**ECS** Esveld Consulting Services BV

**FINAL REPORT**

# Investigation of the train accident on 22 July 2004 near Pamukova, Turkey

**3 September 2004** **Prof.dr.ir. Coenraad Esveld**

Delft University of Technology

**Subfaculty of Civil Engineering**
Section for Road and Railway Engineering
Railway Engineering Group

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**on**

# 22 July 2004

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# Pamukova, Turkey

This investigation was carried out by

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Director of Esveld Consulting Services BV,

in cooperation with Delft University of Technology

3 September 2004

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# 1. INTRODUCTION

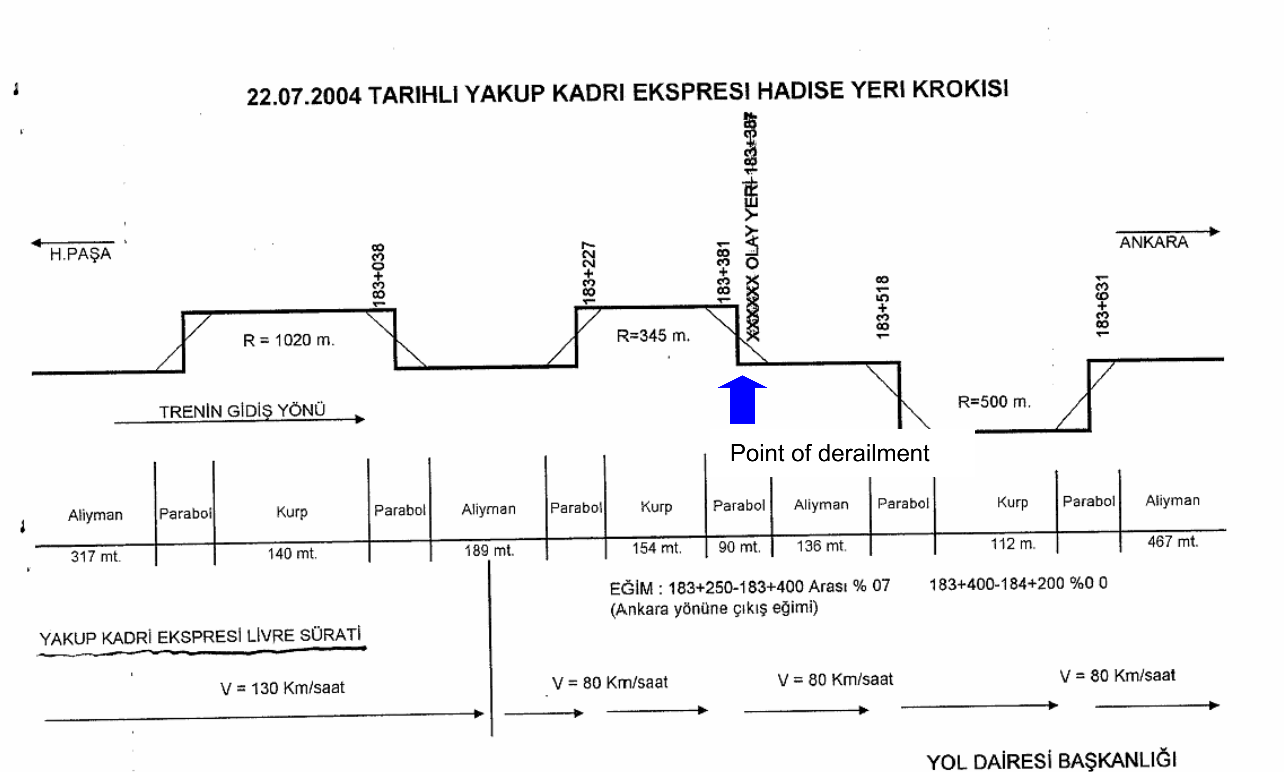
At the request of Turkish State Railways TCDD an investigation was carried out at 29 July 2004. The trip was organized by Mr. Deniz, Director of Foreign Relations Department and translational assistance was provided by Ms. Hülya Cilgi.

The place of the accident near Pamukova was visited and detailed explanation was given by Mr. Erol INAL, Deputy Director General, and various members of his staff.

The track was inspected, ie the part directly before the place of the accident, the place where the derailment was initiated and the part where the track was demolished due to the derailment.

Also a thorough look was given to the rolling stock, and in particular the wheels of the coaches at the side of the track.

# 2. INFORMATION PROVIDED BY TCDD AT THE SITE




According to the information provided by TCDD the last axle of the trailing bogie of the second coach behind the locomotive, traveling from Istanbul to Ankara, derailed at km 183+347. This occurred at the end of the sharp curve with R = 345 m, in the middle of the transition curve. At that time the train had a speed of approximately 132 km/h, whereas the allowable speed was 80 km/h. This second coach subsequently hit a concrete wall (culvert), was detached from the train and was rotated 180 degrees. The first coach was towed by the locomotive for approximately 300 m before locomotive and first coach came to a stand still. The locomotive did not derail and could be moved to the workshop on its own power via the track.

## 3. OBSERVATIONS DURING INSPECTION OF THE SITE ON 29 JULY

When arriving at the site in the late afternoon first the track was walked in the direction from Ankara to Istanbul until the end of the 345 m curve. Subsequently the track was walked in opposite direction. The track consisted of concrete sleepers, 49 kg/m rails and so-called K-fastening system. For details please refer to Appendix C. Some of the sleepers had light damage traces, which were, as explained by Mr. Inal, from earlier derailments of freight wagons.

At the point of derailment no climbing marks could be found.

Figure 1 Point of Derailment

As at this point the wheelset of the second coach had a lateral displacement outside the track of 90 cm it is most probable that the wheelset derailed at an earlier point.

Figure 2 Wheelset was stepped out over 90 cm

In the left hand rail of this picture a rather poor weld can be observed. This weld is at a short distance from the point of derailment in the opposite rail. The influence of a concentrated geometrical defect as caused by this poor weld has been investigated in the simulations with ADAMS/Rail. The transverse rail profile did not show any substantial deviations.

Figure 3 Curve seen from Ankara to Istanbul

Here the track is viewed in the opposite direction with the poor weld now in the right hand rail. The contact band on the rail is at the right place approximately in the middle. There are no lateral shifts and also at the weld the contact band seems to be at the right place.

The fastening system seemed to be in good condition: no loose fasteners between rail and baseplate and between baseplate and sleeper.

Figure 4 Transition curve seen from Istanbul to Ankara

Walking through the curve with R = 345 m. The concrete sleepers are well embedded in the ballast and there is also a enough ballast shoulder to guarantee sufficient lateral track resistance.

During the inspection special attention was given to deviations in the track geometry and in particular to local irregularities. Despite the one poor weld no severe irregularities were found.

Figure 5 Mid of curve seen from Istanbul to Ankara

At the point of derailment there is plenty of ballast. Also from other observations in the track no lateral shifts could be identified.

Figure 6 Ballast shoulder at point of derailment (Istanbul - Ankara)

In Figure 7 damage to the sleepers and fastening system is clearly seen. The right hand wheels were riding on the sleepers close to the left hand rail.

Figure 7 Track damage between point of derailment and Culvert (Ist - Ank)

The track just before the culvert. Here the same damage to the track is observed as seen in the previous picture.

Figure 8 Damage to the track near Culvert (Ist - Ank)

The culvert with the concrete wall to which the derailed car (second car behind the loc) collided. From here on the accident escalated. The second coach turned around over 180 degrees and caused the derailment of 3 other cars.

From here on the track was partially destroyed and repaired before my visit to the site took place.

Figure 9 Concrete wall of culvert (Ist - Ank)

Here some of the replaced damaged sleepers are stored.

Figure 10 Replaced damaged sleepers left of Ist - Ank

Special attention was given to the wheels because they constitute an important link between vehicle and track. Special attention was given to the occurrence of worn wheels and also hollow wheel threats and false flanges.

In general it could be concluded from the inspection that the wheels were in good condition and no abnormal deviations could be found.

Figure 11 First bogie of derailed coach

Figure 12 Left wheel derailed bogie second coach

Figure 13 Right wheel of first bogie derailed coach

Figure 14 Coach right of track Ist - Ank

Figure 15 Wheels derailed bogie

Figure 16 Wheel detail derailed bogie

Figure 17 Wheel detail derailed bogie

Figure 18 First coach behind the loc

Figure 19 Wheel 1 of first coach

Figure 20 Wheel 2 of first coach

## 4. ADDITIONAL INFORMATION ON PAPER

By TCDD a set of papers was handed over containing information relevant to the accident. The most important parts used in this investigation are attached in the appendix C. From the graph of the tachograph it can be observed that the actual speed at the time of the derailment is about 132 km/h (after correction of the figures on paper with a factor of 1.2).

The strip chart of the track recording car was provided and the TCDD authorities stated that the geometrical deviations presented were all within the tolerances laid down in the specifications. It was impossible to receive these data in a digital format for processing in the numerical simulations. Also it was not clear what the relationship was between the measured geometry and the real geometry, i.e. the so-called transfer functions.

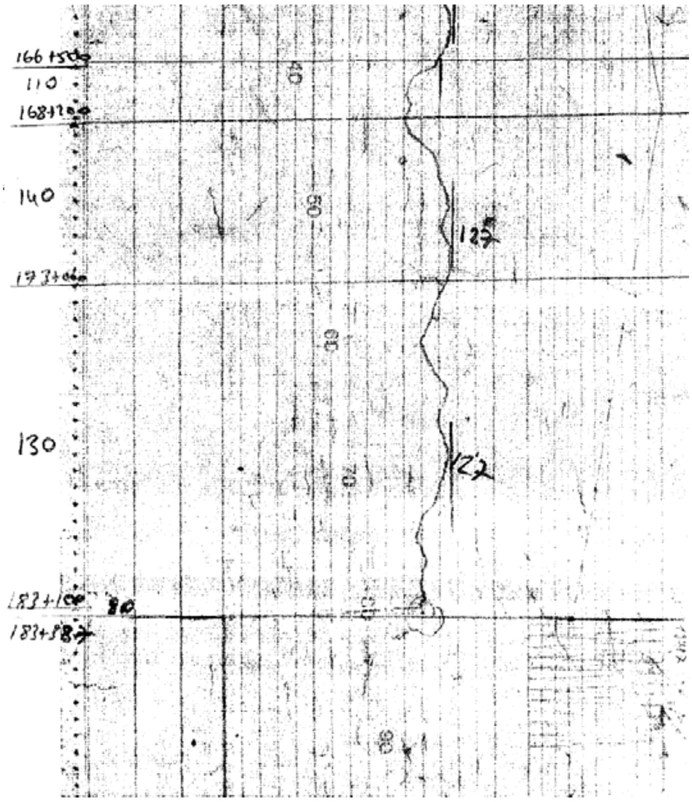



Figure 21 Speed chart. The values should be multiplied by a scale factor of 1.2


Figure 22 Track recording car chart

# 5. ANALYSES WITH ADAMS/RAIL

From the data provided by TCDD the non-compensated lateral acceleration at 132 km/h could be calculated.

$$a_{nc} = \frac{v^2}{R} - \frac{h}{s}g = \frac{\left(\frac{132}{3.6}\right)^2}{345} - \frac{130}{1500}9.8 = 3.05\frac{m}{s^2}$$

This acceleration is about 3.0 times the allowable value. As such manual calculations are insufficient to explain the derailment it was decided to carry out a comprehensive analysis with the ADAMS/Rail computational package. For details on the package please refer to the next chapter 5.1 and also to [2].

Due to the limited time available to analyze the derailment it was decided to take the track and vehicle components from the ADAMS/Rail library. For the rails the German S49 (Figure A.1) was taken and for the wheels the UIC S1002 profile (Figure A.2), which are quite close to the Turkish components. The coach with Y32 bogies was more or less standard and it was available in the ADAMS/Rail library. The analyses have been restricted to just one coach, i.e. the coach which derailed initially (Figure A.3). To model the complete train was too much work to do in the relatively short period.

First the track was just modelled with design curve geometry, without rail geometry imperfections. In this situation no derailment conditions could be generated (Figure A.4).

