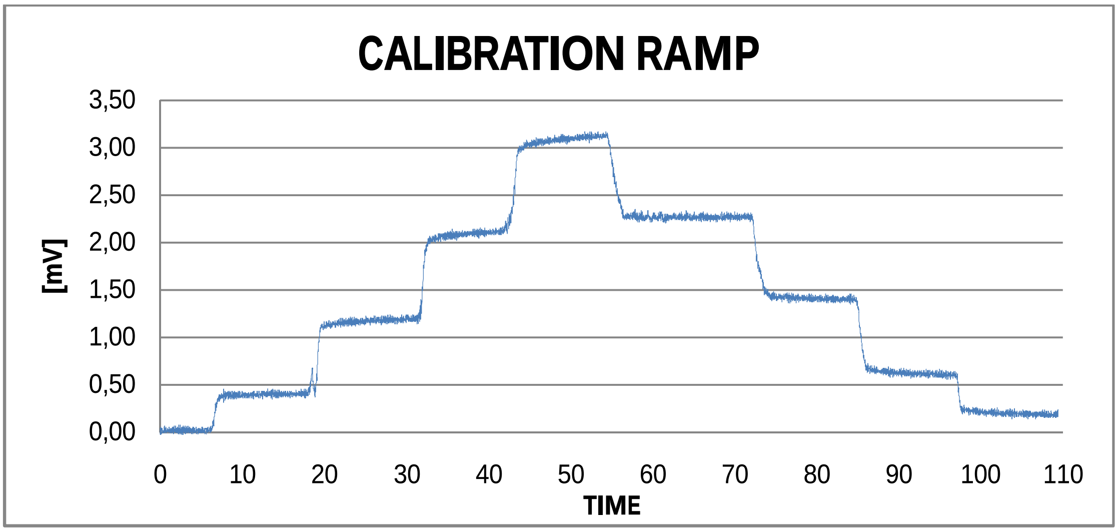
$$\frac{\Delta V_{out}}{E} = \frac{\Delta R_1}{4R} - \frac{\Delta R_2}{4R} + \frac{\Delta R_1}{4R} - \frac{\Delta R_4}{4R}$$

Substituting the gauge factor definition it's possible to obtain the relation between the deformation of the material and the difference of tension measured by the bridge:

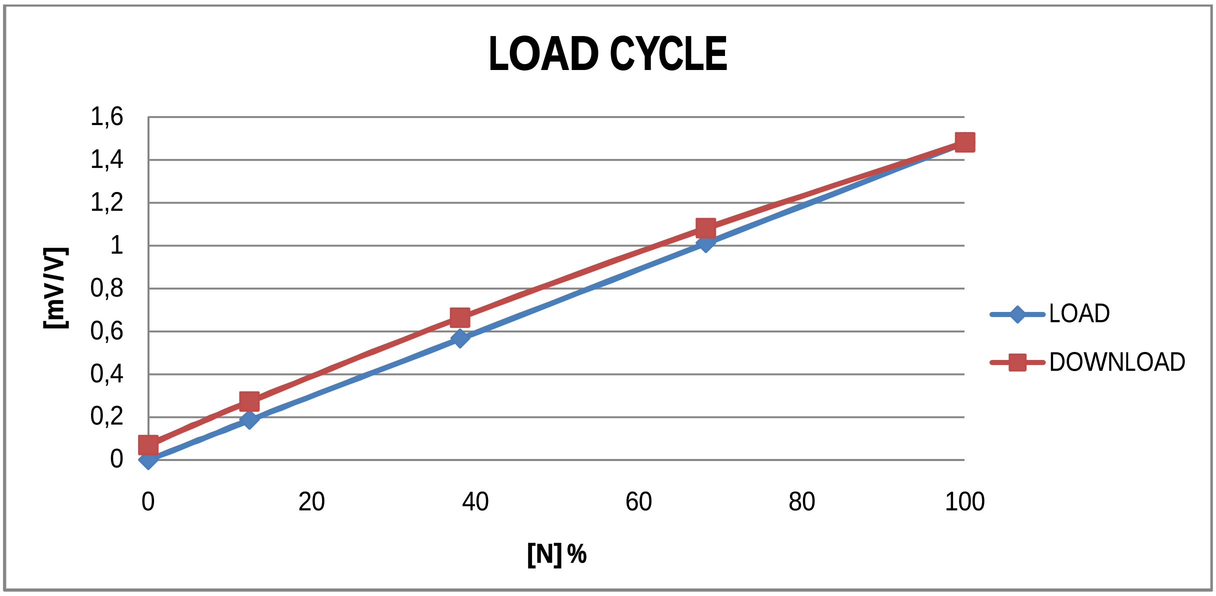
$$\boldsymbol{\frac{\Delta V_{out}}{E} = \frac{K}{4}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)}$$

2.2.3 Calibration of bridges

Once strain gauges are glued and connected with wires at SOMAT, they are ready to perform their scope. To obtain an accurate and precise result the load cell compose by strain gauge has to be calibrated. So fixed the ski or arm in a rigid support, strain gauges are connected on a channel of SOMAT and zeroed: there are some window on SOMAT who drives the user to the zeroing of the bridge, to nominating the channel and other features. Then using dead weight as masses, the cell is loaded and SOMAT gives an output as this:



Load cell gives an output depending on input and V_S. This value could change in different systems, so for simplicity VOUT is dimensionless: V_{OUT}/V_S. Plotting load on x axis and voltage on y axis (taking the average value 5 seconds after setting the new mass, if the result is linear it is a good cell.



The slope of the LOAD line is the sensitivity of the cell [mV/N], and the opposite value is the calibration constant of the cell è[N/mV]. These values change if V_S change. Using the calibration constant, is simple to find an applied load because it just do the multiplication of constant and unbalance of the bridge. Dimensions are:

$$[N] = \left[\frac{N}{mV}\right] * [mV]$$

2.2.4 Deformation measures

Simplifying assumptions are taken: ski is considers as a beam at constant section. The same thing for arms. Weight effects are neglected. The fixed section of the coupled ski and arm is the section where there are the screws. Note that the strain gauges are not glued on the same section, so during the analysis , using the calibration constant of the bridges, the values of bending moment is changed and reported on the same section. This section is that where strain gauges are glued on arms.

Another assumption is that the beam is an elastic corps, an isotropic model and his deformation maintains plane the bending sections. So Navier law and Hooke Law for bending moment could be used:

$$\sigma = \frac{M_f}{J}\frac{h}{2} \quad ; \quad \varepsilon = \frac{\sigma}{E}$$

where :

- **σ** is the strength
- **ε** is the deformation caused by bending moment
- **E** is the elastic modulus
- $\mathbf{M_f}$ is the bending moment
- **L** the length of the beam
- **W** is the modulus of bending resistance equal to 2 J/h.

Temperature effects are neglected in this experience, its effects are compensated by internal resistances into the box of the SOMAT. So the deformation measured by the strain gauge will be the follow (quarter bridge):

$$\varepsilon = \frac{4\Delta V_{out}}{KV_s}$$

In the characterization tests, loads and displacements are known, so applying a linear regression of the results it's possible to calculate the stiffness of the material. It's assumed a unitary weight for every value of load.

$$F = k * f + cost$$

where:

$$k = \frac{\sum_{i=0}^{m} f(x_i) * \sum_{i=0}^{m} x^2 - \sum_{i=0}^{m} x_i * \sum_{i=0}^{m} x_i f(x_i)}{\sum_{i=0}^{m} x_i^2 - (\sum_{i=0}^{m} x_i)^2}$$

$$cost = \frac{\sum_{i=0}^{m} x_i f(x_i) - \sum_{i=0}^{m} x_i * \sum_{i=0}^{m} f(x_i)}{\sum_{i=0}^{m} x_i^2 - (\sum_{i=0}^{m} x_i)^2}$$

- **m** are the numbers of loads
- **x** are displacements
- **f(x)** are loads

2.3 LABORATORY INSTRUMENTATION

The follow instruments were used for tests:

- Slytech Bench

The bench is used to obtain the edge load profile of ski. The load cells provide the forces. The ski release a load distribution on every neoprene plates' surface, but the load cells notice a punctual forces. So the analysis are carried out with the hypothesis of punctual forces acting on the ski. A complete description of bench is given in the last chapter.

- Aluminum boot

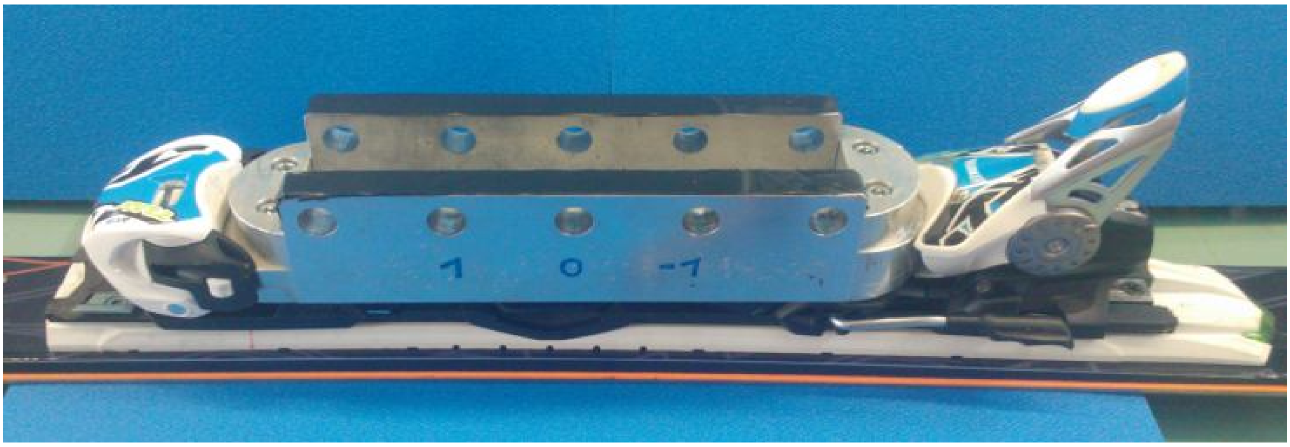


Fig. 31: Aluminum dummy boot

This object simulates a ski-boot. It is used for the tests on the bench because its presence permits to transfer on the ski the force given by motor. This is a kind of simulation of the forces release by the skier on ski. Load is applied on position number 1, not in the centre, because in the reality the COP of the foot is near the ball of foot.

- Spitfire 168

Built with a full wood core sandwiched between 2 sheets of titanium, this ski offers exceptional and precise edge hold. Built from the combination of a slalom tip and a GS body, it really offers 2 skies in one. Sidecut: 126-74-109 R14.

- Wood arm

The presence of this arm in front of the binding plates permits to distribute a part of the load (peak on tip) on the shovel. It works as a bracket fixed on the anterior part of the binding, and the opposite side acts as a fulcrum.

- Strain Gauges.

Strain gauges measure the deformation on the materials in which they are glued. When the grid of the strain gauge is deformed there is a variation on his resistivity, so if it is applied on a Wheatstone bridge there is a displacement on output values (mV). Then, from this displacement, deformations could be measured. There are two strain gauges on every objects, six in total.

- DATA LOGGER

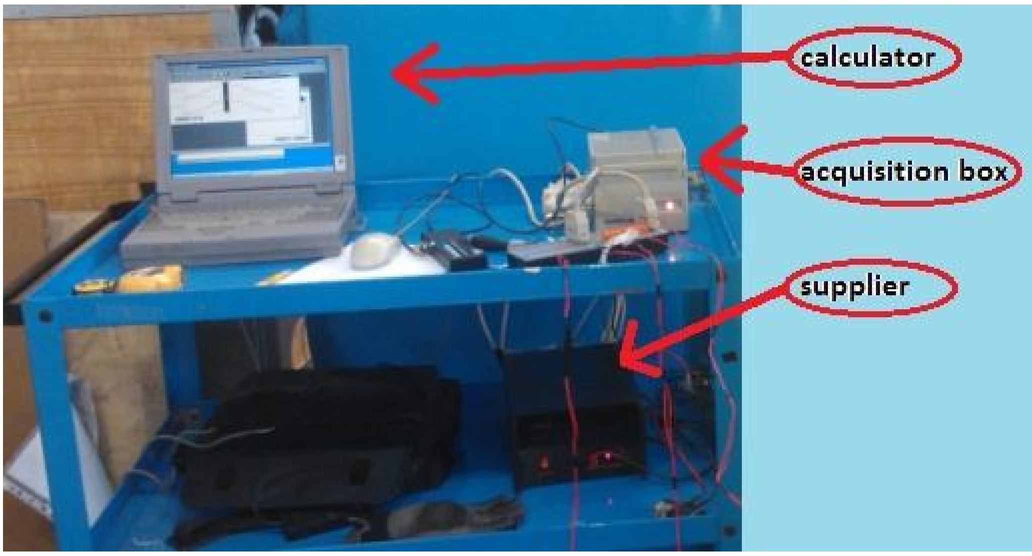


Fig. 32: bench with Somat, calculator and supplier for in laboratory tests

SOMAT is a software included in a calculator station. There is also an acquisition box for taking data outside of the laboratory using a 12V battery. In this case , acquisition box and calculator are connected together and feeds by a supplier at 2,11V.

- Comparator

Fig. 33: Comparator Mitutoyo

Comparator measures the displacement of a point of one object when it is loaded with a forces. The displacement is shown on a display in mm. Tests are effectuated reading the displacement after 5 seconds after the application of the forces.

- Rod weight carrier;

- Cables for electric connections;

- Twentieths caliber;

- Masses

Masses are used to create the forces applied on ski or on arms to characterize them. It is important using masses that not take over full scale the comparator, and values not so bigger than the loads released by the bench. List of masses:

Number of masses	[kg]
1	1
1	1,585
3	2
1	3,353
1	3,85
1	4,06
1	5

4.4 TESTS SETTINGS

4.4.1 Summary of the experience.

Before of testing, it is important follow a list of actions to prepare materials and instrumentations of laboratory to obtain valid and repeatable test. The use of strain gauges is functional, because they allow the user to detect the deformation of the material at any point in which they are applied. Strain gauges provide good data if they are installed in the correct manner.
The first step of test is sticking the strain gauges on arms and on ski. They are glued for reading deformation given by bending moment, so with their longitudinal axes parallel to longitudinal ski axes.
Then it is created a secure system of wires for the integrity of strain gauges and that doesn't disturb the user, for example during skiing or during tests on the bench.
Cables are connected on SOMAT. All the connections are quarter bridge, because for every channel is associated one strain gauge. SOMAT does a calibration of every channel. The sensitivity imposed is 1 E.U. = 1 mV. Where E.U. are the engineering units. In this case $\mu\varepsilon$.
When superstructures are ready for use, they are installed on a rigid support as a beam: one side is fixed and the opposite is free to put loads. This test permits to calculate the calibration constant of wood arm. The names of this test is: "wood_sr".
Spitfire is provided with two strain gauges to measure deformation given by bending moment on the shovel.
The calibration constant of the ski is given by the same test, changing the settings of the rigid support. Ones calibration is done for all objects, if the user observes and analyses the signal from SOMAT, it's simple to obtain the loads applied.
Load is given by the bench. To simulate a skiing the user have to test the ski for every possible angle. In this case the angles are from 0° to 60° in step of 10°.
Tests are done with arm installed on ski. The names of this tests is: "ski+w".
It's important associate the text files containing data form bench with the respectively text files given by SOMAT. Bench gives load, SOMAT provides the signal.
In the last part of the experience signals and loads from the bench were analyzed and compared. It is important to observe how much stiffness of ski and arm changes when they are coupled. So there are other test to do for measuring the stiffness of the material before the use on the bench.

2.4.2 Load cycle

The load cycle is not the same on different test because the user don't want to overcome the full scale of the comparator.

The calibration constants of arms is given by this load cycle: 1.585 , 3.353 , 3.85 , 4.06 kg; (1 cycle).

For only ski calibration the load cycle is this: 5 , 2 , 2 , 1 kg; (1 cycle).

For the calibration of the only shovel : 1 , 2 , 2 , 2 kg; (4 cycles).

For the calibration of shovel and arms together: 3.85, 4.6, 4.06 kg; (1 cycle).

For torque calibration of shovel and arm coupled : 0.8, 3.85, 4.6, 4.06 kg (1 cycle).

2.4.3 Calibration of wood arm fixed on rigid support

This picture shows the instrumentations and the wood arm fixed on a rigid support.

Fig. 34:Global view of wood arm loaded and data acquisition

Analysis are reported in the next paragraph (3.6).

2.4.4 Calibration of only shovel and shovel coupled with wood arm

Shovel was fixed like in the picture and loaded at 100mm from the extremity. The distance from force to strain gauge is 515mm. This configuration was repeated for the next calibration test with arms.

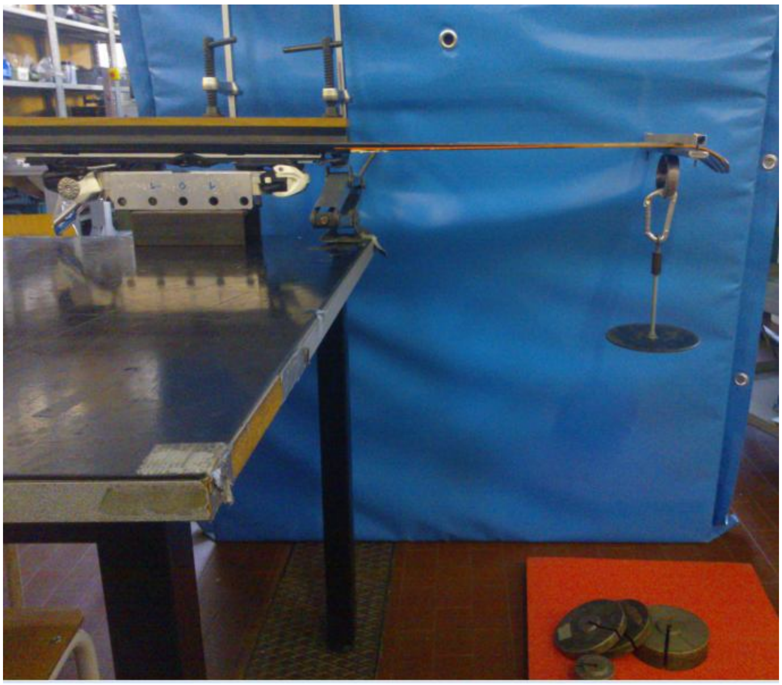


Fig. 35: Bending moment calibration bench

2.4.5 Calibration of shovel torsion and shovel + arm torsion

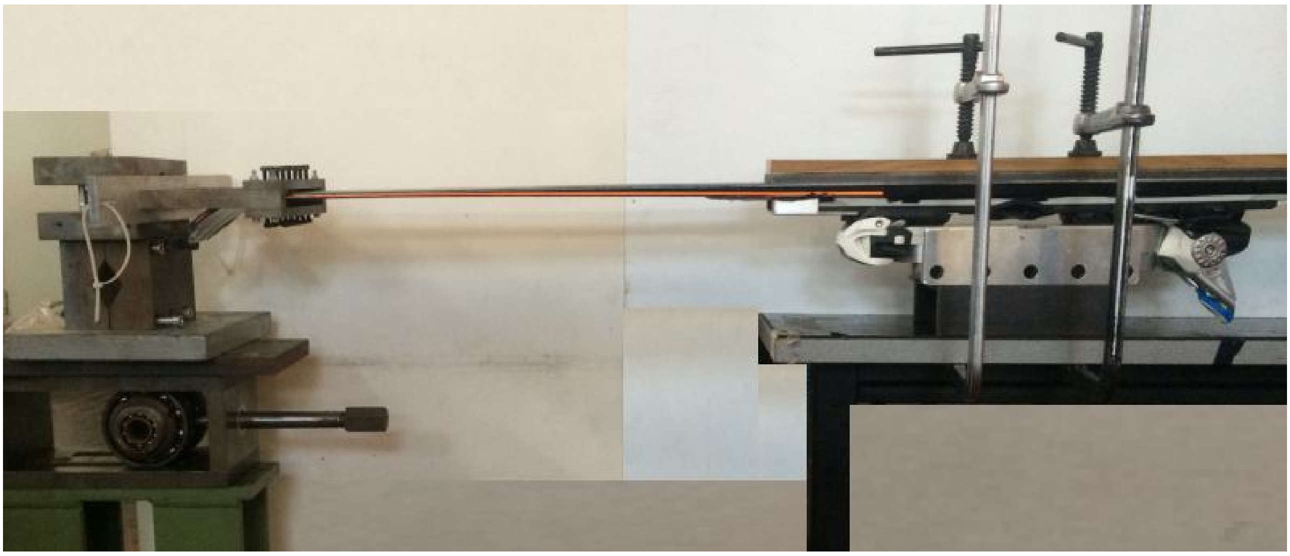


Fig. 36:Torque calibration bench

This picture shows the bench used to calibrate the torsion of shovel and arm. Ski is fixed with the aluminum dummy boot and two clamps. A steel beam and a wood beam are disposed on the ski to protect his surface. The tip of shovel is insert on a rotating box. Two series of screws lock the shovel into de rotating box. Load is applied on the extremity of the box. Torque on strain gauges is calculated as difference from the two strain gauges output.

2.5 ANALYSIS OF RESULTS

This paragraph explains the development of the analysis. The objective is to find how much bending moment change in the different configuration of ski and arm coupled.

The calibration of the bridges permits to calculate the calibration constants. These constants were used to convert the signals of strain gauges in forces or bending moments. Using the previous calibration tests, the sensitivity of a Wheatstone bridge is defined as:

$$S = \frac{\max(y_i)}{full\ scale\ of\ load} \quad [mV/N]$$

The calibration constant is the reverse of sensitivity:

$$\boldsymbol{C = S^{-1}}$$

Once calibration constant and SOMAT signals are known, load is calculated as:

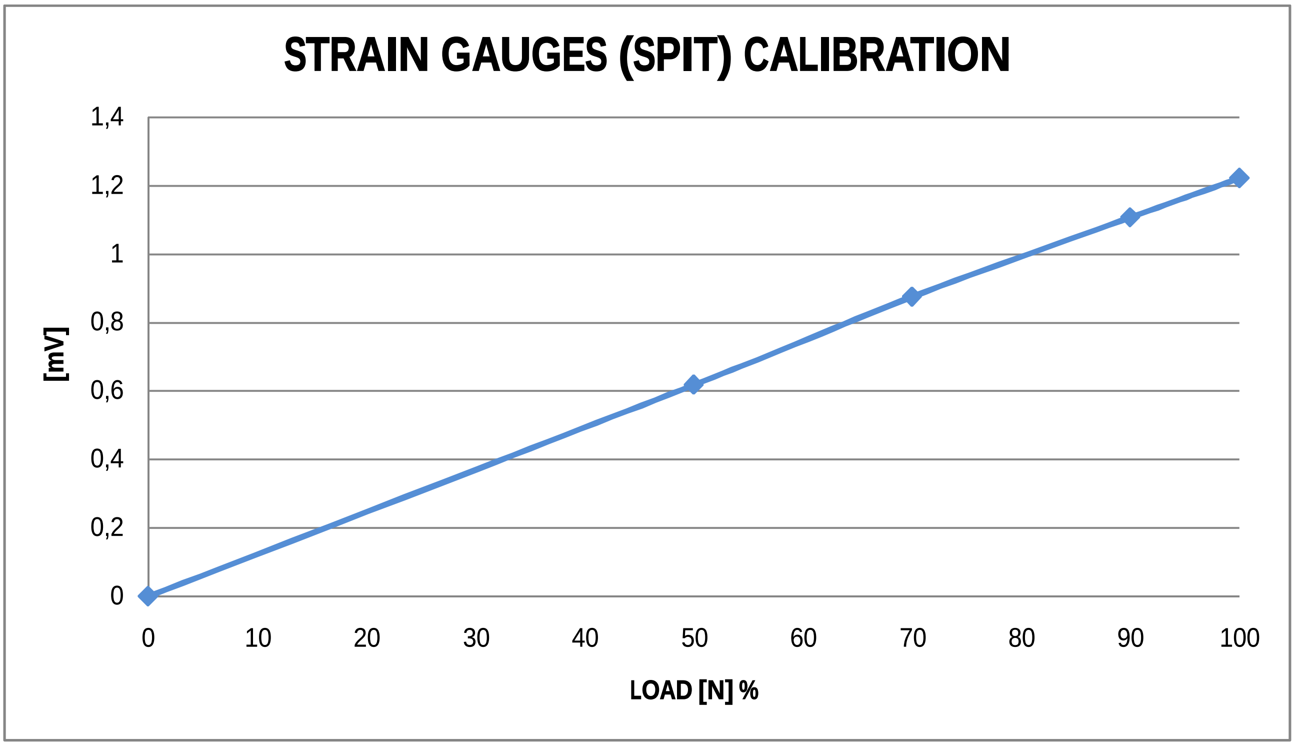
$$load = C * signal \quad ; \quad [N] = \left[\frac{N}{mV}\right] * [mV]$$

2.5.1 BENDING MOMENT CALIBRATION

2.5.1.1 Spitfire 168 (only shovel)

Only shovel results table:

force applied [N]	bending moment [Nm]	SOMAT output [mV]
0,00	0,00	0,000
49,05	25,26	0,293
68,67	35,37	0,415
88,29	45,47	0,525
98,10	50,52	0,579



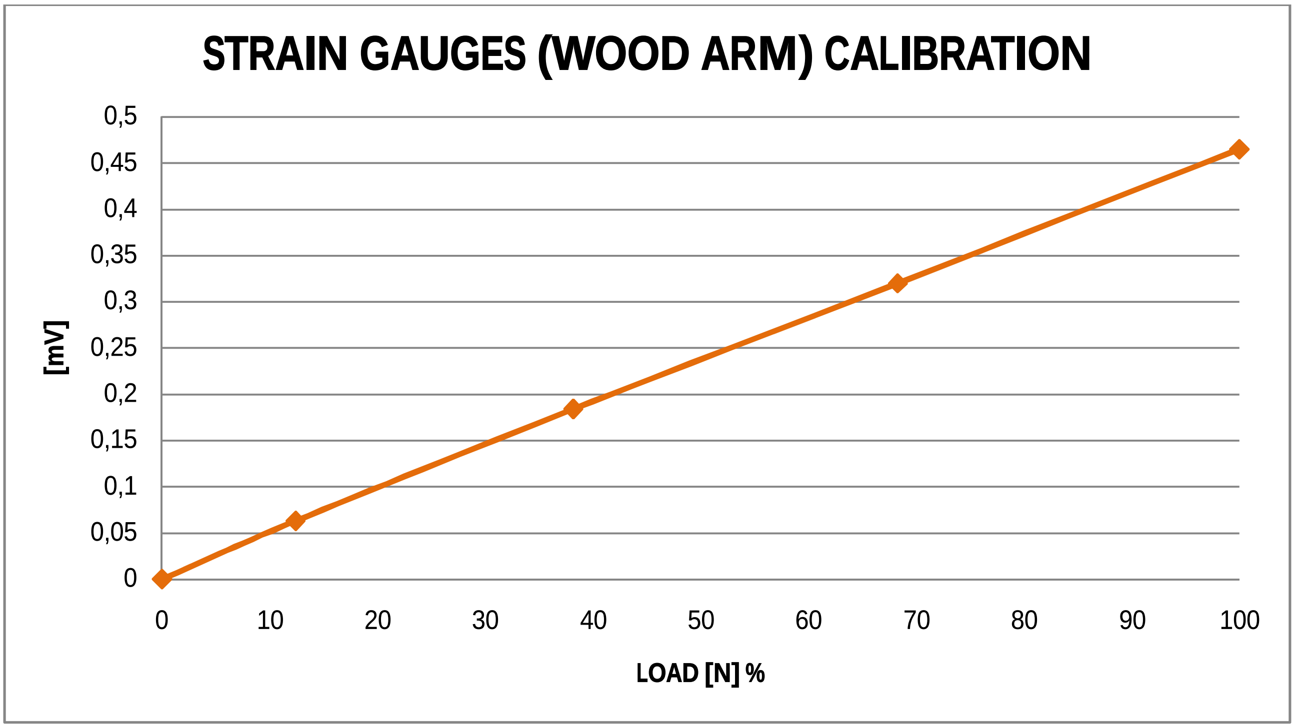
Spitfire 168 sensitivity and calibration constant:

$$S = 0{,}024 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C} = \mathbf{41,17}\ [\frac{\boldsymbol{Nm}}{\boldsymbol{mV}}]$$

2.5.1.2 Wood arm on rigid support

Wood arm results table: bending moment is calculated as force multiplied for distance of strain gauges from force, in this arm is 191mm.

force applied [N]	bending moment [Nm]	SOMAT output [mV]
0,00	0,00	0,000
15,55	2,97	0,063
47,92	9,15	0,184
85,69	16,37	0,320
125,52	23,97	0,465



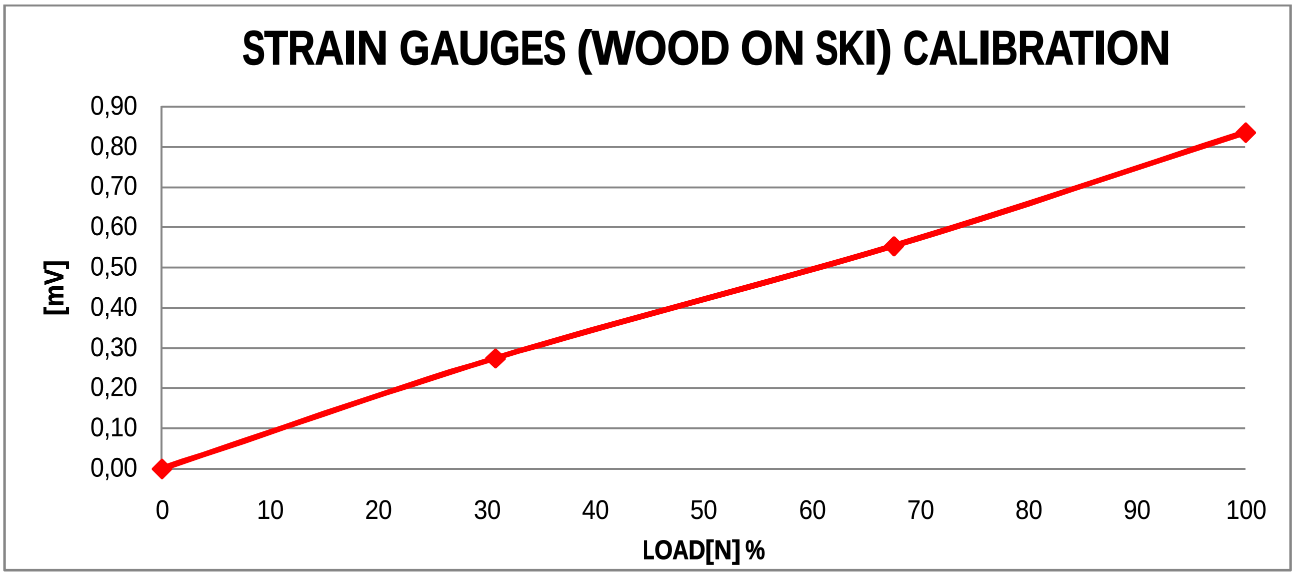
Wood arm sensitivity and calibration constant:

$$S = 0{,}04 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C = 24{,}53} \left[\frac{\boldsymbol{Nm}}{\boldsymbol{mV}}\right]$$

2.5.1.3 Wood arm coupled on ski

Wood arm calibration on ski is reported in this table:

force applied [N]	bending moment [Nm]	SOMAT output wood [mV]
0	0	0
37,7685	19,45078	0,27
82,8945	42,69067	0,55
122,7231	63,2024	0,84



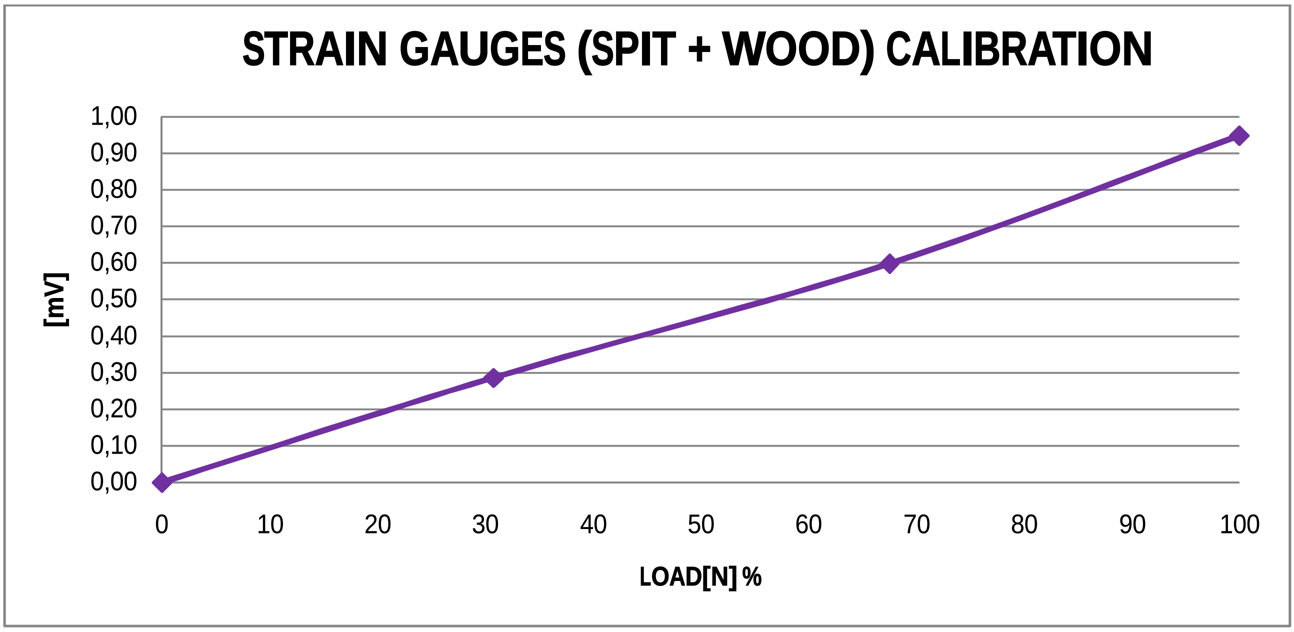
Wood arm coupled sensitivity and calibration constant:

$$S = 0{,}014 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C = 72,67\left[\frac{Nm}{mV}\right]}$$

2.5.1.4 Spitfire 168 (shovel) + wood arm

Shovel + arms results table: the bending moment reference is that calculated for shovel

force applied [N]	bending moment [Nm]	SOMAT output sh+w [mV]
0	0	0
37,7685	19,45078	0,29
82,8945	42,69067	0,6
122,7231	63,2024	0,95



Spitfire 168 sensitivity and calibration constant:

$$S = 0{,}016 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C} = \mathbf{64{,}05}\ [\frac{\boldsymbol{Nm}}{\boldsymbol{mV}}]$$

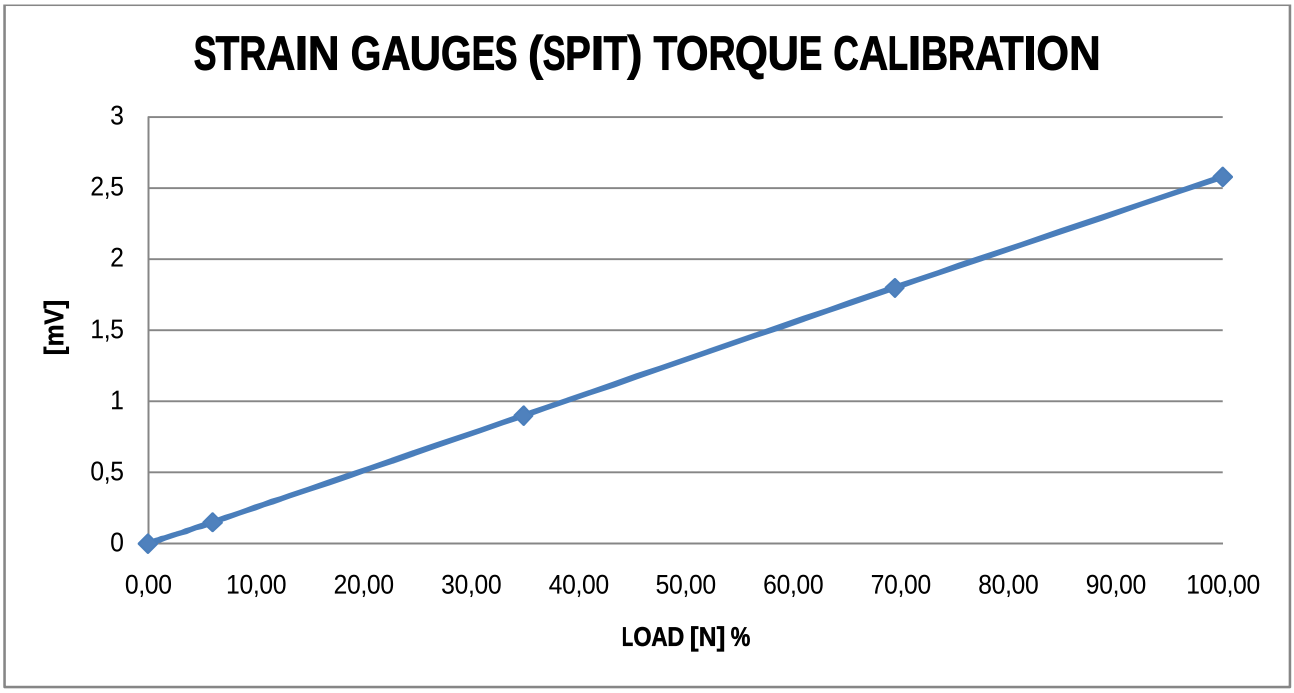
2.5.2 TORQUE CALIBRATION

2.5.2.1 Only shovel

Tables resumes the results:

Only shovel:

force applied [N]	torque [Nm]	SOMAT output [mV]
0	0	0,00
7,848	1,29492	0,15
45,6165	7,526723	0,90
90,7425	14,97251	1,80
130,5711	21,54423	2,58



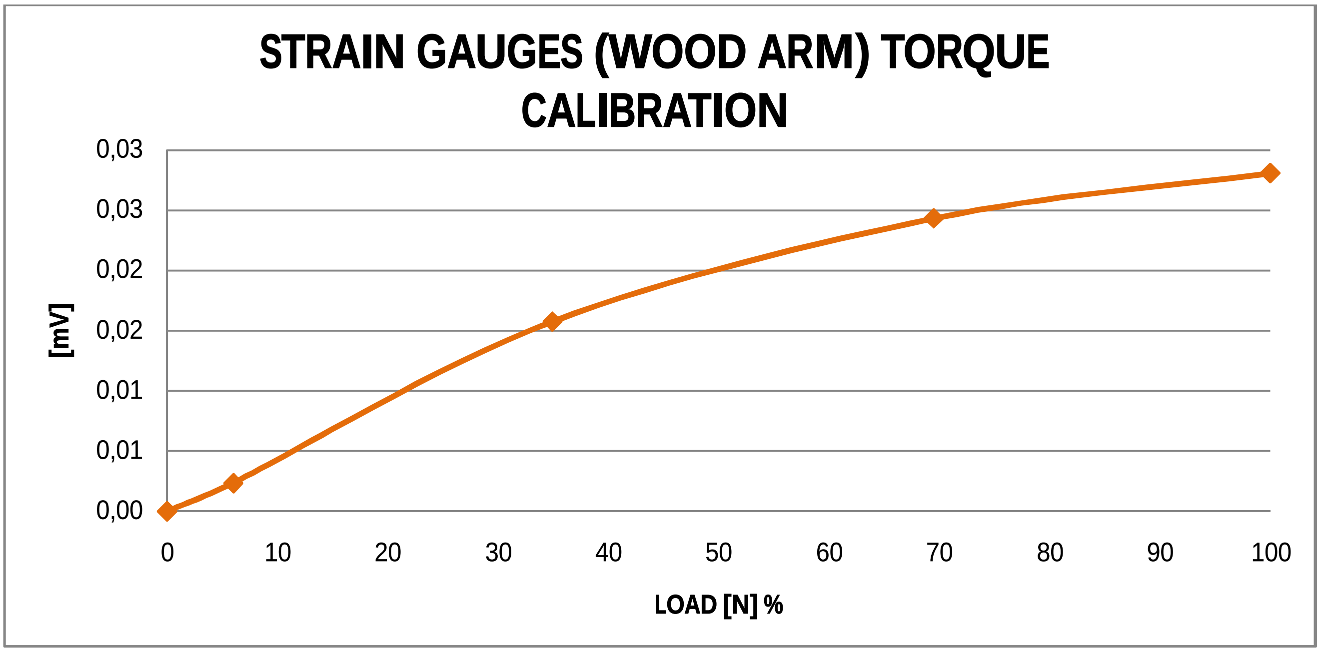
Spitfire 168 sensitivity and calibration torque constant:

$$S = 0{,}0066 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C = 150,52\left[\frac{Nm}{mV}\right]}$$

2.5.2.2 Wood arm on ski

Tables resumes the results:

force applied [N]	torque [Nm]	SOMAT output wood [mV]
0	0	0
7,848	1,29492	0,002
45,6165	7,526723	0,016
90,7425	14,97251	0,024
130,5711	21,54423	0,028



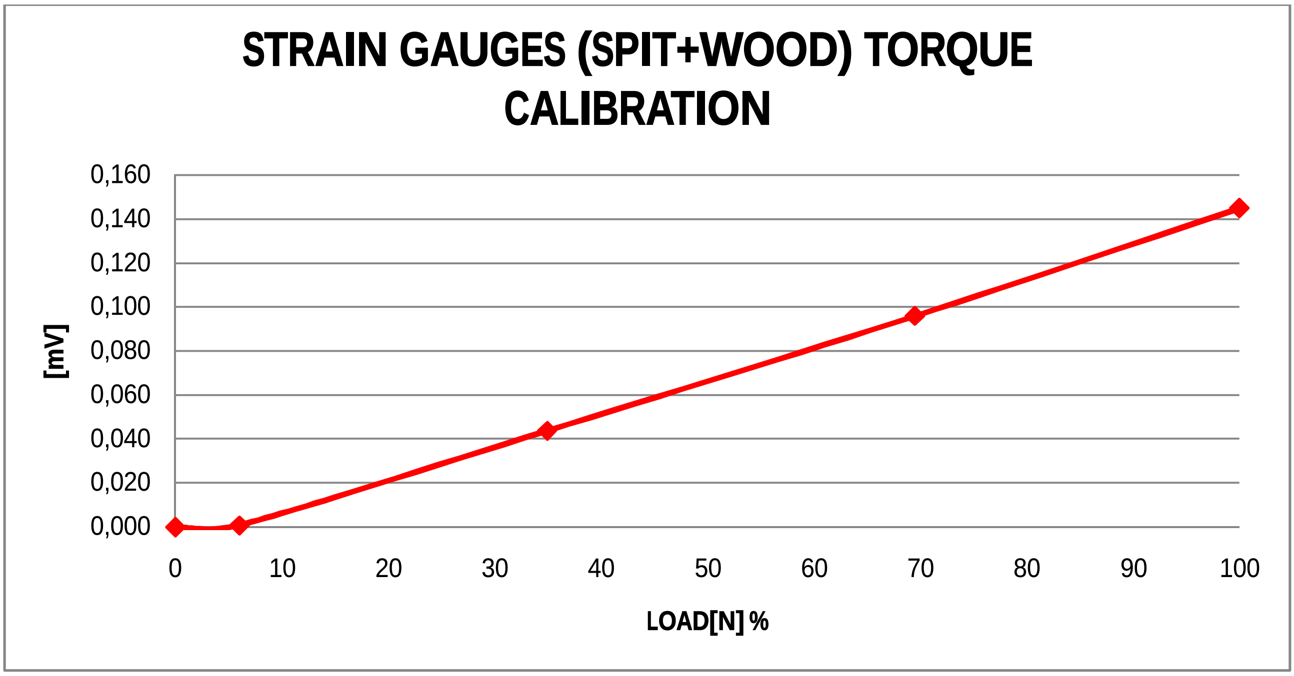
Resin arm sensitivity and calibration torque constant:

$$S = 0{,}0014 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C = 705{,}41\left[\frac{Nm}{mV}\right]}$$

2.5.2.3 Ski coupled with wood arm

Tables resumes the results:

force applied [N]	torque [Nm]	SOMAT output sh+w [mV]
0	0	0
7,848	1,29492	0,001
45,6165	7,526723	0,044
90,7425	14,97251	0,096
130,5711	21,54423	0,145



Spitfire 168 + wood arm sensitivity and calibration torque constant:

$$S = 0{,}007 \left[\frac{mV}{Nm}\right] \quad ; \quad \boldsymbol{C = 145{,}18\left[\frac{Nm}{mV}\right]}$$

2.6 RESULTS SUMMARY

This tables reports all the calibration constant found during calibration test.

- Bending moment:

CONFIGURATION	BENDING MOMENT CALIBRATION CONSTANT [Nm/mV]
SHOVEL	41,17
WOOD ARM _R.S.	24,53
WOOD ARM ON SKI	72,67
SHOVEL+WOOD	64,05

- Torque :

CONFIGURATION	TORQUE CALIBRATION CONSTANT [Nm/mV]
SHOVEL	150,52
WOOD ON SKI	705,41
SHOVEL+WOOD	145,18

These constants were used for analyzing tests on Slytech bench and for in-field runs. Torque constants are very high because of lower value of differences between the two strain gauges in the respective bridge.

Chapter 3: BENCHES FOR EDGE LOAD PROFILE TESTING

3.1 INTRODUCTION

An accurate knowledge of ski structural and mechanical properties is very important for users. A key point for the comprehension of these properties is the distribution of pressure at the edge.
The principal bench's function is given a diagram of pressure along an effective length of the ski, when it is pressed against a bed of calibrated load cells. This diagram is called Edge Load Profile.
The bench is equipped with 21 uniaxial load cells of 100mm width and with a linear actuator able to press any type of ski at different edge angle from 0° to 60°. Each cell provides a value of load, and the total output is the final diagram, where it's clearly revealed the presence of critical spot along the ski, point where the contact with the ground is missing, and point where there are peaks of load.
The study of Edge Load Profiles is complex, but an accurate development of their shape provides a tool for ski qualification and design improvement.
Researcher and ski manufacturer developed different typologies of benches and several activities were carried out for measuring the static edge pressure profile when a ski is pressed against the bench with different angles and loads. These are experimental diagrams and data, but in-field data are very few, so benches are used to simulate different type of snow simply modifying the stiffness of springs under the load cells, or changing the pressured material (neoprene) with other foam typologies. The output curves are qualified as engineering ski "footprint", different on any ski and any load and angle configuration. Then the results are compared by users and correlated with subjective evaluations about the performances in the field.

3.2 MATERIALS AND METHODS

3.2.1 SLYTECH BENCH

Slytech Workbench is a specific lab equipment to test skies that gives a static simulation of ski itself during the curve. Principal parts of this workbench are:

- 21 uniaxial planar load cell, fixed to a rigid frame.
- A linear actuator with axis adjustable in a vertical plane is used to load any type of ski on a bed of load cells: the edging angles can be varied at steps of 10°, ranging from 0° to +/- 70°. On each cell, the contact takes place between the ski sole and the stiff neoprene surface supported by each load cell.
- An aluminum dummy boot sole to connect ski to the previous actuator. This sole presents 5 positions of application of the load spaced of 50 mm from the boot midpoint: position placed at +50 mm from the boot midpoint was used in the tests.
- Acquisition system connected on a pc.

It's reported a schematic representation of Slytech workbench and its components.

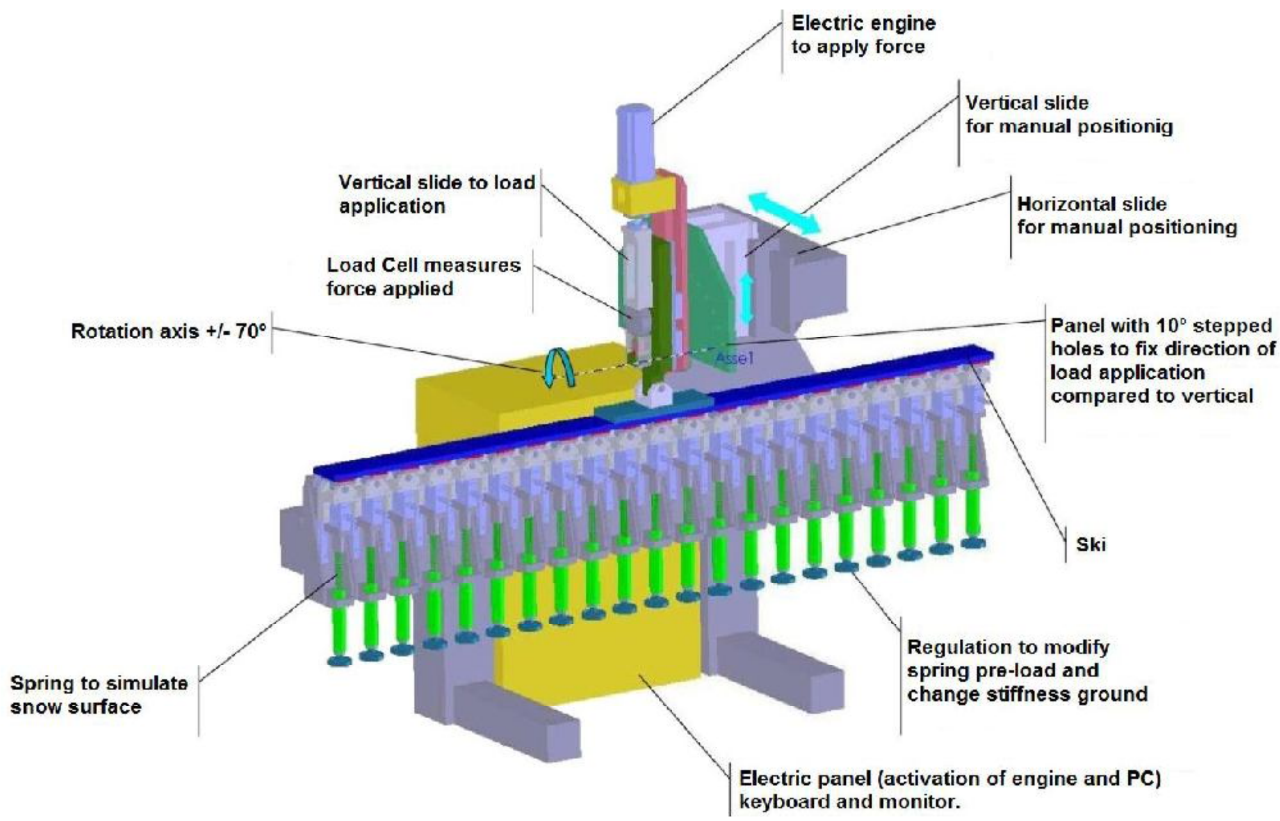


Fig. 37: 3D model of Slytech bench

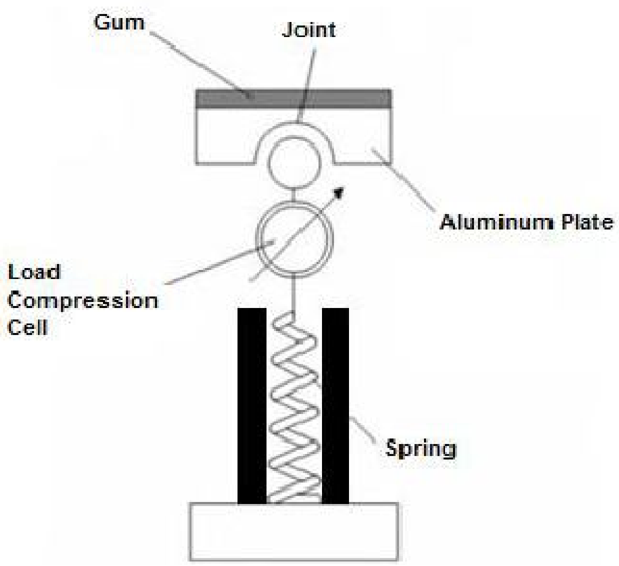


Fig. 38: Simplify 2D model of load cell + spring

A single cell is made by a moving aluminum plate with following dimension (LxWxT 110x100x8 mm); underneath it there is a joint that allows transferring force at one of the 21 compression load cell. Plates are regularly spaced of 2mm from each other.

Spring placed under load cell simulates the different ground stiffness; it can be replaced with a very high stiffness element to reproduce surfaces very stiff. Joint that links load cell with the aluminum plate allows rotation around axis orthogonal to longitudinal length of the ski. On the surface of each aluminum plate is posed a plate of PVC on which is glued a layer of neoprene, a gum where ski can transfer its load. Neoprene has the property that is deformable for long repeated cycle without permanent print or deformation. Another peculiarity is the lesser grip of neoprene with surface, in this case the metallic edge of a ski. Very low grip is a point of improving workbench performances. How it’s observable in the following picture, this workbench allows simulating different inclination of the ski on the plates and this correspond to different edging angle during a curve.

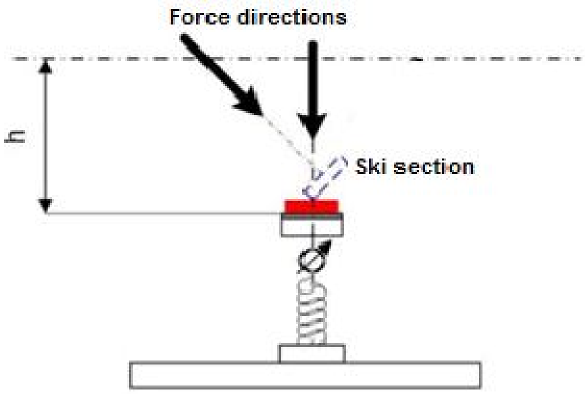


Fig. 39: Example of force directions on ground

During a ski test, each cell measures a load value and it is acquired by the computerized system, so in real time the load distribution on the cell is displayed on a graph, given an immediate idea of the characteristic of the ski. Each test can be stored in a database on the PC memory of the workbench itself to make possible the comparison between every tests performed.

The bench includes a system for introducing a known compliance at each load cell by using springs of known elastic constant and adjusting the spring preload with a set of screws from underneath: in addition, the contact surface can be modified by interposition of foams of different properties simulating the snow in different conditions.

Fig. 40: Slytech bench, old configuration, 40 degrees inclined

After the new modifies the length of one single plate of load cell is 103,5mm. This measure is introduced on the analysis of data to develop the Edge Load Diagrams. Ski is pressed against the bed of neoprene. Now the bed has a new configuration. The original aluminum plate is the same, but neoprene is glued on a PVC support 5mm thick, because this new disposition permits to use different type of surface who want to simulate the different hardness of the snow, preserving the aluminum plates.
The stiffness of every spring could be change rotating the screw under the same spring. The normal bench disposition is rigid, so with all screws closed. This disposition where called: “very hard” or “ice”. The second disposition is with screws only 17mm closed, and called “hard”. The third disposition is with all open screws, and called “medium”. This three disposition permits to obtain different stiffness of the springs and to simulate different kind of snow using the same neoprene surface. These names were given to compare Slytech bench with Rocker bench, that is in the University of Chemnitz laboratory’s and this have very low value of stiffness for ground plates.

3.2.1.1 TEST METHODS

Different skies are tested on this bench, choosing one ski from each pair. For example: Nordica Spitfire168 and Nordica SL165. The edge loading test consists on applying an increased load from 500 N to 1400 N with increasing edge angles, as reported on the table:

Angle [°]	Load [N]
0	500
10	600
20	700
30	850
40	1000
50	1200
60	1400

Load is applied over the cell n°11 by the vertical actuator that is powered by an electric motor unit with an holding torque of 6 Nm. A load cell is installed under the vertical cylinder, and has the function of control the load implemented on the software (retroaction system).

To calibrate the bench and permits to obtain the same value of applied load on each cell a rectifier steel beam is disposed on the neoprene bed to help also the gluing action of neoprene on PVC plates and to avoid deformation of the same ones before cells calibration.

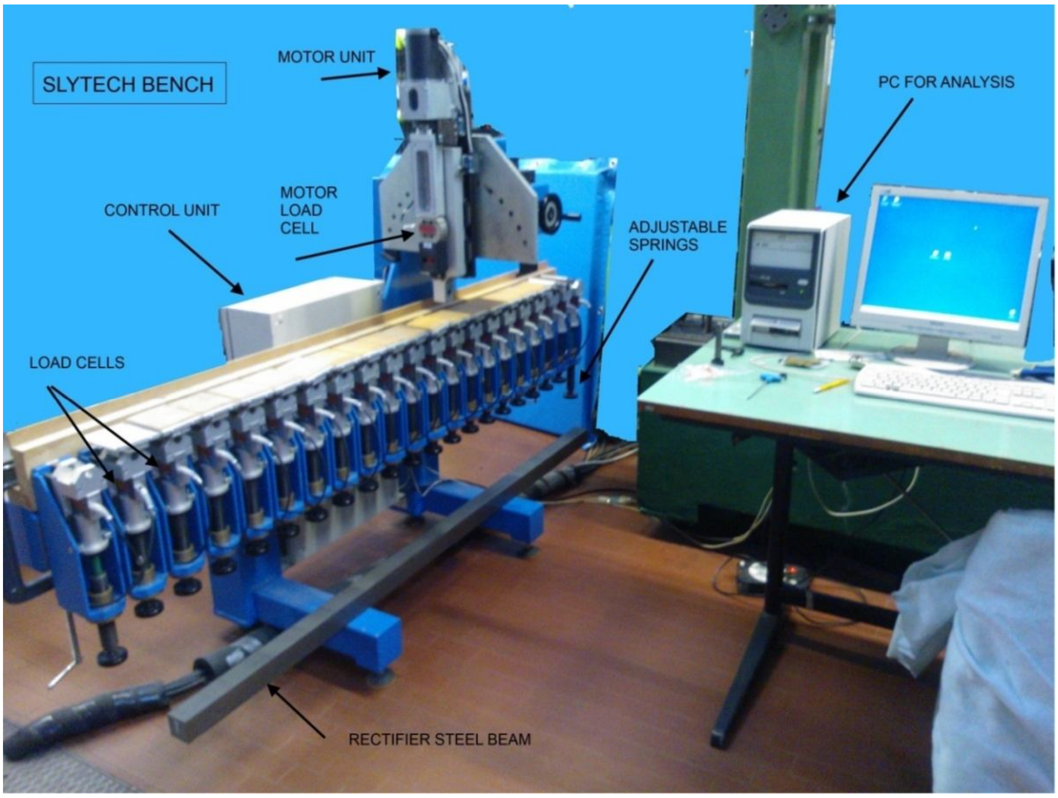


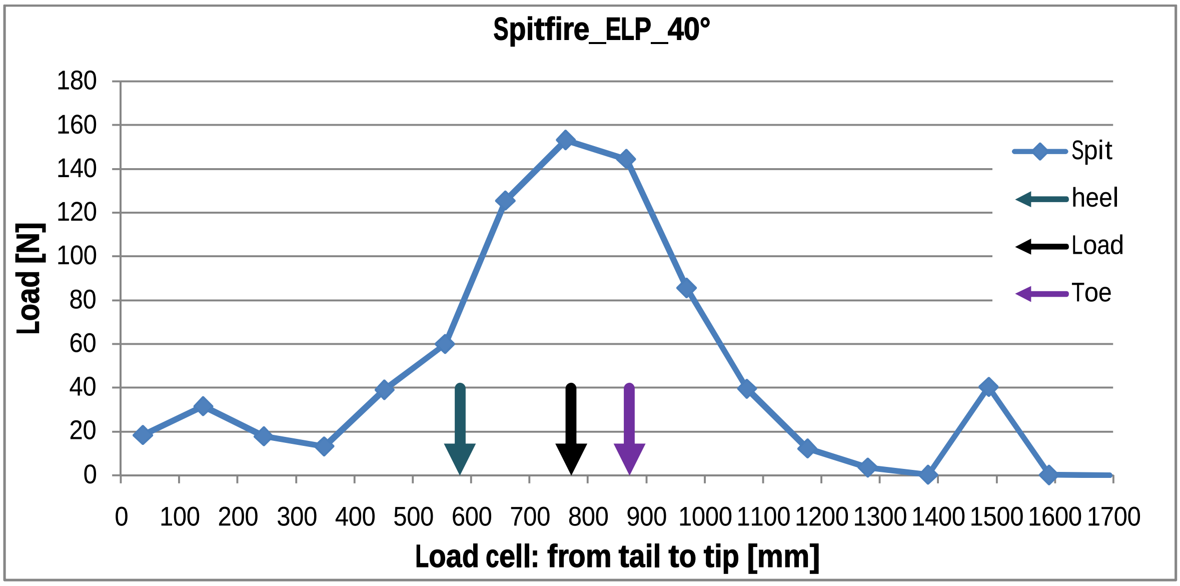
Fig. 41: Current disposition of the bench in University of Padua laboratory

The output data from each load cell are recorded by a software on a .txt file and then converted in graphs using Office Excel. At each test is associated a .txt file.

Loads measured at the i-th cell are plotted along the ski length to obtain the Edge Load Profiles (ELP): the load cell position could be normalized to the ski length to compare skies with different length. For each edging angle the bench provides different ELP for any type of ski. These difference are coming out from ski length, sidecut, construction and binding plate position and properties. These curves will be correlated in future with the grip and carving behavior of the skies form field tests.

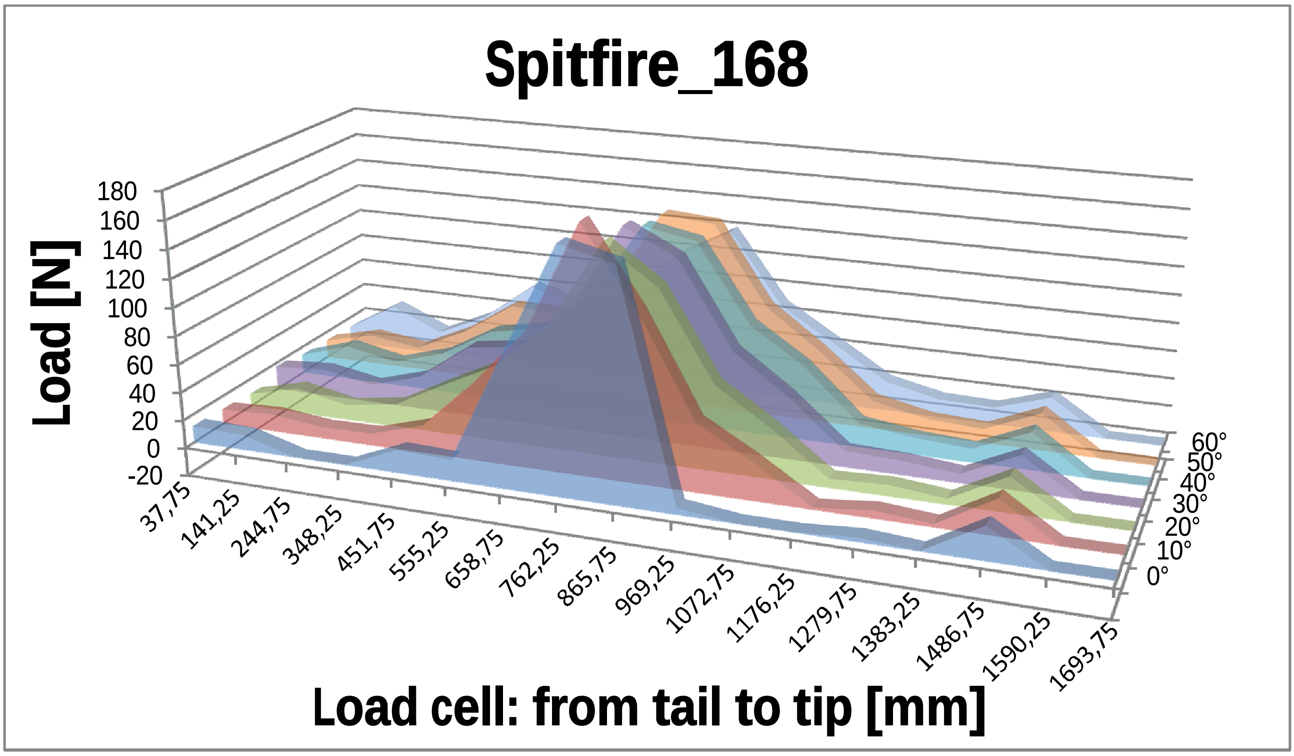
There are two types of diagram: single angle diagrams, and global angles diagrams.

Example of a single angle diagram:



Each point of the curve is an output of the respective load cell. They are interpolated with a spline line.

Example of a global angle diagram:



These are Edge Load Profiles of the same ski loaded in all the possible angle: note that the principal peak in the centre decreases with angle, tail and tip peaks increase with angle and the plateau in front of the bindings less increases with angle, but it is important because this permits ski to have a great area of contact with the snow during skiing at high curvatures. This plateau could be changed and increased modifying the ski internal structure, or changing bindings position, or coupling the ski with external superstructures of elastic compensation, like wood arm installed in front of bindings, or with integral wood plate in which bindings are screwed.

3.2.2 ROCKER TESTER

Rocker tester, property of Chemnitz University is equipped with 15 polyethylene sliders, an electric vertical cylinder and load cells to measure the forces released on them.

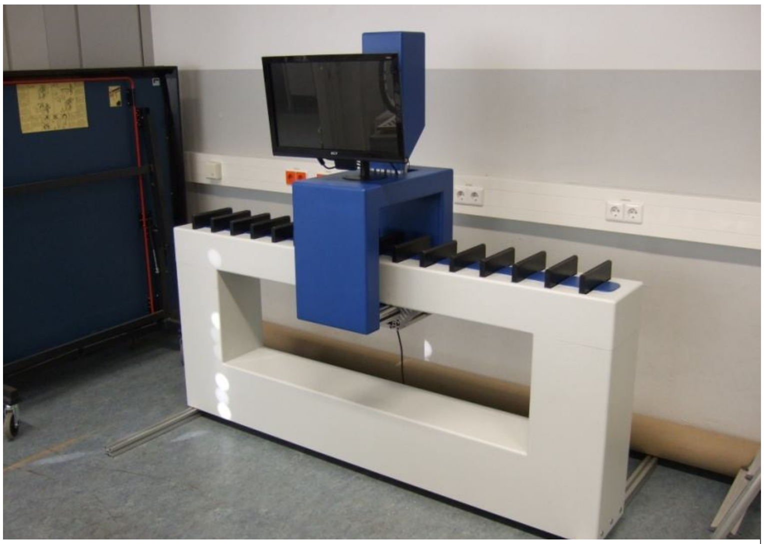


Fig. 42: Rocker Tester in Chemnitz University

Sliders are composed by hall-sensors who measure the displacement when a load is applied on them; sliders have two different kind of springs on their base. There are two spring per slider: soft springs (0,81 N/mm = spring rate of 1,6 N/mm) and hard springs (1,642 N/mm = spring rate of 3,284 N/mm). These two dispositions are respectively called “super soft” and “soft”, this to compare with Slytech ground stiffness that is always greater than Rocker. The principal function of the springs is that of simulate different kind of snow that skiers might encounter.

Sliders are located at a distance of 120mm between them. They are dimensioned for a maximum deflection of 19 mm, so maximum load of 62,396 N.

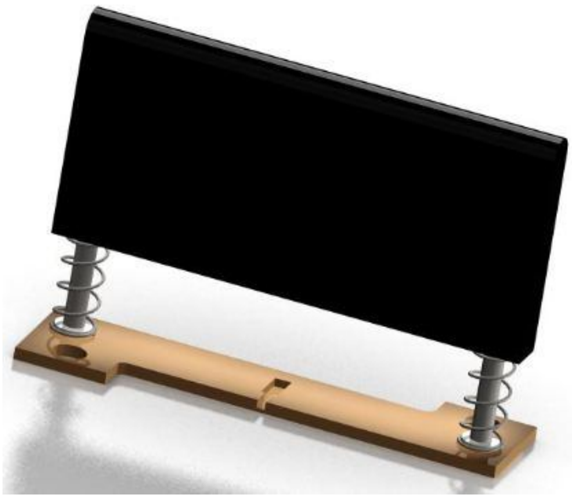


Fig. 43: Polyethylen (PE-1000 reg. black) Slider

3.2.2.1 TEST METHODS

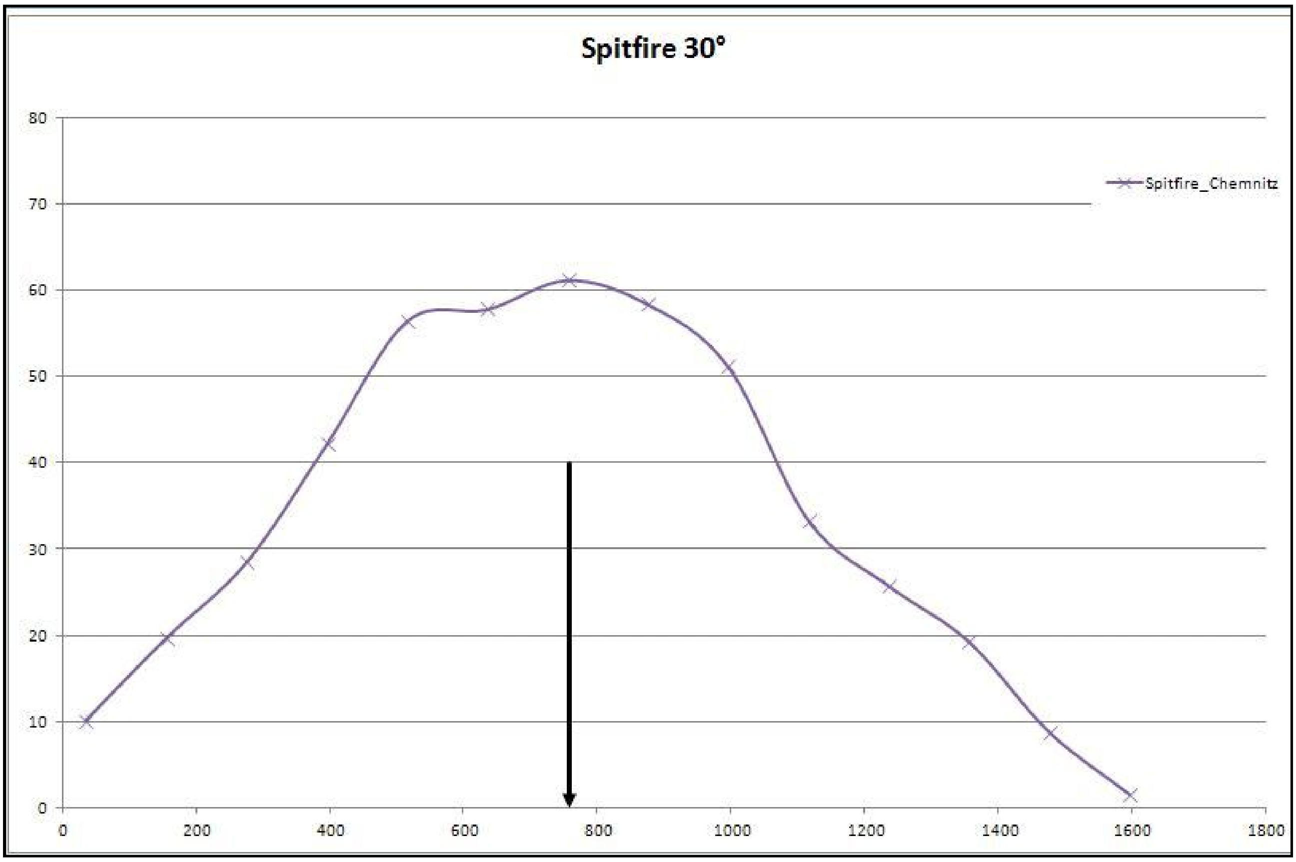
In Rocker bench loads is applied with an electric cylinder that can develop forces until 2000 N. Load cells installed can measure until 1000 N. Tests are made using the harder springs and only three inclination.

Angle [°]	Load [N]
0	350
20	500
30	600

The outputs of this bench are the displacements of sliders (**f_i**); springs stiffness are known (**K_i**), so it is simple to obtain the respective forces (**F_i**) and the Edge Load Profile of the ski tested:

$$F_i = K_i f_i$$

Example for one measure:



In this diagram ski-tail is at the left, ski-tip at the right site, the black arrow shows the point of application of load who is fixed for all tests. Stiffness of spring is constant so this diagram, giving displacements as output, could give an idea of the internal rigidity of the ski (product EJ). Lower value of rigidity represent a ski easier to flex.

3.3 LIST OF SKI TESTED

SKI			SLYTECH BENCH							ROCKER TESTER	
BRAND	MODEL	LENGHT	ICE _ PD	ICE _ CH	HARD _ PD	HARD _ CH	MEDIUM _ PD	MEDIUM _ CH	BLUE FOAM	SOFT	SUPERSOFT
NORDICA	GS	1820	X	X							
NORDICA	ELCAPO	1850	X	X						X	X
NORDICA	EDT	1680	X	X							
NORDICA	ELPACO	1740	X	X						X	X
NORDICA	TRANSFIRE	1680	X	X	X	X	X	X		X	X
NORDICA	SLR	1650	X	X	X	X	X	X		X	X
NORDICA	SPITFIRE	1680	X	X	X	X	X	X	X	X	X
NORDICA	SPITFIRE+WOOD	1680	X	X	X		X				
NORDICA	HELL	1750	X	X	X	X	X	X		X	X
HEAD	RALLY	1670	X	X						X	
FISCHER	HYBRID_C 7.0	1610	X	X						X	
FISCHER	HYBRID_R 7.1	1610	X	X						X	
FISCHER	HYBRID_C 7.5	1680	X	X	X	X	X	X		X	
FISCHER	HYBRID_R 7.5	1680	X	X	X	X	X	X		X	
ATOMIC	GSD2	1820	X	X							
ATOMIC	GS_NOBR	1820	X	X							
ATOMIC	D2SL	1600	X	X	X	X	X	X		X	
ELAN	AMPH_C	1680	X	X						X	
ELAN	AMPH_R	1680	X	X						X	
SALOMON	KART	1650	X	X						X	
SALOMON	XRACE	1640	X	X						X	

For each ski tested a 3D ELP and a picture are reported.

