Wheel profile selection

REVISION

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1 INTRODUCTION

The purpose of this document is to propose a new wheel profile for the units of Tallinn. The new profile intends to improve the wheel to rail interaction, the wear rate and the dynamic behaviour of the vehicle.

CAF has a great experience in selecting the appropriate wheel profile, suspension parameters, etc to optimize the wheel to rail interaction and wear rate, while ensuring a good dynamic behaviour for all conditions in which the unit will operate.

Some points of improvements have been identified in the actual TLT wheel profile (KT4) and that is why a new wheel profile is going to be proposed. The selection of the new wheel profile is based on the behavior when running through new Ri60 and Ri62 rail profiles vertically mounted. The rail profiles are almost equal, except for the groove width and keeper profile. In Appendix A the differences of both of the profiles can be observed.

In this document the study of current and new CAF wheel profile is presented. The wheel profile plays a key role in the dynamic behavior of the units and in the lasting of the wheels. That is why the study will focus on two main aspects:

- The wheel to rail interaction.
- Wear rate evaluation.

2 DESCRIPTION OF THE WHEEL

In the following section a geometrical comparison of both of the wheel profiles has been carried out. The planes of each of the wheel profiles can be found in Appendix B.

The current TLT profile (KT4) and the proposed CAF wheel profile has been aligned and superimposed as shown in the following figure. The actual TLT wheel profile is represented in red while the new wheel profile is presented in green.

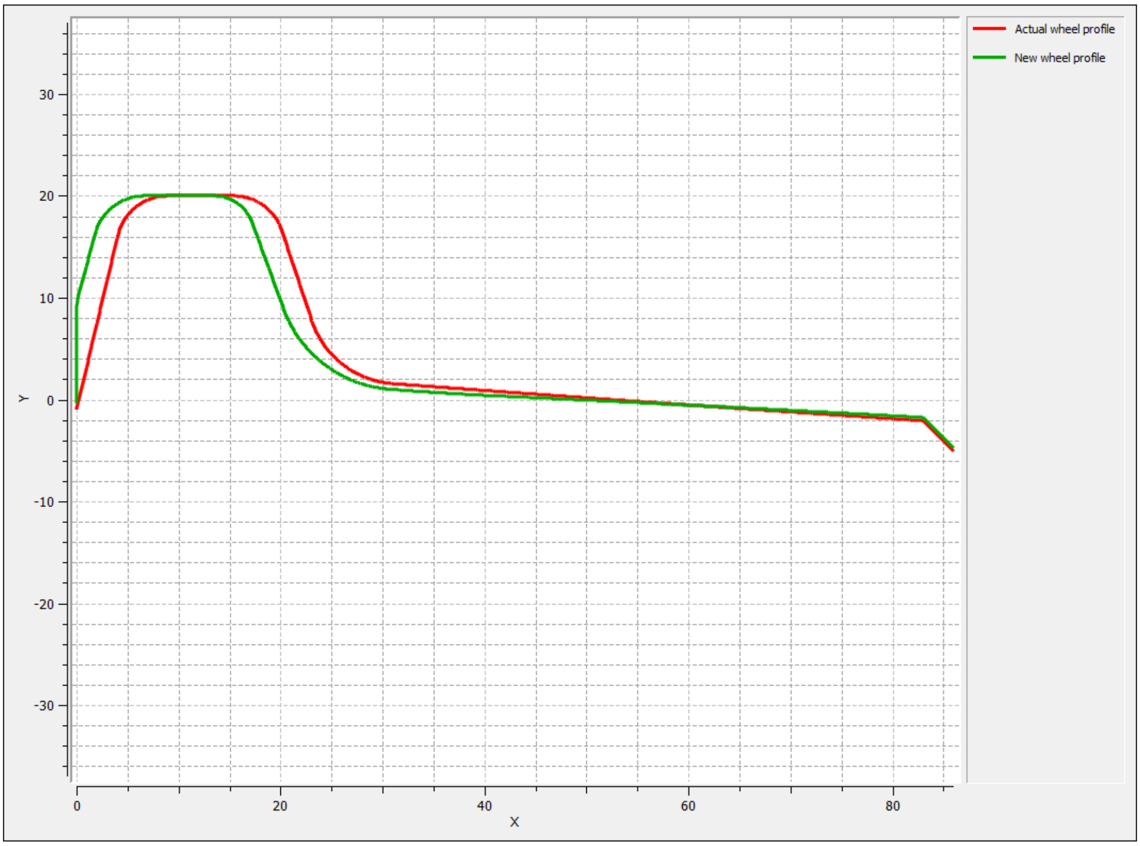


Figure 1. Actual and new wheel profile.

As it can be concluded from the figure, one of the main differences lies on the translation of the flange towards the inner face of the wheel. As will be explained in the following sections, the aim of this translation is to make bigger the clearance between the wheel and rail. Moreover, the tread has been also modified with the aim of improving the wheel to rail interaction and the dynamic behavior of the vehicle.

In the following figure the main parts of a wheel are identified.

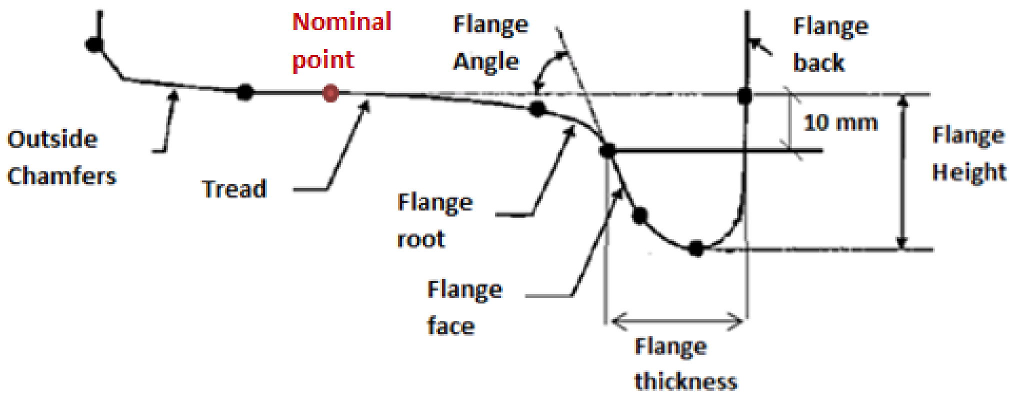


Figure 2. Main Wheel parts

The table below summarizes the main characteristics of the profiles. So as to compare the characteristics of the different profiles, a nominal point has been selected, located at 59mm from the inner face of the profile.

	Actual TLT wheel profile	New CAF wheel profile
Flange thickness (mm)	20	20
Flange height (mm)	20,5	20,5
Flange angle (deg)	71.5	70
Flange root radius (mm)	9	12
Tread initial angle (deg)	4	2,9
Distance between inner face (mm)	1017	1017

Table 1.Comparison of actual and new wheel profile

As it can be observed in the table above, the main characteristics of the TLT actual wheel profile, flange thickness and flange height, have been maintained in the proposed profile. The purpose of maintaining these main characteristics was to design a profile that could run through the line of Tallinn without too many differences.