As no detailed information about the track geometry other than the traces on paper was available, and it was not known what kind of transfer functions for the Turkish recording car were applicable, it was decided to add short wave irregularities according to the Dutch standards from ProRail, the Dutch Infra Manager. The track irregularities are mainly in the wave band 0 – 25 m. In The Netherlands the following standards apply for this waveband:

- Alignment: 80 % of the tracks have a standard deviation less than 1 mm
- Level: 80 % of the tracks have a standard deviation less than 1.5 mm

The track recording car data were scaled in order to achieve the required level of the standard deviation and the following cases shown in Table 1 were analyzed.
Table 1. Analyzed track cases

| Speed | Track case 1 | Track case 2 (wave band 0-25 m) | | Track case 2 with rail joint | Track case 2 with external forces |
|---|---|---|---|---|---|
| | Just design geometry | $\sigma_{vert}$ = 1.5 mm<br>$\sigma_{lat}$ = 1.0 | $\sigma_{vert}$ = 2.0 mm<br>$\sigma_{lat}$ = 1.5 mm | $\sigma_{vert}$ = 2.0 mm<br>$\sigma_{lat}$ = 1.5 mm | $\sigma_{vert}$ = 2.0 mm<br>$\sigma_{lat}$ = 1.5 mm |
| 22 m/s | o | o | o | - | o |
| 28 m/s | o | o | o | - | o |
| 36 m/s | o | o | o | o | o |
| 42 m/s | o | - | - | - | - |

Track case 1 is modelled with design geometry only, i.e. without rail geometry imperfections. Track case 2 is the curved track from track case 1 supplemented with measured track irregularities within the wave band 0-25 m. The analyses were carried out for speeds of 22, 28, 36 and 42 m/s (80, 100, 130 and 150 km/h respectively). The examples containing short wave irregularities in the waveband 0-25 m are presented in the Figure A.5 - A.9. In addition track case 2 was extended with a geometrically poor rail joint in the right hand rail (Figure 3 and 4) and finally track case 2 was combined with an external lateral force and an external vertical uplifting force, both of 20 kN, to simulate buffering and mechanical imperfections in the system.

## 5.1 Model description

ADAMS/Rail 2003 computational package has been used to perform derailment simulation tests. ADAMS/Rail is the part of the ADAMS computational package for analyses of the multi–body systems specially designed for the simulation of the railway vehicles.

To build a rail vehicle, it is necessary simply to supply the required assembly data into forms that use familiar rail engineering naming conventions. This allows to quickly define front and rear bogies (including wheel sets, bogie frames, primary and secondary suspensions, dampers, and anti-roll bars) and bodies. ADAMS/Rail will then automatically construct the subsystem models and full-system assemblies building a complete, parameterized model of a new railway vehicle.

To model tracks, one can define the track centerline by specifying the analytic layout parameters: curvature, cant, and gauge. Track measured data are specified as irregularity parameters: alignment, cross level, and gauge variation. Rail profiles and inclination can progressively be evolved along the track to carefully model switch layouts

Now one can run the virtual prototype through a battery of kinematic, static, and dynamic tests to determine the vehicle's stability, derailment safety, clearance, track load, passenger comfort, and more.

ADAMS/Rail has been benchmarked with other main multi-body dynamic packages. Results of ADAMS/Rail benchmarking have been presented in Vehicle System Dynamics Supplement [1] and greatly correspond with the results from other programs.

The passenger wagon was modelled in the ADAMS/Rail computational package. A standard ERRI passenger vehicle model has been described using standard subsystems available in ADAMS/Rail [2], see Figure 23. For our simulations a rail profile S49 with inclination 1:40 and a wheel profile S1002 have been used. The track has normal 1435 mm wide gauge. Vehicle parameters are presented in the Table A.1.

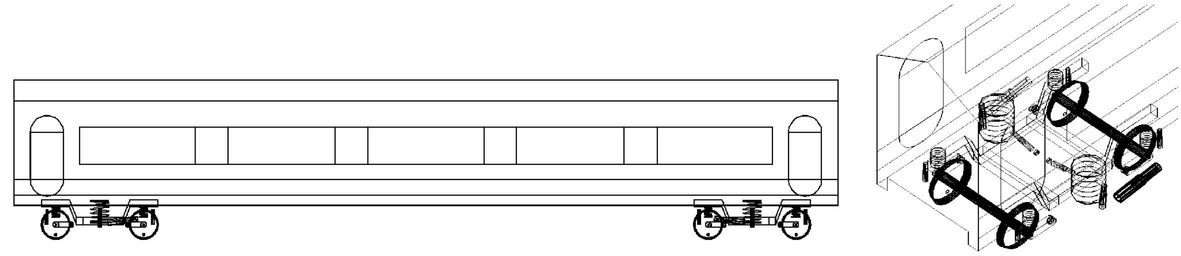


Figure 23. Schematic presentation of the ADAMS/Rail vehicle model

In all presented cases the vehicle simulations have been performed on the track consisting of a 144 m straight track continuing into 90 m transition curve, then switching into the 64 m right turn curve with R=345m and 90m transition curve and ending with 112 m straight track. Cant is 130 mm. The vehicle travels with a speed of 22 m/s, 28 m/s and 36 m/s (exactly 79.2 km/h, 100.8 km/h and 129.6 km/h respectively).

Measured track irregularities have been used in the dynamic simulations. These irregularities do not exceed any allowable limits. Vertical and lateral irregularities for left and right rail are shown in Figures A.5 - A.9. The first 100 m of the track has zero irregularities to provide stable starting conditions for the passenger vehicle. Irregularities for the right side are shifted forward over 1m. Lateral irregularities are shown as mirror image because of the coordinate systems in ADAMS/Rail.

## 5.2 Derailment coefficient

To estimate vehicle safety one can analyze the possibility of derailment. Various formulae exist as a guide for the derailment process, which gives the ratio between lateral and vertical forces for a particular wheel/rail combination. This ratio usually called the ”derailment ratio” is denoted as Y/Q, where Y and Q are respectively the lateral and vertical forces at the flange contact. The derailment ratio Y/Q is used as a measure of the running safety of railway vehicle. Several theories have been developed to establish the Y/Q ratio. One of the most widely used is Nadal’s theory [3]. His formula takes into account the influence of the wheel flange angle, the wheel/rail friction coefficient and the wheel/rail forces on the possibility of wheel climb derailment. This principle is expressed in the Nadal formula:

$$\frac{Y}{Q} = \frac{\tan\alpha - \mu}{1 + \mu\tan\alpha}, \qquad (1)$$

where $\alpha$ is the angle between wheel flange and the horizontal line; $\mu$ is the friction coefficient.

The limiting Y/Q ratios for various combinations of friction coefficient and contact angles are shown in Figure 24. For particular combinations of the friction coefficient and the contact angle the Y/Q ratio exceeds the corresponding limiting value and derailment can occur. The theory of Nadal is used to establish the limit for the Y/Q derailment ratio. Normally, the derailment conditions are formulated as:

- $\frac{Y}{Q} \geq 1.2$ over a distance of 2m; in ADAMS/Rail this is a so-called derailment alarm;
- at the same time wheel climbing should occur over a sufficient height so that the flange can step over the rail.

According to UIC leaflet 518 a safe maximum value of $\frac{Y}{Q} = 0.8$ over 2 m is recommended.

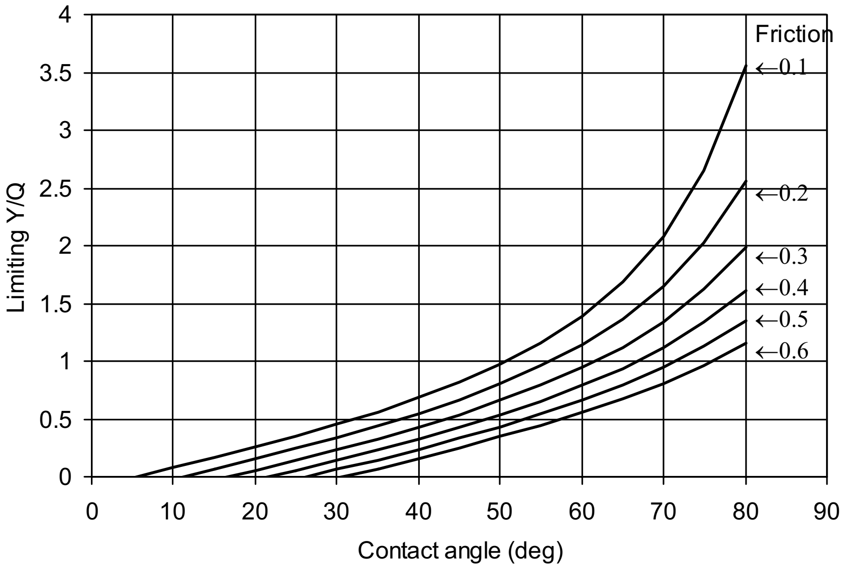



Figure 24. Nadal's derailment criteria

## 5.3 Results of the dynamic simulations

In the present report only a limited number of the most important cases is described. A complete set of all simulations made will be published in a separate TU Delft report [4]. The results of the dynamic simulations in ADAMS/Rail for speeds of 22 and 36 m/s, using the measured rail irregularities (see Figures A.5 – A.9), are presented in the Appendix B. At speeds of 22 and 36 m/s also simulations were carried out with external forces. This was to investigate how sensitive the system is for small disturbances due to buffering and small mechanical imperfections. In all presented simulations measured irregularities from the Dutch Infra Manager ProRail have been used and these were scaled such that $\sigma_{vert}$ = 2.0 mm, $\sigma_{lat}$ = 1.5 mm and $\sigma_{cant}$ = 1.2 mm.

The case with the measured irregularities and a dipped rail joint imperfection on the right hand rail have been studied, but the graphical results were not included in this report. The main conclusions from that case were that the rail joint had just influence on the right wheel contact forces, but had little influence on the left wheel forces and could not be the source of the derailment.

The results of dynamic simulations are presented in Figures B.1 to B.16 of the Appendix B. In each Figure the derailment coefficient, the lateral contact force, the vertical contact force and the vertical wheel displacement for just one wheel are shown. Since the results for the 2nd and 3rd wheelsets were omitted each set of four Figures corresponds to one simulation. The wheelsets are numbered from the beginning to end of the vehicle from 1 to 4 and left and right wheels are marked. Left wheels correspond to the outer side of the curved track.

First the case with measured irregularities but without any external forces will be considered. The derailment coefficients are shown in Figures B.1 (a) - B.8 (a). The highest derailment coefficient can be observed at the 1st left wheel. For 22 m/s the derailment coefficient is high but below the critical value of 1.2. With the increase of the speed the derailment coefficient rises as well for all wheels. For 28 m/s the derailment coefficient reaches the limiting value (not shown) and for 36 m/s exceeds the limiting value. Also at a speed of 36 m/s the vertical displacements of the wheels are high (see Figures B.1 (a-d) - B.8 (a-d)) and there are more situations of loss of the contact between wheel and rail. The high derailment coefficient, vertical wheel displacement and loss of contact result in a high risk of vehicle derailment at this speed of 130 km/h.

In order to simulate the effect of adjacent cars in a moving train, additional vertical and lateral forces have been applied to the rear end of the car body. Both forces have a magnitude of 20 kN. The vertical force is pointed upwards and creates unloading of the rear bogie. The lateral force is pointed to the outside of the curve. For the speed of 22 m/s the forces were applied from 13 till 18 seconds and for the speed of 36 m/s the forces were applied from 8 till 11 seconds. Due to this choice the forces are acting in the same part of the track in both speed cases. The results of the dynamic simulations for the case of measured irregularities with additional external forces have been presented in the Figures B.9 - B.16.

One of features of the ADAMS/Rail program is that when the wheel has no contact with the rail, i.e. the vertical and lateral forces in the contact patch become zero, the derailment coefficient becomes equal to the last known value. This means that even if the wheel is lifted over the rail and there is a risk of derailment, the derailment coefficient can be within the limits. This can be clearly seen in Figure B.16 at time from 8 till 9 seconds when the wheel is lifted over the rail and initiates a derailment. It can be observed that the wheel is lifted over 10 mm (Figure B.16 (d)) and the contact forces became equal to zero (Figure B.16 (b, c)). But during the wheel lift, at the time of 8-9 seconds, the derailment coefficient is still equal to 0.4-0.2 (Figure B.16 (a)). This means that not only the derailment coefficient should be checked, but also the vertical wheel displacement to recognize the risk of a derailment.

Comparing the set of Figures B.1 - B.8 with the set of Figures B.9 - B.16 reveals that external forces have very little influence on the 1st wheelset and do have a high influence on 4th wheelset. Application of a vertical unloading force and a lateral force to the rear side of the car body increases the derailment coefficient of the 4th wheelset, produces higher vertical and lateral forces in the contact patch and also results in high vertical displacements of the 4th wheelset. Moreover, the influence of external forces is much higher at the speed of 36 m/s than it is at the speed of 22 m/s. Application of the external force at the speed of 22 m/s does not lead to the creation of a derailment situation. But at the speed of 36 m/s the derailment coefficient for the left wheel of the 4th wheelset is obviously exceeding the limit (see Figure B.15 (a)). Also the right wheel of the 4th wheelset is loosing contact with the rail (see Figure B.16 (d)). This situation is extremely critical and in fact constitutes a derailment.

## 6. ADDITIONAL REMARKS

In my international consulting career, I have made many investigations of the quality of railway tracks. On the 29th of April 2004, during the inspection of the site where the accident took place, I could establish that there were no abnormalities in the infrastructure, (including rails, sleepers, ballast, fastenings etc.), from the beginning of the curve (183+227) to the point where the bogie derailed (183+387) and about 20 m onwards to the point where the wagons were dispersed (183+407). All the infrastructure I have inspected at the site seemed to be of good quality in line with the UIC standards.