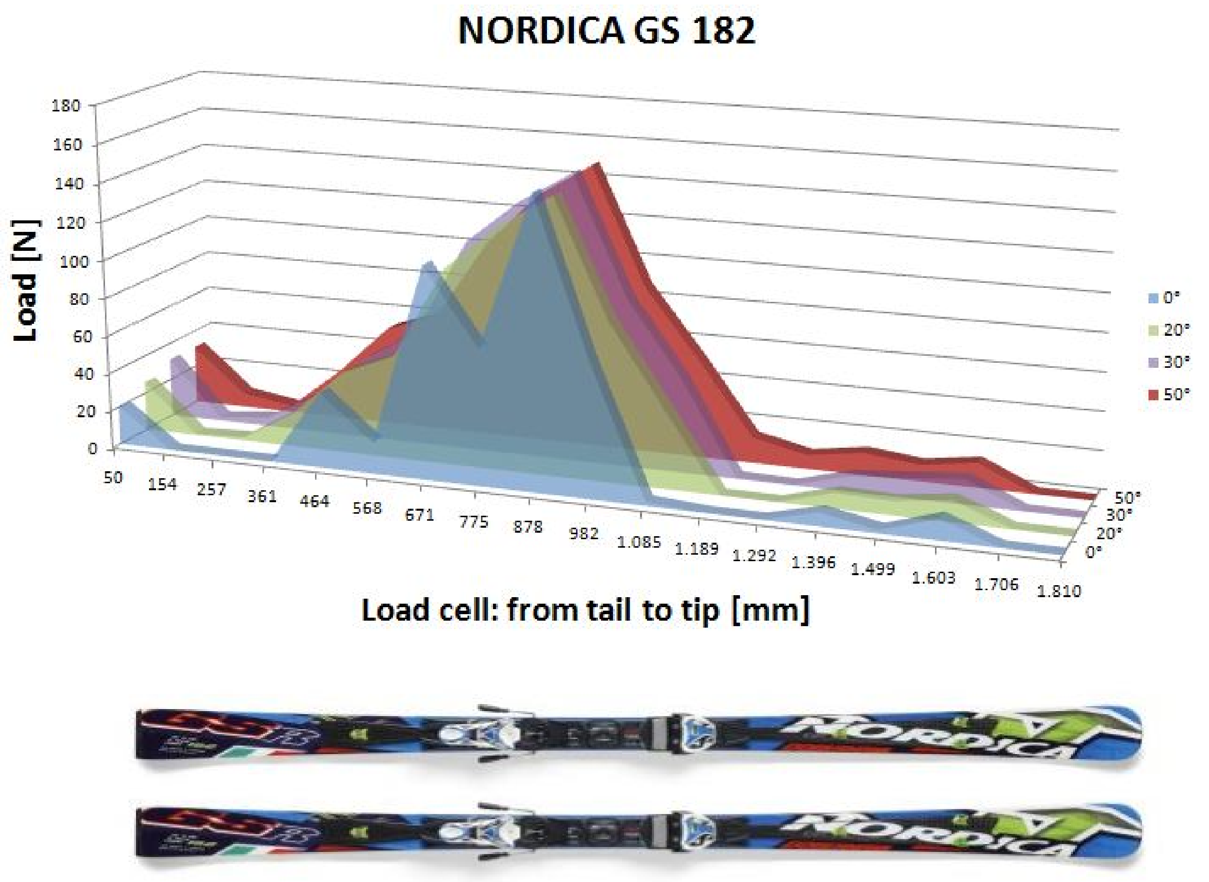


Fig. 44: Nordica GS 182

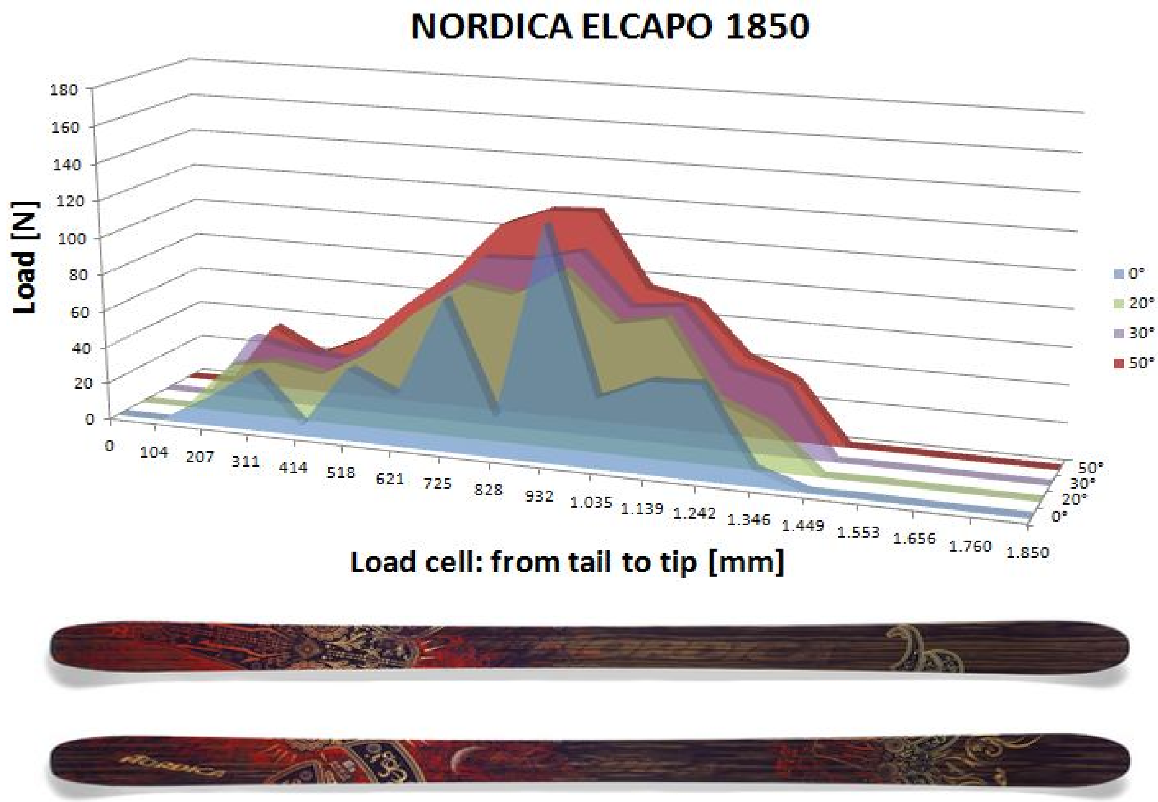


Fig. 45: Nordica EL CAPO 185

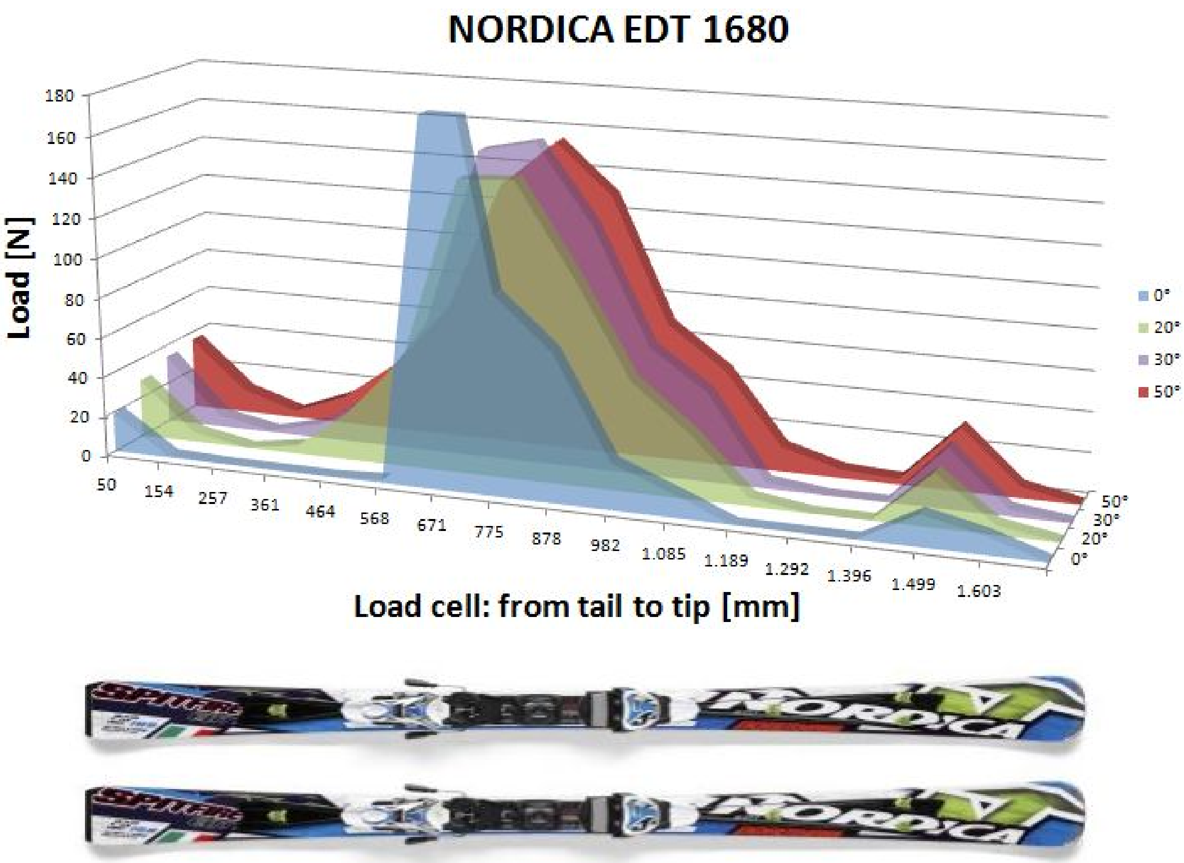


Fig. 46: Nordica Spitfire EDT 168

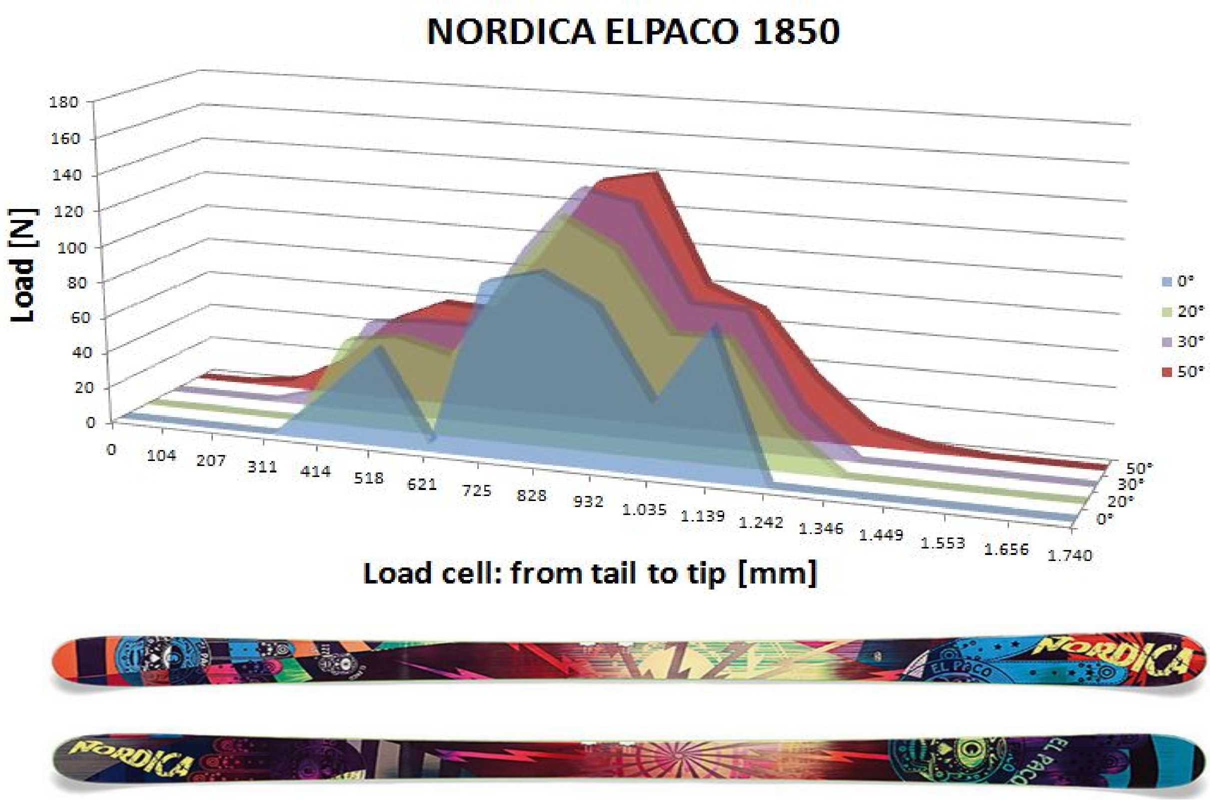


Fig. 47: Nordica EL PACO 174

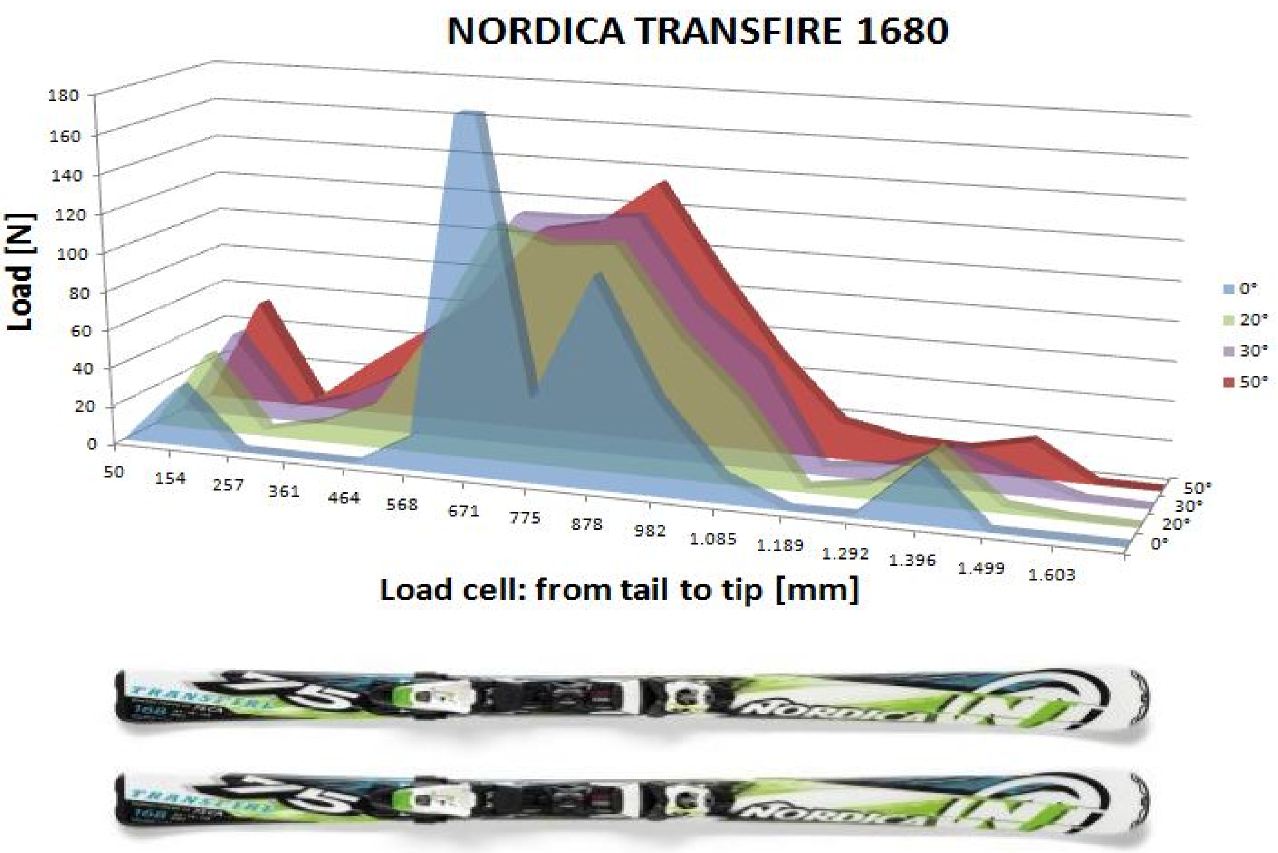


Fig. 48: Nordica Transfire 168

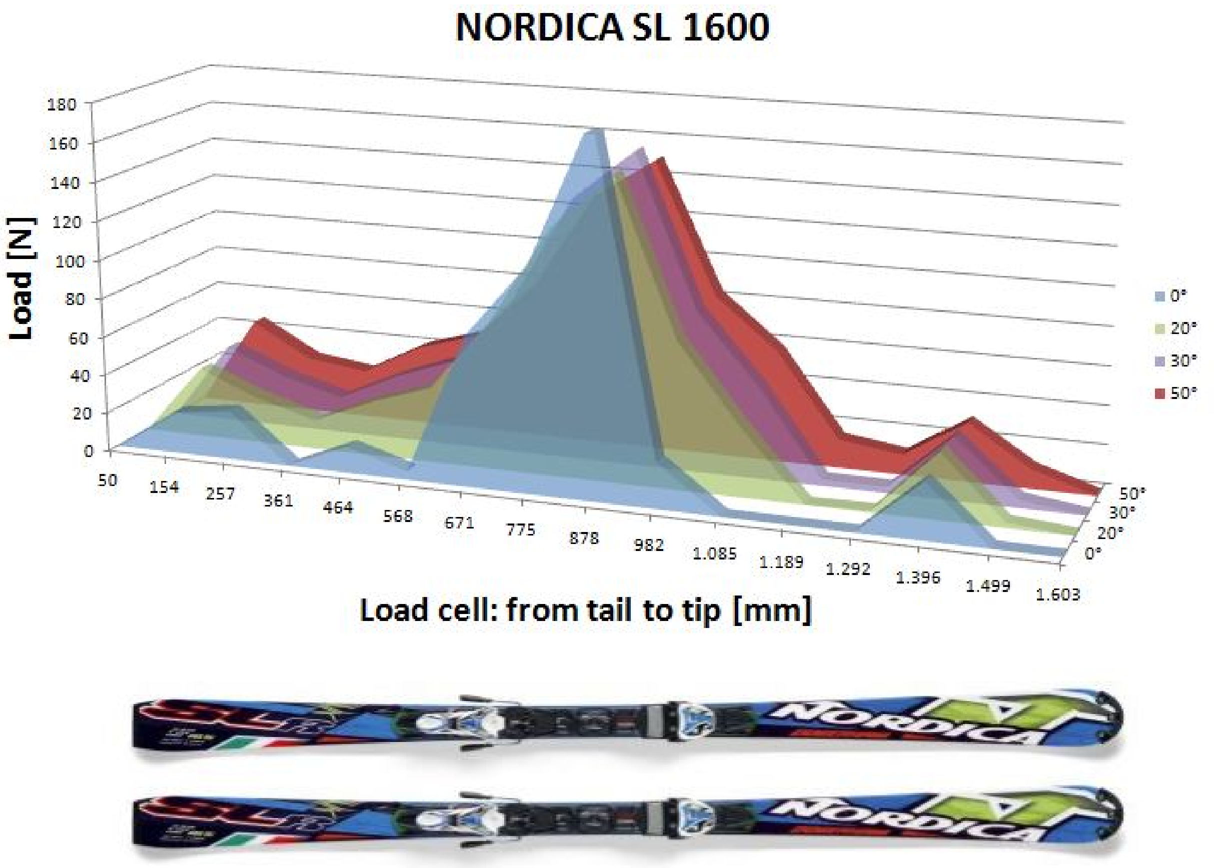


Fig. 49: Nordica SLR 165

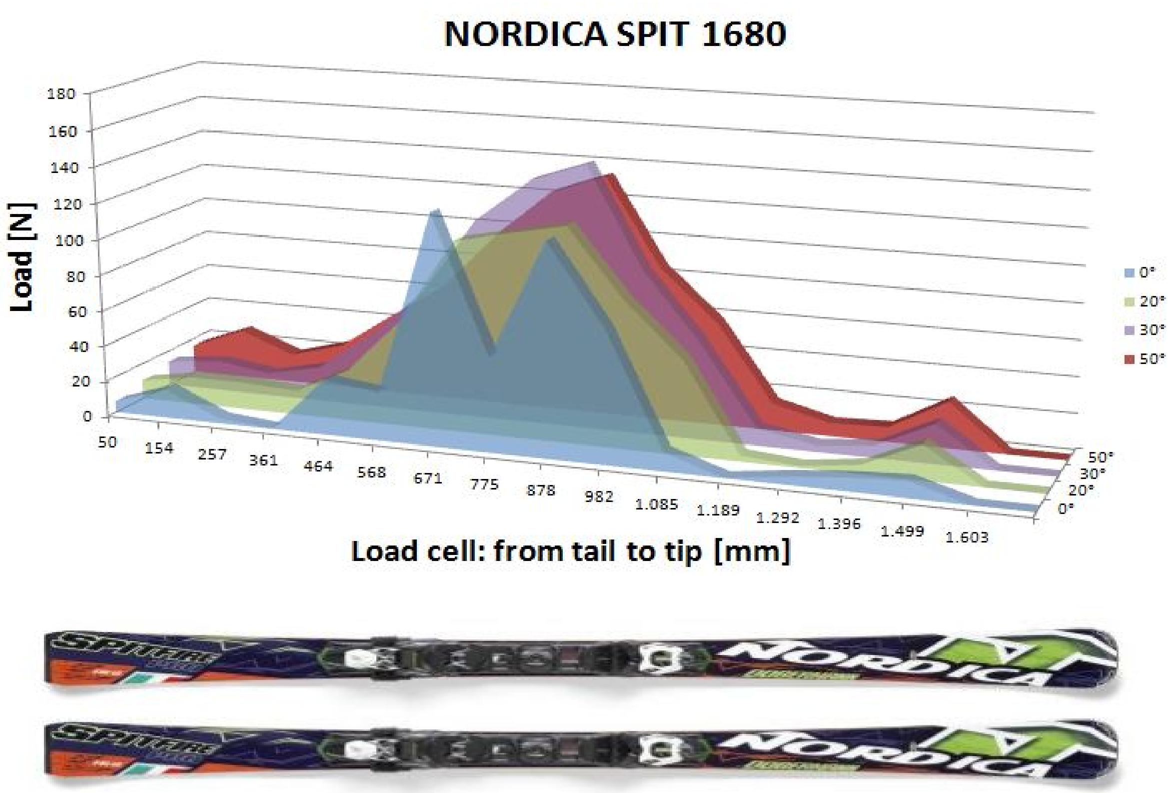


Fig. 50: Nordica Spitfire 168

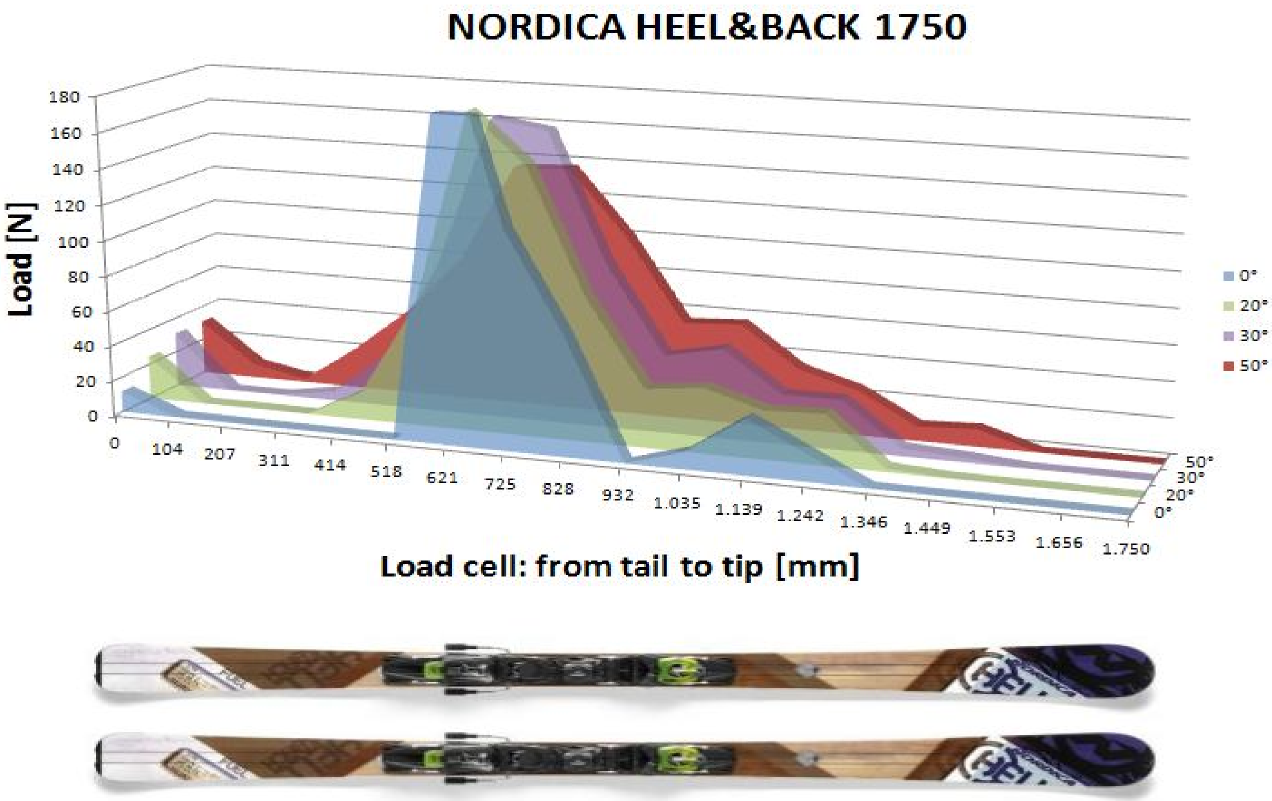


Fig. 51: Nordica Heel&Back 1750

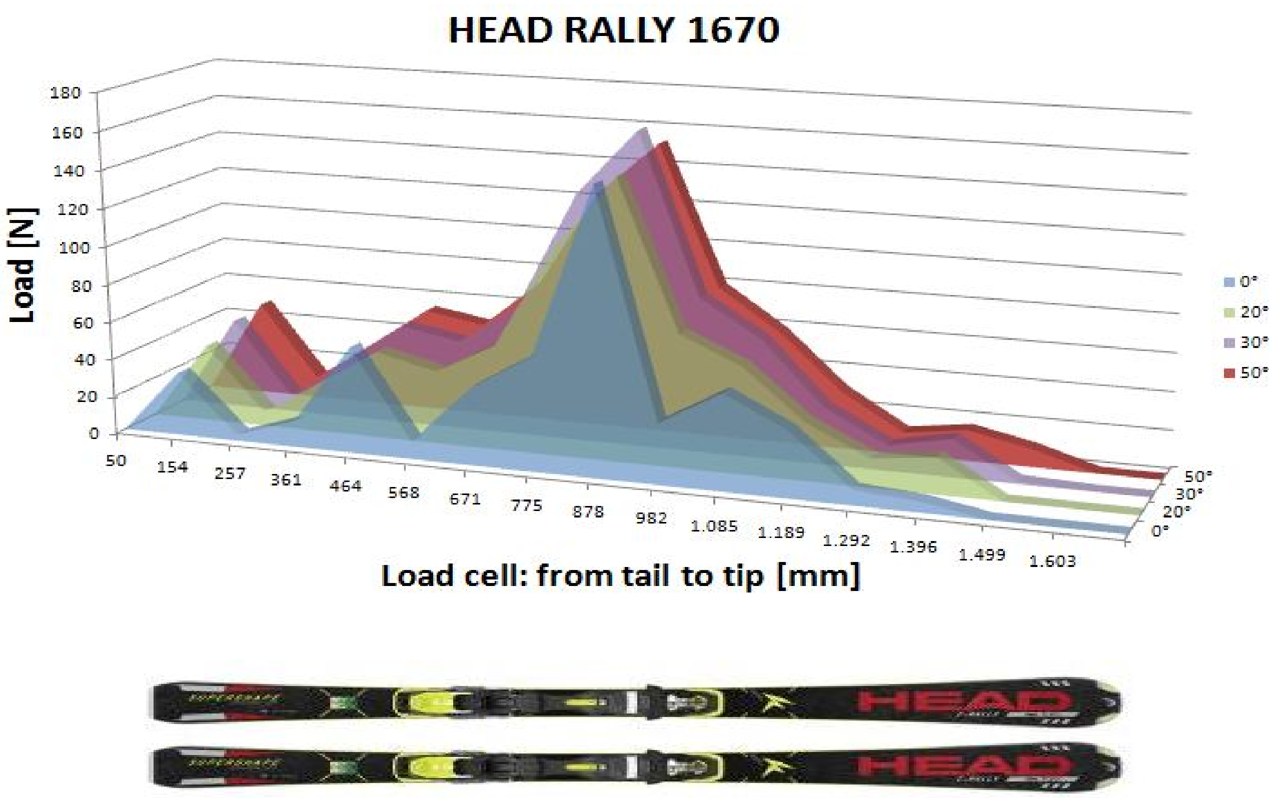


Fig. 52:Head Rally 167

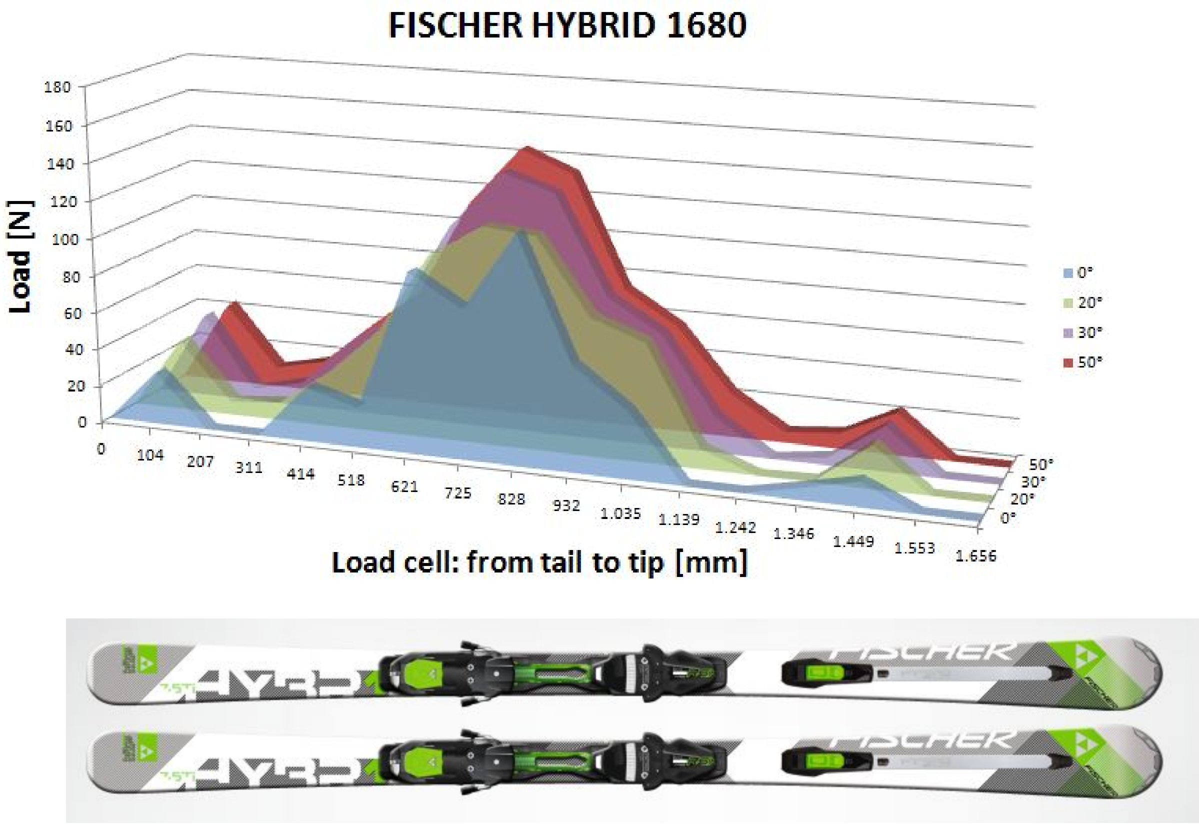


Fig. 53: Fischer Hybrid 168

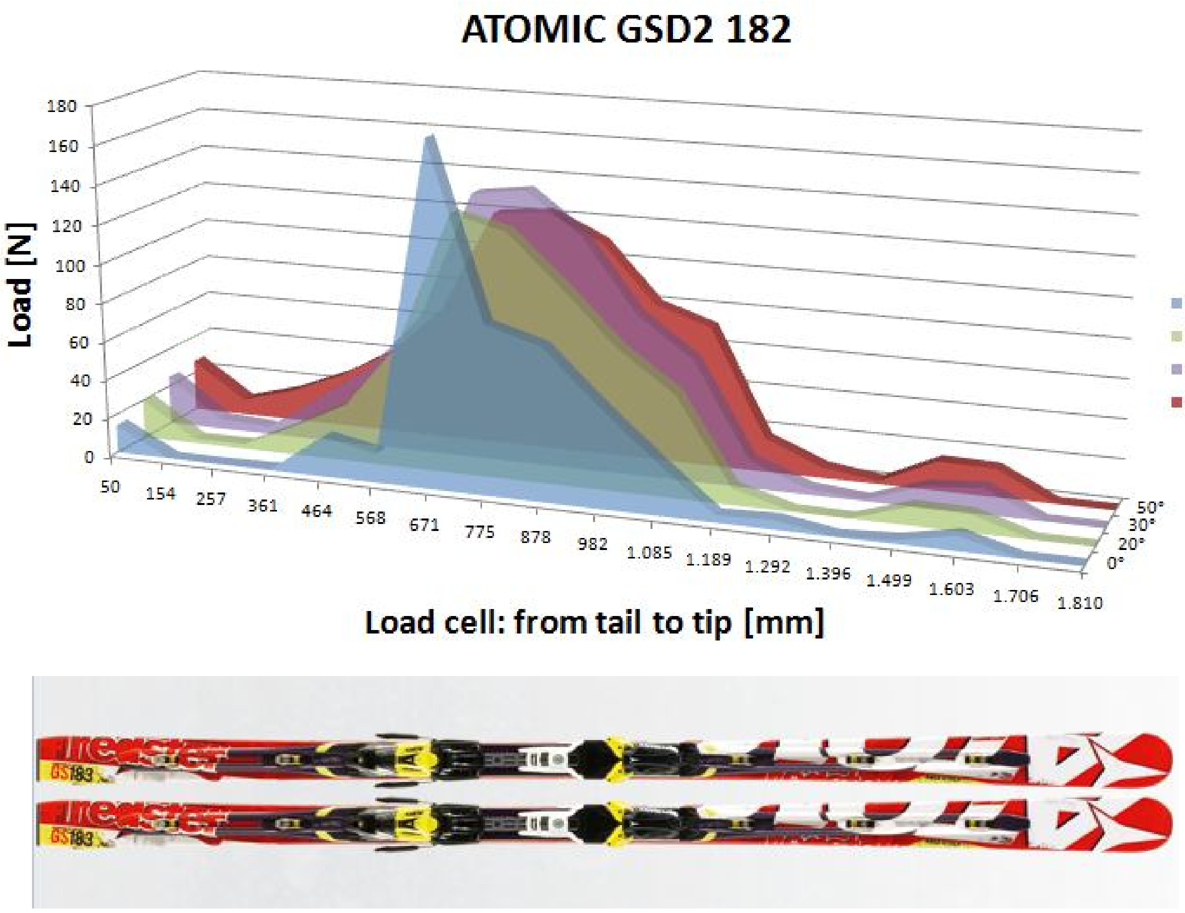


Fig. 54: Atomic GS 182

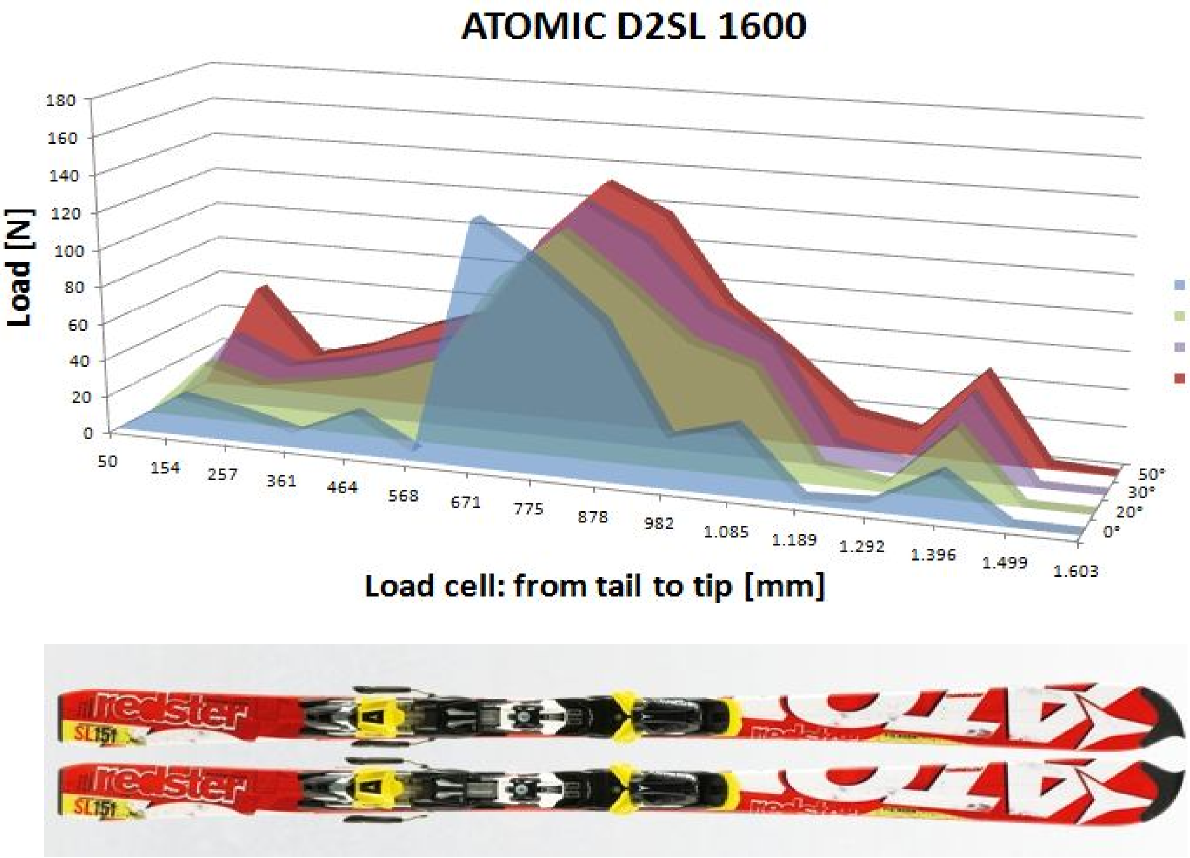


Fig. 55: Atomic SL 160

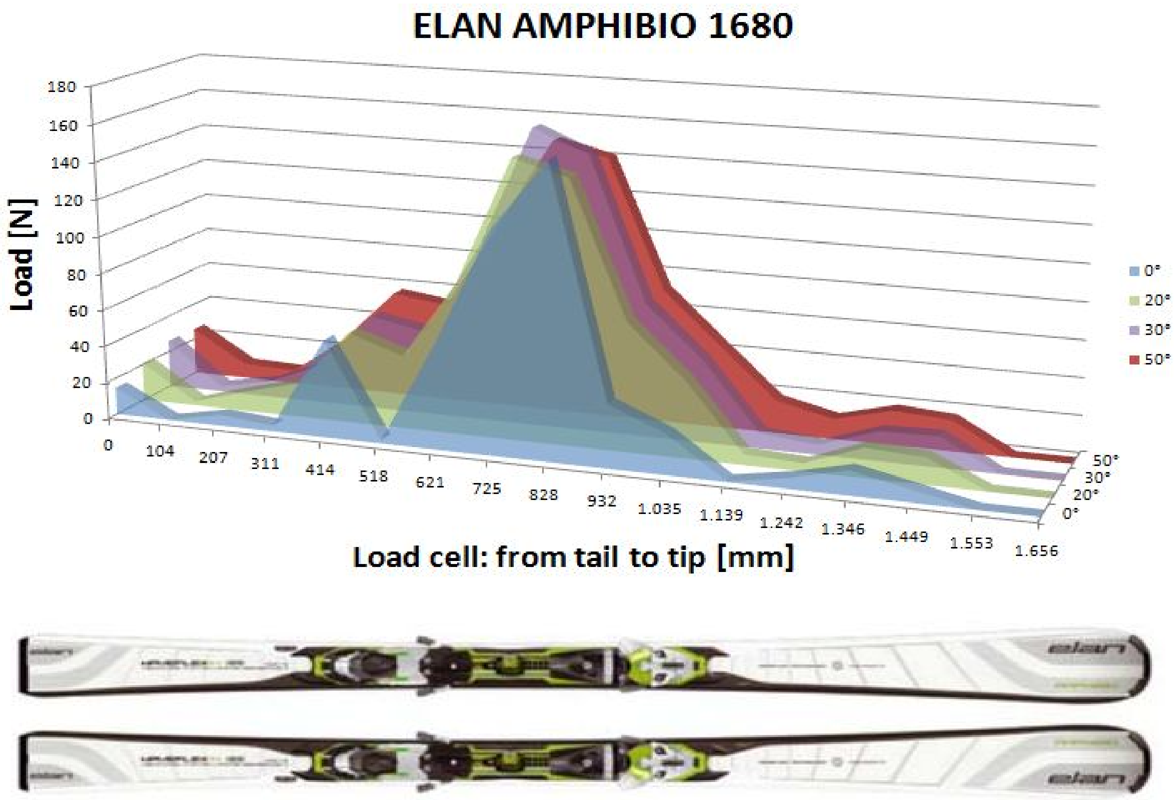


Fig. 56: Elan Amphibio 168

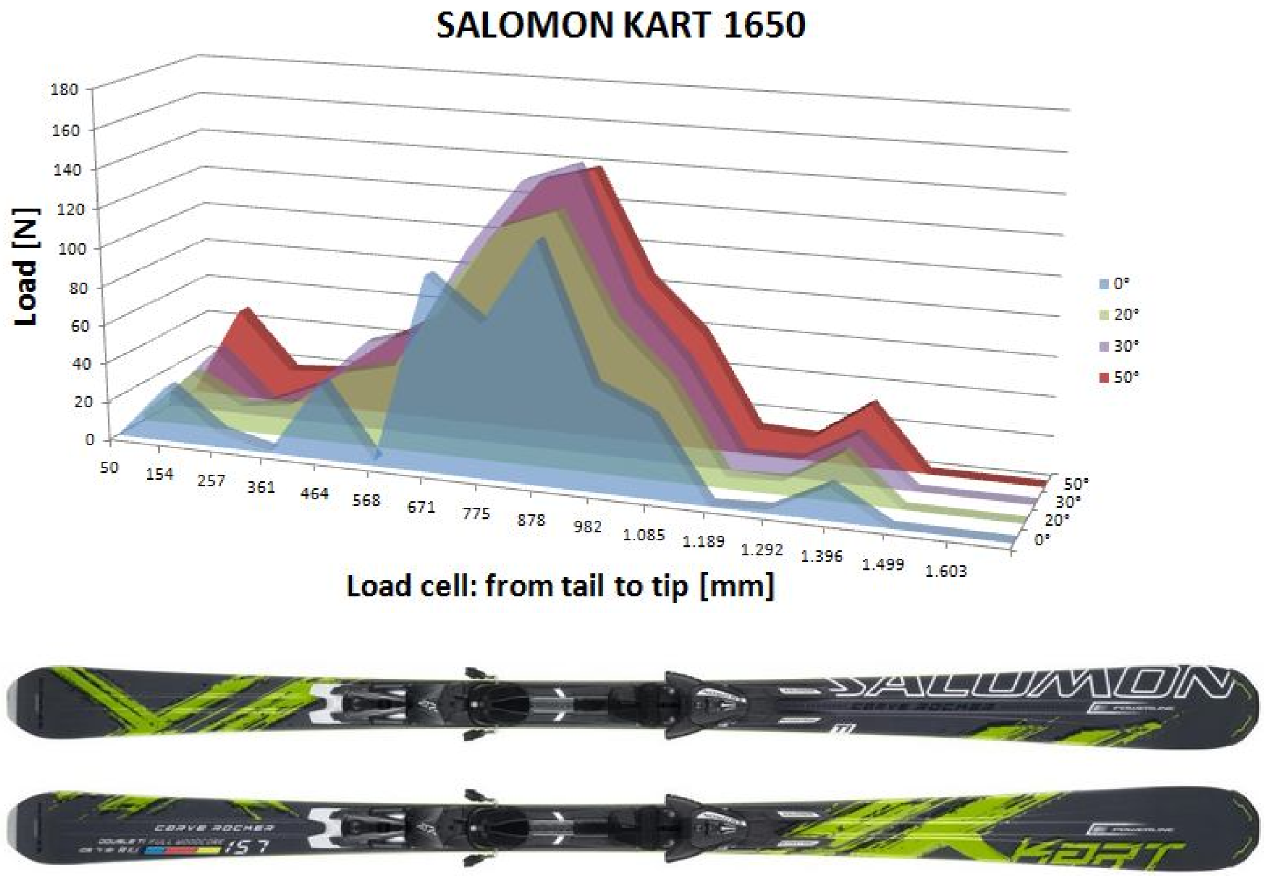


Fig. 57: Salomon Kart 165

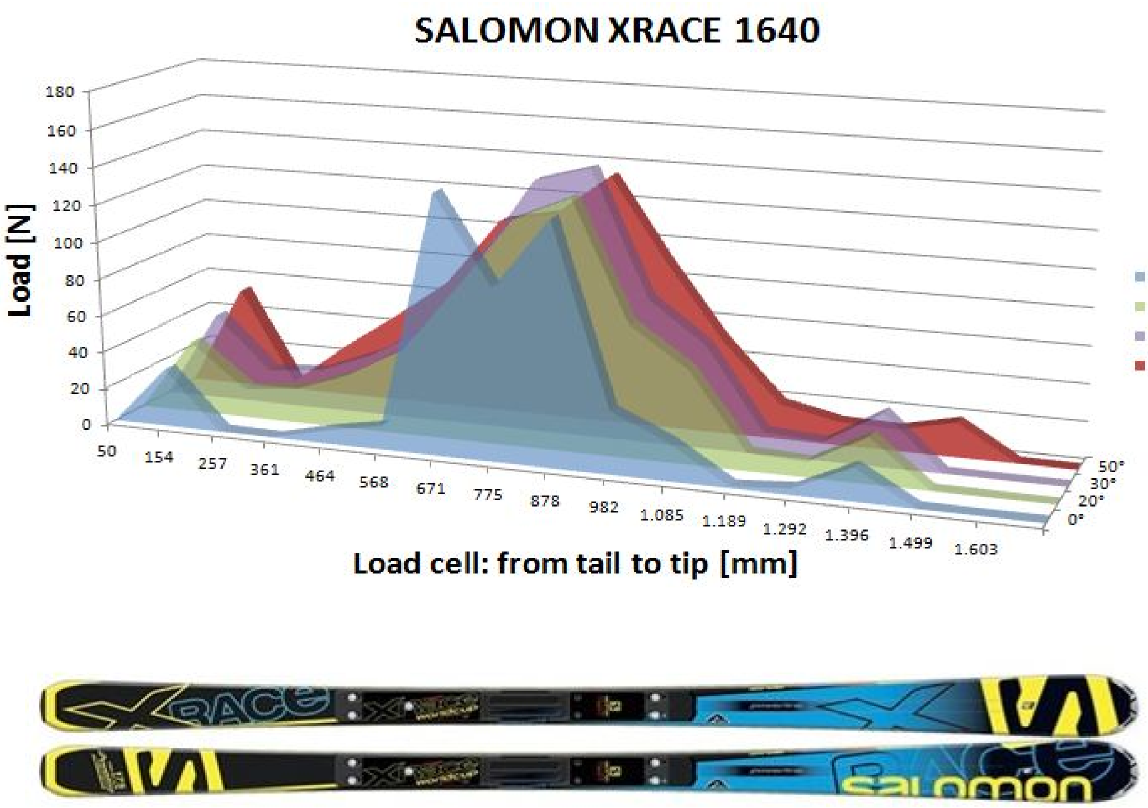


Fig. 58: Salomon Xrace 164

3.4 BRANDS COMPARISONS

Padua bench is provided of screws which open and close the springs. So it's possible to set springs at different configuration of the ground. Skies could be tested with **different ground stiffness**, this to simulate different kind of snow. For example ice, hard snow, soft snow. The minimum value of stiffness is 10 N/mm. The hardest stiffness is obtained with rigid configuration of screws.
Chemnitz bench has only two configuration of stiffness, both lower than Padua minimum. So Chemnitz bench provides results on soft snow and very soft snow.
The same ski could be tested applying this five different "snow". Diagrams could be set for these different stiffness.

The previous table contains green cells who indicate the configuration of bench during the test. Each test was effectuated at 0°, 20° and 30° with Padua and then with Chemnitz load when the screws of bench is all closed ("ice configuration"). Stiffness of ground was changed on Slytech bench in "hard" and "medium" value and some ski was tested. In total 71 type of test were done in Padua changing these variable: skies, edge angle, loads and ground stiffness. 22 test were done in Chemnitz.
Different brands typology of ski could be compared by diagrams, for example:

- Racing ski
- All mountain ski
- Freestyle ski

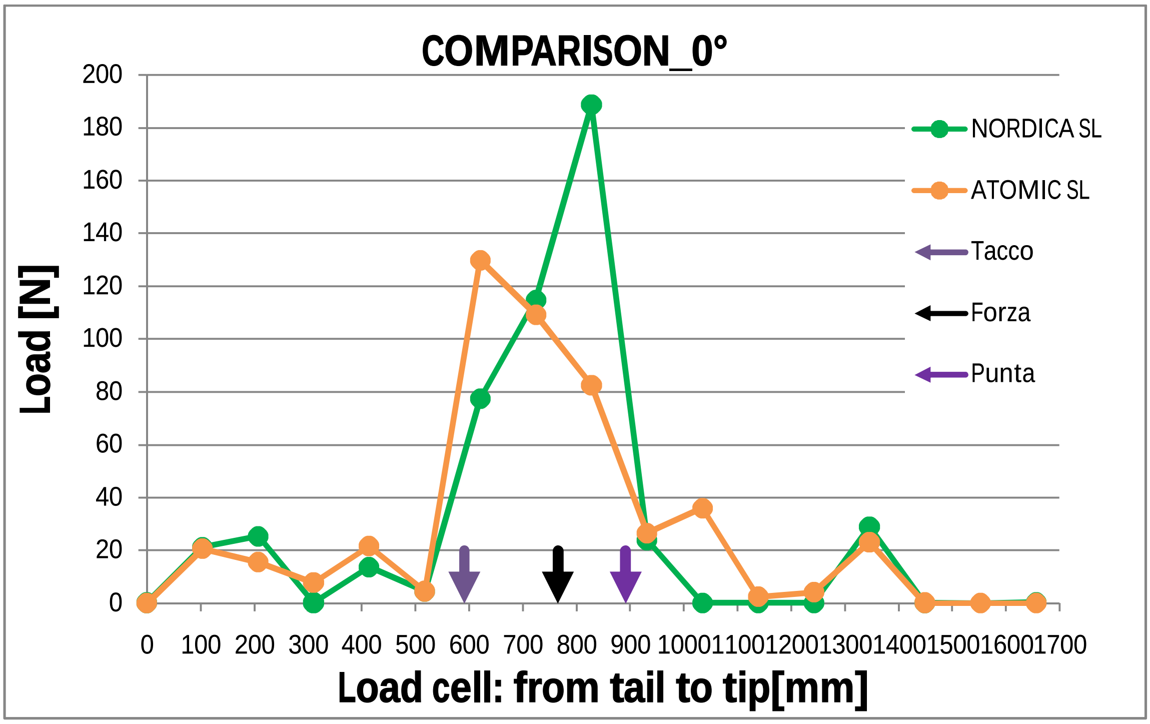
There are reported some description taken from producers , diagrams and comments about these ski clusters. It's important observing the central part and the shovel part of each diagram to understand the differences.

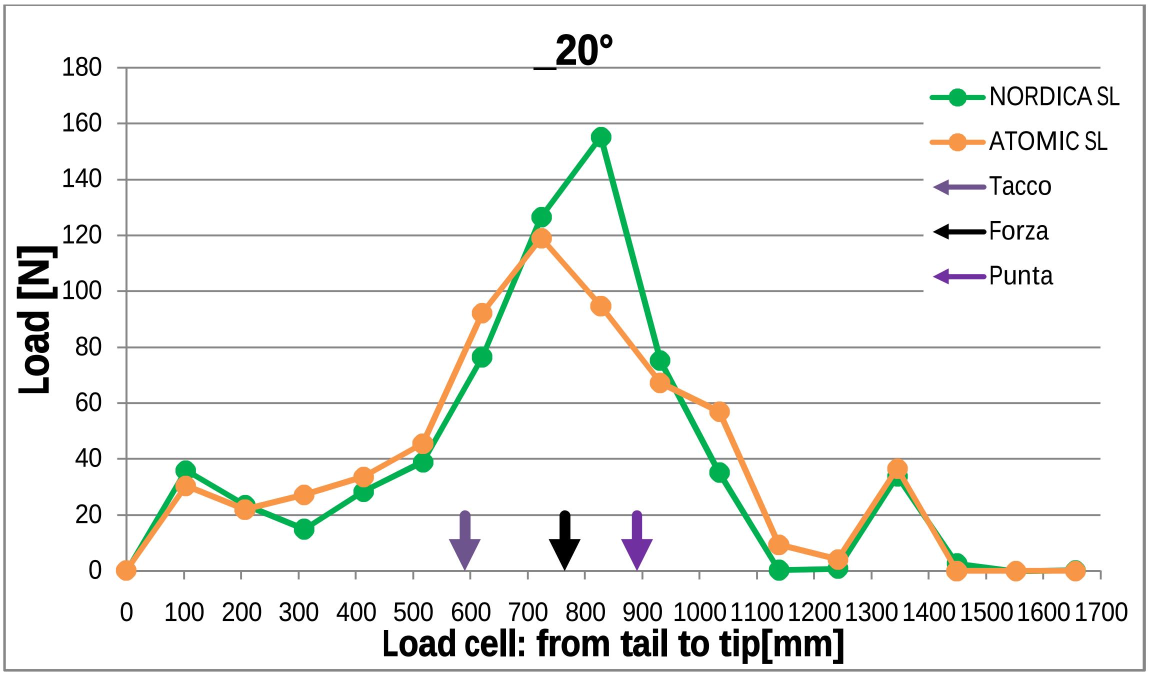
3.4.1 RACING

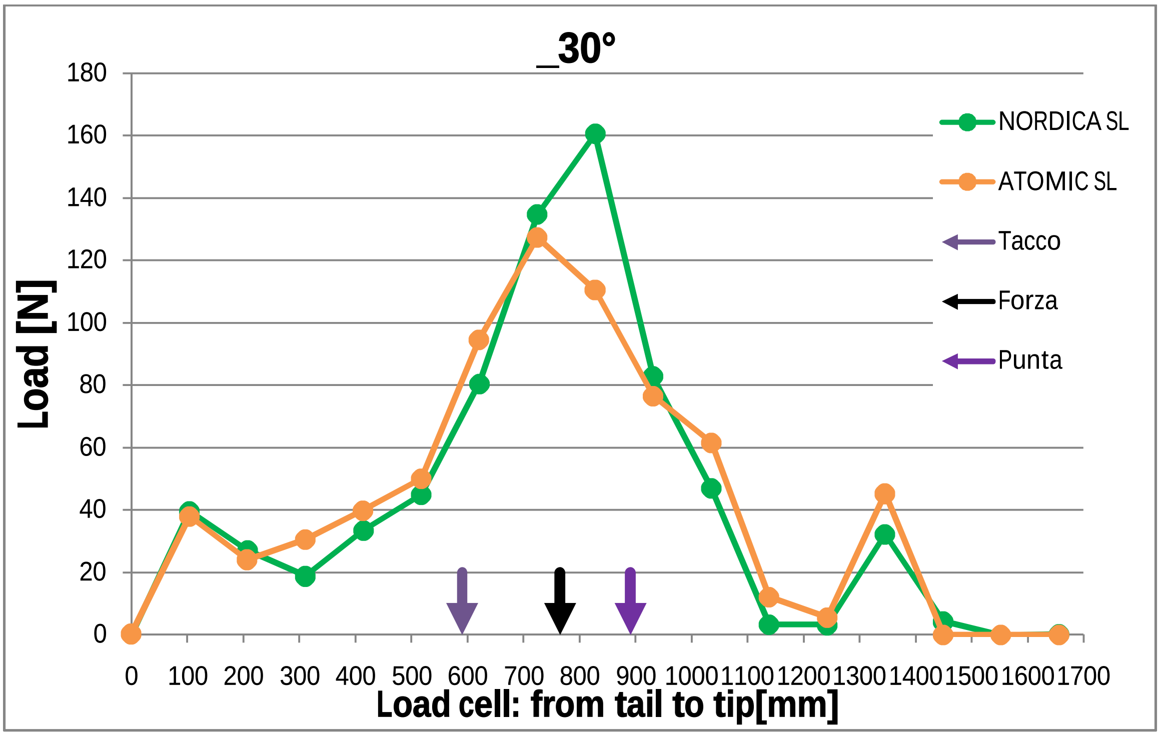
3.4.1.1 SL

For skiers who want change rapidly direction and high velocity.

- ATOMIC SL: Ski structure is combined by two surface to provide the optimal rigidity. The innovative flex zone offers rapid changes of direction and a great pull without avoiding the skier carving with a dynamic style. Shockilla is a material who absorb vibration and offers better sliding. Edge load is hard and affordable thanks to new technology Power Transmission Bridges.
- NORDICA SL: This skies are projected in Italy with the same World Cup construction. Harmonic steel is used and a wood aim provides rapid curves and efficiency on hard snow. EVO plate gives a better stability and precision in curves like a World Cup ski.



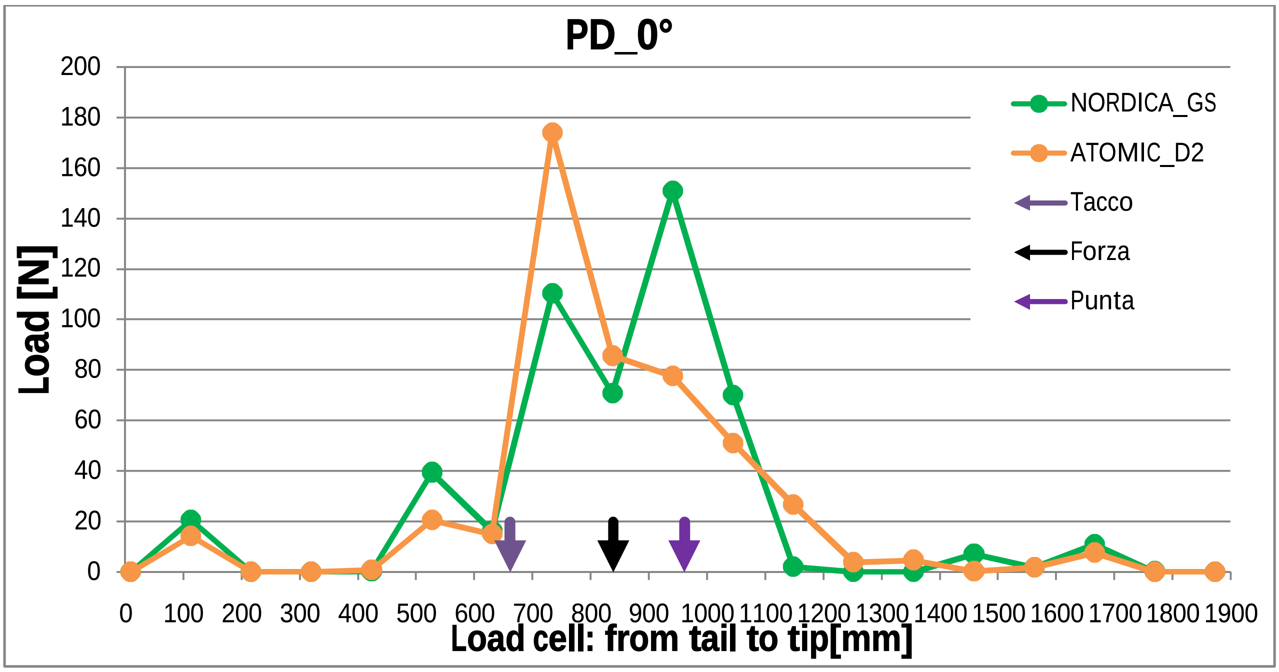


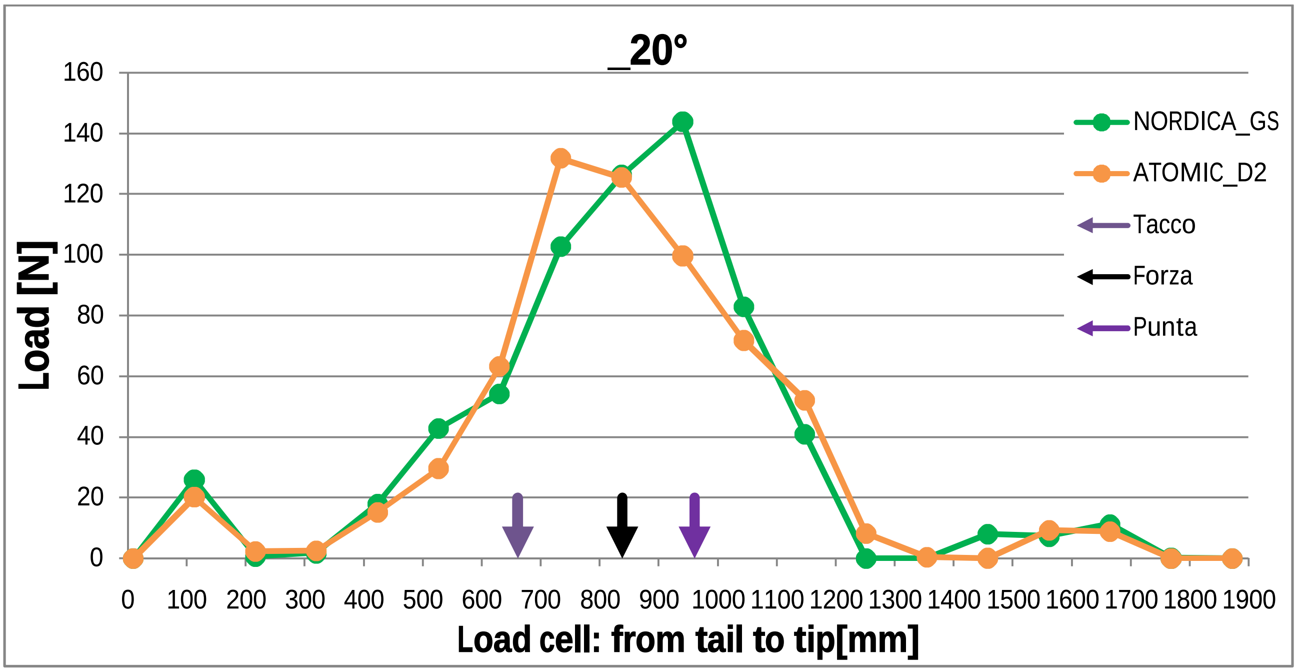


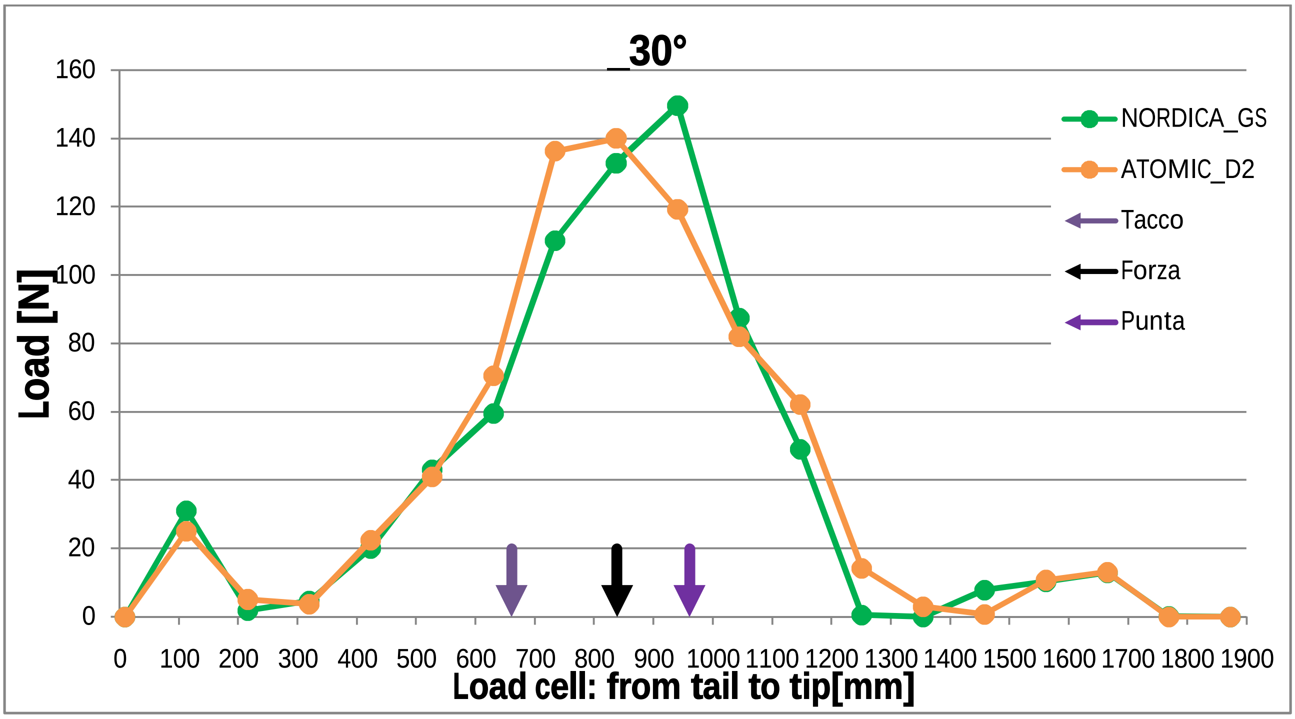
3.4.1.2 GS

Skies with dynamicity on performances at high velocity and max agility at low velocity.

- ATOMIC GS: This ski permits easy impostation of curves, without compromising the edge load and performances. This ski absorb vibration and transmit energy on edges with the same technology of SL ski. Skiing style is very accurate and easier with minus strength.
- NORDICA GS: Brought for professional skier and amatory athletes who search high level of performance and an experience near at World Cup skiing. Projected in Italy provides stability and precision in every slope.







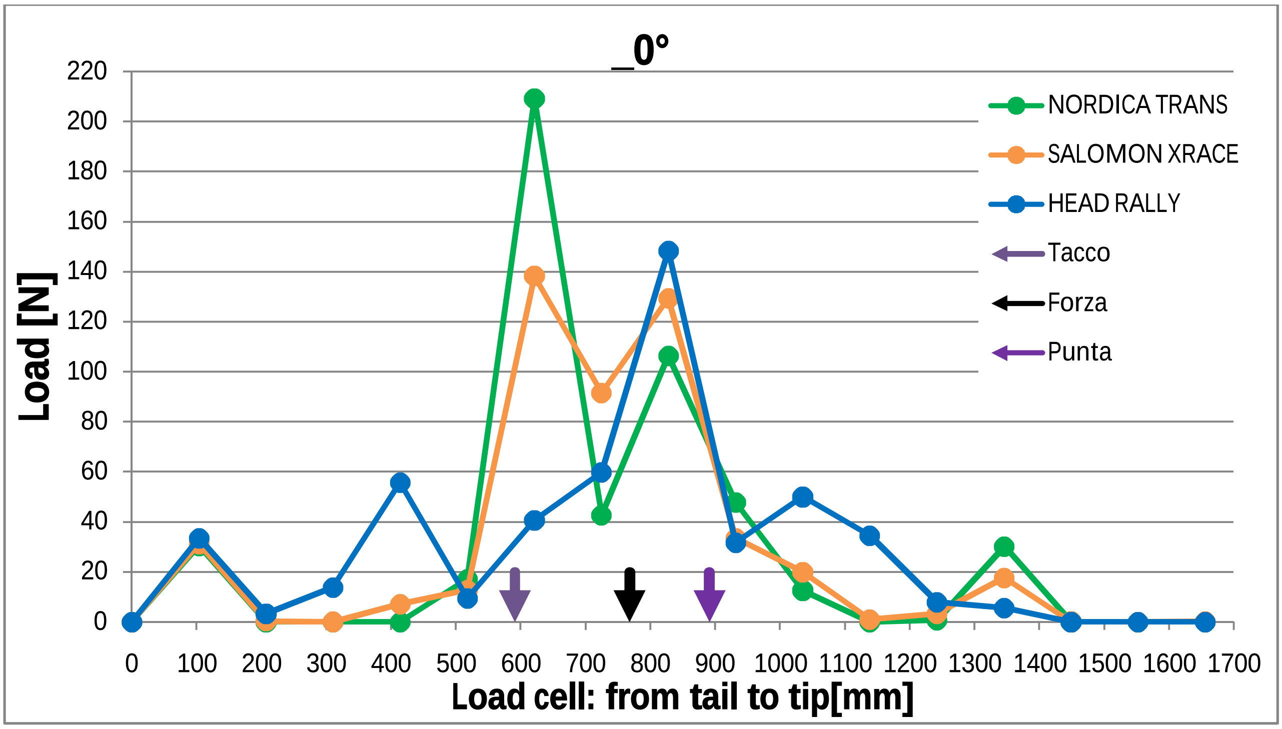
The substantial difference between SL and GS ski is the presence of a peak on shovel tip. SL ski provides a peak who grows with angle from 30N to 50N. GS skies provides a continuous presence of load on shovel from tip to his middle position, there is a sort of extended peak. So GS fills better the shovel but reports a valley in front of bindings. The same observation for SL that has a valley always present. Tail part of diagram is better filled for SL ski, instead GS reports a single peak an a valley.

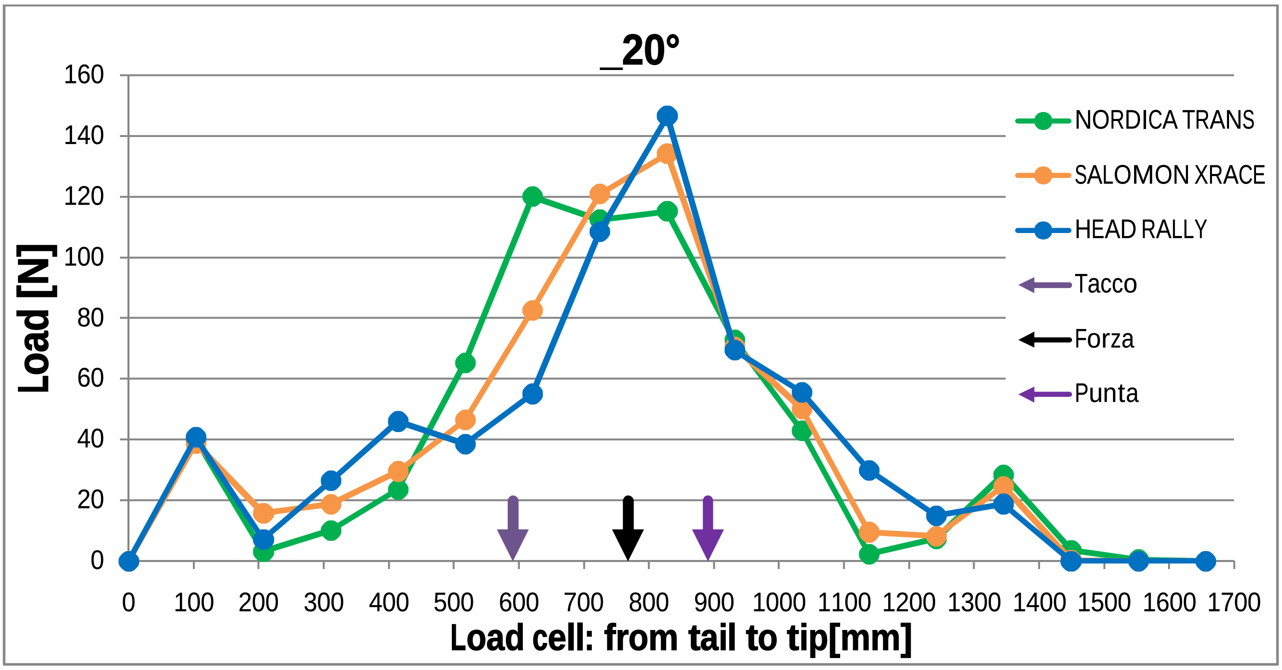
3.4.1.3 RALLY

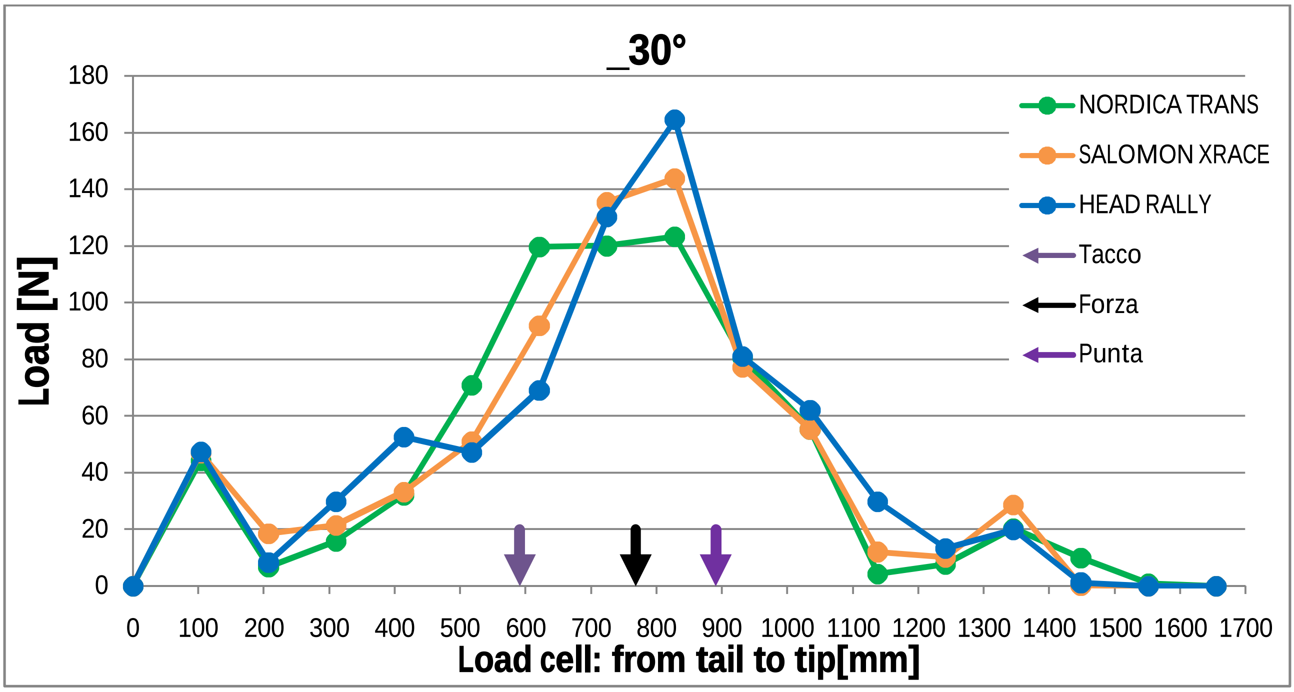
NORDICA TRANS: an intermediate skier needs for a precise and easy ski, built for help him on technical progress in different utilization conditions. This ski offers a rocker peculiarity and a new cam-Rock technology evolution.

SALOMON XRACE: World Cup technology and intuitive shapes permit skiers to choose the proper ski basing on velocity and curvature radius.

HEAD RALLY: this is a Giant slope model , with new technological sidecut and characteristics like KERS and intelligence surface RD Racing.



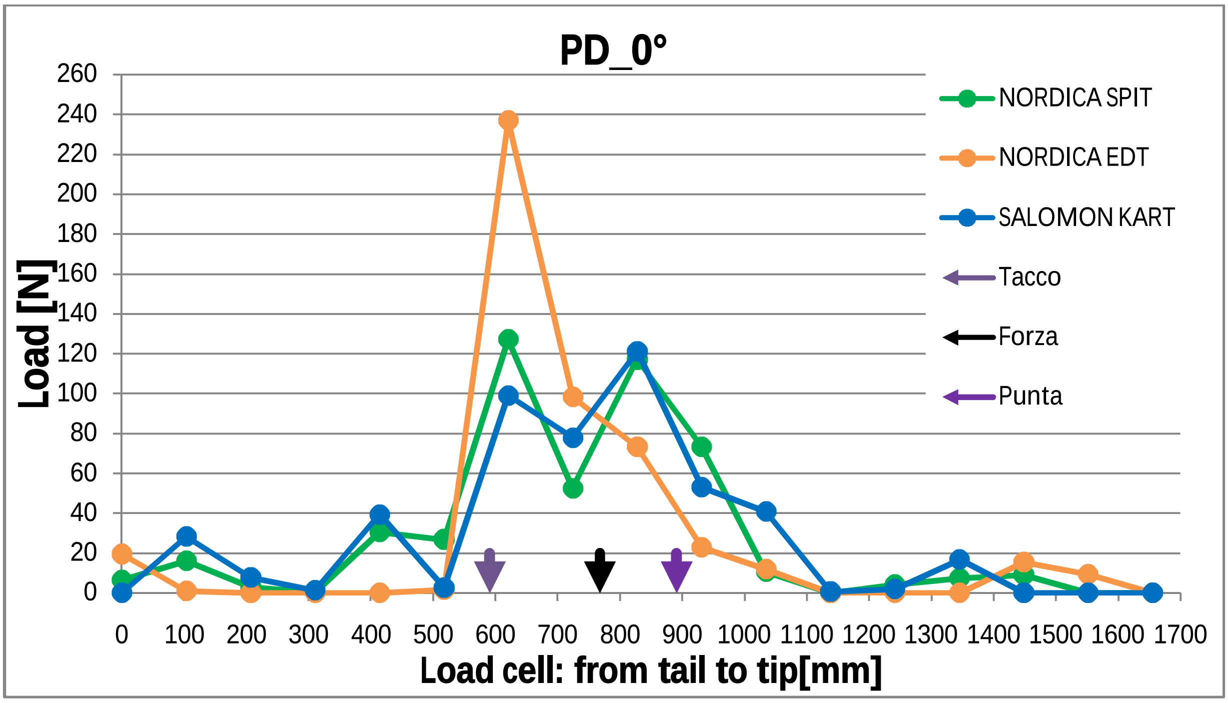


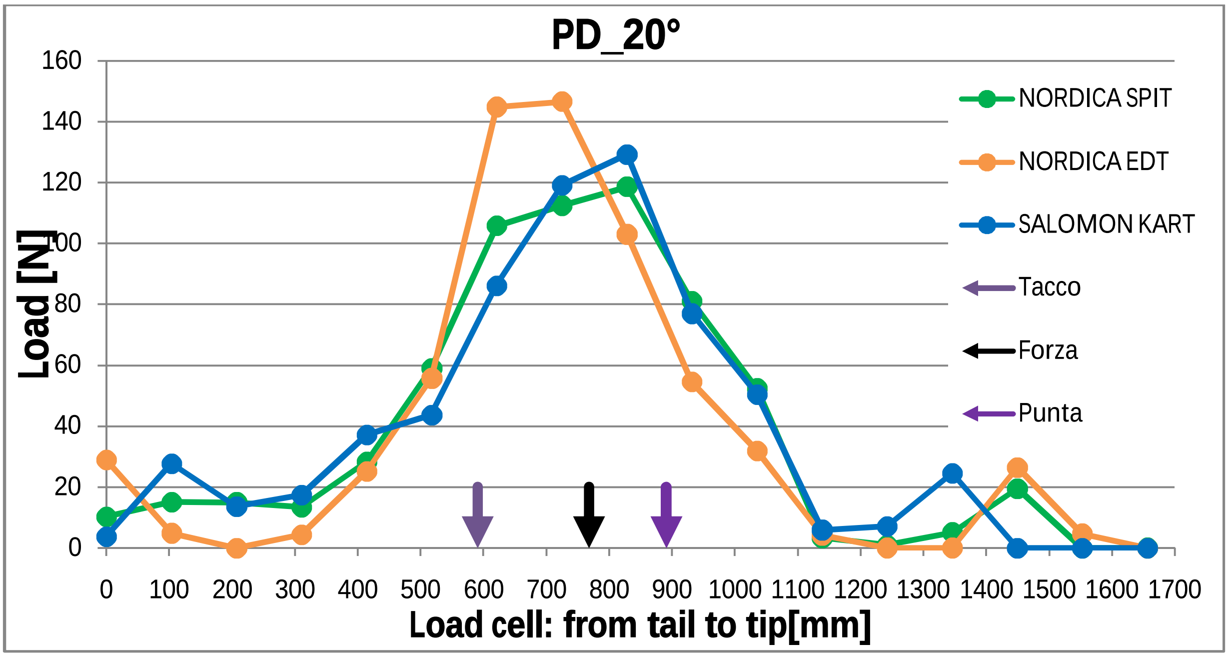


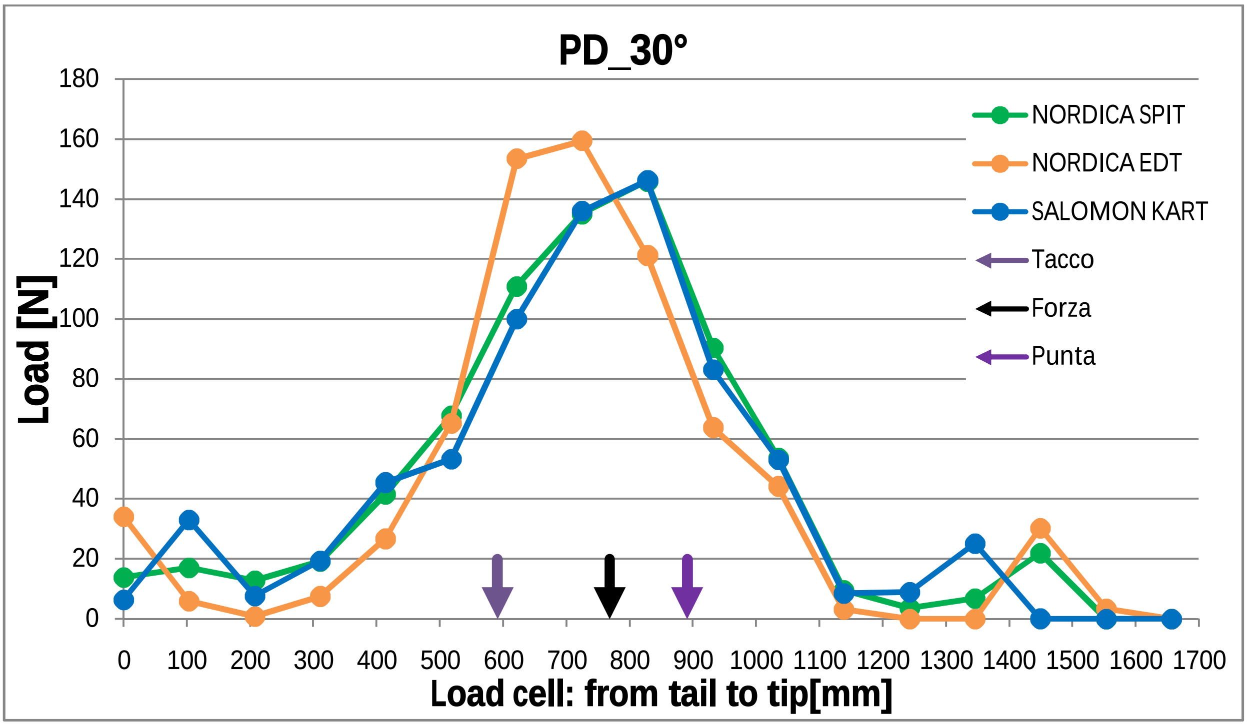
Nordica Transifire provides a peak of shovel that decreases with angle, and there is a growing of load in shovel with angle.
Salomon Xrace have the same behavior of Nordica Transfire in shovel and in tail zone, but not in the central were it is lesser filled. His peak on tip is always present and it increases with angle.
Head Rally don't have peak on shovel and results that his shovel is always loaded in all effective length. This is the better ski for this type of family.
The rocker peculiarity of this skies permits to have always load near the central part of the shovel.

3.4.1.4 PROGRESSIVE SKI

- NORDICA SPIT: spitfire were brought with a integral wood aim captured on two plates of titanal that offers an edge holding very precise. They are the combination of a slalom shovel and a GS core.
- NORDICA EDT: Efficient Dynamic Technology (EDT) is a technology who permits to earn a lot of energy and to grow the force transmission. This innovation, applied for first on boots and now on ski, gives better performance. A special carbon league gives greater flex on shovel, an incisive curve entering and more stability on every skiing situation.
- SALOMON KART: this is a ski to enjoy in the slope, it is an all-round with carve Rocker and sidecut for short curves. Each skiers could feel safety on this ski.