The wheel selected must be geometrically compatible not only with the main line, which will be proved in this document, but with switches and crossings as well. With respect to this last one, it is responsibility of TLT to ensure that the wheel profile has no interface problems in these line sections.

3 WHEEL TO RAIL INTERACTION

A detailed wheel rail interaction analysis is required in order to verify that the wheel has an adequate performance when running through the specific track characteristics of this project.
In general terms, the following main aspects have been considered:

- Contact position.
- Conicity evaluation.
- Wheel-rail performance analysis under lateral displacement.

3.1 Contact position

The contact points between the wheel and rail profile has been analysed. For this study the rail contact with tread and flange has been taken into account. The contact between the flange back and keeper has not been considered. The contact between flange back and keeper will be taken into account in the following sections and when realizing the dynamic analysis of the vehicle.

In the following figures the red lines drawn represent the contact point between the rail and the wheel. The contact position is shown for both of the wheel profiles (actual TLT and CAF proposed profile) with the ri60 and ri62 rail profile (both are equal without considering keeper).

In Figures 3 and 4 initial contact point considering nominal track gauge and nominal distance between wheel inner faces is represented in red.

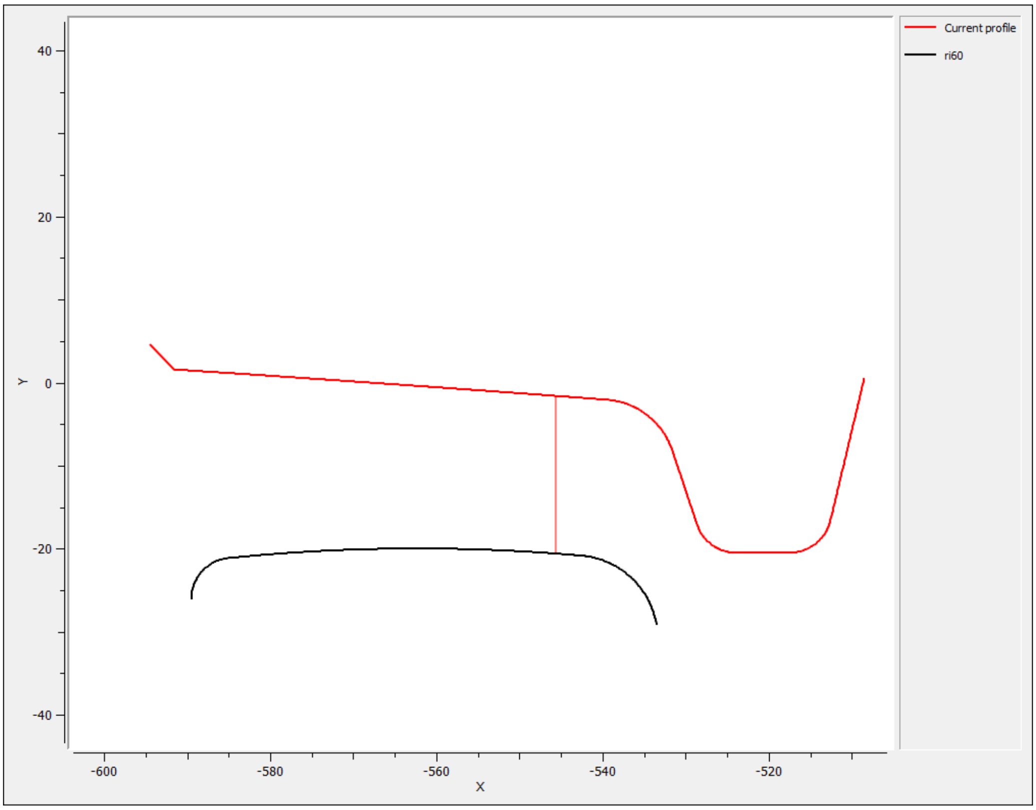


Figure 3. Initial contact point. Current TLT profile.

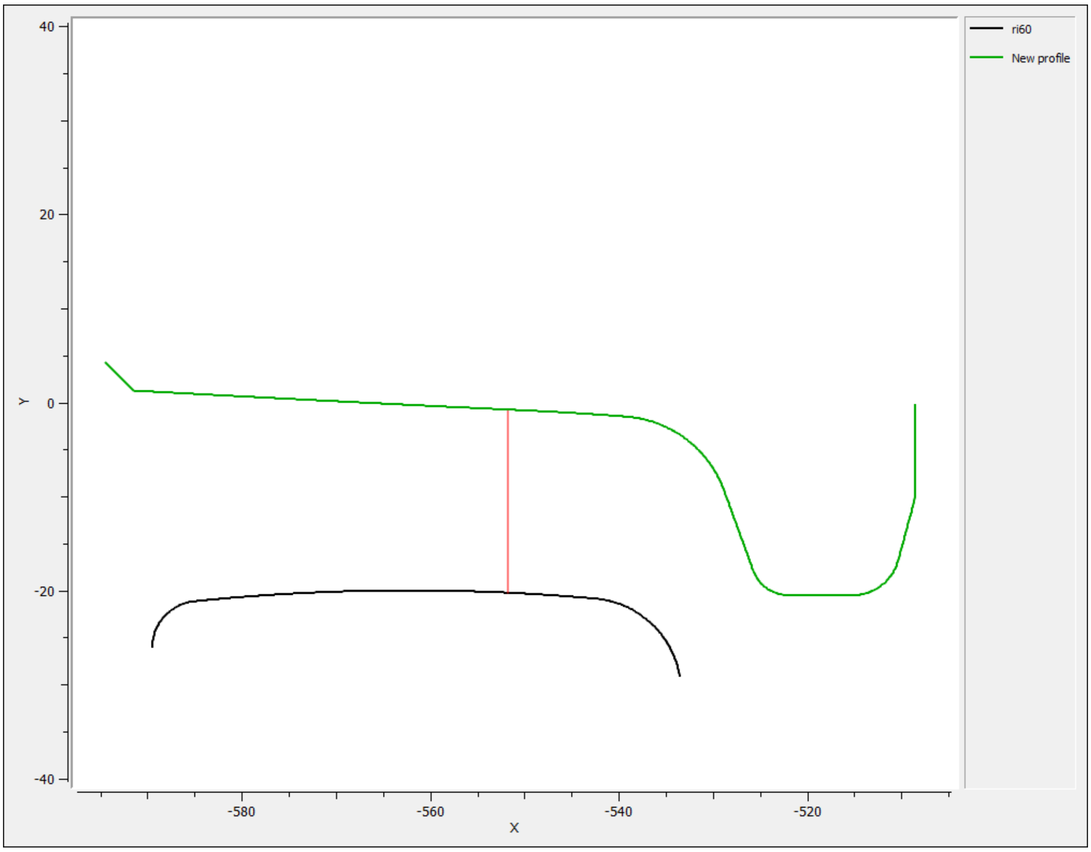


Figure 4. Initial point. CAF proposed Wheel profile

As it can be concluded from the figures above, the initial contact point in the KT4 TLT current profile (Figure 3) is closer to the flange than in the CAF proposed profile (Figure 4). This larger clearance helps to protect the flange and avoids the excessive wear in the flange face. A more accurate analysis of the clearance between the rail and the wheel profile will be carried out in the following sections.