## 7. CONCLUSIONS

The additional investigations carried out after the inspection in Turkey on 29 and 30 July confirm the earlier conclusions issued in the preliminary report:

1. No abnormalities in the track could be observed during the inspection on 29 July 2004;
    a. No geometrical imperfections which could have been responsible for the initiation of a derailment could be found;
    b. No lateral track shifts were observed which means that the track had sufficient lateral resistance to withstand lateral train forces and forces due to continuous welded rail (CWR);
2. As regarding rolling stock no significant wheel profile deviations could be observed.
3. The excess of the speed limit should be considered as one of the main causes of the derailment initiation.

The additional investigations showed that it is hardly possible to explain a derailment without advanced calculations such as made by TU Delft with the ADAMS/Rail package. These analyses revealed that:

4. No derailment would occur at 80 km/h;
5. At 100 km/h no derailment would occur, but the situation is then already rather critical;
6. At 130 km/h severe wheel climbing could be observed and small disturbances in the system could then easily lead to a derailment

**Overall conclusion:**
The exceedence of the speed limit should be considered as the main cause of the derailment. No significant influences of any track component on the derailment could be established.

Zaltbommel, 3 September 2004.

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Post Scriptum
In APPENDIX D the findings of some other experts are discussed

# LITERATURE

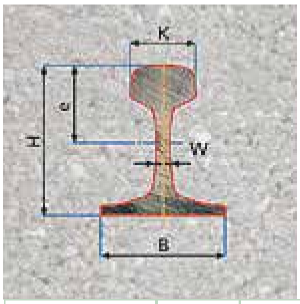
1. The Manchester benchmarks for rail vehicle simulation/ ed. By S. Iwnicki, Swets & Zeitlinger, Lisse, 1999, ISBN 90-265-1551-0
2. ADAMS/Rail Help Guide, 2002. http://www.mscsoftware.com/products/
3. Dukkipati, R.V., Vehicle Dynamics, Boca Raton, CRC Press, 2000. ISBN 0-8493-0976-X
4. Esveld, C, Markine, V.L. and Shevtsov, I.: Analysis of the Turkish railway accident near Pamukova: Dynamic simulations with ADAMS/Rail, TU Delft, September 2004

# APPENDIX A.

Table A.1. Parameters of the vehicle for the dynamic analysis

| Model parameter | Metro | Measurements |
|---|---|---|
| Car body | | |
| Mass m | 32000.0 | kg |
| Inertia moment Ixx | 56800.0 | $kgm^2$ |
| Inertia moment Iyy | 1970000.0 | $kgm^2$ |
| Inertia moment Izz | 1970000.0 | $kgm^2$ |
| | | |
| Body length | 24.0 | m |
| Body height | 3.0 | m |
| Body width | 2.2 | m |
| Bogie | | |
| Mass m | 2615 | kg |
| Inertia moment Ixx | 1722 | $kgm^2$ |
| Inertia moment Iyy | 1476 | $kgm^2$ |
| Inertia moment Izz | 3067 | $kgm^2$ |
| Center mass relative to part | 0.0, 0.0, -0.14 | m |
| Lateral width | 2.0 | m |
| Sideframe height | 0.2 | m |
| Sideframe width | 0.15 | m |
| Sideframe vertical location | 0.15 | m |
| Bolster width | 0.2 | m |
| Bolster z offset | 0.5 | m |
| Wheelset | | |
| Mass m | 1503.0 | kg |
| Inertia moment Ixx | 810.0 | $kgm^2$ |
| Inertia moment Iyy | 810.0 | $kgm^2$ |
| Inertia moment Izz | 112.0 | $kgm^2$ |
| Wheelbase | 2.56 | m |
| Tape Circle Distance | 1.5 | m |
| Radius | 0.46 | m |
| Axle length | 2.0 | m |
| | | |
| Axle box | | |
| Mass m | 155.0 | kg |
| Inertia moment Ixx | 2.1 | $kgm^2$ |
| Inertia moment Iyy | 5.6 | $kgm^2$ |
| Inertia moment Izz | 5.6 | $kgm^2$ |

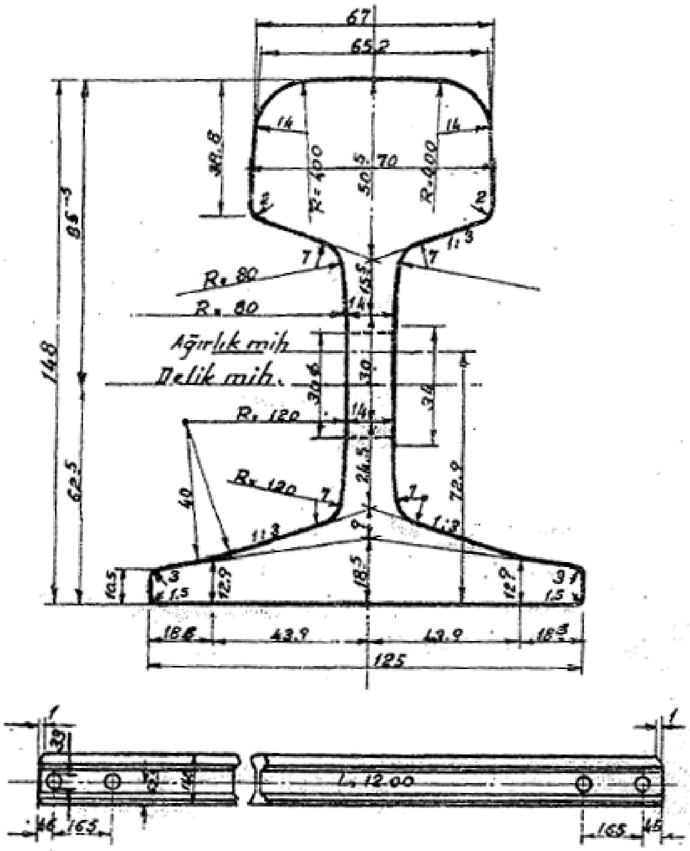
Stiffness and damping properties are not included in the table as they are mostly non linear and cannot be presented in simple table.




| Rail section | Weight G [kg/m] | Height H [mm] | Base B [mm] | Head K [mm] | Web W [mm] | Cross section [cm²] | Moment of inertia [cm4] | Section modulus [cm3] | Neutral axis e[mm] |
|---|---|---|---|---|---|---|---|---|---|
| S7 | 6,75 | 65,00 | 50,00 | 25,00 | 5,00 | 8,60 | 51,60 | 15,20 | 33,95 |
| S10 | 10,00 | 70,00 | 58,00 | 32,00 | 6,00 | 12,74 | 85,70 | 24,40 | 35,12 |
| S14 | 14,00 | 80,00 | 70,00 | 38,00 | 9,00 | 17,83 | 154,00 | 36,84 | 41,80 |
| S18 | 18,30 | 93,00 | 82,00 | 43,00 | 10,00 | 23,31 | 278,00 | 58,04 | 47,90 |
| S20 | 19,80 | 100,00 | 82,00 | 44,00 | 10,00 | 25,22 | 346,00 | 66,80 | 51,80 |
| S24 | 24,43 | 115,00 | 90,00 | 53,00 | 10,00 | 31,12 | 569,00 | 97,30 | 58,52 |
| S30 | 30,03 | 108,00 | 108,00 | 60,00 | 12,30 | 38,25 | 606,00 | 108,41 | 55,88 |
| S33 | 33,47 | 134,00 | 105,00 | 58,00 | 11,00 | 42,64 | 1040,00 | 155,00 | 66,33 |
| S41_r=10mm | 41,38 | 138,00 | 125,00 | 67,00 | 12,00 | 52,71 | 1384,00 | 196,00 | 69,34 |
| S41_r=14mm | 40,95 | 138,00 | 125,00 | 67,00 | 12,00 | 52,17 | 1368,00 | 191,55 | 69,80 |
| S49 | 49,43 | 149,00 | 125,00 | 67,00 | 14,00 | 62,97 | 1819,00 | 240,00 | 75,77 |
| S54 | 54,54 | 154,00 | 125,00 | 67,00 | 16,00 | 69,48 | 2073,00 | 262,00 | 79,12 |
| NP46 | 46,55 | 142,00 | 120,00 | 72,00 | 14,00 | 59,30 | 1605,00 | 223,85 | 71,70 |
| EB 50T | 50,10 | 151,00 | 140,00 | 72,00 | 15,00 | 63,82 | 1988,00 | 247,88 | 80,20 |
| EB 63 | 62,95 | 151,00 | 140,00 | 73,70 | 30,00 | 80,19 | 2171,00 | 263,00 | 82,55 |
| UIC54 | 54,43 | 159,00 | 140,00 | 70,00 | 16,00 | 69,34 | 2346,00 | 279,00 | 84,03 |
| UIC60 | 60,34 | 172,00 | 150,00 | 72,00 | 16,50 | 76,87 | 3055,00 | 335,35 | 91,10 |
| UIC54A | 65,39 | 159,00 | 140,00 | 70,00 | 28,00 | 83,22 | 2512,00 | 291,00 | 86,33 |
| UIC60A | 61,11 | 142,00 | 150,00 | 72,00 | 28,00 | 77,85 | 1866,00 | 244,00 | 76,57 |

Figure A.1.a. Applied rail profile S49.

| TCDD | MALZEME SERİLERİ | SERİ | ANA GRUP | TÂLİ GRUP |
|---|---|---|---|---|
| RAY (49,05 Kg/m. Demir/travers için) BETON | | 15 | 01 | 001 |




| Sıra | Birim | Malzemenin Cins ve Ölçüleri | | | Resim No |
|---|---|---|---|---|---|
| 001 | Kg. | 11,88 m | Normal Ray boyu: 18,00 m. | | T A-35/39 A |
| 002 | " | 11,92 m | Kısa raylar: 17,82 | | |
| 003 | " | 11,96 m | 17,88 | | |
| 004 | " | 12,00 m | 17,94 | | |
| | | 18,00 | | | |
| | | Metre tul ağırlığı | 49,05 | Kg | |
| | | Kesit alanı | 6248 | mm² | |
| | | Atalet anı 1/X | 1797 | Cm4 | |
| | | " " I/Y | 319 | Cm4 | |
| | | Mukavemet anı W/X | 246 ~~239~~ | Cm³ | |
| | | " " W/Y | 51 | Cm3 | |

Figure A.1.b. The Turkish S49 rail profile.

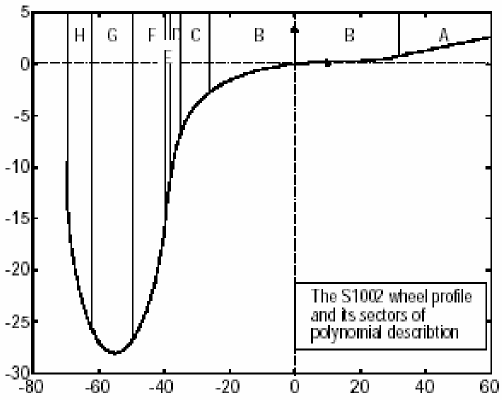



Figure 1: Wheel Profile S1002

# 1 Description of the S1002 Wheel Profile

The wheel profile function $r_1(\xi)$ discussed here is based the standard profile S1002, which is defined section wise by polynomials up to degree 7. The profile and its sections are shown in Fig. 1.

The polynomials are defined by

$$
\begin{array}{llcl}
\text{Section A:} & F(s) & = & a_A - b_A s \\
\text{Section B:} & F(s) & = & a_B - b_B s + c_B s^2 - d_B s^3 + e_B s^4 - f_B s^5 + g_B s^6 - h_B s^7 + i_B s^8 \\
\text{Section C:} & F(s) & = & -a_C - b_C s - c_C s^2 - d_C s^3 - e_C s^4 - f_C s^5 - g_C s^6 - h_C s^7 \\
\text{Section D:} & F(s) & = & a_D - \sqrt{b_D^2 - (s + c_D)^2} \\
\text{Section E:} & F(s) & = & -a_E - b_E s \\
\text{Section F:} & F(s) & = & a_F + \sqrt{b_F^2 - (s + c_F)^2} \\
\text{Section G:} & F(s) & = & a_G + \sqrt{b_G^2 - (s + c_G)^2} \\
\text{Section H:} & F(s) & = & a_H + \sqrt{b_H^2 - (s + c_H)^2}
\end{array}
$$

and

| | $A$ | $B$ | $C$ | $D$ |
|---|---|---|---|---|
| $a$ | 1.364323640 | 0.0 | $4.320221063\,10^{+3}$ | 16.446 |
| $b$ | 0.066666667 | $3.358537058\,10^{-2}$ | $1.038384026\,10^{+3}$ | 13. |
| $c$ | – | $1.565681624\,10^{-3}$ | $1.065501873\,10^{+2}$ | 26.210665 |
| $d$ | – | $2.810427944\,10^{-5}$ | $6.051367875\,10^{+0}$ | – |
| $e$ | – | $5.844240864\,10^{-8}$ | $2.054332446\,10^{-1}$ | – |
| $f$ | – | $1.562379023\,10^{-8}$ | $4.169739389\,10^{-3}$ | – |
| $g$ | – | $5.309217349\,10^{-15}$ | $4.687195829\,10^{-5}$ | – |
| $h$ | – | $5.957839843\,10^{-12}$ | $2.252755540\,10^{-7}$ | – |
| $i$ | – | $2.646656573\,10^{-13}$ | – | – |
| $\xi_{\min}$ | 32.15796 | $-26$ | $-35$ | $-38.426669071$ |
| $\xi_{\max}$ | 60 | 32.15796 | $-26$ | $-35$ |

Figure A.2.a. Wheel profile S1002 applied in the ADAMS simulations.

