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PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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D5.3.1 Report on wheel/axle design – possible mass reduction

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1. Application of the calculation procedure to the Czech Pendolino wheel

The endurance design procedure has been applied to the Czech Pendolino wheel from the same wheelset on which the load measurements were performed in this project (see Deliverables D1 and D2). This wheel was formally designed according to the UIC_210_5 (calculation report CRS_RC_L106_1.

From the calculation report, in the worst condition (flanging curve with worn wheel) for the most stressed node we found a safety coefficient **η = 1.108** (for new wheel the report gives a minimum safety coefficient **η = 1.137)**.

The load values used in this report are:

	UIC_210_5	
	Q	Y
Straight Load case 1	104.2 kN	-
Curve in flange Load case 2	171 kN	76 kN
Curve not in flange Load case 3	-	-
Switch Load case 4	104.2 kN	35 kN

Table 1 – Load used to check the Pendolino wheel following the UIC_210_5 standard.

Where Q is the vertical load and Y the lateral load. The positions and the directions (and versus) of loads are the same described in Figure 1.
The permissible stress amplitude is used by the norm is 180 MPa.

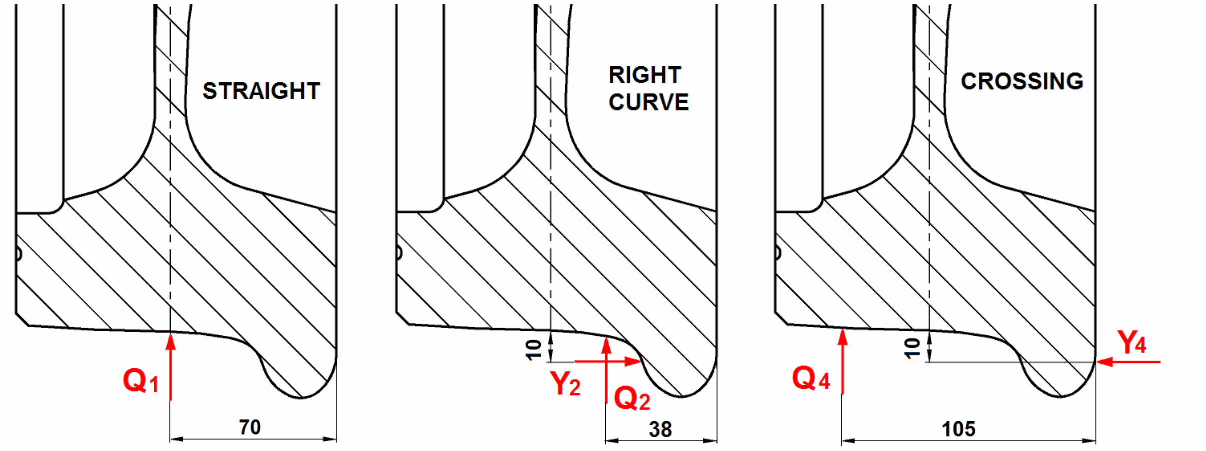

Figure 1 Position and direction of application of the forces according to UIC 510.5

2. Wohler Curve

Figure 2 shows the Wohler curve for solid-wheels in material R8T based on full scale fatigue tests at constant loading; these tests were carried out by Lucchini Sidermeccanica during the Hyper-Wheel project.

The confidence vale is 99.95%,. The knee-point is at 236MPa with a cycle of about $2 \cdot 10^6$.

As suggested by LBF the slope of the second part of the curve is k' = (2·k)-1 where k is the slop of the first part (k=5).

R is the cycle ratio of tests, R = $\sigma_{min}/\sigma_{max}$: R=-1 : an alternate-symmetric cycle load on the wheels tested.

So at 10^7 cycles the fatigue limit was about 200MPa.

This curve was considered a conservative reference for the wheel design.