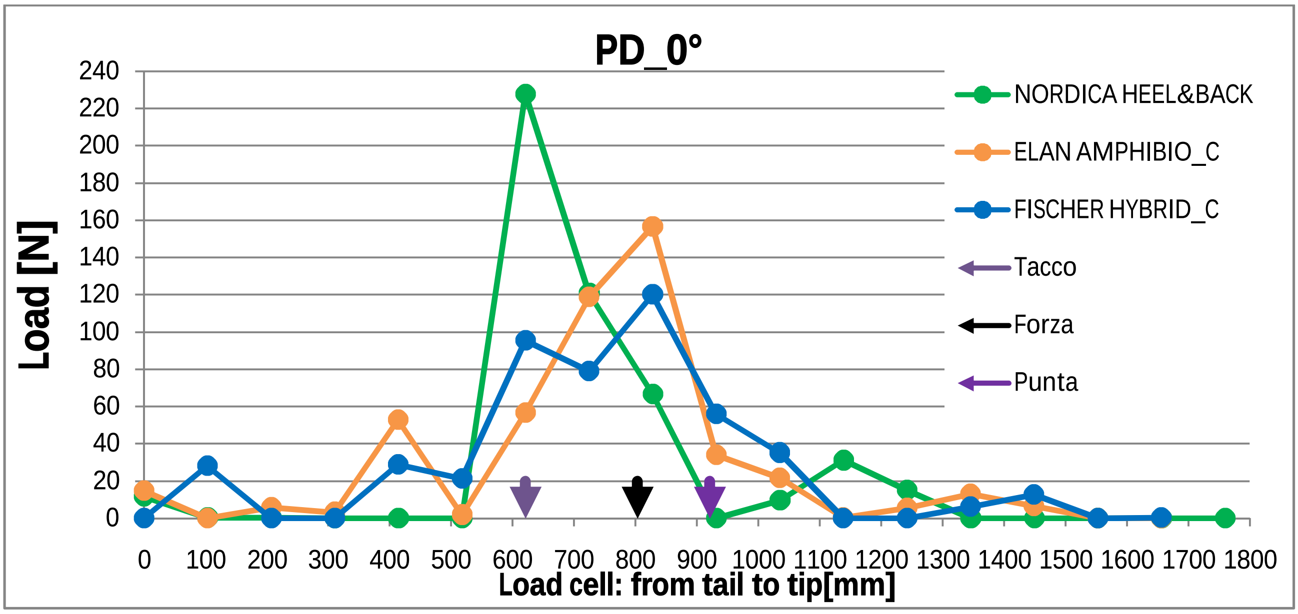


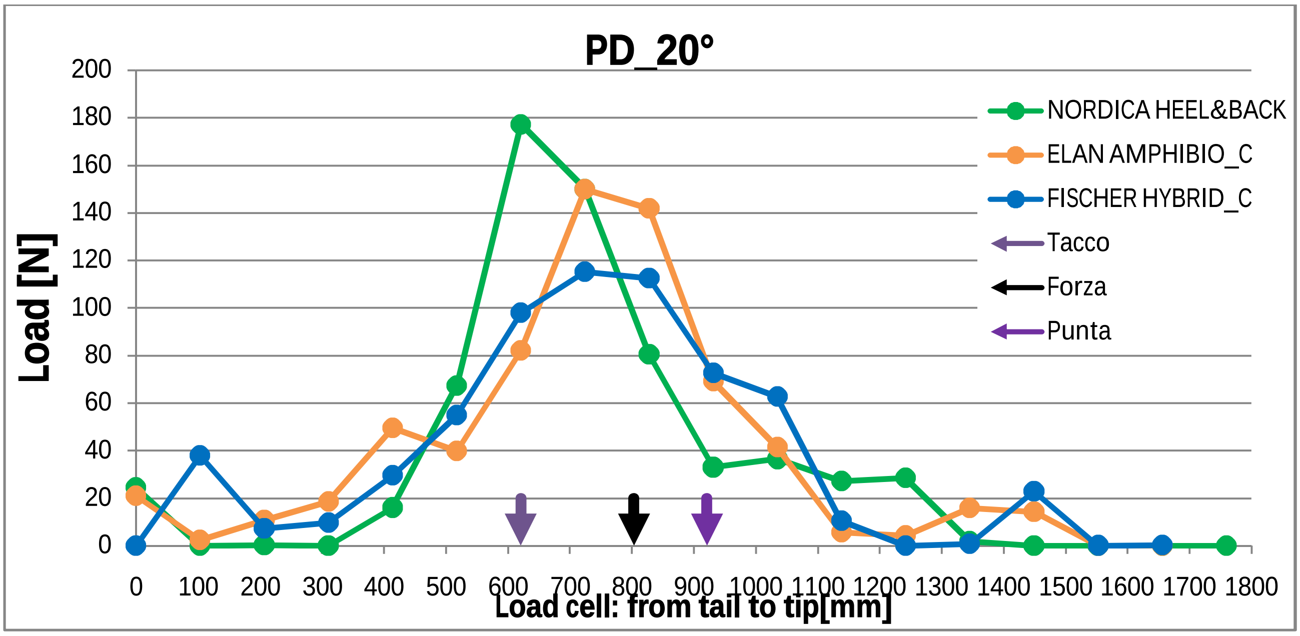


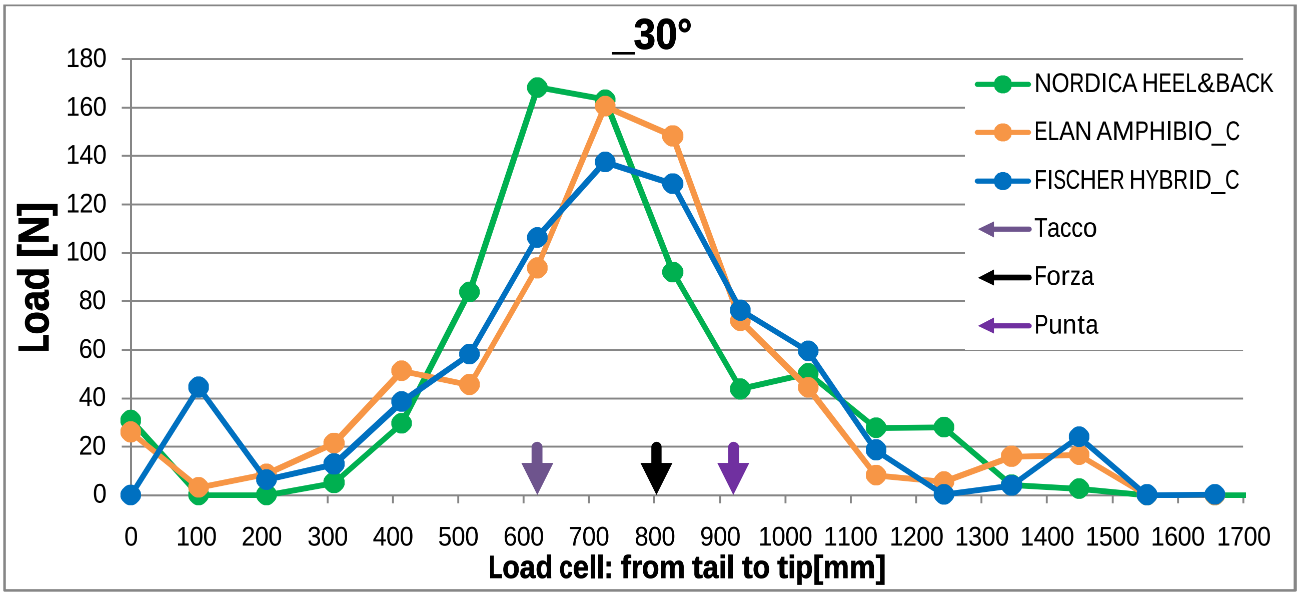
Progressive skies is very similar at a SL ski. There is always a peak on shovel, a valley near the peak. The only differences is given by Salomon Kart that have the peaks on tail and tip translated near the centre of the ski. EDT and Spitfire follow the same profile load, even if EDT has a higher line in central part and an extended valley on shovel.

3.4.2 ALL MOUNTAIN SKI

- NORDICA HEEL&BACK: Ski of Hell & Back family could run everywhere. Good for slope and wood sentence. It has a great flexibility on fresh snow and an incredible adaptability on slopes variations, thanks to an energetic and gradual elastic answer. Solid edge profile on hard snow. The rebound of ski is predictable. Ski is light and reduce strength on fresh or warm snow. The use of EVO plate gives a direct transmission of load at ski.
- ELAN AMPHIBIO: in this ski rocker and camber profile are combined. The construction with new technology Power Wood-core and the reinforce Fiberglass give flexibility and excellent load profile in every curve. The DST combines a straight edge in the internal side of ski, and a partial straight edge on the external one for an easier utilization. So in a curve the external ski has a great contact with snow (thanks to camber) and the internal ski has a reduction of contact with snow thanks to rocker mode.
- FISCHER HYBRID: A good choice for people who wants all in one. For the best of both worlds: Fischer Hybrid Technology transforms the ski with a click from a merciless runner pro into an Off runner-Pro for awesome turns in powder. This is made possible by an integrated rocker which can be switched on and off as required. The perfect addition: Soma Hybrid 12 Plus boots featuring HIKE/RIDE/LOCK system and additional On/Off runner mode. For skiers who do not want to be limited to choosing one route because of their skis.


PD_0°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800
Load cell: from tail to tip[mm]
NORDICA HEEL&BACK
ELAN AMPHIBIO_C
FISCHER HYBRID_C
Tacco
Forza
Punta


PD_20°
Load [N]
200
180
160
140
120
100
80
60
40
20
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800
Load cell: from tail to tip[mm]
NORDICA HEEL&BACK
ELAN AMPHIBIO_C
FISCHER HYBRID_C
Tacco
Forza
Punta

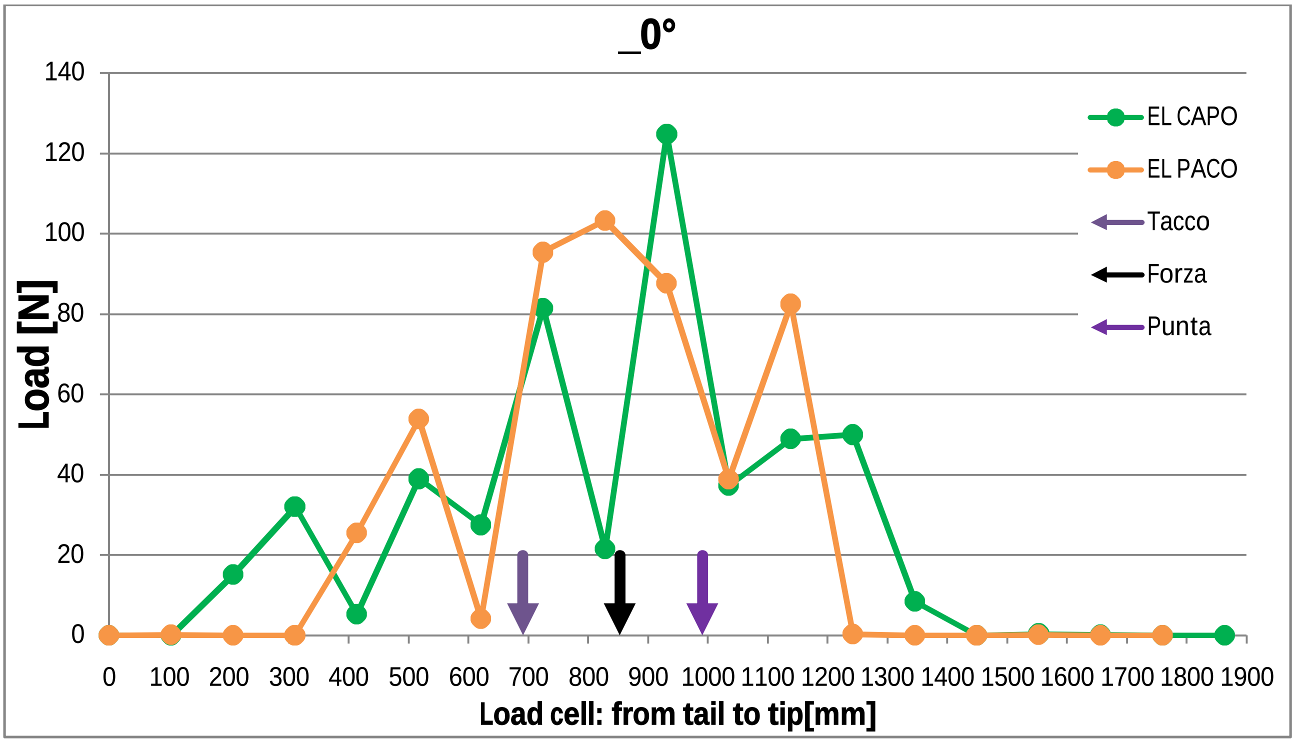

_30°
Load [N]
180
160
140
120
100
80
60
40
20
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700
Load cell: from tail to tip[mm]
NORDICA HEEL&BACK
ELAN AMPHIBIO_C
FISCHER HYBRID_C
Tacco
Forza
Punta

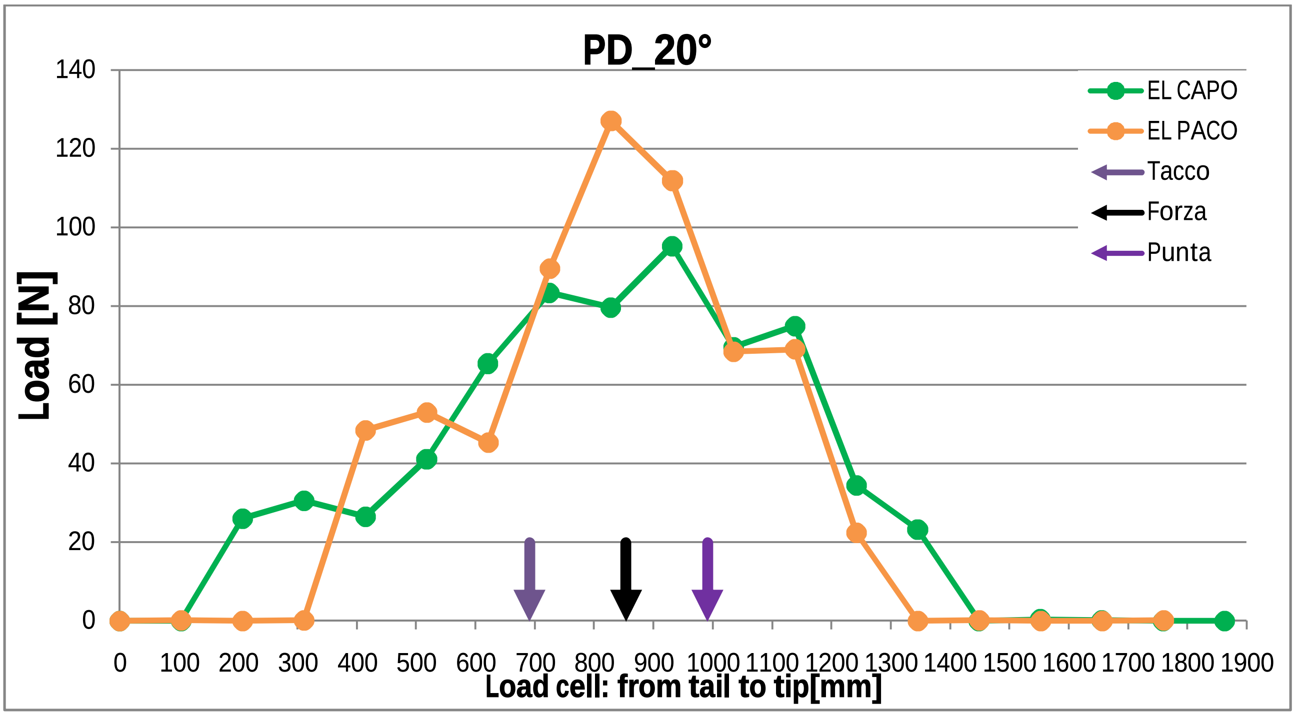
All mountain ski is adaptable at different typology of ground and styles. This diagrams is near at SL an GS family because Fischer hybrid has a tip peak similar at a SL ski, instead Elan Amphibio has an extended peak on all shovel length, like a GS ski. Nordica Heel&Back is a bit different from the other two because his soft structure on shovel and tail provides less value of edge load profile on his extreme part with the growing of the edge angle. This ski is clustered with the other two because the producers includes the ski on this family. It's interesting to note that tail profiles are similar for each ski, then only Fischer Hybrid shows a peak, the other a plateau.

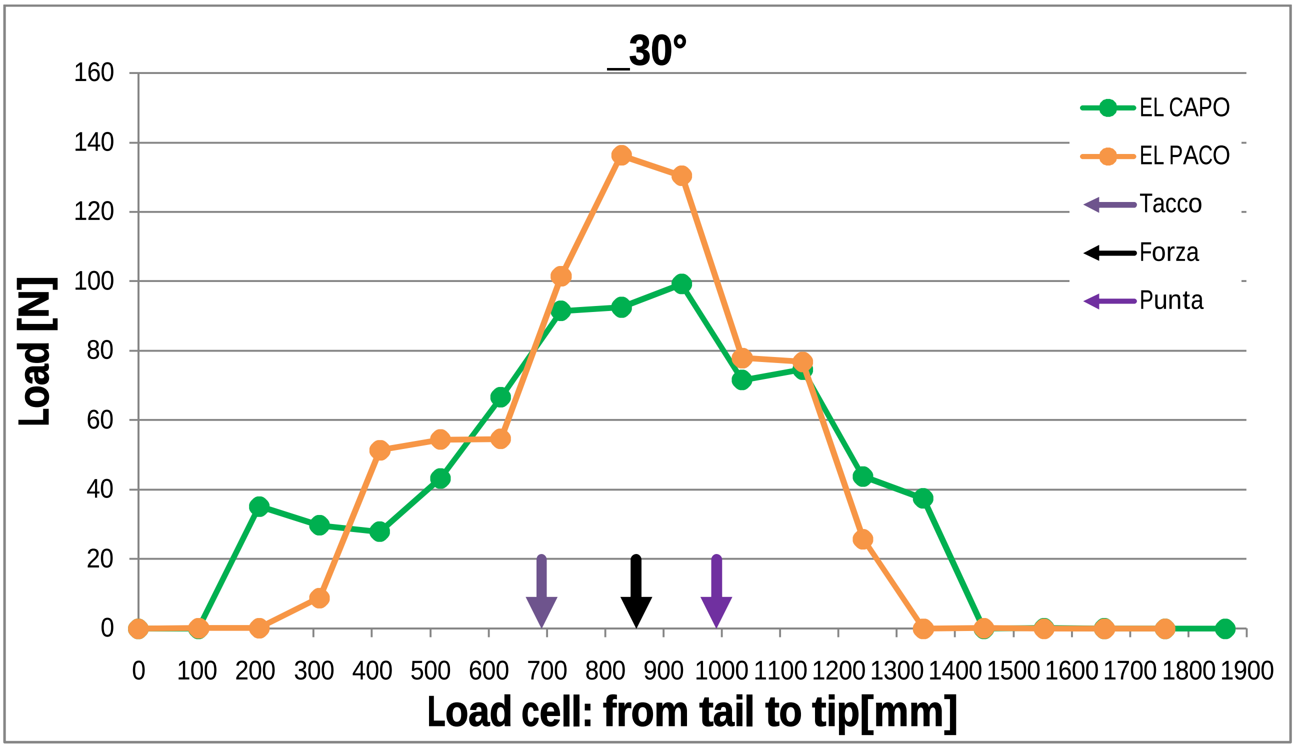
3.4.3 FREESKI

Freeski cluster is composed by freestyle and freeride family of ski. The first is projected with stiffness adapted at evolutions in parks giving the higher stability in landings on fresh snow. Then the ideal length of ski centre and wood aim provides durability, robustness and high performance.

- NORDICA ELPACO: very adapted for parks woods or on fresh snow.
- NORDICA EL CAPO: his ski centre at 107mm takes his versatility at an higher level. His smoothed tip permits to dominate each type of ground.







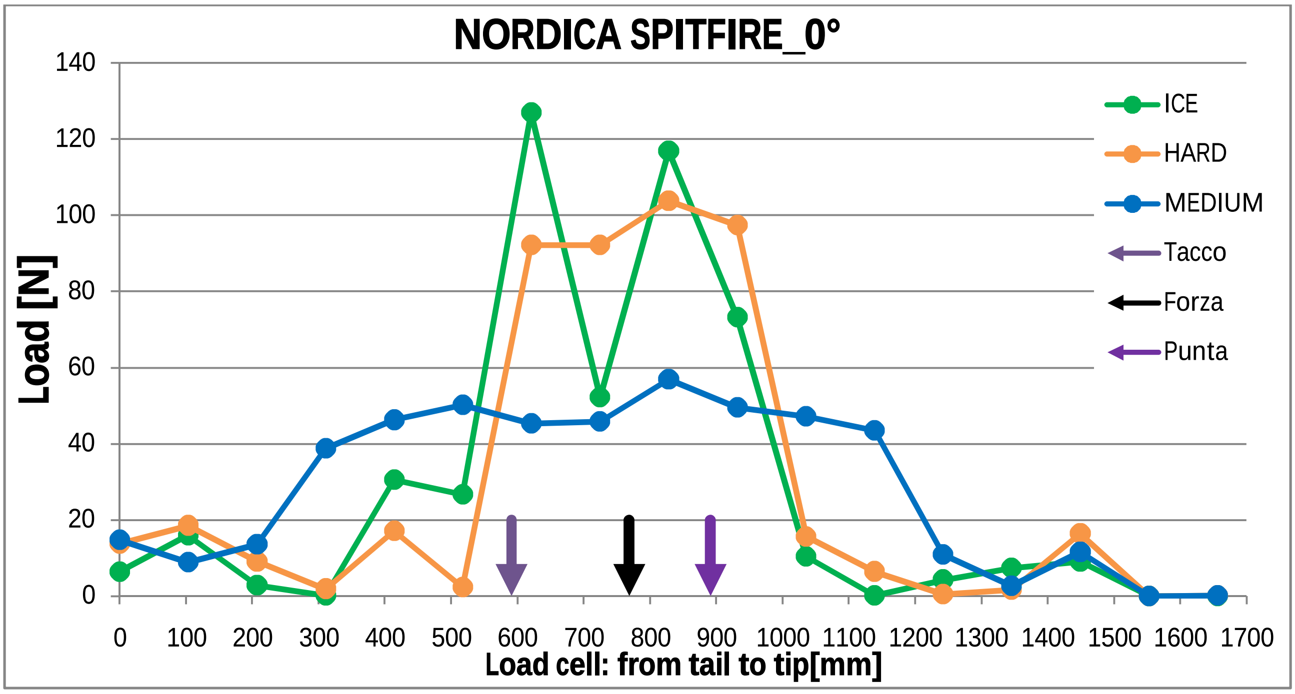
Nordica EL PACO is substantially concentrated on central part and provides a great peak in the centre of the ski, this because of very low stiffness of ski extremities. The description says that is very adapted for park, woods and fresh snow because and the diagrams shows that is good for this type of skiing. Load is concentrated in the centre, so the capability of turning of a skier is facilitated in the powder snow, but also on evolution because the moment of inertia is extremely reduced.

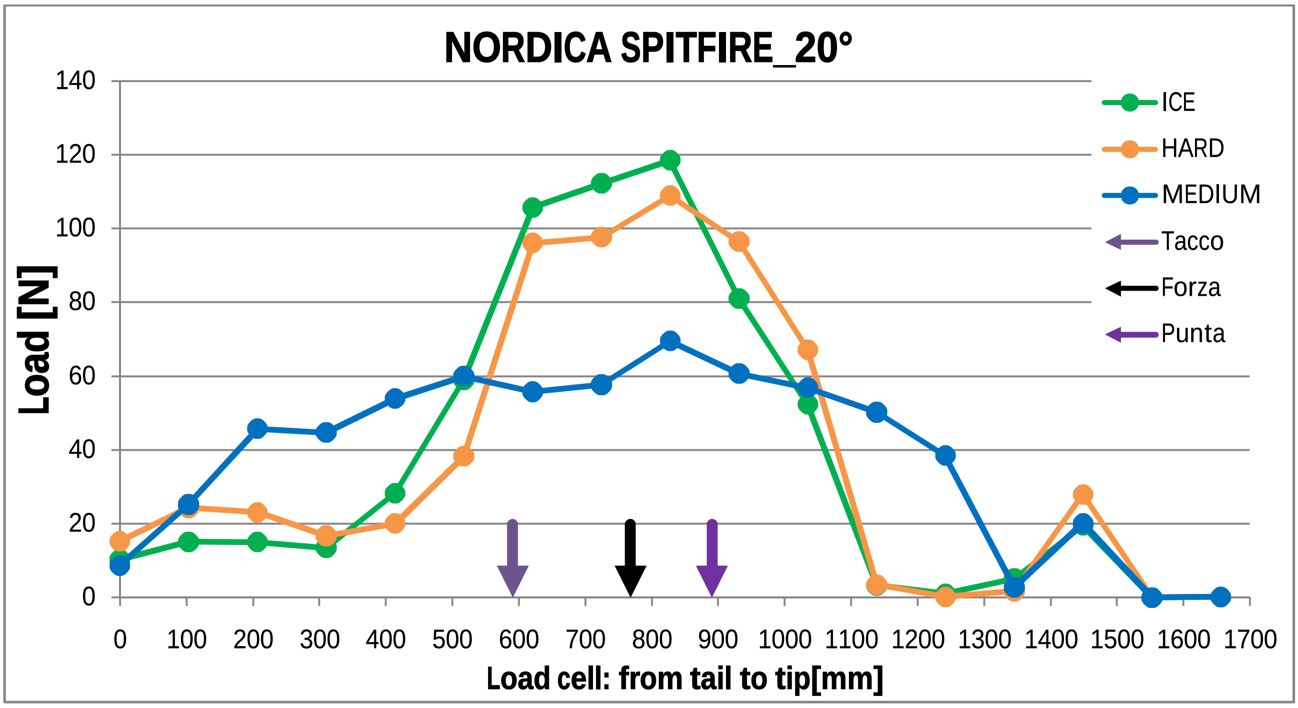
The substantial difference with EL CAPO is restricted on central peak, that is lower because the profile of load is a bit extended on tail, and it permits the ski to be used in different type of snow and slopes.

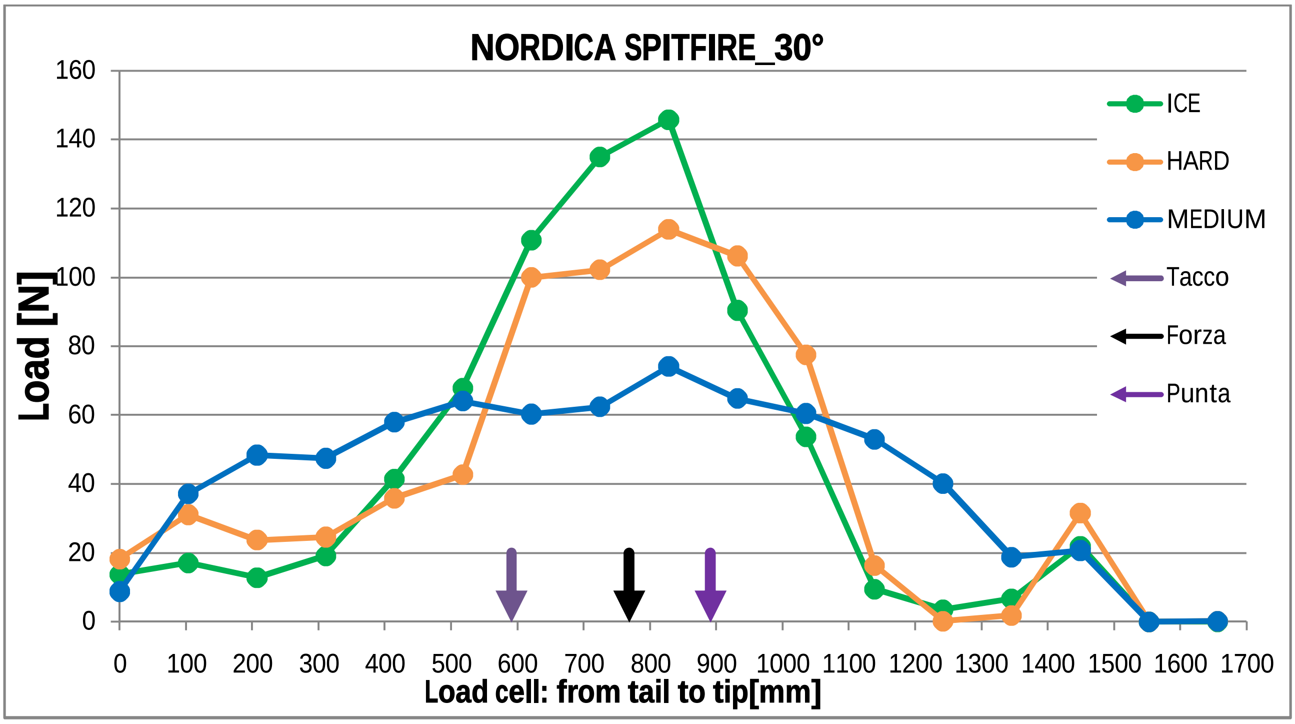
3.5 TYPE OF SNOW COMPARISON

Slytech bench has the possibility to change the ground stiffness, and so to try the ski on different typology of snow hardness. The previous tests were done in ICE configuration: all screws closed and load is released directly at the load cell. Now two type of snow were created: the first with screws closed only of 17mm and it was called HARD SNOW, the second with all screws open, and called MEDIUM snow. In these two configuration the load cells are influenced by the presence of the springs and they will provides lesser value of load with respect the harder configuration. Ski analyzed in this configuration are the follow six and it's reported three diagrams for each one:

3.5.1 Nordica Spitfire

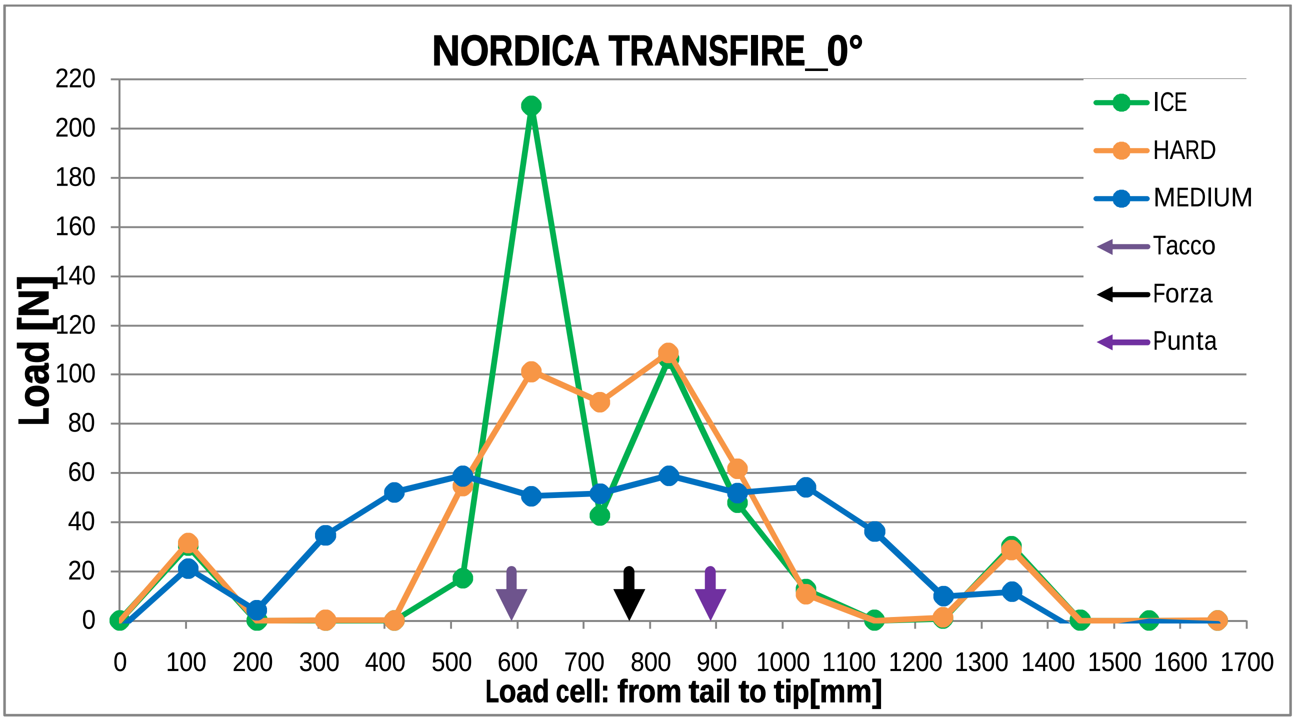


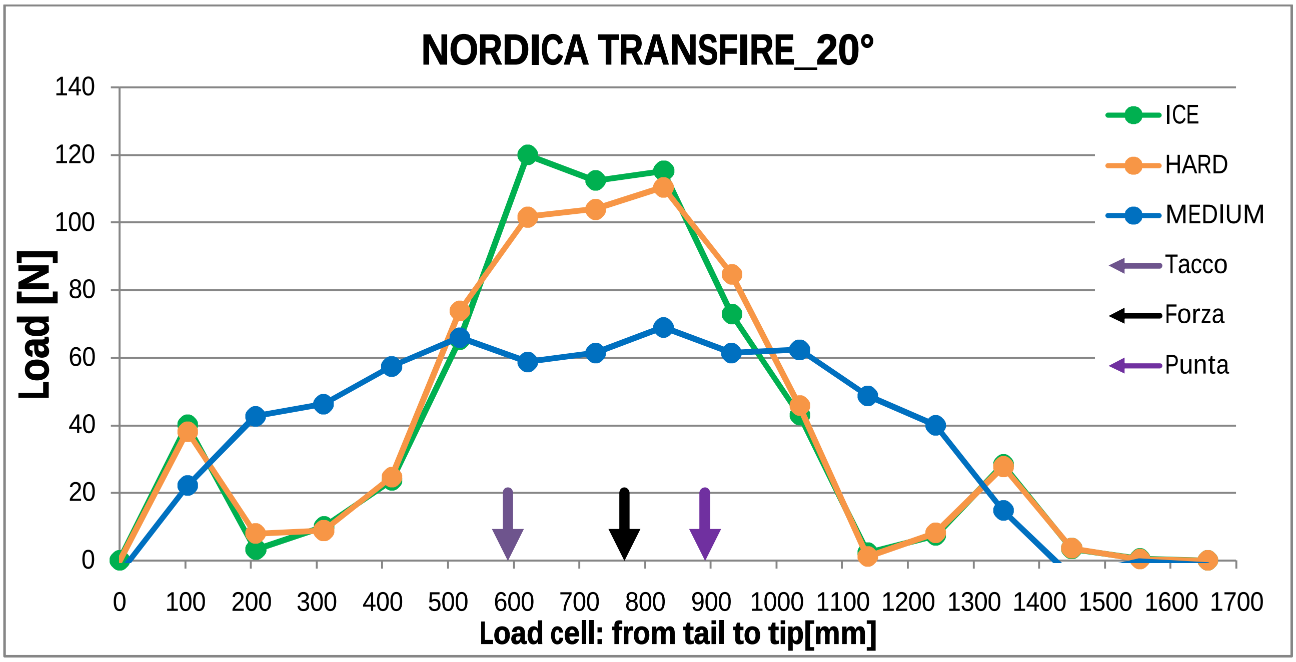


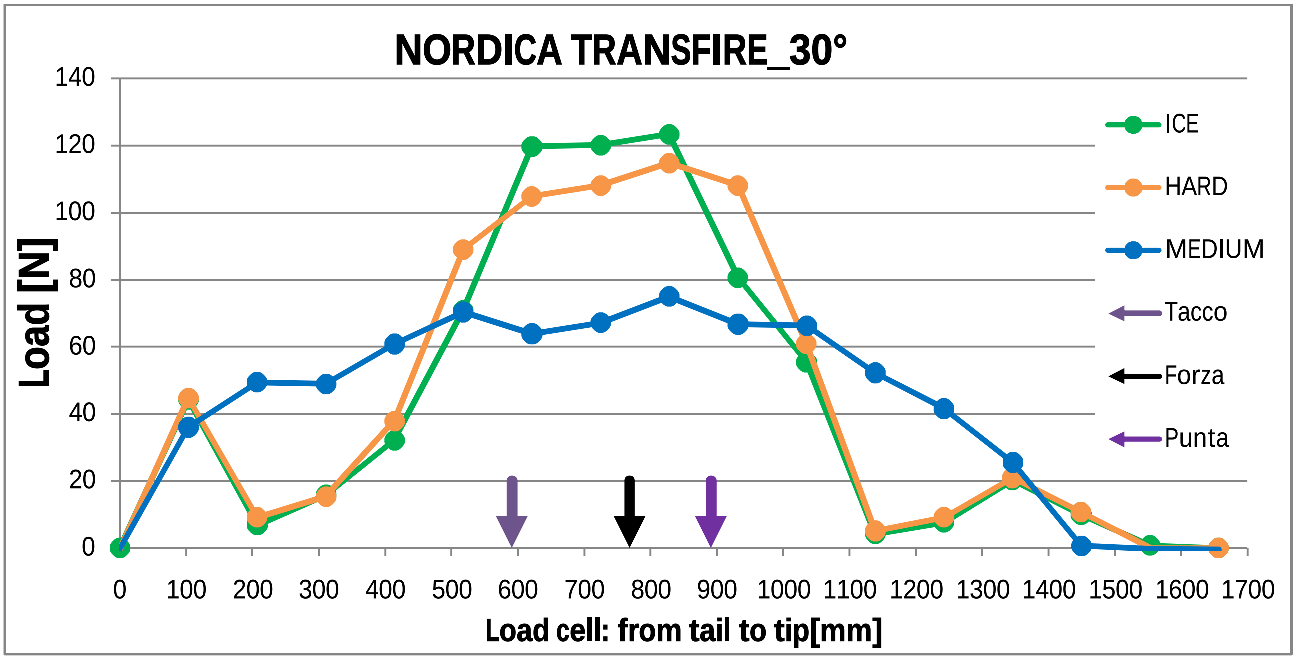


Hard configuration of snow with respect of ice configuration provides a decreasing of the central peak and an increasing of the peaks of tip and tail. Spitfire maintain the tip peak for each type of snow. In the medium stiffness of snow there is a flatten profile for this ski very similar at a rigidity EJ diagrams obtained in Nordica Flex bench.

3.5.2 Nordica Transfire

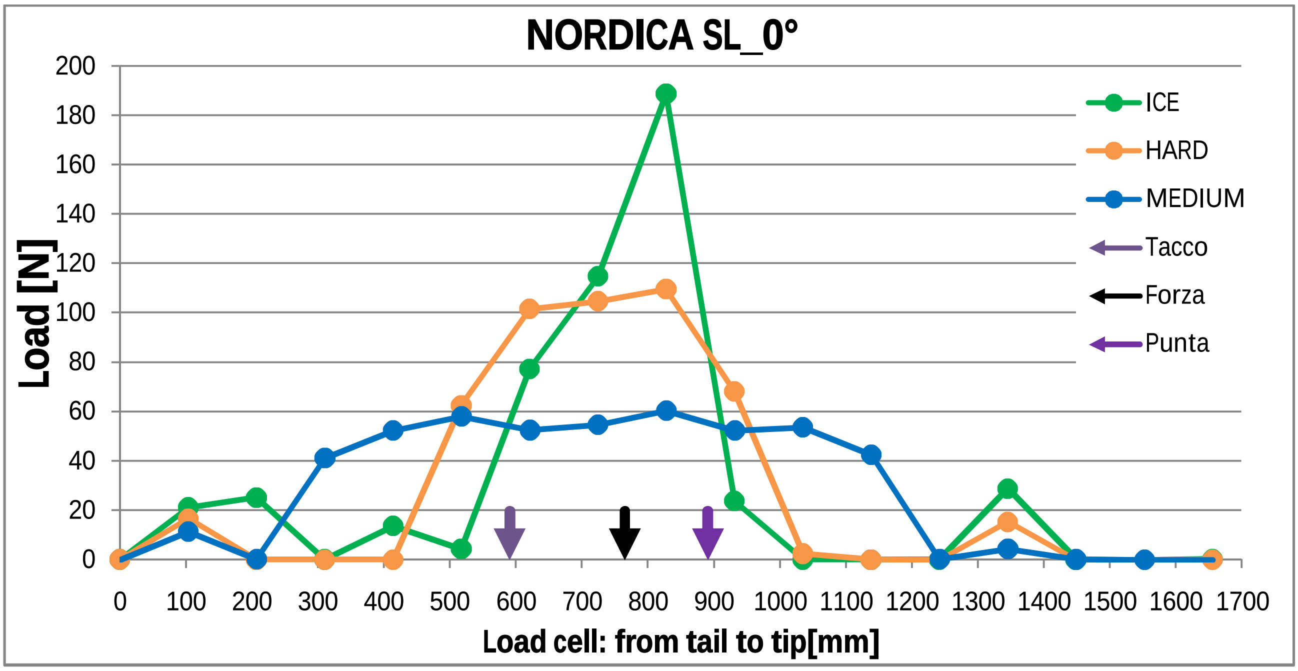


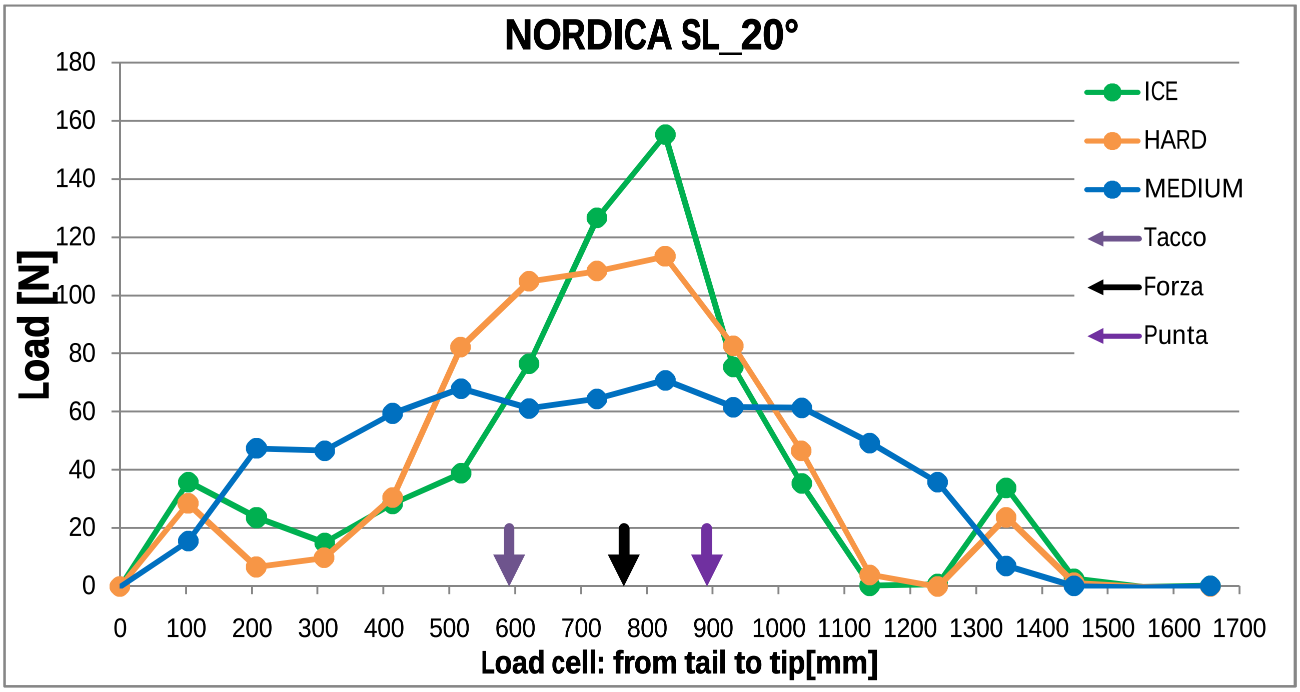


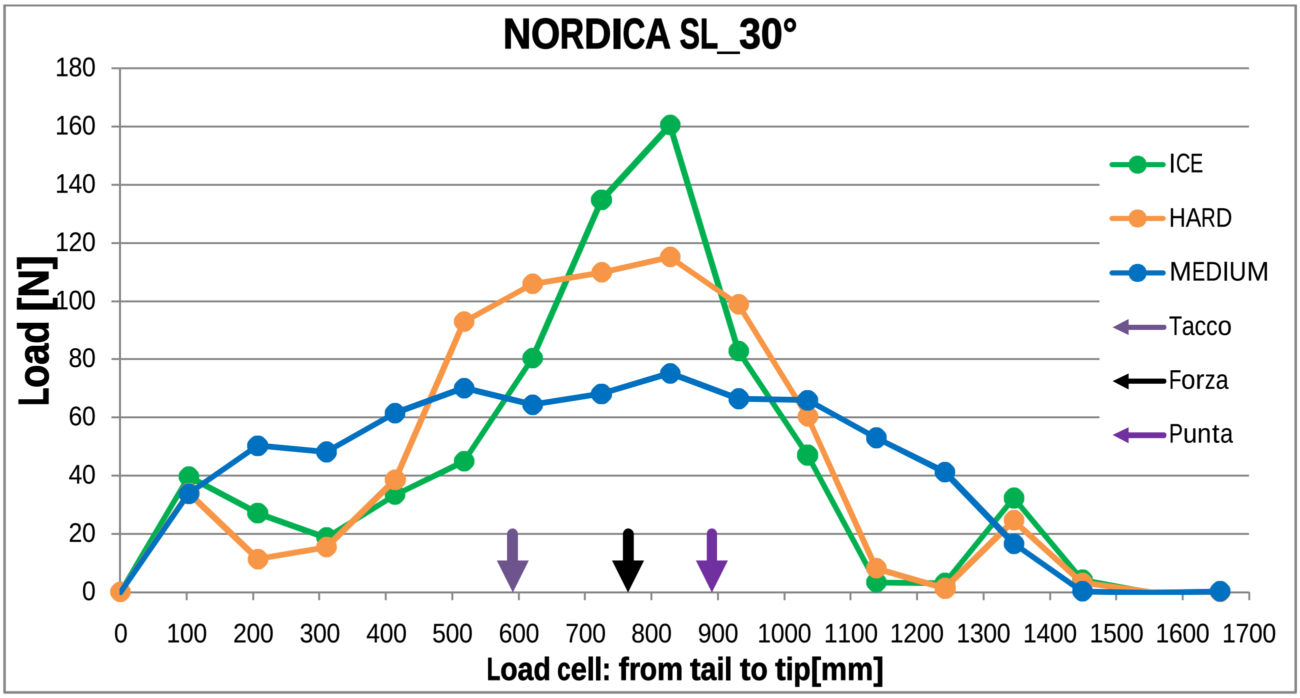


Transfire with respect of Spitfire maintain the profile in ice and hard configuration of snow, also peaks on tip and tail have the same value. The third configuration, gives a parabolic profile of the ski and the point of valley in harder configuration became higher than the previous peak. So peaks in harder configuration are the lower extreme value of the parabolic profile in medium stiffness of snow.

3.5.3 Nordica SLR

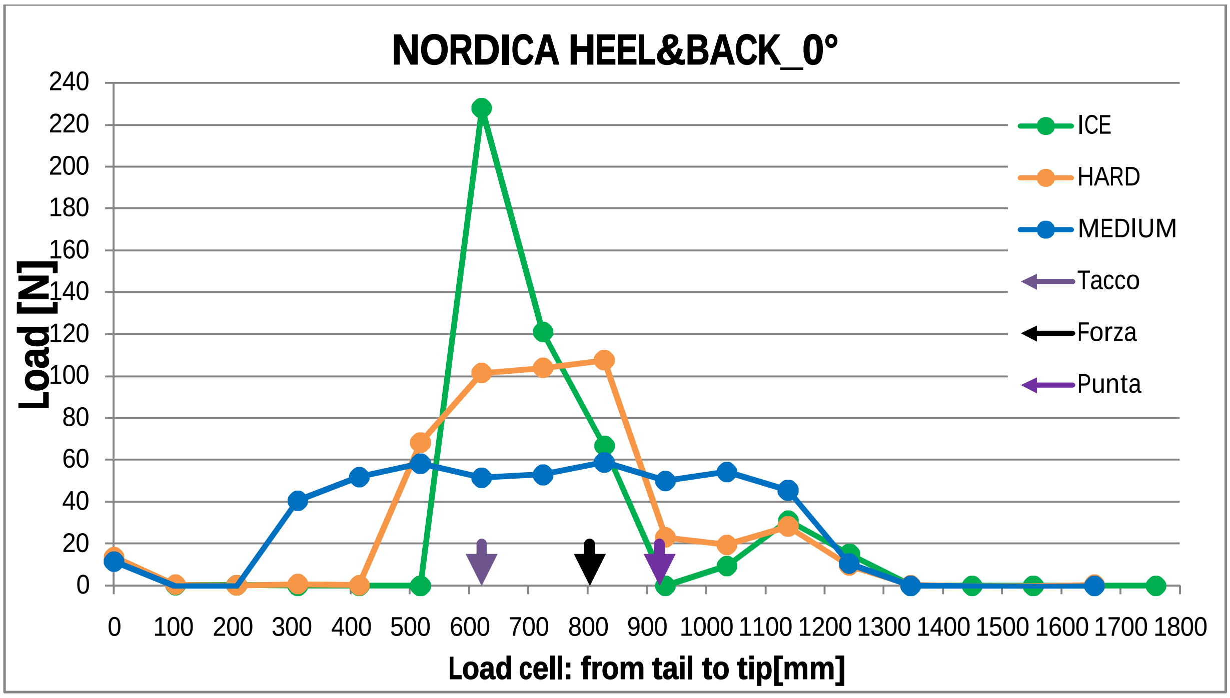


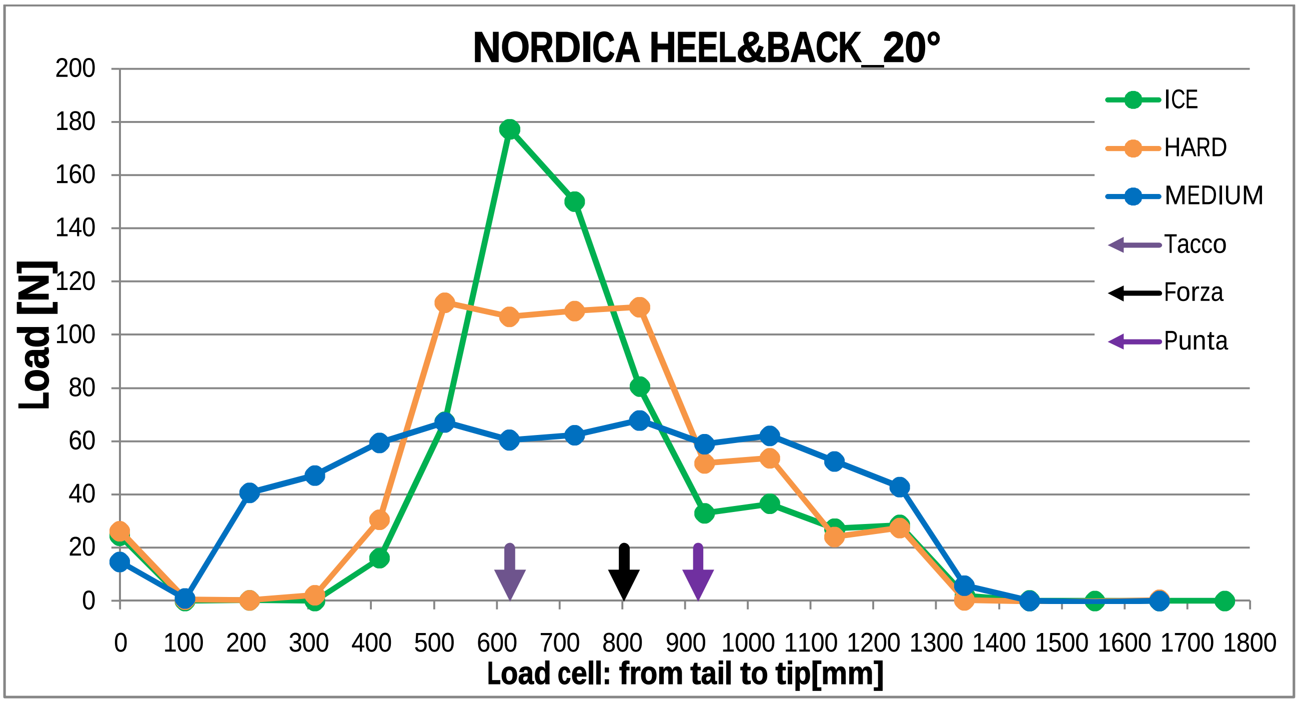


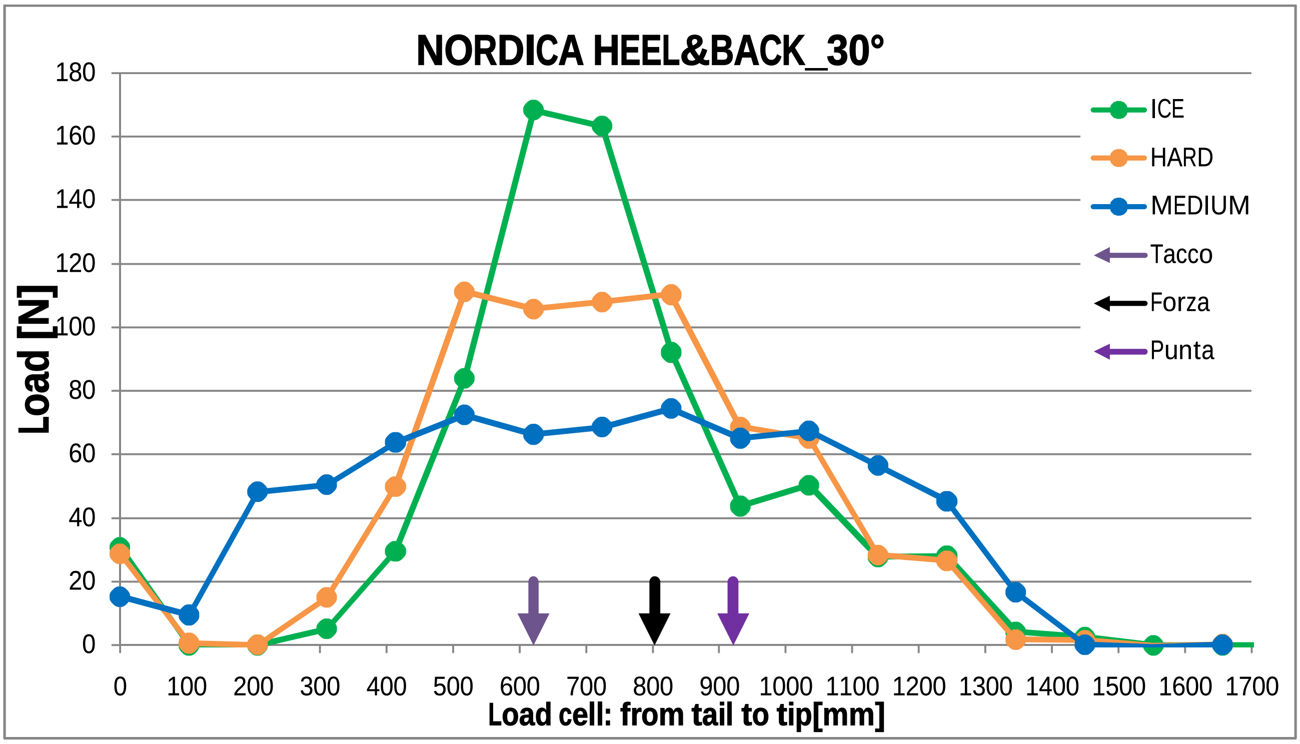


This ski, like the precedent Spitfire maintains the peaks on shovel and tail and a decrease of central peak from ice to hard snow. The behavior of ski is the same for ice and hard snow. In medium snow stiffness the profile change and become linear in the central part until the extremes.

3.5.4 Nordica Heel&Back

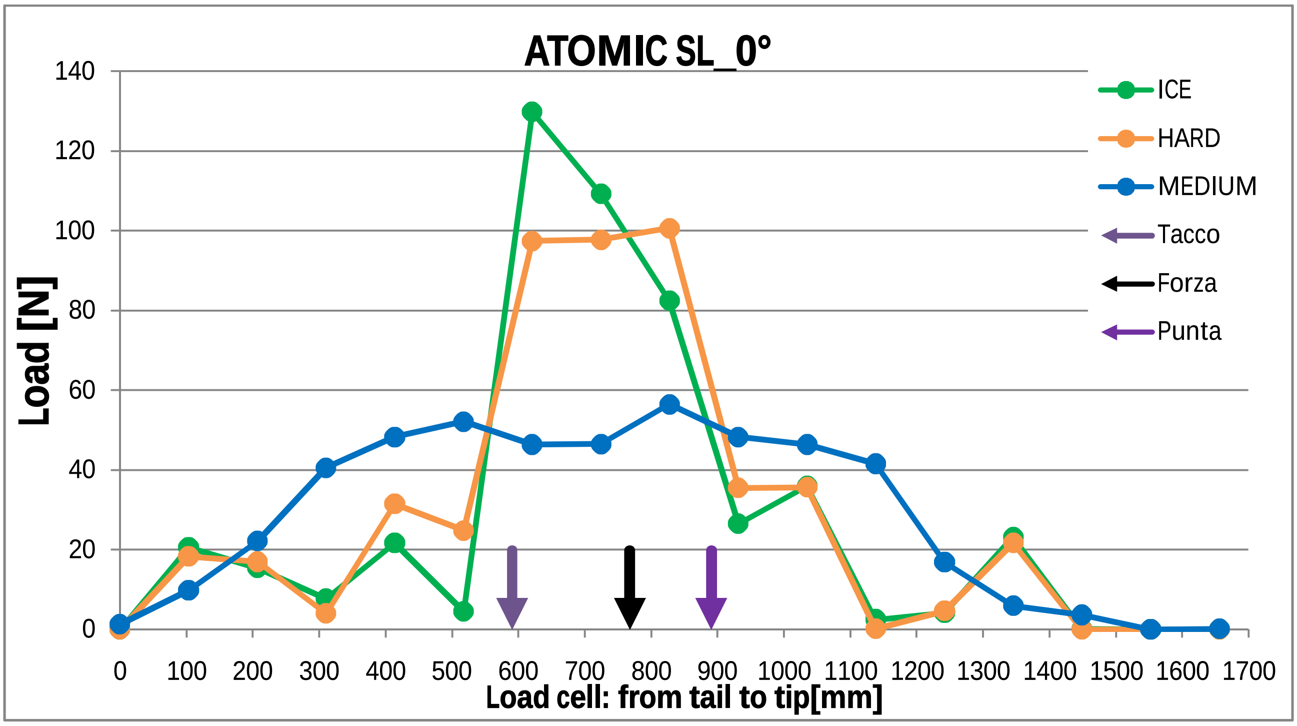


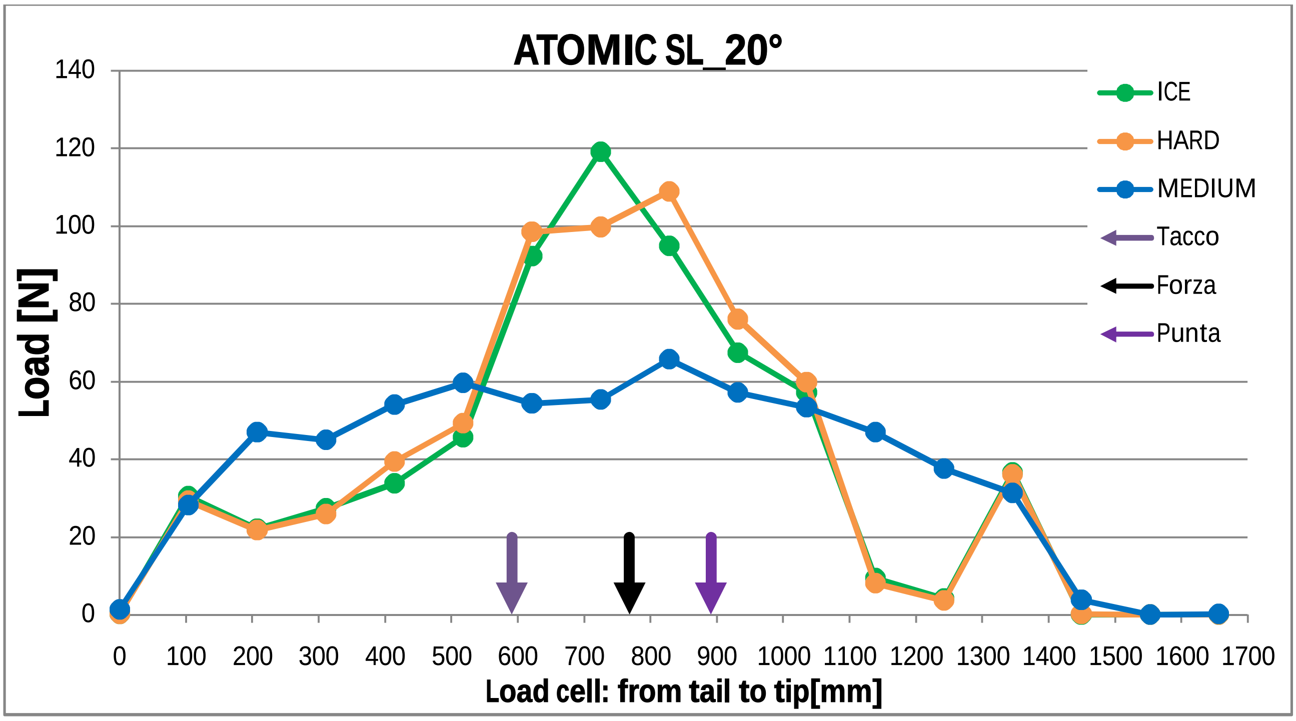


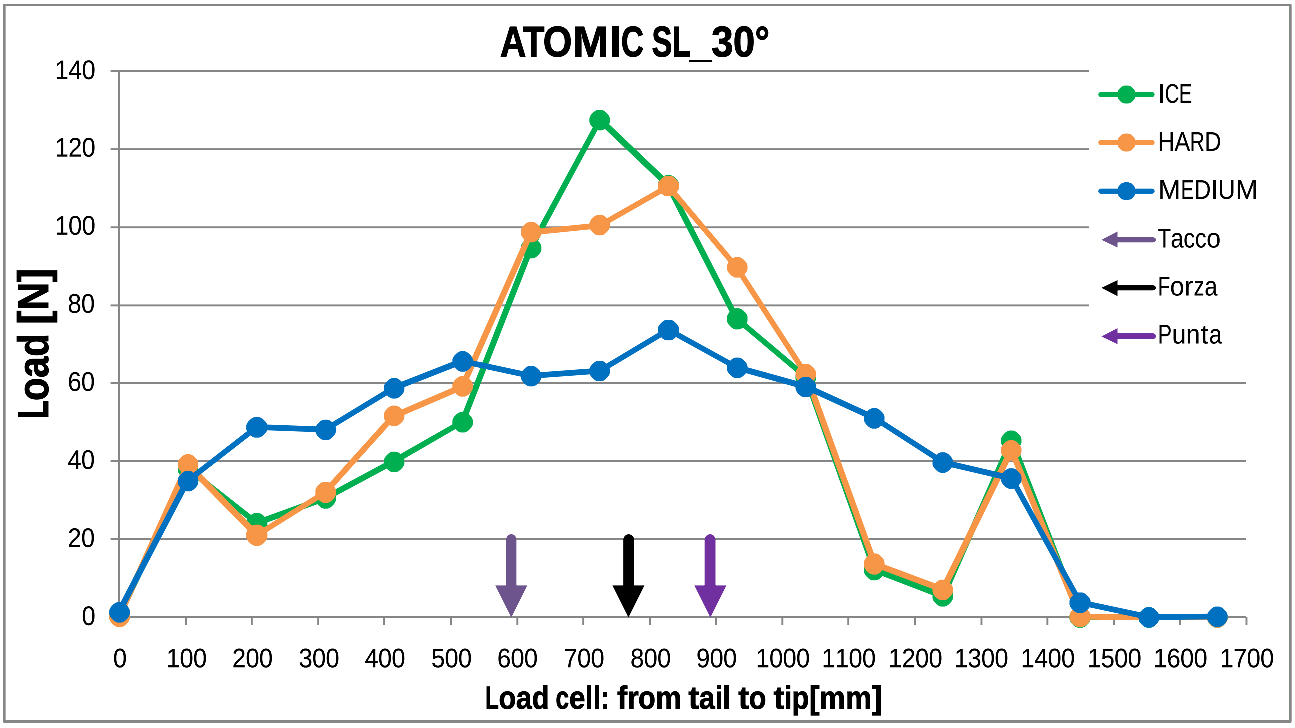


This ski adapted for softer type of snow provides for each angle the same profile curves with for each type of snow. Hard and medium is very similar in the central part, but in medium configuration of stiffness, there is a better filling of load profile. The soft structure of the extremities of this ski is confirmed in this diagrams. In an ice configuration the only difference with respect of the hard is the growing of the central peak. This ski is very adaptable for different surface and values of load don't decreased so much increasing the edging angle.

3.5.5 Atomic D2SL

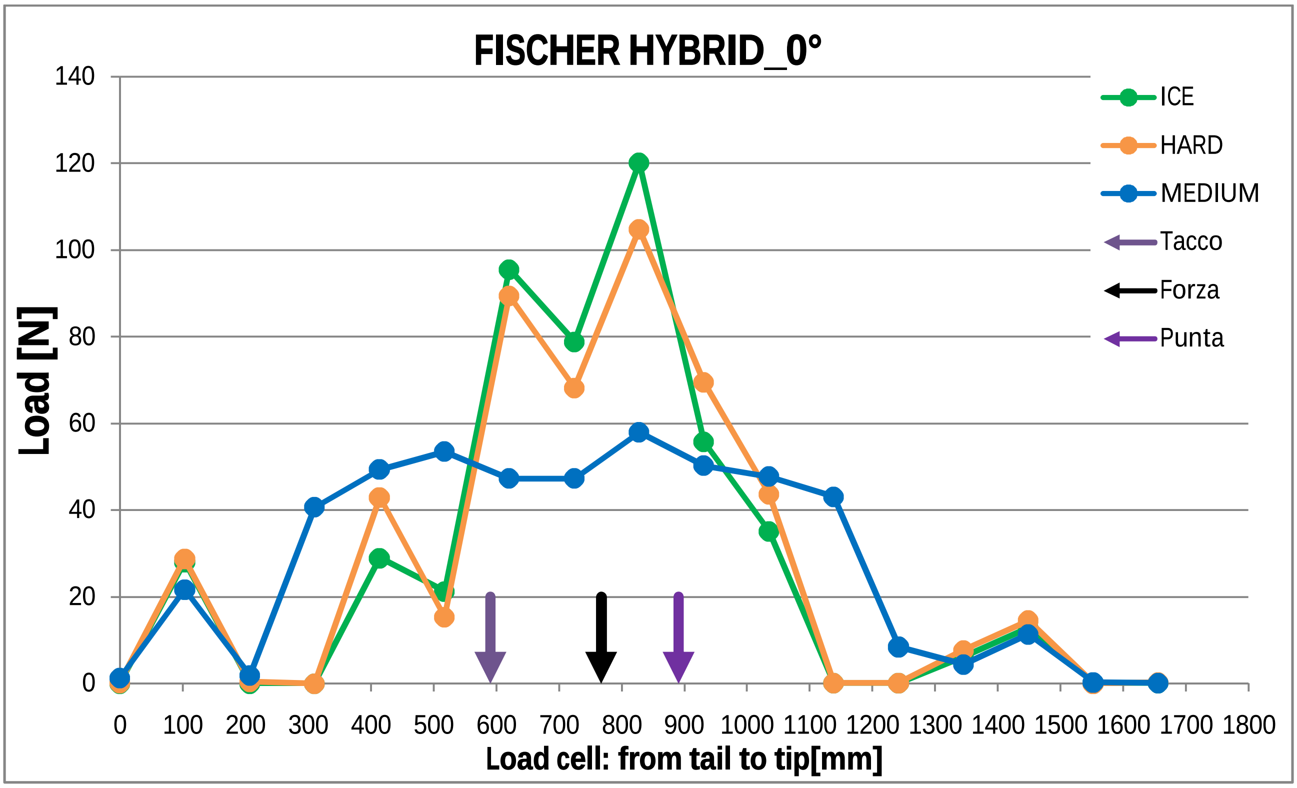


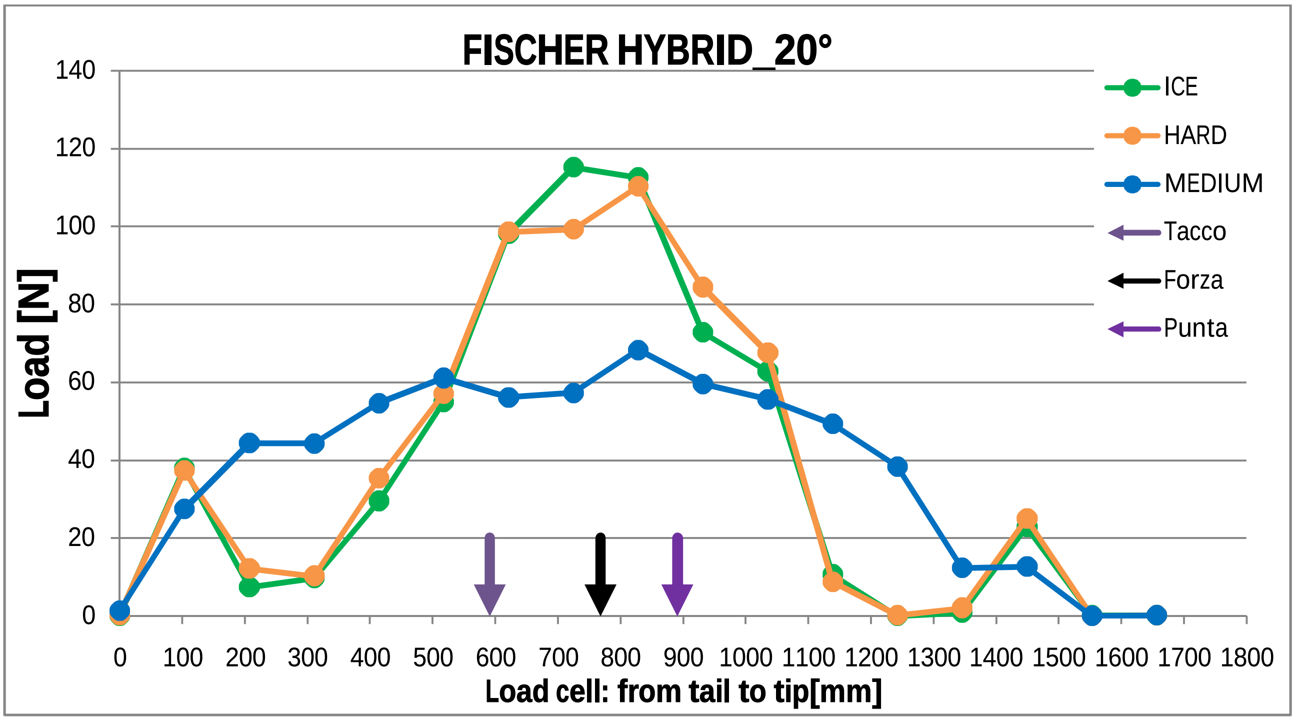


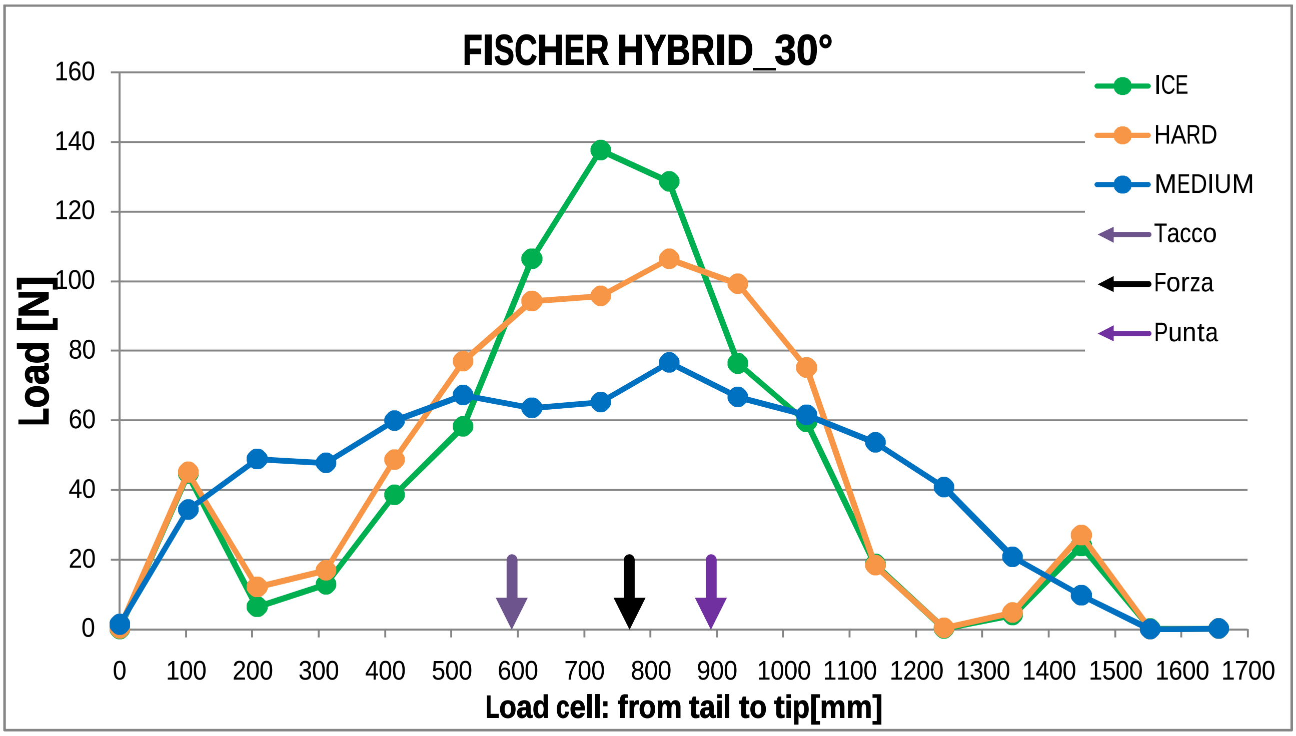


Slalom style of this Atomic SL is comparable with Nordica Spitfire or Nordica SL ski. The presence of shovel and tail peak due to sidecut of the ski and a valley in front of the binding is the classic profile of a slalom ski. In medium configuration of snow nothing change with respect of the other ski tested: the profile became constant in the central part and linear near the extremities.

3.5.6 Fischer Hybrid 7.5







Like the previous ski, Fischer Hybrid shows his aim of SL ski adapted for an all mountain use. The peak on shovel is maintained for each angle and also the behavior of curves is the same for each snow stiffness. there are no great differences against the other ski when snow became softer and peaks decreased for giving a parabolic profile at the curves.

3.6 SLYTECH BENCH TESTS (bending moment and torsion)

3.6.1 Spitfire in original configuration

It's reported the medium value given by the strain gauges and an equivalent value of the force applied by the actuator. Results table:

degree	Tip degree	[kg]	Shovel [mV]	Torque [mV]
0°	0°	50,16	0,245	0
10°	8,2°	60,53	0,304	0,582
20°	17,8°	69,5	0,405	0,59
30°	28,7°	83,79	0,496	0,605
40°	39°	100,32	0,630	0,631
50°	49°	119,66	0,769	0,67
60°	58,9°	139,55	1,028	0,732

3.6.2 Spitfire coupled with wood arm

It's reported the medium value given by the strain gauges and an equivalent value of the force applied by the actuator. Results table:

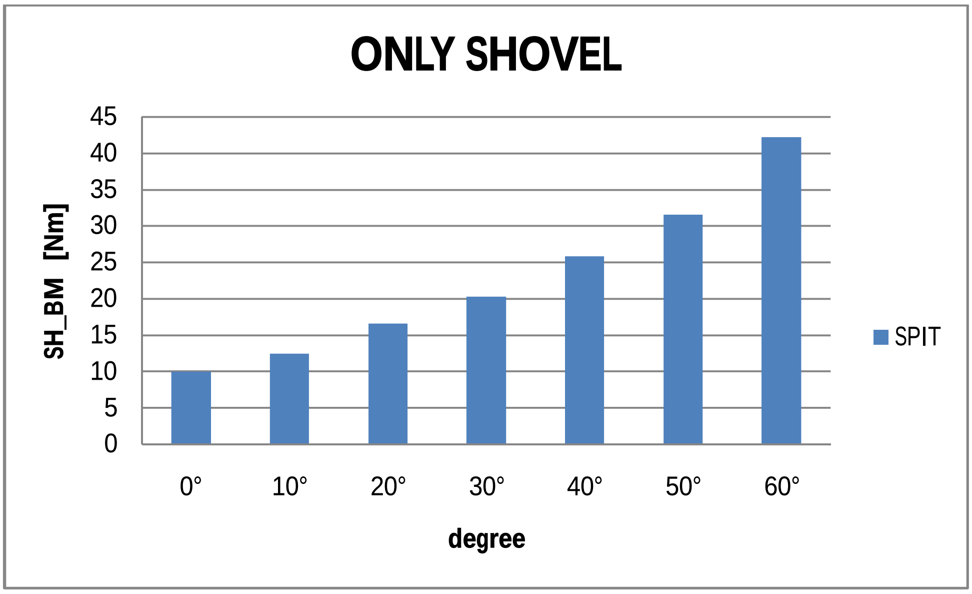
degree	Tip degree	[kg]	wood [mV]	sh+wood [mV]	Torque wood [mV]	Torque sh+w [mV]
0°	0°	50,16	0,298	0,298	0	0
10°	7,7°	60,53	0,325	0,323	0,006	0,0003
20°	17,5°	69,5	0,392	0,386	0,033	0,001
30°	27,2°	83,79	0,457	0,459	0,049	0,003
40°	36,4°	100,32	0,540	0,536	0,05	0,082
50°	46,9°	119,66	0,643	0,659	0,063	0,065
60°	57,1°	139,55	0,821	0,863	0,075	0,146

Fig. 59: Use of inclinometer for shovel torsion

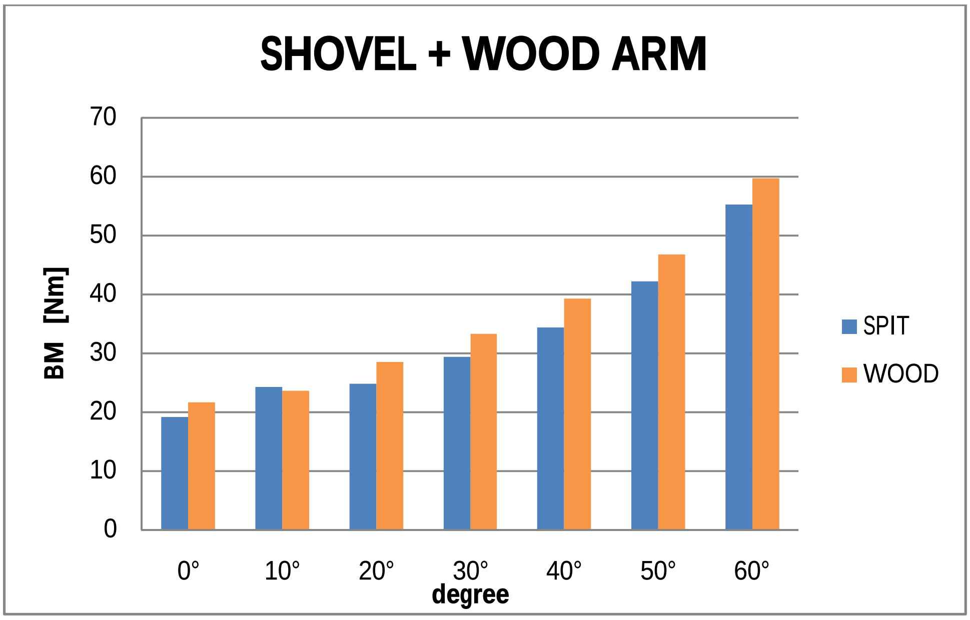
3.7 BENDING MOMENT FROM STRAIN GAUGES ON SLYTECH BENCH

Once the previous calibration constants are known, it's possible to analyze the data given by the tests on experiences from Slytech bench. The ski is inclined from 0 to 60 degrees in step of 10°. For all the analysis it's assumed the shovel as a fixed beam. The bond is assumed on the section where there are the screws who connect arm to ski. The following histograms show the bending moment given by the unbalance of the Wheatstone bridges.

- SPITFIRE 168



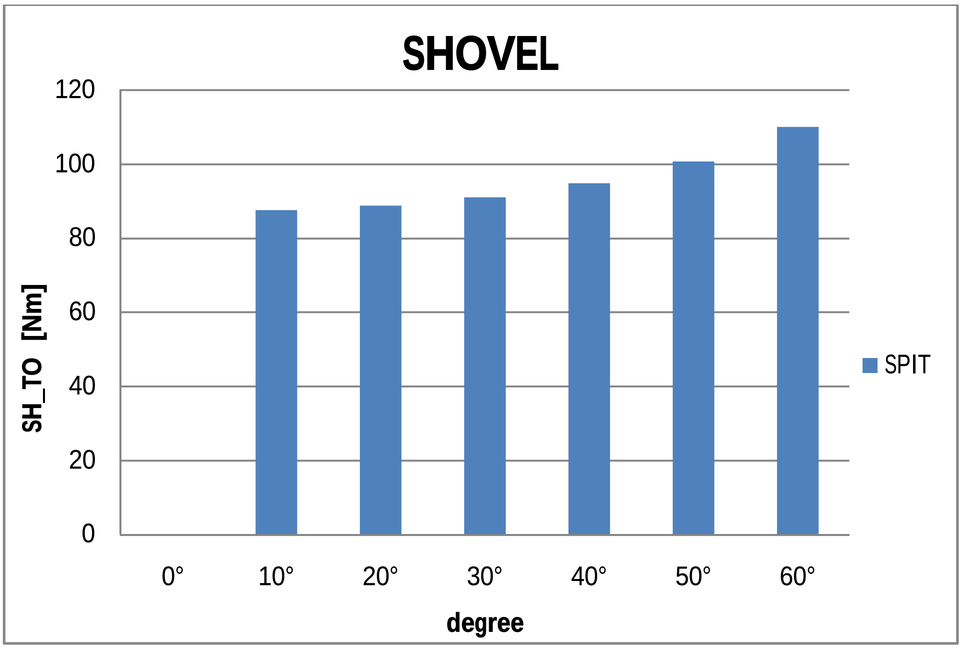
- SPIT + WOOD



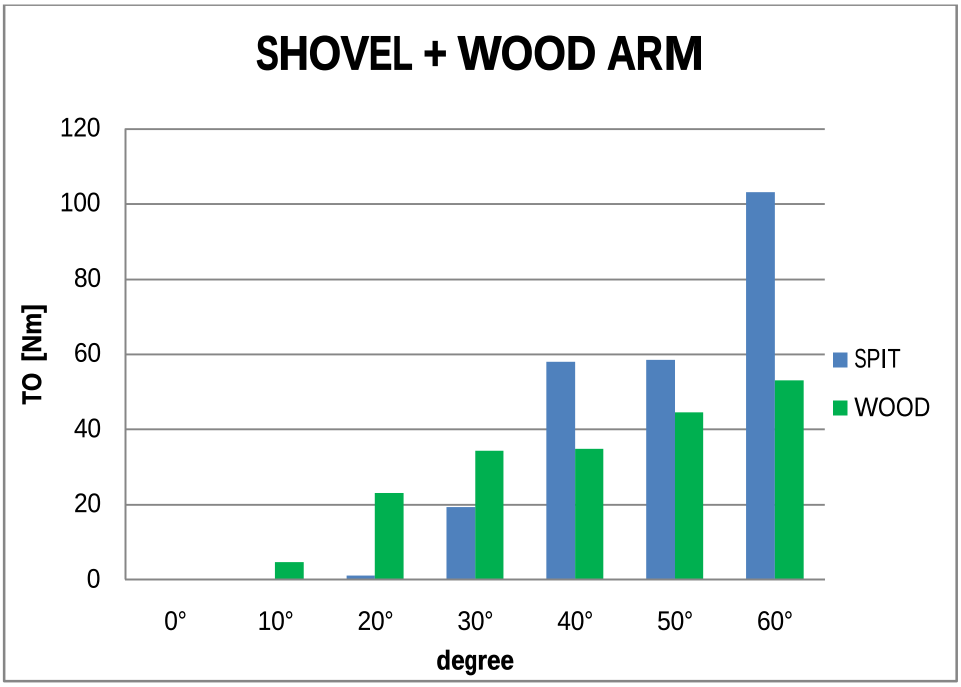
3.8 TORQUE FROM STRAIN GAUGES ON SLYTECH BENCH

The following histograms show the torque given by the unbalance of the Wheatstone bridges.