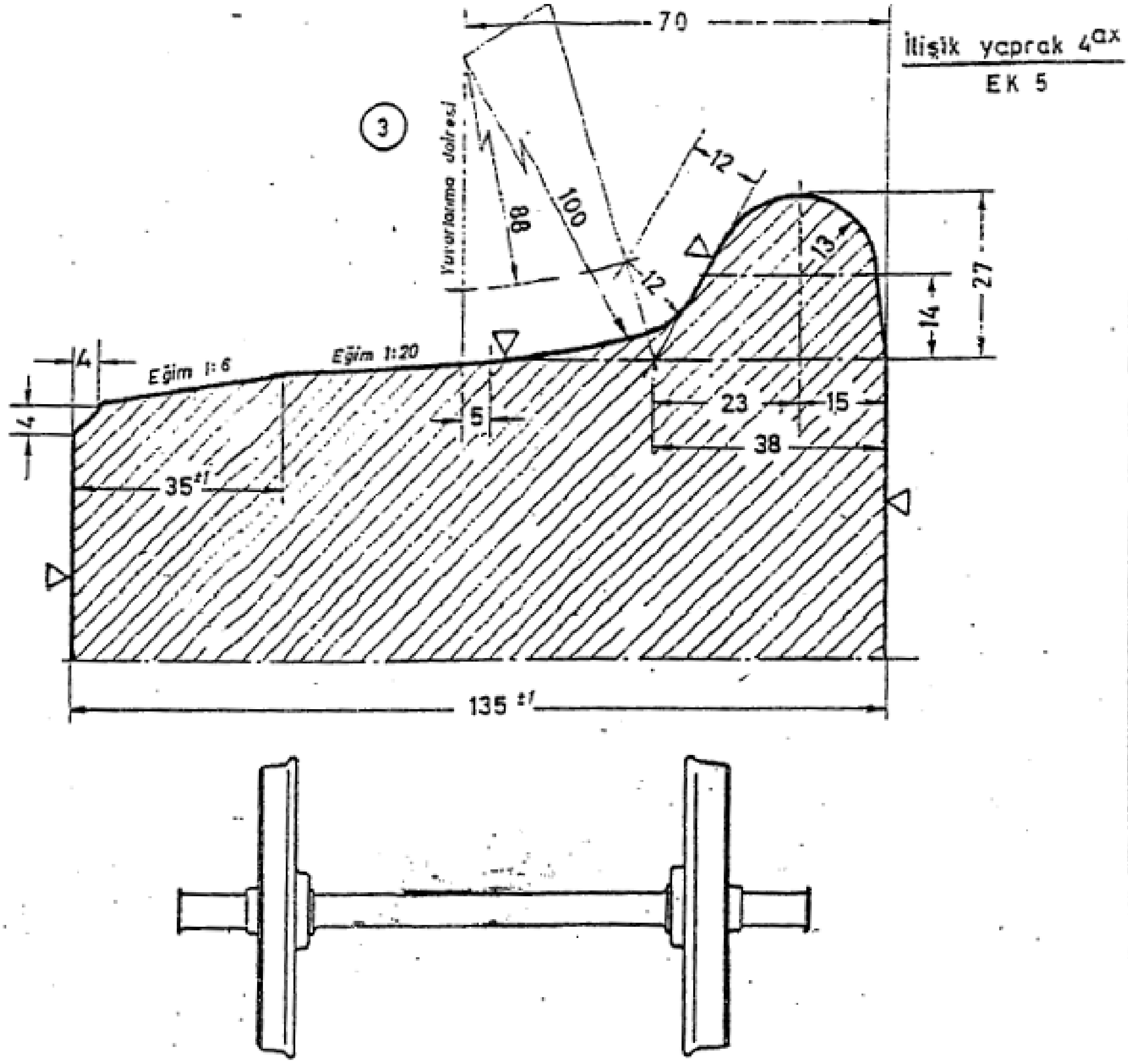
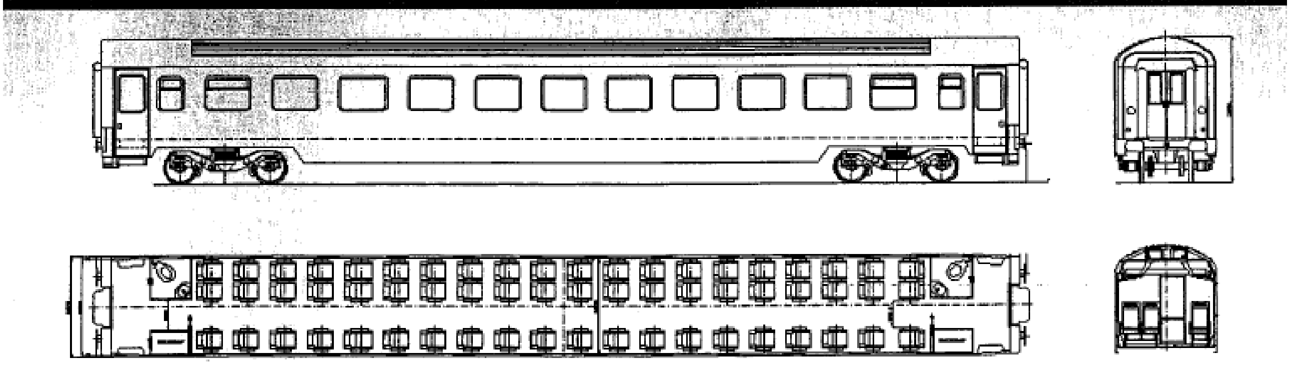



Figure A.2.b. Turkish wheel profile.

# TVS 2000 SERİSİ VAGONLAR



## TVS 2000 PULMAN VAGON

TÜVASAŞ tarafından tasarlanan TVS-2000 PULMAN VAGON; serisinin ilk örneğidir. Seyir emniyeti, yolcu konforu,iç dekorasyon ve renk seçiminde estetiğe önem veren özgün bir anlayışın ürünüdür.

Hafif yapıda kaynaklı çelik konstrüksiyon olarak üretilmiştir. Etkin bir korozyon, ısı ve ses izolasyonu yapılmıştır. İç dekorasyonda modüler tasarım anlayışı ile üretilmiş SMC kaplama panelleri kullanılmıştır. Koltuklar uzun yolculuklarda yolcu konforunu sağlayacak şekilde ergonomik olarak tasarlanmıştır.

Yolculuk sırasında bilgi vermek ve müzik dinletmek amacıyla müzik yayın sistemi mevcuttur. Maksimum yolcu konforunu sağlamak amacıyla, vagon tam otomatik iklimlendirme sistemi ile donatılmıştır.

160 km/h hıza uygun imal edilmiş çift kademeli düşey süspansiyon sistemine sahip Y 32 bojileri kullanılmıştır.

*TVS-2000 Pullman Coach designed by TÜVASAŞ is the first member of its series. It is produced with an original approach at which running safety, passenger comfort, internal decoration and hormony in colouring among the objects were the starting points.*

*The car body is manufactured in a lightweight welded steel construction. Maximum insulation is made against to corrosion, heat and noise. Hot pressed reinforced fibreglass panelling is used for internal decoration in a modular design. In order to provide maximum passenger comfort even on long trips, seats ergonomically designed.*

*Loudspeaker system informs the passengers during journey and makes possible to listen music. In order to ensure maximum passenger comfort, the coach is equipped with full-automatic air conditioning system.*

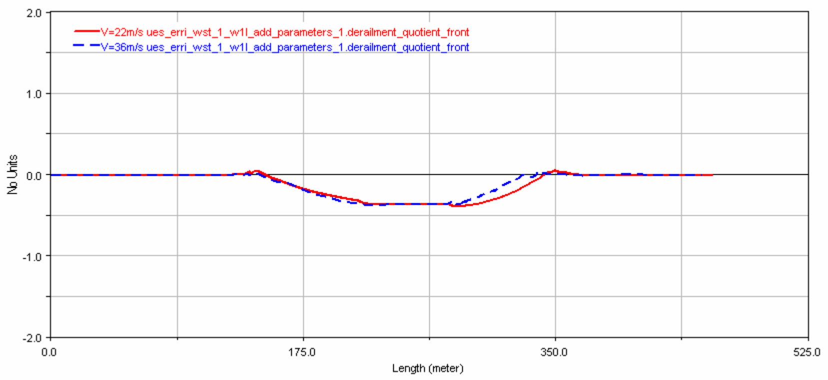
*Y-32 bogies designed for 160 kmph speed with double stage vertical suspension system are used.*

### TEKNİK KARAKTERİSTİKLER
### TECHNICAL CHARACTERISTICS

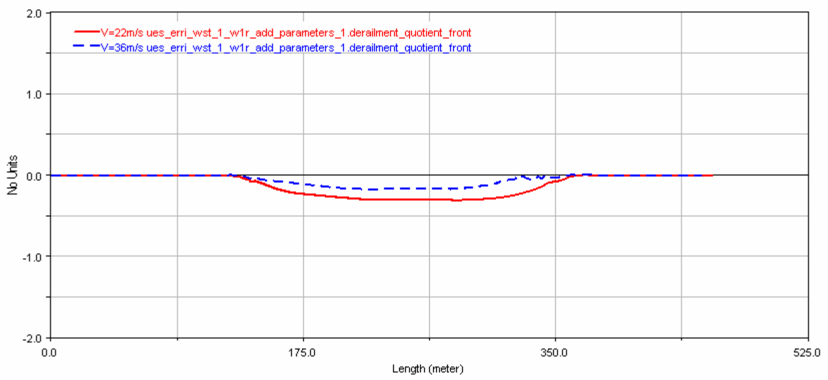
| | | |
|---|---|---|
| Ray Açıklığı | Track gauge | 1 435 mm |
| Tampondan Tampona Vagon Boyu | Total lenght over buffers | 26 400 mm |
| Boji Göbek Eksenleri Arası Mesafe | Center pin distance | 19 000 mm |
| Vagon Genişliği | Carbody width | 2 825 mm |
| Vagon Yüksekliği | Body height from top of rail | 4 050 mm |
| Döşeme Yüksekliği | Floor heigth from top of rail | 1 250 mm |
| Hareketli Basamak Yüksekliği | Folding step height | 565 mm |
| Araç Ağırlığı ( boş / dolu ) | Vehicle weight (empty/full) | 42 / 47 tons |
| Dış kapılar | Side entrance doors | Swing sliding pneumatic doors |
| Alın Duvar Geçit Kapıları | End doors | Sliding pneumatic doors |
| Boji | Bogie | Y - 32 |
| Tekerlek Çapı ( Yeni / Aşınmış ) | Wheel diameter (new/worn) | 920 / 870 mm |
| Minimum Kurp Yarı Çapı | Minimum curve radius | 150 m |
| Servis Freni | Service Brake | Pneumatic disc brake |
| Maksimum Hız | Maximum speed | 160 kmph |
| Gabari | Kinematic gauge | UIC 505-1 |
| Koltuk Düzeni | Seating arrangement | 2+1 |
| Oturma Yeri Sayısı | Seating capacity | 60 |
| Aydınlatma Düzeni | Illmunation system | Fluorescent (indirect) |
| İklimlendirme Sistemi | Air conditioning system | Heating : 40 kW, Cooling : 35 kW, Fresh air : 1200 $m^3/h$ |

Figure A.3. Turkish Coach with Y32 bogies.

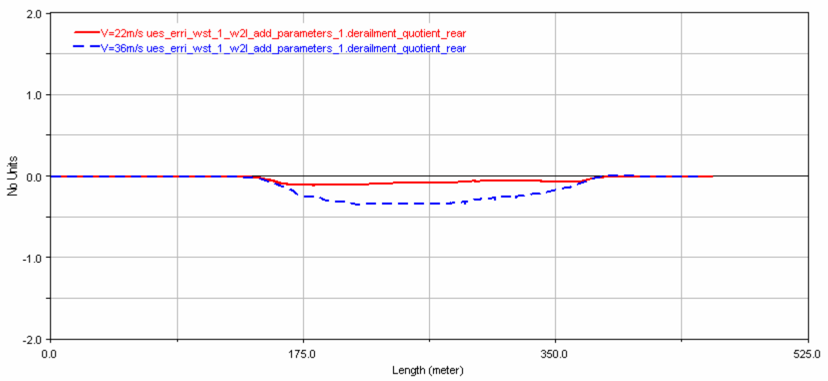
## Simulation results. Railway track without irregularities



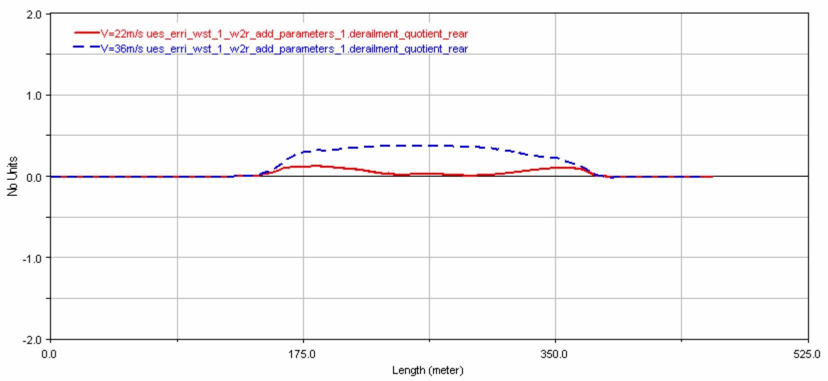

a) 1st left wheel




b) 1st right wheel




c) 4th left wheel




d) 4th right wheel

Figure A.4. Derailment coefficients for speed V=22m/s and 36m/s (80km/h and 130 km/h). Railway track is without irregularities.