The following figures show the points in contact between the rail and the wheel as the wheelset is moved laterally. In figure 5 the contact points for the actual wheel (KT4) are represented and in figure 6 the ones for the new wheel profile.

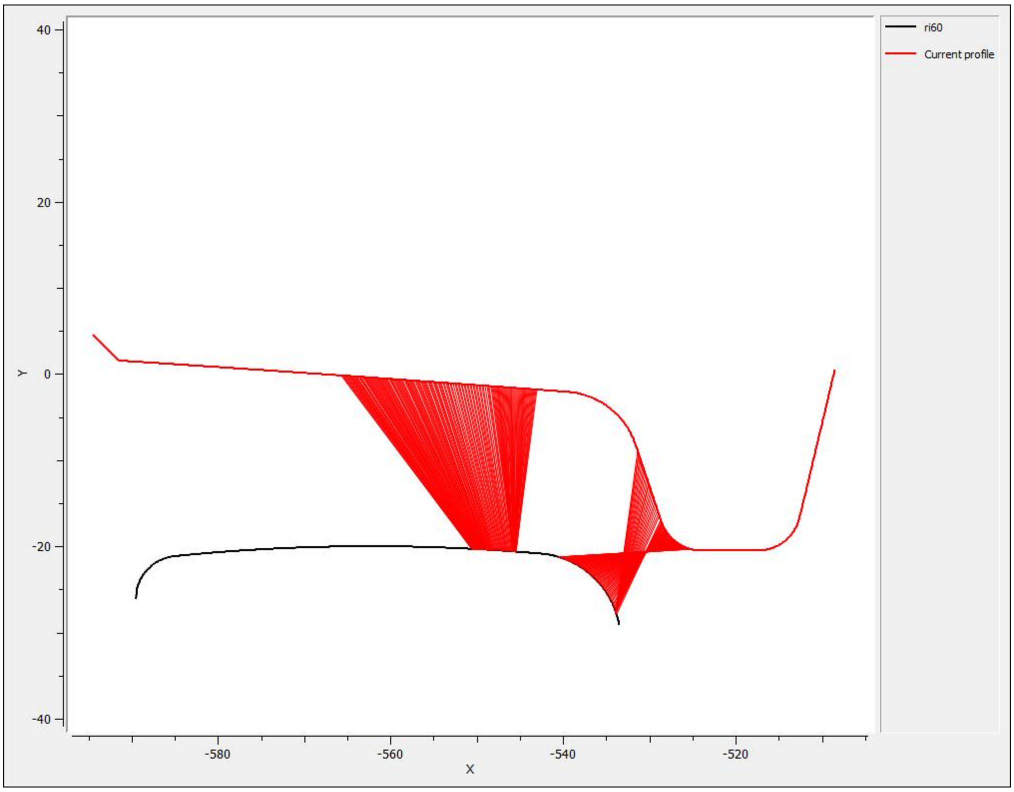


Figure 5. Contact points between actual TLT (KTA4) Wheel profile and rail

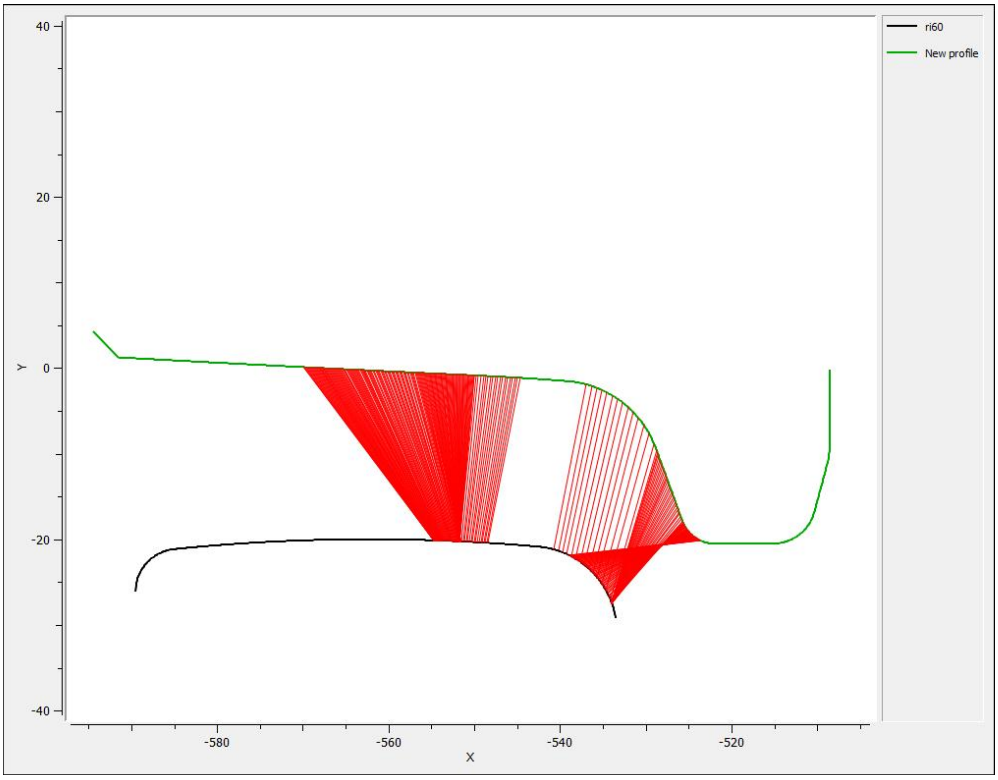


Figure 6. Contact points between the proposed Wheel profile and rail profile.

When comparing the contact points in the two wheels some advantages for the new CAF wheel profile can be highlighted. On one hand, greater conformity can be seen in the initial contact point when the rail is in contact with the proposed wheel profile. Higher conformity can cause lower contact stresses and consequently, lower initial wheel and rail wear.

On the other hand, the transition from tread to flange contact with the proposed wheel profile is smoother than with the actual wheel profile. This helps on distributing wear more homogeneously and on reducing flange wear.

3.2 Conicity

The equivalent conicity of each wheel-rail combination has been calculated according to EN15302 standard. The conicity of the wheel is an essential parameter so as to obtain an appropriate performance of the vehicle. When designing a wheel profile, it is important to look for a compromise between a low conicity to ensure sufficient stability in straight line sections, but high enough to ensure a good performance when running through a curve, reducing wear and derailment risk. Common values of conicity in conventional wheelsets vary from 0.04 to 0.08 in new wheel and rail conditions.

The following picture shows the results for both of the wheel profiles.