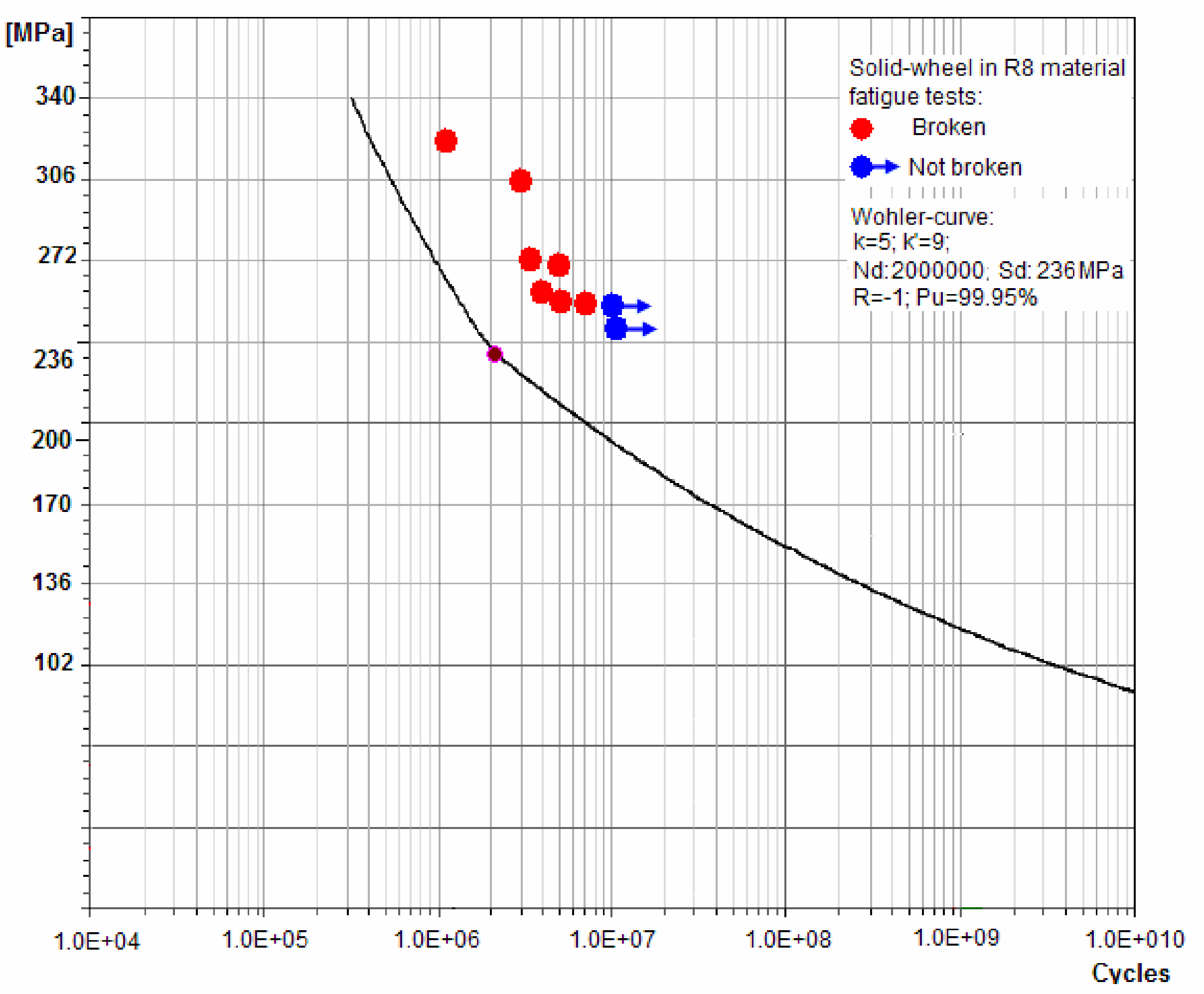

Figure 2 – Wohler-curve used in "Palmgren-Miner method"

3. Load Spectra

LBF sent to Lucchini Sidermeccanica the load spectra for each running condition extrapolated to the theoretical wheel life of 6M cycles. Each number of repetition given in the various matrixes, corresponds to the relative vertical (Q) and Lateral (Y) force levels the load interval between one load level and the following one is 1kN.

Figure 3 shows the convention of load, acceleration and speed direction performed during the measurements.

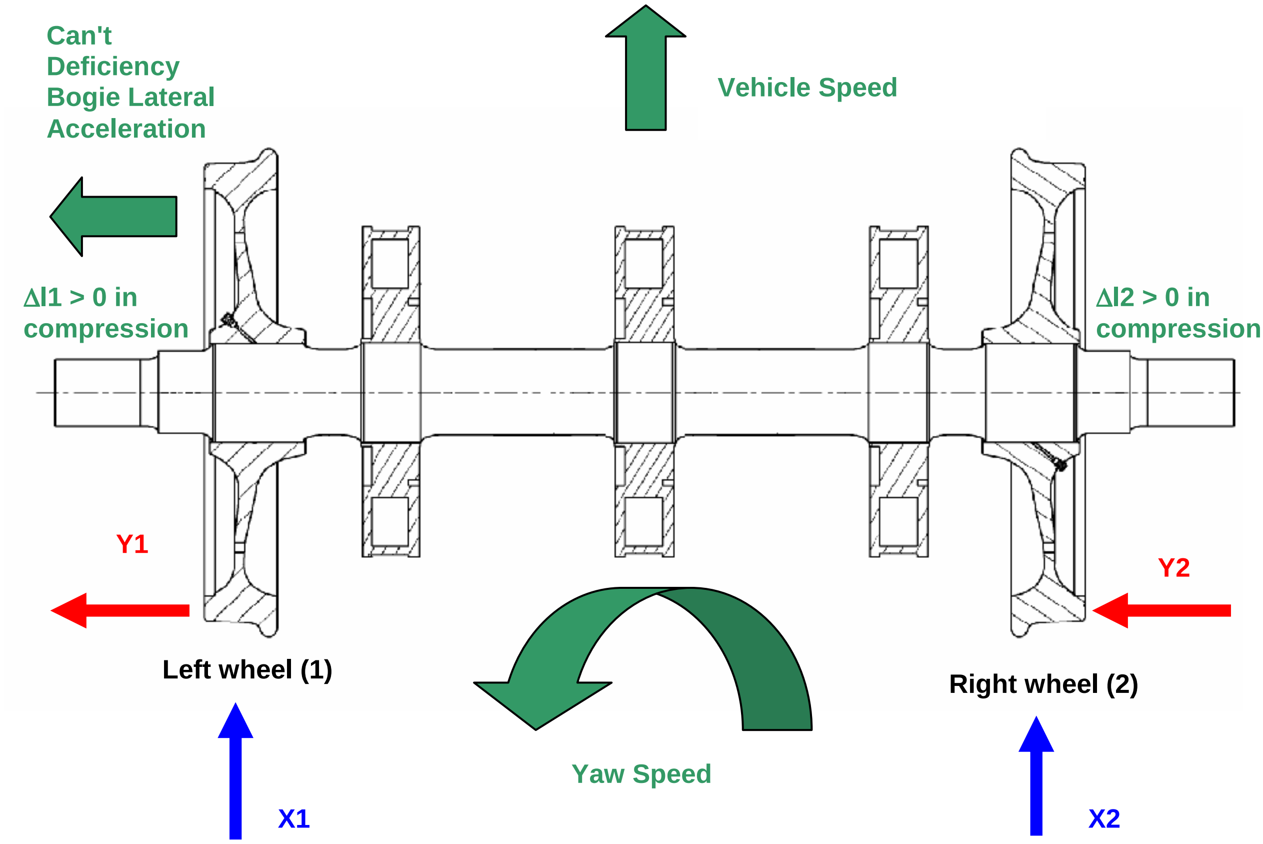

Figure 3 – Convention for the versus of spectra loads

For the wheel 1 we obtained:

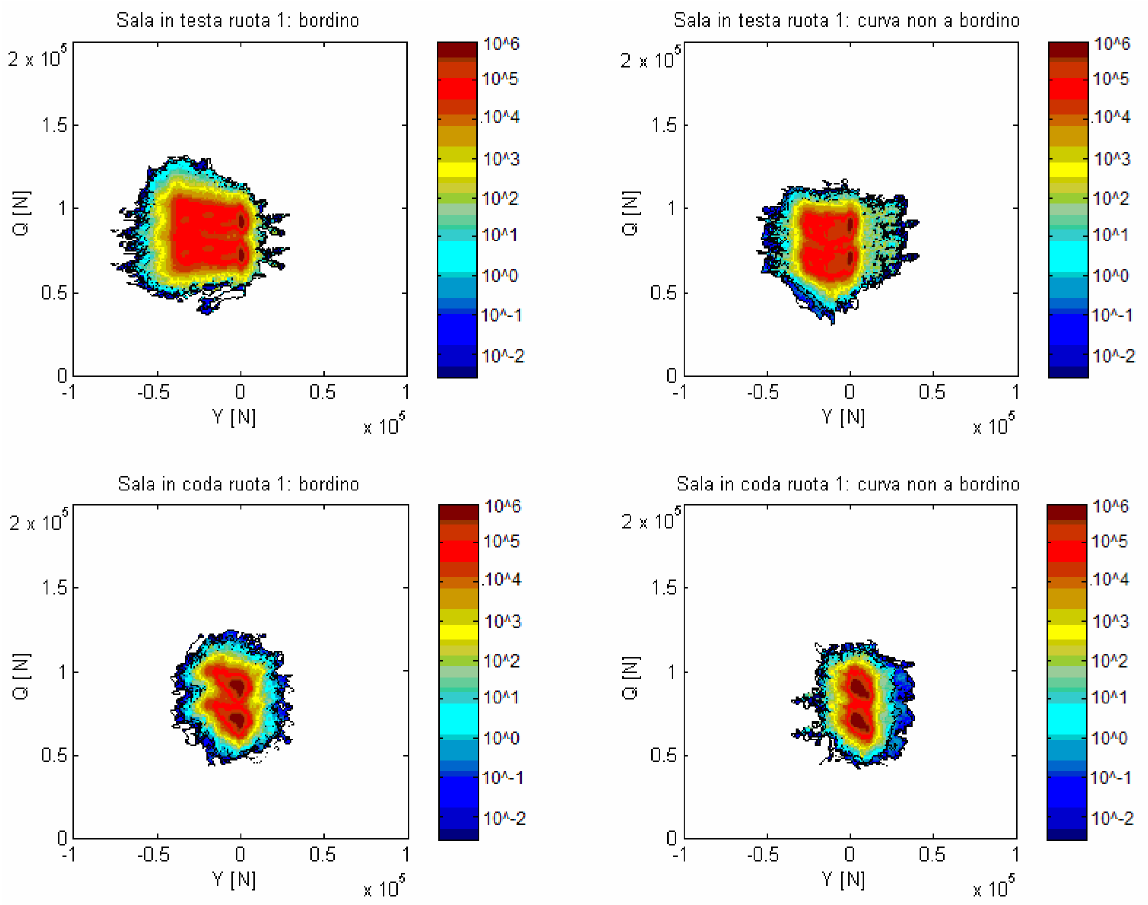

Figure 4 – Load spectrum for wheel 1, leading wheelset and trailing wheelset in curve

For this representation we used a logarithmic scale, in order to increase the visibility of the less occurring loads that could be also the higher loads acting on the wheel. The white colour, in the graphs, represents the load cases that never appear in data acquisition. The spectra are defined for two cases:

- Unloaded vehicle: the low part of the graphs ;
- Full loaded vehicle: the high part of the graphs where the force Q is shifted of 20kN.

For simplicity, we consider the vehicle running for half life fully loaded and for the rest half life unloaded, in order to cover the overall in service conditions.