## Track irregularities

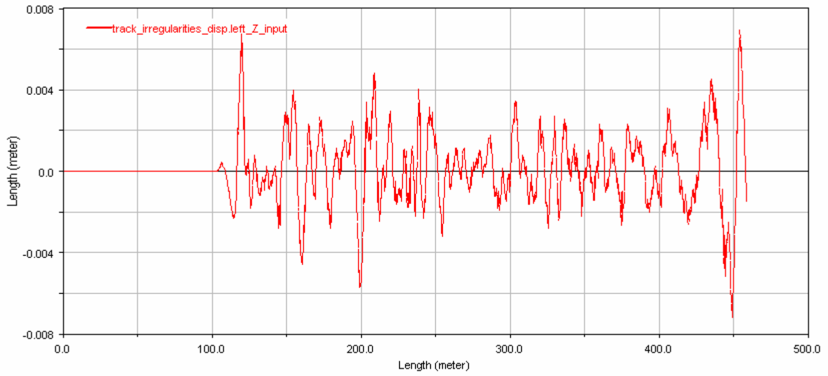



Figure A.5. Left rail vertical track irregularities. $\sigma_{vert}$ = 2.0

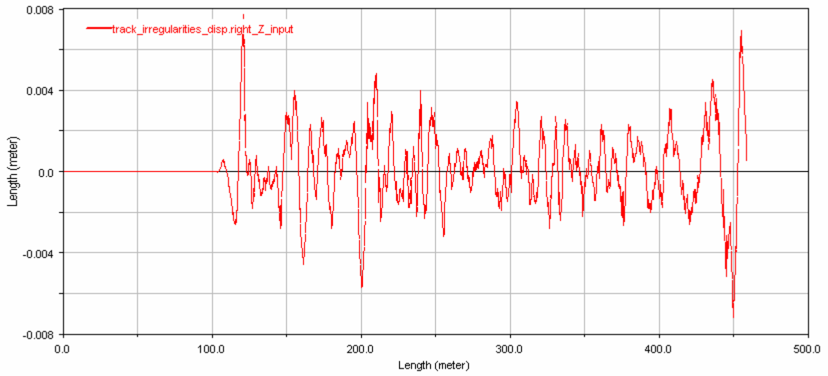



Figure A.6. Right rail vertical track irregularities. $\sigma_{vert}$ = 2.0

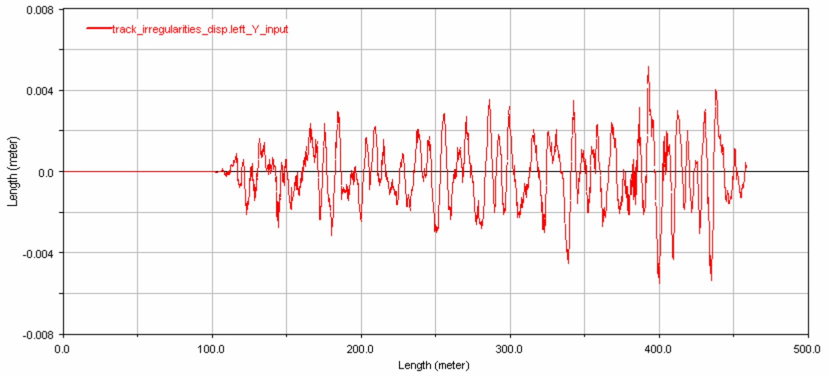



Figure A.7. Left rail lateral track irregularities. $\sigma_{lat}$ = 1.5

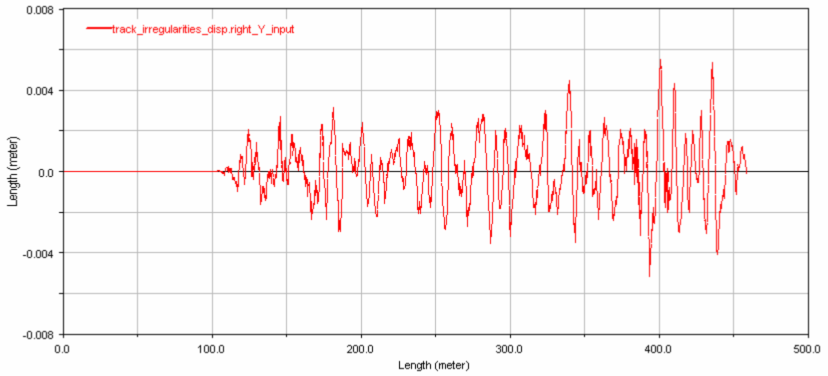



Figure A.8. Right rail lateral track irregularities. $\sigma_{lat}$ = 1.5

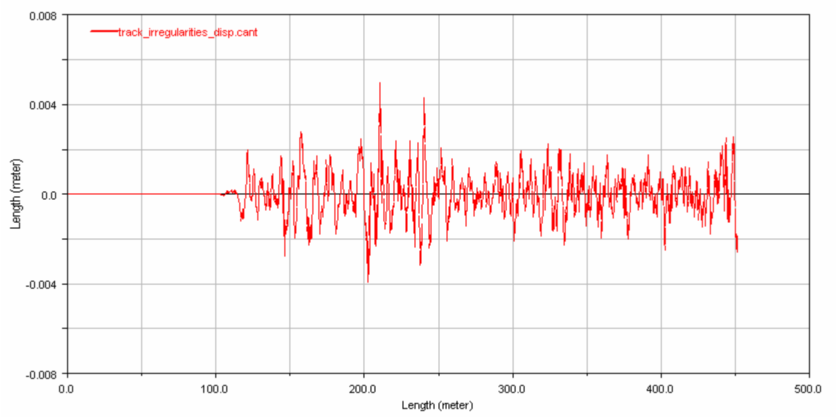
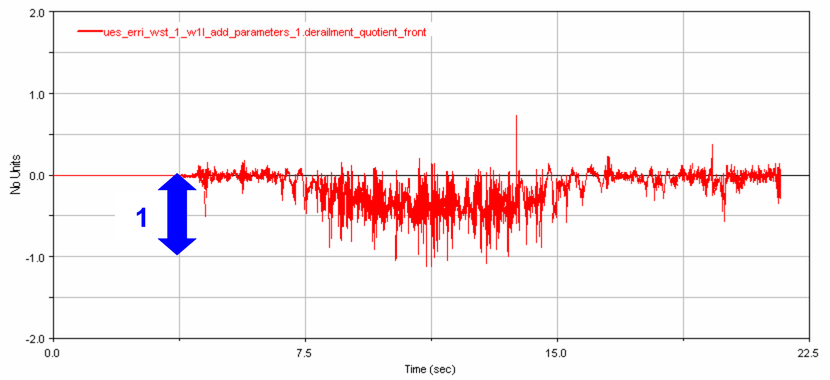



Figure A.9. Cant track irregularities. $\sigma_{cant}$ = 1.2

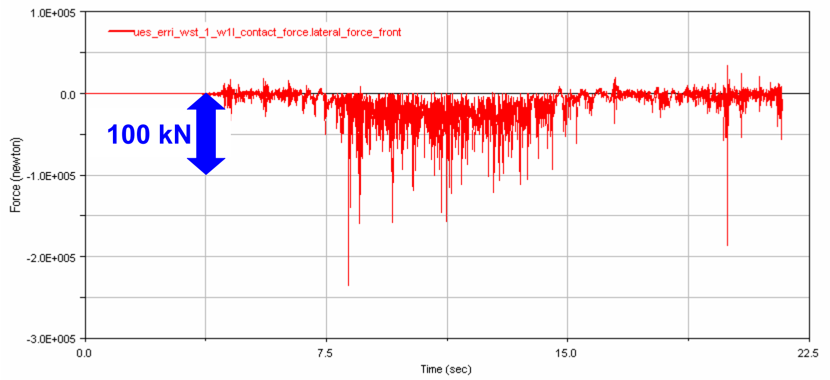
# APPENDIX B.

In this appendix results of dynamic simulations are presented. On the horizontal axis the simulation time is presented. For speed of 22 m/s the scale is 7.5 seconds and for speed of 36 m/s the scale is 5 seconds. For plots of the derailment coefficient (figure (a)) the vertical scale is 1 and dimensionless. The lateral contact force (figure (b)) is measured in Newton (N) and the scale is 100kN. The vertical contact force (figure (c)) is measured in Newton (N) and the scale is 250kN. The vertical wheel displacement (figure (d)) is measured in meters (m) and the scale is 0.003m (3 mm). The origin of the wheel coordinate system is placed in the centre of the wheelset axle and that is why wheel the displacement starts from 0.46m.

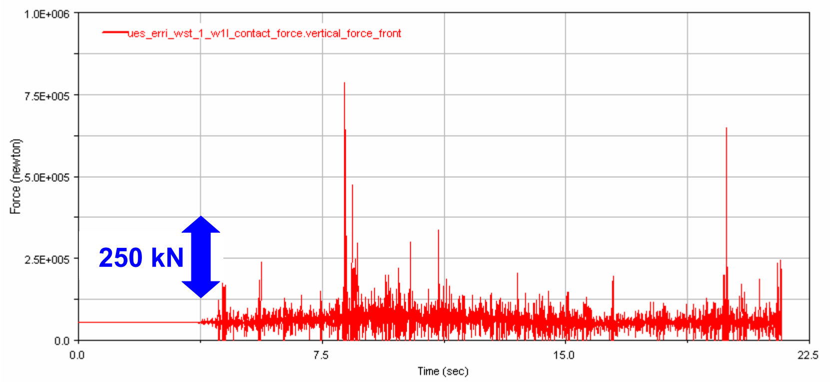
## Simulation results. Railway track with irregularities