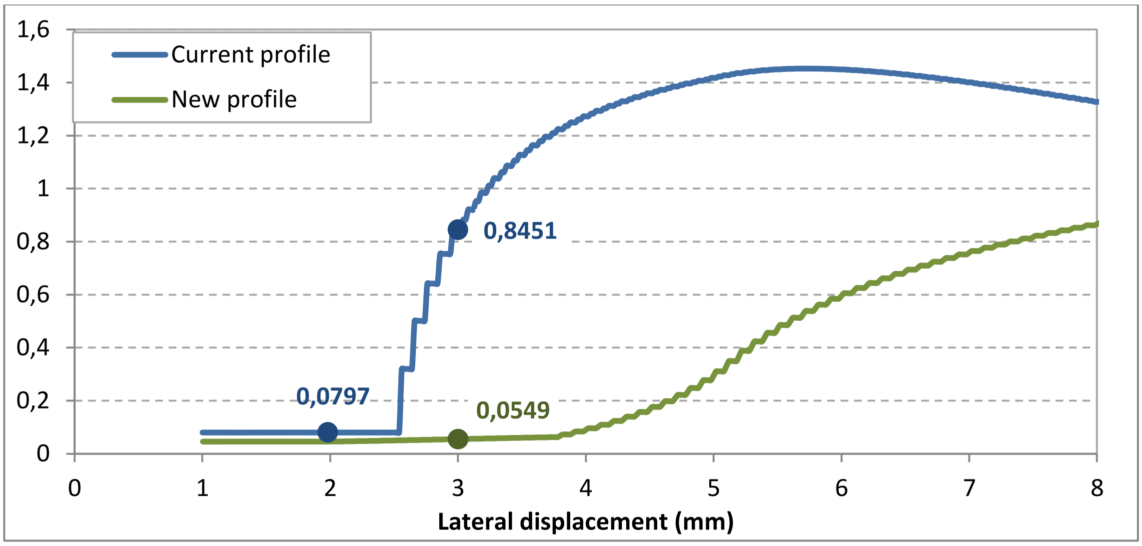


Figure 7. Conicity of current and new Wheel profile.

As it can be seen in Figure 7, when calculating the conicity at 3mm, there is a big difference between the different profiles. The conicity for the actual TLT wheel profile (0.8451) is quite higher than the conicity in the CAF proposed wheel profile (0.0549). This occurs due to the fact that the contact between the rail and wheel flange occurs before the 3mm of lateral displacement of wheelset in the actual TLT wheel profile. This results on a sudden rise of the conicity, as can be observed in the above figure.

At low lateral displacements (below 2.5mm) the conicity of both of the profiles is quite similar and for these displacements of the wheelset it is expected the two profiles to have a similar performance.

3.3 Wheel rail interaction

The performance of the wheel under lateral movements has a great influence in the wear rate of the wheels and in the dynamic performance of the vehicle. A correct ΔWheel radius variation and contact angle variation with lateral displacement helps on distributing wear homogeneously and improves the vehicle performance in terms of ride quality.

3.3.1 Wheel radius variation

As the wheelset is moved laterally, due to the conical shape of the wheel profile, the rolling radius of one wheel increases while the one of the other side decreases. The variation of the rolling radius is analysed in order to evaluate the predicted wear and ride quality.

An instantaneous wheel rail radius change implies that there is a low conformity between wheel and rail and this can lead to high wear rates and possible deterioration of lateral ride quality. On the contrary, a smooth variation of the wheel radius leads to a more homogeneus wear patron and to an improvement on the lateral comfort.

In the following figures the rolling radius variation for all of the wheel and rail combinations can be observed.

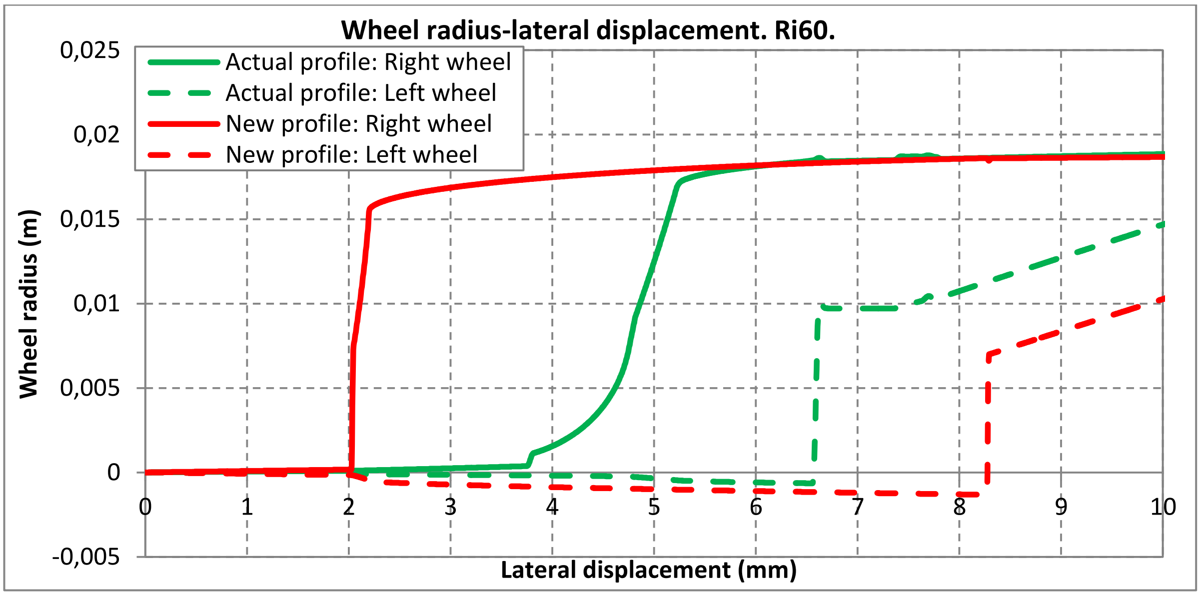


Figure 8 shows the comparison of the new and actual TLT wheel profile on Ri60 rail profile.