- SPITFIRE 168



- SPIT + WOOD

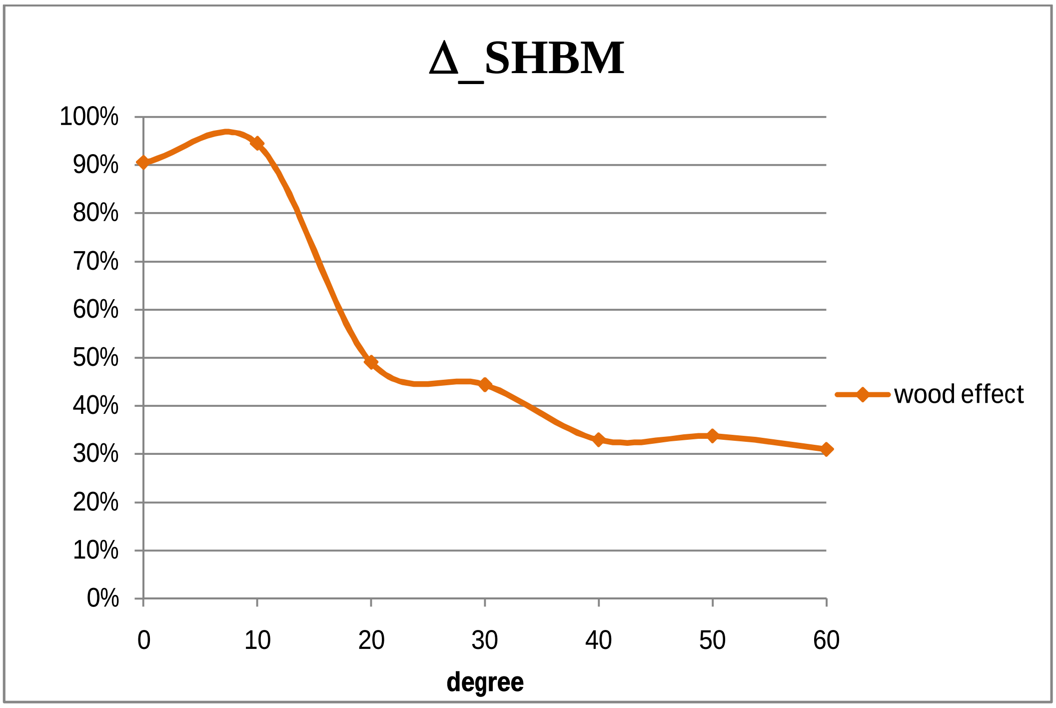


3.9 DIFFERENCES OF BENDING MOMENT ON SHOVEL WITH AND WITHOUT WOOD ARM

Resume table:

	sh [Nm]	sh+w [Nm]	Δ%
0°	10,032	19,116	90,6%
10°	12,486	24,278	94,4%
20°	16,596	24,736	49,0%
30°	20,334	29,367	44,4%
40°	25,820	34,335	33,0%
50°	31,537	42,187	33,8%
60°	42,173	55,252	31,0%

Resume plot:

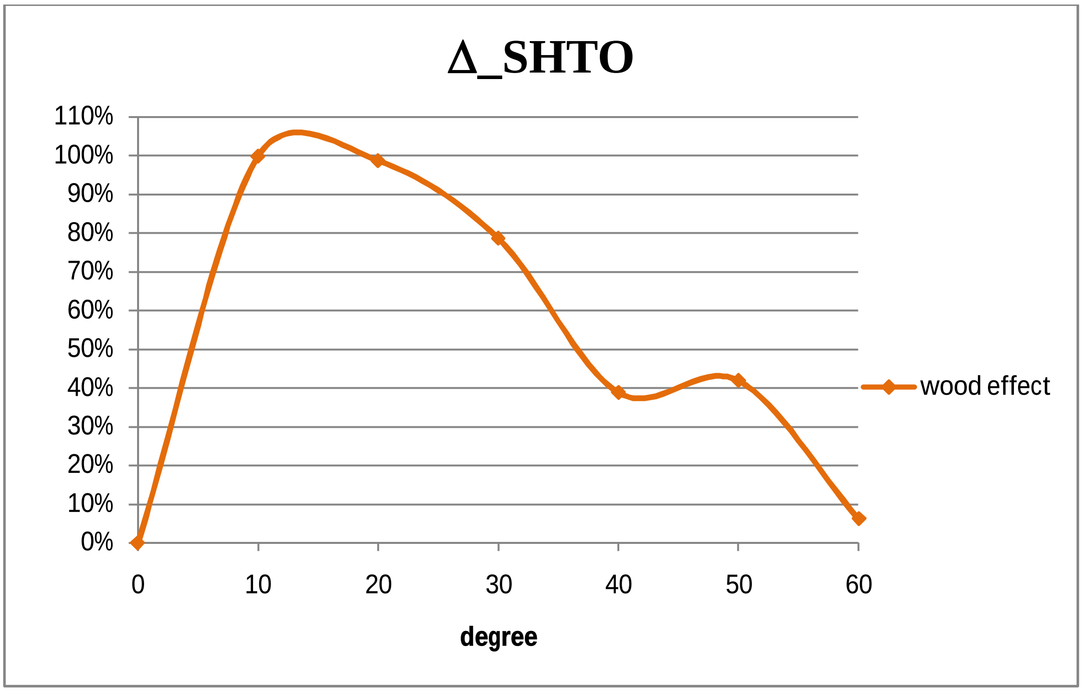


3.10 DIFFERENCES OF TORQUE ON SHOVEL WITH AND WITHOUT WOOD ARM

Resume table:

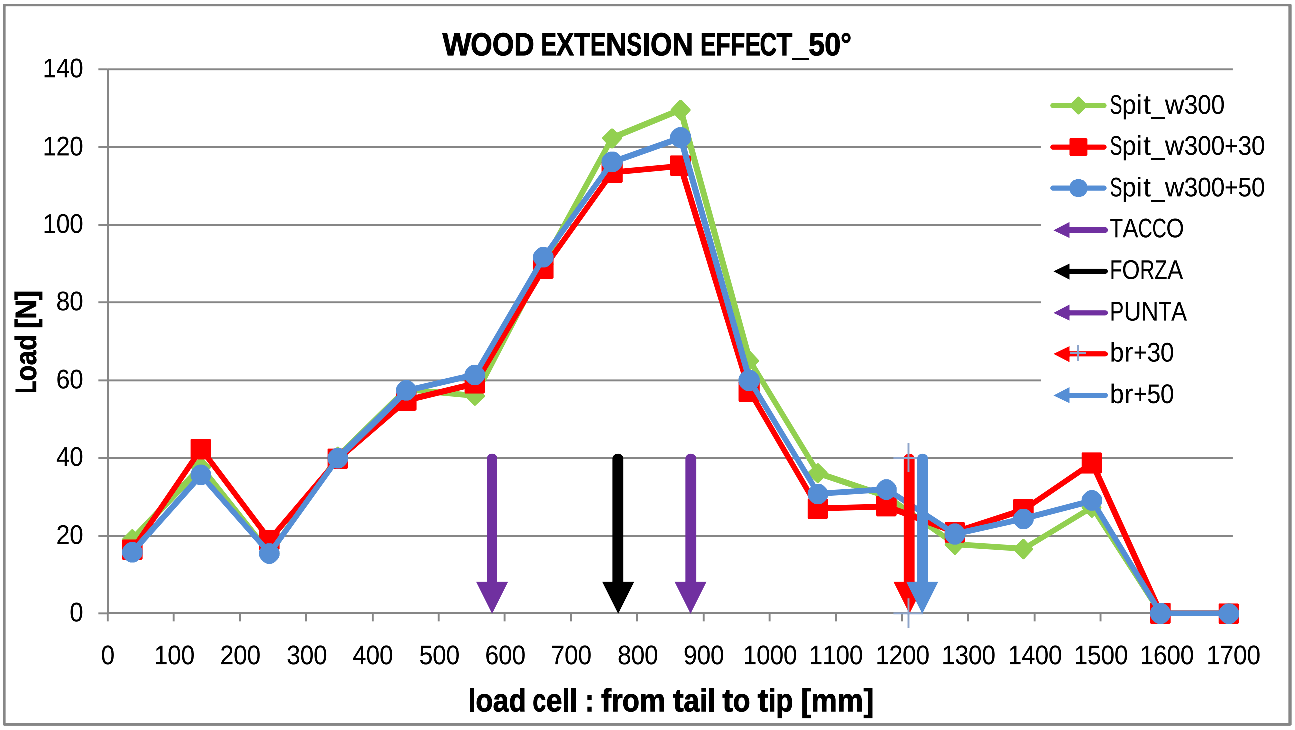
	sh [Nm]	sh+w [Nm]	Δ%
0°	0,000	0,000	0,0%
10°	87,601	0,186	99,8%
20°	88,838	1,202	98,6%
30°	91,056	19,445	78,6%
40°	94,911	58,064	38,8%
50°	100,840	58,595	41,9%
60°	110,059	103,168	6,3%

Resume plot:

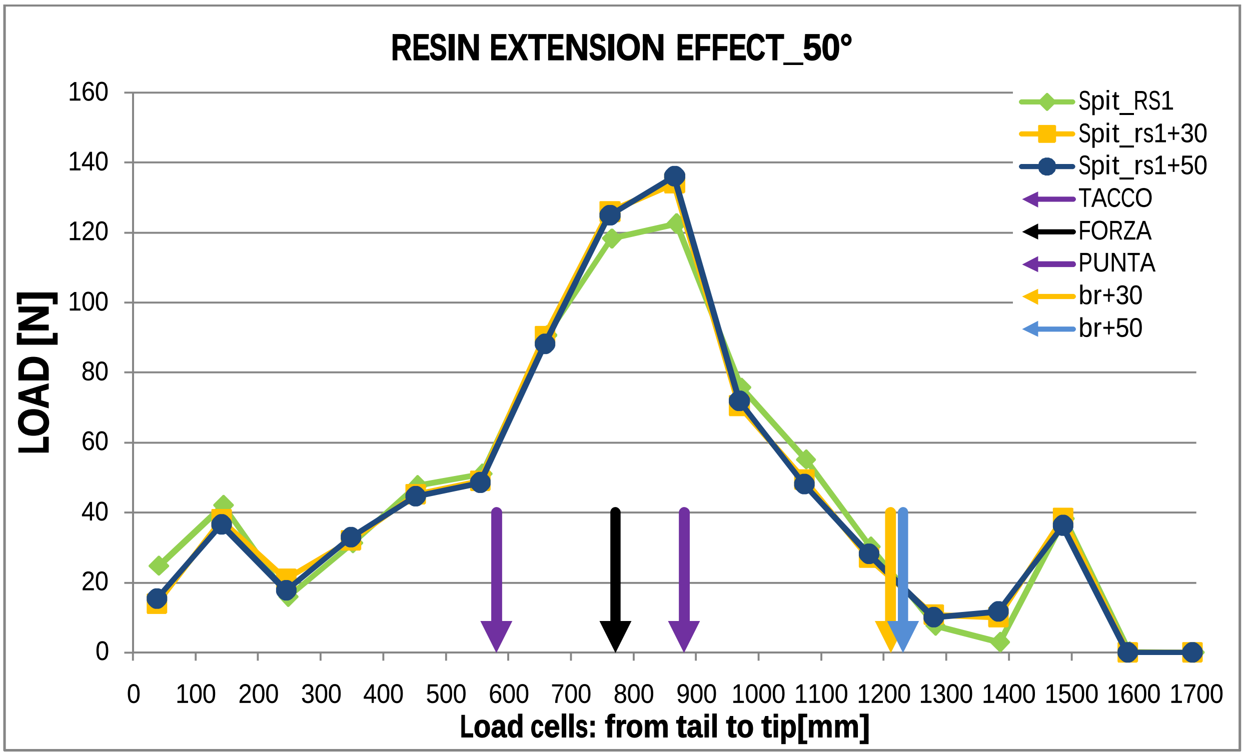


3.11 ARM EXTENSION EFFECT ON E.L.P.

Effect on edge load profiles shows that the first configuration (length of 300mm) is retained the best configuration for each material. It's reported the ski+wood configuration diagram at 50°.



Green line (w300) is the better configuration because peak on shovel is low and diagram is better filled. When extension grows peak grows on +30 and then came back at the first value on +50, losing the effect of arm presence. Then it's observable that on tail and on the center part of the ski the diagram doesn't change, so the presence of extension don't change significantly the ski behavior on slopes.



3.12 FUTURE TASKS (summary for ski effective length)

Other comparisons could be made on effective length of ski during skiing, always maintaining the comparisons on typology. Edge Load Profile are useful to create an algorithm who permits to calculate the effective length of the ski during a curve. This because Edge Load Profile shows how pressure of edge is distributed on ground. It's possible looking that there are three principal peaks of load on tail, on central part and on tip, but on shovel and behind the binding there are also valleys who often present some local minimums in the range of zero. So it's possible to think that the parts who show valleys in the Edge Load Profile don't contribute at the transfer of the pressure from edge to snow. Hypothesis about the calculation of the threshold value were done:

- 5% of maximum global load peak;
- 10% of maximum global load peak;
- 10% of the difference between maximum global load peak and maximum local load peak;

All the loads lesser than threshold value are avoided in calculation, so the effective length of the ski becomes the sum of segments of ski who shows edge load profiles higher than threshold value. Effective length is divided with total length to obtain a percentage value for comparing the same ski with different plates or different kind of ski, different brands, different snow stiffness. This to shows how much length of the ski is used when skiers deal with a curve. High or low effective length permits the user to choose different kind of ski in function on hardness of snow or in function on the type of run that they want to deal.

Total effective length will not be the 100% of ski length because of the geometry of ski: the last part of tail and the first part tip never come in contact with the ground. For example in spitfire168: total length is 1680mm, part who never touch: 50 mm on tail and 100 mm on tip. So total is reduced at 1530mm and maximum percentage accessible is 92%.

Some example of effective length, calculated like ratio of length of ski who transfer load over 5% of threshold value and nominal length, are reported in the next table: (type of snow is ICE). Effective length is reported as an index always lower than 1.

EDGING ANGLE	NORDICA SPITFIRE	FISCHER HYBRID _ C	FISCHER HYBRID _ R	SALOMON KART
0°	0,6606	0,5122	0,6058	0,6927
20°	0,7856	0,6686	0,7172	0,8355
30°	0,8128	0,6798	0,7532	0,8671

The following three tables show effect of snow stiffness:

SNOW STIFFNESS: ICE				
EDGING ANGLE	NORDICA SPITFIRE	ATOMIC D2SL	FISCHER HYBRID _ C	FISCHER HYBRID _ R
0°	0,6606	0,7411	0,6628	0,6595
20°	0,7856	0,8153	0,7904	0,7910
30°	0,8128	0,8345	0,8004	0,7933

SNOW STIFFNESS: HARD				
EDGING ANGLE	NORDICA SPITFIRE	ATOMIC D2SL	FISCHER HYBRID _ C	FISCHER HYBRID _ R
0°	0,7343	0,7465	0,7010	0,6643
20°	0,7898	0,8123	0,7940	0,8270
30°	0,8339	0,8516	0,8241	0,8480

SNOW STIFFNESS: MEDIUM				
EDGING ANGLE	NORDICA SPITFIRE	ATOMIC D2SL	FISCHER HYBRID _ C	FISCHER HYBRID _ R
0°	0,9185	0,8656	0,8995	0,8645
20°	0,9227	0,8655	0,9022	0,8713
30°	0,9265	0,8600	0,8950	0,8726

Effective length of ski grows decreasing snow stiffness, like it’s happen in the reality because snow is soft and the reaction on ski is became a flat profile of pressure who involves all the ski length. Higher values recovered was for Nordica Spitfire with medium stiffness snow at 30° of inclination.

These last tables show the percentual difference of effective length on Nordica Spitfire when angle is changed and snow stiffness is fixed. 0° configuration is the base for comparison.

NORDICA SPITFIRE						
EDGING ANGLE	ICE	Δ% ANGLE	HARD	Δ% ANGLE	MEDIUM	Δ% ANGLE
0°	0,6606	-	0,7343	-	0,9185	-
20°	0,7856	18,92%	0,7898	7,56%	0,9227	0,46%
30°	0,8128	23,04%	0,8339	13,56%	0,9265	0,87%

Effective length grows with angle for each snow stiffness, but in different percentage. For example, in medium stiffness, variations are less sensible.

Taking ICE stiffness as base for comparison, this table shows percentual differences, fixing angle and changing ground stiffness:

NORDICA SPITFIRE					
EDGING ANGLE	ICE	HARD	Δ% ICE-HARD	MEDIUM	Δ% ICE-MED
0°	0,6606	0,7343	11,16%	0,9185	39,04%
20°	0,7856	0,7898	0,53%	0,9227	17,45%
30°	0,8128	0,8339	2,60%	0,9265	13,99%

Effective length grows decreasing ground stiffness, but the difference from ice to soft is higher than ice-hard difference. So effective length is very sensible at variations of snow stiffness.

3.13 DISCUSSIONS ON SLYTECH BENCH OUTPUT

The bench output reveals the presence of critical spots along the ski where either the contact to the ground was missing or non-uniform peaks were present, thus confirming the utility of the bench in the ski qualification process for their design improvement.
The latter consideration is the major direction of development of the study: once completed, it will allow correlating the presence/absence of peaks/plateau/valleys in the Edge Load Profiles with the carving and racing properties of skis in the field tests.
These analyses will be carried out together with other structural and dynamic properties of the skis such as the global/local bending stiffness, the torsion stiffness, the effective carving radius, the dynamic damping of shovel and the ski rebound properties.
In addition, pilot tests showed that the use of foams of different consistency, applied to the load cells in order to simulate different types of snow, can result in a set of Edge Load Profiles that are sensibly different from those obtained on a flat rigid surface, generally reducing the peak loads and the extension of the unloaded areas. There is an uniformity of load along all effective length of ski, as an in-field soft snow. In fact, respect and ice slope where the uniformity of load is very low because less ski surface interacts with snow, when snow is softer, there is a reaction force who brake the ski due to an higher volume of snow brushed, and skier fell the needing of growing the force to move on curves. In this last case ski effective length grows because of higher volume of snow where skier interact.

From the higher number of ski and tests effectuated on the bench, some conclusions about Edge Load Profile were discovered:

- the Edge Load Profile is a repeatable curve that can be measured as the peculiar “footprint” of each ski on the snow;
- the Edge Load Profiles of different skis should be correlated with their field test ranking (“good”, “average” or “bad” scoring) in order to identify the target Edge Load Profiles that have be preferred for each market segment or for various snow conditions;
- the Edge Load Profiles have to be seen as one of the engineering parameters to be evaluated for an integrated approach to ski functional design;
- the measured Load Profile will be helpful in the validation of numerical analysis of the ski-snow interface.
- Edge load profile of the same ski, but coupled with superstructures shows how rigid became the ski and how the superstructure stiffness influences the deflection of shovel.

3.14 CONCLUSIONS

In these tests bending moment on shovel of ski grows in presence of a superstructure, this because the stiffness grows and the total structure as to be loaded with greater force to obtain the same deformation. The presence of wood arm, for example, doubles the bending moment for little carving angles (0°-10°) then there is a growth of 50% for medium angle (20°-30°) and then the growth value became constant at 30% for highest angles (40°-60°). So the greater effect is for lower angles.

In the case of torque, the last plot show greater resistance of the superstructure at lower angles, where torque is very small with respect of the original configuration of ski. Then values of difference decreases with edge angle.

The experience shows that wood arm, who has young modulus comparable with ski, could absorb higher value of bending moment with the same deformation of the original configuration. Value of stiffness are reported in the chapter of characterization of ski and superstructures.

This values are calculated in laboratory, where temperature is 20°C, so in field test it’s expected differences on peak values of a curve. Also snow stiffness influences the results because skiers have to spent greater force for bending the ski when snow is warmer.

The presence of a superstructure helps skiers because with the same deformation of the ski they could enter in a curve easily respect to the original configuration.

Edge load profiles derivate from Slytech bench, who simulates a skiing profile, shows that shovel is better loaded in front of the bindings. This because ski grows his stiffness and changes his property. The presence of an extension for superstructure shows that diagrams don’t significantly change for ski+resin configuration. For ski+wood configuration there is some variation on shovel peak but the filling of load on shovel is substantially the same. So it was retained that the original configuration is the better solution for future study or developments.

Feedbacks from skiers are important in this case, because the idea of a superstructure is good if there are good answers from testers of different experiences.

Chapter 4: FLEX BENCH OF NORDICA GROUP LABORATORY

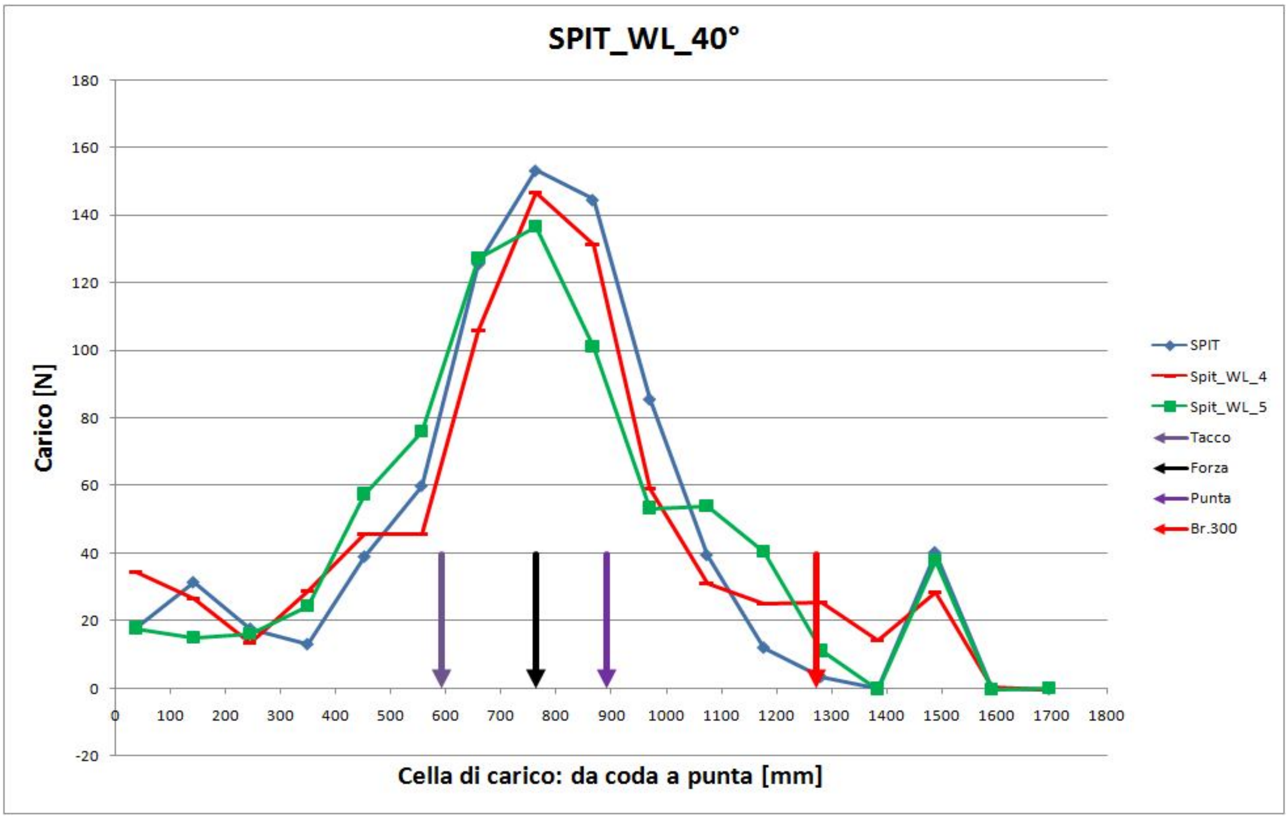
4.1 INTRODUCTION

Ski rigidity change in presence of different plate and superstructure. Flexion tests did in laboratory on the axial compression machine shows that different kind of plate provides significant effect on ski rigidity. The same typology of ski provides different curves, so each ski is different on his internal structure. This peculiarity was confirmed comparing edge load diagrams of Slytech bench test where a couple of ski was tested using the same superstructure, before applied on one ski and after applied on the other one. In this case the superstructure was an integral plate of wood, called WL on tests. Two coupled ski (one pair) provide differences on edge load diagrams in front of the tip of bindings. So he hypothesis is that the internal ski rigidity is different. But also the internal rigidity of the superstructure could change for each piece of wood. On next paragraph there are examples of this internal structure different.
Tecnica (Nordica group) in his factory in Giavera del Montello (TV-Italy) have the possibility of effectuate rigidity test on ski. Their laboratory is provided of some machinery for testing skies and boots with a lot of different kind of test: at weather temperature and in cold conditions are tested flexion, torsion, fatigue, impact, water isolation, buckle closures and other measurements. The interest of this thesis is on the bench of flexion and torsion, and looking where and how it’s possible to operate to change the flexibility.

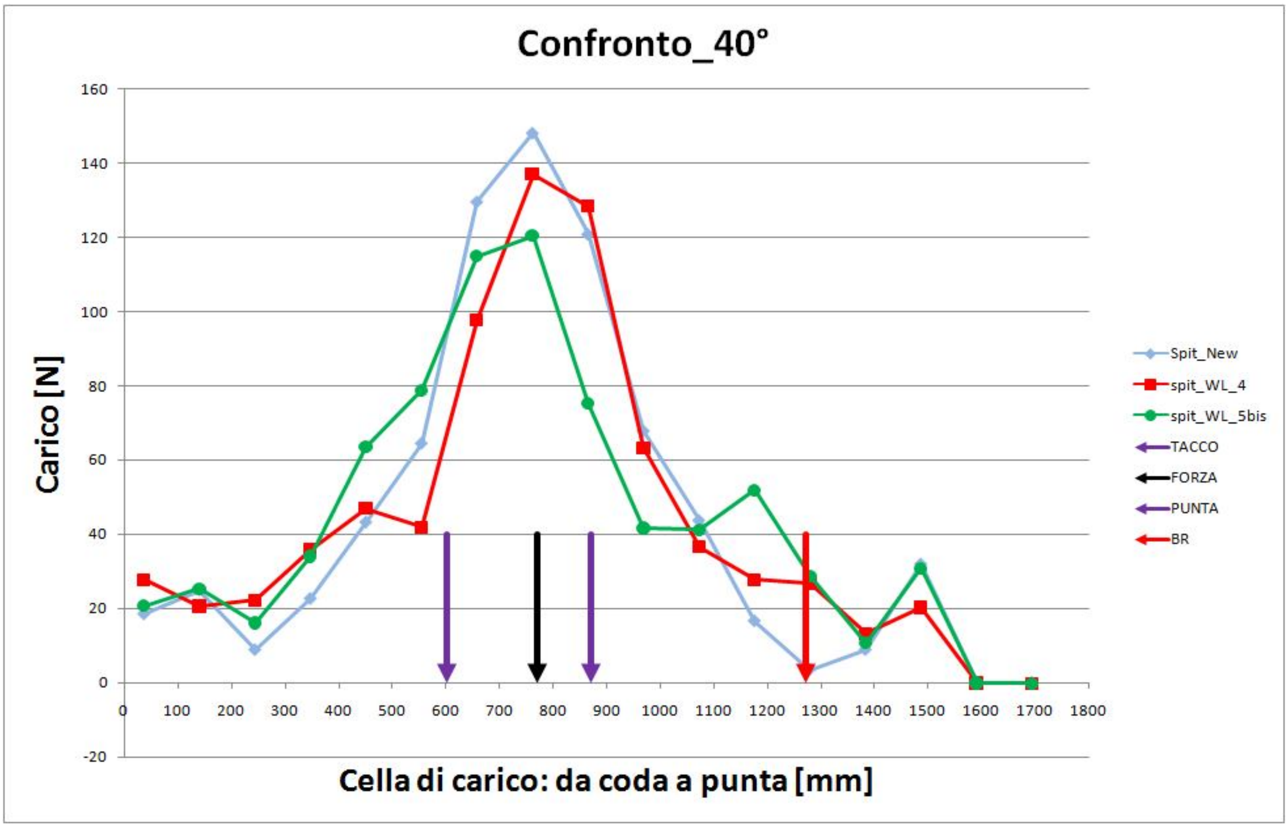
4.2 PRELIMINARY TEST ON SLYTECH BENCH OF AN INNOVATIVE INTEGRAL PLATE

The idea of an integral plate starts in parallel with the idea of a floating superstructure (unique piece for Piston Marker plate). One plate is fixed, the second is fixed but there is the possibility of changing the configuration (with or without arm).
Both solutions are good because they permits to release the bending moment on a bond situated under the tip of binding. Both solution need of new matrix for industrial mould technology.
In Padua laboratory were produced different kind of integral wood plate, as seen in the following figures: spitfire proto + WL 4 and his couple + WL 5.
These were the first integral plate coupled ski studied on Slytech bench. They were different as edge load profiles could shows.

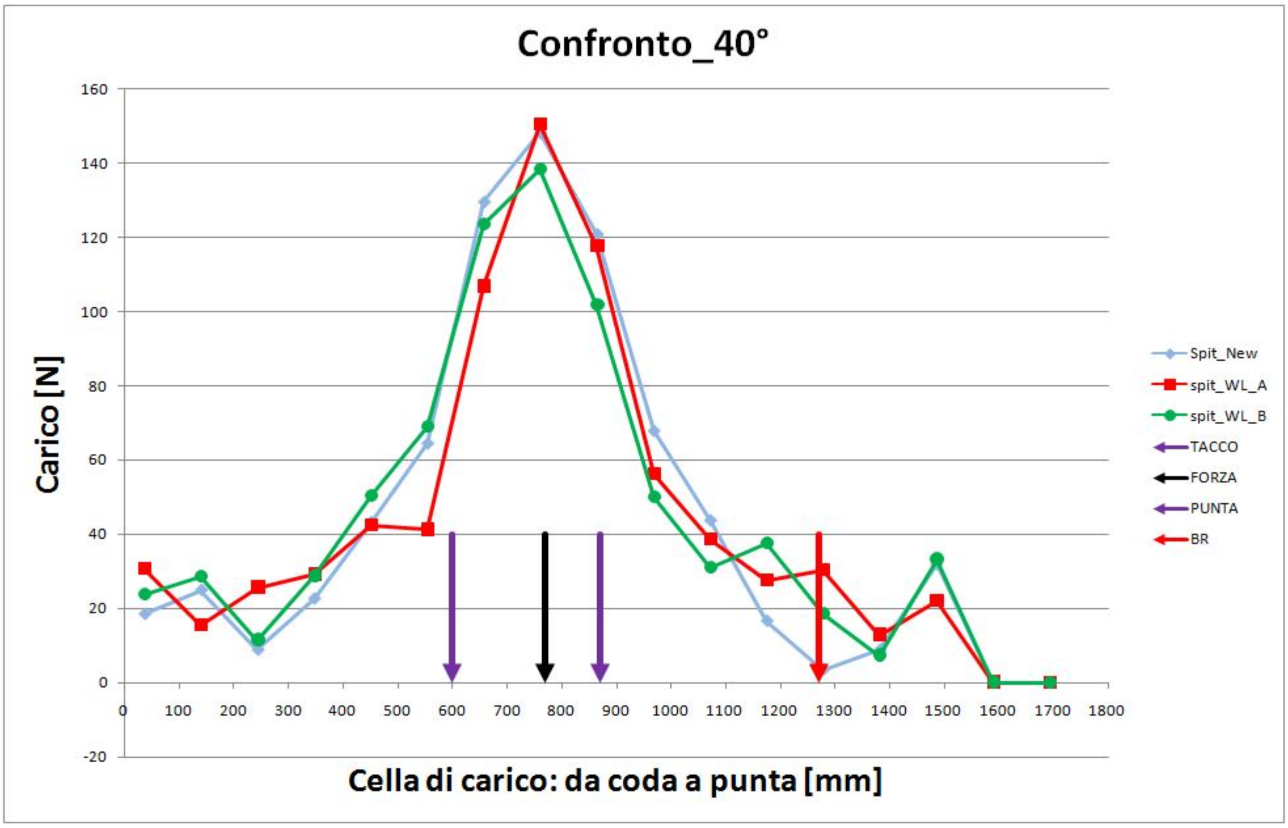
Fig. 60: Couple of Spitfire Proto + integral wood plate (preliminary model)



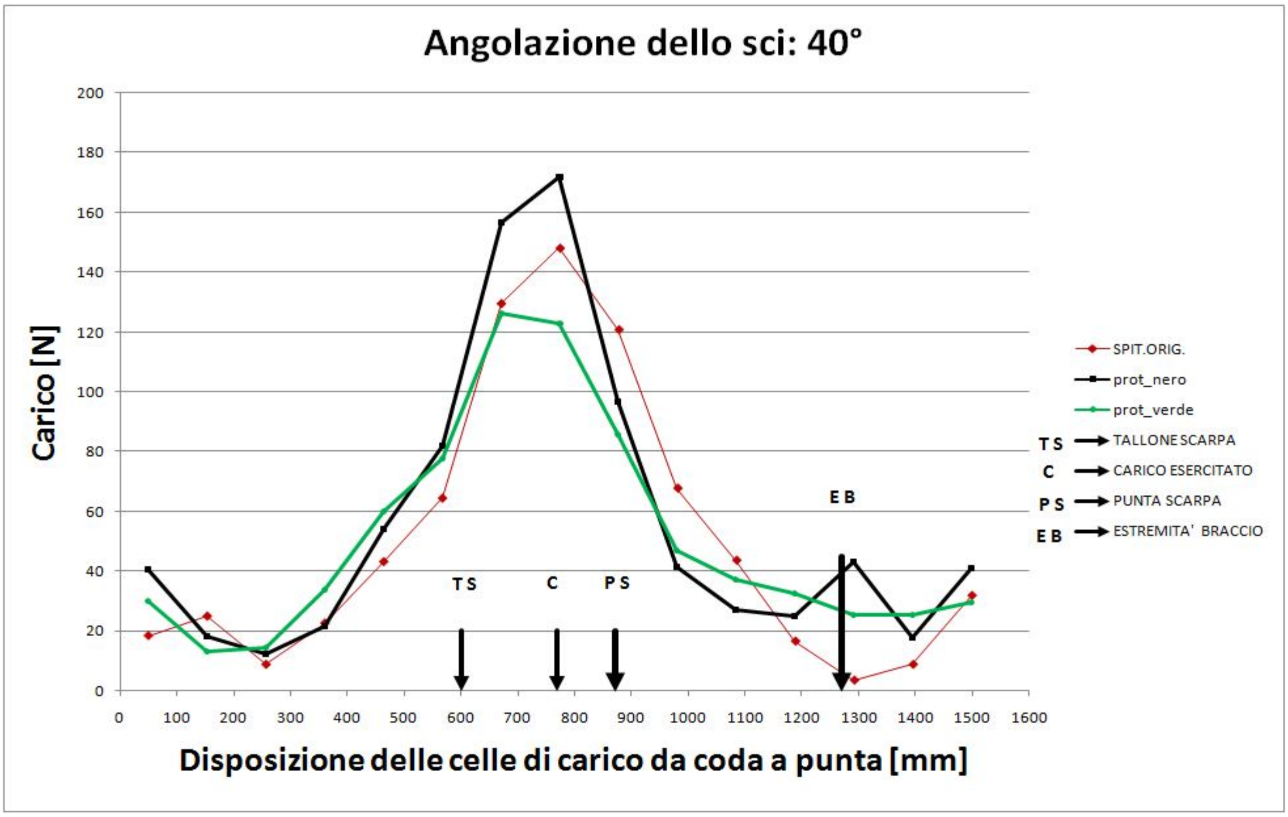
It's evident the difference on shovel: spitfire+WL4 is better than +WL5 that have the same tip peak and the same valley of a spitfire without superstructure. For spitfire+WL5 where effectuated some modify on superstructure but with bad results, the long arm never provides solution that came near the spit+WL4 profile. For example:



Spit+WL5bis in this case provides a double peak on shovel and not a uniform distribution similar at spit+WL4. There was no convergence on results. Then a successive step was producing other two new integral superstructure and apply them on the same couple of ski, because it was think that wood have change his property of rigidity and they were not modifiable so.
This is an example of new prototypes:



There were some differences but arms were modifiable cutting away material were load and rigidity were high. In this case WL_B is more rigid than WL_A because of greater peak on tip and the presence of a valley. Ski was much rigid and could not deflect in the upper part of arm extremity.
Last comparison was made maintaining one spitfire proto (called NERO) that have the best distribution of load, and changing the second ski with a Spitfire Dobermann (called VERDE). This to demonstrate that equal long arm provides no differences if coupled with similar ski. But results were different, and this is possible to look in the next plot:



Spitfire VERDE assumed a constant distribution and not a double peak.

It was decided that the problem of differences is due to internal shovel rigidity. Some test of characterization of ski were did and show that there are differences on a range of 5-7% between a couple of ski. The same results for arms.

The last solution thought was that of try the couple of ski (see in figure) in slopes, to understand with subjective evaluation which is the best diagram of the two, and so furnish a line for successive development of prototype.

Before of this in-field test, skies were tested on Nordica bench to look where rigidity is different and to understand were operate in future, because from Slytech bench is very difficult giving an interpretation on local rigidity of ski. In the occasion it was tested also the Spitfire 168 + EVO R + W300 , to have an idea of the stiffness and rigidity of ski used for in-field test.

These in figure are the final plate solution.

Fig. 61: last solution of integral plate on two different ski

4.3 GENERAL DESCRIPTION

The flexion bench in Nordica laboratory permits to calculate the product EJ that is the rigidity researched. EJ is the product of Young modulus (E), which represent how much the material has to be strength to have a unitary deformation, and moment of inertia around the bending axis of a general section of the ski.
This bench is provided of two floating clamps composed by two cylinder beam: one where ski is leaned, the second beam is leaned on ski and look locally the ski. Two auto-centering clamps look ski transversal motion during test.
The procedure of clamping follow the normative ISO 5901 on flexion of ski, with this exception: the bond on shovel is imposed at 200mm from tip and not at 280mm.

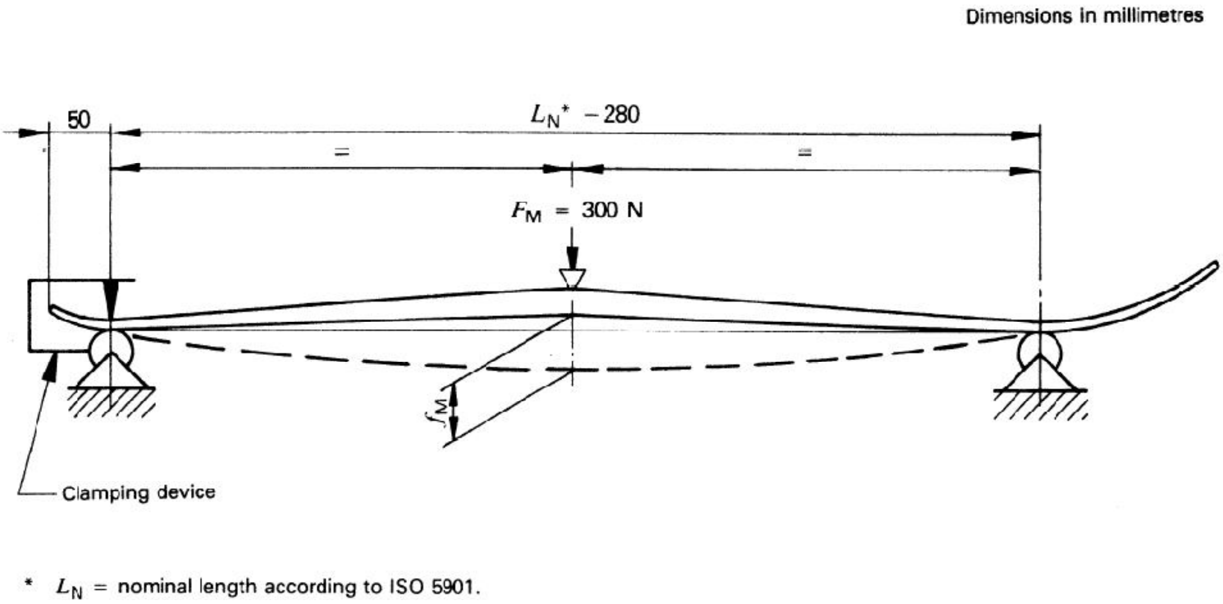


Fig. 62: Standard ISO 5902-1980

Fig. 63: Example of ski clamped and loaded on Nordica Flex Bench

The software who commands the bench required an input about nominal length of ski. Once input is given it provides two number: the first is the position of tail clamp, the second represent load position. It's possible to read the position thanks two meters disposed under the bench on which run an arrow indicator. Load is applied by a cylinder, and it's constant for each point of test: 350N. A second system of cylinders and actuators moves an arm who dispose an LVDT measurement sensor on the lower surface of the ski.

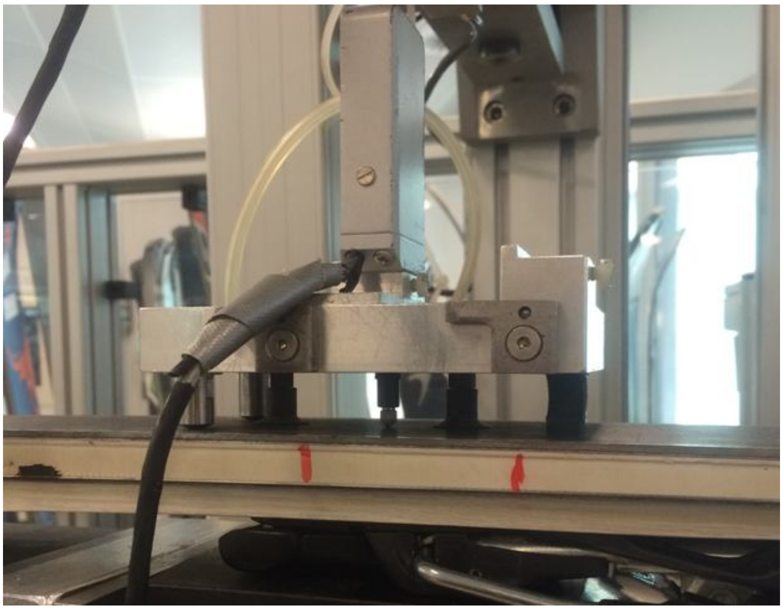


Fig. 64: LVDT sensor applied on ski lower surface

This lecture is effectuated for all the effective length of ski in step of 50 mm from tail to tip. For each step the machine repeats the same motions. Particular attentions are given at the first point of acquisition (zero of machine): this is not at 50mm from tail bond, but at 100mm because of sensors platform geometry. After the lecture of the first point, a saving file name is request by the software, and once it was insert test could start. The results of measurement is a curve in Cartesian plane, where x-axis is the position of LVDT, and y-axis is the product EJ named rigidity of the ski.

EJ is the constant number who connects bending moment and curvature in the equation of elastic line: from the theory about elastic line, (who represent the deformed shape of a structure) the relation between distributed load and bending moment is:

$$-q = \frac{d^2 M_f}{dz^2}$$

Assuming the hypothesis that ski is a beam supported on the two extremities: q is a constant distribution of load on ski upper surface, calculated like a ratio between force applied by the actuator and effective bending length. Z is the length variable.

Bending moment equation:

$$M(z) = \frac{qL}{2} z - q\frac{z^2}{z} = -\frac{d^2\eta}{dz^2} EJ$$

1st Integration:

$$\frac{d\eta}{dz} EJ = -\frac{qL}{4} z^2 + q\frac{z^3}{6}\ c1$$

2nd Integration:

$$\eta EJ = -\frac{qL}{12}z^3 + \frac{q}{24}z^4 + c_1 z + c_2$$

C_2 = 0 because η=0 at z=0; $\frac{d\eta}{dz}$ = 0 in z=1/2 , so C1 = $\frac{qL^3}{24}$.

Elastic line equation obtained is:

$$\boldsymbol{\eta EJ = \frac{qL^3}{24}z - \frac{qL}{12}z^3 + \frac{q}{24}z^4}$$

It’s difficult estimate the product EJ from this equation without knowing displacements. The sensor on ski measure the local deflection of ski (curvature): from theory of elastic line the relation between curvature of ski and bending moment is:

$$\frac{d^2\eta(z)}{dz^2} = -\frac{M_f}{EJ(z)}$$

So it’s possible to built, using the software, a curve of EJ for all the elongation of ski length in variable Z. examples are given in next paragraph.

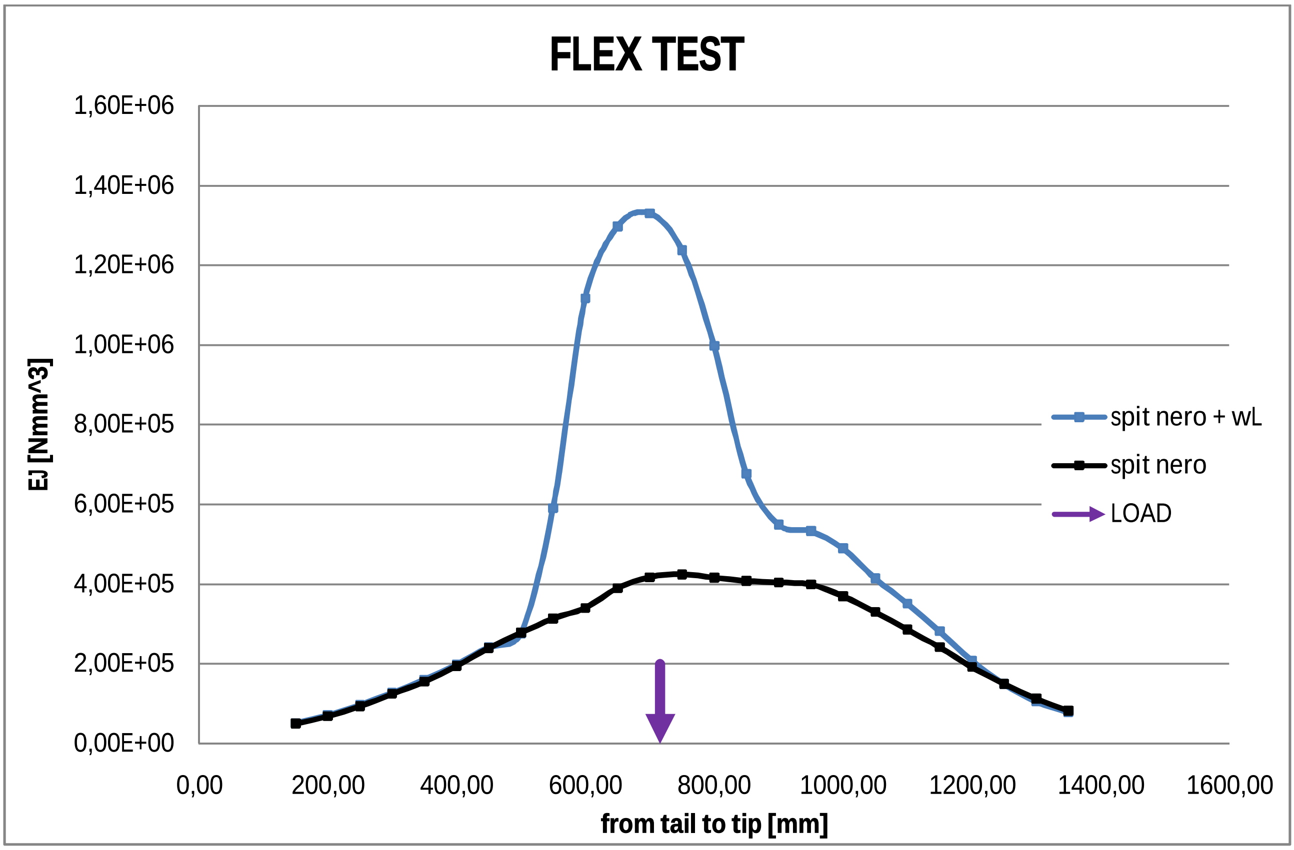
4.4 LIST OF SKI TESTED AND PLOT NAMES

TEST 1: SPITFIRE 168 PROTO + INTEGRAL WOOD PLATE **(SPIT NERO + WL)**
TEST 2: SPITFIRE 168 PROTO **(SPIT NERO)**
TEST 3: SPITFIRE 168 DOBERMANN + INTEGRAL WOOD PLATE **(SPIT VERDE + WL)**
TEST 4: SPITFIRE 168 DOBERMANN **(SPIT VERDE)**
TEST 5: SPITFIRE 168 DOBERMANN + EVO R + WOOD ARM **(SPIT VERDE + W300 + EVO R)**
TEST 6: SPITFIRE 168 DOBERMANN + EVO R **(SPIT VERDE + EVO R)**

4.5 PLOT OF RESULTS AND COMPARISONS

- COMPARISON OF TEST 1 AND TEST 2

Comparison of ski Nordica Spitfire 168 NERO coupled with wood integrated plate (called WL on plots) and the same ski original without plate:

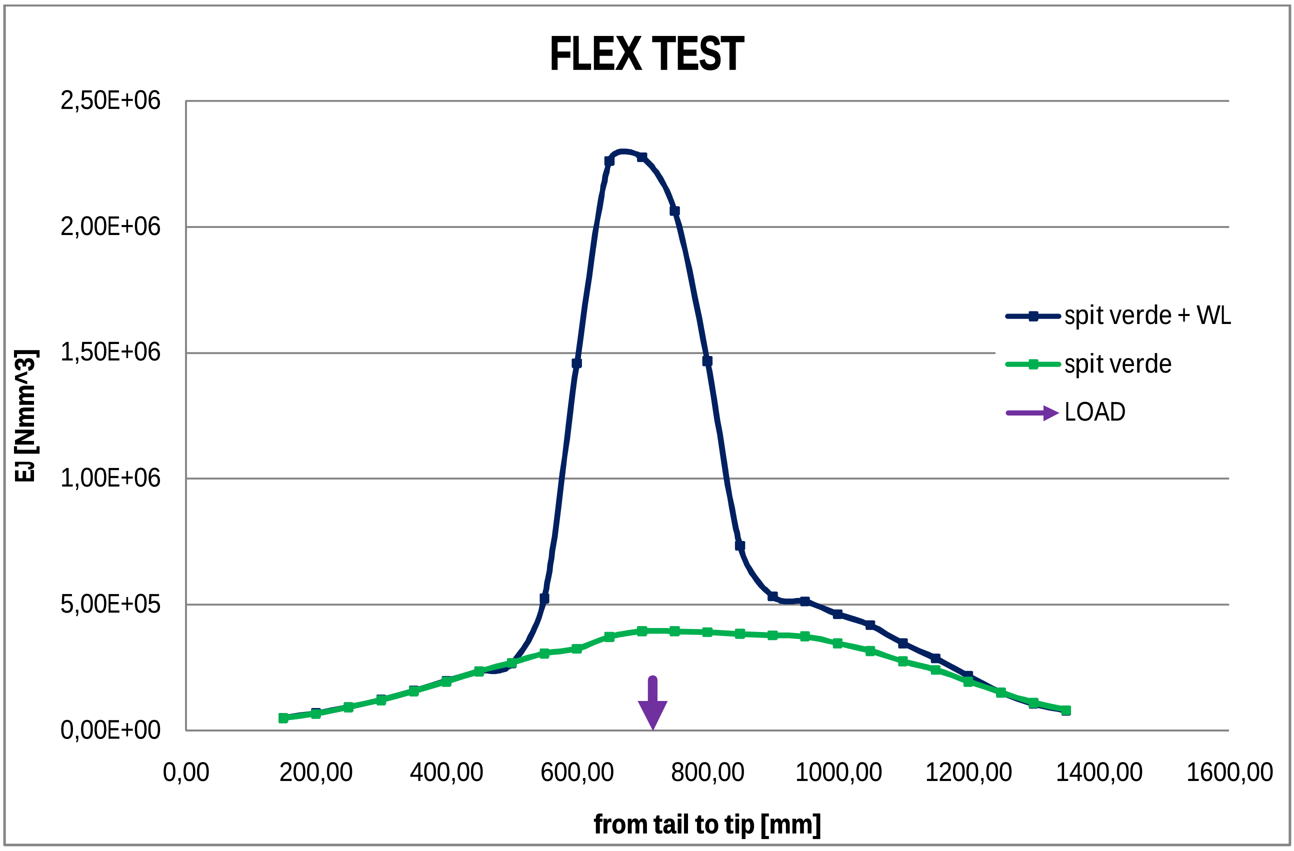


The lower curve represent the ski who is simply able to flex because of low rigidity EJ. It means that skier have to use lesser force to bend this ski.

Fig. 65: flexion of Spitfire NERO 168 + WL

- COMPARISON OF TEST 3 AND TEST 4

Comparison of ski Nordica Spitfire 168 VERDE coupled with wood integrated plate and the same ski original without plate:



The lower curve represent the ski without plate. The presence of WL plate influence shovel rigidity also in this ski.

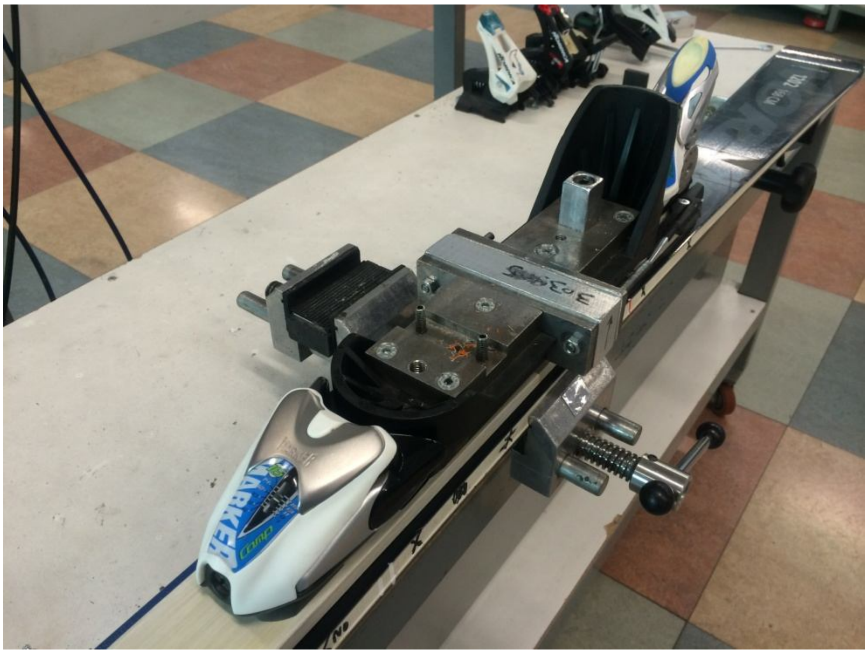
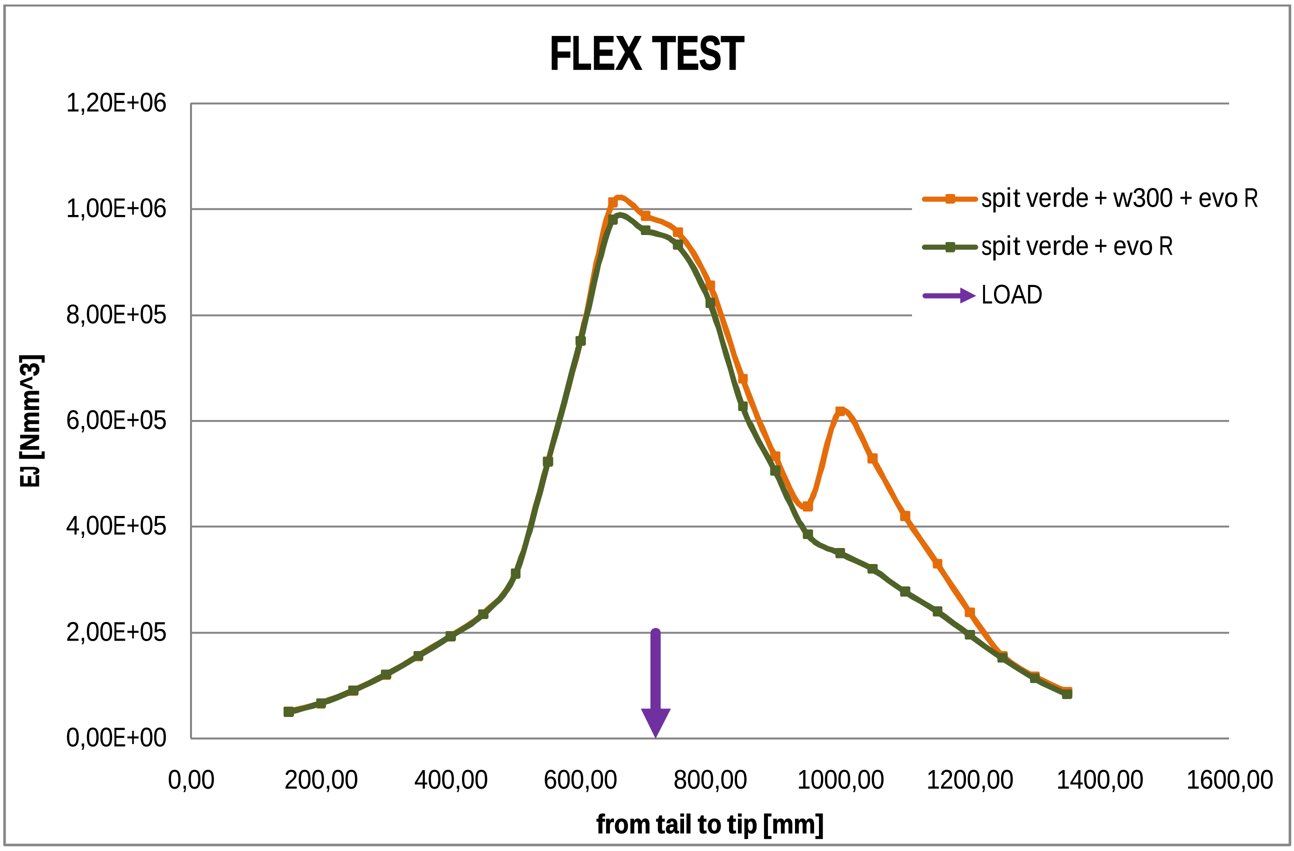


Fig. 66: Particular of preparation of Spitfire with aluminum boot for tests

- COMPARISON OF TEST 5 AND TEST 6

Comparison of ski Nordica Spitfire 168 VERDE coupled with plate EVO R and with superstructure W300 and the same ski original without W300:



In this plot is evident a singular change of rigidity on the section where W300 is fixed on ski.

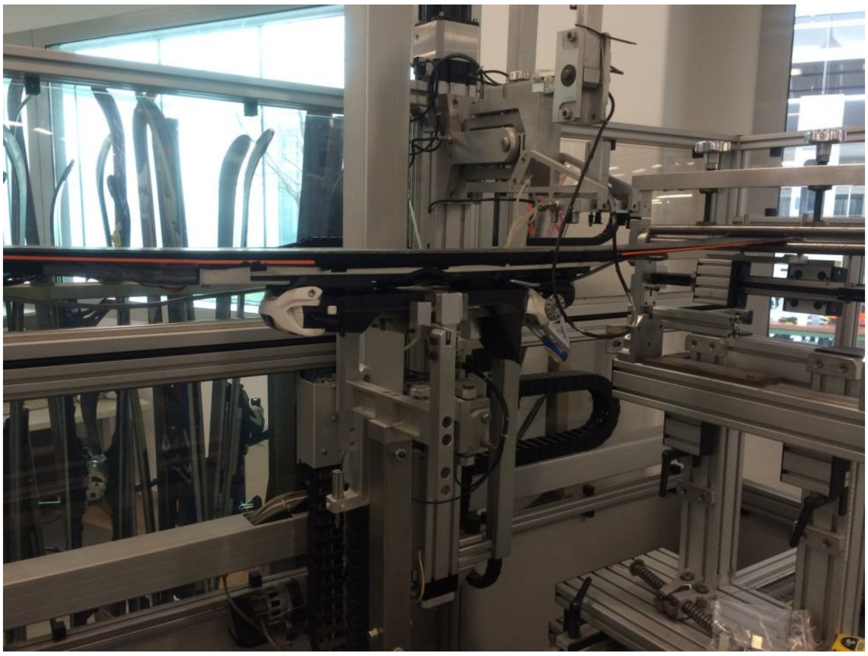
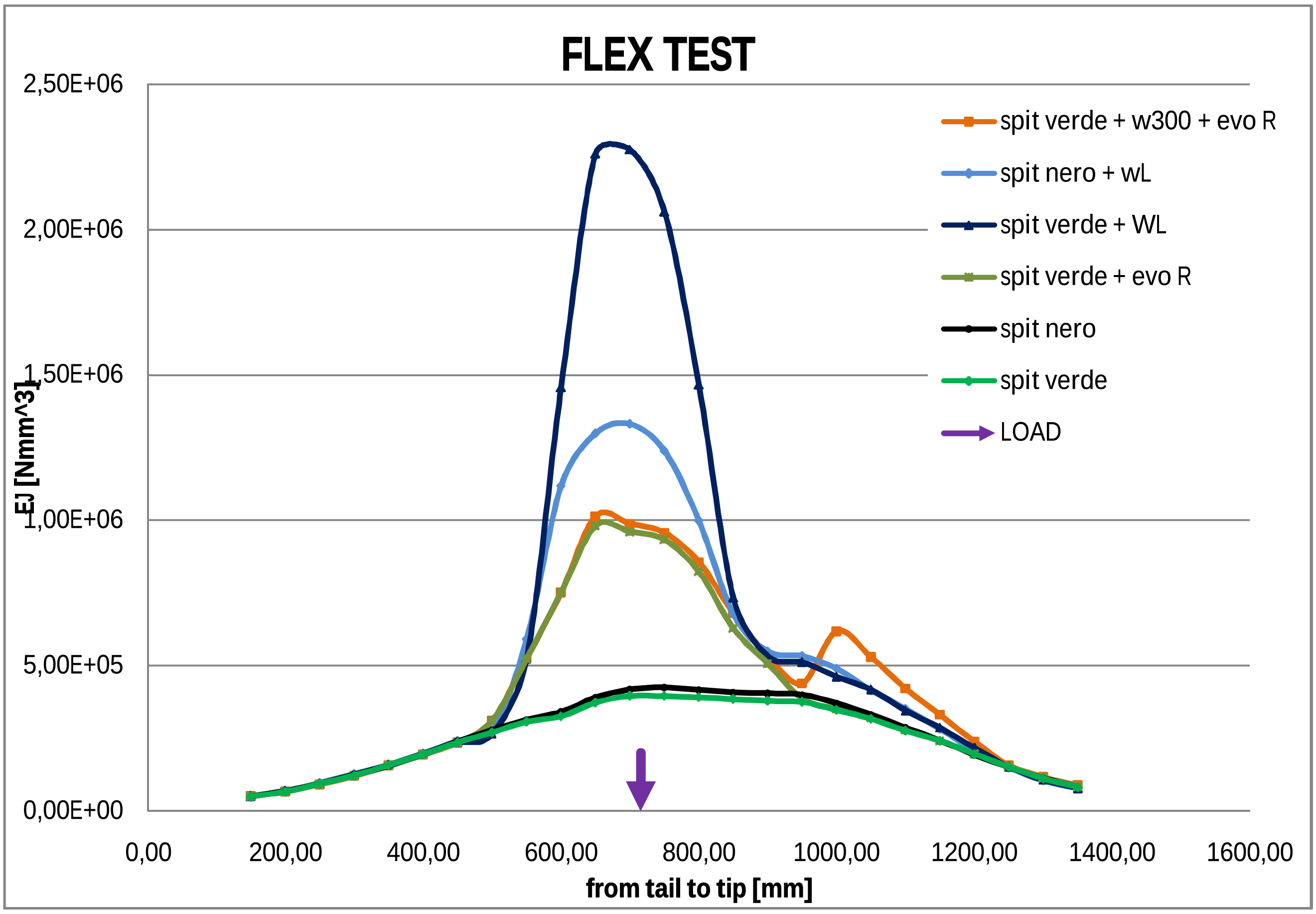


Fig. 67: Spitfire VERDE 168 + EVO R + W300

4.6 DISCUSSION AND CONCLUSIONS

Other plots show comparison of the three skies coupled with superstructures (WL and W300) and ski without anything on hit:



Considering only shovel zone, the maximum growth of rigidity is given only from W300 superstructure, the other two are equal, but differs so much in the central part of ski. Looking at the "spit NERO" and "spit VERDE" they are substantially equal. So the growth of rigidity in central part, that is the double between the two configuration, is extremely connected at integral plate wood.

Comparisons on Nordica flex bench is important to study properties that Slytech bench in Padua is not in grade to explain looking at edge load diagrams. Internal properties from edge load diagrams are only results given by the experience of a good diagram's interpreter. Deflection of ski is easy if ski product EJ is lower. If rigidity on shovel is soft, ski could deflect more than the normal configuration and permits to release and distribute the load in all shovel length , and not only on the tip. The peak of load on tip presents in the original configuration is lower when a superstructure is applied on ski.

The best result in shovel edge load profile is given by integral wood plate, but only for "spit NERO", and this is confirmed by rigidity test where shovel is softer than "+ W300". But in the central part only the presence of EVO R plate seems to be best of integral plate because wood has Young modulus greater than POM. Integral plate configuration shows diagrams without significant singularity, because plate is integral and made of the same material.

As conclusions of this experience it was understand that each ski needs of his proper superstructure because of difference on internal structure of the same ski. For a series production this is not good because of industrial costs and production time lost on flexion test of each ski.
Another peculiarity is that ski sold as pair is internally different but not so much to change significantly the diagrams.
The final choice on production is based on the creation of a superstructure that is able to satisfy a range of ski size, and able to be product in series with the lowest and cheapest manner.

Chapter 5: DATA COLLECTION AND ANALYSIS OF IN-FIELD TEST

5.1 INTRODUCTION

Mountain and snow are insidious place for effectuating test: there are much variables that could change in sudden way. The first problem that a skier can observe is the lower temperature with respect of laboratory one and variation of pressure and humidity in the air. This factors could influence the answer of sensors like accelerometers, strain gauges or electro-goniometers. Also the data collectors and cables could become aware of this weather influences.
For field tests the instrumentations used were prepared with protections like silicon, tape , cotton and other features. It's very important follow a list of task, and to be very rigid in the execution of every point of the list, because tests have to be as much as possible repeatable changing, as possible, the lesser number of variables (temperature, pressure, snow, slope, style).
Once testers arrive at slopes instrumentations and skier were prepared and dressed. Skier safety in first of all, so all the dispositive used have to be lesser invasive as possible: cables, data collectors and thermometers used are present but skiers have to feel freedom in motion and no hurts during the execution of tests.
Tests were repeated two times for each variable change. Test with the same set of variables have to be repeated faster as possible because snow change her properties during the day. Also skiers have to be as much as possible repeatable in his motion and style of skiing.
Tests were effectuated in San Vito di Cadore (BL-Italy) on San Marco slope. This slope is ideal for doing in-field test because inclination is constant for all her length, and width is so high for wide carving style.

5.2 OBJECTIVE OF IN-FIELD TESTS

These test permits to compare forces and bending moments on ski obtained during real skiing with those obtained in laboratory tests. Ski is provided with a superstructure of wood material. It's expected that the presence of this superstructure change the sensation of skiing and the forces that act on the ski shovel.

5.3 INSTRUMENTATION ADOPTED FOR IN FIELD TESTS

- NORDICA SPITFIRE 168
- SUPERSTRUCTURE OF WOOD (W300)
- STRAIN GAUGES
- SOMAT DATA ACQUISITOR
- POCKET DATA COLLECTOR
- ELECTRO-GONIOMETERS (EGN)
- CABLES
- TAPE

5.4 PREPARATION OF INSTRUMENTATION

This phase of in-field experiences was carried out in the laboratory. Strain gauges were glued on ski following their restrictive procedures: on a shovel of Spitfire 168 four uni-axial strain gauges compose a flexion Wheatstone full bridge and two bi-axial strain gauges composed a torsion Wheatstone full bridge. The other ski have only two mono-axial strain gauges glued in parallel near the edge of the ski. They are singular connected in a Wheatstone quarter bridge. Wood superstructure, as the last ski, is provided with two strain gauges connected in the same way.

One ski is provided with two plates who measure vertical forces.

Strain gauges and the first part of cables who connect them are covered with silicon to avoid that snow and water come in contact with cables. Contacts provide bad signals or no signals at data logger.

Data logger was set in the laboratory, and calibrated in in-field because of temperature and pressure effects.

Cables and wires is shield to avoid rumors on signals. Shooks and drops have to be inexistent: the firsts could broke data collectors or the acquisition box; the seconds could cause rips on cables connection or welded areas.

Data collector, in this case a SOMAT, is disposed in a appropriated rucksack. The inner side of this rucksack are filled with foam rubber that have two characteristics: protection from hurts and isolation from external temperature. In a apposite box under the rucksack is disposed a 12V battery and a general switch. A second switch is installed near the left shoulder of the rucksack. This is the start and stop switch for tests, and his lever have not to move in OFF position during skiing.

Cables are connected at SOMAT with a box were are presents resistors who permits at SOMAT to understand which are the channels and which are the typologies of Wheatstone used for each channel.

This is an example of ski instrumented:

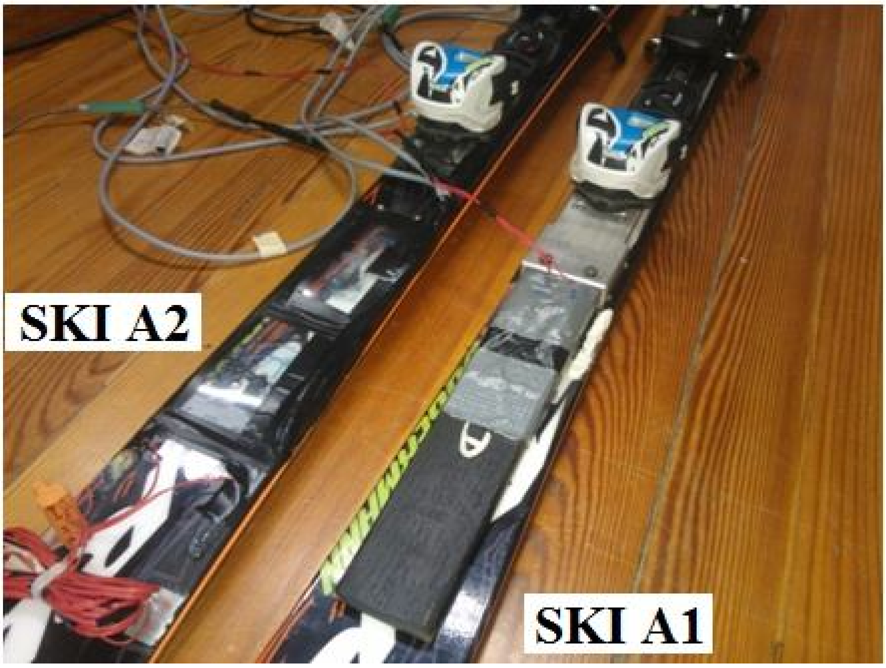


Fig. 68: Example of ski instrumented, one of them is coupled with a wood superstructure

5.5 PREPARATION OF THE SKIER

In in-field skier was dressed with all the instrumentation used. In this tests were present two set of instrumentation connected at SOMAT: one set was skies and wood superstructure, the other one was clips, buckles and electro-goniometers (EGN) attached to boot and skier shank for measure boot flexion during ski. This list resumes the tasks effectuated before skiing:

- Attachment of two EGN on boot to measure shell-cuff angle; one is connected with SOMAT, one with a BTS Pocket data collector.
- Attachment of a third EGN who measure cuff-tibia angle and connected at Pocket; EGN have to have his two parts in the same plane, so on the tibia is fixed a plate who permits that. Cotton pieces and tape were used to attach EGN on this plate.
- Dressing of boot.
- Cables of clips and EGN were passed under the pants of skier to protect the same cables and to avoid that cables fall down under ski during a motion in the slope.
- Cables of skies were passed over the pants and looked with tape. Cables were not fixed , they have to follow skiers movements.
- All cables enter in the box of SOMAT and fixed with strips.
- EGN on boot and clip were protected from snow with a nylon sack and fixed with tape.
- Clamping of ski.
- Attachment of ski plate at Pocket.

Fig. 69: Preparation of tester before skiing (28-02-2014)

5.6 LIST OF TASKS TO FOLLOW DURING TESTS

After the dressing phase, skier arrived at the starting point of the slope. This starting point was the same for all runs. In this moment it starts the video of the run. This is a list of tasks that testers and skiers have to do when they effectuate a run.

- Start video.
- Turn in ON position the general switch of SOMAT (wait 30-40 seconds because the data collector has to go in regime phase).
- Turn in ON position the second switch near the shoulder. This is the trigger switch and acquisition starts. In field acquisition are collected at 400 Hz of frequency.
- Put clip on boot closures and close boot with the sequence assigned for the run.
- Turn on the Pocket collector and start his acquisition.
- Open bindings, and then clamp the ski.
- Flex leg to have a zero on plate.
- Make three forward flexion with legs.
- Make three bumps of ski (this is a signal for start).
- Ski lifting to have zero on ski
- Start skiing.
- The first part of slope was done with free carving, the name of this style for analysis is NORMAL: skier have to be as much as possible repeatable in this phase else the data will change and repeatable test fail.
- Once the skier ended the first part he stopped and bumped three times the ski with plate.
- Start the second style: wide carving. The curves have to be larger as possible (use of all the width of slope).
- Second stop of skier before the last change of inclination of slope. Make three bumps of ski with plate.
- Start the last part of ski slope. This is a part with SHORT carving, curves are repeated with high frequency.
- Last stop in the end of slope.
- Skier did three bumps and stop the Pocket acquisition.
- Open of boot buckles and clips.
- Stop SOMAT acquisition turning OFF the trigger switch.
- Turn OFF the general switch of SOMAT to preserve the battery.
- Stop video

Fig. 70: Particular moment of buckles closure

5.7 SKI SET UP

The first session of skiing, in data Febraury 28, ski used were spitfire 168 (see fig.58).

Left ski (SKI A1) was coupled with arm and the following measures could be provided:

- arm bending moment (ARBM)
- arm torque (ARTO)
- shovel bending moment (SHBM)
- shovel torque (SHTO)

Right ski (SKI A2) could measure shove torque.

The second session of skiing, in data March 10, ski used were spitfire 168 (SKI A1) on right and Nordica SLR (SKI B) on left because it was used this runs to measures angles and moments for another thesis.

The measures that could be provided on right ski are:

- arm bending moment (ARBM)
- arm torque (ARTO)
- shovel bending moment (SHBM)
- shovel torque (SHTO)

On left ski:

- Vertical force on tip and heel binding
- Ankle moment
- Shell-cuff angle
- Shell-tibia angle
- Forces on buckle closures

Fig. 71: ski used in session 2 (10-03-2014)

5.7 TABLE OF RUNS PERFORMED

SESSION	NAME	DATA	TIME	SLOPE	SKI USED	SNOW PROPERTY	TESTER
1	RUN 1	28/02/2014	10:30	SAN MARCO	A1+W , A2	HARD	STEFANO GORI
1	RUN 2	28/02/2014	10:50	SAN MARCO	A1+W , A2	HARD	STEFANO GORI
1	RUN 3	28/02/2014	11:10	SAN MARCO	A1+W , A2	HARD	STEFANO GORI
1	RUN 4	28/02/2014	11:30	SAN MARCO	A1 , A2	HARD	STEFANO GORI
1	RUN 5	28/02/2014	12:00	SAN MARCO	A1 , A2	MEDIUM	STEFANO GORI
1	RUN 6	28/02/2014	12:15	SAN MARCO	A1 , A2	MEDIUM	STEFANO GORI
2	RUN 7	10/03/2014	10:40	SAN MARCO	A1+W , B	MEDIUM	STEFANO GORI
2	RUN 8	10/03/2014	11:00	SAN MARCO	A1+W , B	MEDIUM	STEFANO GORI
2	RUN 9	10/03/2014	11:20	SAN MARCO	A1 , B	MEDIUM	STEFANO GORI
2	RUN 10	10/03/2014	11:50	SAN MARCO	A1 , B	SOFT	STEFANO GORI
2	RUN 11	10/03/2014	12:30	“NERA”	A1 , B	SOFT	STEFANO GORI
2	RUN 12	10/03/2014	13:10	“NERA”	A1+W , B	SOFT	STEFANO GORI

5.8 TESTS CONDITIONS

The independent research variable was substantially the presence or not of the wood superstructure. Run effectuated with arm provides difference in skier sensation, overall when snow is softer, this because ski length during carving is bigger and skier use more force to flex the ski. The presence of a superstructure reduce this force from skier and help him entering and exiting from a curve.

A second independent variable can be found in the type of skiing: normal or wide carving turns showed the larger differences with respect to short carving. In short carving shovel and tip of ski is lesser used and skiers load more the tail of the ski to change with high frequency the position of ski edges and to turn.

Weather variables can be temperatures and pressure. Humidity was substantially constant during the day. Tests were effectuated from 10:00 to 14:30 and temperatures were growing during the time of skiing.

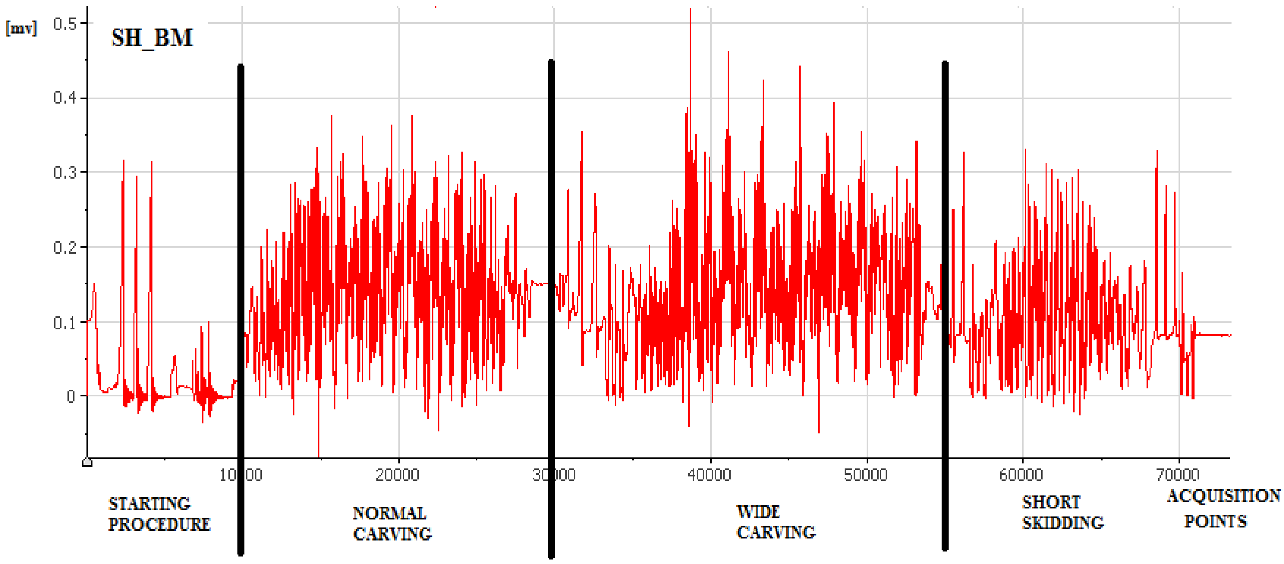
Slope inclination varied during the last two runs because of weather condition. “Nera” slope first part is a wall without sun during the day, so snow conditions tend to stay more constant.