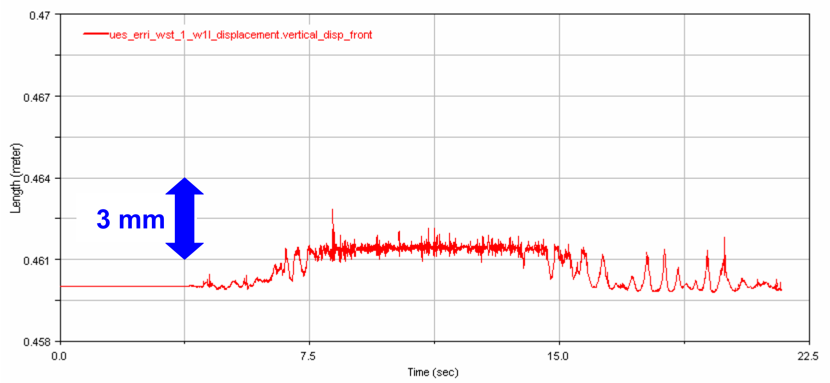

a) Derailment coefficient




b) Lateral contact force

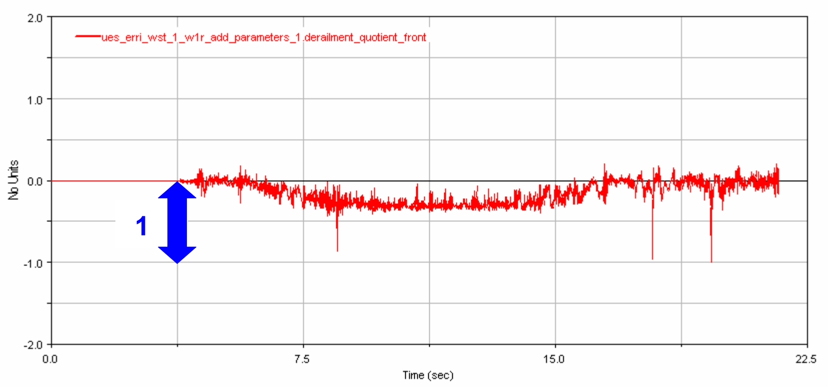



c) Vertical contact force

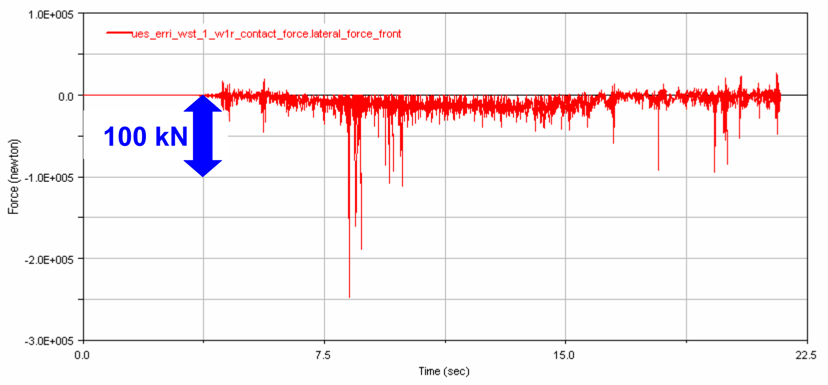



d) Vertical wheel displacement

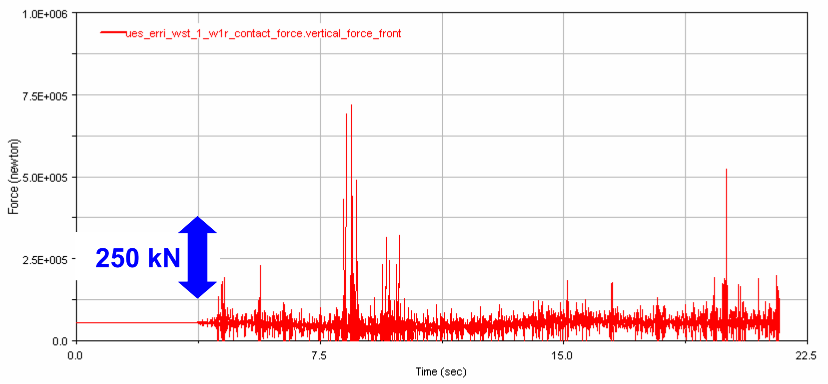
Figure B.1.Results for speed V=22m/s (80km/h). 1st wheelset, left wheel



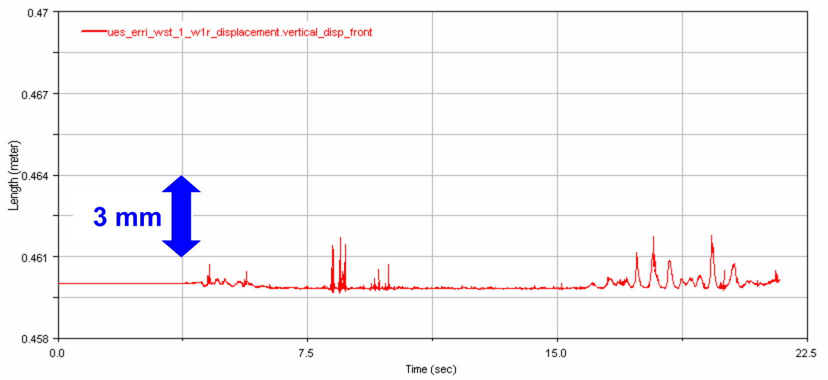

a) Derailment coefficient




b) Lateral contact force

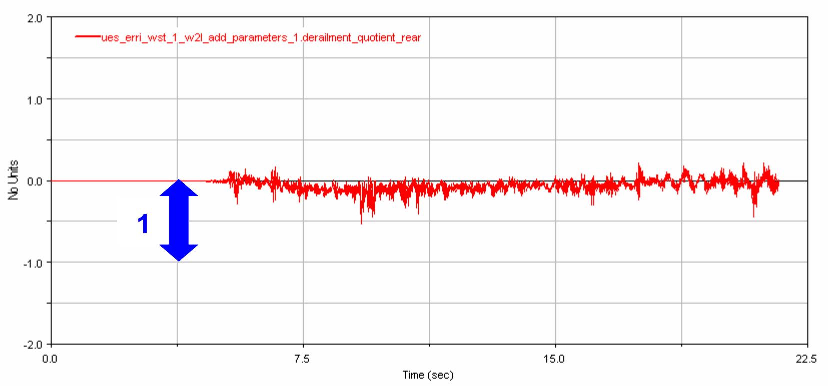



c) Vertical contact force

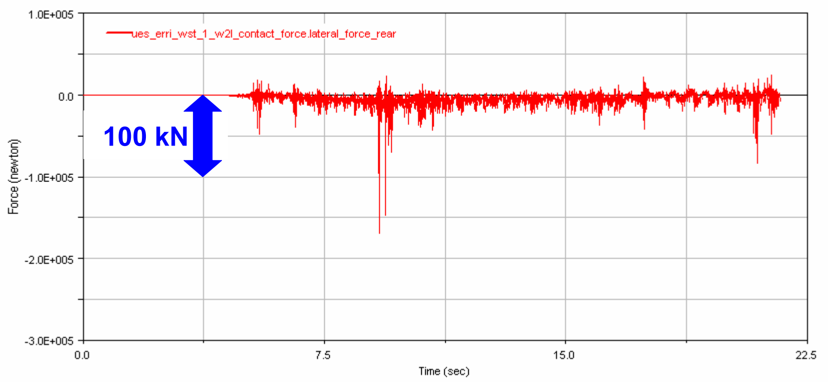



d) Vertical wheel displacement

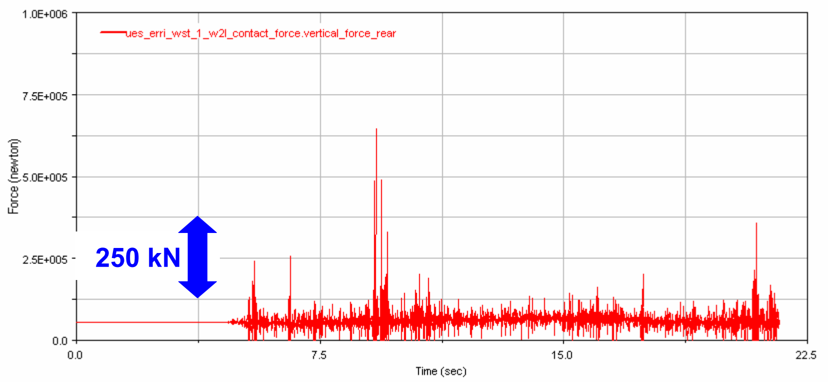
Figure B.2. Results for speed V=22m/s (80km/h). 1st wheelset, right wheel



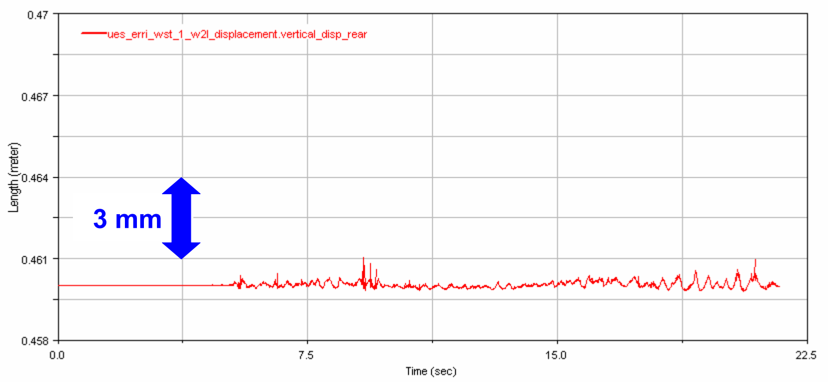

a) Derailment coefficient




b) Lateral contact force

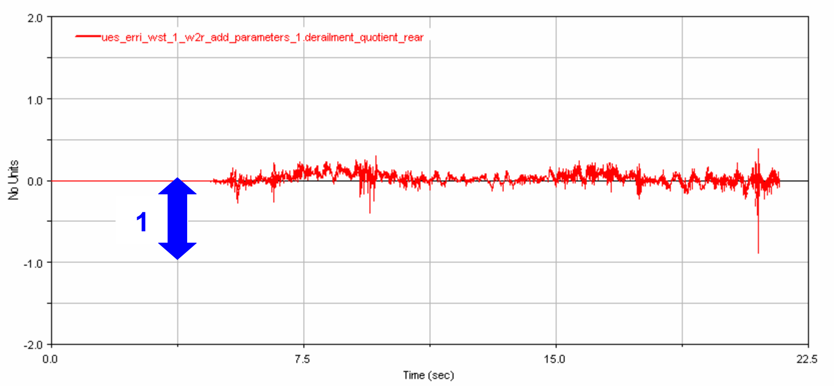



c) Vertical contact force

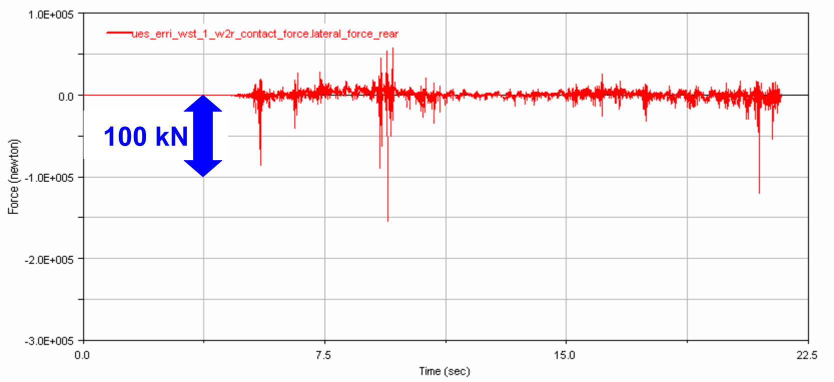



d) Vertical wheel displacement

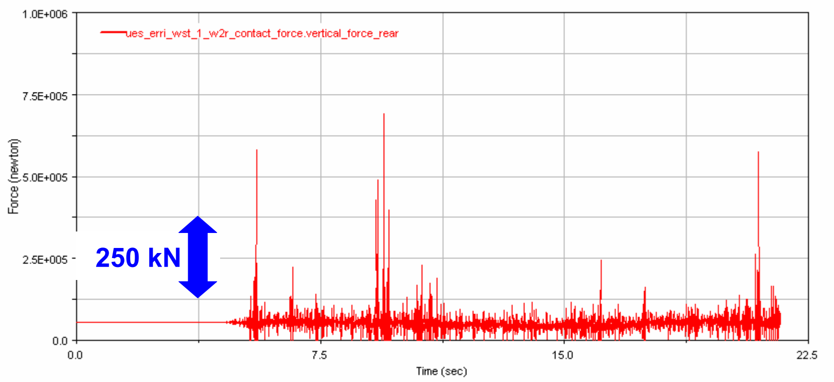
Figure B.3. Results for speed V=22m/s (80km/h). 4th wheelset, left wheel