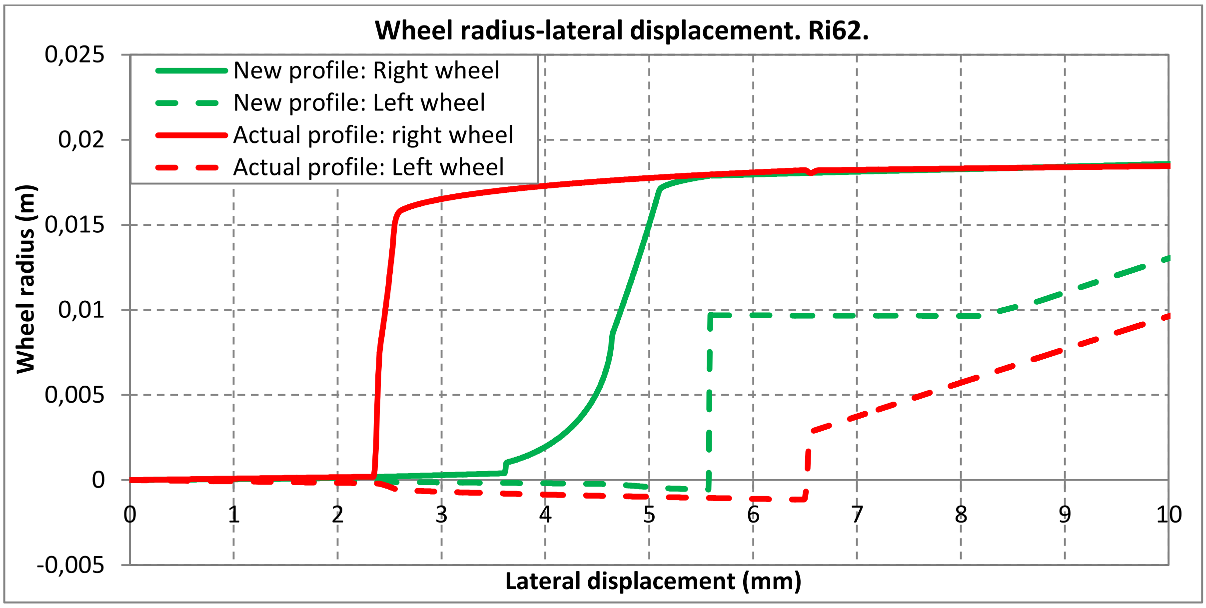
Figure 8. Wheel radius-lateral displacement. Rail profile: Ri60.

An increase in the allowable lateral displacement before contact with the flange can be observed when analyzing the variation with the new CAF wheel profile. Moreover, the transition from tread to flange face is smoother, what helps on obtaining a more homogeneous wear distribution both on wheel and on rail profiles.

As for the contact with the keeper rail, striped lines, the allowable lateral displacement before contact is lower with the new wheel profile. The clearance between the profile and keeper is smaller with the new profile, what could lead to higher wear rates in the keeper rail. Nevertheless, the clearance between flange back face and keeper rail with the new profile is still bigger than the clearance between the rail and wheel flange, what is considered to be an acceptable clearance to keeper rail.

CAF considers more important to ensure a better performance in the rail to wheel interaction that in the keeper and flange back interaction, ensuring always that the contact between the flange back and keeper is adequate.

In the following figure the comparison on the new and actual wheel profile on Ri62 rail profile can be observed.



With the exception of the groove width and the keeper shape, the rail profiles found in Tallinns line are equal. Consequently, the rolling radius variation with lateral displacements have similar performance in both of the rails (Figures 8 and 9).

Figure 9. Wheel radius-lateral displacement. Rail profile: Ri62.

The benefits of the new wheel profile are the bigger clearance between rail and flange face and the smoother transition from tread to flange. These improvements influence directly on the wear rate and the performance on lateral ride quality of the vehicle.

3.3.2 Contact angle variation

The contact angle is a decisive parameter that is defined as the angle between the tangent straight line in the contact point and the parallel to the wheelset axis. This parameter determines how the transition from tread to flange will be and helps on the protection of the flange or specific tread areas from excessive wear.

The diagram below shows the behavior of the contact angle depending on the lateral movement of the wheelset with respect to the track for the current TLT wheel profile and new CAF wheel profile when running on new Ri60 and Ri62 profiles.

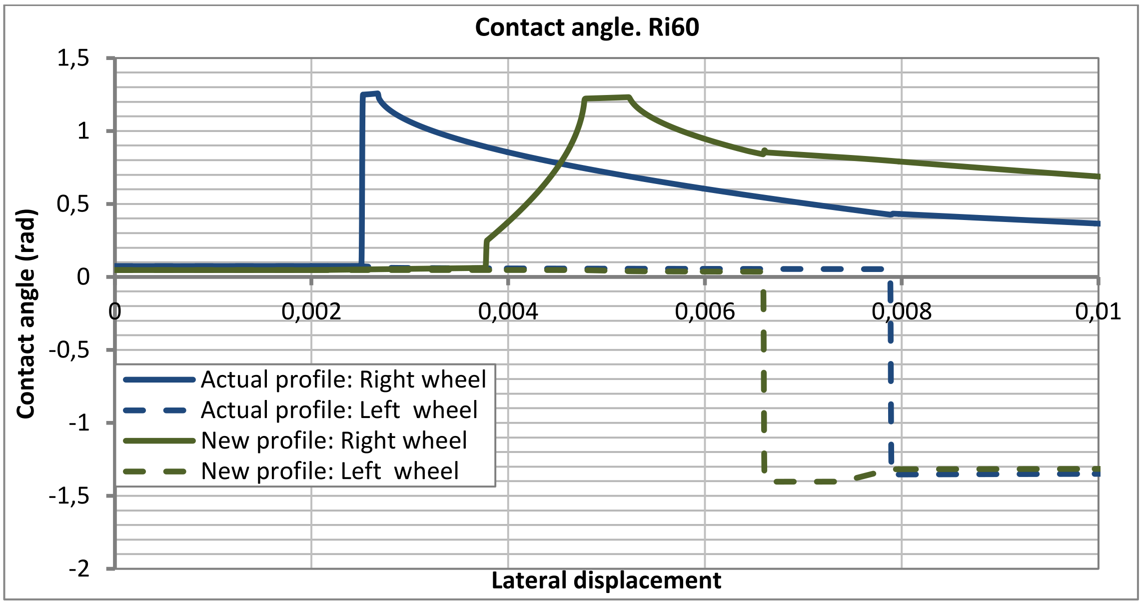


Figure 10. Contact angle. Rail profile: Ri60.

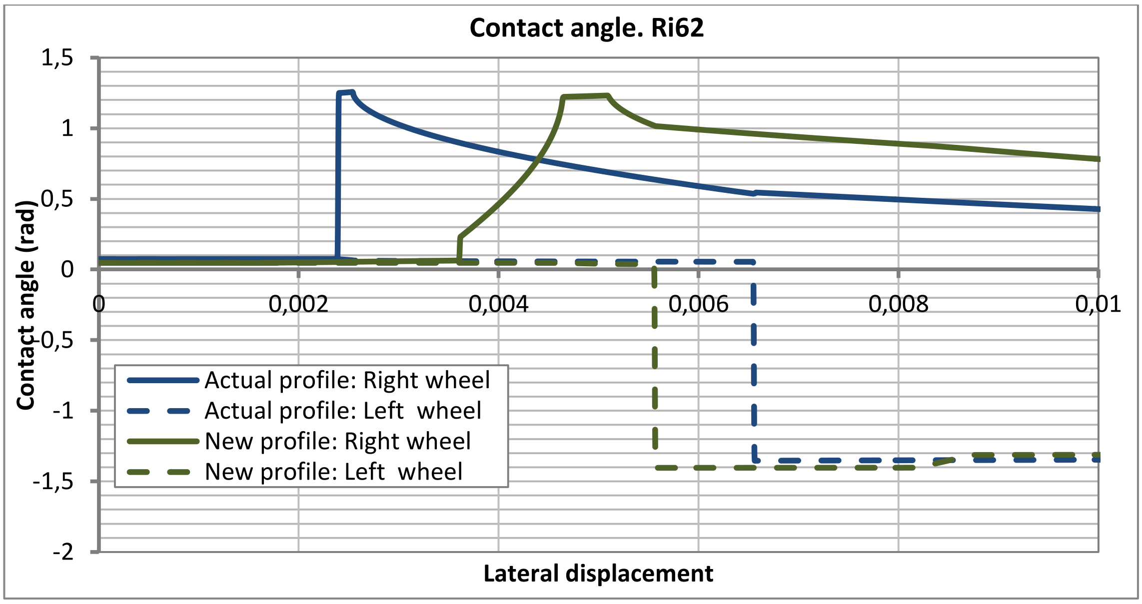


Figure 11. Contact angle. Rail profile: Ri62.