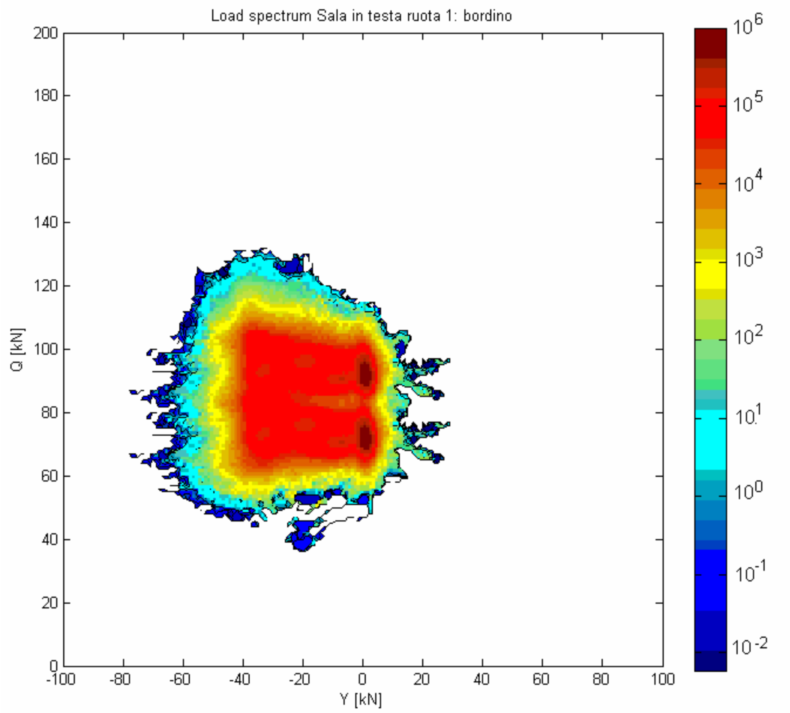

Figure5 – Wheel 1 (leading wheelset) curve in flange

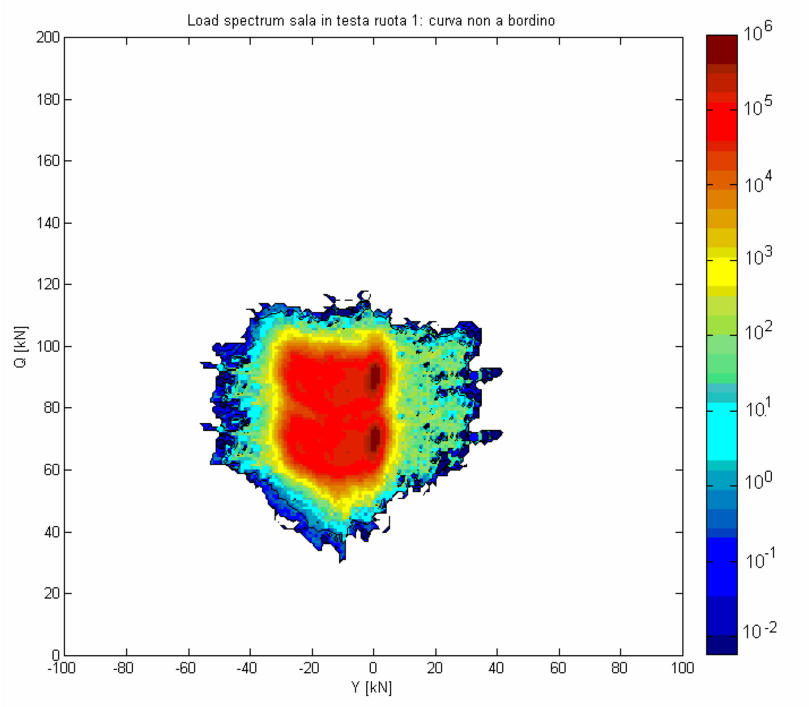

Figure 6 – Wheel 1 (leading wheelset) curve not flange

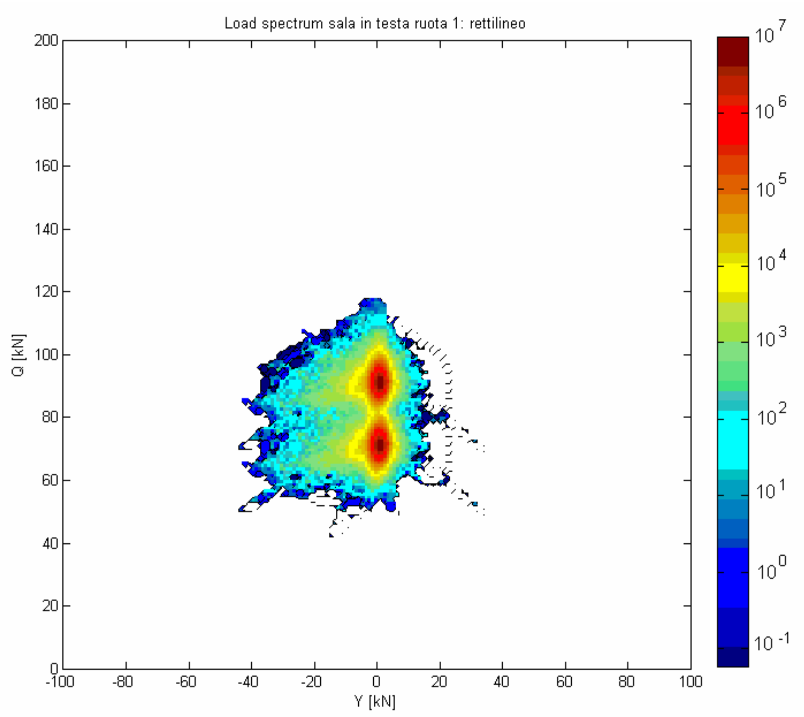

Figure 7 – Wheel 1 (leading wheelset) in straight running

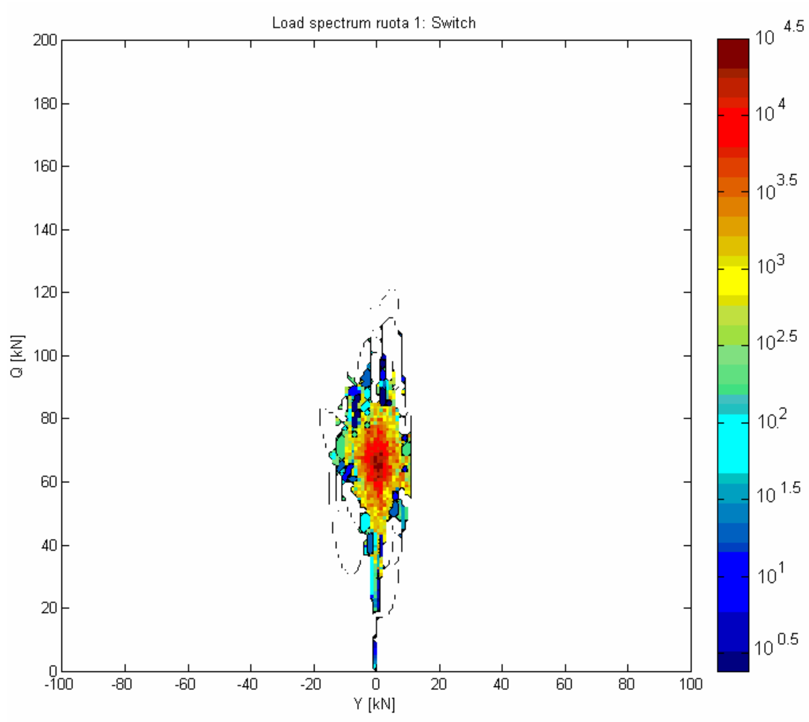

Figure 8 – Wheel 1 over switch

For the wheel 2:

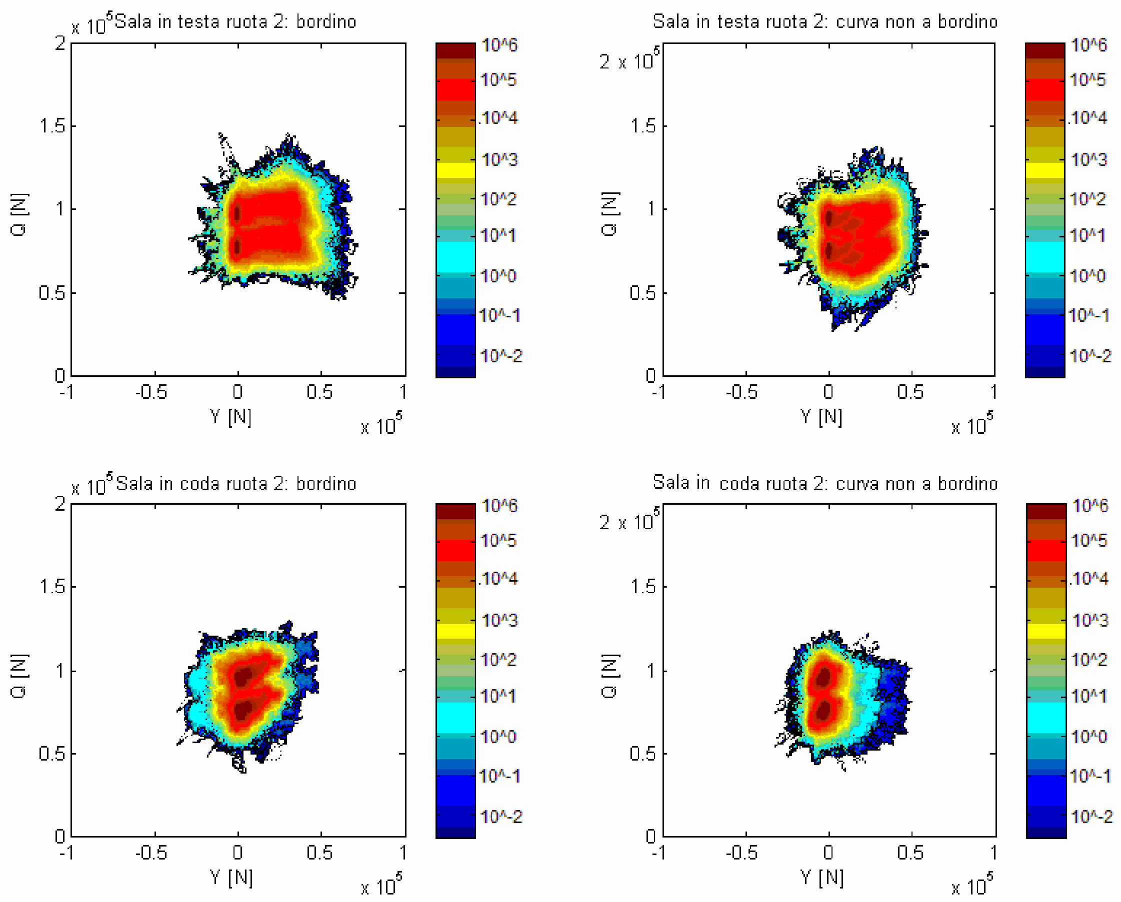

Figure 9 – Load spectrum for wheel 1, leading wheelset and trailing wheelset in curve