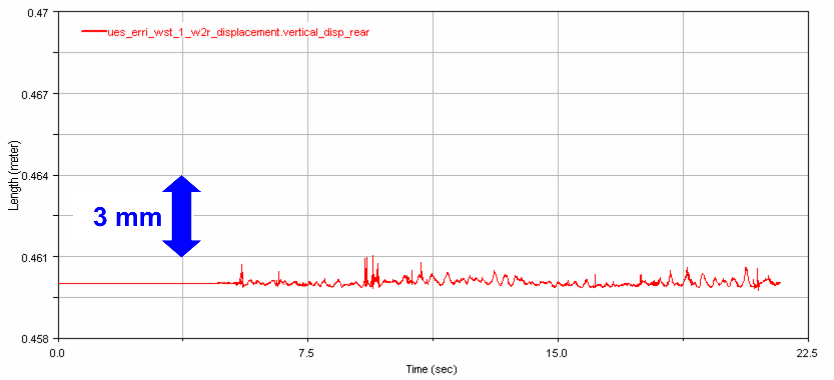

a) Derailment coefficient




b) Lateral contact force

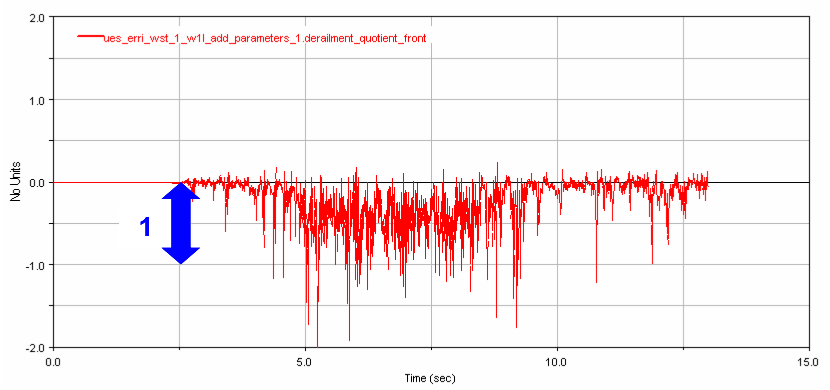



c) Vertical contact force

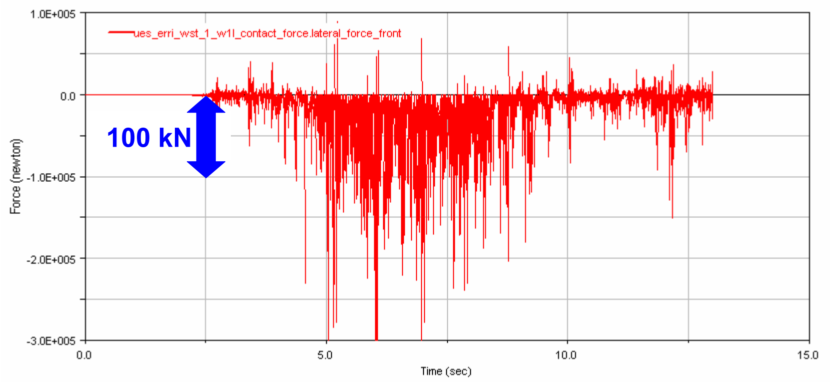



d) Vertical wheel displacement

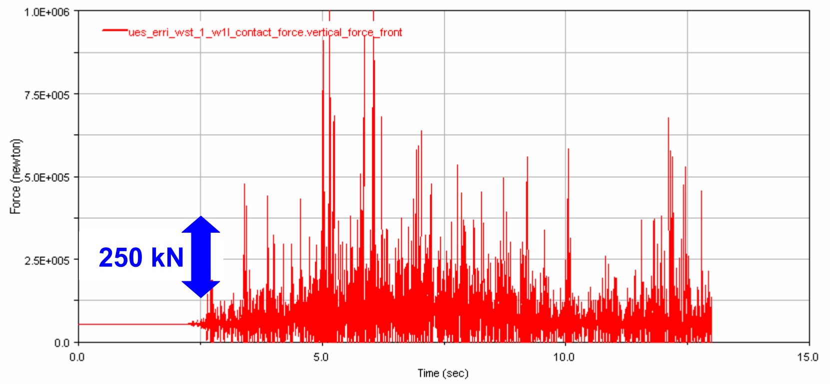
Figure B.4. Results for speed V=22m/s (80km/h). 4th wheelset, right wheel



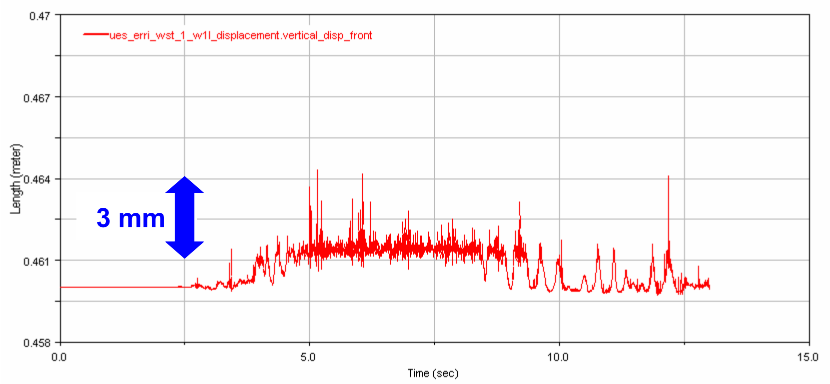

a) Derailment coefficient




b) Lateral contact force

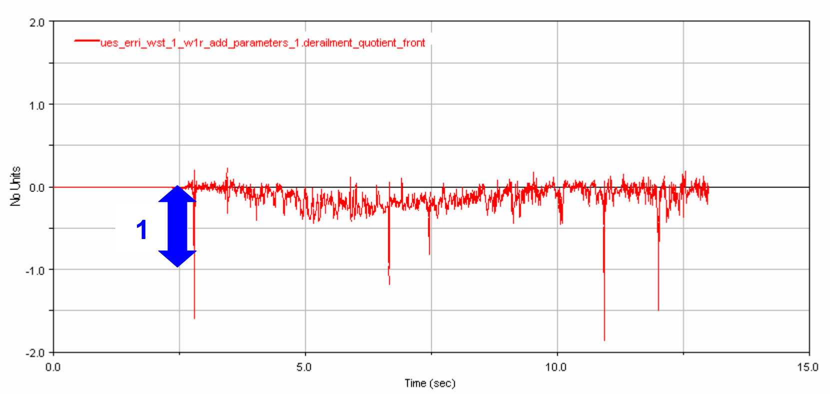



c) Vertical contact force

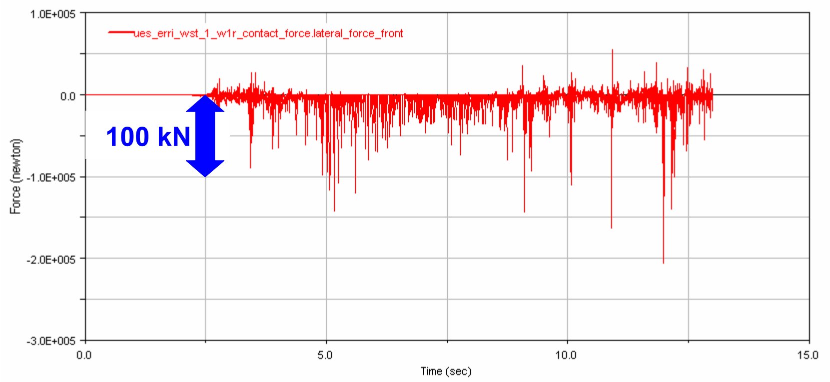



d) Vertical wheel displacement

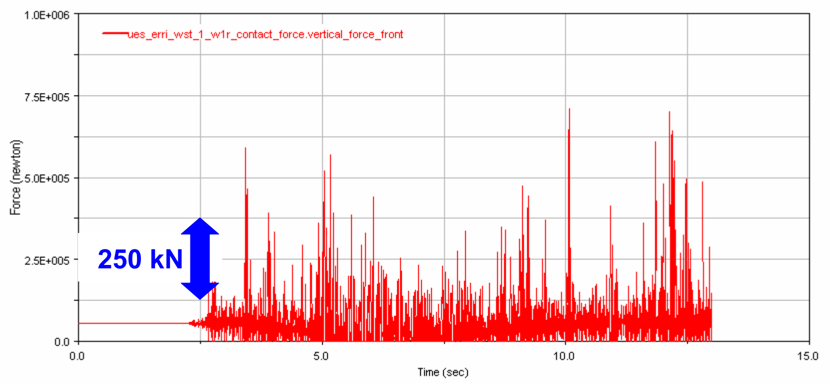
Figure B.5. Results for speed V=36m/s (130km/h). 1st wheelset, left wheel



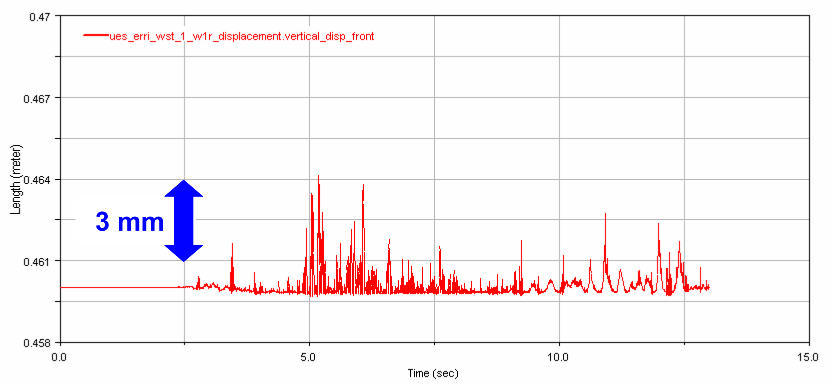

a) Derailment coefficient




b) Lateral contact force

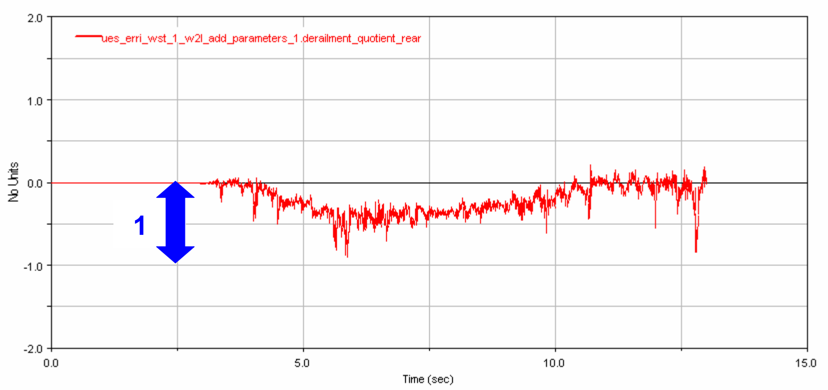



c) Vertical contact force

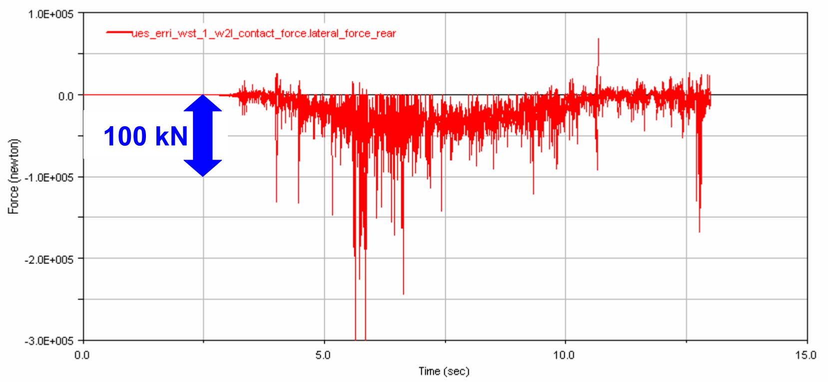



d) Vertical wheel displacement

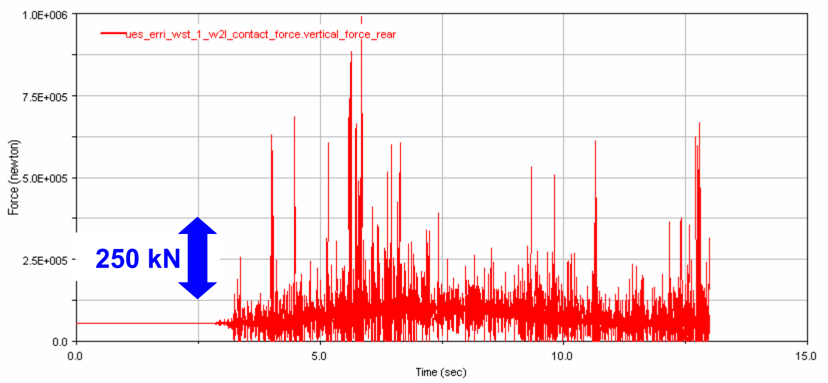
Figure B.6. Results for speed V=36m/s (130km/h). 1st wheelset, right wheel