Owing to the fact that both rails are almost equal, the contact angle variation under lateral displacement has a similar performance when running through both rails. As for the current wheel profile the transition from tread to flange face, from low angles to high angles, is very sharp at 2mm of lateral displacement. As observed when analyzing the rolling radius variation the transition is instantaneous and a little lateral displacement of the wheelset is allowed before contacting the flange. Moreover, although the flange face angle is smaller (1.5 degree) in the CAF proposed wheel profile, the lateral displacement that the contact point is in the flange face is bigger (straight horizontal line in figure 11). This implies that flange climbing will occurs in a bigger lateral displacement. With the new wheel profile a more homogeneous transition is obtained at a higher lateral displacement, improving the wear rate and the lateral ride quality of the vehicle.

4 WEAR RATE EVALUATION

The wear rate of the wheels during their life depends on many parameters of the train and the track, including wheel and rail profiles, suspension parameters, track lubrication, track quality, worn rail and wheel profiles etc.

The aim of this section is to compare the actual wheel profile with the proposed wheel profile considering new rail and wheel profiles. A qualitative comparison of the two wheel profiles has been carried out, comparing the wear rate generated with actual and proposed wheel profiles when running on new rail profiles.

Simulations of curving behaviour have been done in order to quantify the improvements of the proposed solution. For the evaluation on the wheel wear calculations have been performed from curve radius of 19m up to 150m. For each of them the curve equilibrium position has been obtained. Running speed has been imposed so that it does not exceed the maximum design speed (80Km/h) and a maximum cant deficiency of 115mm (1m/s2 of lateral unbalanced acceleration).

Wear index has been calculated with the following formula:

$$Wear\left(\frac{N}{mm^2}\right) = \frac{|F_x \cdot v_x| + |F_y \cdot v_y|}{a}$$

Where

F_x: Longitudinal creep force (N)
v_x: Longitudinal creep (adimensional)
F_y: Lateral creep force (N)
v_y: Lateral creep (adimensional)
a: Contact area (mm^2)

The next figure includes the results of wear as a function of curve radius for each wheel for the vehicle running with the actual TLT wheel profile. As the wheel does not contact with the keeper rail in none of the curve radius, the wear indexes obtained when running through the Ri60 and Ri62 rail profiles are the same.

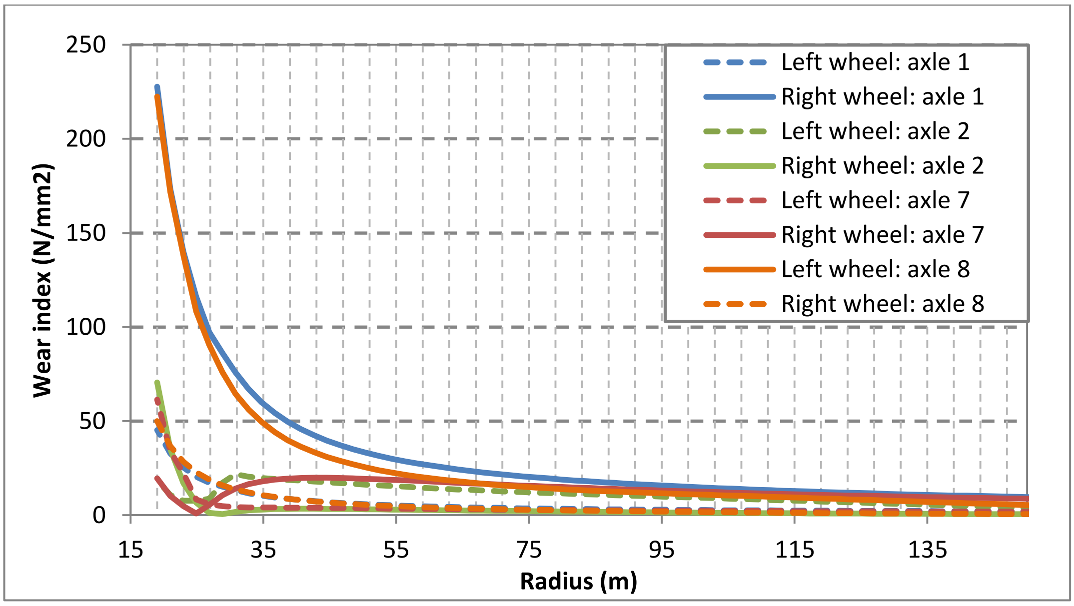


Figure 12. Wear rate actual TLT wheel profile

The next figure includes the results of wear as a function of curve radius for each wheel for the vehicle running with the proposed CAF wheel profile.

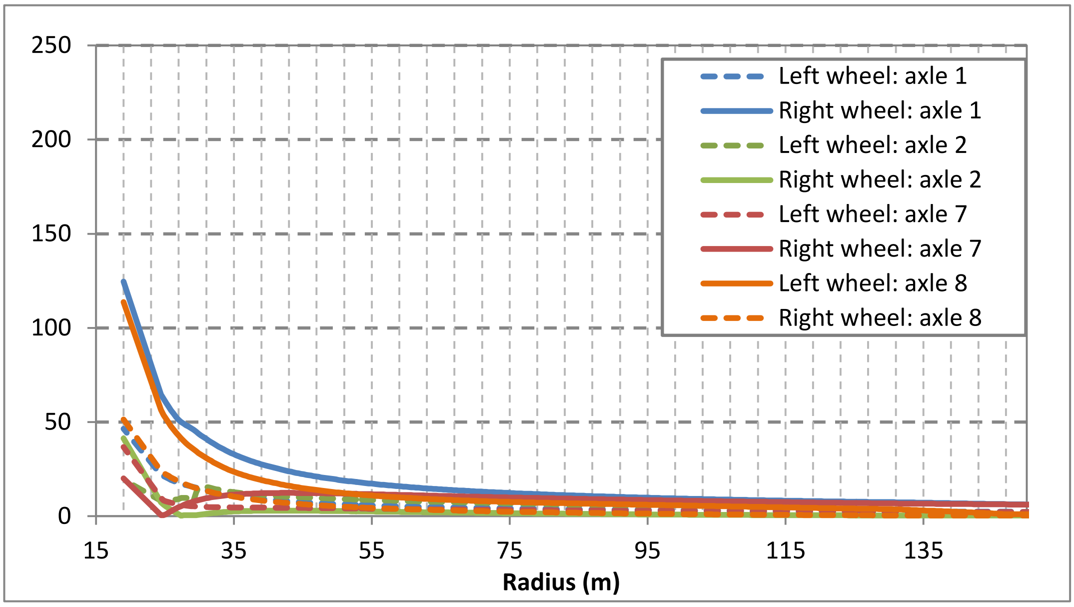


Figure 13. Wear rate new CAF Wheel profile

It can be seen that the wear index is considerably reduced with the proposed wheel profile, what implies that the expected wear will be considerably reduced with the new wheel profile.