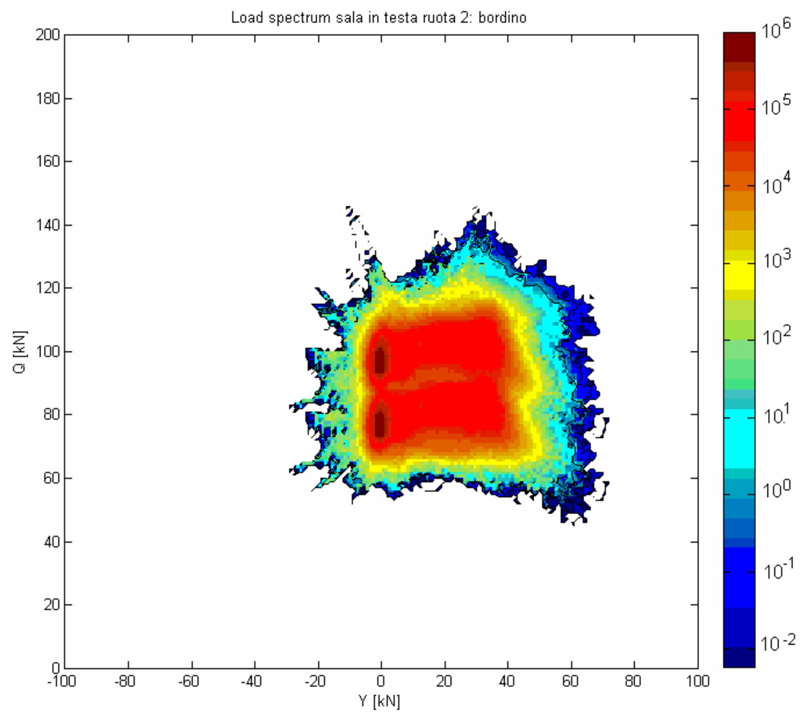

Figure10– Wheel 2 (leading wheelset) in curve in flange

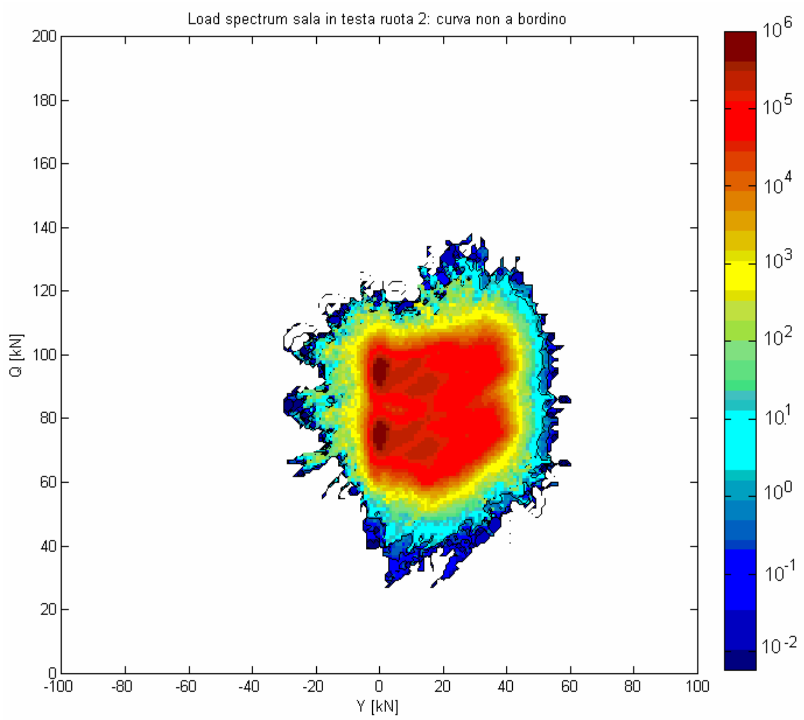

Figure11– Wheel 2 (leading wheelset) in curve not in flange

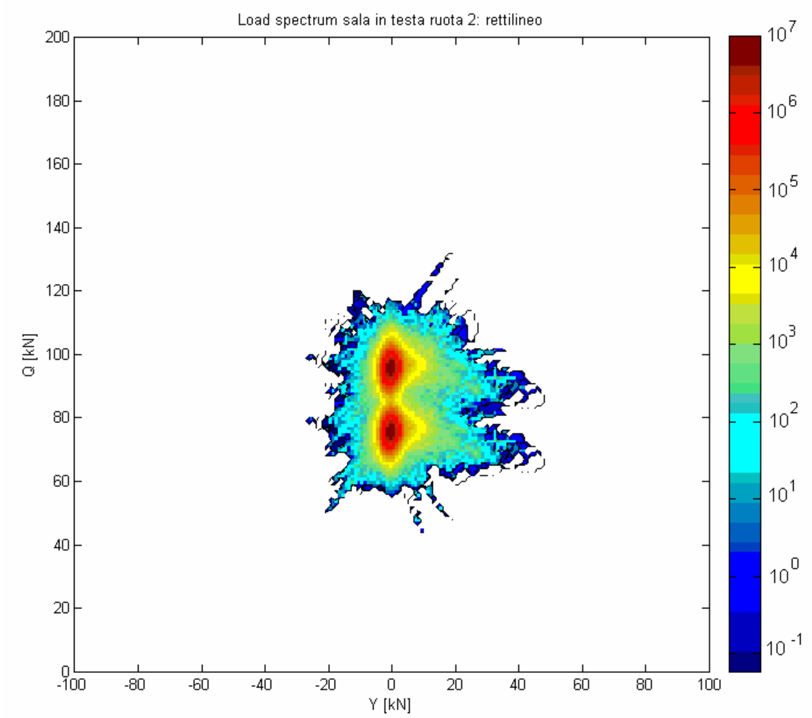

Figure 12 – Wheel 2 (leading wheelset) in straight

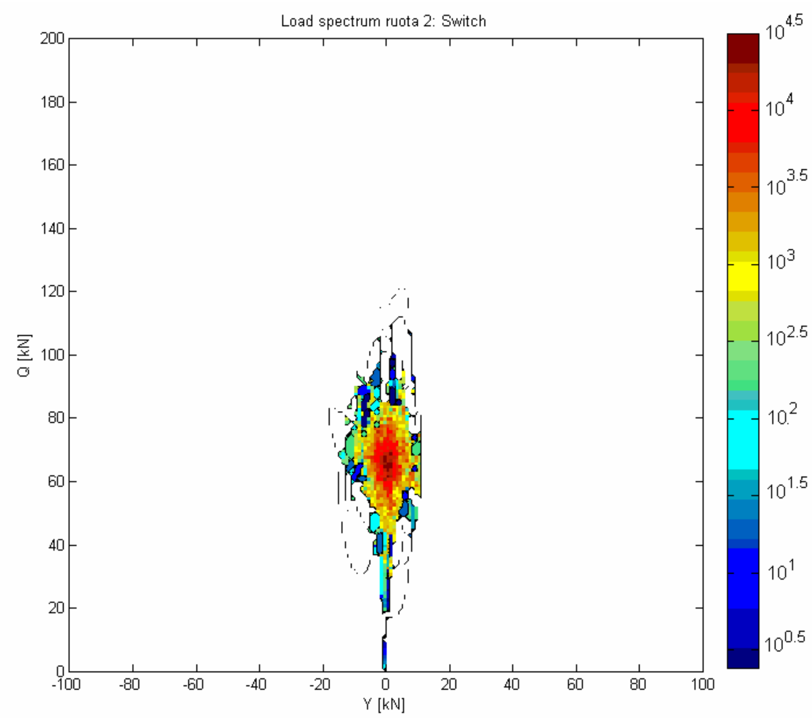

Figure 13 – Wheel 2 in switch

These spectrum matrixes were been used like explained in section 1 to calculate the total damage fraction.

4. Total Damage Fraction

Following the Palmgren-Miner method for estimate the total life of a mechanical component, we implemented in Matlab a program. The input to this program are the spectrum matrixes and the Ansys result files for the six forces that act in the load cases, the output is the total damage fraction for each node of the web in the Ansys analysis.

The intermediate result is the stress spectra for each node ; figure 14 shows this diagram for the most critical node (with the highest damaging factor) and the wohler curve for R8T wheel material. For this wheel the maximum stress is about 220 MPa.

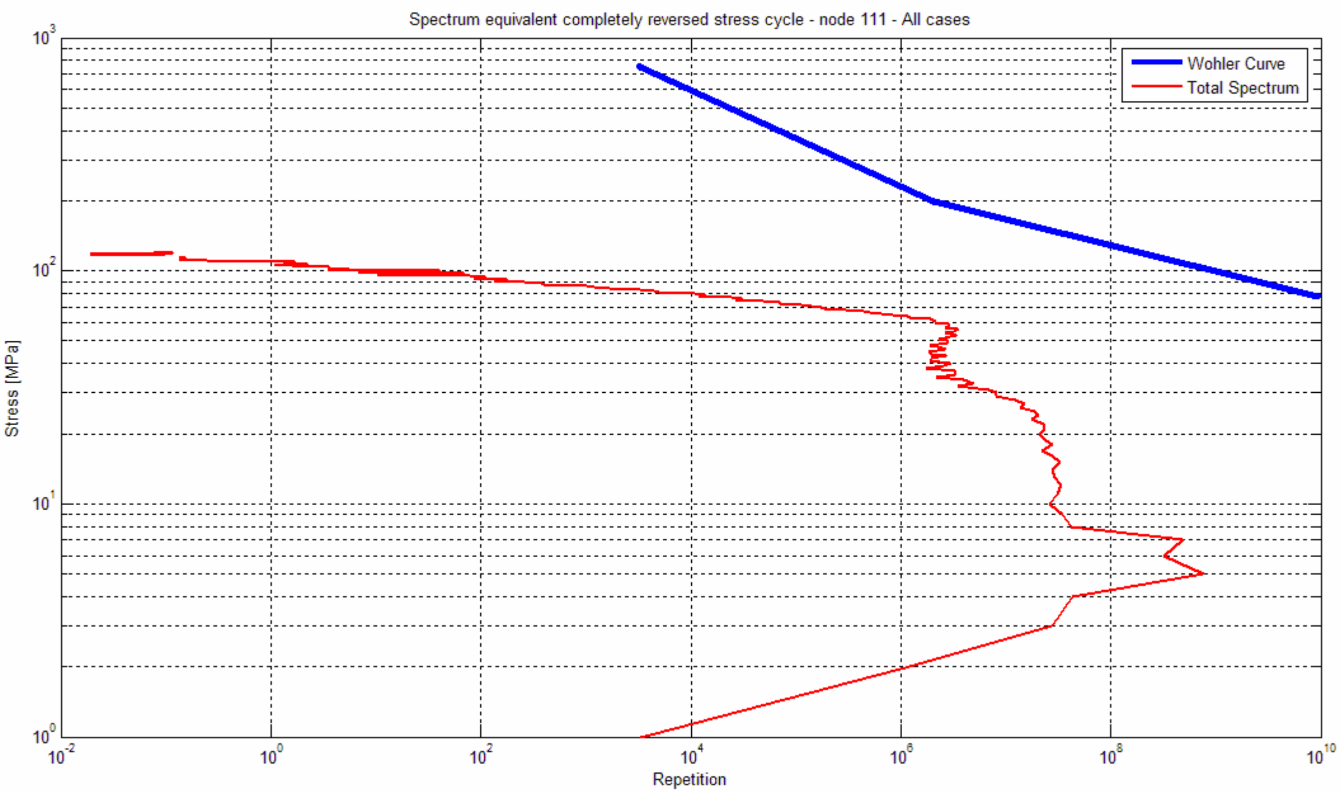

Figure 14 Original wheel; stress spectra for most critical node; Wohler curve for R8T

We have performed the analysis for the original wheel (311kg) of the Pendolino Cechia then we reduced the web thickness reducing the weight of about 40kg (12% less from the original weight) and repeated the calculation.