Fig. 72: San Marco slope in San Vito di Cadore ski area

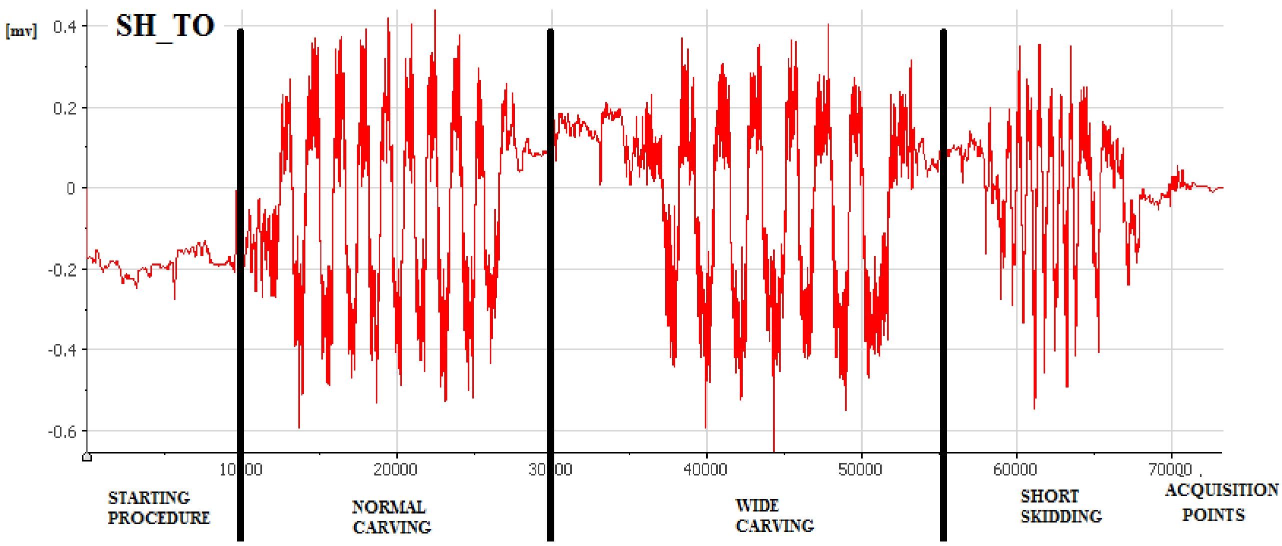
5.9 ANALYSIS OF TESTS

When skier finish all the runs, data acquired are downloaded from Pocket and from SOMAT. Analysis is concentrated on shovel and superstructure flexion and torsion. It was noted that flexion bridge don't give results, so it was keep flexion and torsion on shovel and on superstructure and torsion on the other ski bridge. Flexion is calculated like medium value of the two strain gauges output. Torsion is calculated as difference of output. Torsion from full bridge was calculated only for runs did on 28th Feb. The respective calibration constant were calculated in laboratory and the procedures are describe in the following chapters.

This is an example of shovel flexion in a total in-field run (data filtered at 5 Hz low pass):

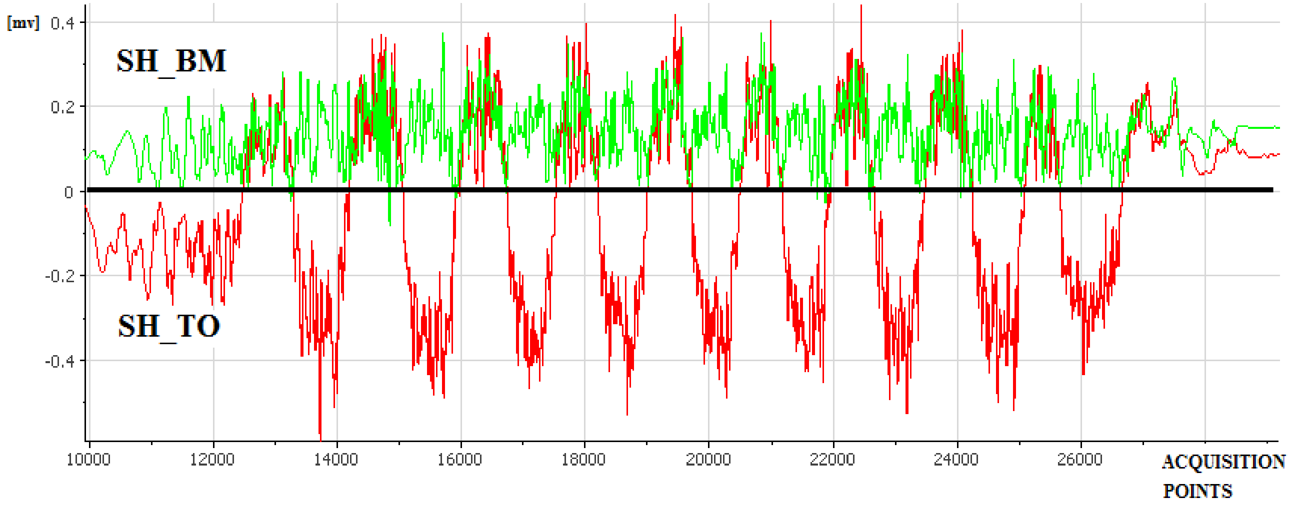


In this signal it's possible individuate the three style of skiing, but to individuate the singular curve there are two way: synchronize signals with video or observing torsion signals. Torsion bridges was calibrated for obtaining positive output when skier curves at left (ski torque at right) and negative output when skier curve at right (ski torque at left). This is an example of torsion in the total length of slope (data filtered at 5 Hz low pass):

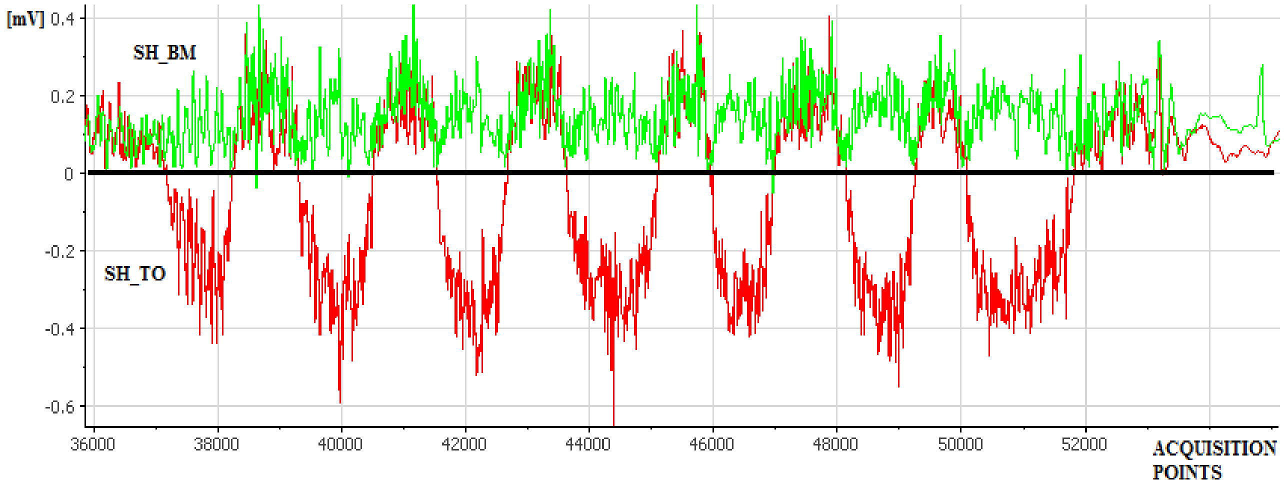


Zooming the three styles (torsion in red and flexion in green):

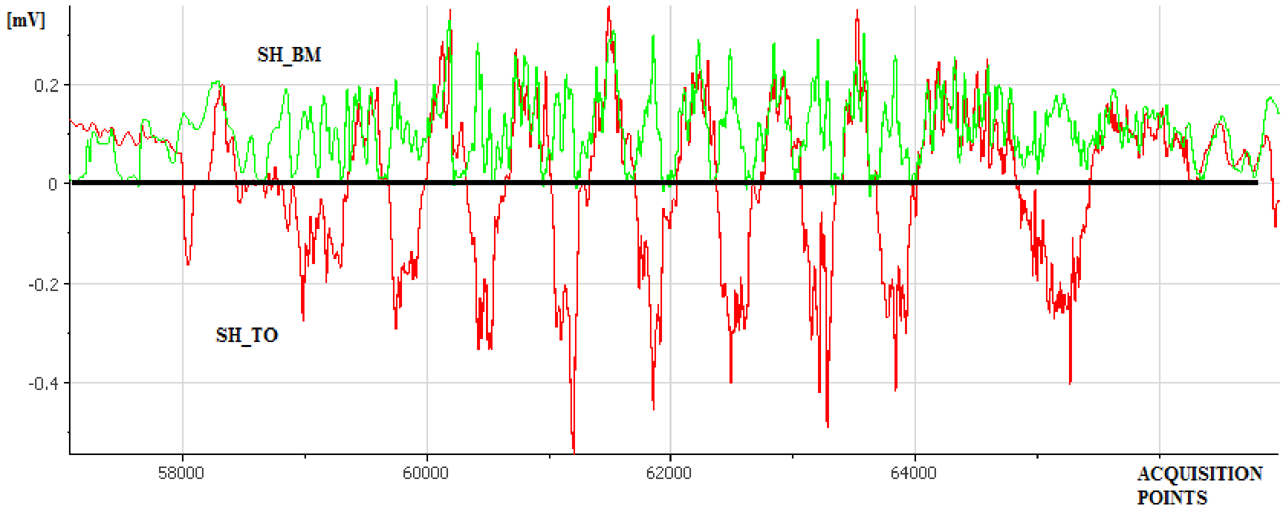
1)NORMAL CARVING



2)WIDE CARVING

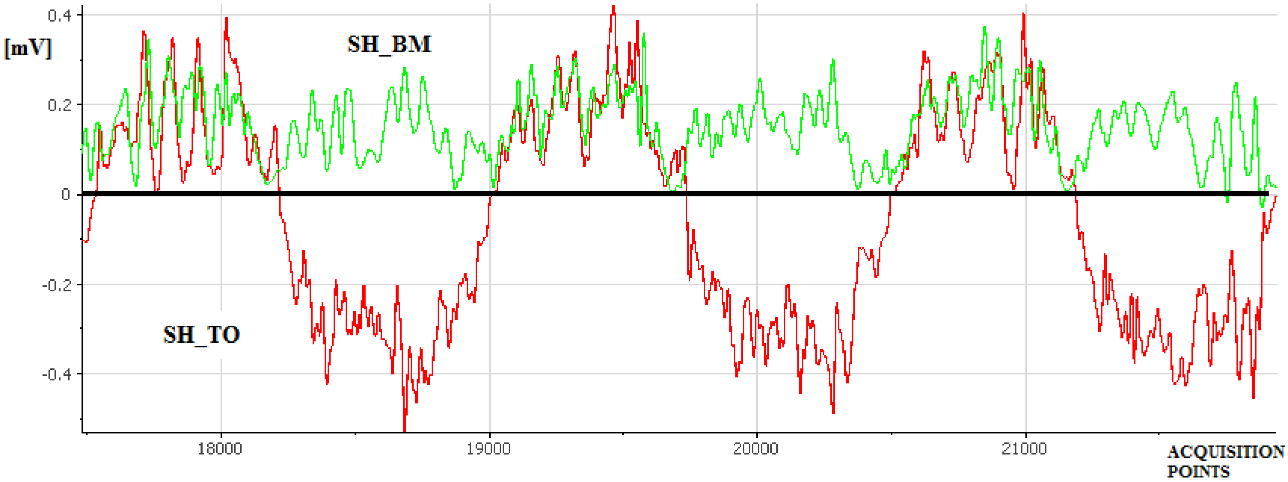


3)SHORT SKIDDING

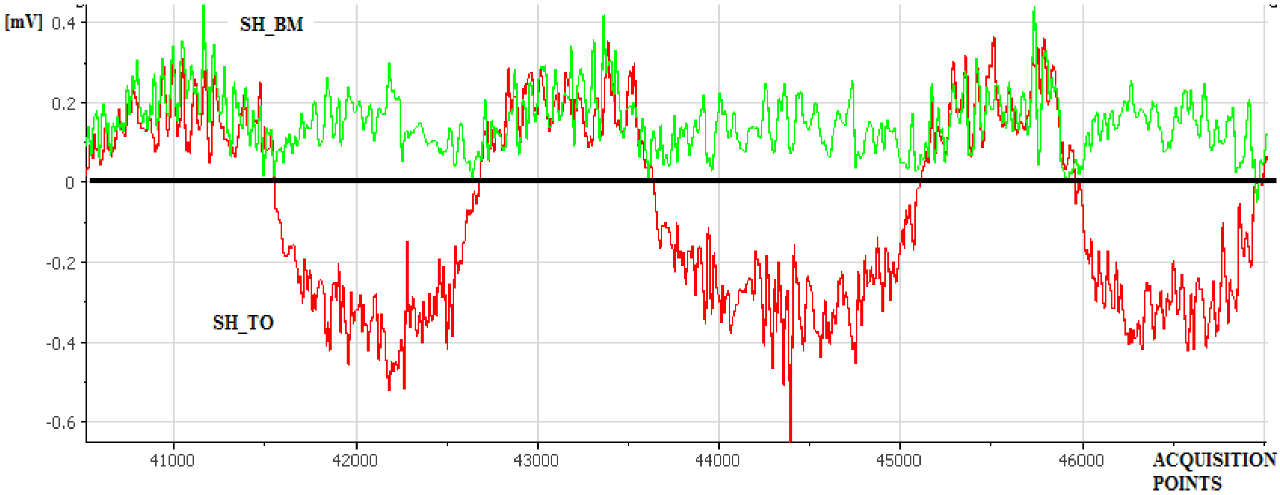


Zooming three consecutive curve for each style:

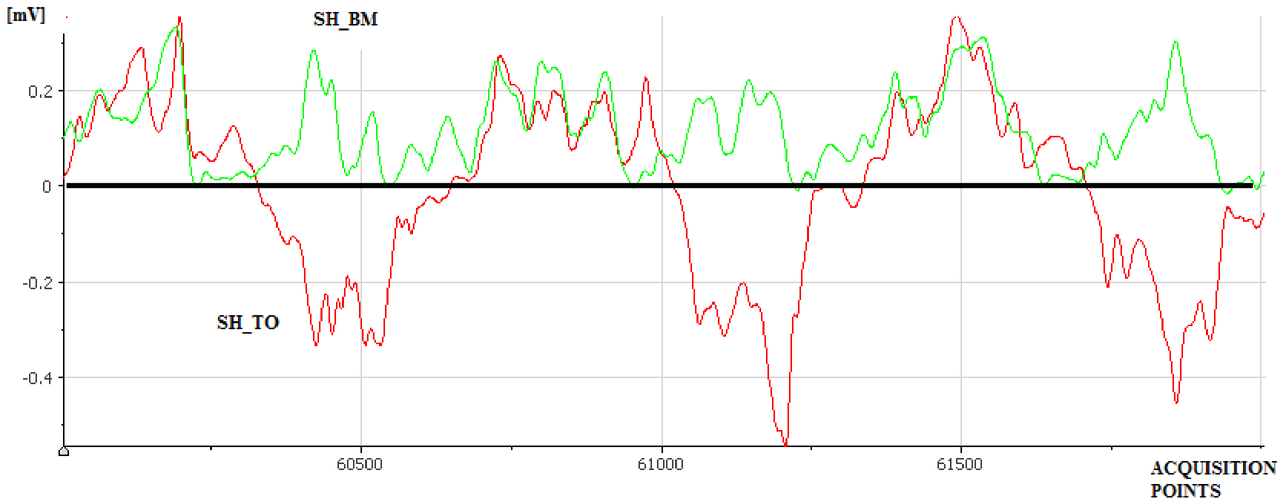
1)NORMAL CARVING



2)WIDE CARVING



3)SHORT SKIDDING



The following tables resumes the results coming from signals, after filtering with a low pass filter at 25 Hz, to cut away disturbs on signal. Bending moment is calculated like medium value of three peaks found on

signals for each of three consecutive curves. This curves were considered in the middle of a skiing style for not including transitory effects caused by starting and stopping procedures.
In “Nera” slope were done only two styles: one short skidding the wall and one normal in the valley part of slope. Values reported on tables are just multiply for the respective calibration constant. Calibration constant who permits to transform [mV] in [Nm] were calculated in laboratory with procedures explained in the next chapters. In the last row are reported the total mean value of bending moment relieved in in-field and standard deviation.

1)NORMAL CARVING (values in [Nm])

SKI	A2 int TORQUE	A2 ext TORQUE	A1 ext ARM fl	A1 int ARM fl	A1 ext ARM to	A1 int ARM to	A1 ext SH+ar fl	A1 int SH+ar fl	A1 ext SH+ar to	A1 int SH+ar to	A1 ext SH fl	A1 int SH fl	A1ext SH to	A1 int SH to
RUN1	9,07	11,22	55,68	39,9	69,21	10,58	40,11	33,99	23,58	0,77	-	-	-	-
RUN2	10,47	8,48	63,68	35,36	61,79	22,34	55,79	30,98	15,45	8,5	-	-	-	-
RUN3	9,56	10,13	39,78	26,98	68,17	5,88	34,64	25,28	11,55	2,98	-	-	-	-
RUN4	11,06	9,42	-	-	-	-	-	-	-	-	75,62	52,67	14,05	6,16
RUN5	10,09	8,45	-	-	-	-	-	-	-	-	76,7	65,81	17,89	1,2
RUN6	8,07	10,31	-	-	-	-	-	-	-	-	78,32	64,44	18,89	2,58
RUN7	-	-	57,85	28,66	53,61	26,57	47,92	26,6	11,41	5,39	-	-	-	-
RUN8	-	-	39,89	26,21	59,25	11,29	71,14	48,61	12,32	4,09	-	-	-	-
RUN9	-	-	-	-	-	-	-	-	-	-	83,79	64,51	5,15	8,52
RUN10	-	-	-	-	-	-	-	-	-	-	97,71	55,25	5,42	8,08
RUN11	-	-	-	-	-	-	-	-	-	-	68,7	62,38	10,94	7,98
RUN12	-	-	37,21	26,56	55,96	25,63	26,81	17,27	9,58	6,88	-	-	-	-
MEAN	9,72	9,67	49,01	30,61	61,33	17,05	46,07	30,46	13,98	4,77	80,14	60,85	12,06	5,75
S.D.	1,07	1,09	11,36	5,68	6,35	8,86	15,9	10,57	5,08	2,77	9,88	5,51	5,96	3,13

2) WIDE CARVING (values in [Nm])

SKI	A2 int TORQUE	A2 ext TORQUE	A1 ext ARM fl	A1 int ARM fl	A1 ext ARM to	A1 int ARM to	A1 ext SH+ar fl	A1 int SH+ar fl	A1 ext SH+ar to	A1 int SH+ar to	A1 ext SH fl	A1 int SH fl	A1ext SH to	A1 int SH to
RUN1	7,59	10,71	65,26	36,09	67,50	26,34	57,61	34,27	19,16	2,89	-	-	-	-
RUN2	9,00	9,23	74,64	44,40	51,53	23,98	55,89	35,19	12,66	6,53	-	-	-	-
RUN3	8,99	10,41	52,81	22,28	64,17	8,70	44,73	22,49	13,24	1,25	-	-	-	-
RUN4	10,30	8,58	-	-	-	-	-	-	-	-	80,90	58,70	17,16	2,66
RUN5	9,95	10,07	-	-	-	-	-	-	-	-	93,00	75,00	19,42	1,25
RUN6	8,09	9,54	-	-	-	-	-	-	-	-	90,00	76,90	18,46	4,06
RUN7	-	-	60,82	47,02	60,20	34,57	56,62	40,66	16,85	5,29	-	-	-	-
RUN8	-	-	42,56	29,77	51,97	28,92	74,17	57,06	15,11	6,97	-	-	-	-
RUN9	-	-	-	-	-	-	-	-	-	-	86,60	59,20	7,51	9,43
RUN10	-	-	-	-	-	-	-	-	-	-	79,30	62,20	6,37	9,78
MEAN	8,99	9,76	59,22	35,91	59,07	24,5	57,8	37,94	15,4	4,59	85,96	66,4	13,78	5,44
S.D.	1,04	0,79	12,2	10,23	7,17	9,67	10,53	12,58	2,67	2,45	5,86	8,83	6,31	3,94

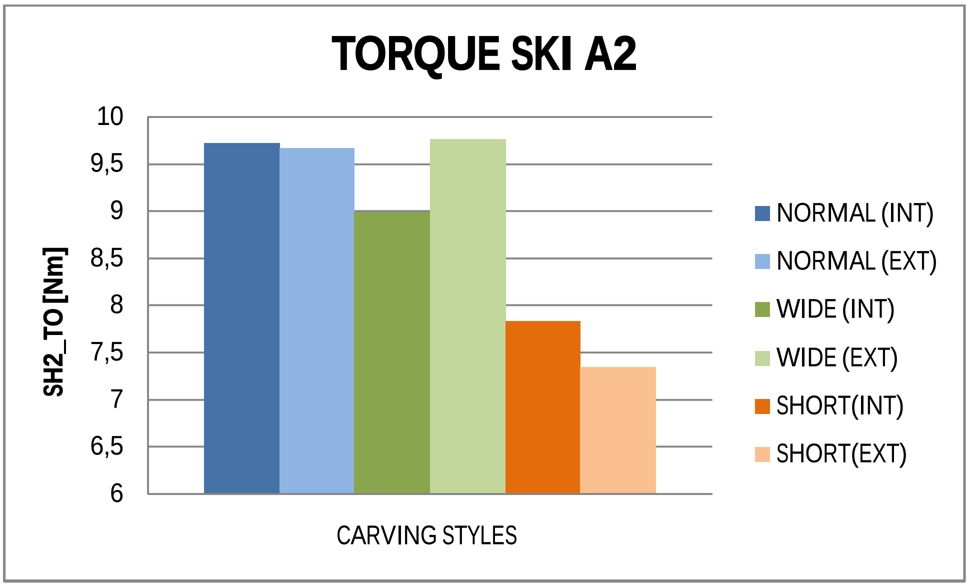
Last two run are not reported because in slope “Nera” were done only normal and short carving.

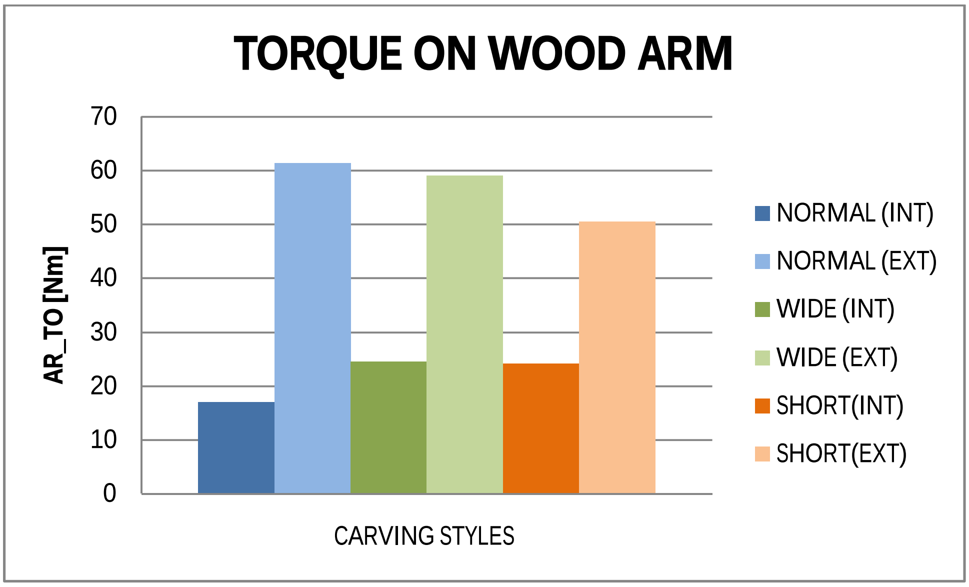
3)SHORT SKIDDING (values in [Nm])

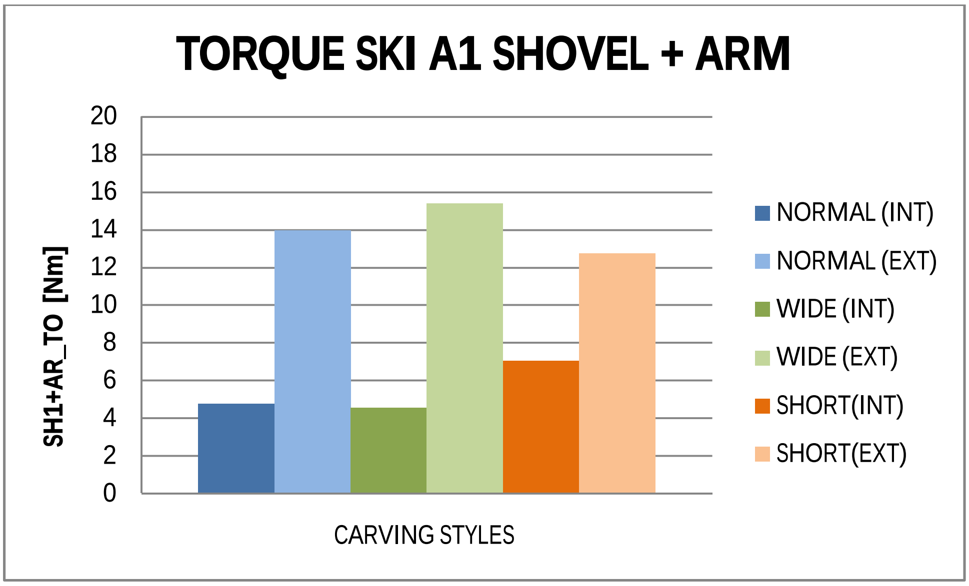
SKI	A2 int TORQUE	A2 ext TORQUE	A1 ext ARM fl	A1 int ARM fl	A1 ext ARM to	A1 int ARM to	A1 ext SH+ar fl	A1 int SH+ar fl	A1 ext SH+ar to	A1 int SH+ar to	A1 ext SH fl	A1 int SH fl	A1ext SH to	A1 int SH to
RUN1	5,29	7,63	35,2	29,37	38,33	28,92	34,7	25,46	14,05	4,67	-	-	-	-
RUN2	8,56	7,16	42,76	31,6	39,98	22,46	37,86	27,76	13,77	13,12	-	-	-	-
RUN3	7,31	8,07	31,22	17,76	45,58	10,82	28,87	18,77	8,9	3,26	-	-	-	-
RUN4	10,3	5,13	-	-	-	-	-	-	-	-	69,3	40	18,47	6,257
RUN5	8,75	6,65	-	-	-	-	-	-	-	-	78,9	60,4	19,14	1,756
RUN6	6,85	9,43	-	-	-	-	-	-	-	-	75,1	44	17,59	0,326
RUN7	-	-	55,87	33,15	55,26	20,46	40,29	22,15	15,11	8,76	-	-	-	-
RUN8	-	-	37,67	28,13	73,36	38,09	68,06	54,63	11,94	5,39	-	-	-	-
RUN9	-	-	-	-	-	-	-	-	-	-	84,5	51,2	7,027	6,113
RUN10	-	-	-	-	-	-	-	-	-	-	78,3	38,9	6,221	4,716
RUN11	-	-	-	-	-	-	-	-	-	-	99,3	64,4	9,182	9,182
RUN12	-	-	62,83	40,24	84,18	4,94	49,95	23,9	15,11	10,16	-	-	-	-
MEAN	7,84	7,35	40,55	28	50,5	24,15	41,96	29,76	12,75	7,04	80,9	49,8	18,4	2,78
S.D.	1,74	1,44	9,53	6,05	14,39	10,14	15,2	14,32	2,44	3,95	10,3	10,7	0,78	3,09

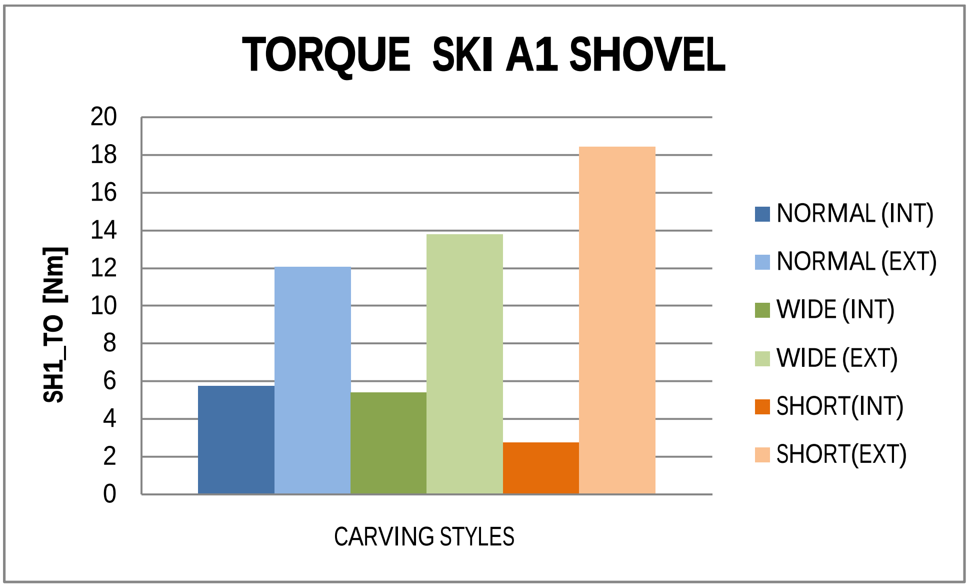
Last two short run were effectuated on slope "Nera".

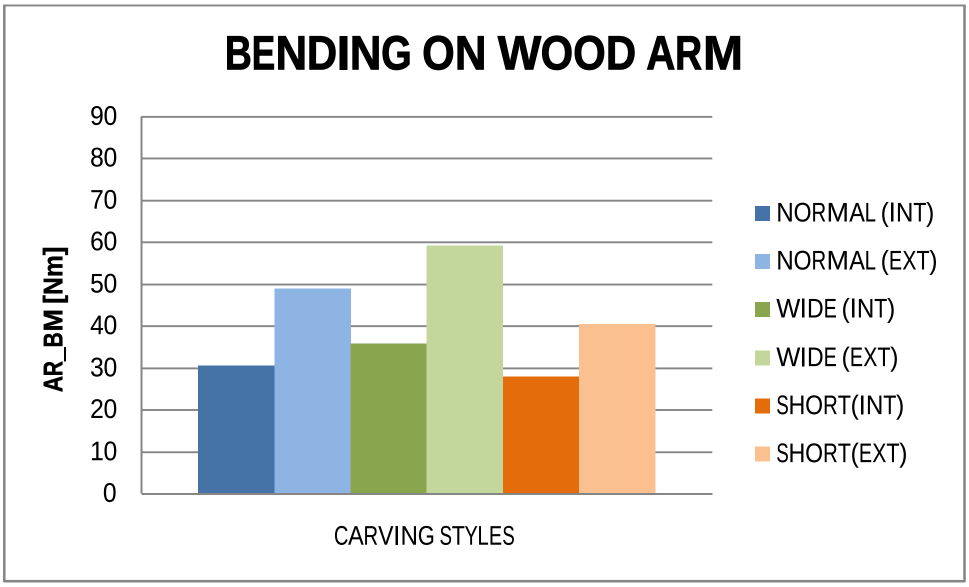
It's reported some histograms about carving analysis (values reported are average value of peaks taken on three consecutive curves):

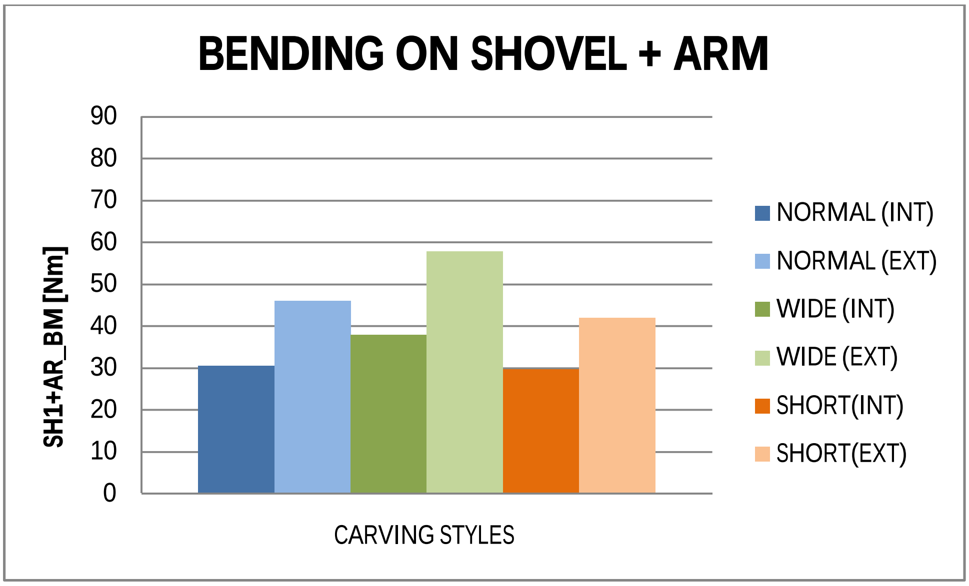


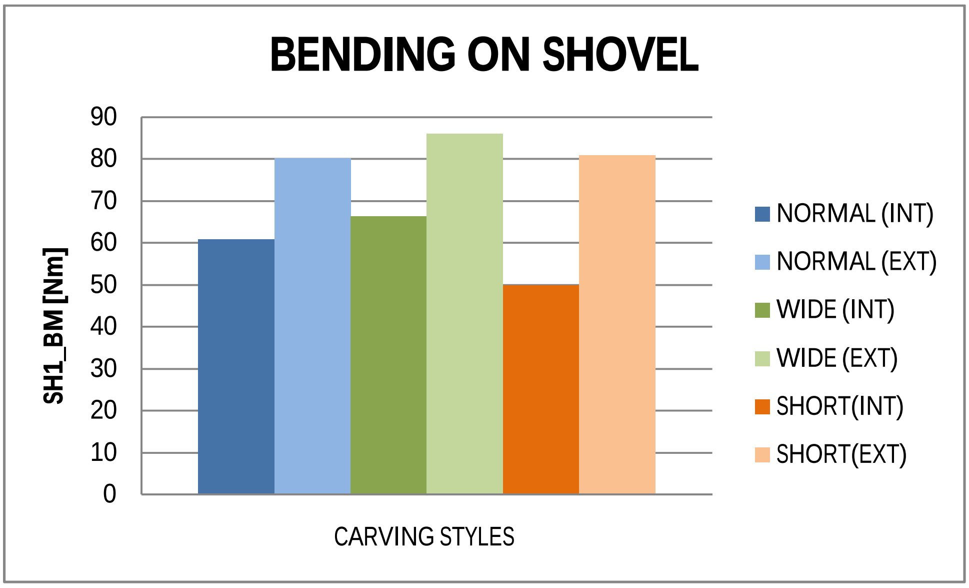

TORQUE ON WOOD ARM
AR_TO [Nm]
70
60
50
40
30
20
10
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)


TORQUE SKI A1 SHOVEL + ARM
SH1+AR_TO [Nm]
20
18
16
14
12
10
8
6
4
2
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)


TORQUE SKI A1 SHOVEL
SH1_TO [Nm]
20
18
16
14
12
10
8
6
4
2
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)

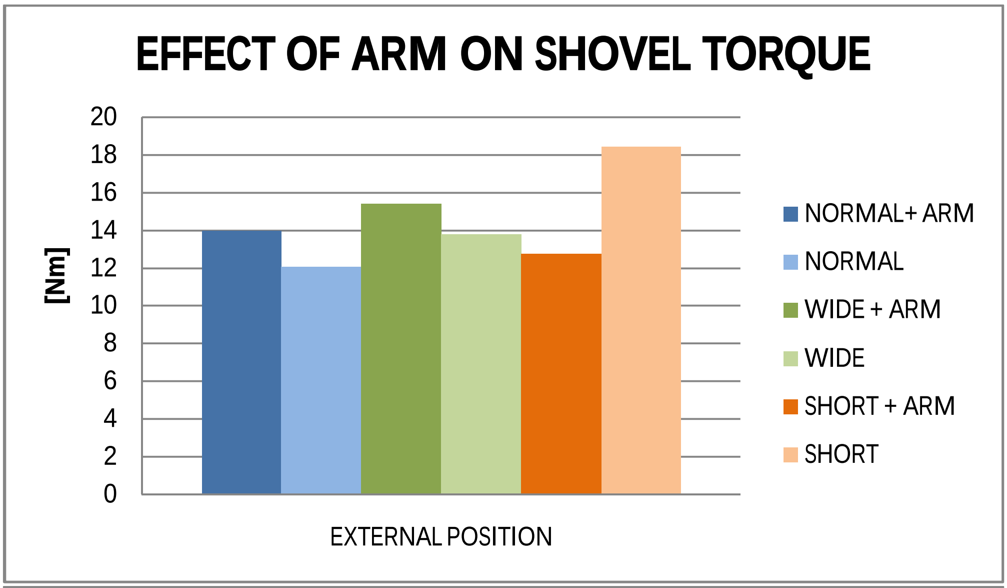

BENDING ON WOOD ARM
AR_BM [Nm]
90
80
70
60
50
40
30
20
10
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)

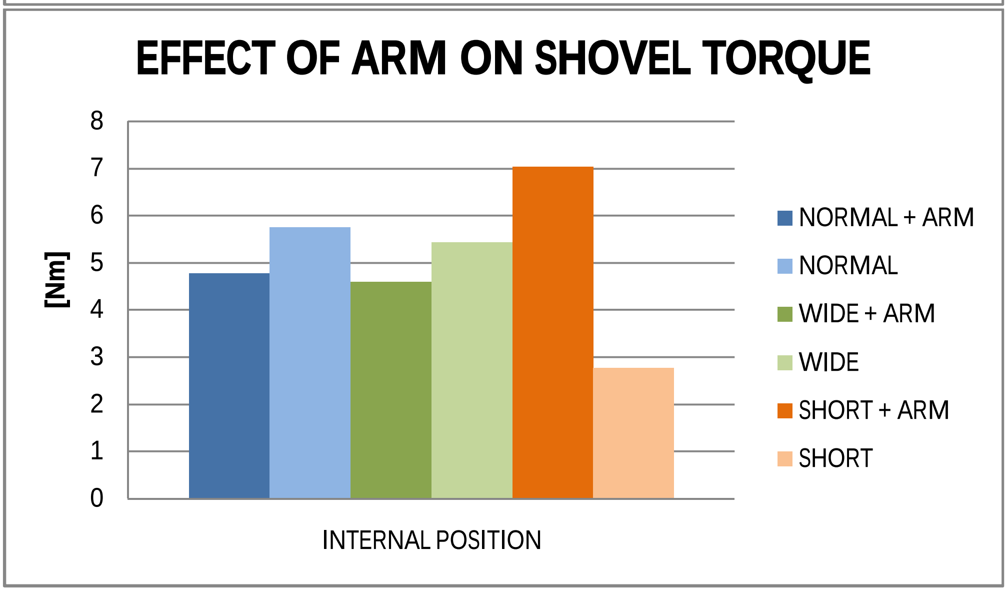

BENDING ON SHOVEL + ARM
SH1+AR_BM [Nm]
90
80
70
60
50
40
30
20
10
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)

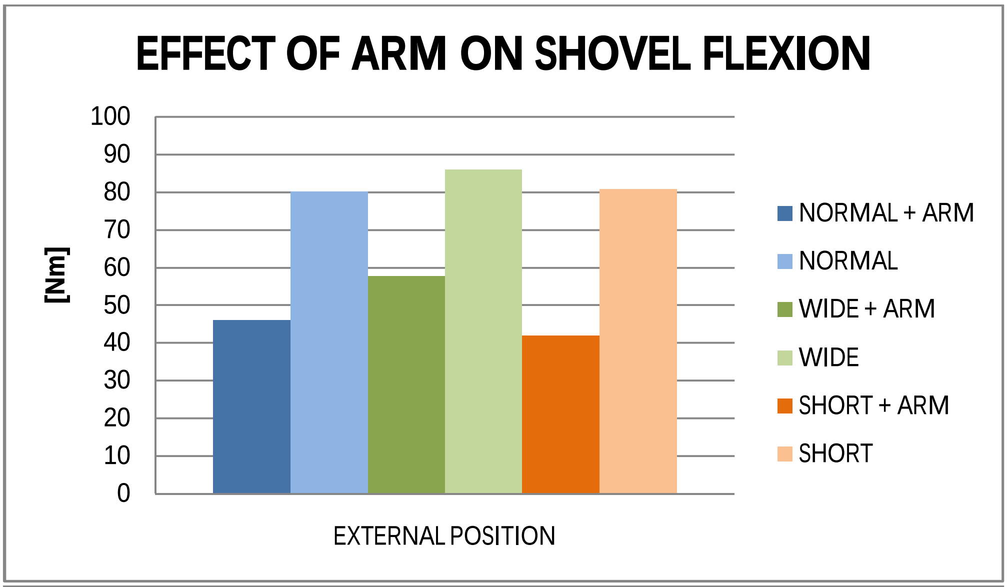

BENDING ON SHOVEL
SH1_BM [Nm]
90
80
70
60
50
40
30
20
10
0
CARVING STYLES
NORMAL (INT)
NORMAL (EXT)
WIDE (INT)
WIDE (EXT)
SHORT(INT)
SHORT(EXT)

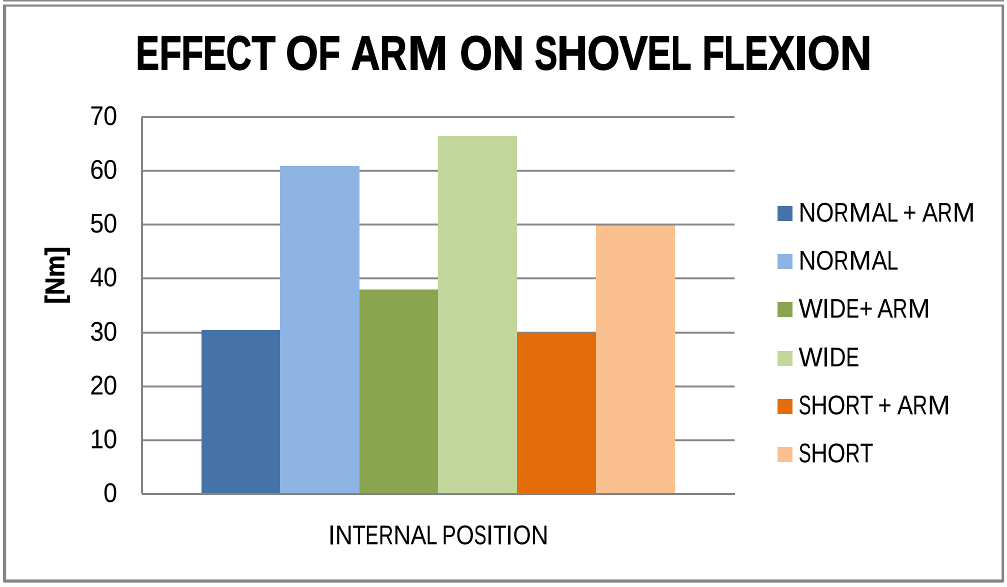
5.10 DIFFERENCES ON RESULTS

In-field texts shows that in a wide configuration of skiing style with superstructure on ski it's relieved the higher value of bending moment when ski was in external position. It's possible to find repeatability on results in a range of some [Nm]. It's possible to look at the maximum amplitude of curve in time in the plot of signals. Wide carving is connected at long curve. Normal carving, as show in histograms has medium value of bending moment. Short carving has minimum value of bending moment and a tight plot of signal for a curve, probably ski have not time to flex his structure because curves are repeated with high frequency and skiers tended to release his weight on tail for searching easily an equilibrium position and to affront curves rapidly for changing edge.
Note that when ski is on the external side of curve the values are higher, and this concords with the reality because skiers download their weight on the external leg when they affront a curve.
About torque, the maximum values are found in normal and wide style in external position of ski when superstructure is present. Without superstructure the maximum of torque is show in short style, due to rapid change of edge.
There are reported some histogram who show the effect of superstructure on shovel torque and on shovel bending moment in the three styles of carving. Position of ski is indicate under the columns.









In case of torque the presence of a superstructure in wood material of 28,42 N/mm of stiffness provides less effect on normal and on wide carving when ski is in both position. Greater effect is present in short carving: shovel is under torsion when there is not arm, but in the internal position the no arm configuration provides a less value of torque with respect to shovel + arm configuration.

In case of bending moment , external or internal position of ski provides the same trend of values: always the presence of the superstructure provides lower value of bending moment in the three styles with respect to the original configuration of the ski. Without superstructure ski flexional range of motion is greater, so ski is able to receive more bending moment. With superstructure ski results more rigid, and his range of motion is lower and part of bending moment is received by the same superstructure. So ski + arm configuration absorb a great bending moment if flexed with the same displacement obtained in original configuration: this effect plays in advantage for skiers who want improve their capabilities pulling with higher value of force in carving and, at the same time, improving the inclination angle of ski.

It's reported a plot for showing an estimation of force who acts on wood superstructure during a run. Taking as reference the values of bending moment calculated in the previous paragraph, and dividing for the distance between strain gauges section and the contact edge of arm on ski, these are the results:

CARVING	SKI POSITION	B.M. [Nm]	FORCE [N]
NORMAL	INT	30,61	160,26
NORMAL	EXT	49,01	256,60
WIDE	INT	35,91	188,01
WIDE	EXT	59,22	310,05
SHORT	INT	28	146,60
SHORT	EXT	40,55	212,30

The following tables report the percentual differences on torque and on bending moment for settings with and without arm, and then differences on torque and on bending moment with respect to the ski position.

TORQUE ON EXTERNAL SKI [Nm]

	SH+ARM	ONLY SH	Δ %
NORMAL	13,98	12,06	-15,92%
WIDE	15,4	13,78	-11,76%
SHORT	12,75	18,4	30,71%

TORQUE ON INTERNAL SKI [Nm]

	SH+ARM	ONLY SH	Δ %
NORMAL	4,77	5,75	17,04%
WIDE	4,59	5,44	15,63%
SHORT	7,04	2,78	-153,24%

B.M. ON EXTERNAL SKI [Nm]

	SH+ARM	ONLY SH	Δ %
NORMAL	46,07	80,14	42,51%
WIDE	57,8	85,96	32,76%
SHORT	41,96	80,91	48,14%

B.M. ON INTERNAL SKI [Nm]

	SH+ARM	ONLY SH	Δ %
NORMAL	30,46	60,85	49,94%
WIDE	37,94	66,4	42,86%
SHORT	29,76	49,82	40,26%

TORQUE ON WOOD ARM [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	17,05	61,33	72,20%
WIDE	24,5	59,07	58,52%
SHORT	24,15	50,5	52,18%

B.M.ON WOOD ARM [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	30,61	49,01	37,54%
WIDE	35,91	59,22	39,36%
SHORT	28	40,55	30,95%

TORQUE ON SHOVEL+ARM [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	4,77	13,98	65,88%
WIDE	4,59	15,4	70,19%
SHORT	7,04	12,75	44,78%

B.M. ON SHOVEL+ARM [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	30,46	46,07	33,88%
WIDE	37,94	57,8	34,36%
SHORT	29,76	41,96	29,08%

TORQUE ON ONLY SHOVEL [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	5,75	12,06	52,32%
WIDE	5,44	13,78	60,52%
SHORT	2,78	18,4	84,89%

B.M. ON ONLY SHOVEL [Nm]	INTERNAL	EXTERNAL	Δ %
NORMAL	60,85	80,14	24,07%
WIDE	66,4	85,96	22,75%
SHORT	49,82	80,91	38,43%

5.10.1 EFFECT OF SUPERSTRUCTURE ON RESULTS

In this table are given the values of shovel coupled with wood arm bending moment, arm on ski bending moment and then a comparison between theoretical sum of these two and the results of only ski shovel bending moment, because if tester was repeatable, the hypothesis is that the presence of superstructure splits the total only shovel bending moment in two components, one absorbed by ski and one by the superstructure. Note that there is some differences from experimental and theory values and they are lesser for ski in internal position, so for ski lower loaded. In tables SH_{EXP} stay for only shovel bending moment.

BENDING MOMENT (EXTERNAL SKI) [Nm]

STYLE	SH+W	W	SH_{EXP}	SH_{TH}	DIFF TH-EXP
NORMAL	46,07	49,01	80,14	95,08	15,71%
LARGE	57,8	59,22	85,96	117,02	26,54%
SHORT	41,96	40,55	80,91	82,51	1,94%

BENDING MOMENT (INTERNAL SKI) [Nm]

STYLE	SH+W	W	SH_{EXP}	SH_{TH}	DIFF TH-EXP
NORMAL	30,46	30,61	60,85	61,07	0,36%
LARGE	37,94	35,91	66,4	73,85	10,09%
SHORT	29,76	28	49,82	57,76	13,75%

5.10.2 COMPARISON WITH SLYTECH BENCH

The follow tables provide a comparison of in-field load acquired for shovel + arm configuration and Slytech bench maximum bending moment received by strain gauges. The percentual differences indicate how much the in-field values are far from laboratory maximum value.

BENDING MOMENT (EXTERNAL SKI) [Nm]

STYLE	SH+W IN-FIELD	SH+W BENCH	Δ% BE-IN
NORMAL	46,07	55,25	-16,62%
LARGE	57,8	55,25	4,61%
SHORT	41,96	55,25	-24,06%

BENDING MOMENT (INTERNAL SKI) [Nm]

STYLE	SH+W IN-FIELD	SH+W BENCH	Δ% IN-BE
NORMAL	30,46	55,25	-44,87%
LARGE	37,94	55,25	-31,33%
SHORT	29,76	55,25	-46,14%

5.11 CONCLUSIONS

Supposing that tester was repeatable on all the runs, it's possible to see that there is a substantial difference on internal and external position of ski during a turn, in fact the external ski is more loaded in bending and in torque. This is right because external ski adsorbed greater part of the centrifugal force that act on skier. This is because skier needs to load more the external leg to equilibrate centrifugal effects.

The presence of arm comports at a growing of bending moment in both position of the ski. But in torque there is a different behavior. External ski torque is greater for normal and wide carving and append the opposite for short skidding. The reverse behavior for the ski in internal position. The presence of arm reduce the value of torque on shovel on short skidding, probably due to high frequency of curves, and skier don't have the time to bend the ski as it's happened for normal and wide styles.

Bending moment in-field results compared with Slytech bench provides that values on slopes are lower than bench. Only for wide carving it's possible to observe a bending moment higher than bench when ski is in external position. This is due to long time available for completing a turn and skier could be able to enter in the turn with a greater angle of inclination. If 55,25Nm comes from 60° of inclination on Edge Load Profile bench, it's possible to suppose that the skier had inclined the internal ski over the 60° in wide carving.

Forces on arm are bigger than forces used in laboratory to characterized superstructure and ski. So a future task could be a new characterization with higher load and watching if the linearity of material is maintained or not.

Chapter 6: DEVELOPMENT AND FINITE ELEMENTS ANALYSIS OF A NEW STIFFNESS COMPENSATION SUPERSTRUCTURE

6.1 INTRODUCTION

Laboratory and in field experiences about ski coupled with compensation arm shows that the better result is given by a wood arm of 300mm length and 28,42 N/mm of bending stiffness. This structure is added to ski with a rigid bound, in these case with 4 screws in front of the anterior binding. This values comes from characterization tests did in laboratory using a wood arm 300mm length.

A new compensation arm is developed with the idea of transfer the rigid bond under the anterior binding and then to extend the plate in a way that plate and compensation arm become a unique piece.
Marker Piston plate could be disassembled in different part, expecially, the anterior one presents the principal core of the plate, a little plate which cover the lower surface of core plate, and a rubber damper.

Fig. 73:Marker Piston plate

The idea is that of reproducing this little plate, extending it in front of core plate and then create a rung from which it starts the compensation arm. The compensation arm has to have the same length and the same stiffness of the single wood arm that presented better results in previous experiences.
The unique piece has the advantage to allow the manufacturer to create plates with embedded arm, without later drilling on ski, like for rigidly coupling a normal arm. The disadvantage would be the creation of new mould for a series production.

This new structure is dimensioned with two kind of material, to have an idea of the volumes occupied when they will be coupled on a ski. Material used are polyamide resin and aluminum.

6.2 DIMENSIONING AND MATERIALS

The study starts from the measurements of length and stiffness of wood arm (characterization studies and tests on Slytech bench). This parameters (explained in the previous paragraph) are the initial point of new arm development.

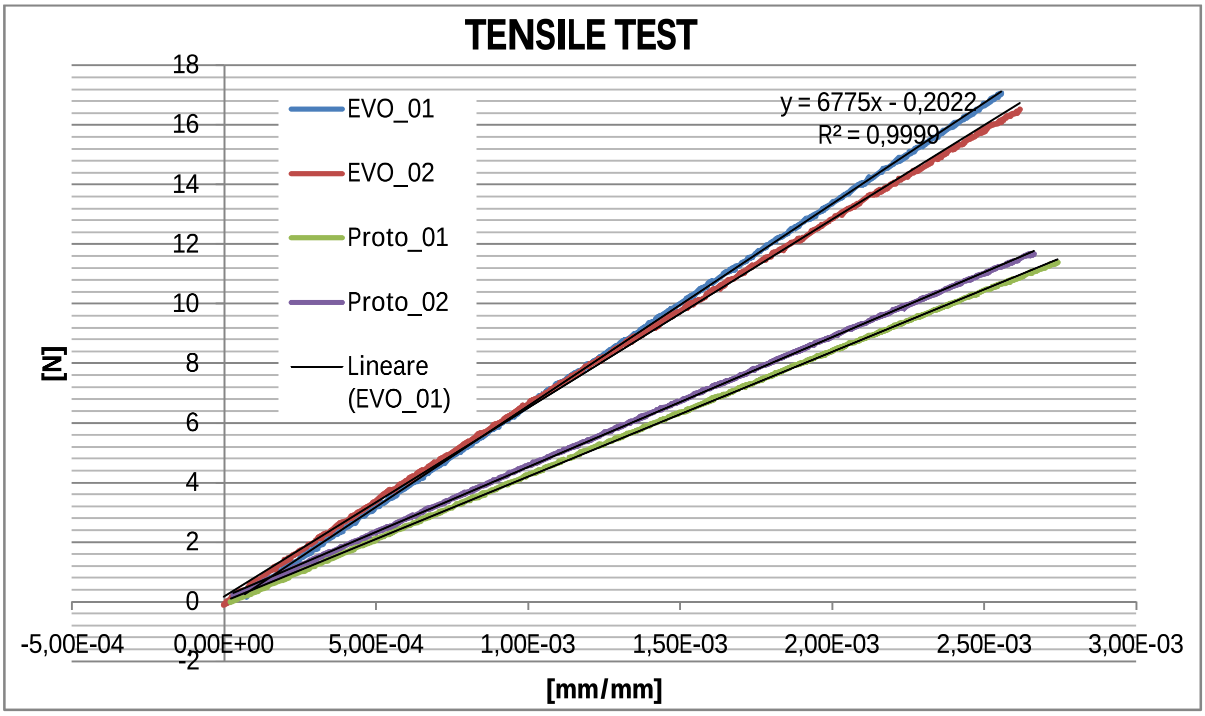
Material used are aluminum and POM (polyamide resin) which has the same rigidity of the material in which plates are made.

Some traction test on MiniBionix were done in laboratory to characterize this material.

This picture provides an example of a traction test of a POM specimen:

Fig. 74: Mini Bionix Traction test

The follow plot represent the answer of traction test machine. By linear interpolation of curve it's possible to obtain Young modulus of the specimen. The highest value of Young modulus, so the greater pendance of the following diagram is chosen for the dimensioning of the new structure.



From traction test of plate specimens in Padua laboratory, Young modulus is:

$$E = \frac{F/A}{\varepsilon} = 6775\ MPa$$

Aluminum Young modulus used is E=70000 MPa.
Marker little plate is simplified in this studies because it was observed that some particular on the plate surface were unnecessary for a future development, and simplify the creation of a new mould.
Eliminated particulars are shown in the figure in red color. Modified particulars in green color.

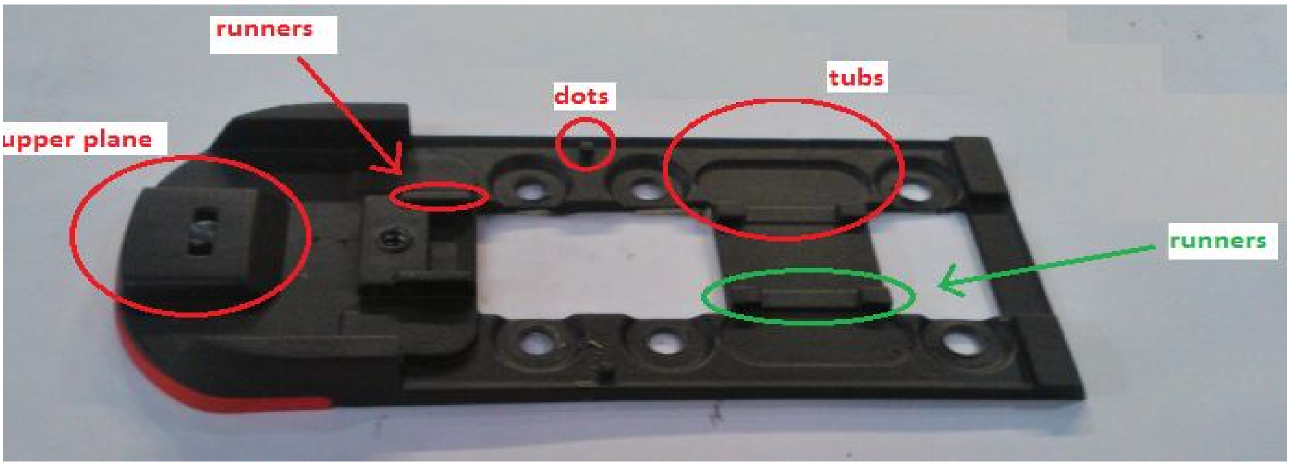


Fig. 75: Little plate particulars

Upper plane and runners next to hit are smoothed, dots are eliminated, tubs are topped up until the principal plane of the plate. Runners in the middle are modified: the four little squares became two extended rectangles. This to simplify the model and to simplify the realization on a drill at numeric control. Other two aims on the long side of the plate are developed to compensate the deformation dues by bending moment.
Preliminary studies were concentrated on the development of little plate with a rung high 13mm extended of 50mm, with upper surface inclined of 3,7°. This for coupling the existent wood compensation arms. The inclination is important, because using this inclination the opposite extreme edge of arm will touch the ski upper surface without preload.

This is an example:

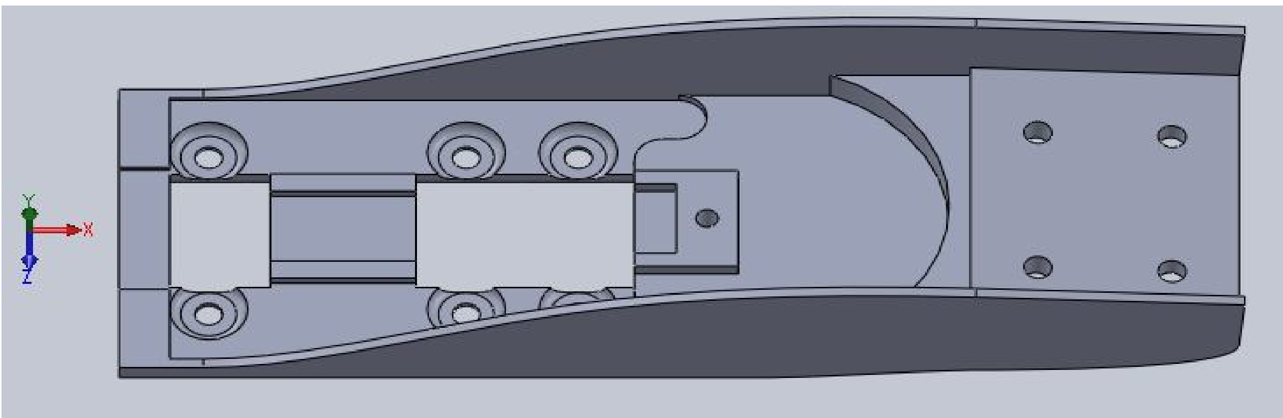


Fig. 76: 3D model of initial aluminum plate

The dimensioning of the unique piece is restricted only at the compensation arm, because it’s retained more important to reproduce a unique piece that have the same bending stiffness of the original compensation arm. Bending stiffness is calculated from the section where ideally arm and plate would be welded. So

dimensioning started from this section. The idea is to create an arm with a U cross section shape and thickness of 3mm.
Example of cross section:

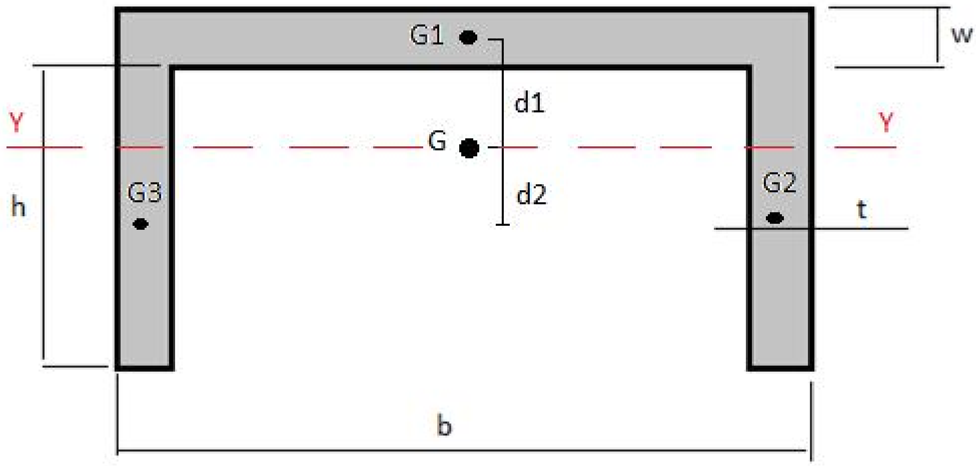


Fig. 77: Cross section used for dimensioning

6.3 ANALYTICAL CALCULATION:

Supposing that the stiffness is 28,42 N/mm, and maintaining the same width of the last section, the only unknown parameter is the high of the cross section:

- bending length: L = 250mm
- width of last section: b = 52mm
- width of first section: b = 66mm (new value from little plate geometry bound)
- cross section moment of inertia equation:

$$J_{YY} = \frac{bt^3}{12} + btd_1^2 + 2\left(\frac{th^3}{12} + thd_2^2\right)$$

Where d1 and d2 are function of h:

$$d_1 = h + \frac{w}{2} - \frac{\frac{bw^2}{2} + bhw + h^2t}{bw + 2ht}$$

$$d_2 = \frac{h}{2} + \frac{t}{2} - d_1$$

- bending stiffness (classic mechanical) equation:

$$K = \frac{3EJ_{YY}}{L^3}$$

Starting from a chosen value for h, the first arm analytical model is a beam of constant width, high and thickness. The analysis is completed applying classic mechanical formulas for beam rigidly bonded on a surface and loaded with a concentrated force on the opposite edge.

Fig. 78: Beam static model

Beam is divided in equal part (Δx=5mm) on his length, this for providing an accurate result. Each part is considered as sub-beam of 5 mm length. So displacements and rotation is given by concentrated forces and bending moment coming from force and distance L-x from force to the considered section :

BM=F(L-x)

Displacement:

$$f_1 = \frac{Fl^3}{3EJ}$$

$$f_3 = \frac{BMl^2}{2EJ}$$

Rotations:

$$\phi_2 = \frac{Fl^2}{2EJ}$$

$$\phi_4 = \frac{BMl}{EJ}$$

Rigid rotation:

$$f_2 = (\Delta x)\phi_2$$

$$f_4 = (\Delta x)\phi_4$$

The sum of f1 f2 f3 f4 repeated for each sub-beam has to give the displacement value that provides 28,42 N/mm of stiffness in the previous experiences. Force applied is 125N. So the total displacement is:

f=F/k = 125/28,42 = 4,39mm

The analysis continues applying an objective research: obtaining the total sum 4,39mm changing one parameter. This parameter is the high of the structure.

In a first approach constant cross section was considered for both materials, so constant high for all the length of the arm. This for having an idea of how much volume occupy the new structure.
Example are shown in these figures: aluminum the first, POM the second.

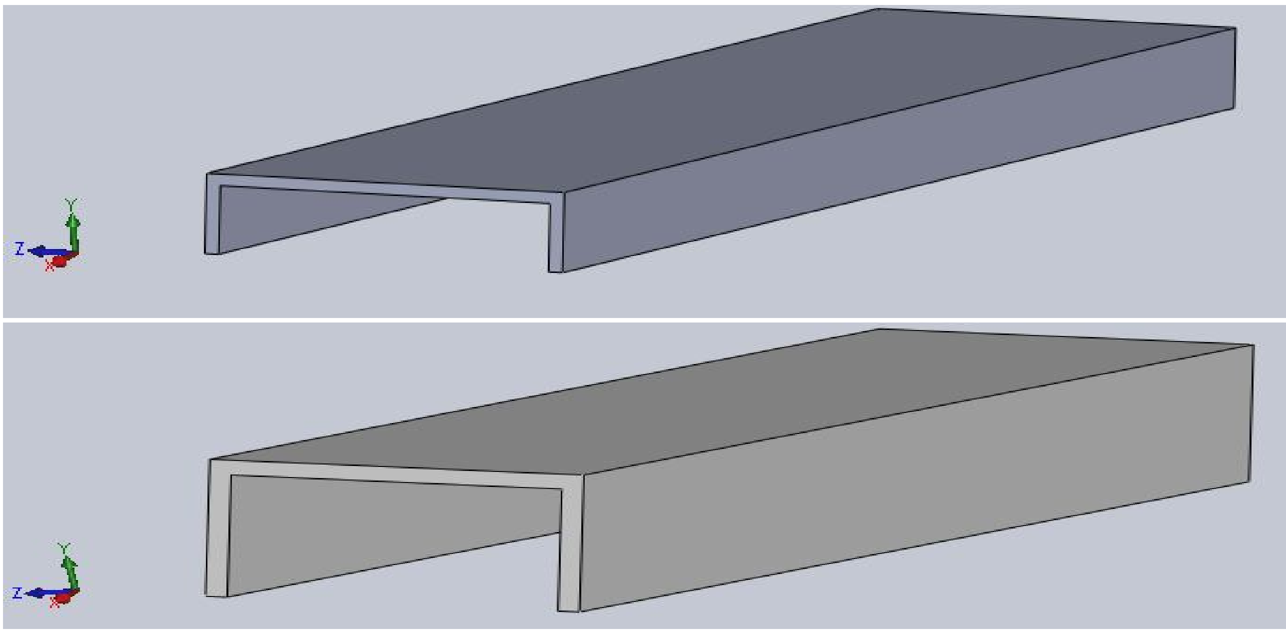
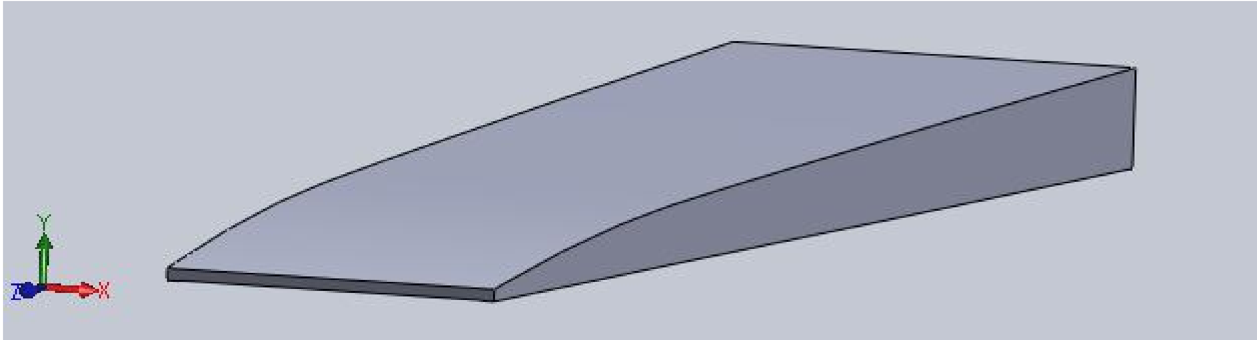


Fig. 79: aluminum (up) and pom (down) 3D model of constant cross section

Then a successive objective research was started applying a parabolic profile at high. Examples are shown in these figures: aluminum the first , POM the second.



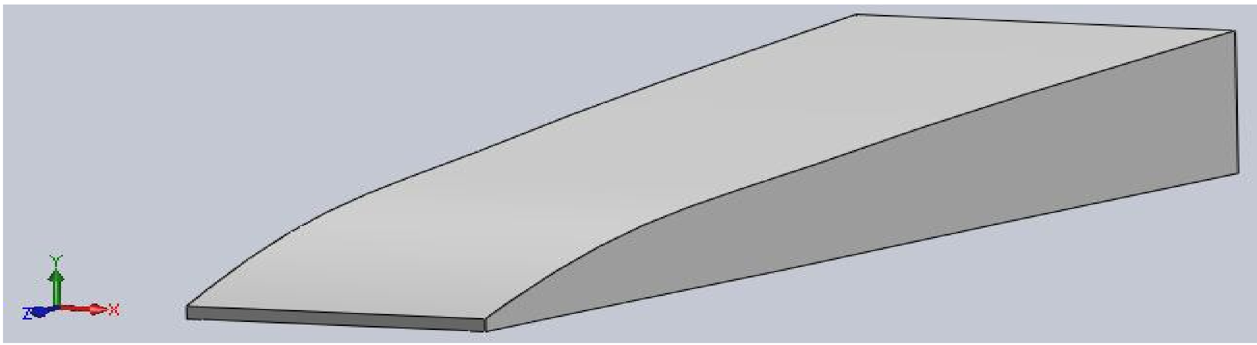


Fig. 80: aluminum (up) and POM (down) 3D model of variable cross section

Parabolic profiles goes from h (vertex) and h_0 (upper profile); the lower profile of arm is a straight line.
Arm width is decreasing from first to last cross section, and it's value goes from 64 to 52 mm for aluminum solution, and from 66 to 52 for POM solution.
Cross sections used for reducing time in 3D modeling are chosen at step of 50mm length.
Table with dimensions in mm (aluminum parabolic profile):

x	b	h	t	w
0	64	14,5	2	2
50	61,6	12,97	2	2
100	59,2	11,24	2	2
150	56,8	9,17	2	2
200	54,4	6,48	2	2
250	52	0	2	2

Table with dimensions in mm (POM parabolic profile):

x	b	h	t	w
0	66	30,15	3	3
50	63,2	26,97	3	3
100	60,4	23,35	3	3
150	57,6	19,07	3	3
200	54,8	13,48	3	3
250	52	0	3	3

The following step was the connection of arm and little plate. Solutions are proposed on the next imagines.

Aluminum profile view is shown in this pictures:

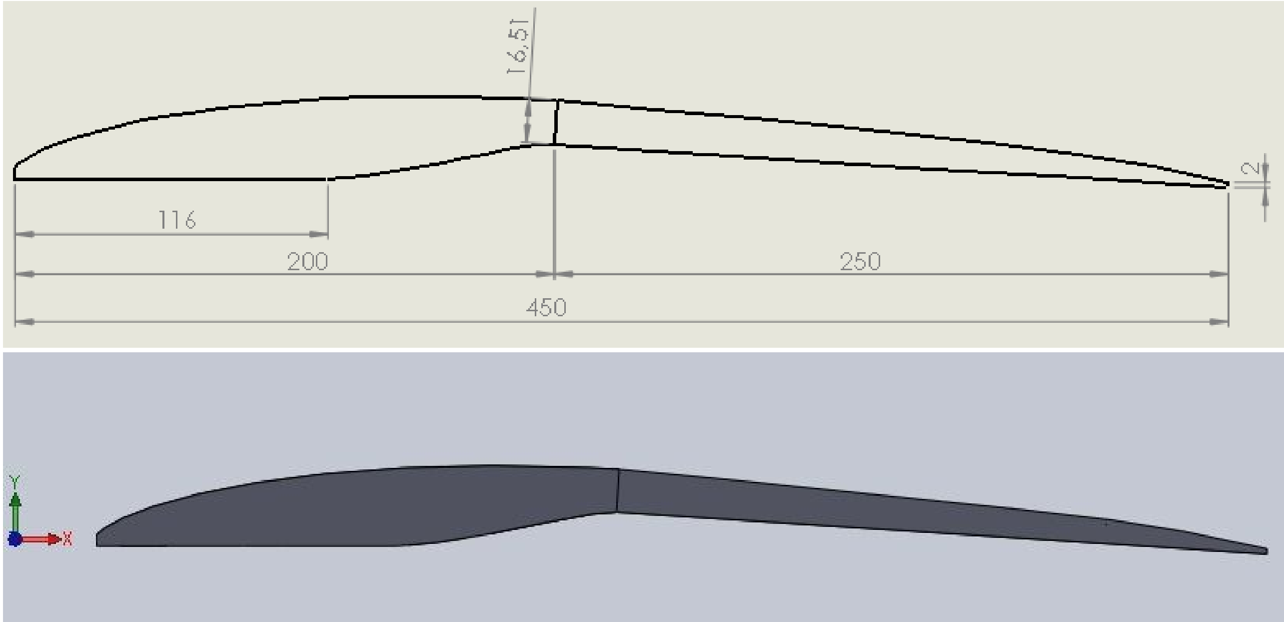


Fig. 81: aluminum unique piece – lateral view

Top view:

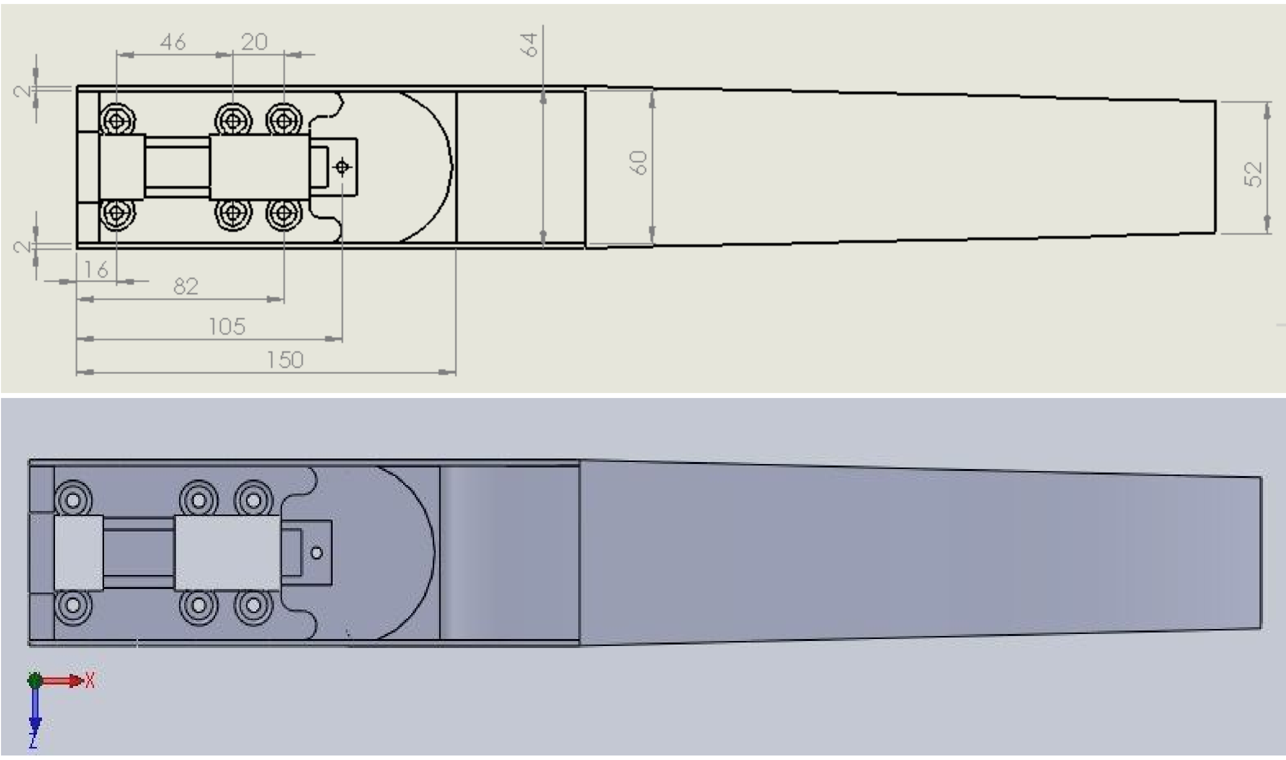
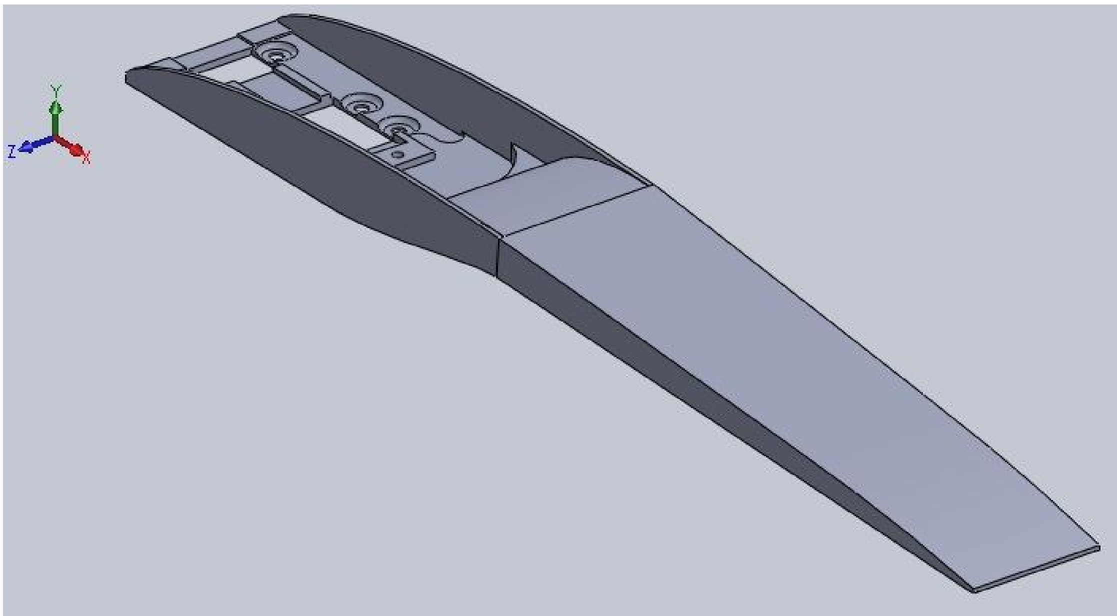


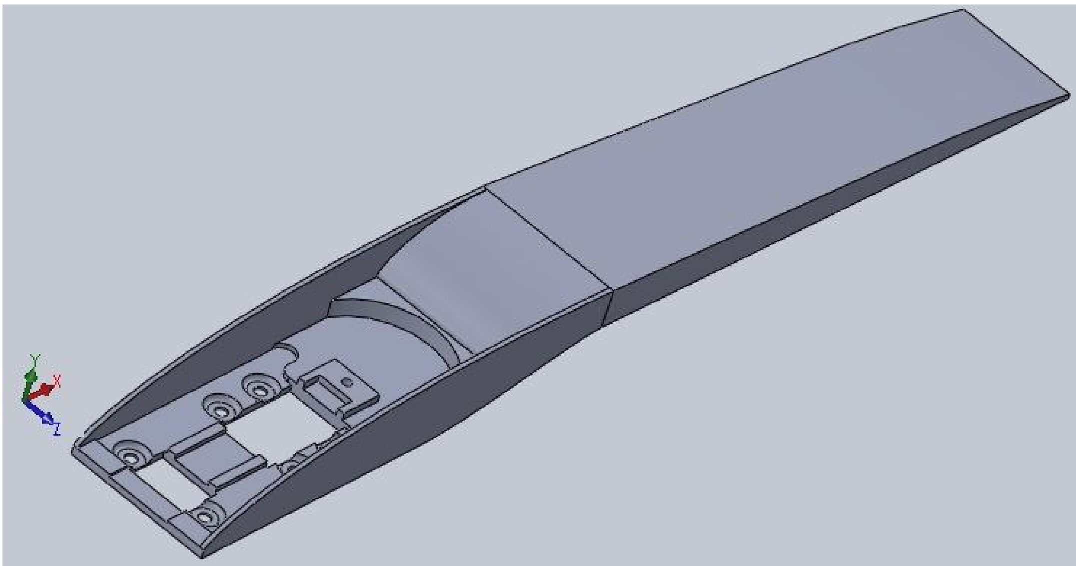
Fig. 82: aluminum unique piece – top view

This model was named : **AL_T2_300_1**

Global views of aluminum unique piece are shown in these figures:



a)



b)

Fig. 83 a – 72 b: aluminum unique piece – global view

POM profile view is shown in this pictures:

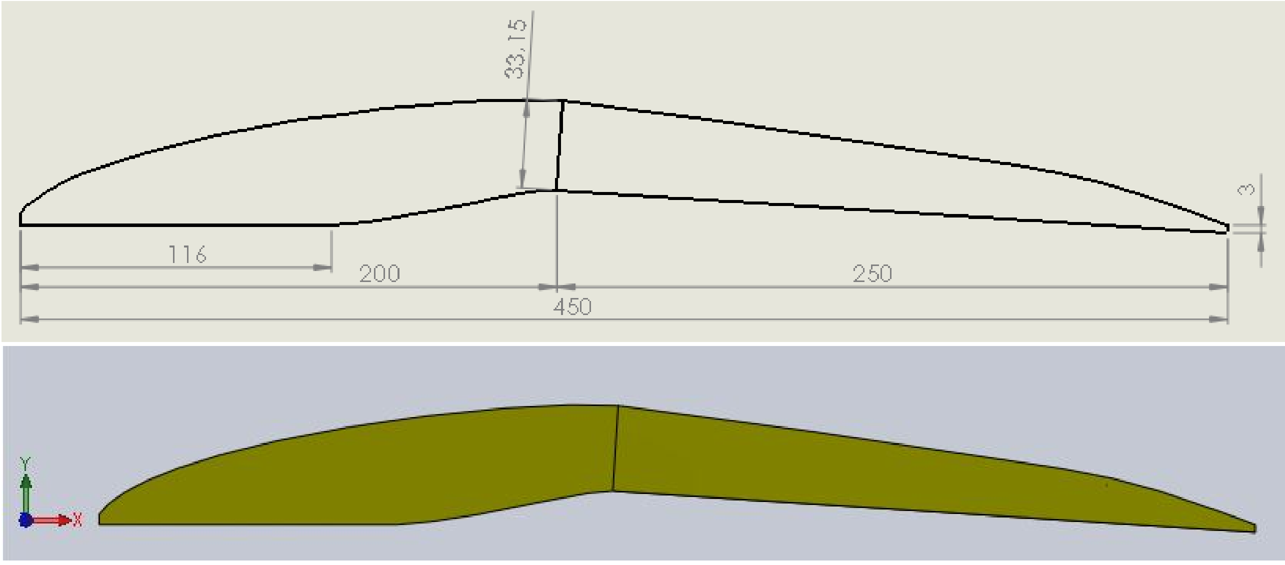


Fig. 84: POM unique piece – lateral view

Top view:

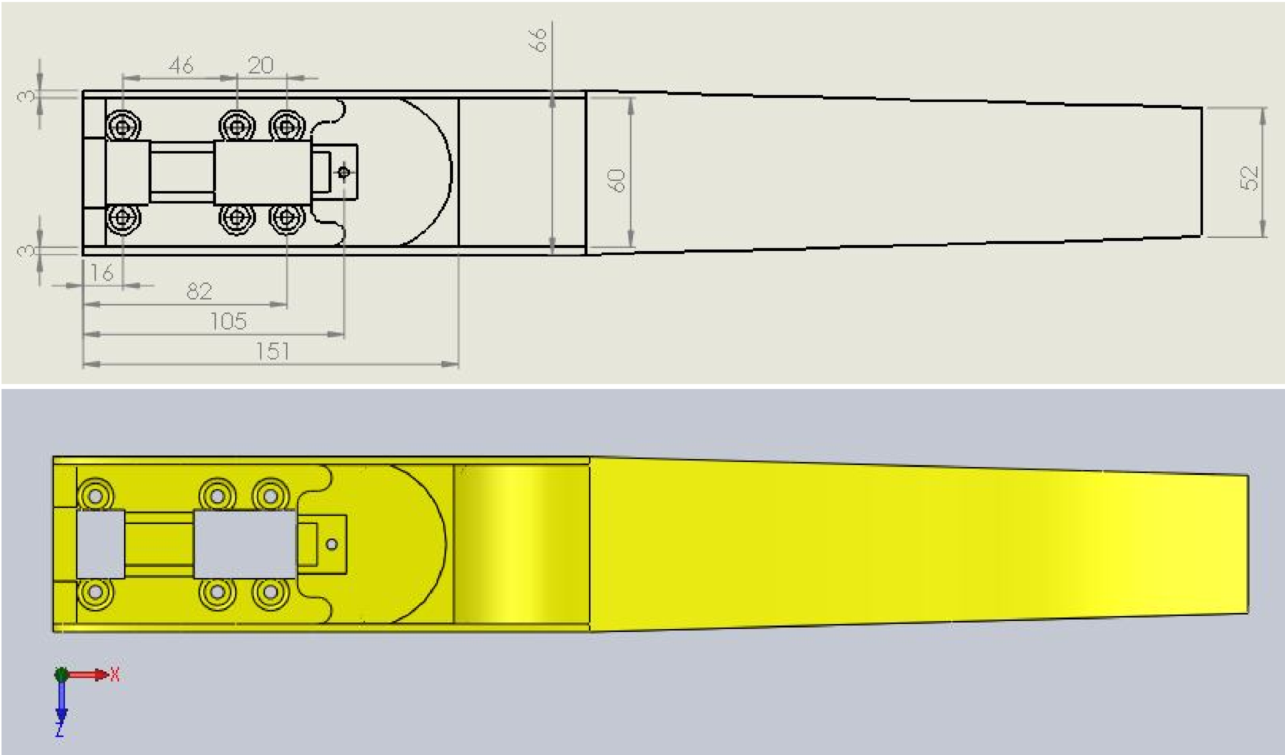
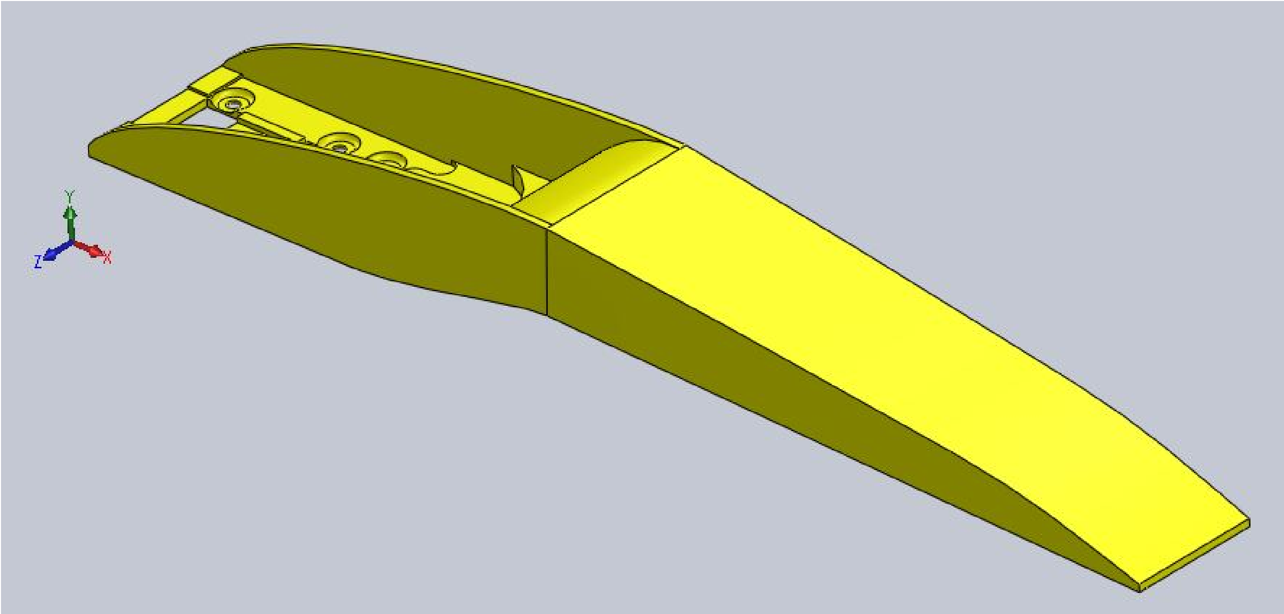


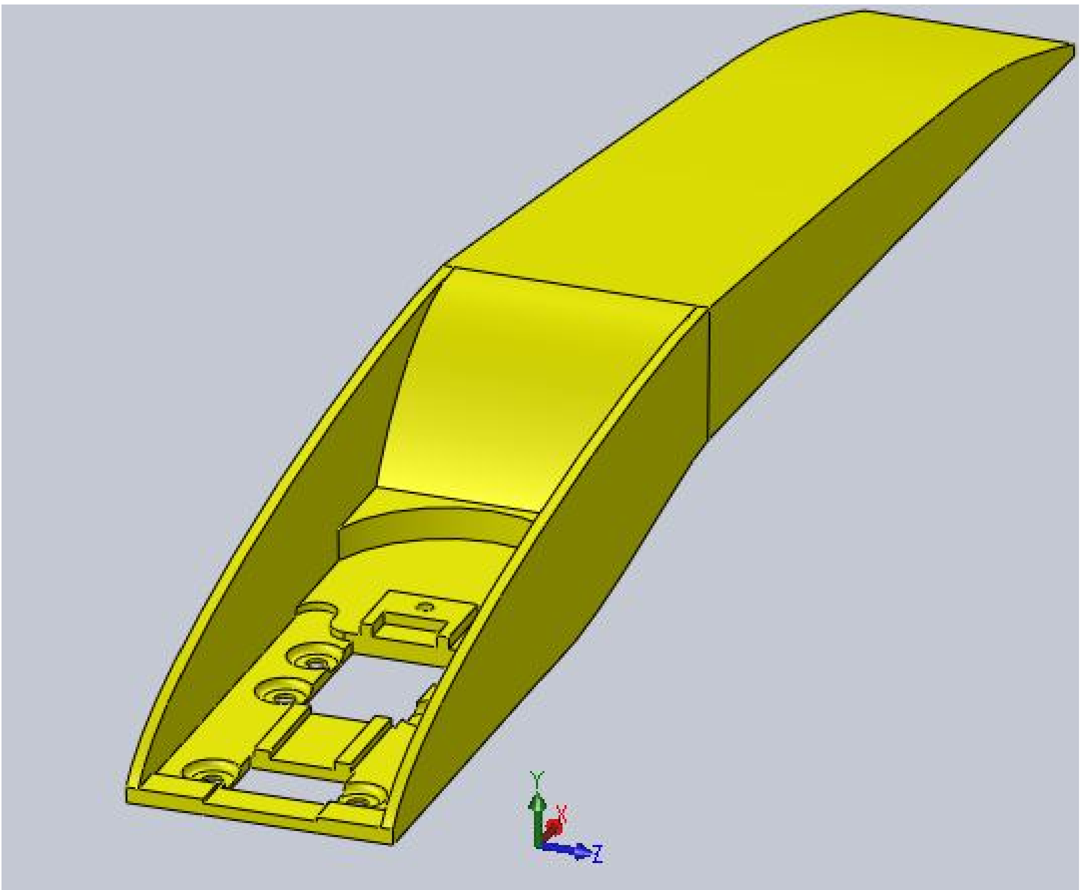
Fig. 85: POM unique piece – top view

This model was named: **POM_T3_300_1**

Global views of POM unique piece are shown in these figures:



a)



b)

Fig. 86: POM unique piece – global view

6.4 NUMERICAL FEM ANALYSIS

FEM analysis is supported by the finite element calculation code ANSYS®. The objective of FEM analysis is find a value of stiffness or of edge displacement. Then this results are compared with the analytical results and verify that displacements of the lower part of the little plate aren't dangerous for ski surface. Displacements in order of 10^{-2}mm are tolerated. In these analysis is imposed an ALLDOF bond for the surface who will came in contact with skies.
Unique piece is simplified before importing the geometry in ANSYS® so the solver will use less memory; it is observable that the piece is symmetric along x axis and rung for attachment with main plate rung is not important for this analysis.