5 CONCLUSIONS

In this document, two different wheel profiles have been assessed with regard to geometrical features, wheel to rail interaction and wear rate. The analysis has covered the following points:

- Geometrical description of wheels.
- Wheel rail interaction.
    - Contact point analysis.
    - Conicity study.
    - Wheel performance under lateral displacement of wheelset (rolling radius variation and contact angle)
- Wear rate evaluation.

As for the geometrical feature comparison, both wheels have almost equal main characteristics: flange height, flange width and flange angle. Nevertheless, some changes have been performed in tread initial angle and in the transition from tread to flange with the aim of improving the conformity of the wheel and rail profiles.

Regarding wheel rail interaction, the changes made in tread and transition to flange have helped on obtaining a higher clearance between rail and flange and a smoother transition to flange face. Consequently, lower contact stresses will be obtained what implies lower initial wear, the flange face will be more protected and a more homogeneous wear patron will be obtained. Moreover, due to the smooth transition a better performance of lateral ride quality is expected.

In addition, wheel wear has been studied for both wheel profiles concluding that the new proposed profile leads to lower wear indexes that the actual one, which can be clearly appreciated at low curve radius.

According to the performed study the new wheel profile shows some advantages regarding rail and wheel wear and lateral ride quality.

APPENDIX A

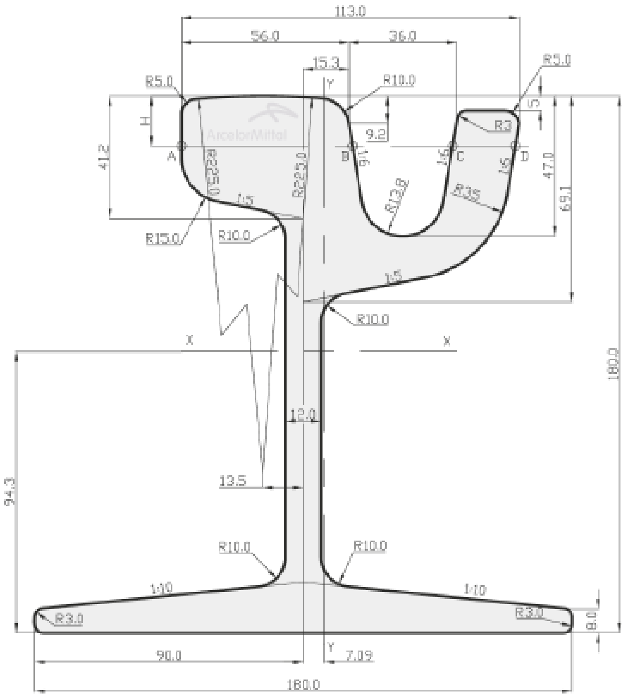


Figure 14. Ri60 rail profile

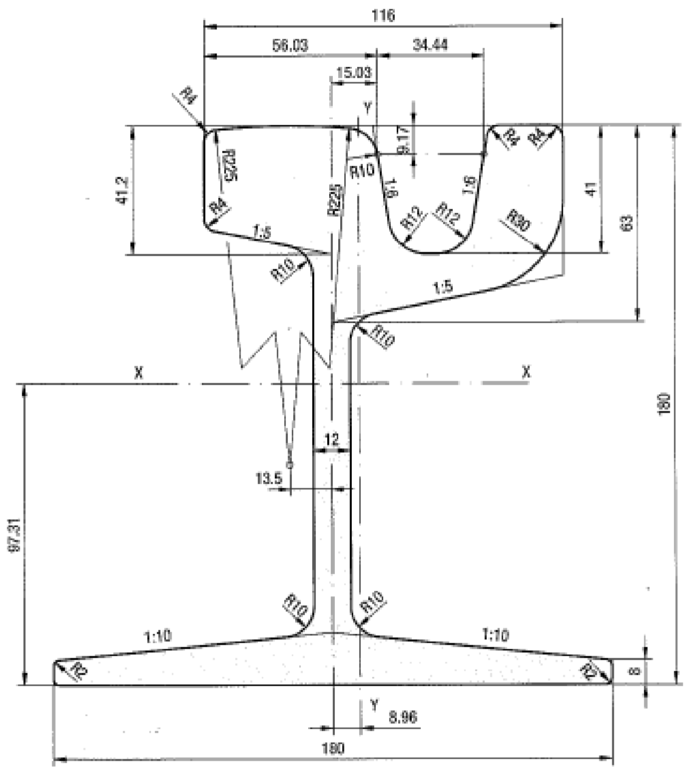


Figure 15. Ri62 rail profile

APPENDIX B

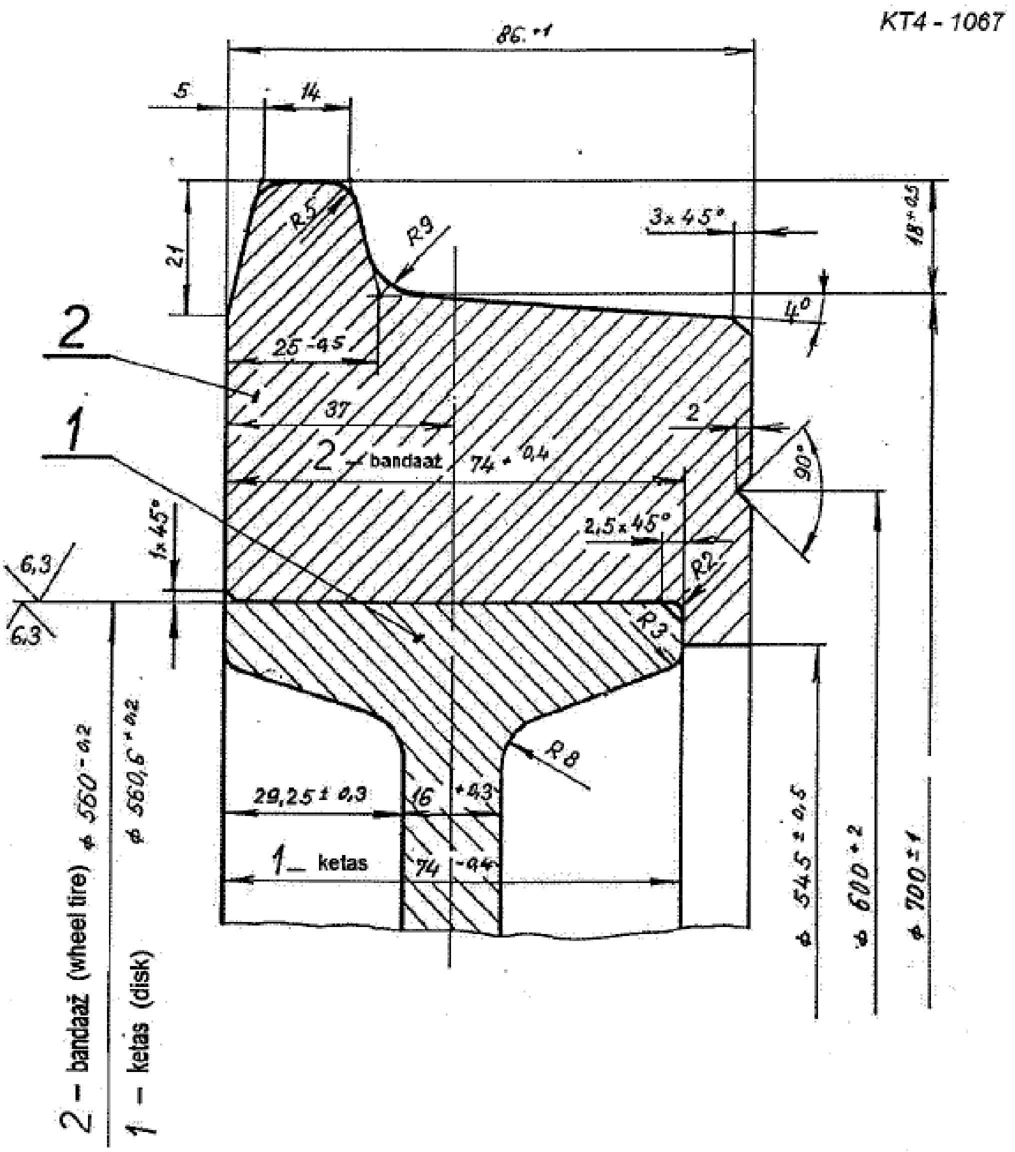
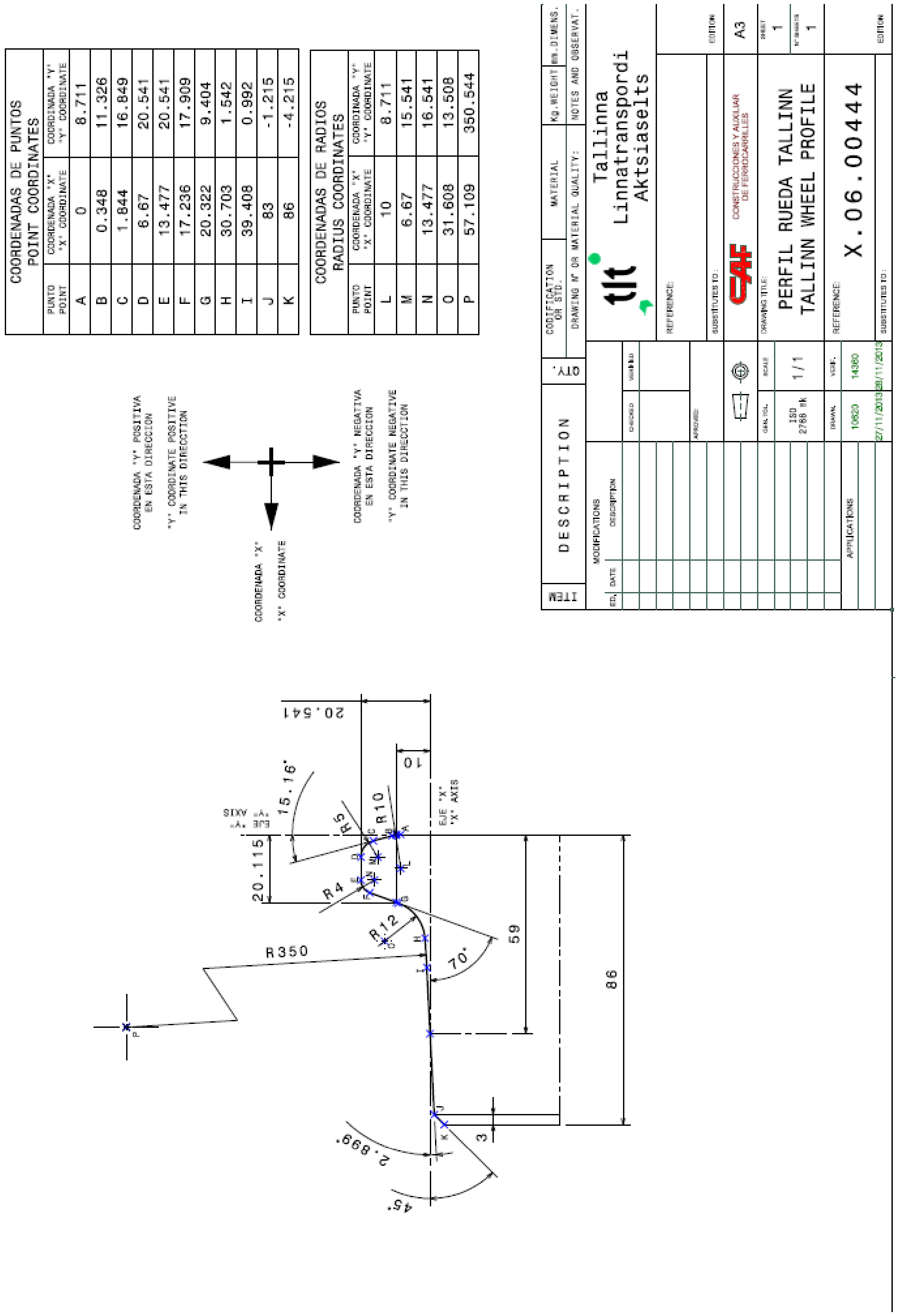


Figure 16. Actual rail profile.



COORDENADAS DE PUNTOS POINT COORDINATES		
PUNTO POINT	COORDENADA "X" "X" COORDINATE	COORDENADA "Y" "Y" COORDINATE
A	0	8.711
B	0.348	11.326
C	1.844	16.849
D	6.67	20.541
E	13.477	20.541
F	17.236	17.909
G	20.322	9.404
H	30.703	1.542
I	39.408	0.992
J	83	-1.215
K	86	-4.215

COORDENADAS DE RADIOS RADIUS COORDINATES		
PUNTO POINT	COORDENADA "X" "X" COORDINATE	COORDENADA "Y" "Y" COORDINATE
L	10	8.711
M	6.67	15.541
N	13.477	16.541
O	31.608	13.508
P	57.109	350.544

Figure 17. CAF Wheel profile