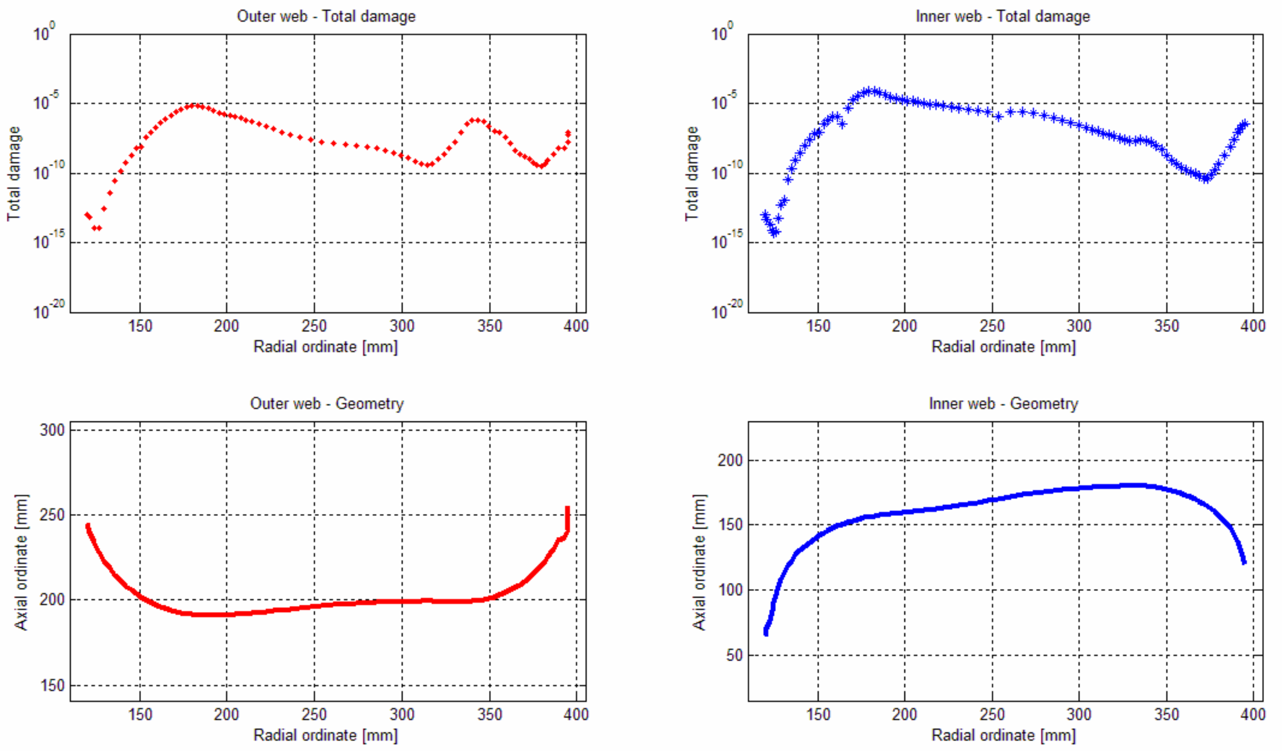

Figure 15– Total damage fraction for the web (the inner part in bleu and the outer part in red) of the original wheel

As shown in Figure 14 the most stressed node is on the inner part of the web and it arrives to have a damage fraction of about 10^{-4}. Therefore, following this method the web mass/thickness could be reduced, reducing the overall un-sprung masses of the vehicle.

Working on the 3D drawing of the Czech Pendolino wheel a new web geometry was defined then the calculation procedure was repeated on this new design obtaining the new damage fraction for all the nodes.

The intermediate result is the stress spectra for each node ; figure 16 shows this diagram for the most critical node (with the highest damaging factor) and the wohler curve for R8T wheel material. For this new wheel the maximum stress is about 300 MPa.