The next paragraphs summarize the steps used for FEM analysis.

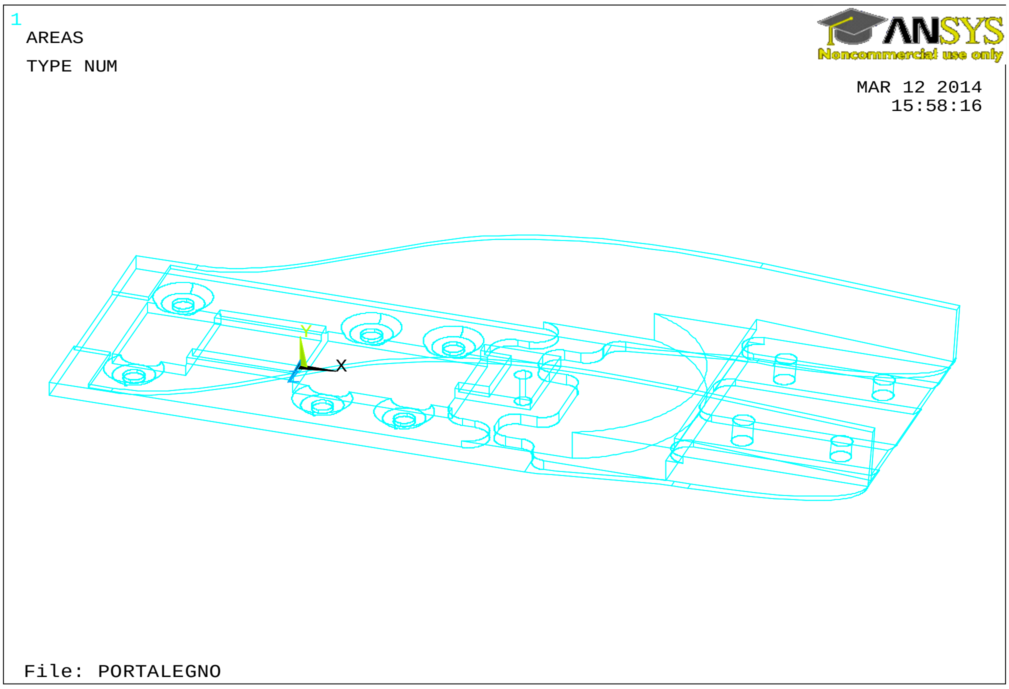
LIST OF FEM ANALYSIS MODELS:

1) Initial aluminum structure
2) Aluminum constant cross section structure
3) POM constant cross section structure
4) Aluminum variable cross section structure
5) POM variable cross section structure
6) Aluminum unique piece structure
7) POM unique piece structure

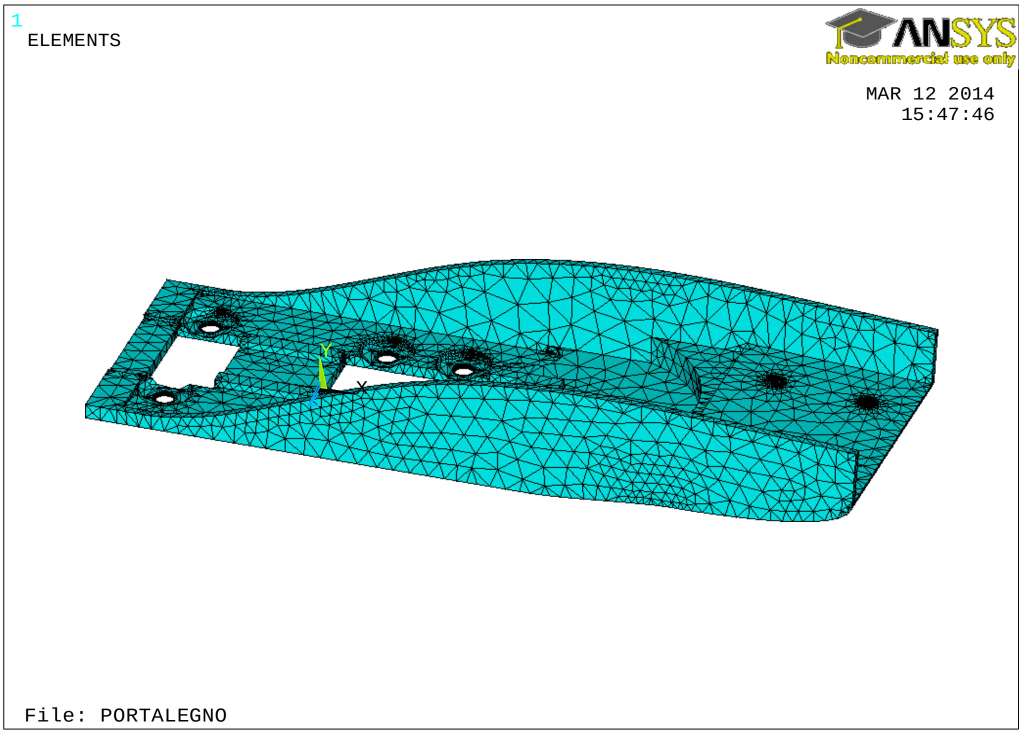
6.4.1 INITIAL ALUMINUM STRUCTURE

Preprocessor

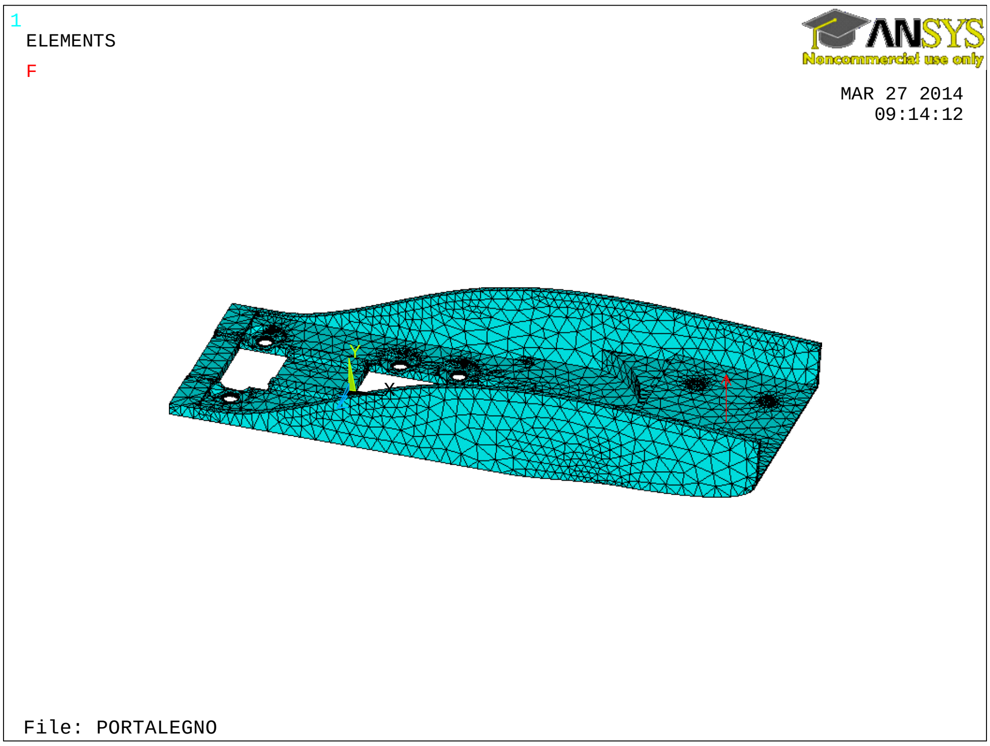
- Import file:



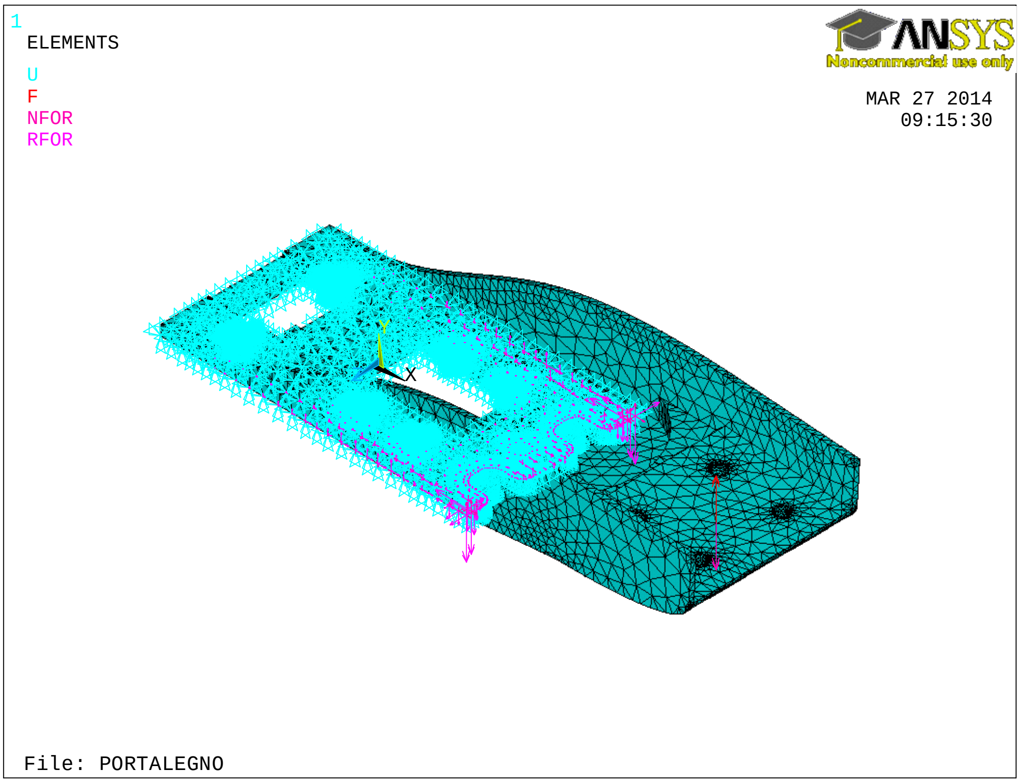
- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=70000 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 2mm



- load: to simplify this analysis it was imposed one force 1687,5 N (coming from bending moment equilibrium) on central node of the rung plate. It's important control the displacements on Y and Z direction, that have not to report collisions with wood arm (when it is coupled with 4 screws), with the core plate and with anterior binding.



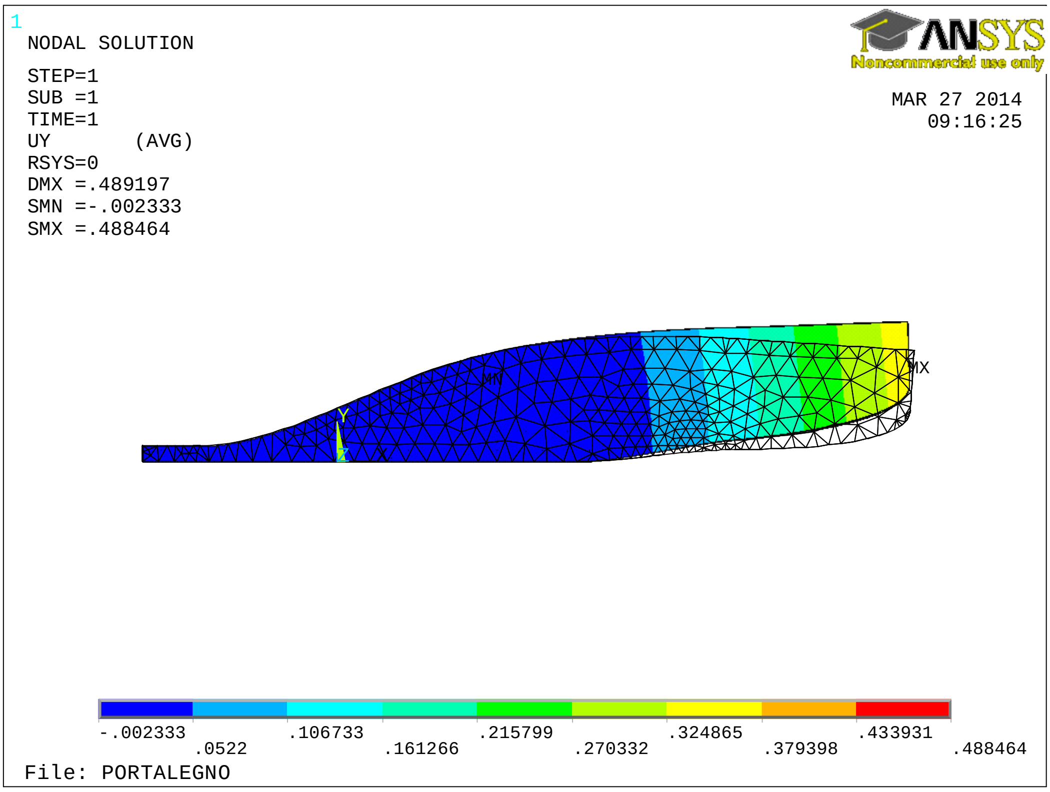
Solution

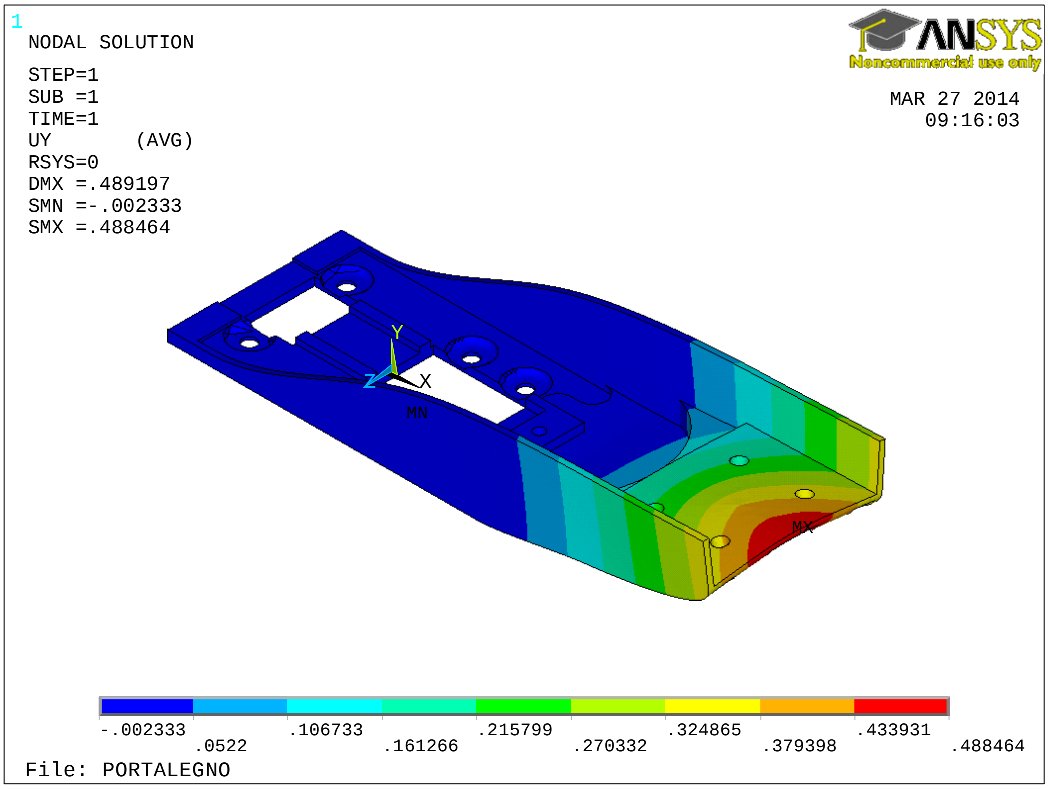


Post processing

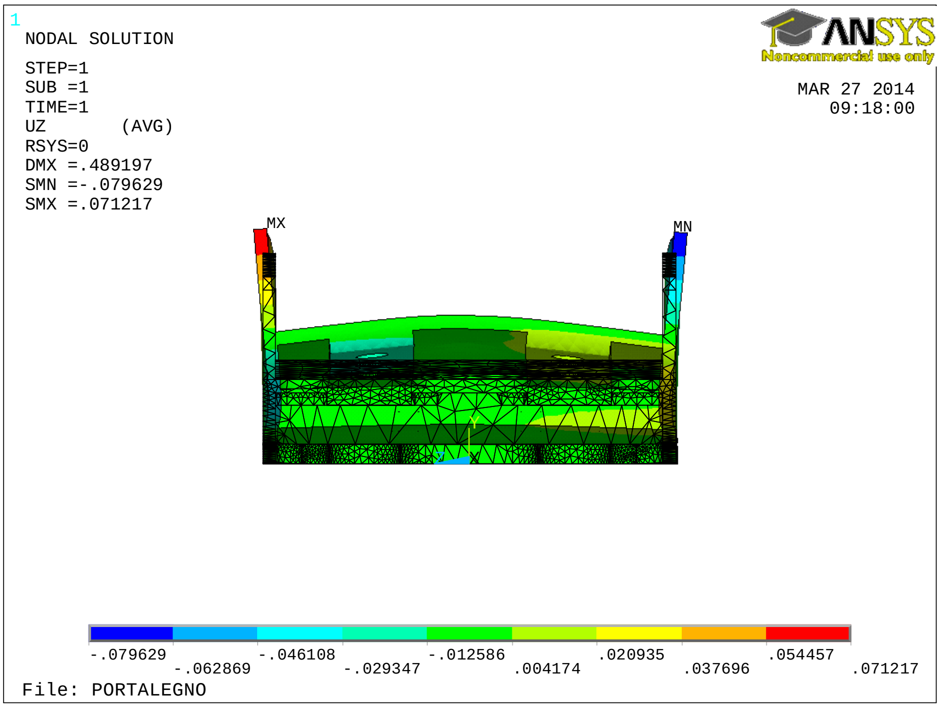
Once ANSYS® finish the calculation and "solution is done" window message compares, the post processing ambient is available for users. It gives plots, graphs, tables and lists coming from the solution.

- Example of deformed shape (Y displacements):

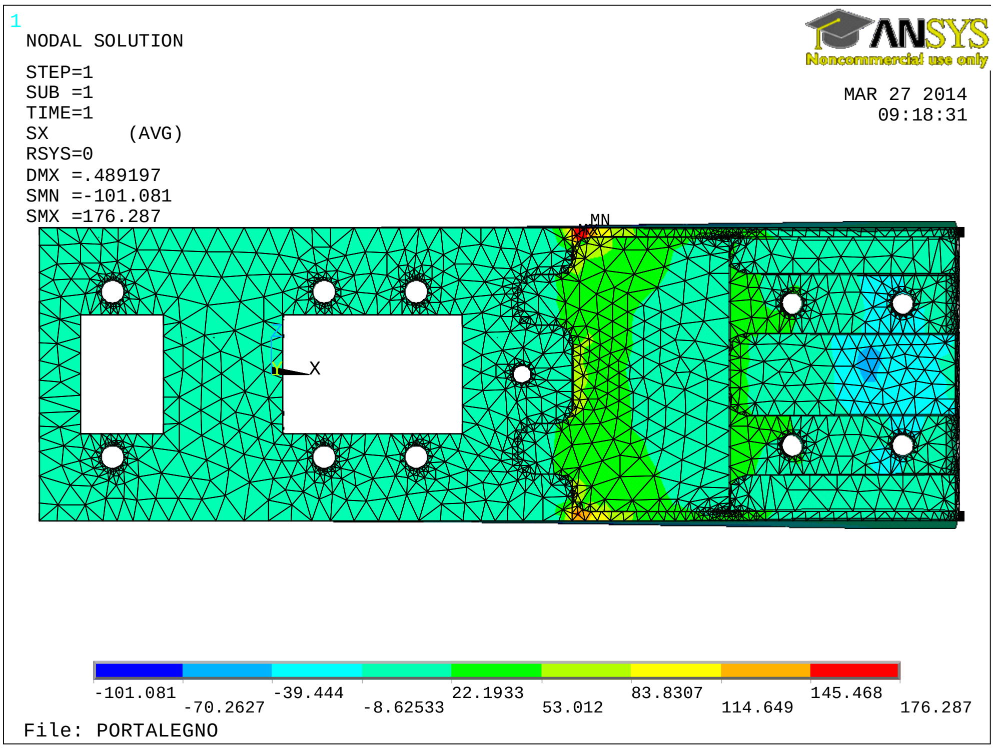




- Z displacements plot (frontal view):



- Stress (σ_{xx}) bottom view:



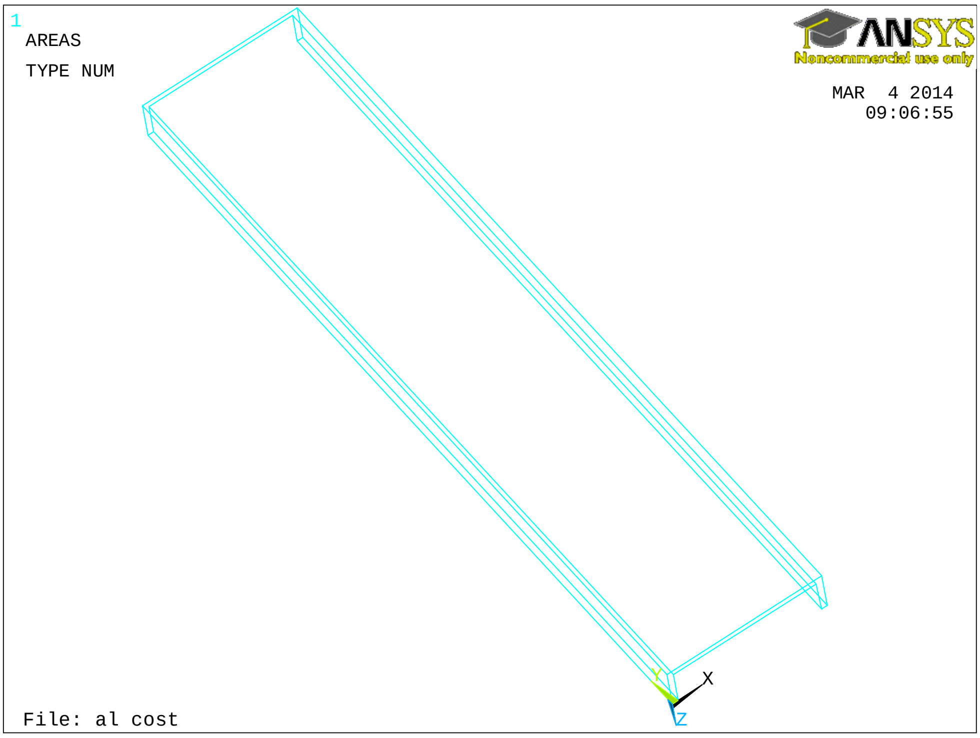
Resume table:

fY FEM [mm]	fZ FEM [mm]	σ XX [MPa]
0,488	0,071	176,28

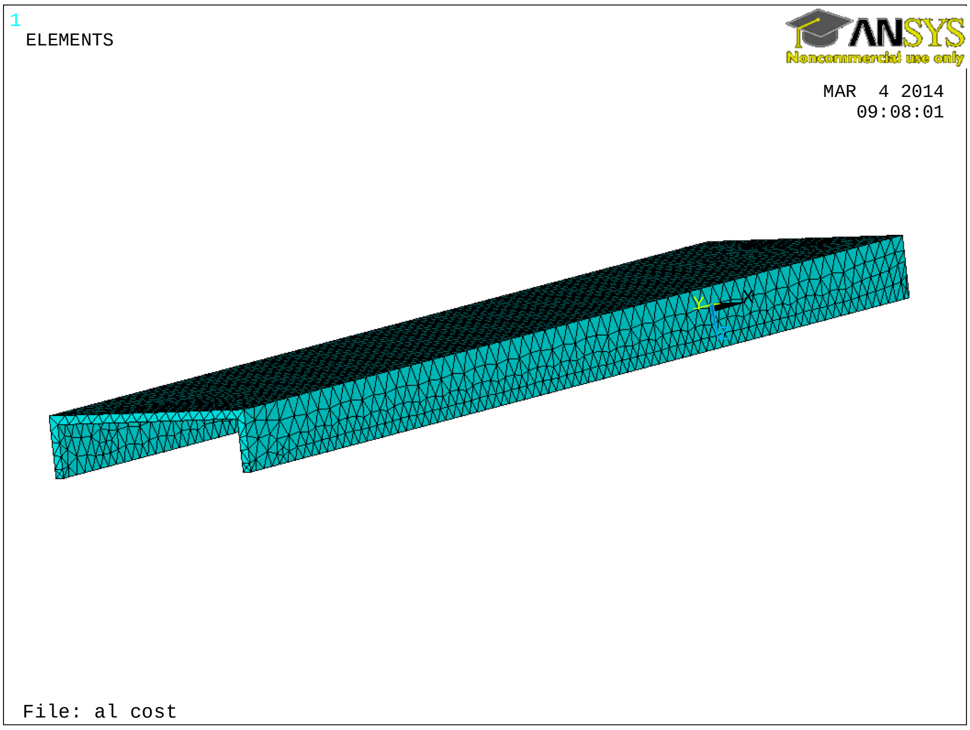
6.4.2 ALUMINUM CONSTANT CROSS SECTION STRUCTURE

Preprocessing

- Imported file:

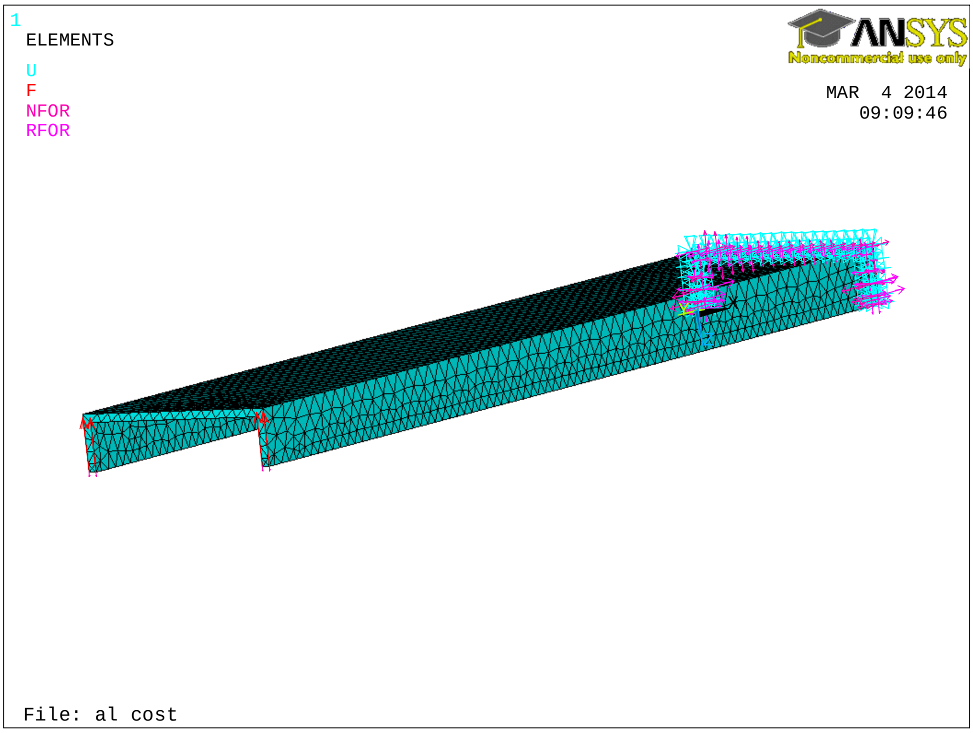


- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=70000 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 2mm



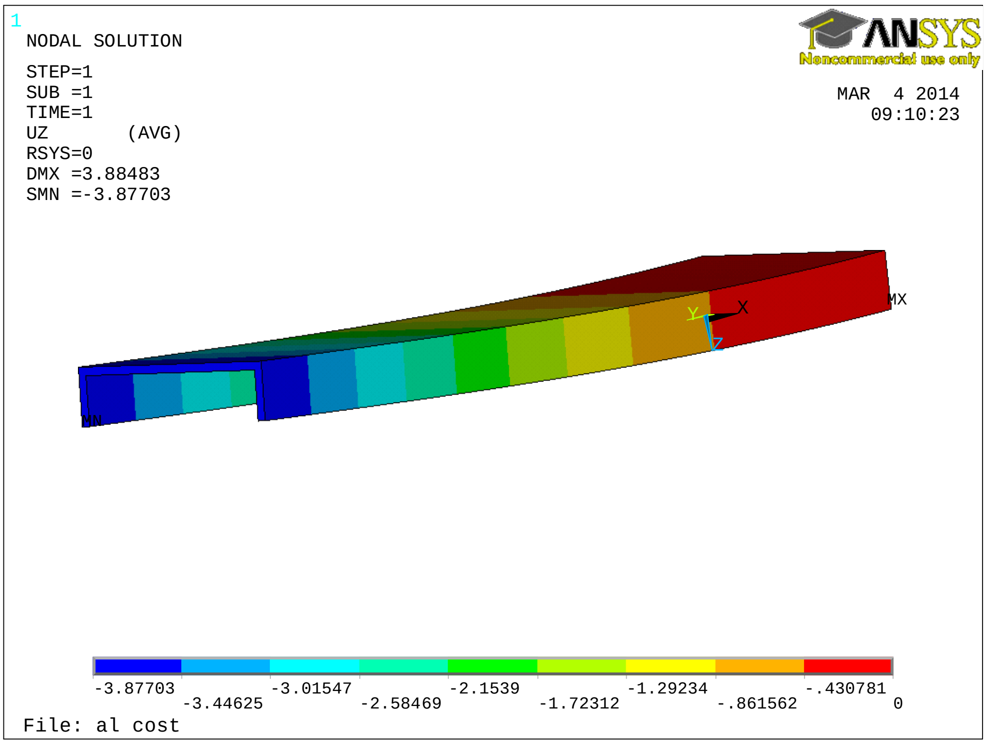
- load condition: load is applied on the extremely edge of arm. Value imposed is: FZ = 125N (divided in four vectors of 31,25N). FZ because the structure was imported in a rotated disposition.

Solution

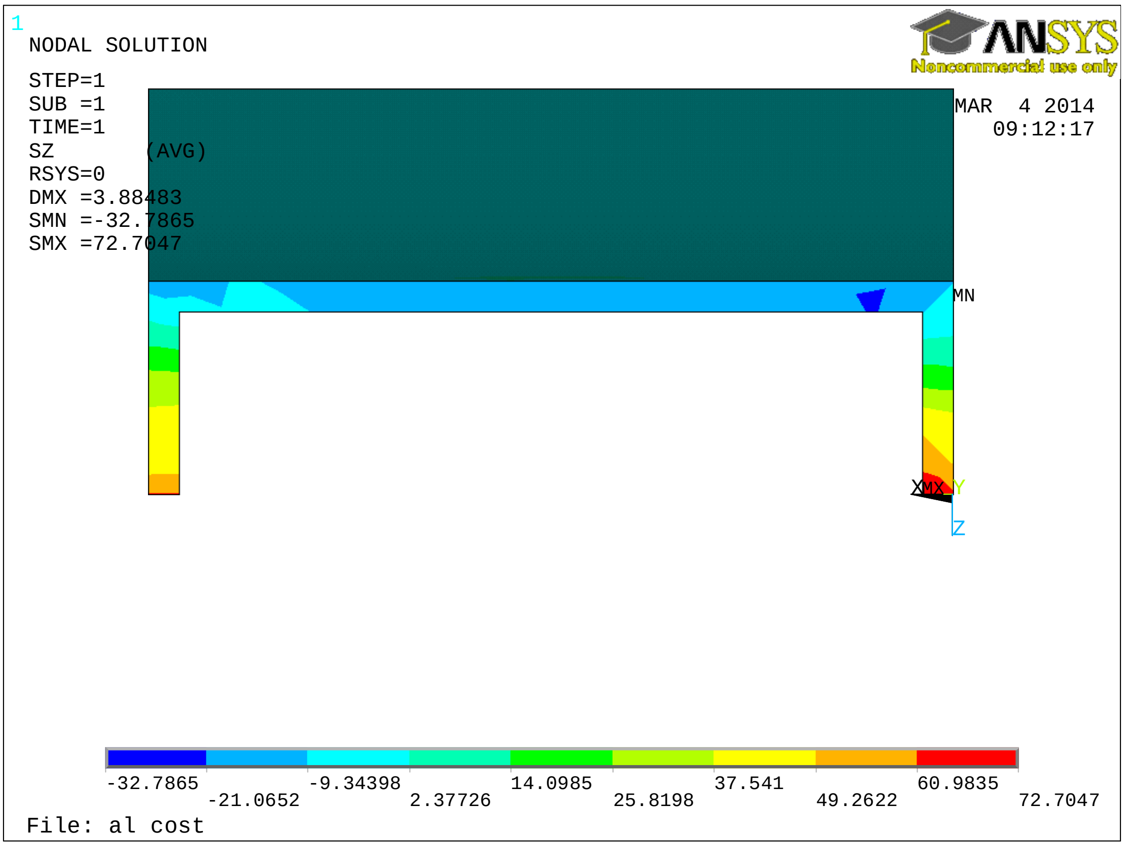


Post processing

- Example of deformed shape and Y displacements (Z displacements in this case):



- Stress (σ_{yy}) rear view (deformed shape):



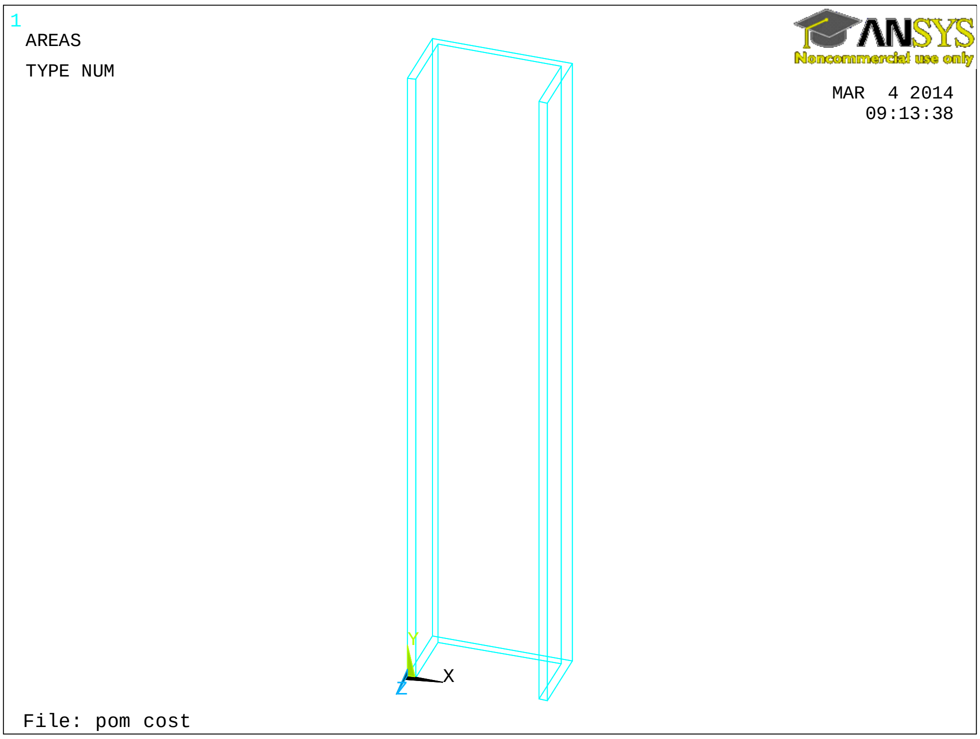
- stiffness calculated like F/f :

$$\boldsymbol{k_{ARM}} = \frac{FY}{Ydisplacement} = \frac{125}{3{,}877} = \mathbf{32{,}24}\,\frac{\boldsymbol{N}}{\boldsymbol{mm}}$$

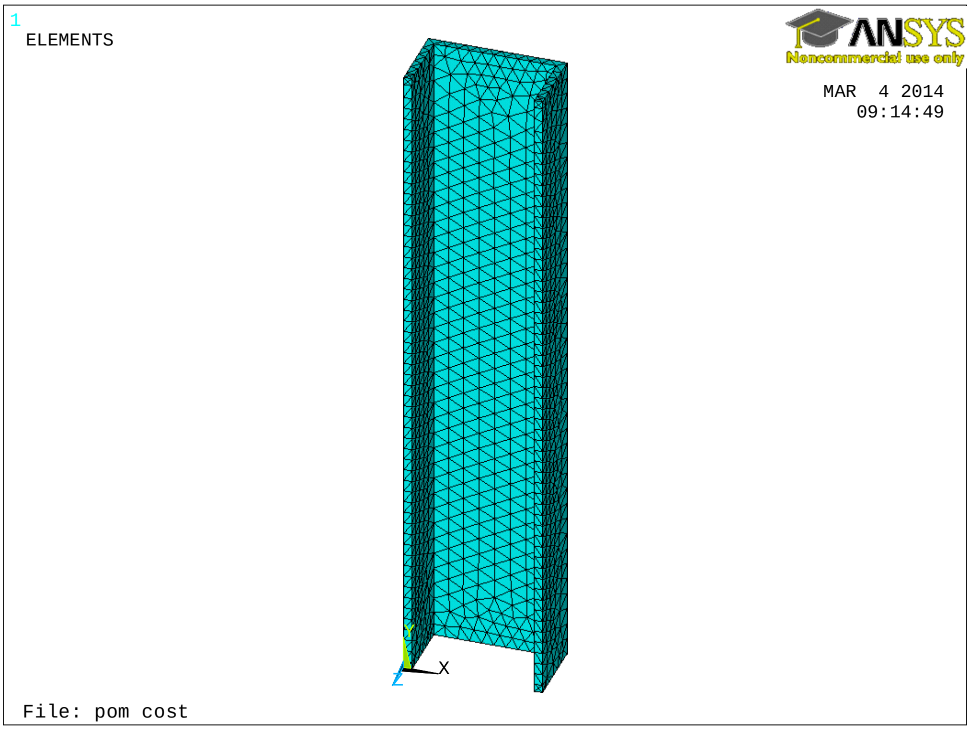
6.4.3 POM CONTANT CROSS SECTION STRUCTURE

Preprocessing

- Imported file:

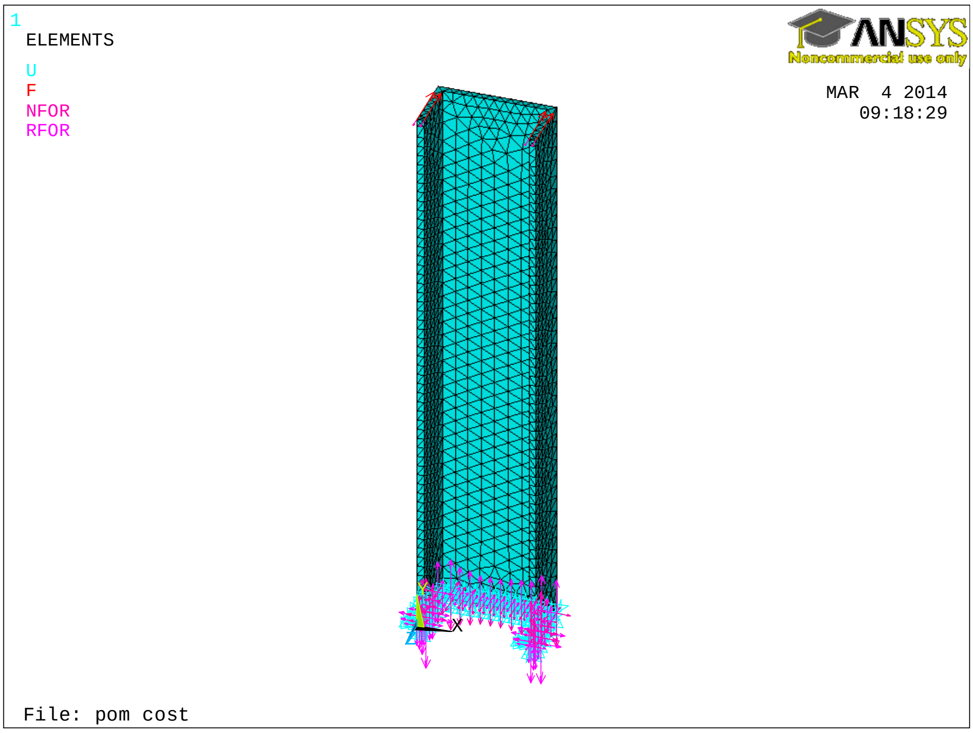


- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=6775 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 3mm



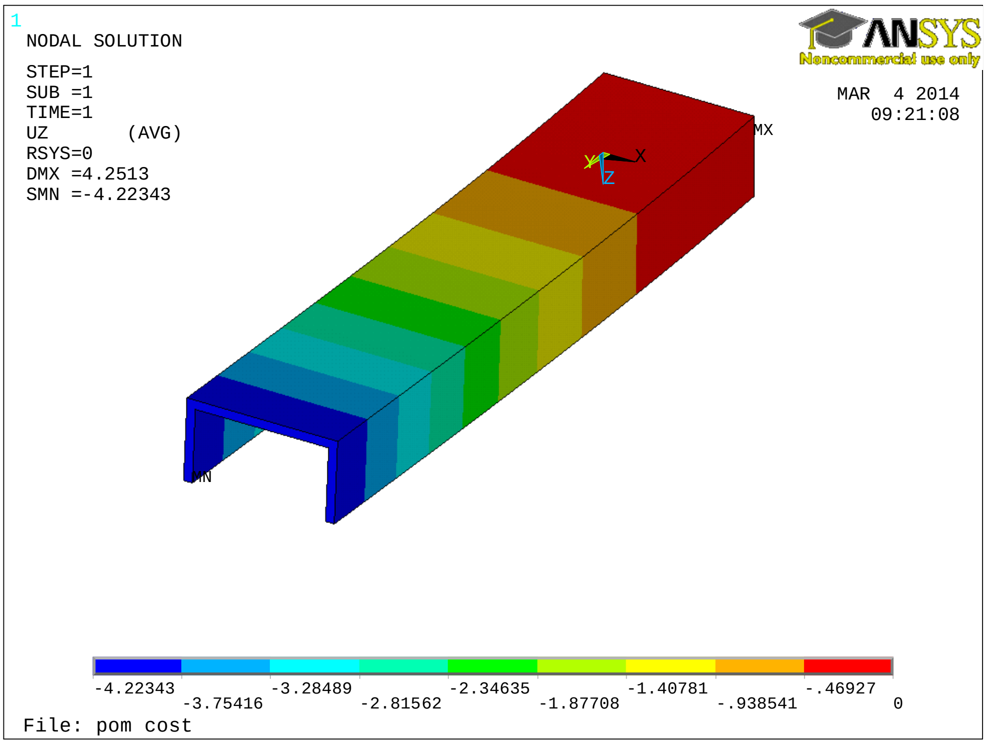
- load condition: load is applied on the extremely edge of arm. Value imposed is: FZ = 125N (divided in four vectors of 31,25N). FZ because the structure was imported in a rotated disposition.

Solution

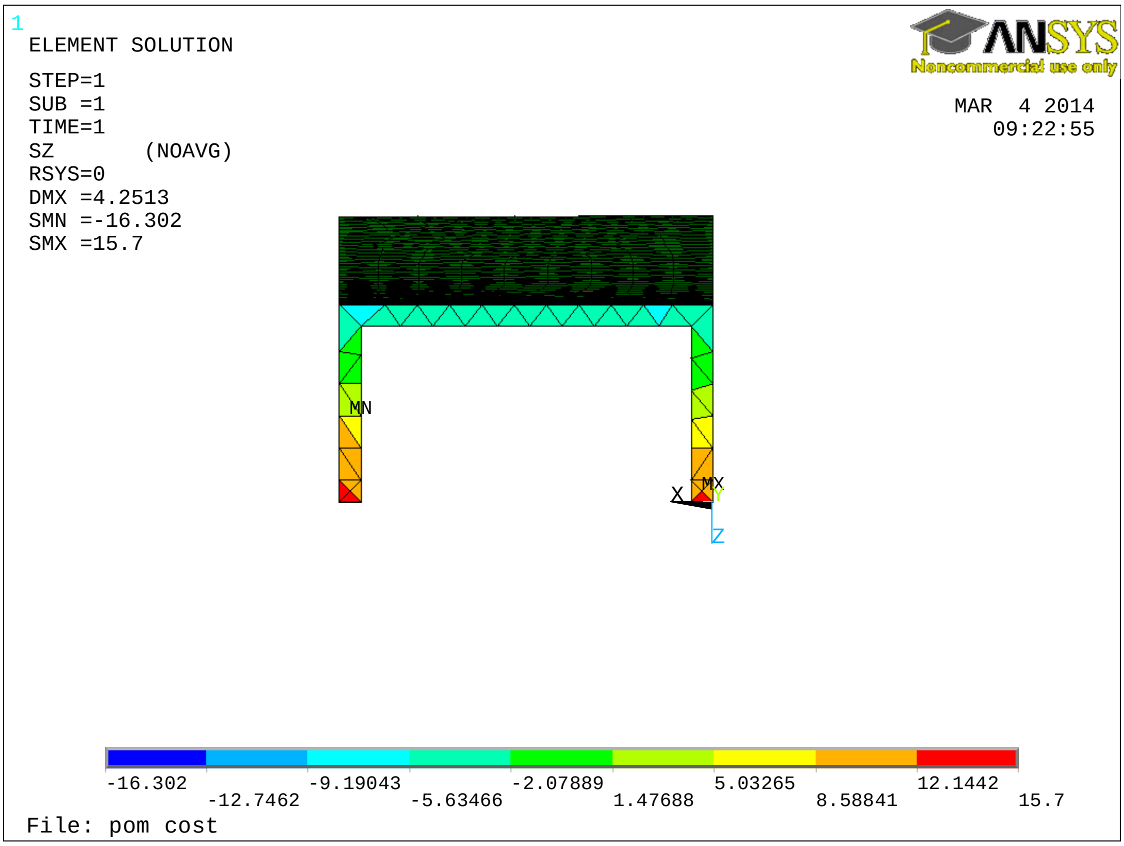


Post processing

- Example of deformed shape and Y displacements (Z displacements in this case):



- Stress (σ_{yy}) rear view (deformed shape):



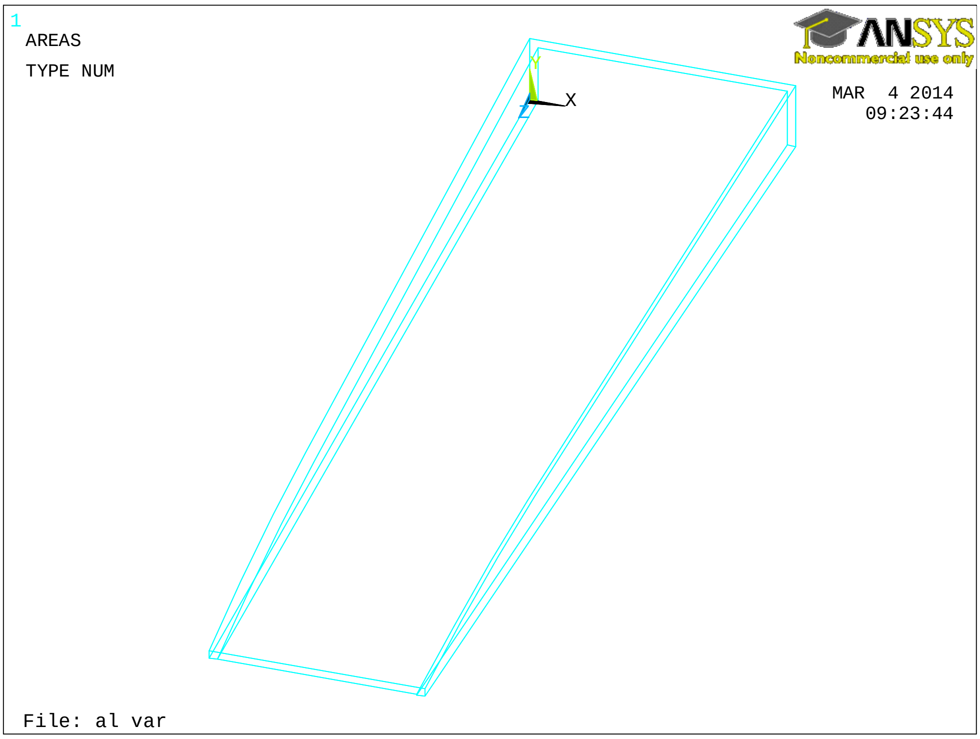
- stiffness calculated like F/f :

$$\boldsymbol{k_{ARM}} = \frac{FY}{Y displacement} = \frac{125}{4{,}223} = \mathbf{29{,}59}\,\frac{\boldsymbol{N}}{\boldsymbol{mm}}$$

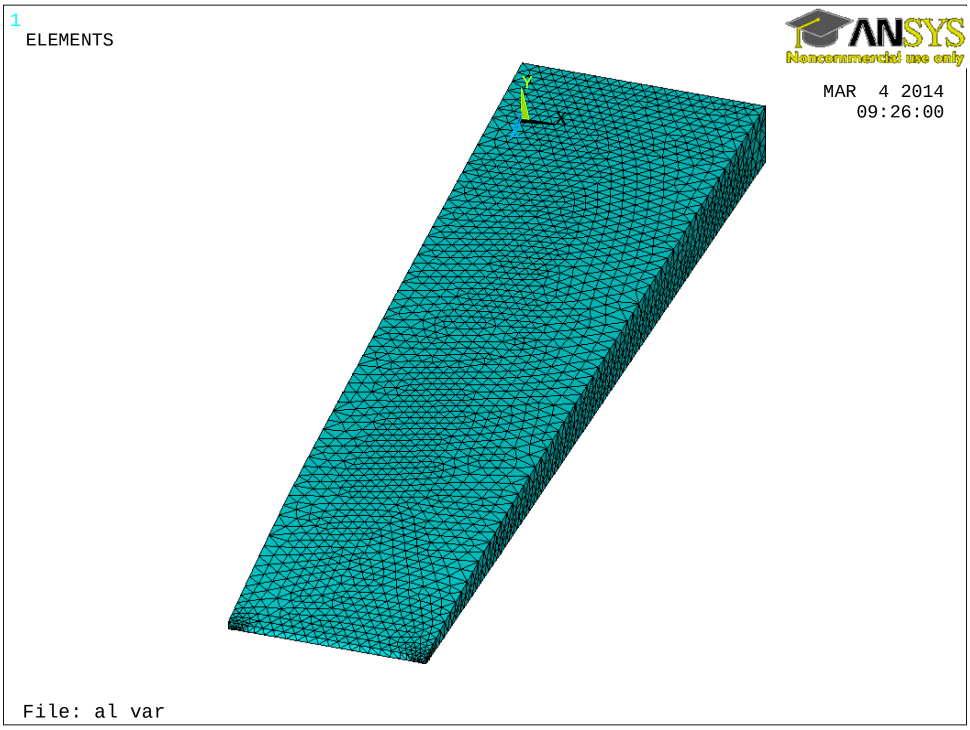
6.4.4 ALUMINUM VARIABLE CROSS SECTION STRUCTURE

Preprocessing

- Imported file:

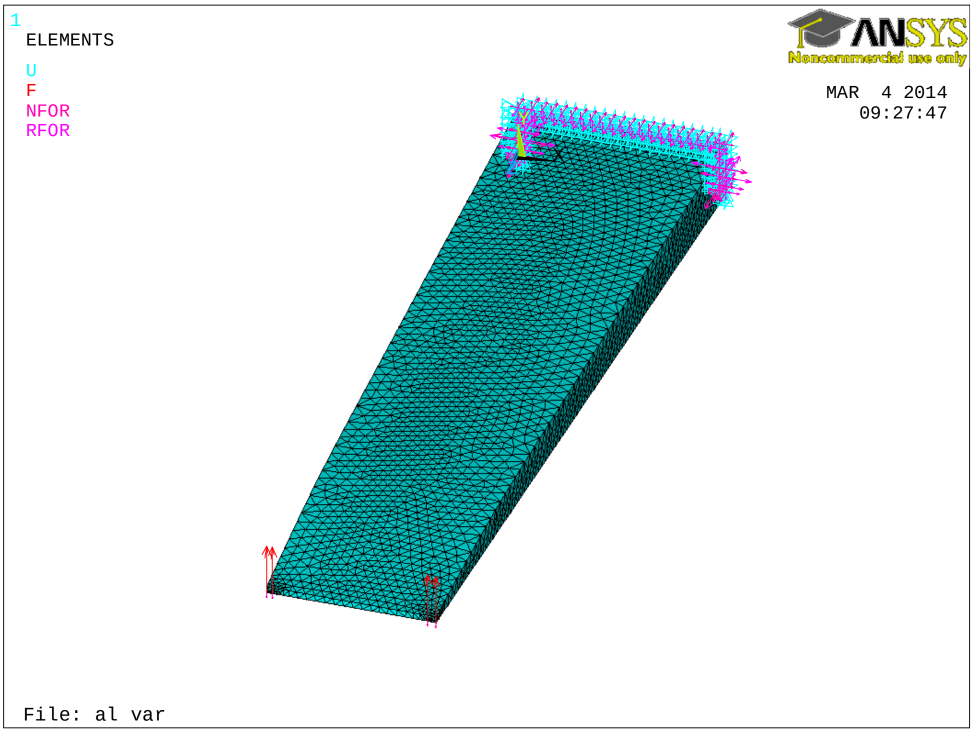


- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=70000 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 2mm



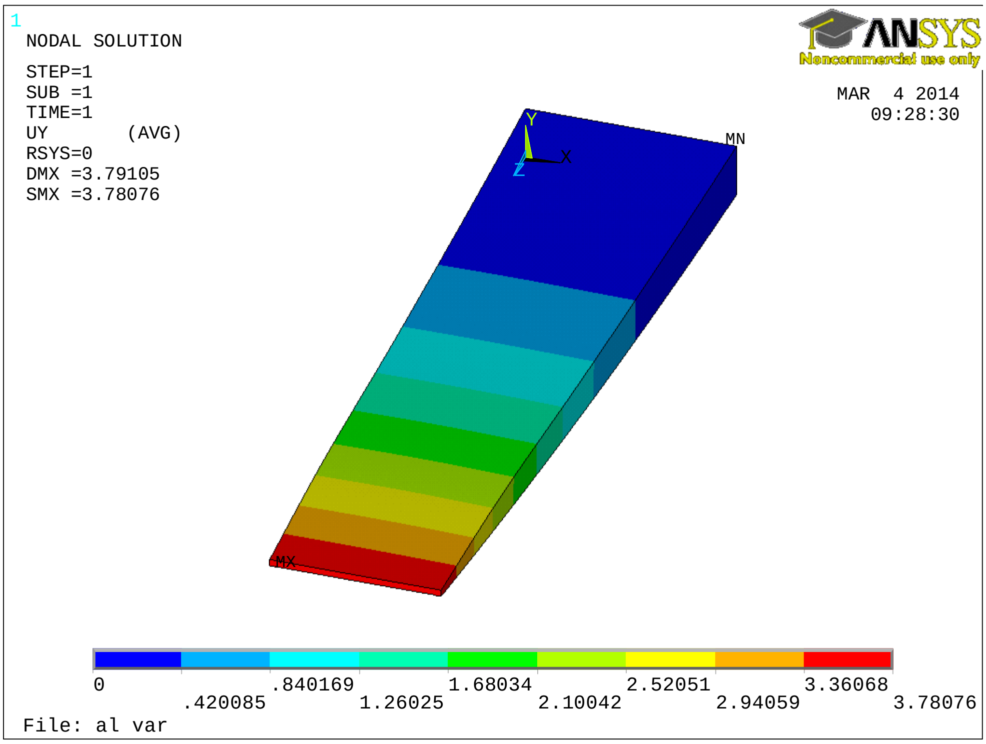
- load condition: load is applied on the extremely edge of arm. Value imposed is: FY = 125N (divided in four vectors of 31,25N).

Solution

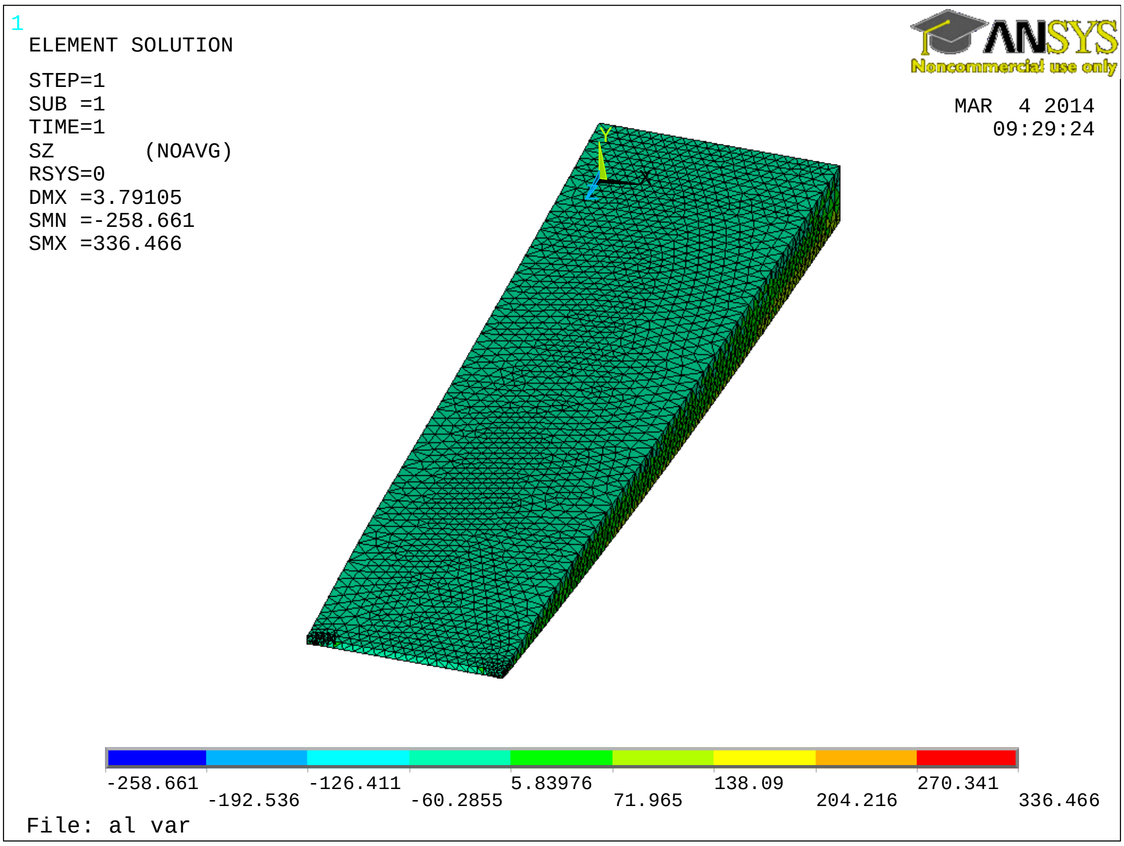


Post processing

- Example of deformed shape and Y displacements:



- Stress (σ_{XX}) isometric view (deformed shape):



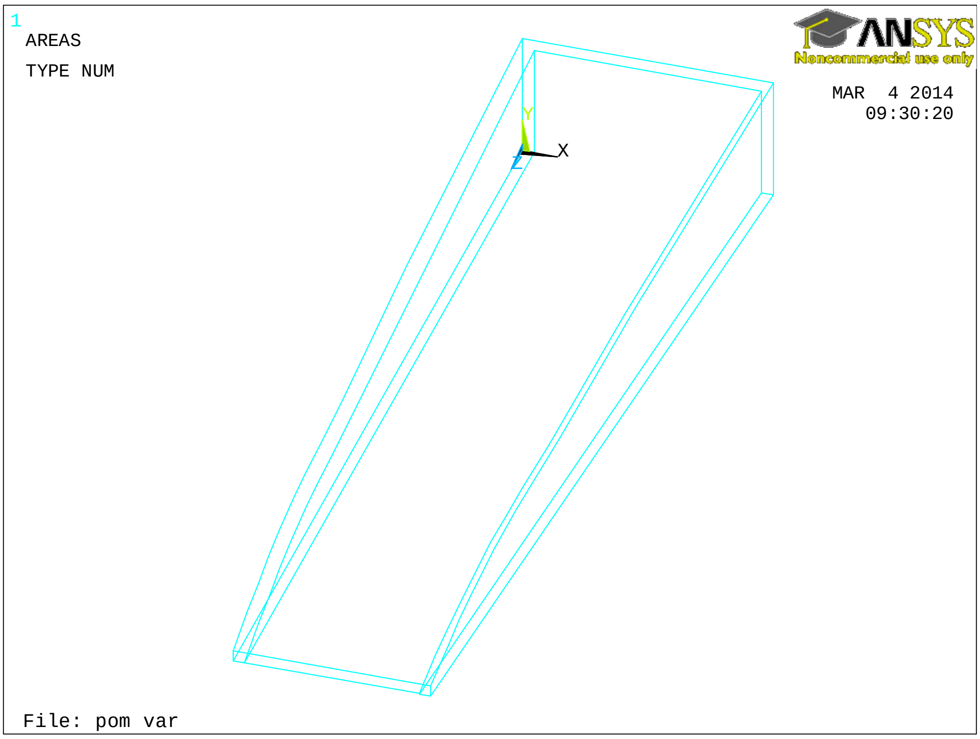
- stiffness calculated like F/f :

$$\boldsymbol{k_{ARM}} = \frac{FY}{Ydisplacement} = \frac{125}{3{,}78} = \mathbf{33{,}07}\frac{\boldsymbol{N}}{\boldsymbol{mm}}$$

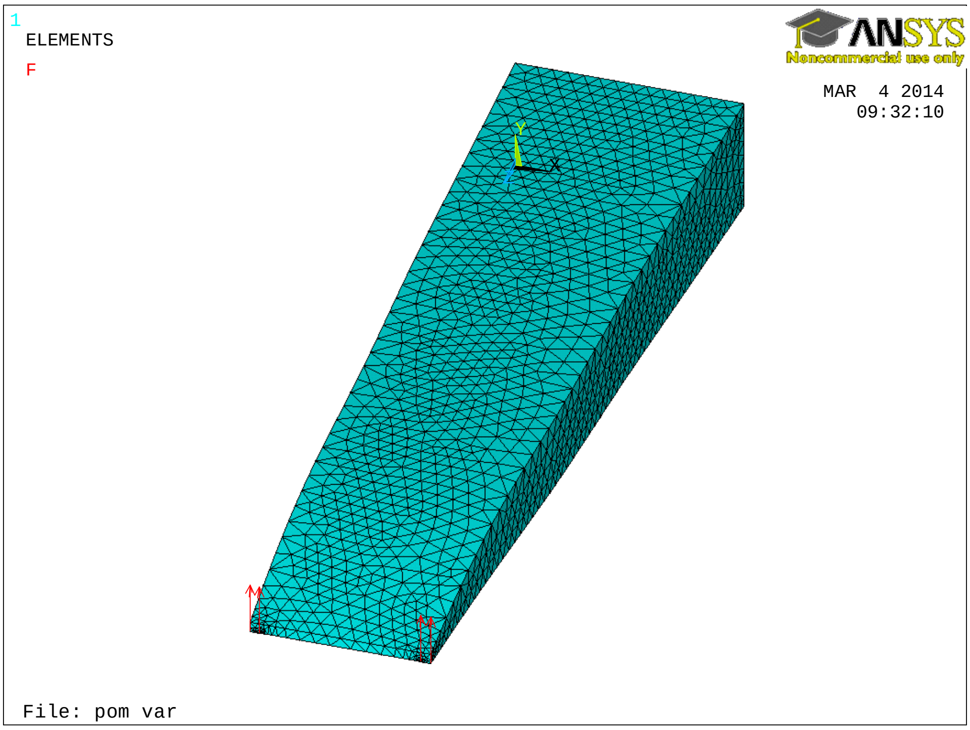
6.4.5 POM VARIABLE CROSS SECTION STRUCTURE

Preprocessing

- Imported file:

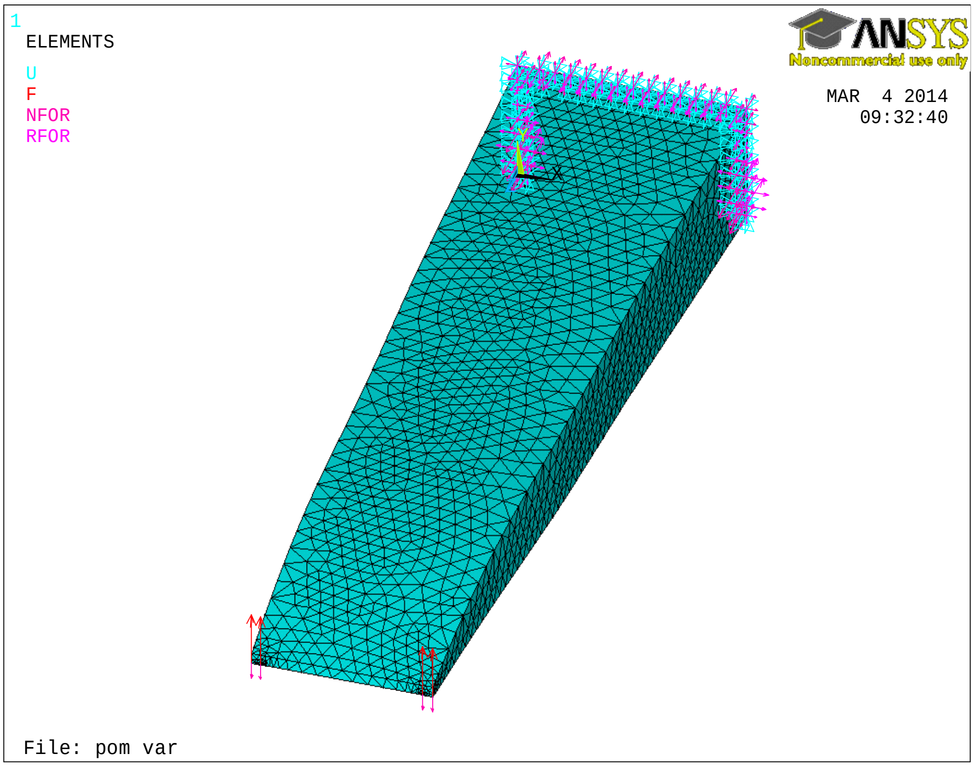


- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=6775 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 3mm



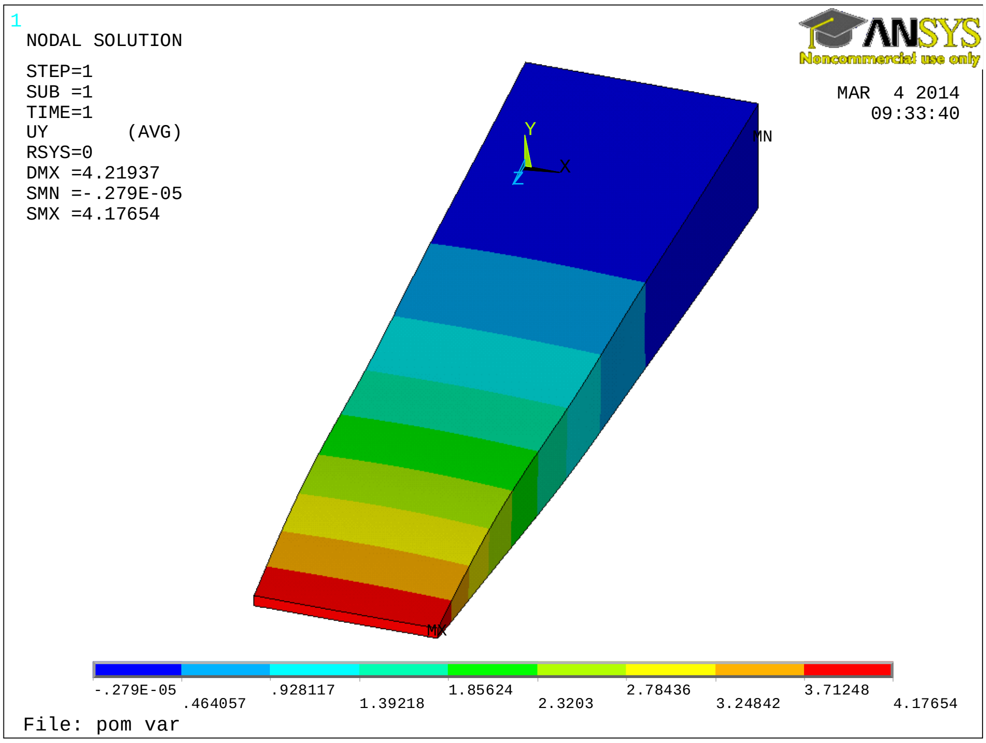
- load condition: load is applied on the extremely edge of arm. Value imposed is: FZ = 125N (divided in four vectors of 31,25N). FZ because the structure was imported in a rotated disposition.