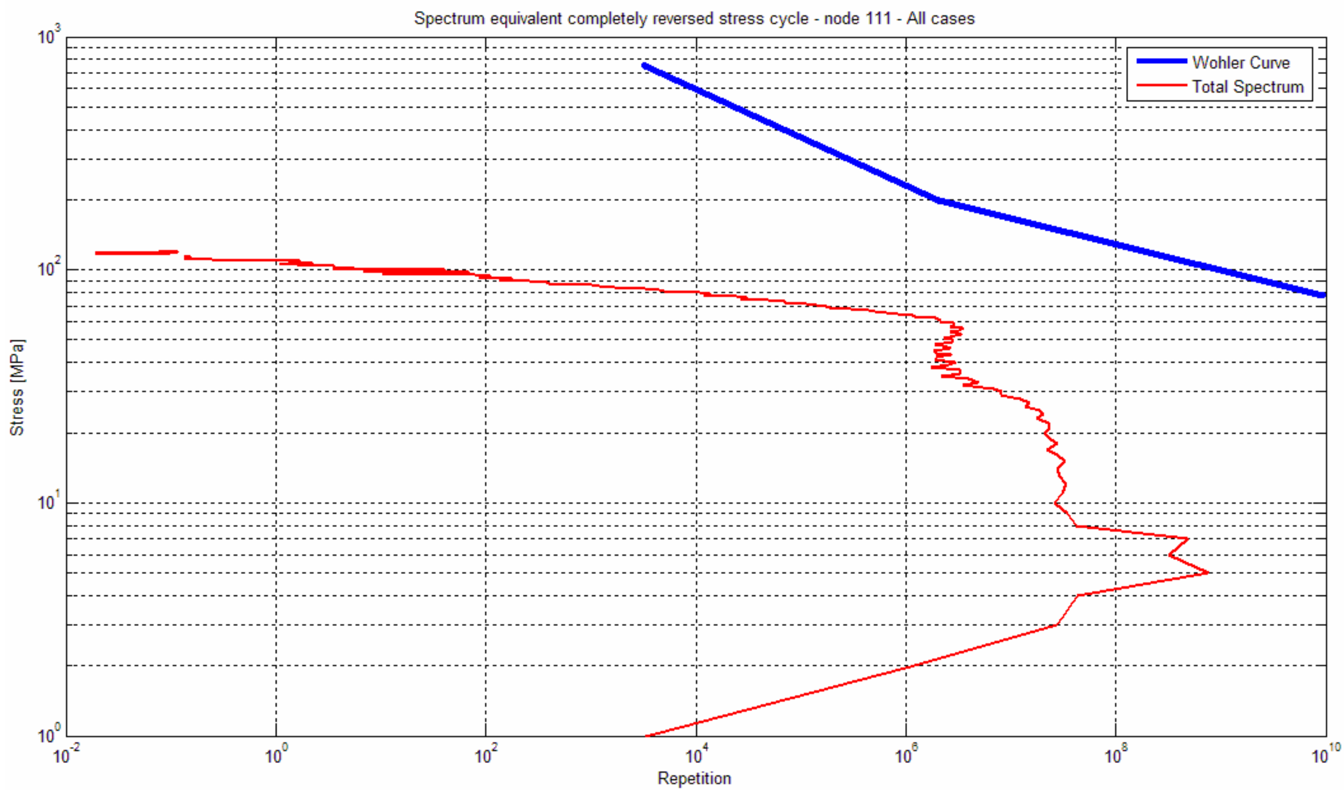

Figure 16 New wheel with 10% less mass; stress spectra for most critical node; Wohler curve for R8T

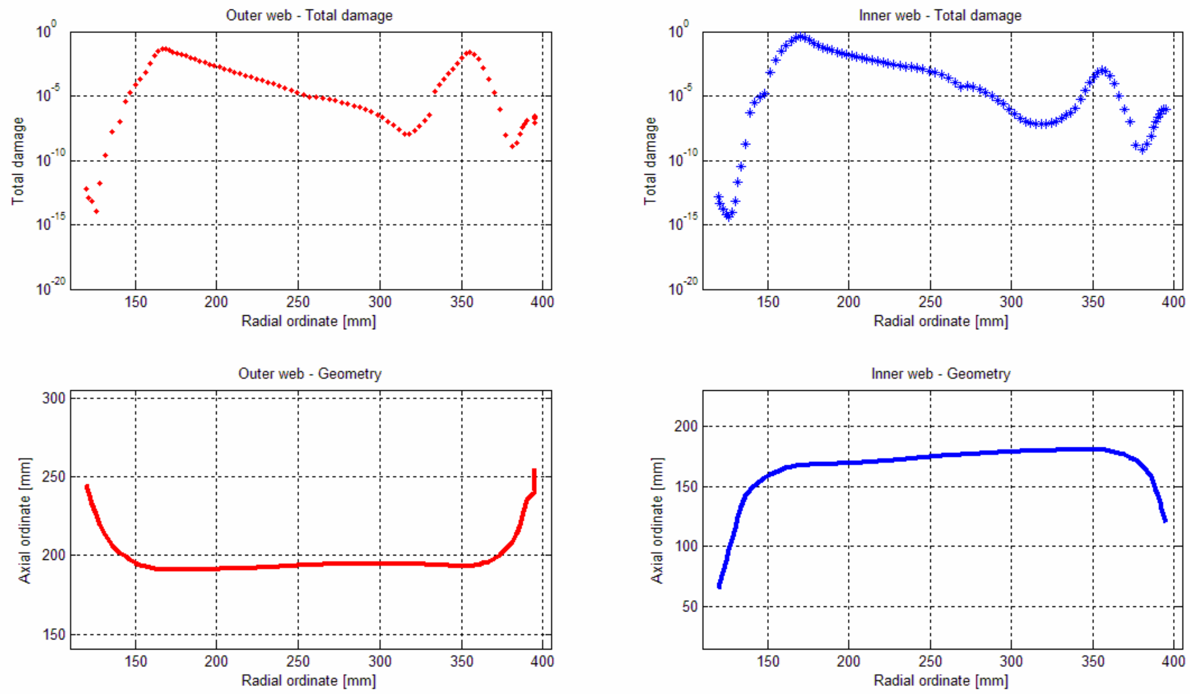

Figure 17 – Total damage fraction for the web (the inner part in bleu and the outer part in red) of the new wheel

Figure 17 shows the fraction of damage founded for the new wheel. The most stressed node is again on the inner web, almost in the same position of the original wheel. It arrives to a fraction of total damage of 0.4 (remember that a fraction of damage of 1 would correspond theoretically to breaking of the component at the end of the proposed life).

LBF analysts use in their FEM analysis a limit of the fraction of damage of 0.5, therefore our new wheel respects the limits accepted for a safe design. Moreover for this project we used a Wohler curve with high restrictions on the confidence gap for a safer forecast of the total damage.

5. Conclusions

This endurance procedure, based on load spectra and Wohler curves, is an alternative method to the standard method defined by UIC510.5.

The example of calculation shows that it is possible to reduce the wheel weight of at lest 10% .

It should be underlined that the load spectra used in the calculation is representative of the Czech railway lines and of the Alsto Czec Pendolino trainset.

For a more general application of the procedure to different railway lines, the load spectra calculated for each case defined in Deliverable D2 can be reassembled considering the new distribution of straight line and curving running conditions.

To compare the two different calculation methods, the UIC calculation is made also for the new wheel applying the same loads defined in table 2.

In table 3 are shown the safety factors for the two wheels, obviously if the safety factor is larger than 1 the life would be infinite If less than 1 the design is not verified.

The safety values show that the UIC method des not enable the verification of the lower weight wheel.

	New wheel (274 kg)		Original wheel (311 kg)	
	new	worn	new	worn
η	**0.67**	**0.63**	**1.137**	**1.108**

Table 3 – Comparison of the minimum safety coefficients between the original wheel and the new one developed with this procedure.

The load values calculated by the UIC_510_5 structure analysis are quite different from the ones read in load spectra. In the Table 3 are summarized the values which the standard UIC_210_5 gives and the maximum valued from the in-service tests during the project Widem.

	Miner				UIC_510_5	
	Q max	Q med	Y max	Y med	Q	Y
Straight	120 kN	90 kN	45 kN	0 kN	104.2 kN	-
Curve in flange	130 kN	95 kN	80 kN	0 kN	171 kN	76 kN
Curve not in flange	120 kN	90 kN	55 kN	0 kN	-	-
Switch	110 kN	65 kN	20 kN	0 kN	104.2 kN	35 kN

Table 4 – Loads used following the two different design procedure.

We can note that the loads fixed by UIC standards are bigger than the medium loads measured with the spectra, and the maximum loads, detected in service, act only for very few revolution cycles in the whole life of the wheel for example for 0.3 meters (0.1 revolution cycle as shown in figures from 7 to 16) on $6 \cdot 10^6$ km.