Solution

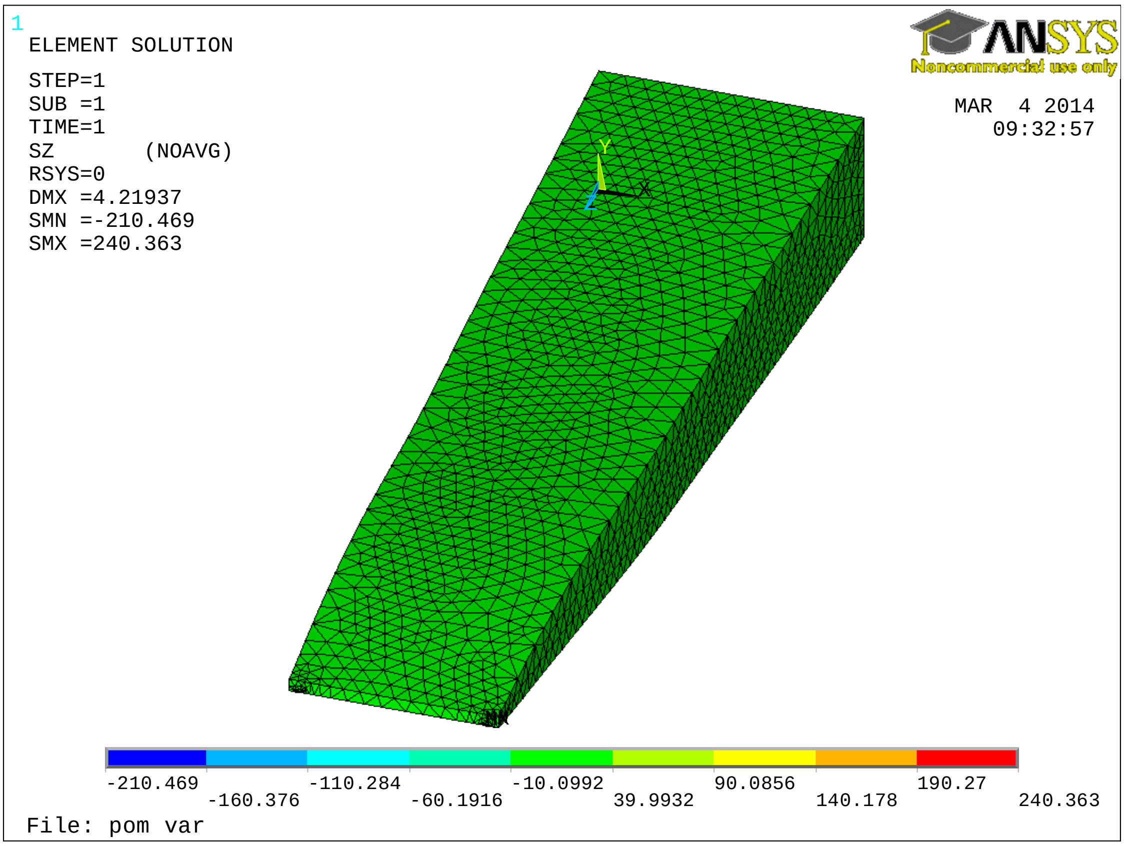


Post processing

- Example of deformed shape and Y displacements (Z displacements in this case):



- Stress (σ_{yy}) isometric view (deformed shape):



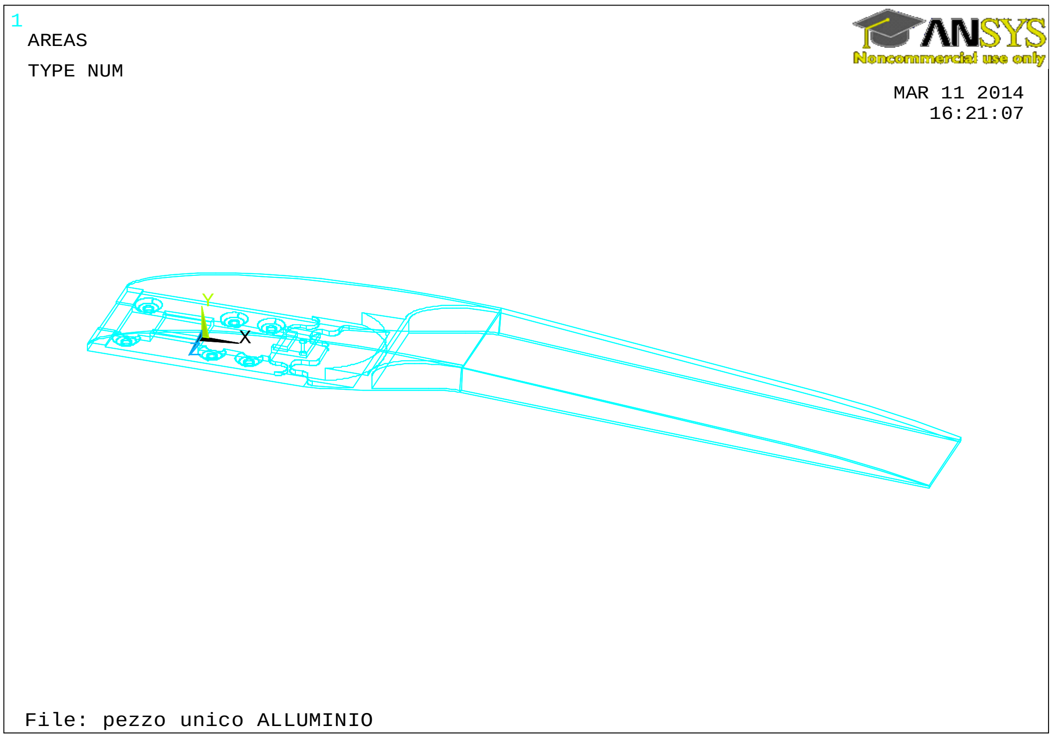
- stiffness calculated like F/f :

$$k_{ARM} = \frac{FY}{Ydisplacement} = \frac{125}{4{,}176} = 29{,}93\,\frac{N}{mm}$$

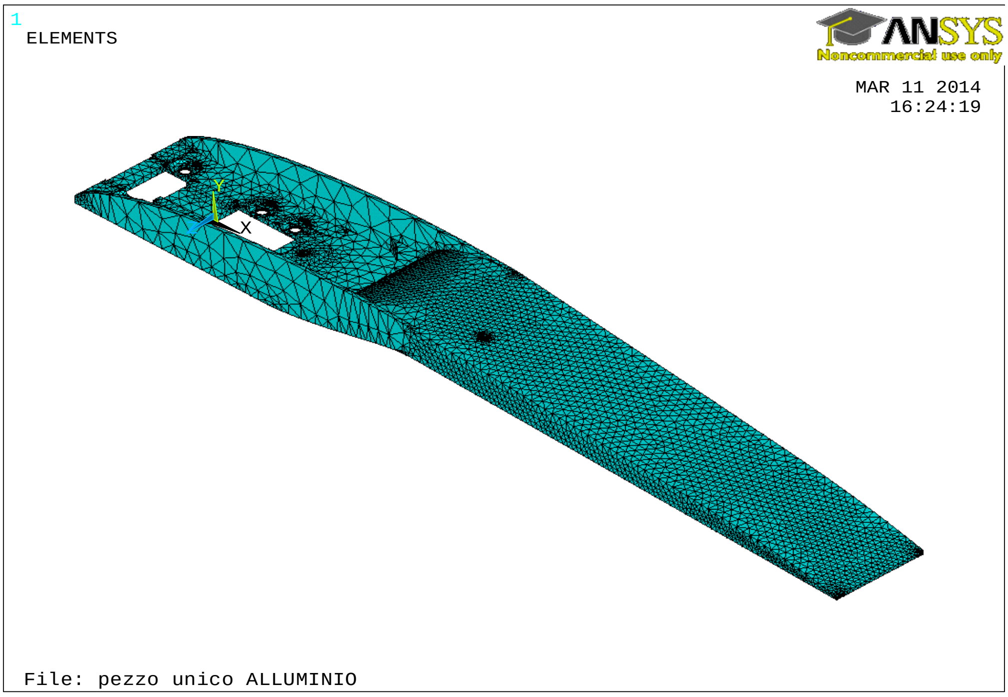
6.4.6 ALUMINUM UNIQUE PIECE STRUCTURE

Preprocessing

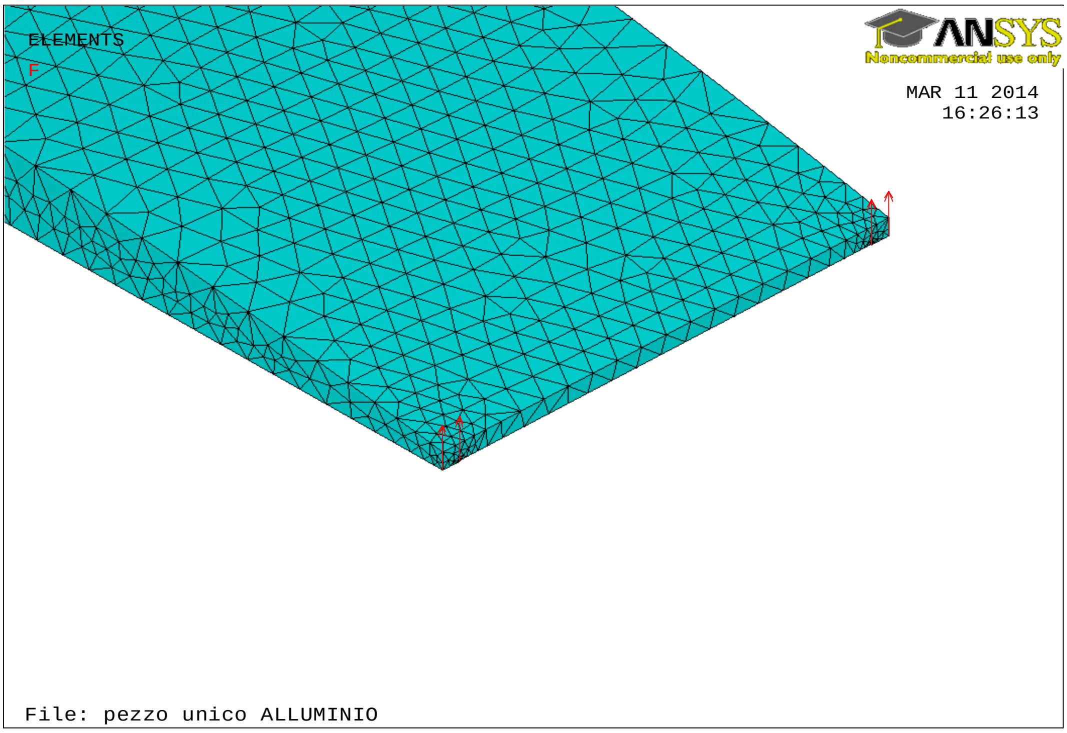
- Imported file:



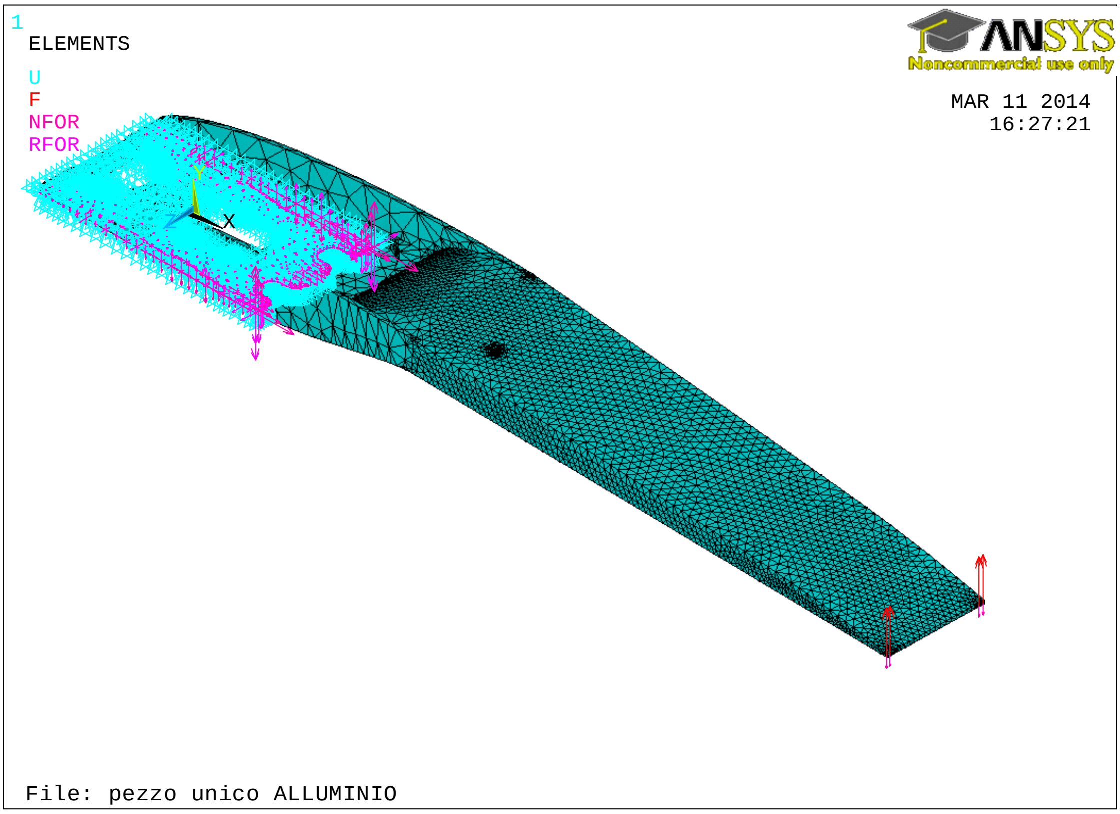
- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=70000 , PRXY=0,3
- boundary condition: bond is the lower surface
- mesh size: 2mm and refined near the ideal welded area



- load condition: load is applied on the extremely edge of arm. Value imposed is: FY = 125N (divided in four vectors of 31,25N).

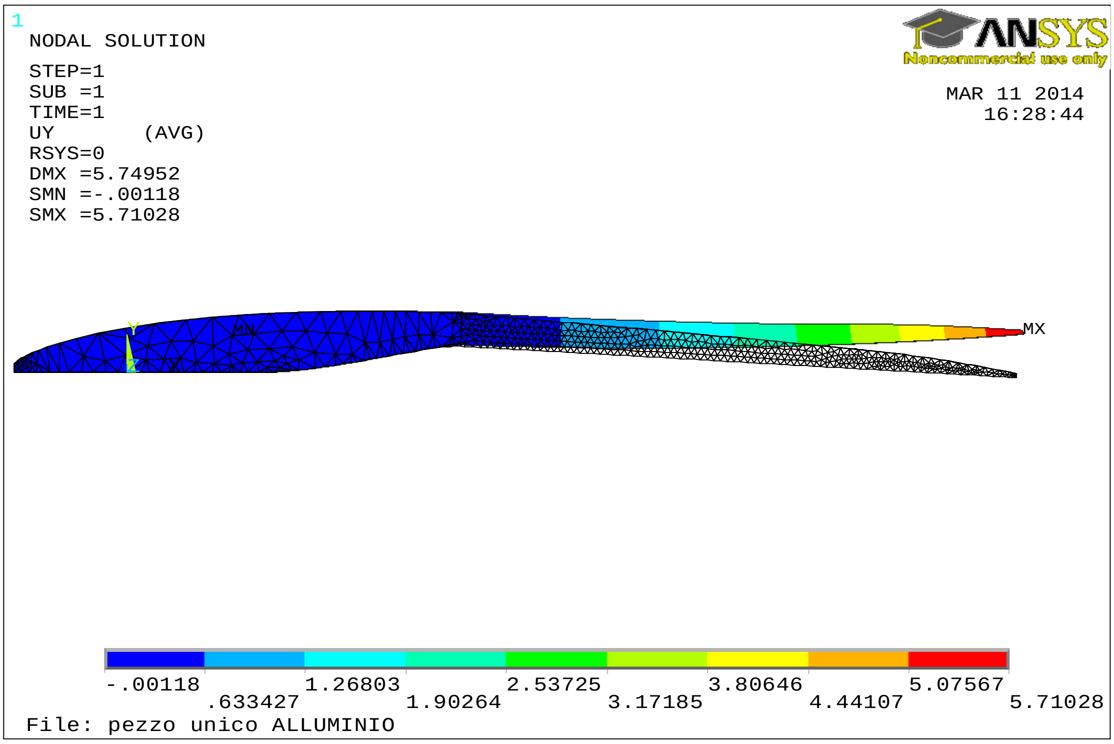


Solution

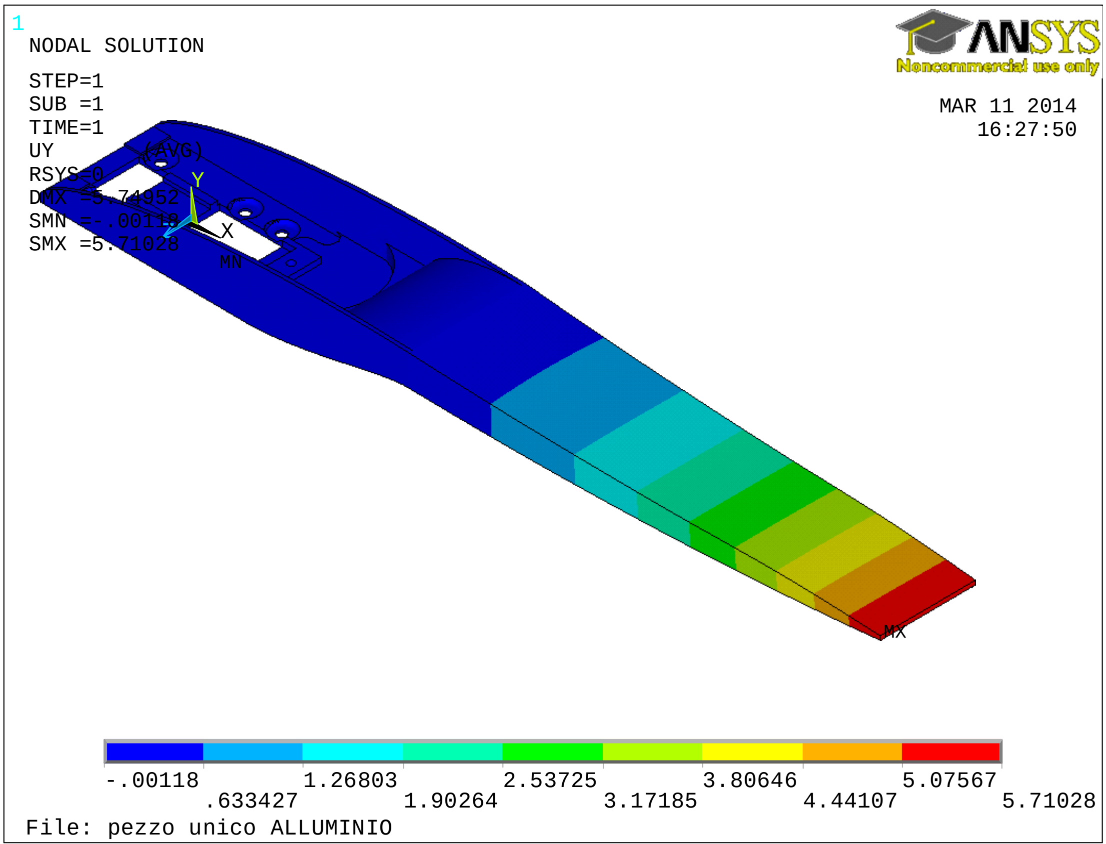


Post processing

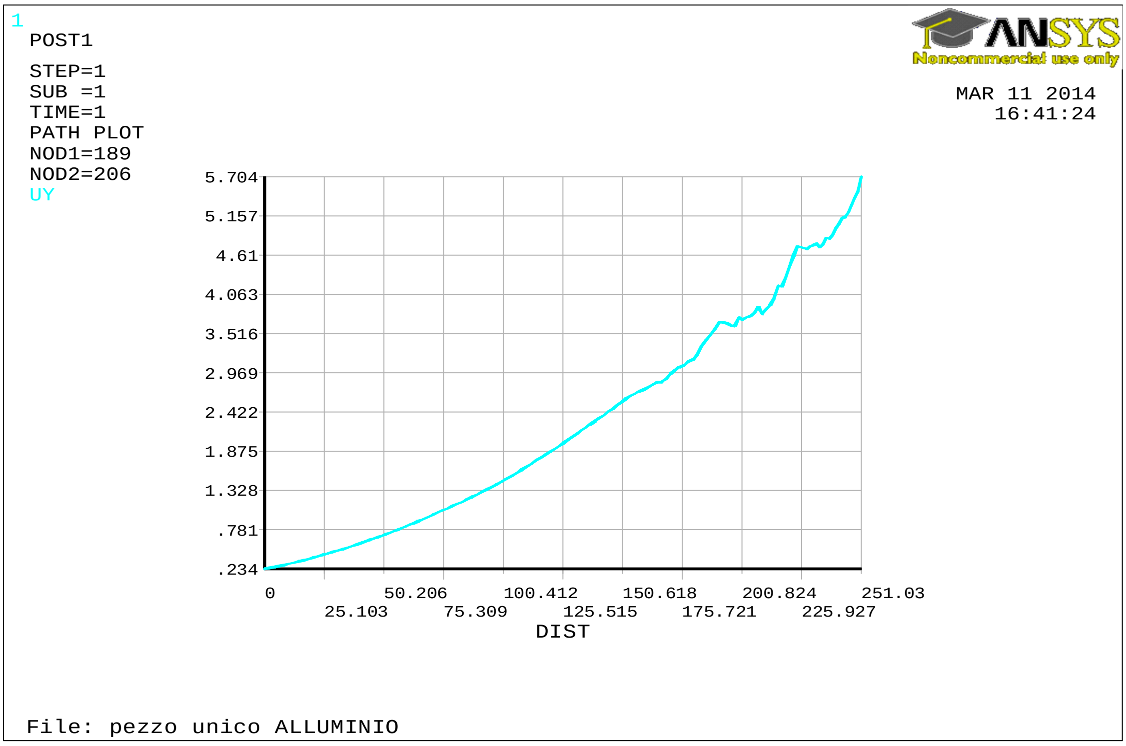
- Example of deformed shape:



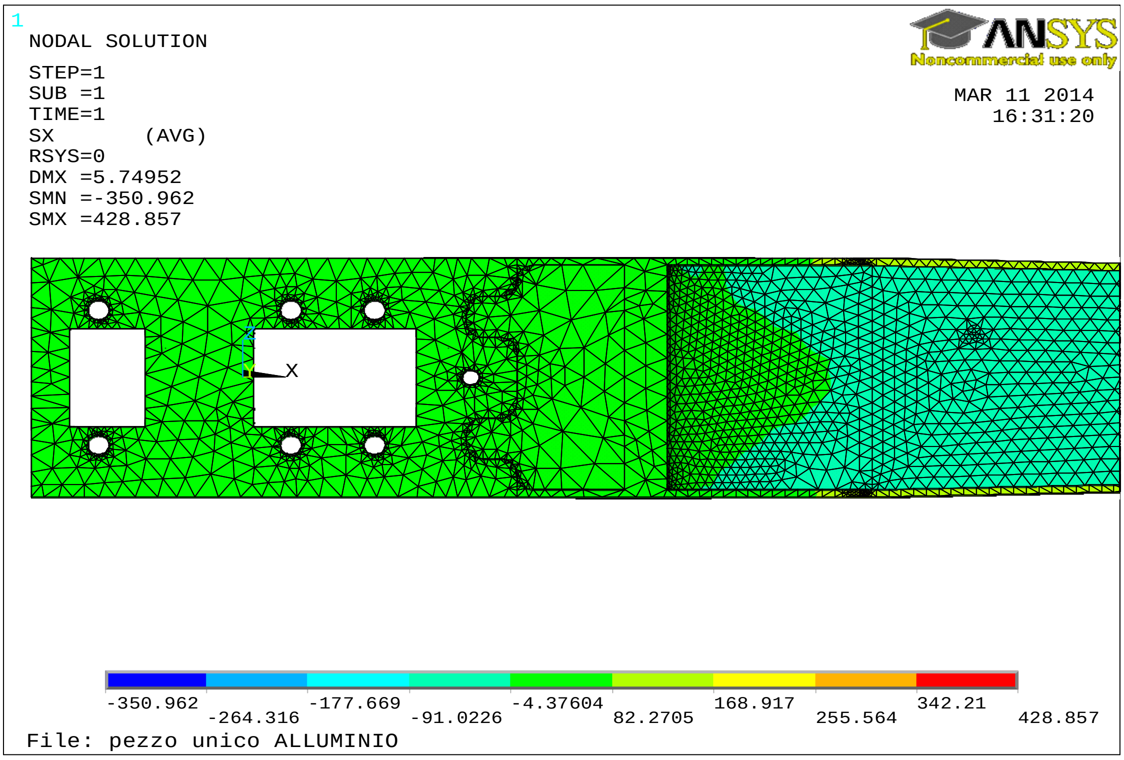
- Y displacements plot:



- Deformation graph:



- Stress (σ_{xx}) bottom view:



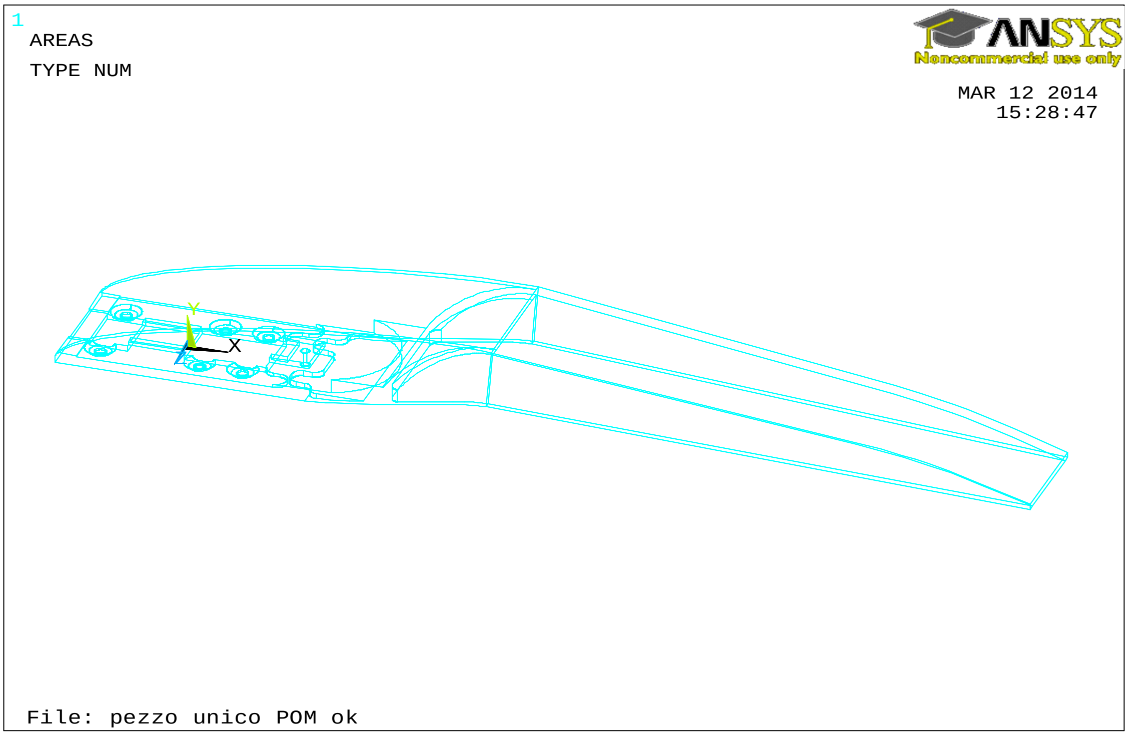
- stiffness calculated like F/f :

$$\boldsymbol{k_{ARM}} = \frac{FY}{Ydisplacement} = \frac{125}{5{,}701} = \boldsymbol{21{,}92\,\frac{N}{mm}}$$

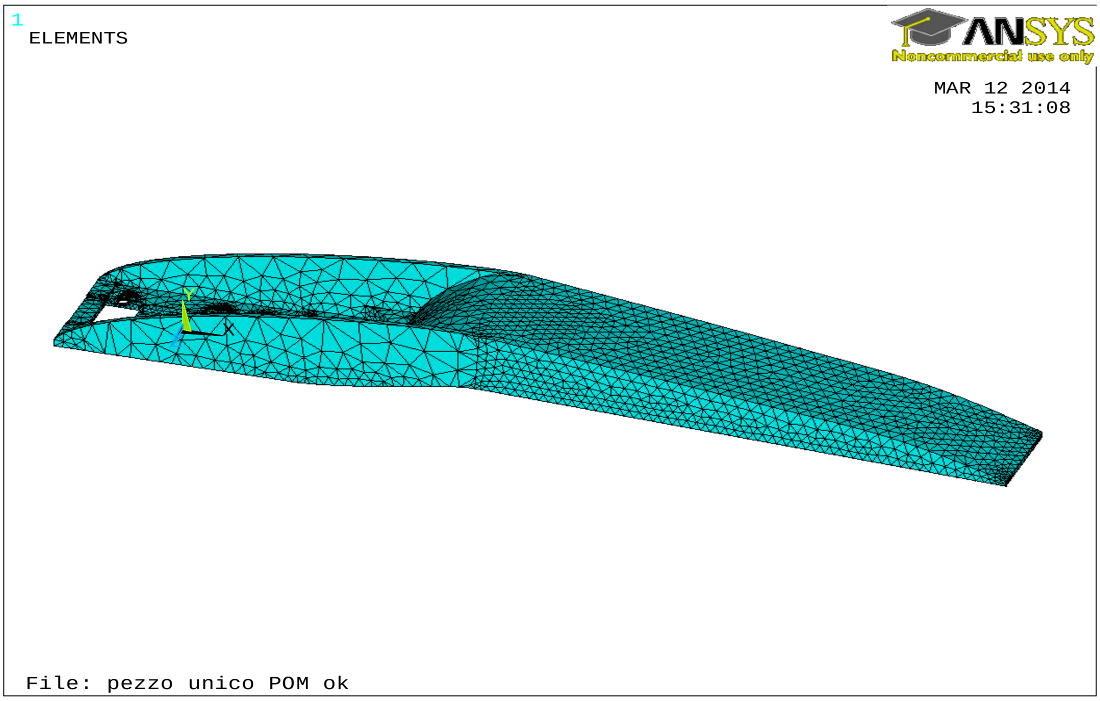
6.4.7 POM UNIQUE PIECE STRUCTURE

Preprocessing

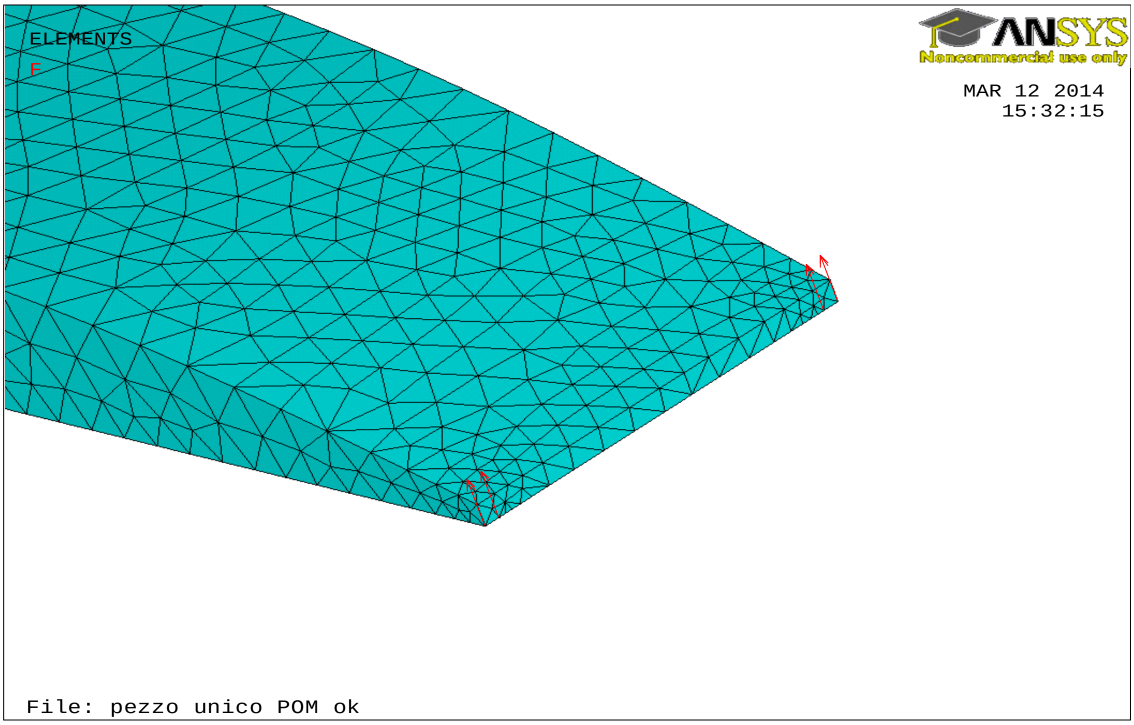
- imported file (in total dimensions):



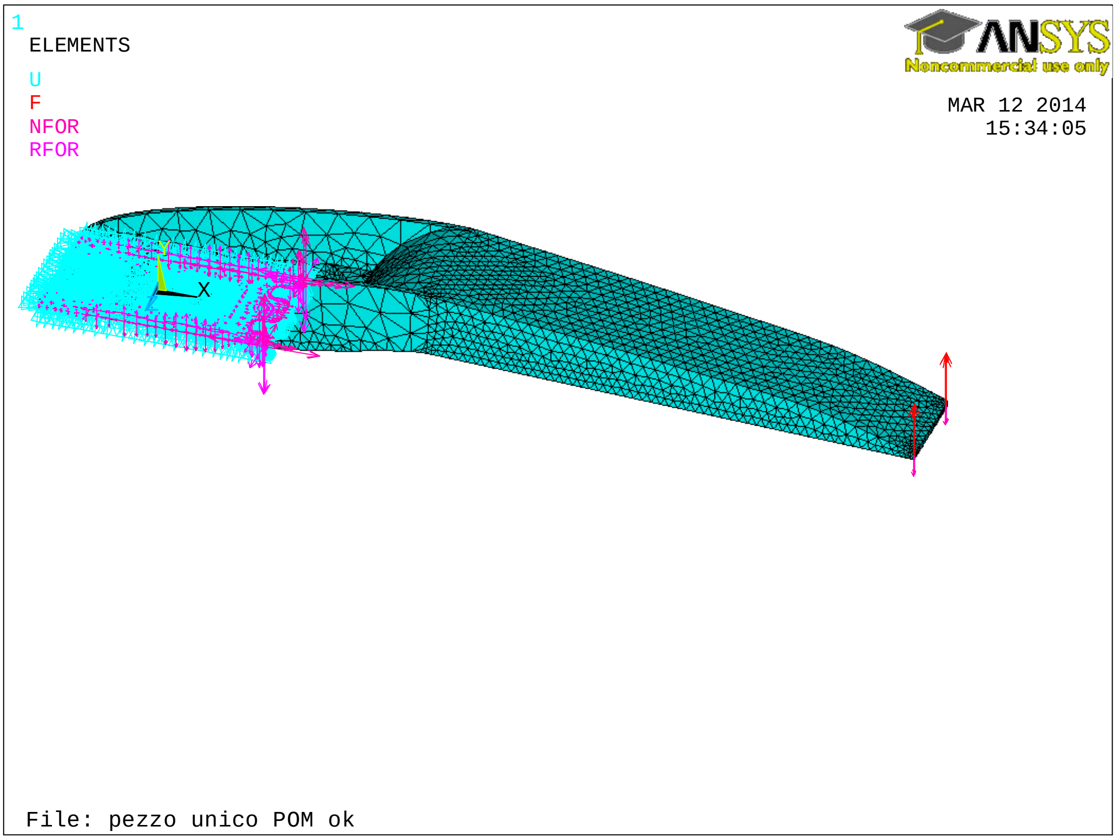
- element type: SOLID 185
- key options: simplified enhanced strain
- material property: linear, elastic, isotropic, EX=6775 , PRXY=0,3
- boundary condition: bond is the lower surface.
- mesh size: 3mm and refined near the ideal welded area.



- load condition: load is applied on the extremely edge of arm. Value imposed is: FY = 125N (divided in four vectors).

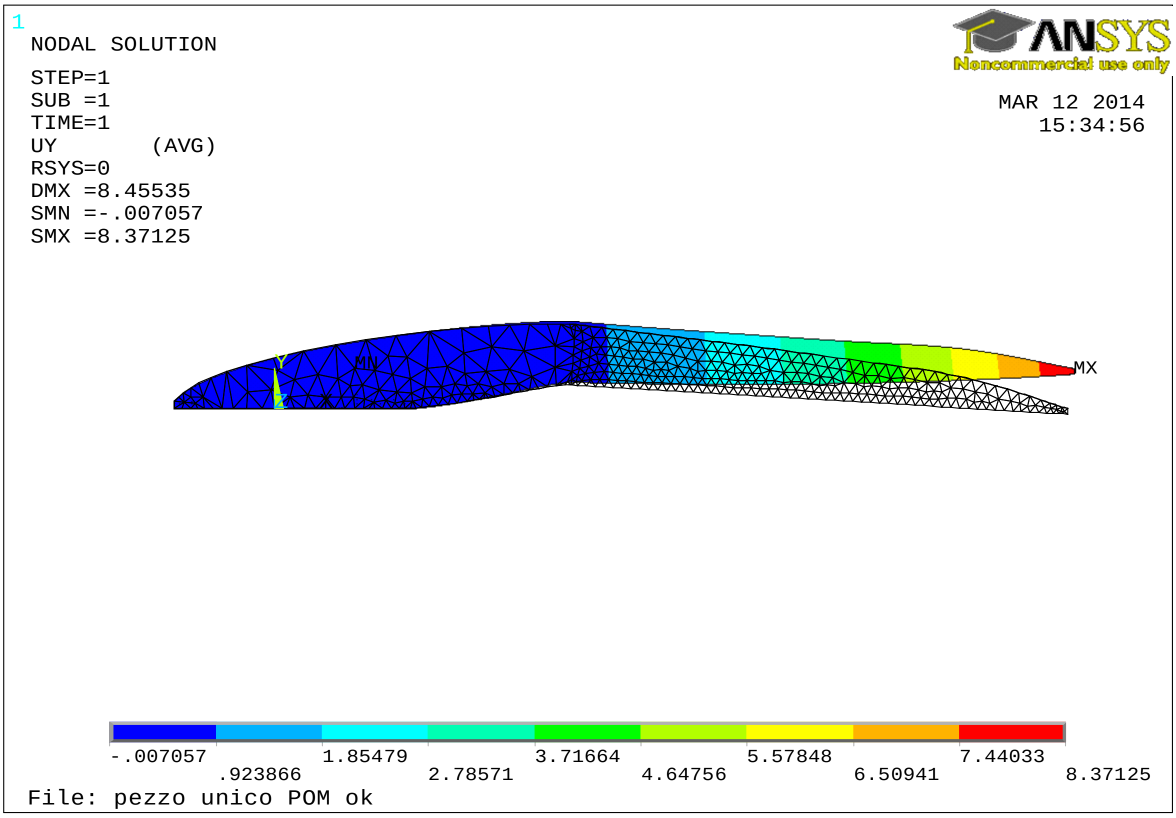


Solution

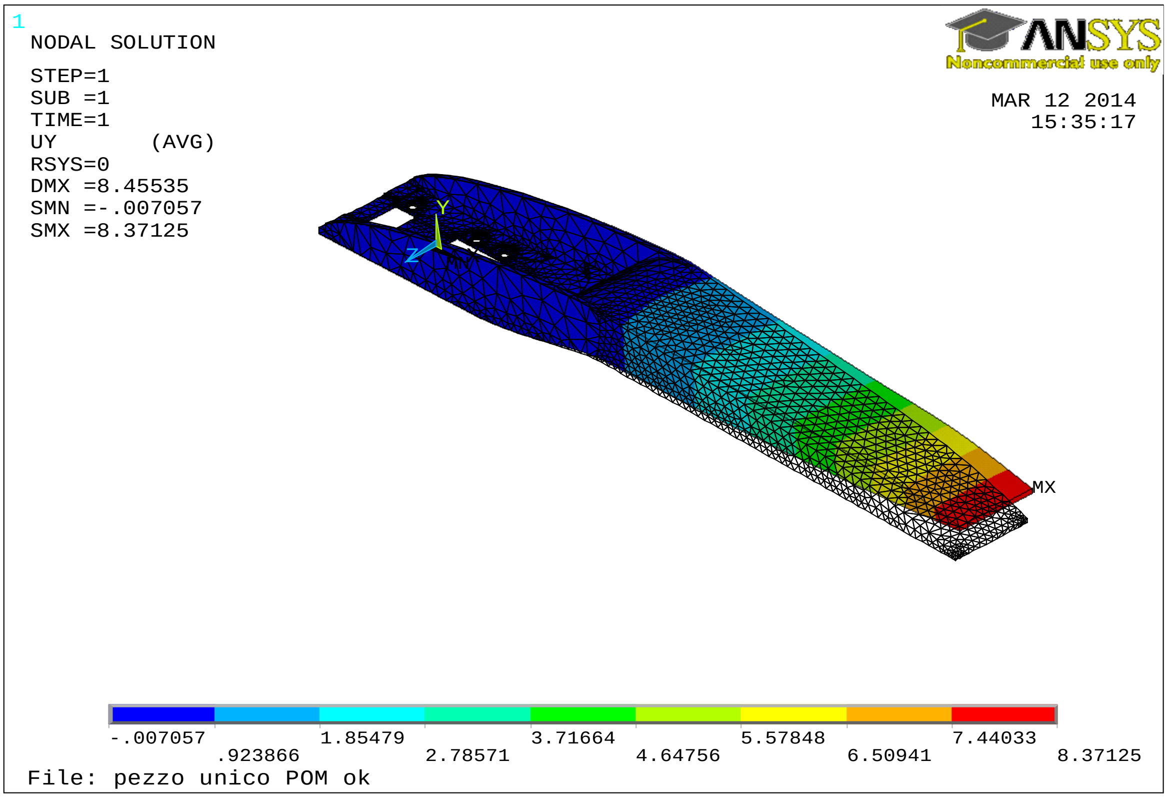


Post processing

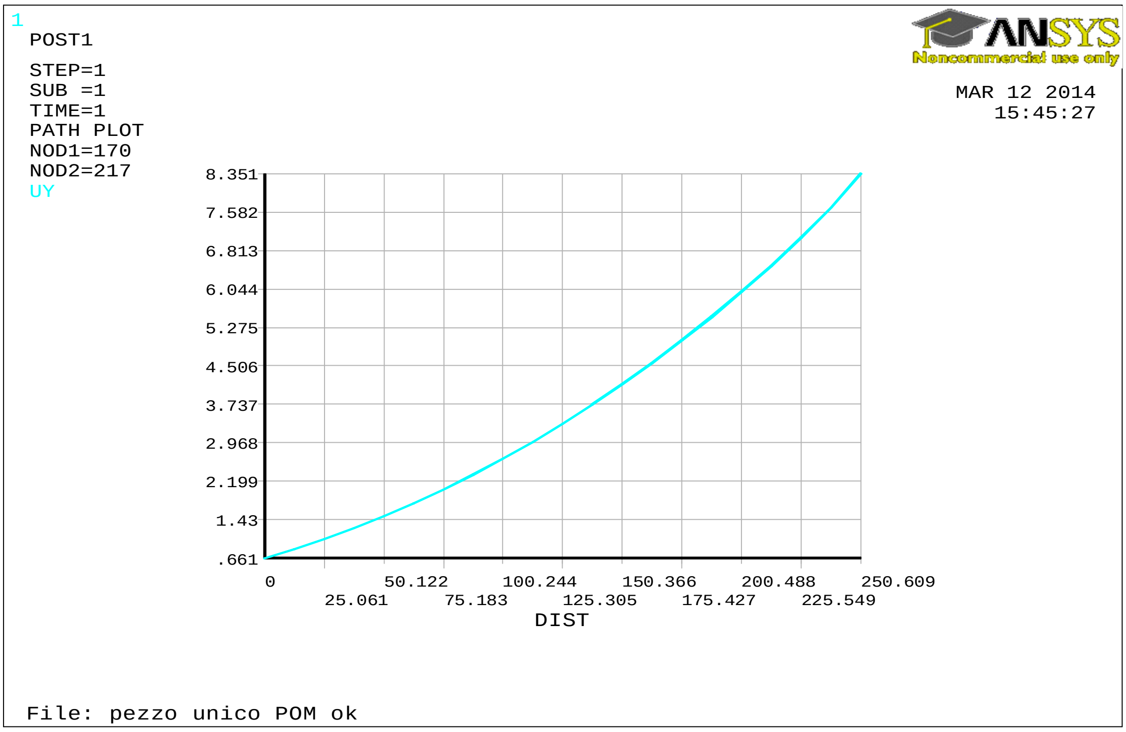
- Example of deformed shape:



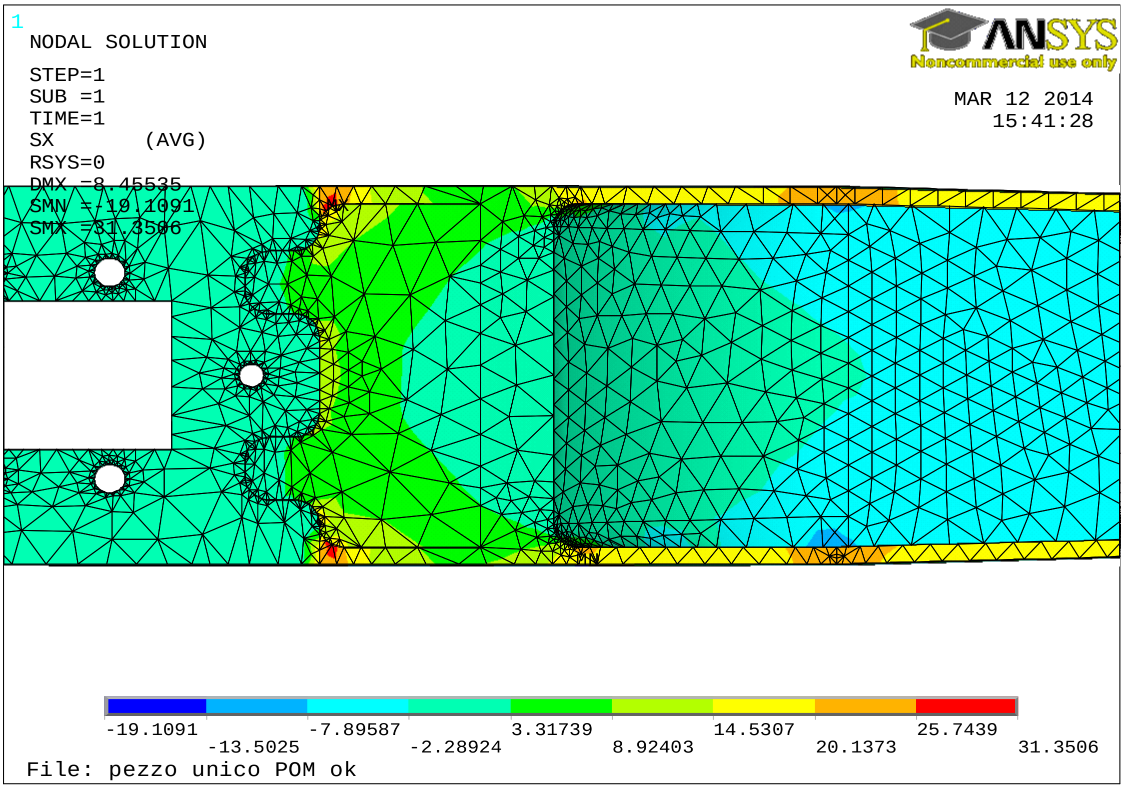
- Y displacements plot:



- Deformation graph:



- Stress (σ_{xx}) bottom view:

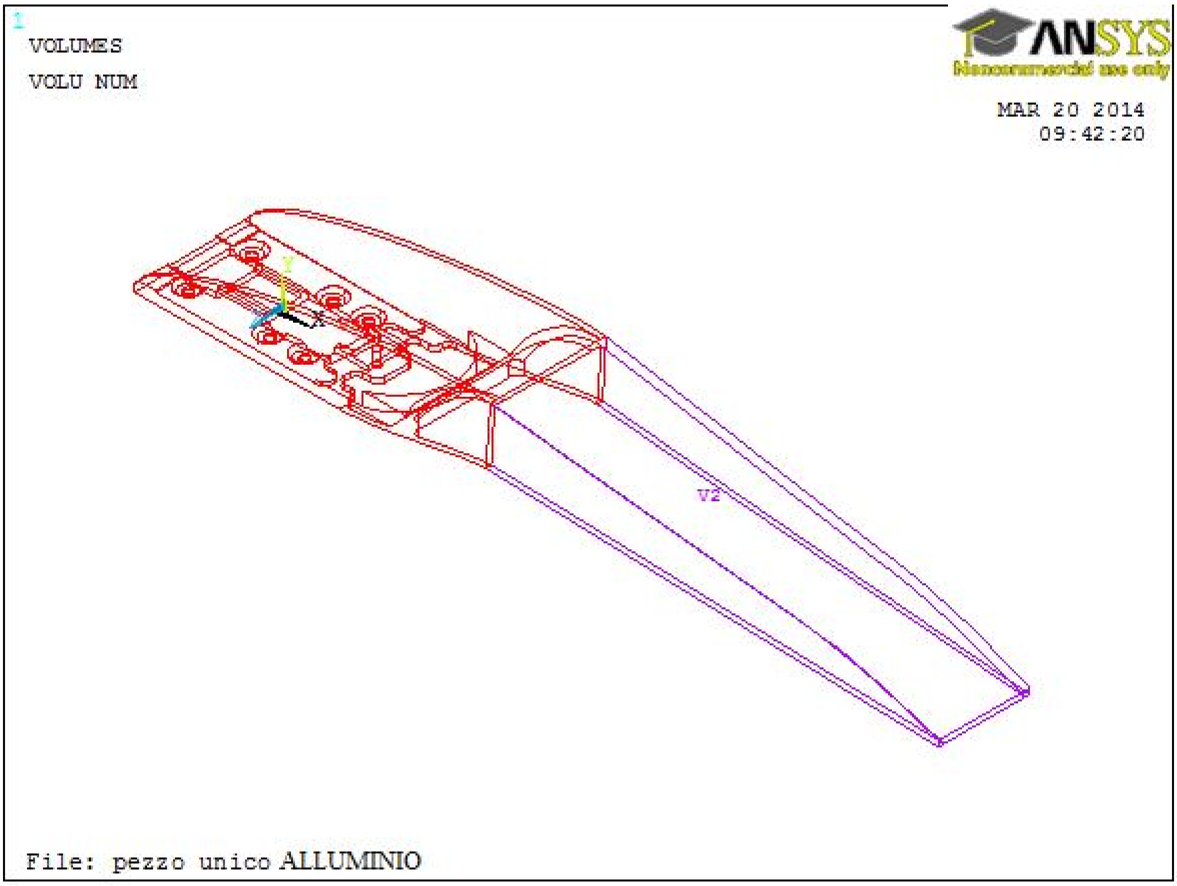


- stiffness calculated like F/f :

$$k_{ARM} = \frac{FY}{Ydisplacement} = \frac{125}{8{,}351} = \mathbf{14{,}97}\,\frac{\boldsymbol{N}}{\boldsymbol{mm}}$$

6.4.8 EFFECT OF PLATE ON DISPLACEMENT OF ALUMINUM UNIQUE PIECE

Displacements FEM results of aluminum unique piece shows higher value. It's possible that the plate influence the total deformation. So it was effectuated a FEM analysis changing the material properties of elements attached to extended part of unique piece.
The follow picture show an example of volumes division:



Volume evidenced with red line has aluminum property (E=70000 MPa). The second in violet has super rigid property (E=10^{14} MPa).
Like in the previous analysis load is applied on the extreme edge of the piece and lower area is fixed with ALL DOF displacement boundary condition.
After the solution calculation the total displacement on Y axis is 1,38 mm , as show in the follow figure.

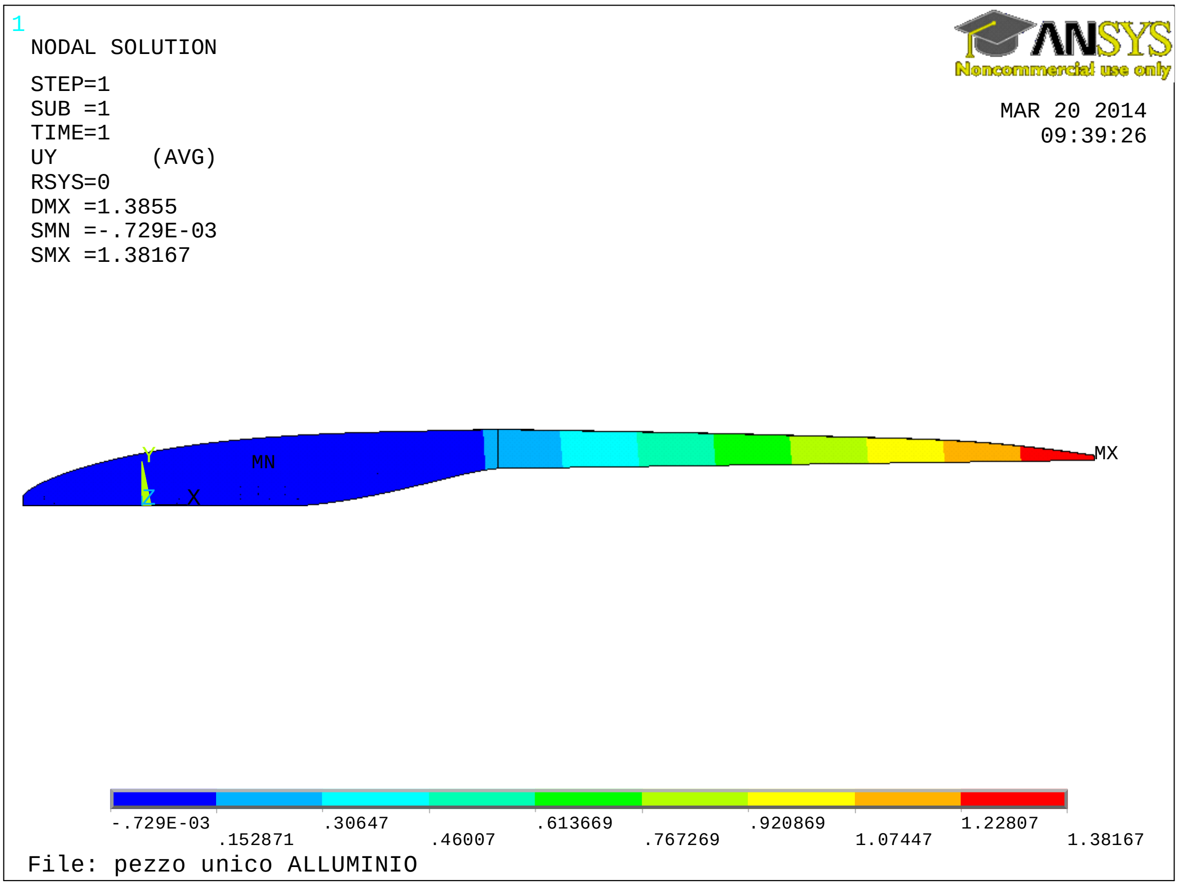
The previous displacement was 5,71mm. The effect of plate on unique piece is 1,38mm. The difference of these two values gives the displacement of the only superstructure part (4,33 mm).

The new value of displacement (calculated from analytical mode) is the difference of old value and the only effect of plate displacement value:

4,39 – 1,38 = 3,01 mm

The new stiffness for a single aluminum beam of variable cross section is:

$$K_{OB\_NEW} = \frac{125}{3,01} = 41,53\ N/mm$$



The following table shows the new values of geometries of arm calculated in objective research of Office Excel.

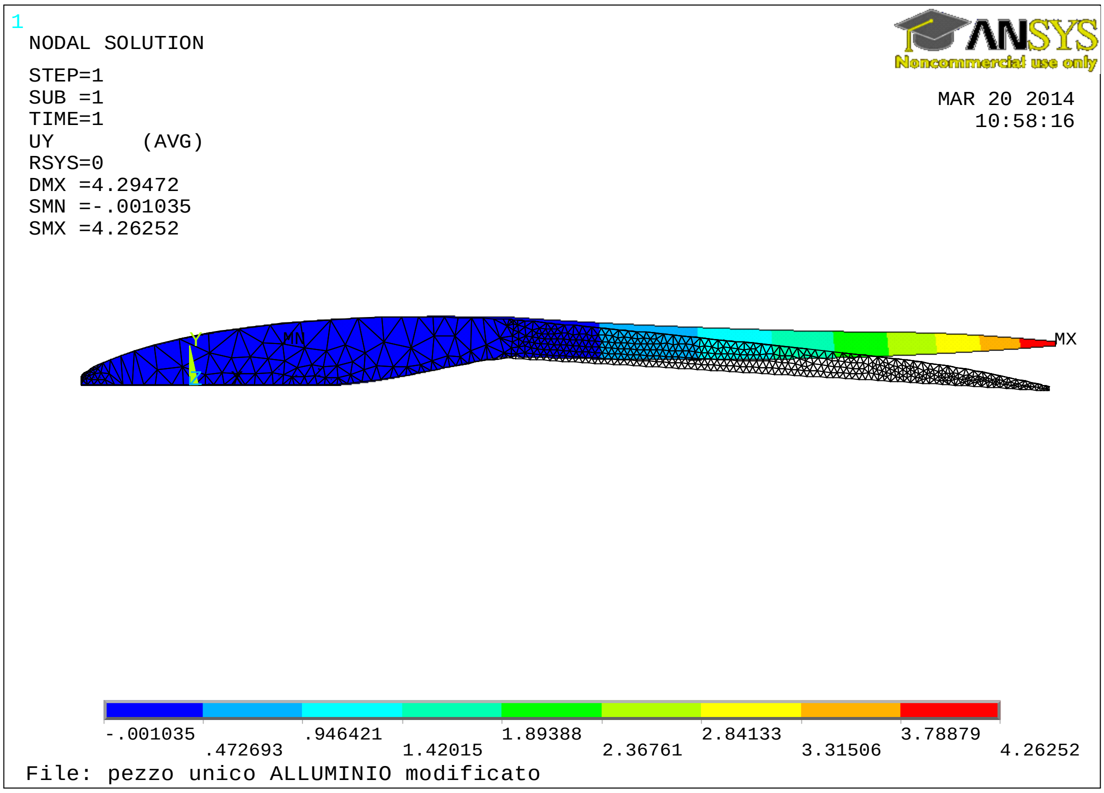
x	b	h	t	w
0	64	16,87	2	2
50	61,6	15,09	2	2
100	59,2	13,06	2	2
150	56,8	10,67	2	2
200	54,4	7,54	2	2
250	52	0	2	2

Repeating the same procedure applied for all the analysis in ANSYS® the final result of displacement on Y axis is 4,26 mm and stiffness is :

$$K_{OB\_NEW} = \frac{125}{4{,}26} = 29{,}34\ N/mm$$

This new model was named: **AL_T2_300_2**

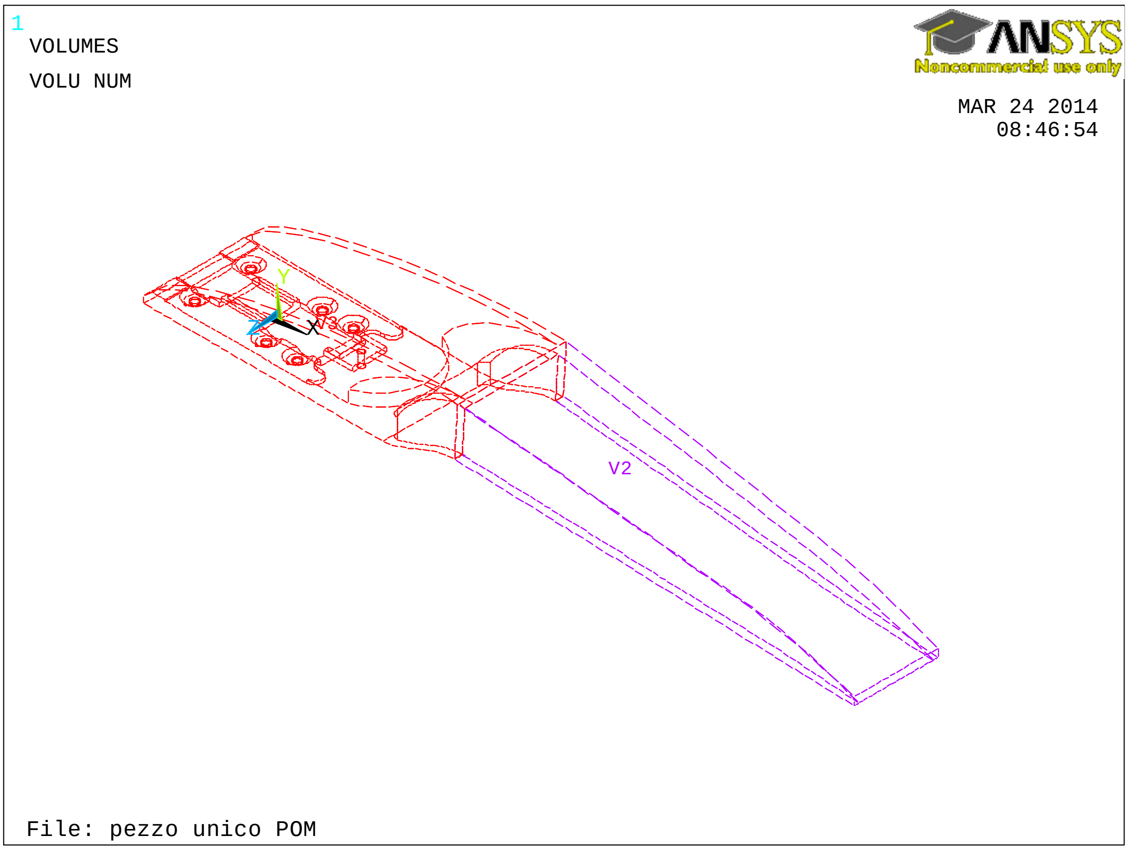
The follow figures shows the displacement on Y axis from un-deformed to deformed shape of unique piece.



Displacement gives by FEM analysis is 0,13mm lower than the analytical expected value. This is acceptable. The effect of plate contributes on 1,38mm , so the **31,4%** of the total displacement.

6.4.9 EFFECT OF PLATE ON DISPLACEMENT OF POM UNIQUE PIECE

POM unique piece shows the same problem of displacement higher than the expected value. The volume on FEM analysis is divided an studied to find the effect of the plate on total deformation.



In a first study the deformation contribute of plate was 3,905mm, and the difference with the numerical displacement was:

$$4{,}39 - 3{,}905 = 0{,}485 \text{ mm}$$

This means that the extended part of the unique piece has to have a stiffness of

$$K_{OB} = \frac{125}{0{,}485} = 258\ N/mm$$

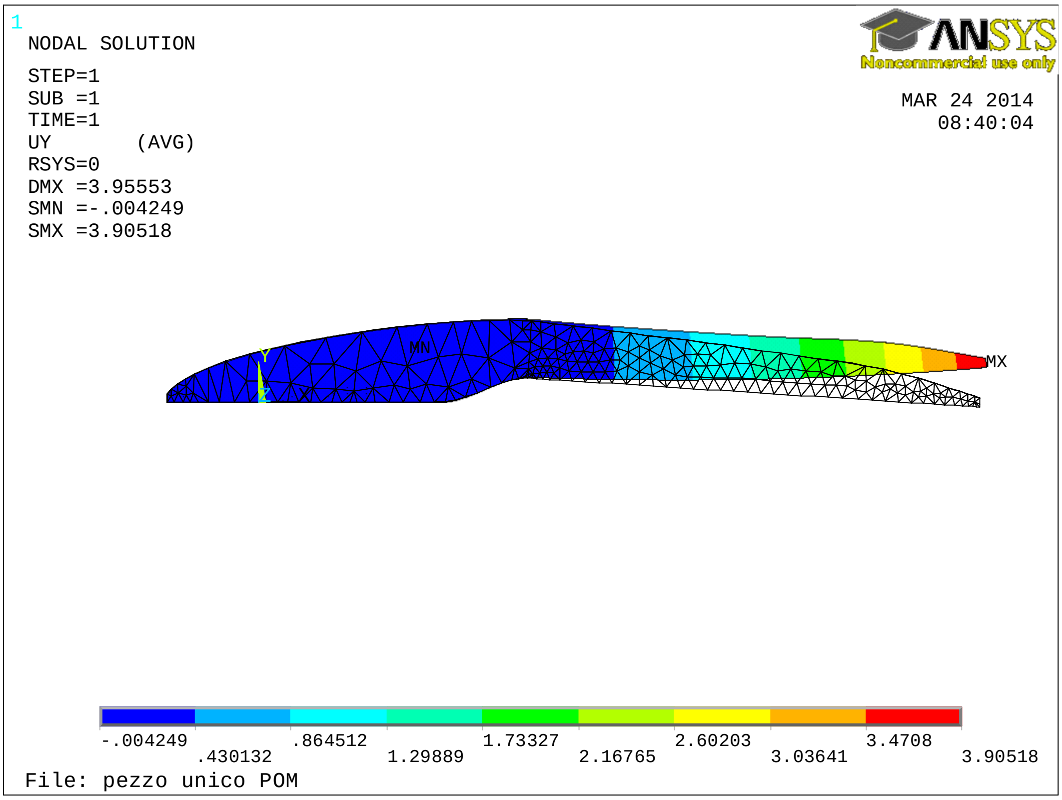
and a height of 70mm. This is not possible for production. So the volume was modified: thickness became of 5 mm for aims, and the attachment on plate of the extended part was reinforced.
Analytically at the extended part was attributed the same stiffness of the aluminum piece (41,53 N/mm).

This is the new value of extended part sections:

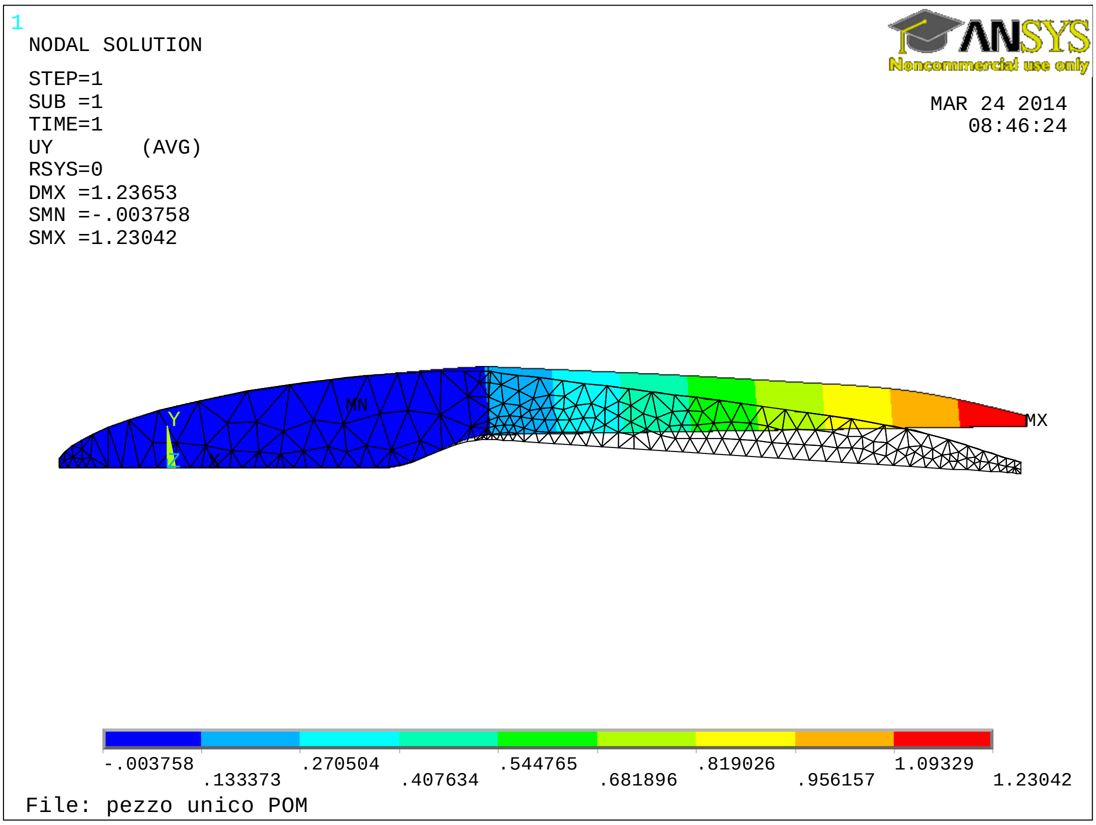
x	b	h	t	w
0	70	26,82	5	5
50	66,8	23,99	5	5
100	63,6	20,77	5	5
150	60,4	16,96	5	5
200	57,2	11,99	5	5
250	54	0	5	5

This new model was named: **POM_T5_300_2**

Repeating the procedure for FEM analysis:



POM new model provides a displacement on Y of 3,905mm , lower than the previous (8,3mm); the effect of plate gives the follow deformation plot:



Displacement is 1,23 mm , the **31,49 %** of the total one.

6.5 RESULTS

The values of displacements and of stiffness are different than the expected ones because analytical analysis provides exact values, and FEM provides approximation due to mesh of volumes.

$$K_{FEM} < K_{AN}$$

In unique pieces stiffness is lesser because in analytical calculation it was considered a bending length of 250mm, but, simulating in ANSYS®, the distance from the free edge of arm and the bond became 336mm. The geometry of the plate influence the total value of deformation in this way (first solution):

MATERIAL	f_{AN} [mm]	f_{FEM} [mm]	$f_{FEM\text{-}PLATE}$ [mm]	PLATE CONTRIBUTION
ALUMINUM	4,398	5,71	0,942	16,50%
POM	4,398	8,371	2,622	31,32%

New analysis on aluminum and POM unique pieces show that the plate part influence the value of total deformation on Y axis.

MATERIAL	$f_{FEM\text{-}PLATE\ EFF}$ [mm]	$f_{SINGLE\ ARM}$ [mm]	$f_{NEW\ FEM}$ [mm]	DIFF % AN - FEM	PLATE CONTRIBUTION
ALUMINUM	1,38	3,01	4,26	2,96 %	31,4 %
POM	1,23	3,16	3,90	11,1 %	31,49 %

This table resumes analytical calculation and numerical calculation of stiffness for the six analysis (for unique pieces is used the last solutions). The percentage are calculate in respect of the FEM values.

material	section	K_{FEM} [N/mm]	K_{AN} [N/mm]	diff.% FEM - AN
AL	COST	32,24	28,42	11,8%
POM	COST	29,59	28,42	4,0%
AL	VAR	33,07	28,42	14,1%
POM	VAR	29,93	28,42	5,0%
AL	UNIQUE P.	29,32	28,42	3,1%
POM	UNIQUE P.	32,01	28,42	11,2%

This last table resumes some properties of the new 3D models:

MODEL	V	m	ρ	E	E/ρ	k/m
	[mm^3]	[g]	[g/cm^3]	[N/mm^2]	[m^2/s^2]	[m^2/s^2]
POM_T5_300_2	248982,3	353,5549	1,42	6775	4,8E-06	8,29E-05
AL_T2_300_2	91962,98	249,2197	2,71	70000	2,6E-05	1,28E-04

6.6 CONCLUSIONS

Looking at the previous table the effect of cross section shows that aluminum differs from POM percentage, who are lower. But when there is the match of arm part with plate part, obtaining the unique piece, these percentage change, and aluminum answers better than POM in finite element analysis (only 3,1% of difference from analytical and numerical).

Aluminum and POM differs of one order of magnitude on Young modulus, so the new modes of unique piece have different thickness to be comparable on high. The presence of the part who connect the unique piece to Piston Marker plate is the same for each model, but the POM one has to be more rigid or the displacements on tip of arm would be over the limit of 4,39mm. This important limit is respected for the last optimization of models. Plate contribution on displacements is 31,4 % for both material.

Fem analysis also provides the values of stress into the structure. In aluminum unique piece stress is very high, but an accurate research of critical zone shows that this critical stress interests volumes of size lower than the tenth of millimeters.

The last optimized model in aluminum would became a prototype thank to Nordica group, and would be tested on Slytech bench to observe his effects. For having lower costs in prototyping , POM unique piece would became a prototype only when aluminum unique piece would give the best results. Good effect are just given by the integral plate in wood material, so the furure comparison would be done with this type of ski and understanding which is the best way for countinuing this superstructure project.

CONCLUSIONS

Influences of snow asperities, temperature, slope inclination, style of carving are evidenced in the final results of comparison of in-field tests. Bending moment and torque calculated in laboratory and in in-field are different, and as expected the first are bigger than the second, except for wide carving where the limit of Slytech bench was exceeded. Maximum laboratory values of Slytech bench is taken as reference, like static test, and from these bending moment value referred at 60° of edge inclination, the comparison could be made with a in-field value, that would be studied as a dynamic value. Values from in-field test is taken as mean value of peaks from signals low pass filtered at 25 Hz to eliminate disturbs.

It’s evident that the carving style change the forces that the tester release to the ski on slopes: for large carving there are the maximum value of bending moment because ski is subjected at maximum flexion for extended time with respect to normal or short carving, so the tester have more time for effectuating the curves and for receive the sensation of maximum load. When ski was in the external position during a curve, it received a greater load with respect to the internal ski, because of centrifugal effect.

The presence of superstructure don’t influence the style of skiing in bending moment and values of only shovel bending moment , as observed for sum of stiffness in characterization chapter, seem to be the sum of shovel coupled with arm and arm bending moment. Eventual differences are due to boundary conditions.

The presence of superstructure is important because to obtain the same deflection of the original configuration, the skier have to release greater force during a turn. Higher is the frequency of edge exchange and lesser is the contribute of superstructure on shovel bending moment, but this is also due to the fact that in short skidding the skier tend to release a great part of load at tail of ski, to receive a bumping effect by the ski, who helps him on edging change.

Nordica group decided to develop a prototype of the new aluminum superstructure, and test would be effectuated in future on Slytech bench. Aluminum was chosen for simplifying the technology of production and to have a prototype easy to elaborate in future with cheaper costs.

The idea is that of create a final model that is adaptable for different size of ski, because laboratory tests reveals that each ski have to be coupled with his specific superstructure, this because each superstructure , made in wood, is internally different by the other. This influences are evident on flexional plot given by Nordica Group flex bench. The impossibility of creating a superstructure adaptable for only a ski is chained at industrial production in series and costs of production, because skies are not all locally equal and this differences are important and immediately evident on Edge Load Profiles.

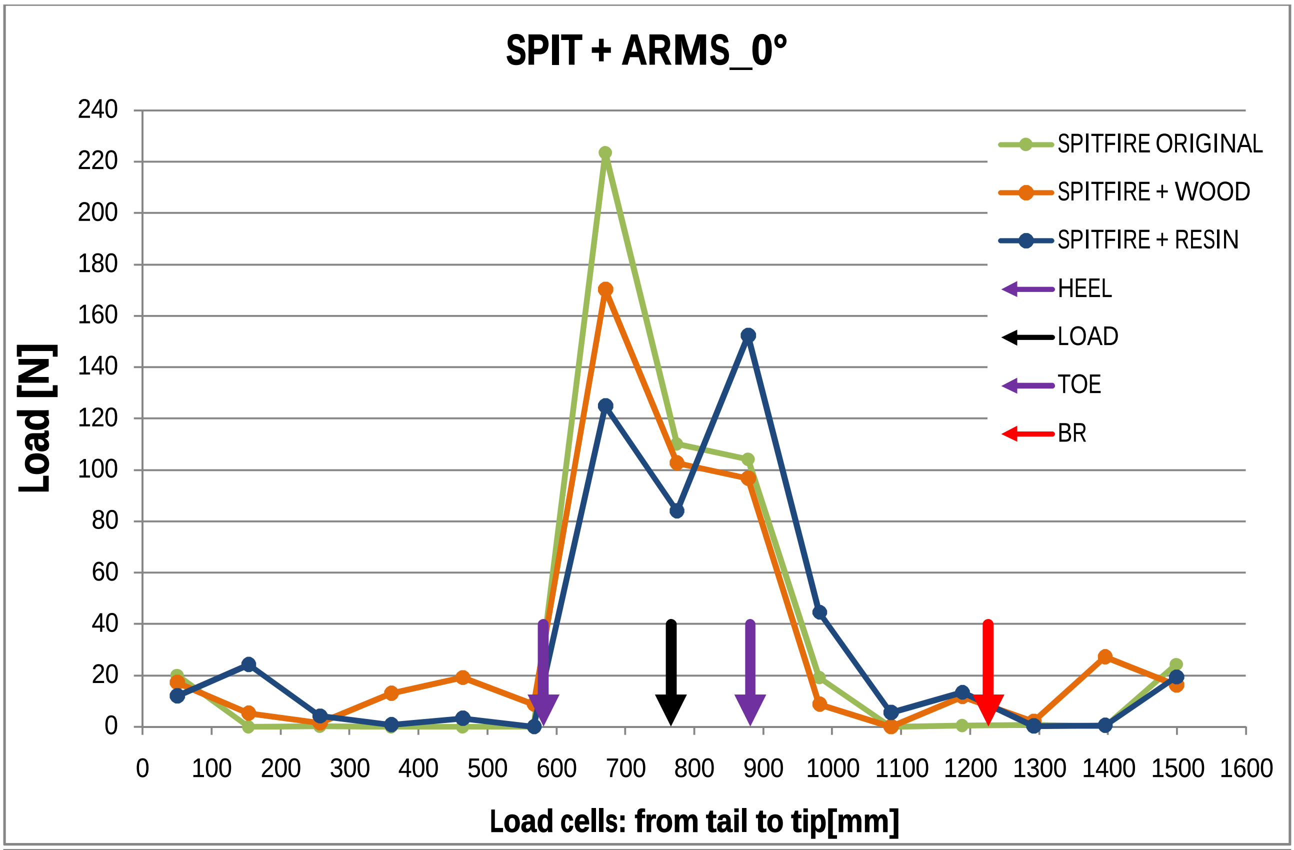
The local stiffness of shovel is not equal for the same couple of ski and this was found on comparisons of the same superstructure coupled in two different ski of the same family and of the same couple. This differences changes the internal property that the superstructure must have for obtaining an edge load profile comparable for the two skies. It returns the problem that each ski has to be coupled with his specific superstructure. But also the same couple of superstructure could be different in internal stiffness and rigidity. Nordica Flex bench provides this peculiarity in production.

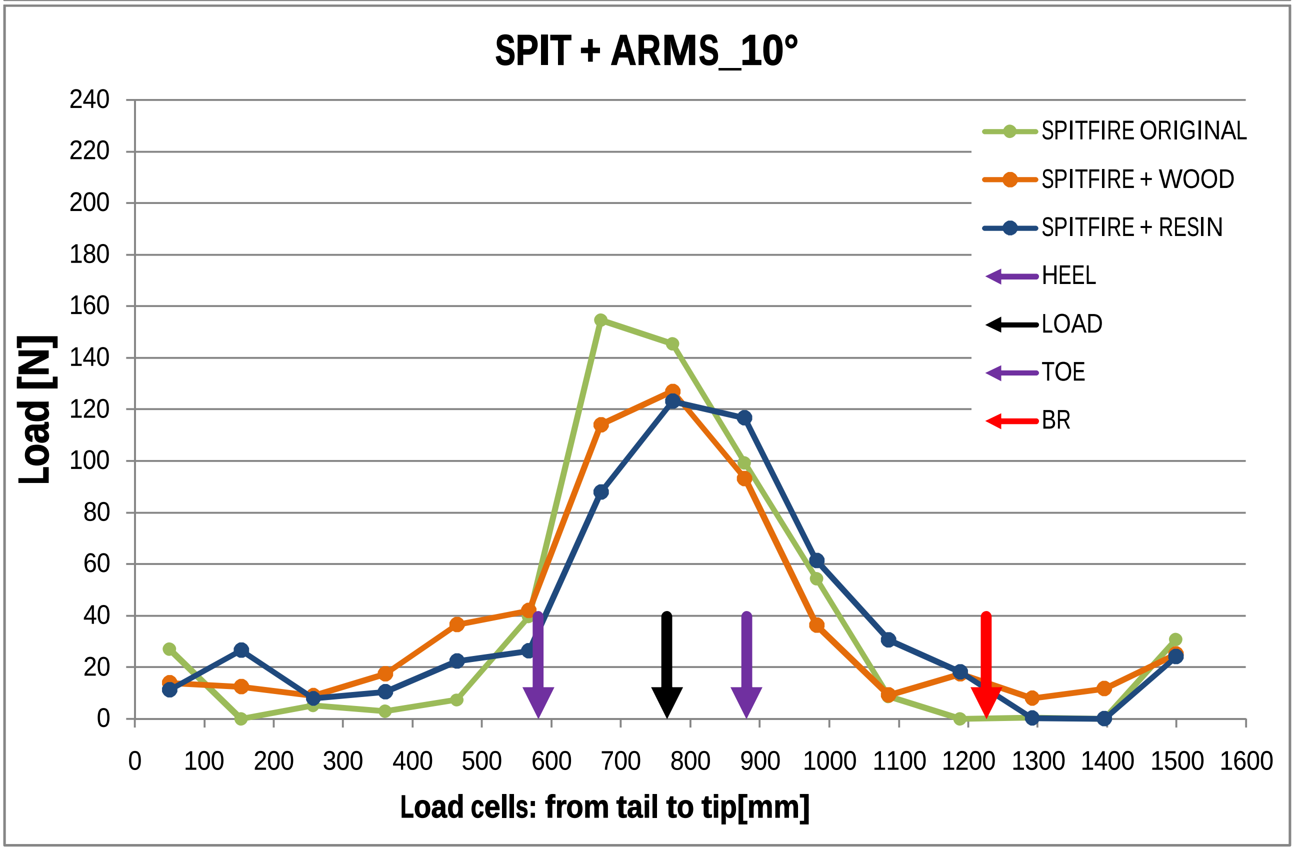
The comparison of different ski on workbenches shows that there is correspondence between different brands. For example Racing SL diagrams are similar for Nordica and Atomic. The same thing append for Rally ski. Progressive skies have diagrams similar to SL ski where are evidenced one peak on shovel, one peak on tail and a valley near the shovel peak. Plateau on diagrams are reported by freestyle ski and all mountain ski, this because of tail and tip flexibility very low with respect of the central part of the ski. This correspondence reflects the fact that Slytech bench is an affordable machine for ski comparisons.

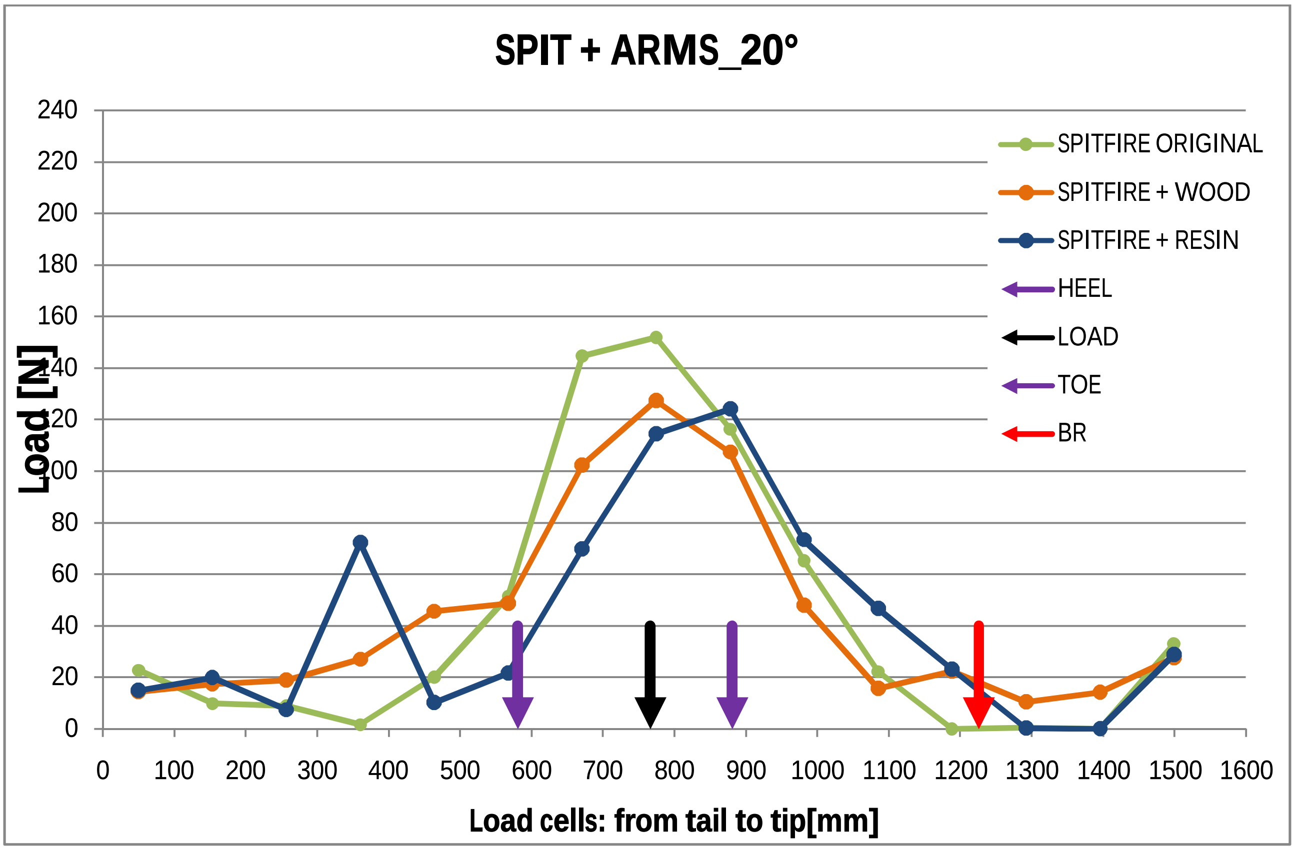
When snow is warmer and softer all the typology of skies shows diagrams that tend to a continuous constant line. Slytech bench with all open screws disposition is interesting for calculate the elastic line of ski deformed shape, when it’s loaded at 0° with a distributed load, as comparison with the single central force flexional test. But to complete this study each load cell have to be matched with sensors of displacements, so this could became a future development of study.

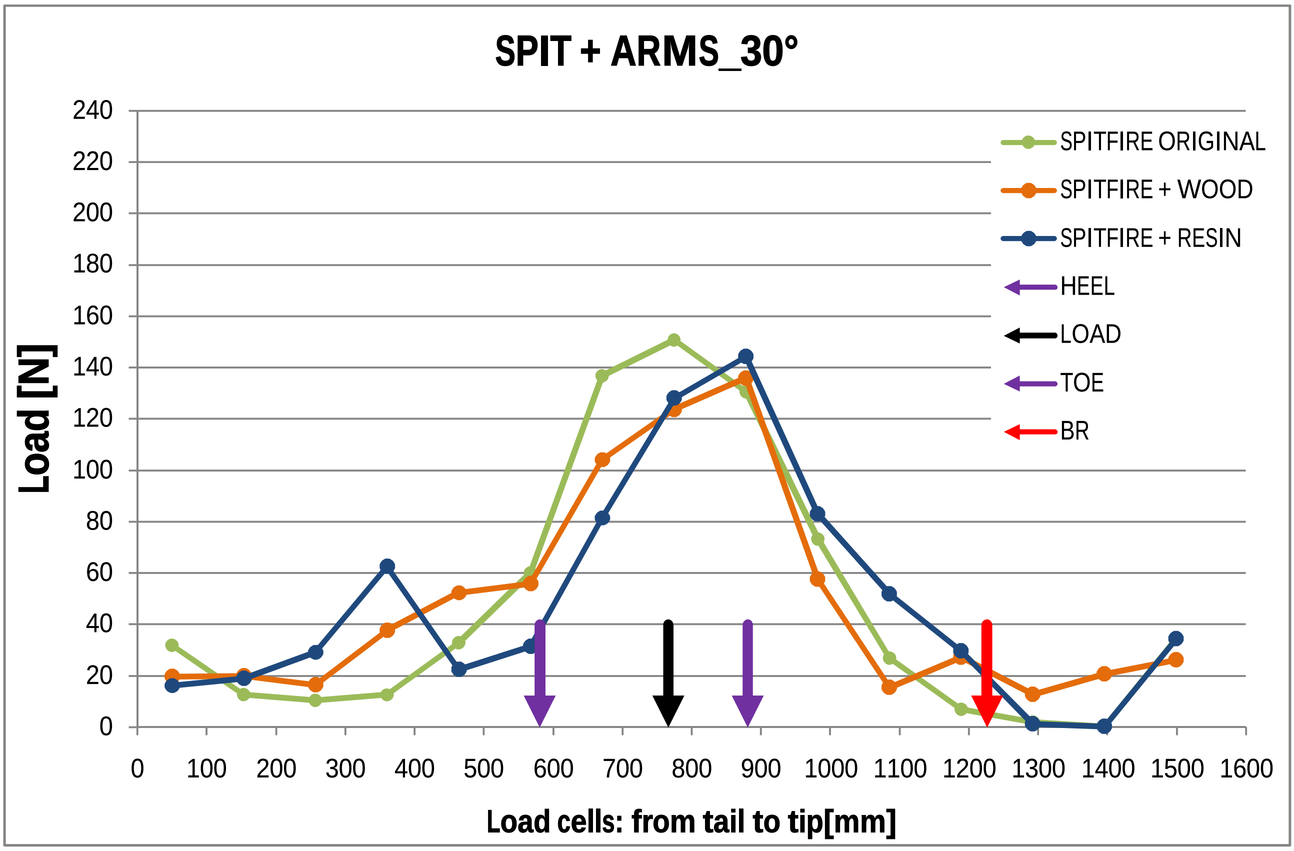
APPENDIX A

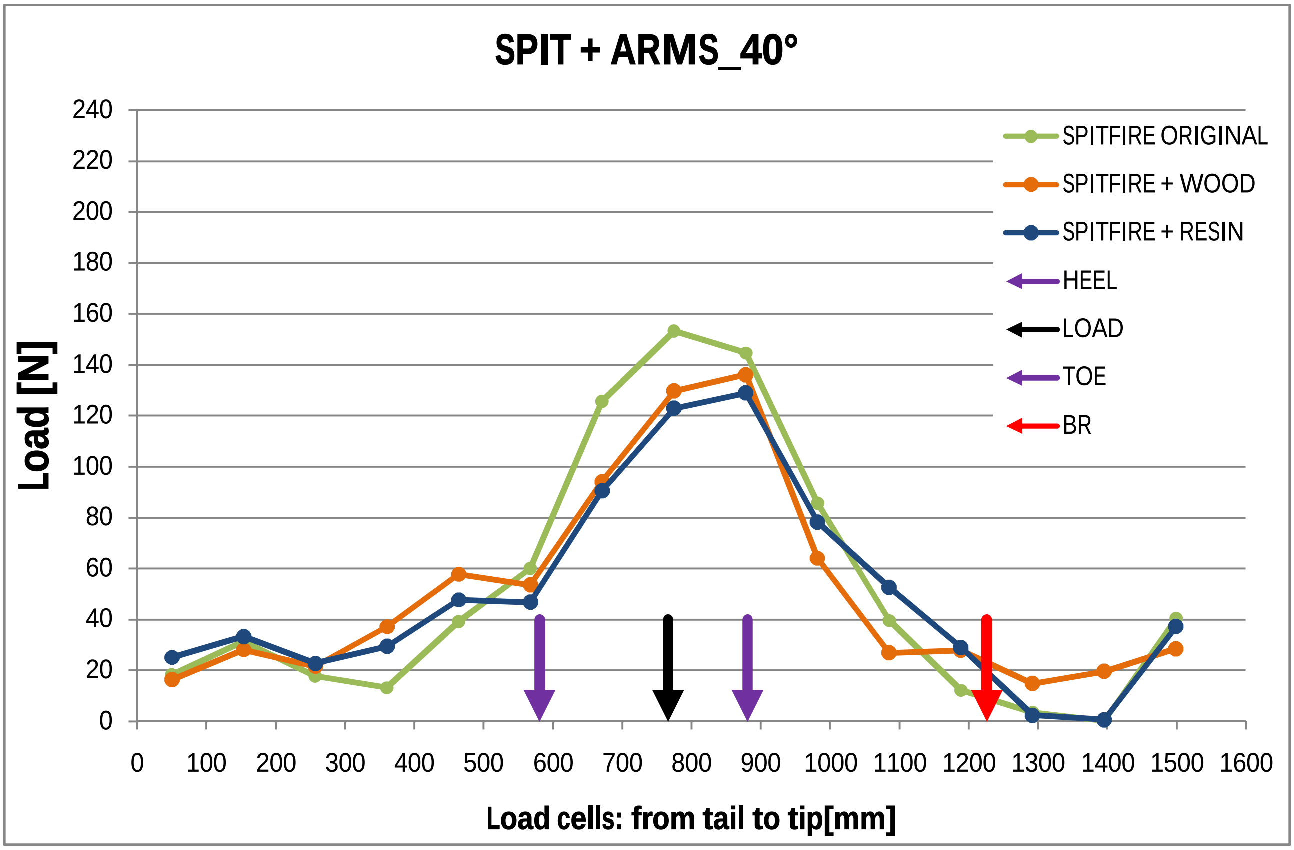
SPITFIRE COUPLED WITH WOOD AND RESIN ARM (DIAGRAMS FROM 0° TO 60°)

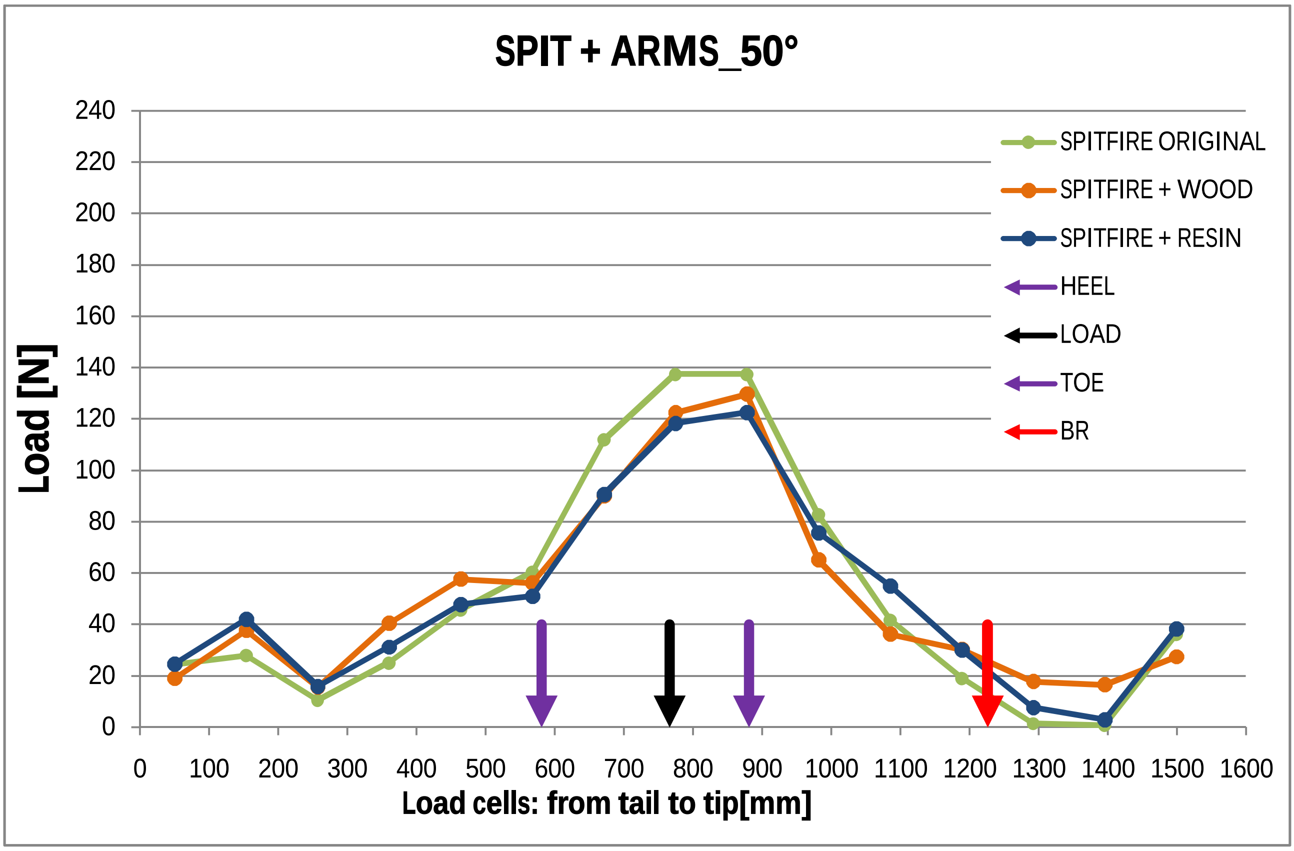


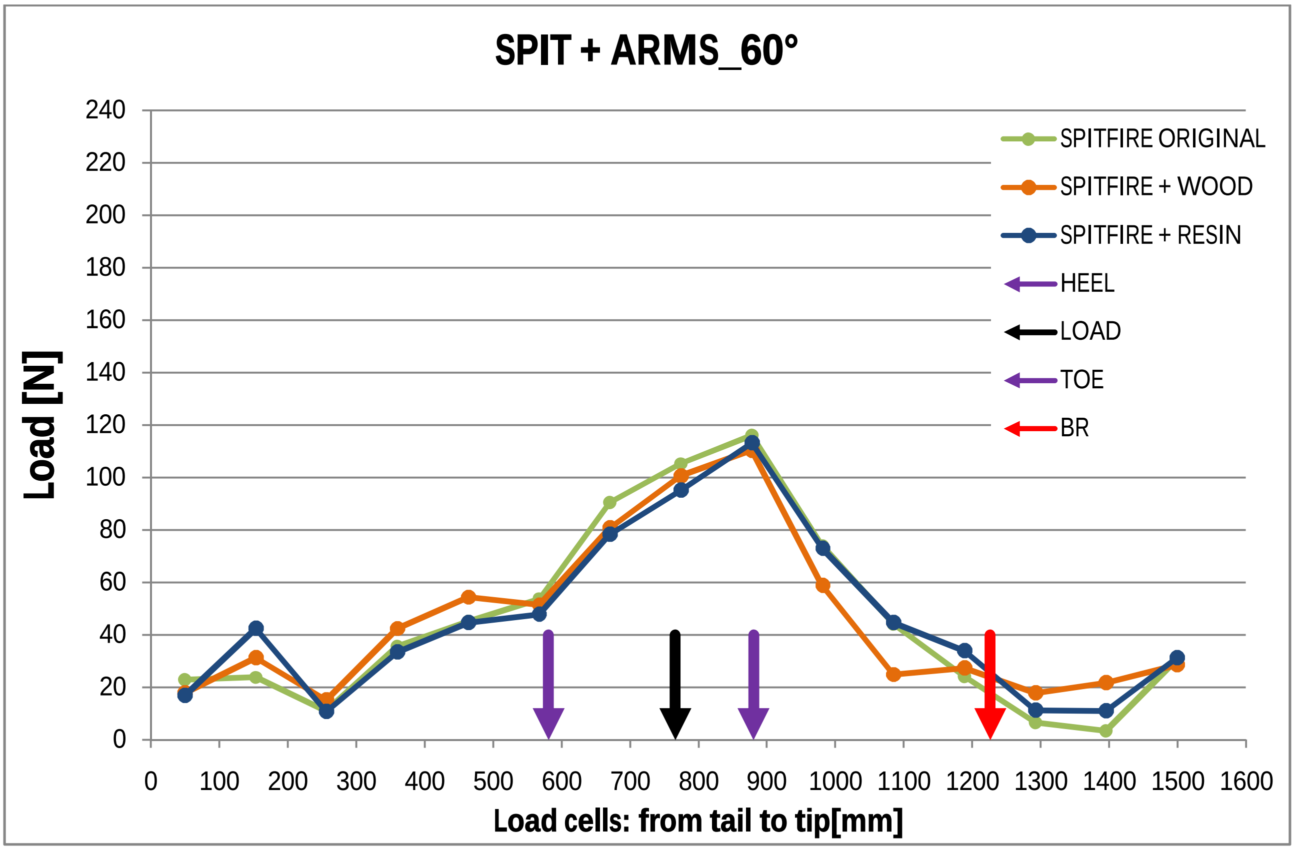



SPIT + ARMS_20°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + RESIN
HEEL
LOAD
TOE
BR


SPIT + ARMS_30°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + RESIN
HEEL
LOAD
TOE
BR


SPIT + ARMS_40°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + RESIN
HEEL
LOAD
TOE
BR

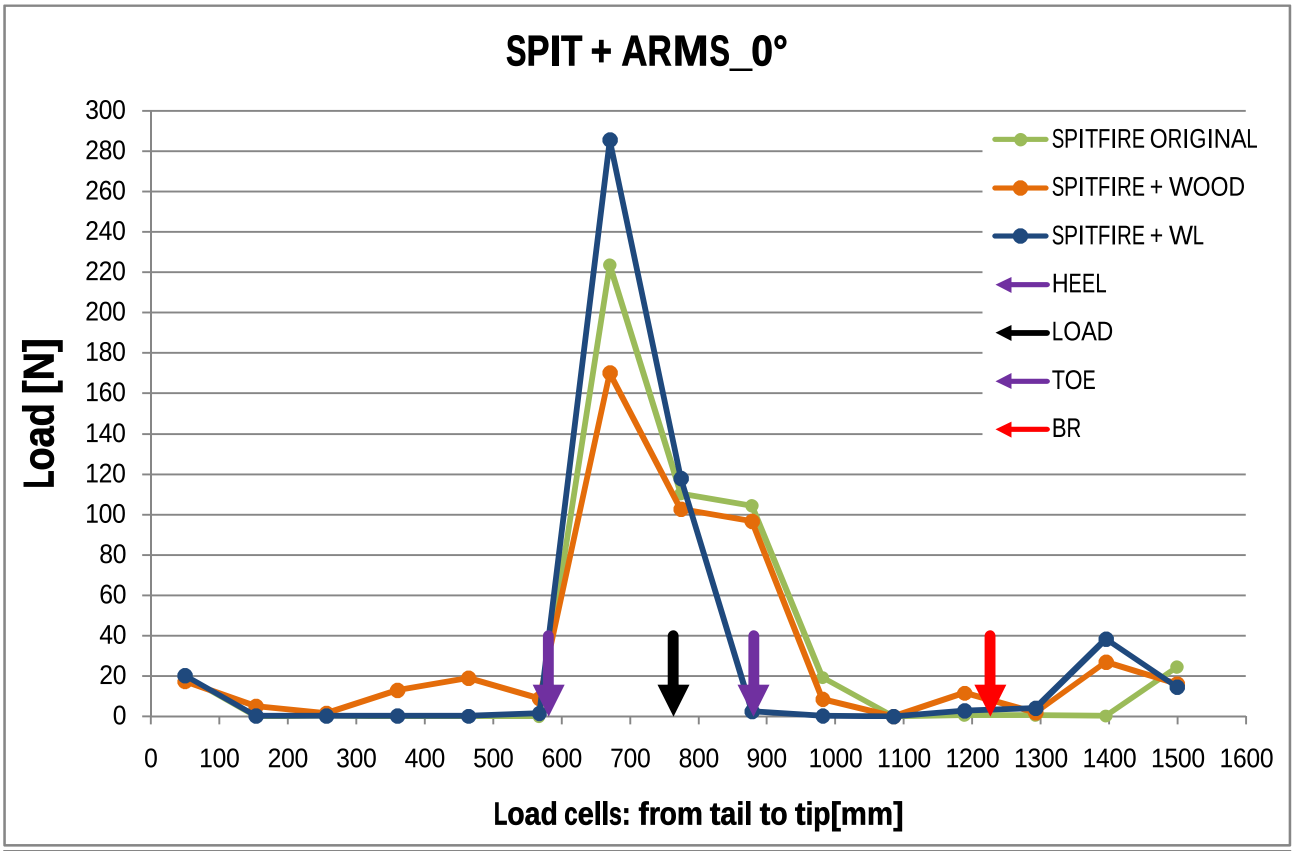

SPIT + ARMS_50°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + RESIN
HEEL
LOAD
TOE
BR

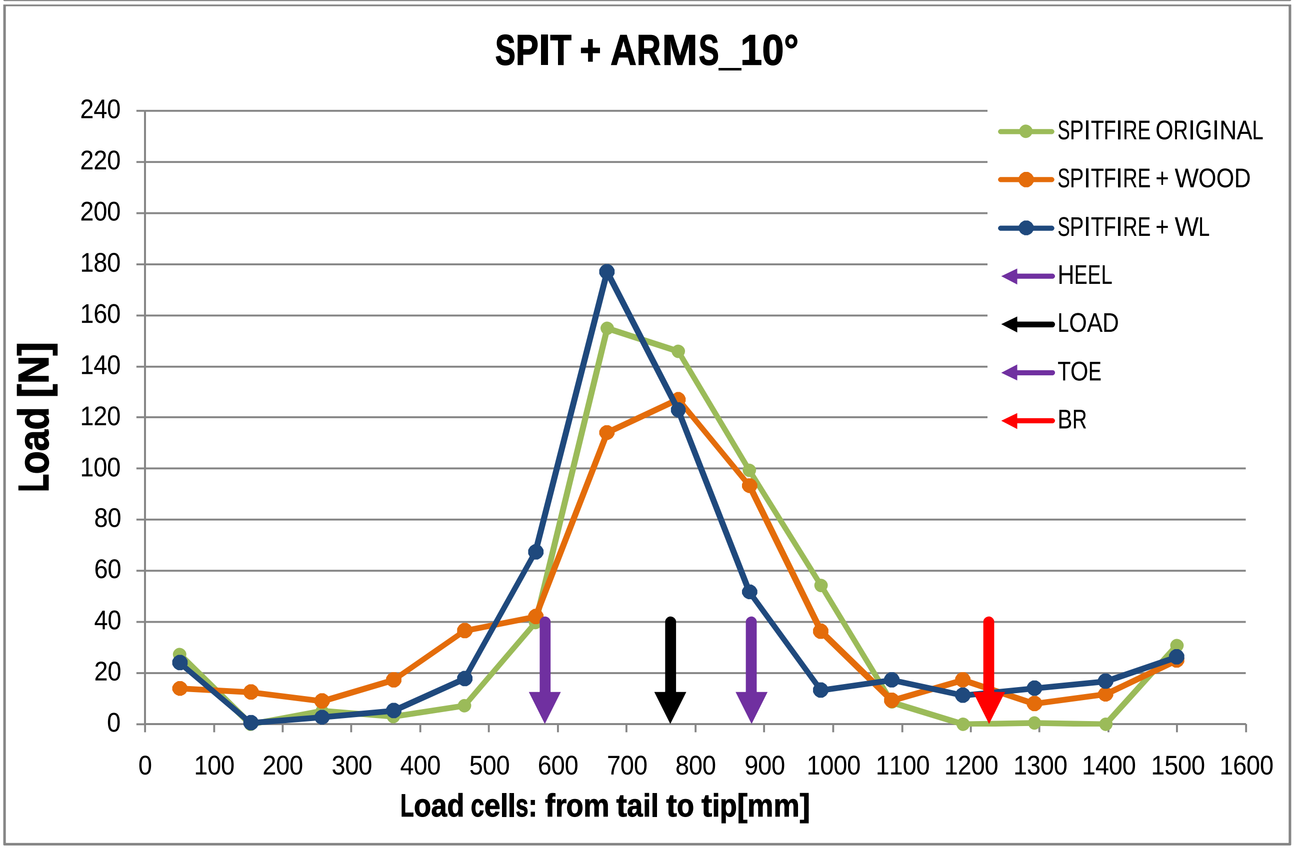


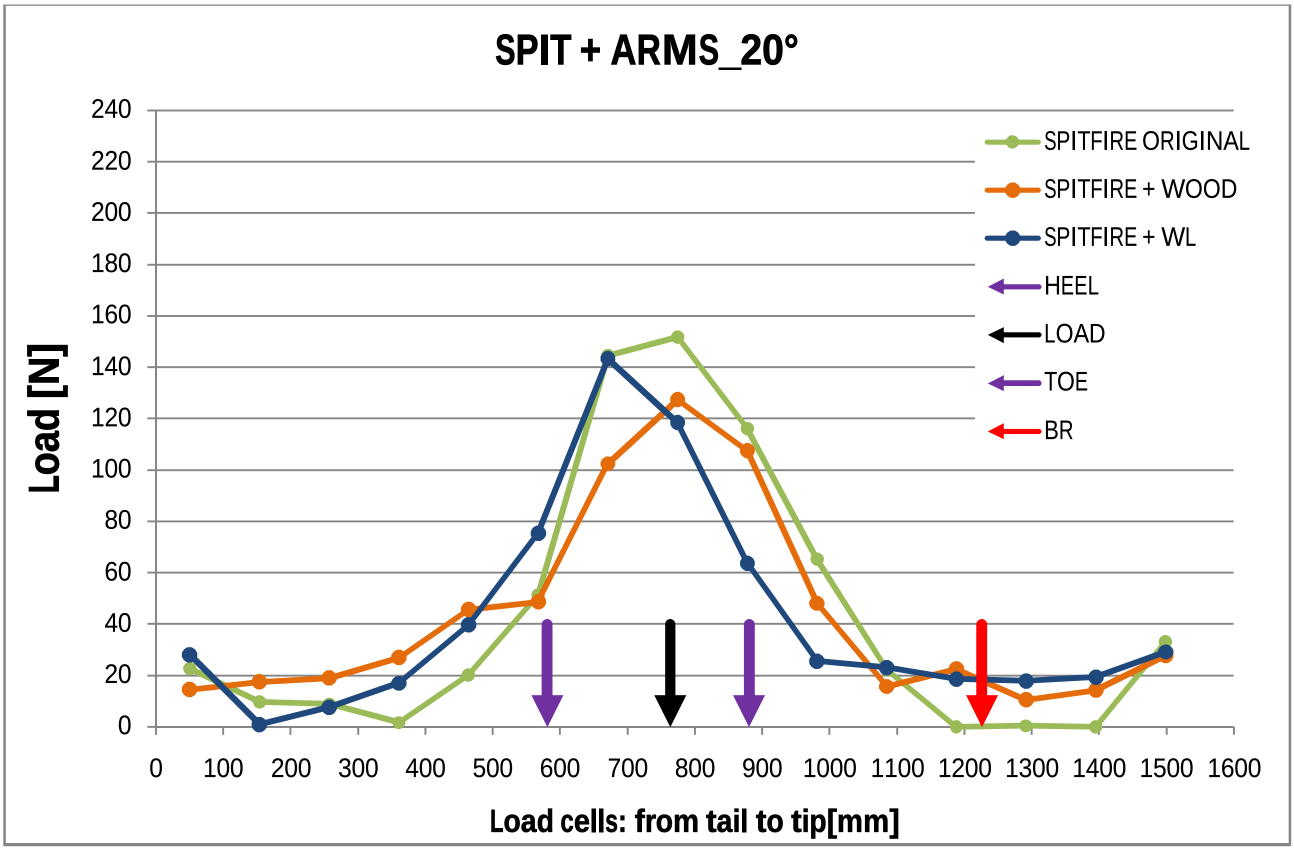
SPIT + ARMS_60°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + RESIN
HEEL
LOAD
TOE
BR

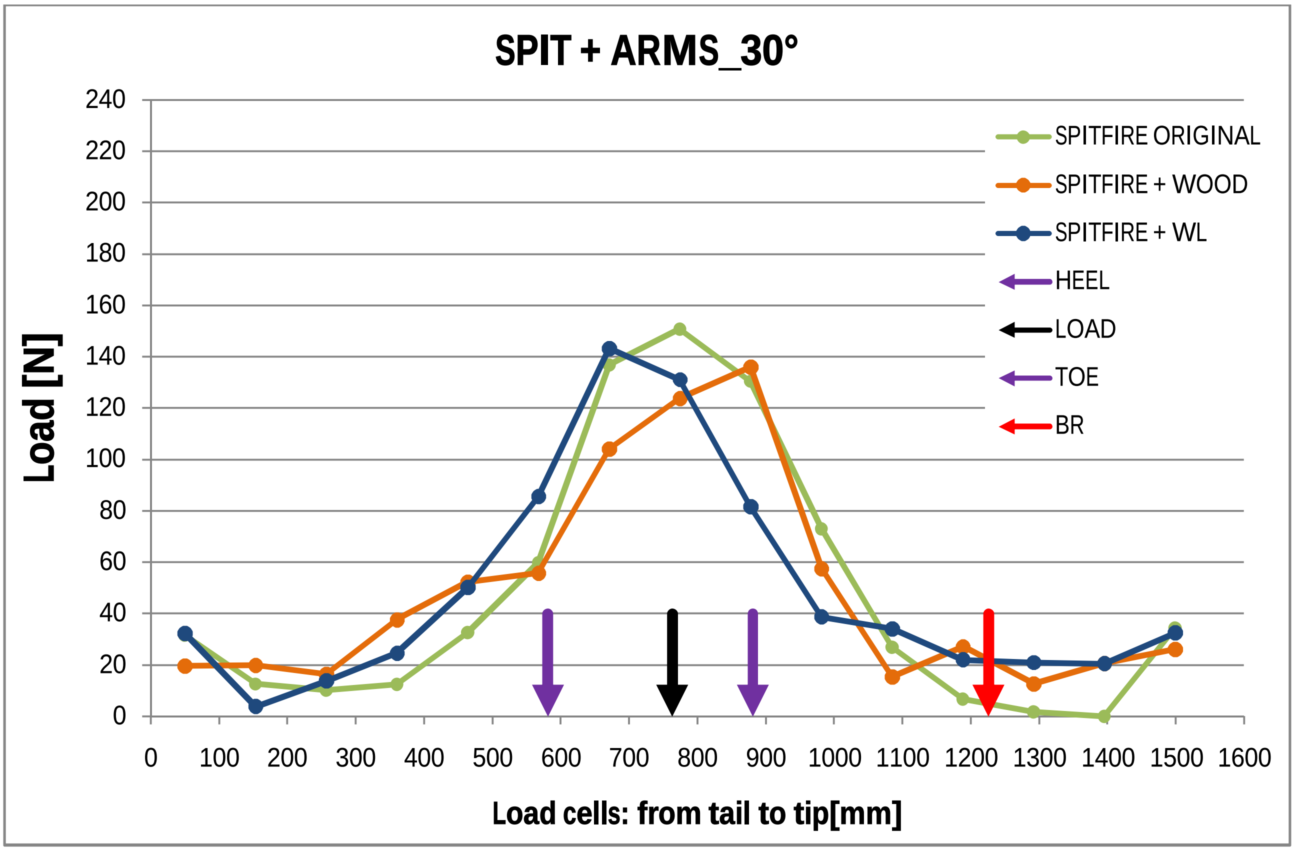
APPENDIX B

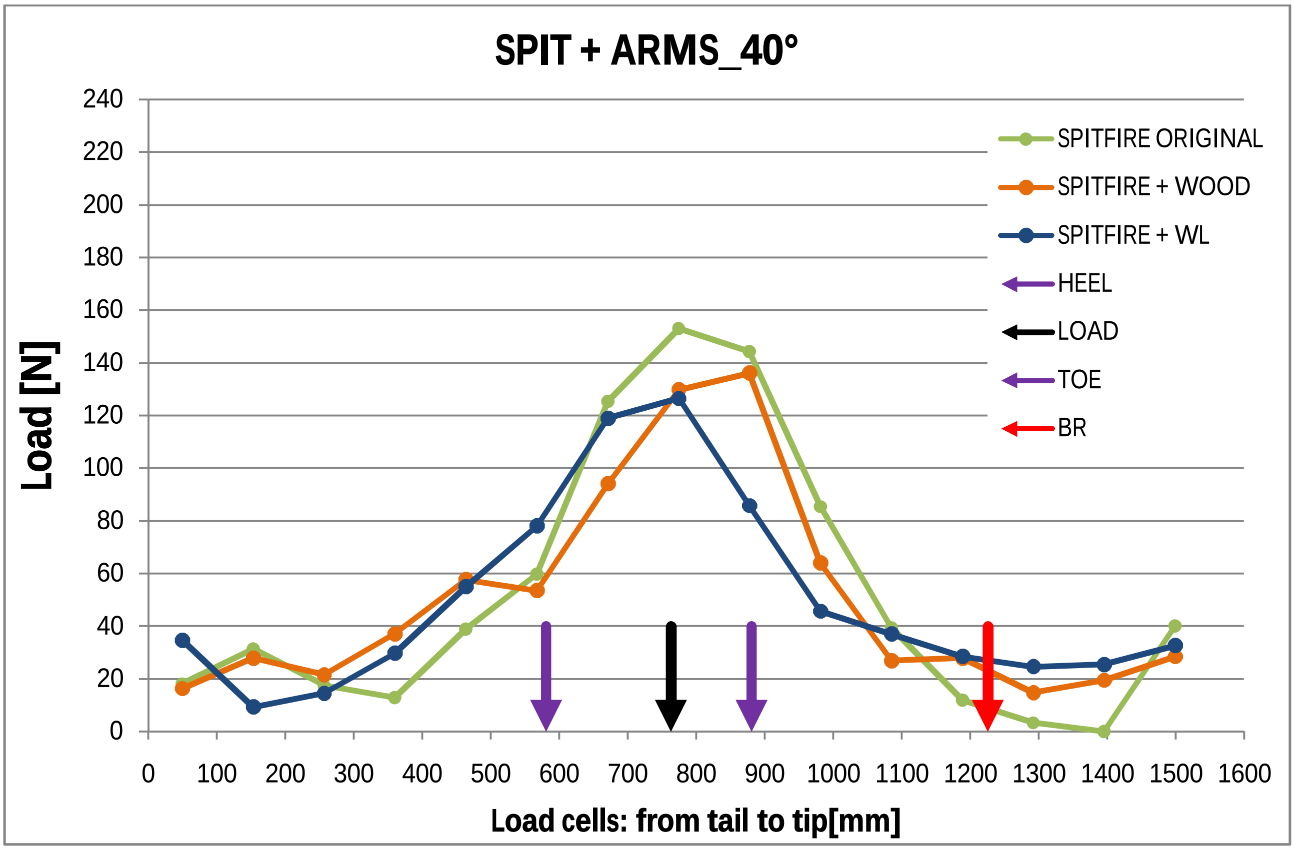
SPITFIRE COUPLED WITH WOOD ARM AND WITH WOOD INTEGRAL PLATE (DIAGRAMS FROM 0° TO 60°)

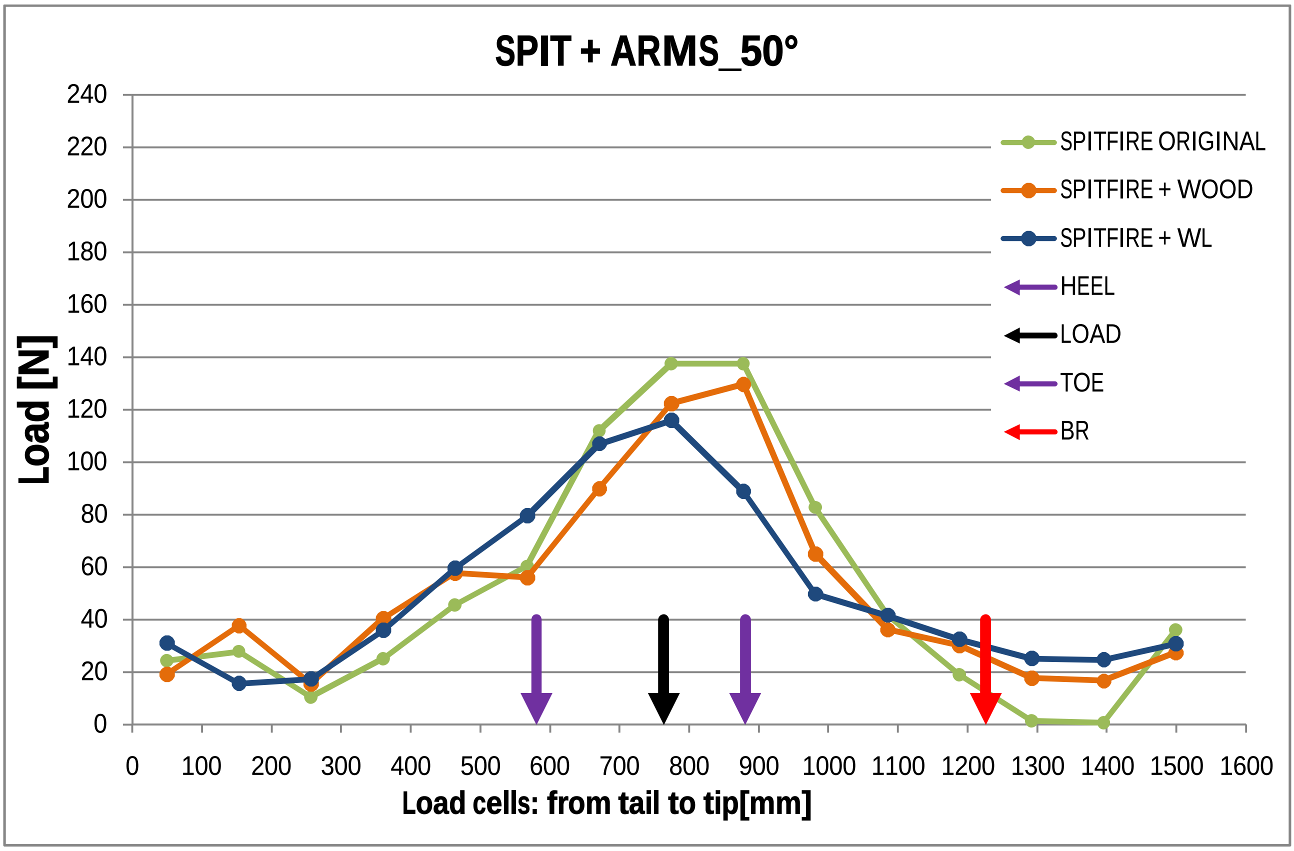


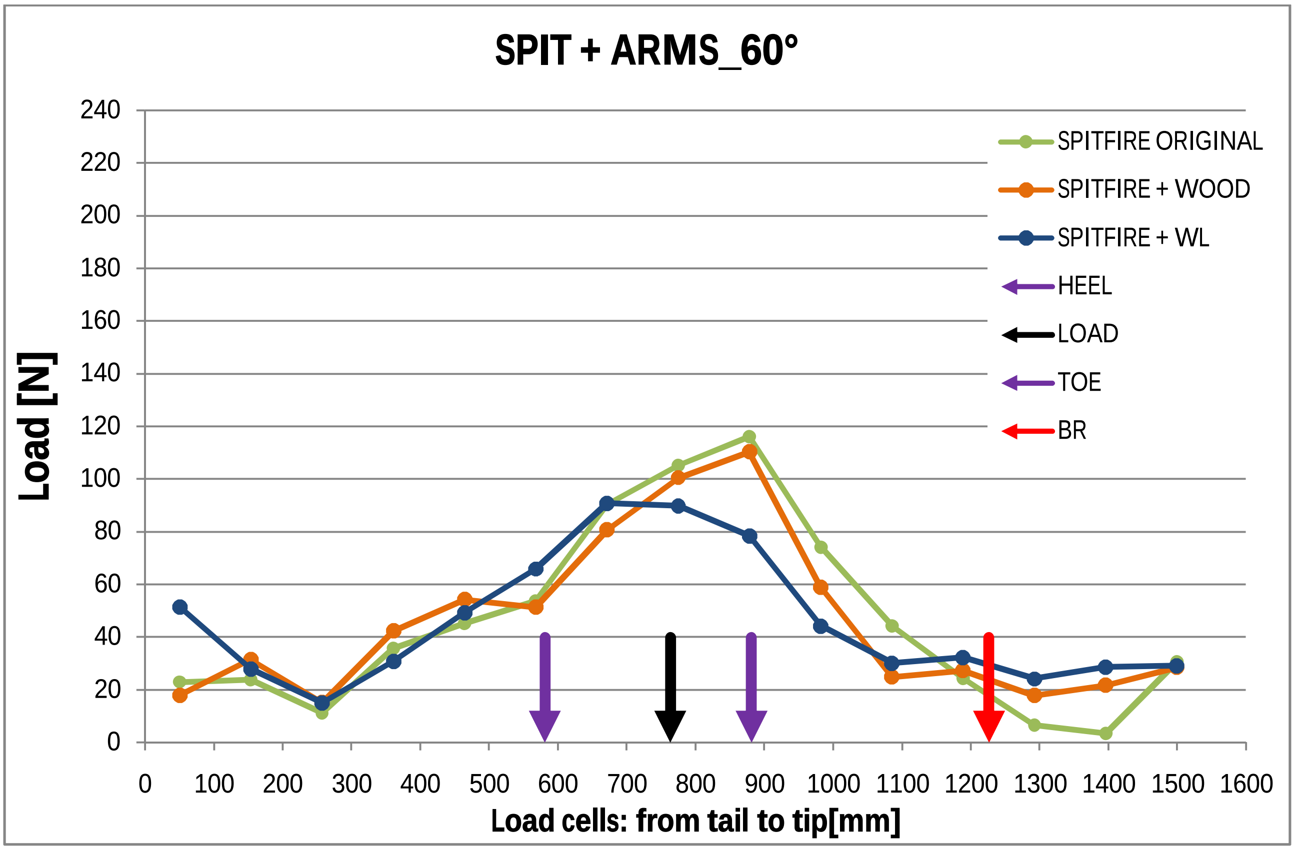



SPIT + ARMS_20°
Load [N]
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + WL
HEEL
LOAD
TOE
BR
0
20
40
60
80
100
120
140
160
180
200
220
240
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600


SPIT + ARMS_30°
Load [N]
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + WL
HEEL
LOAD
TOE
BR
0
20
40
60
80
100
120
140
160
180
200
220
240
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600


SPIT + ARMS_40°
Load [N]
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + WL
HEEL
LOAD
TOE
BR
0
20
40
60
80
100
120
140
160
180
200
220
240
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600


SPIT + ARMS_50°
Load [N]
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + WL
HEEL
LOAD
TOE
BR
0
20
40
60
80
100
120
140
160
180
200
220
240
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600

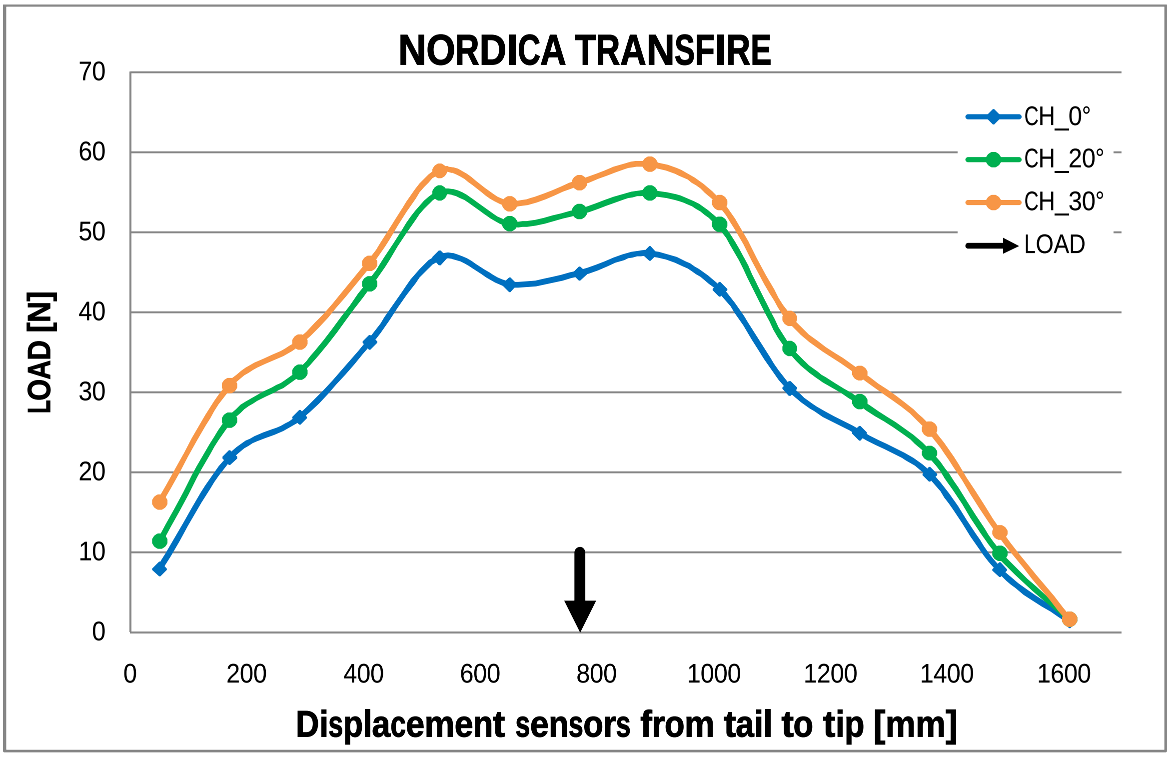

SPIT + ARMS_60°
Load [N]
240
220
200
180
160
140
120
100
80
60
40
20
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
Load cells: from tail to tip[mm]
SPITFIRE ORIGINAL
SPITFIRE + WOOD
SPITFIRE + WL
HEEL
LOAD
TOE
BR

APPENDIX C

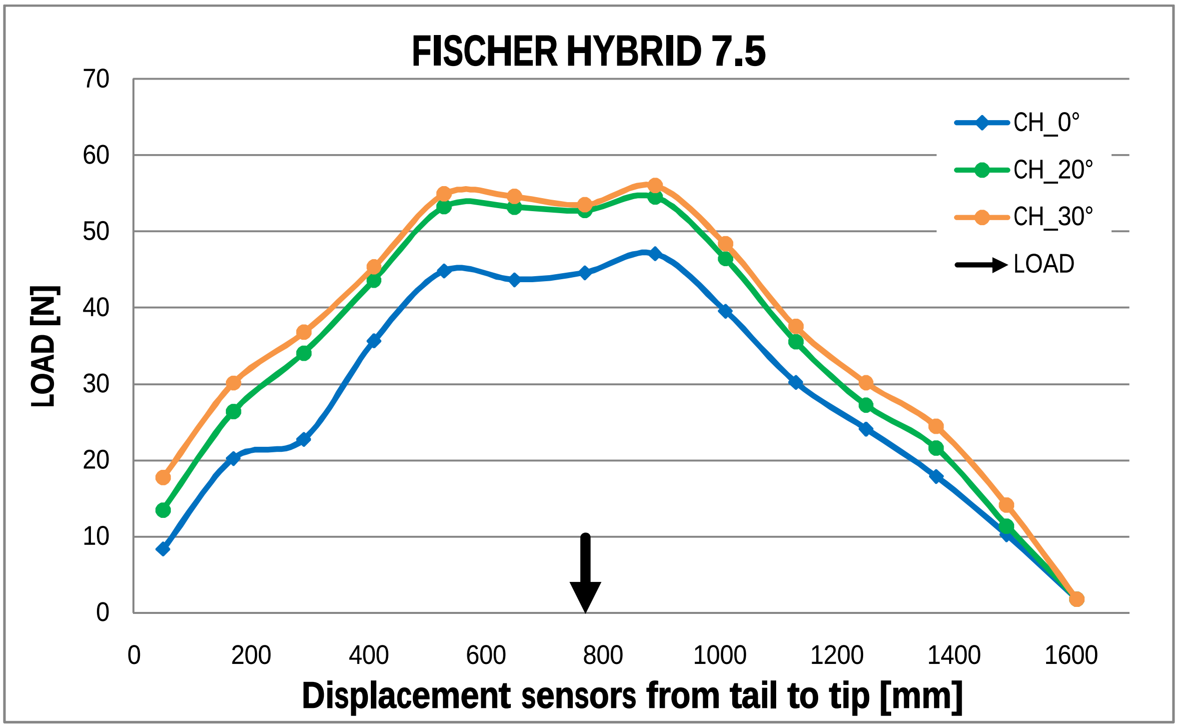
EXAMPLES OF DIAGRAMS FROM CHEMNITZ (ROCKER TESTER)

Three type of ski diagrams were chosen and reported

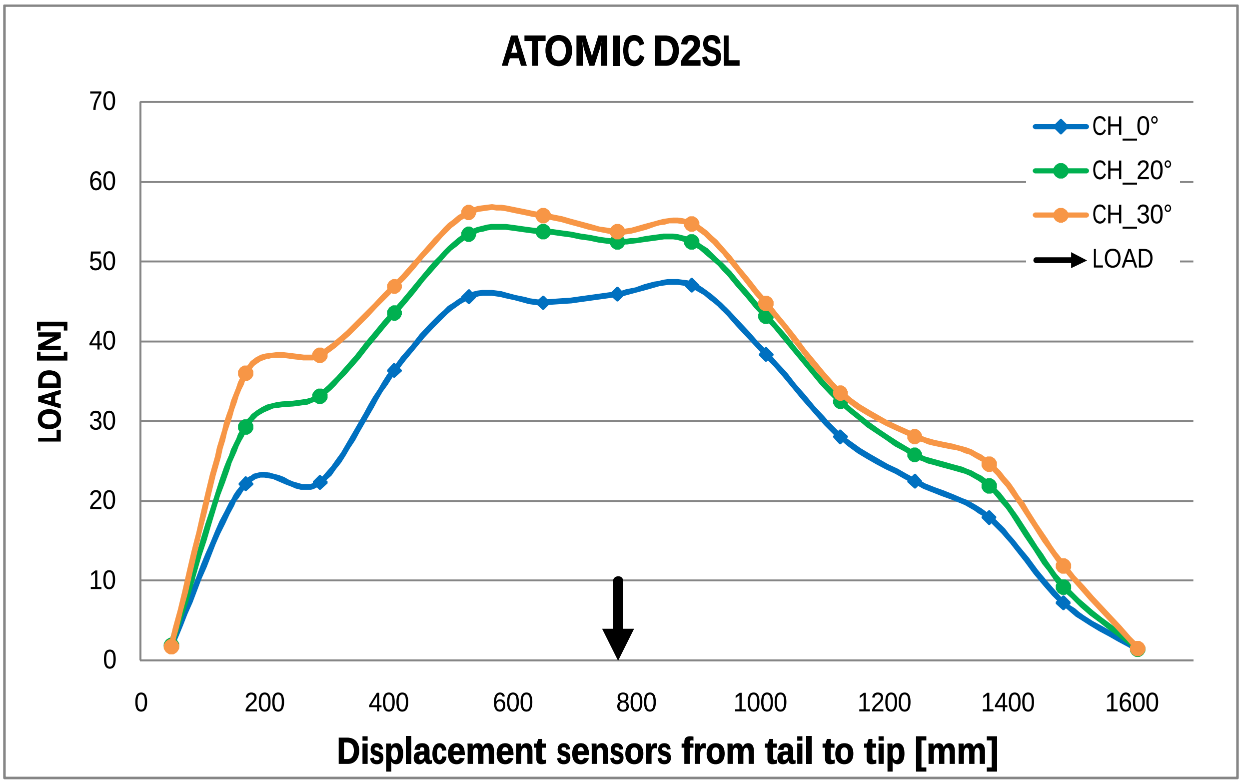
- Nordica Transfire



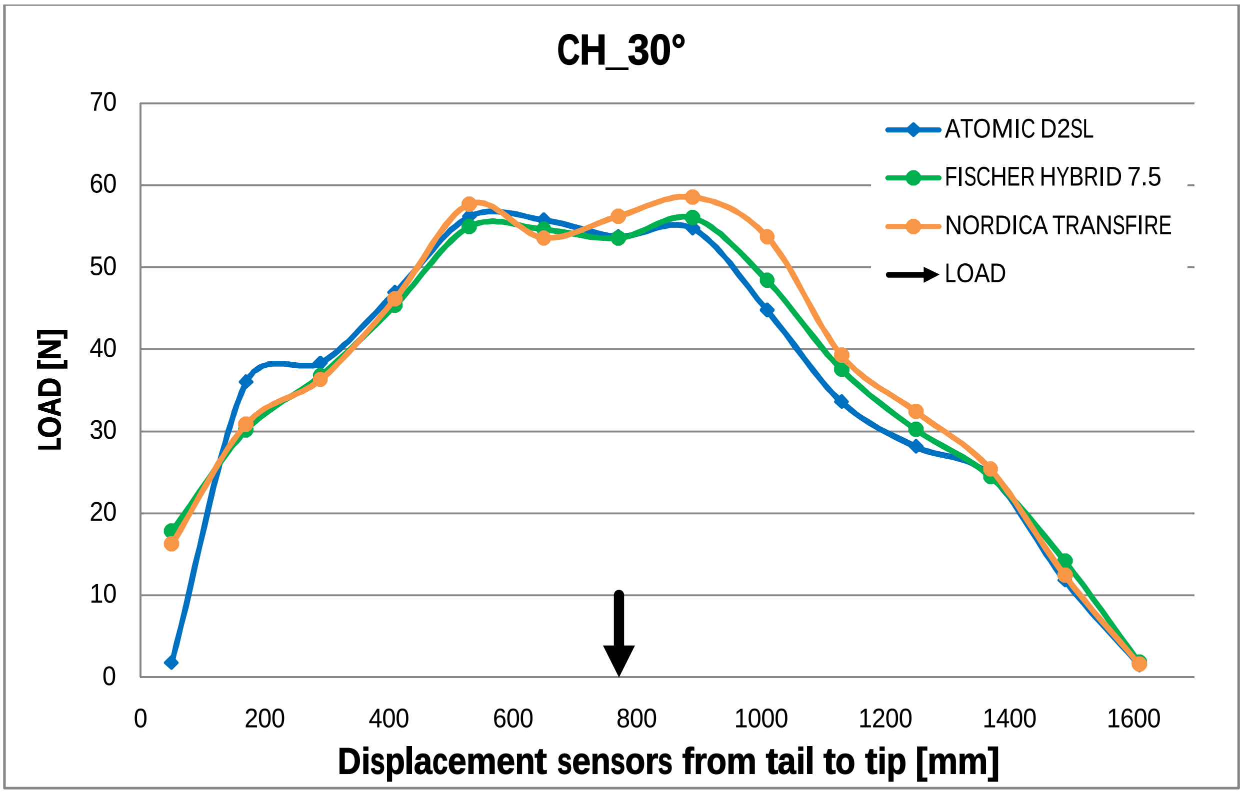
- Fischer Hybrid 7.5



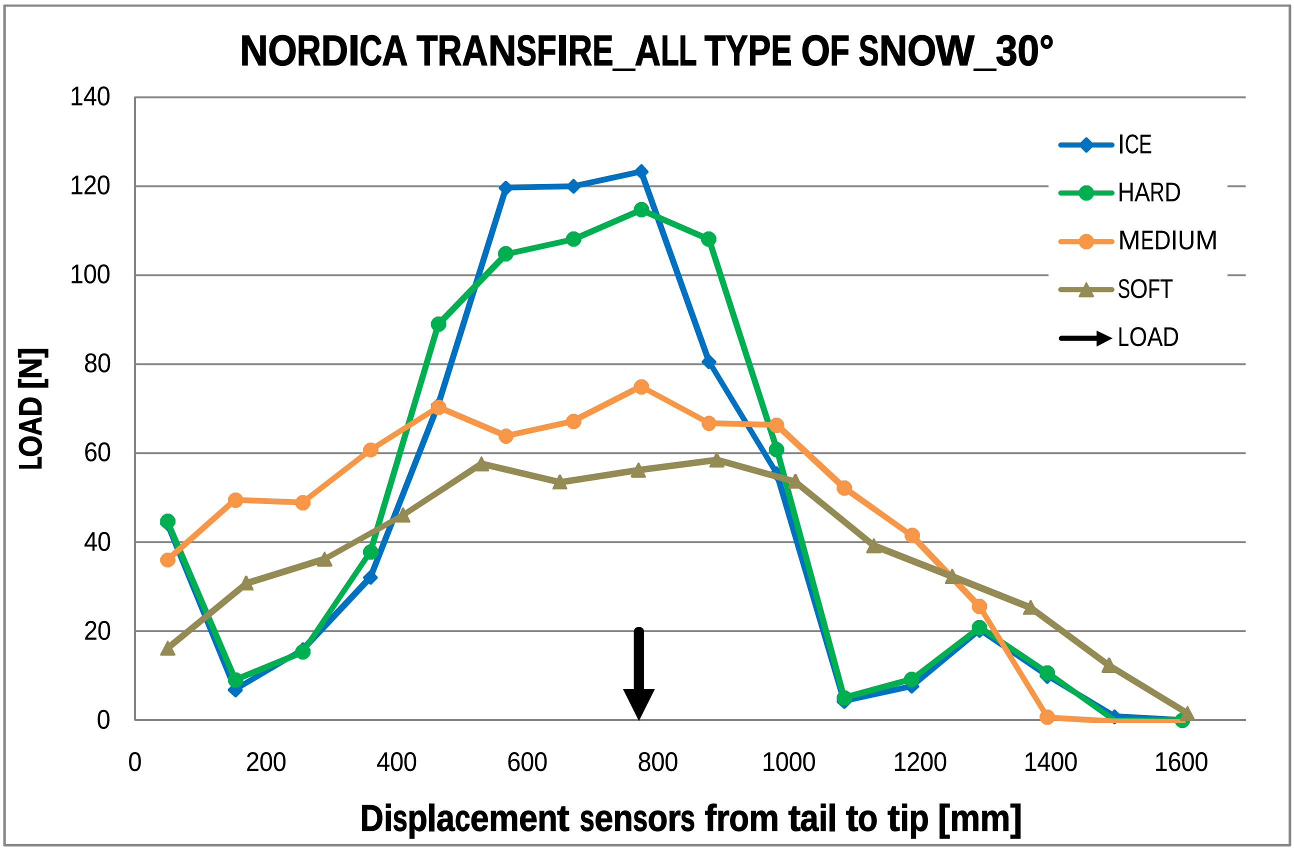
- ATOMIC D2SL

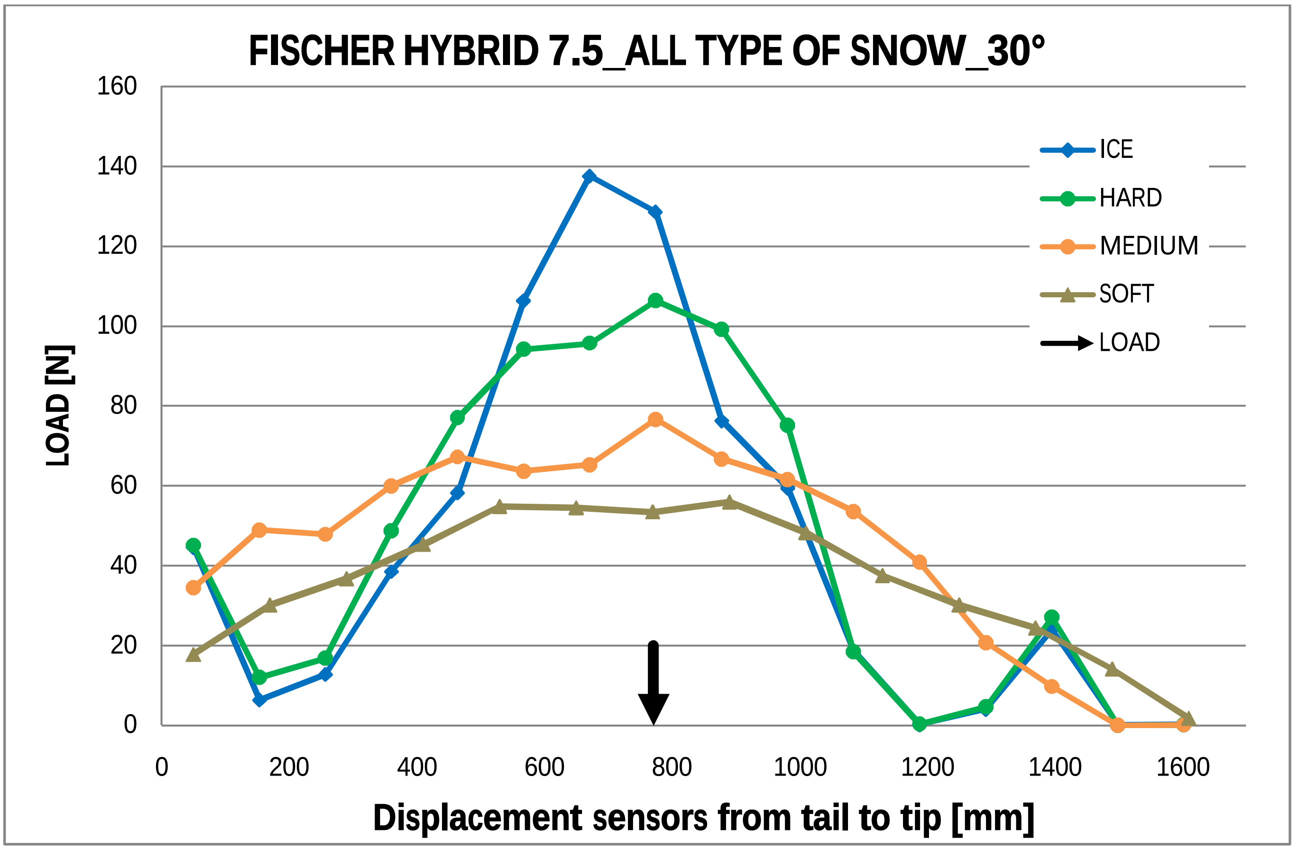


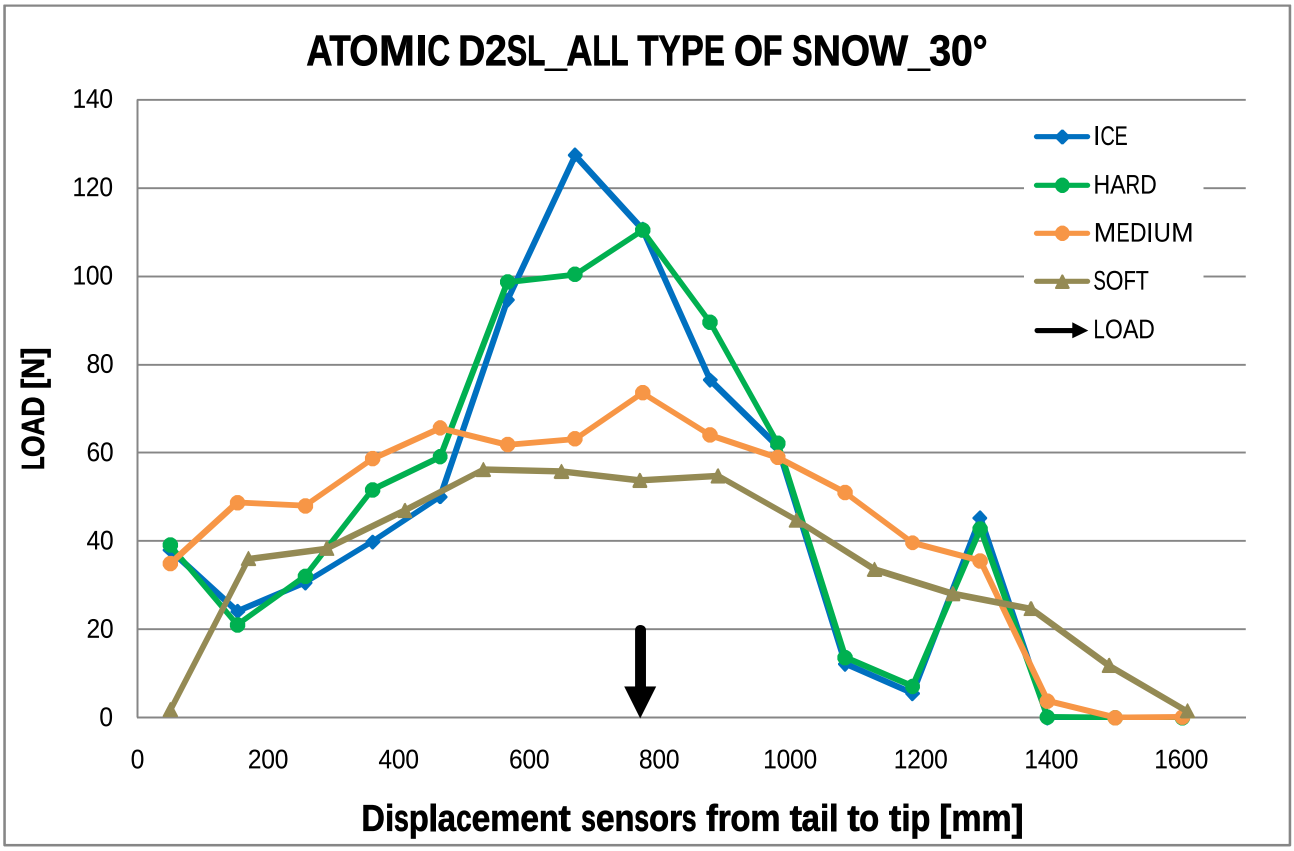
Example of comparison at 30° of this three skies:



It’s now reported the last three diagrams of this three ski tested in all type of snow:





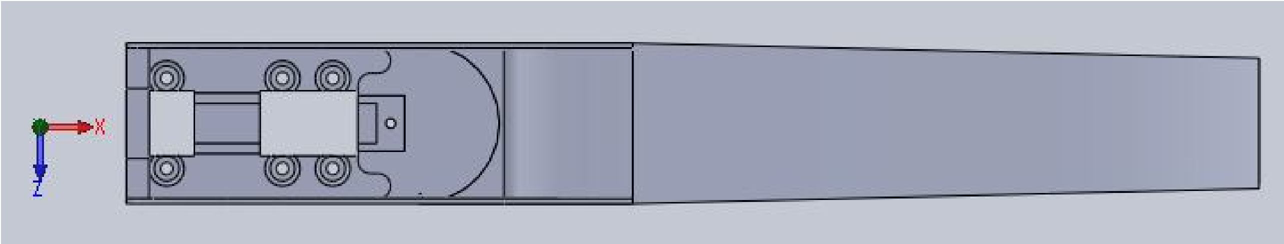


Comments for this last diagram regard the difference on shovel of these ski. For each ski medium and soft snow configuration provides edge profile very similar because all the length of ski came in contact with the ground with greater force with respect to ice and hard condition. Load is distributed in all the length of the ski in homogeneous way and internal property of ski don't influence ski performances. Medium curves arrive at zero before soft curve because in Slytech bench, even if screws are all open there is not a great displacement of the ground and ski always end to touch ground on the wider part of the shovel tip. In Chemnitz bench the plates with lower stiffness permit to ski to touch the plate under the tip of shovel (so with a greater effective length) and provides a diagram where zero is intercepted in a point at 100-200mm after the medium curve zero.

APPENDIX D

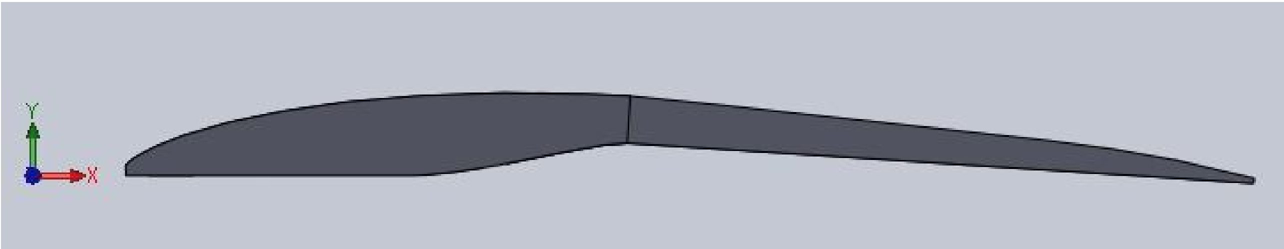
D1. NEW MODEL OF ALUMINUM UNIQUE PIECE

TOP VIEW



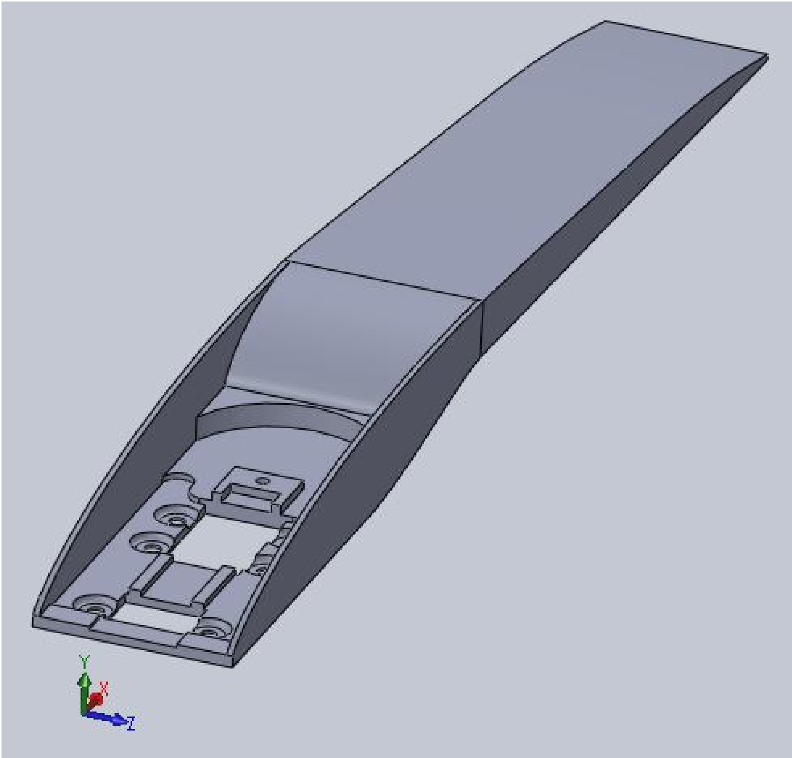
a)

LATERAL VIEW



b)

GLOBAL VIEW

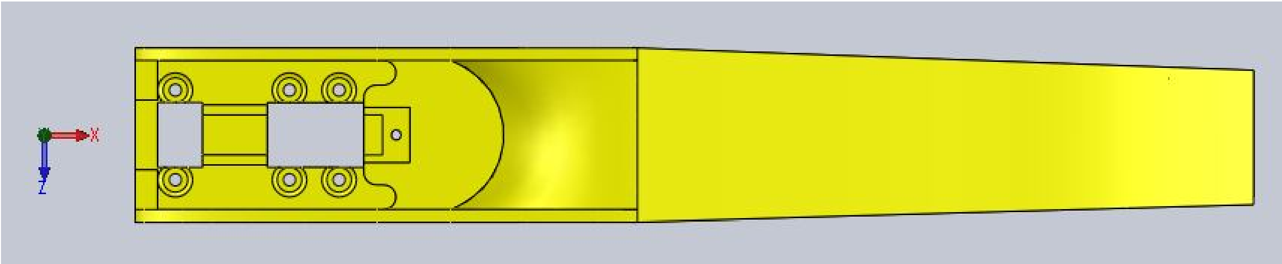


c)

Fig. 87: aluminum 3D new model , top (a), lateral (b), and global view (c)

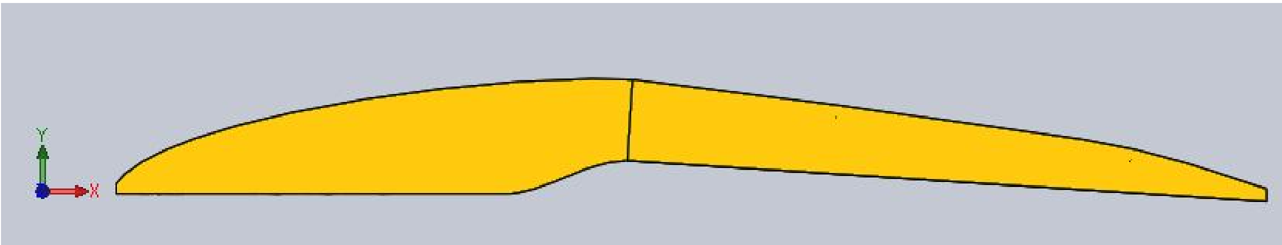
D2. NEW MODEL OF POM UNIQUE PIECE

TOP VIEW



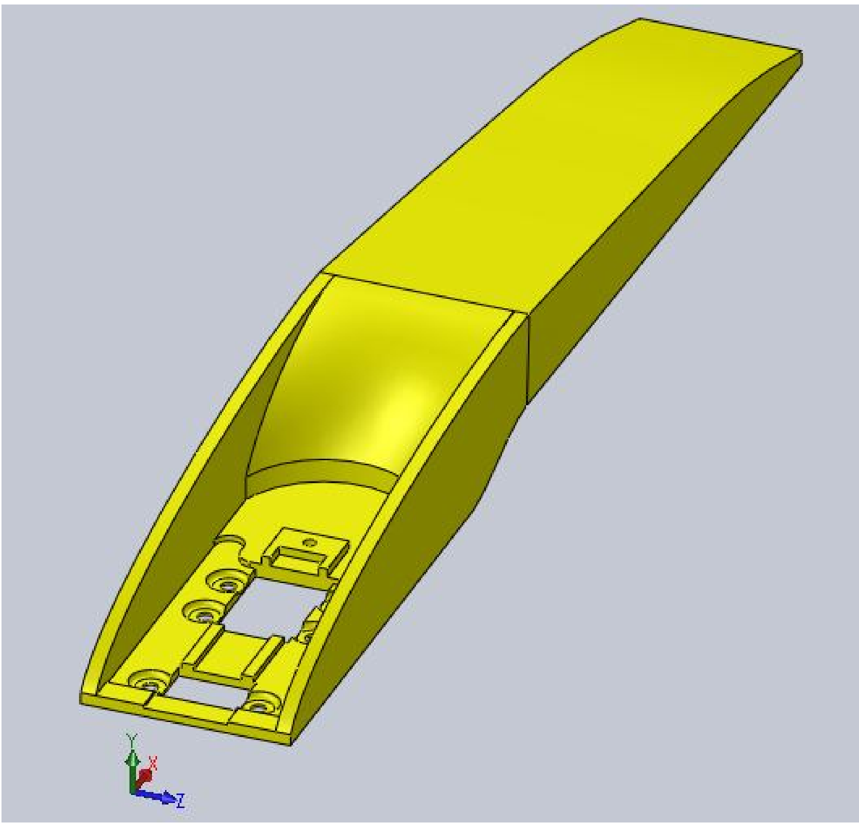
a)

LATERAL VIEW



b)

GLOBAL VIEW

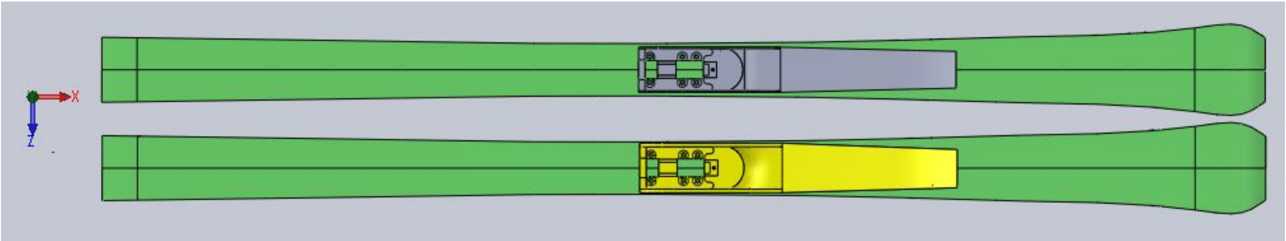


c)

Fig. 88: POM 3D new model, top (a), lateral (b), and global view(c)

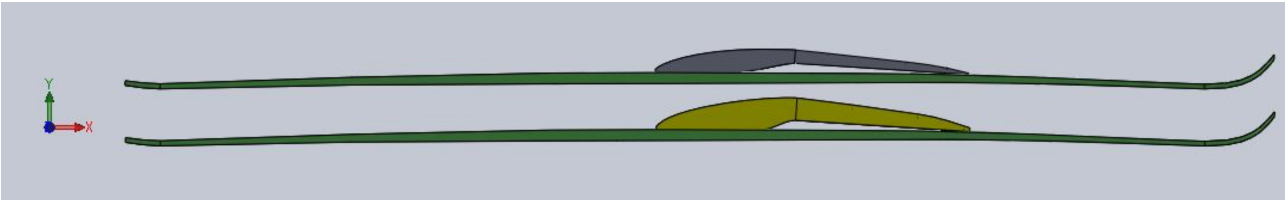
D3. SKI AND NEW SUPERSTRUCTURE COUPLED

TOP VIEW



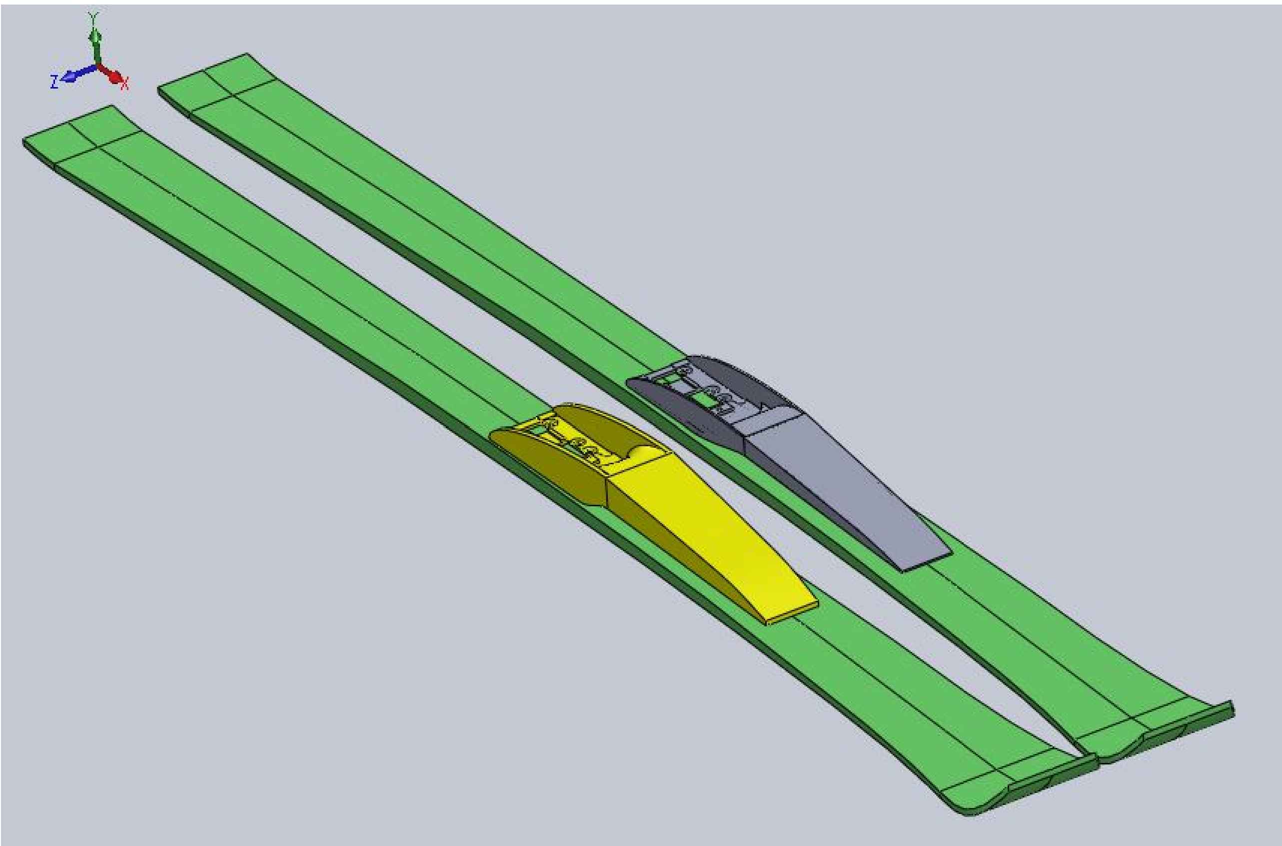
a)

LATERAL VIEW



b)

GLOBAL VIEW



c)

Fig. 89: 3D example of new unique pieces matched on ski

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