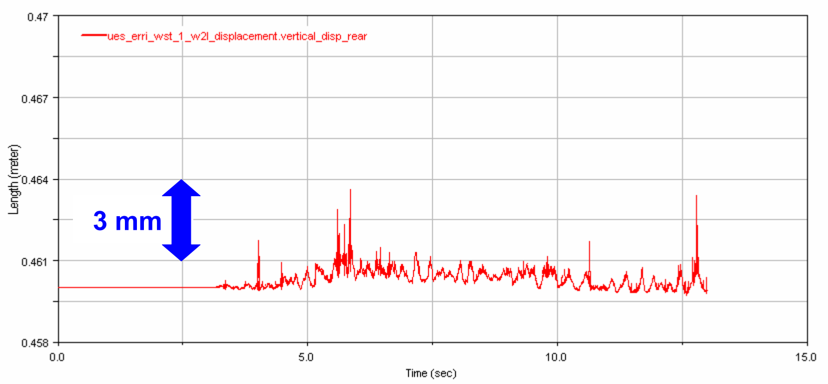

a) Derailment coefficient




b) Lateral contact force

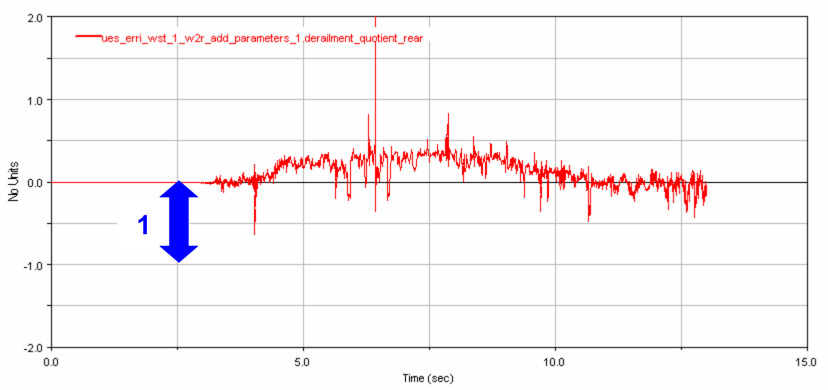



c) Vertical contact force

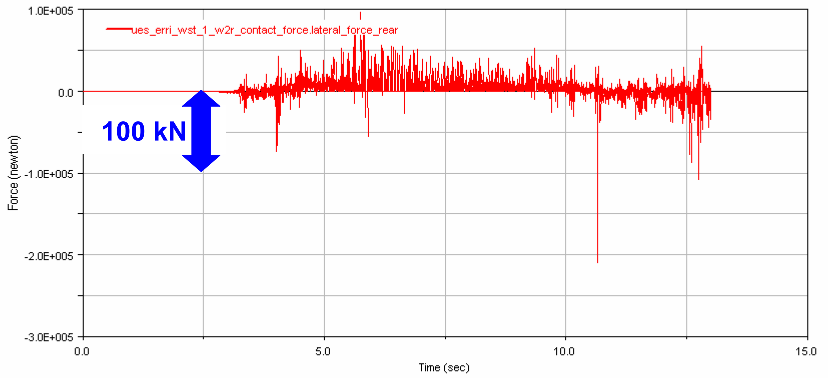



d) Vertical wheel displacement

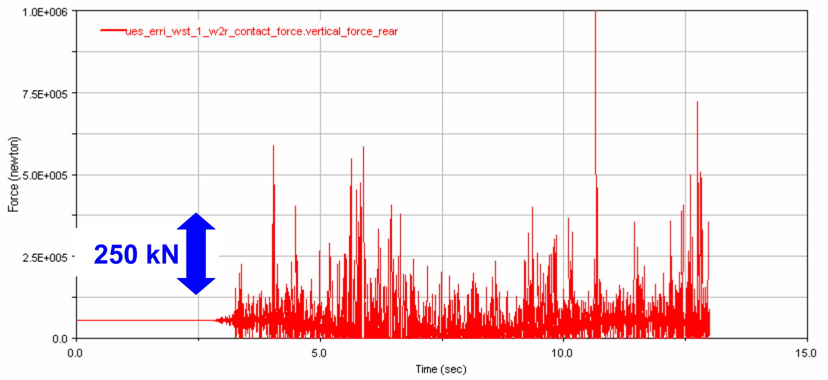
Figure B.7. Results for speed V=36m/s (130km/h). 4th wheelset, left wheel



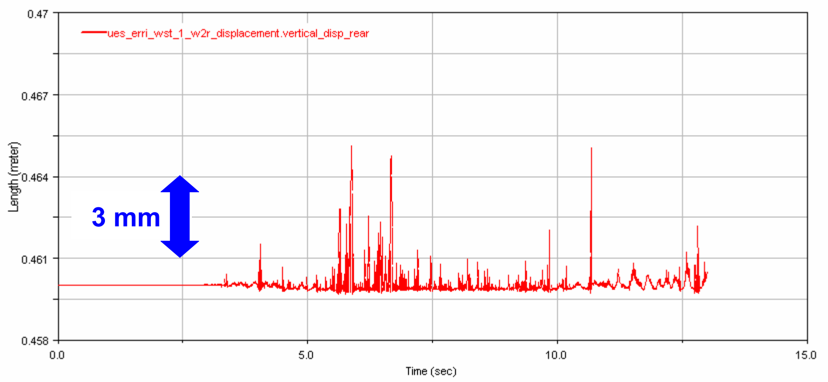

a) Derailment coefficient




b) Lateral contact force



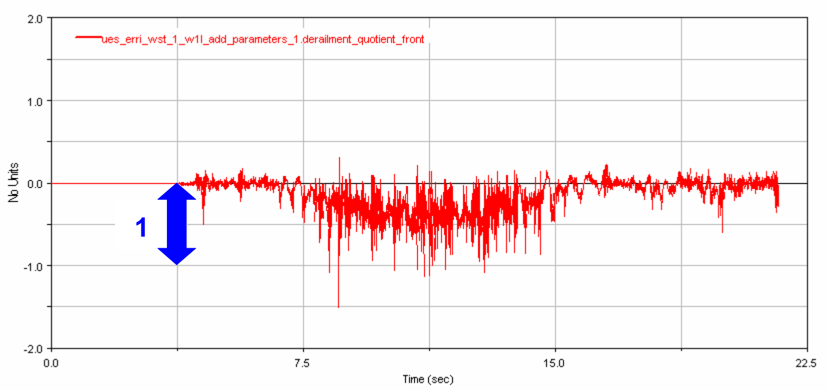

c) Vertical contact force



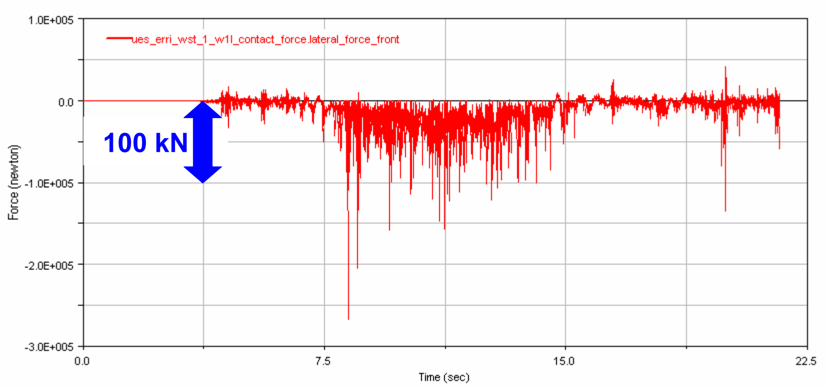

d) Vertical wheel displacement

Figure B.8. Results for speed V=36m/s (130km/h). 4th wheelset, right wheel

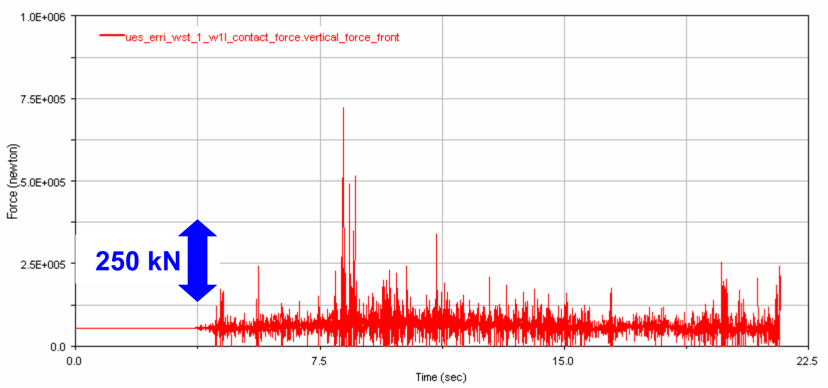
## Simulation results. Railway track with irregularities. External forces



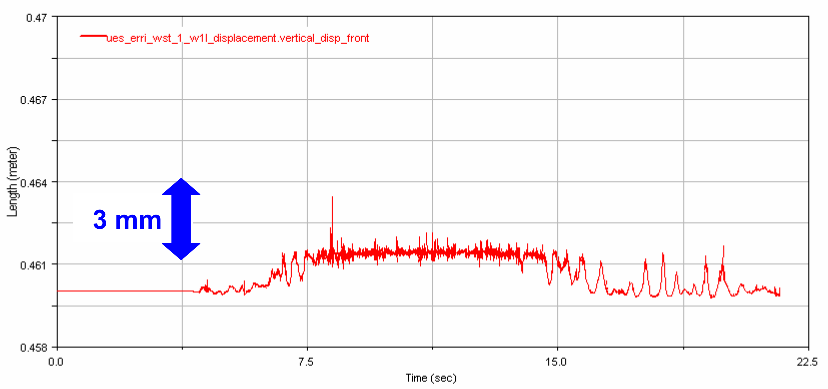

a) Derailment coefficient




b) Lateral contact force

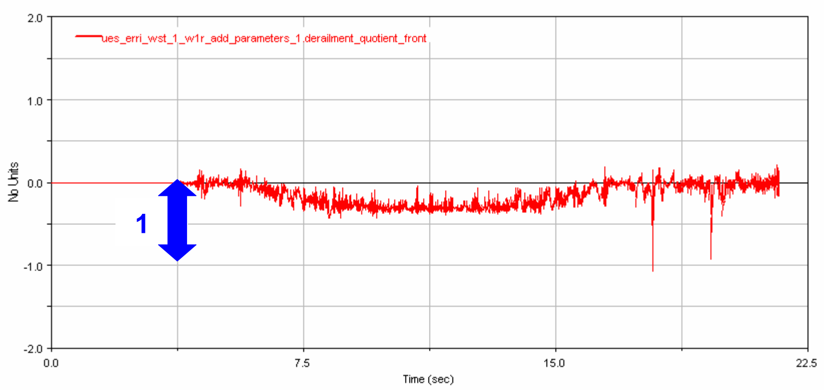



c) Vertical contact force

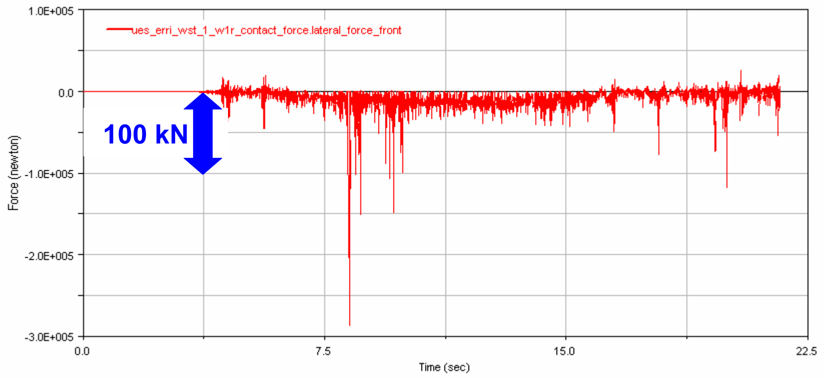



d) Vertical wheel displacement

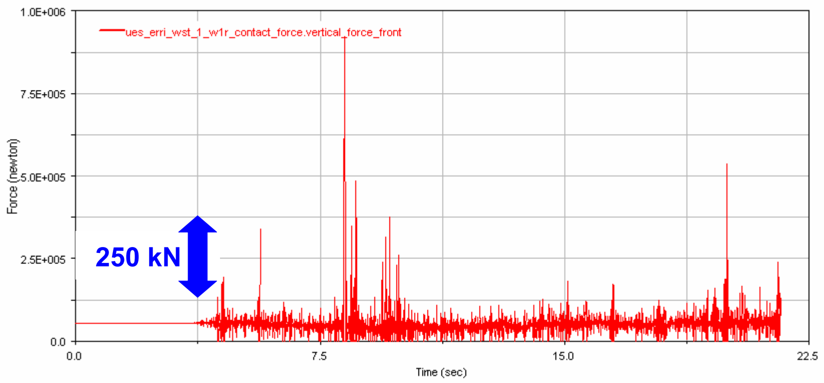
Figure B.9. Results for speed V=22m/s (80km/h). 1st wheelset, left wheel



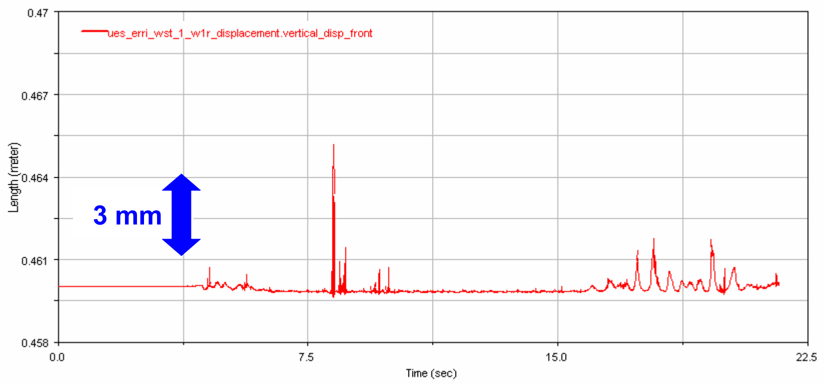

a) Derailment coefficient




b) Lateral contact force

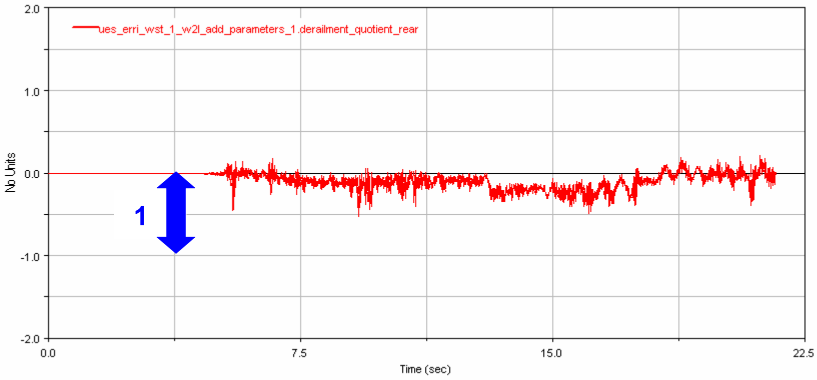



c) Vertical contact force

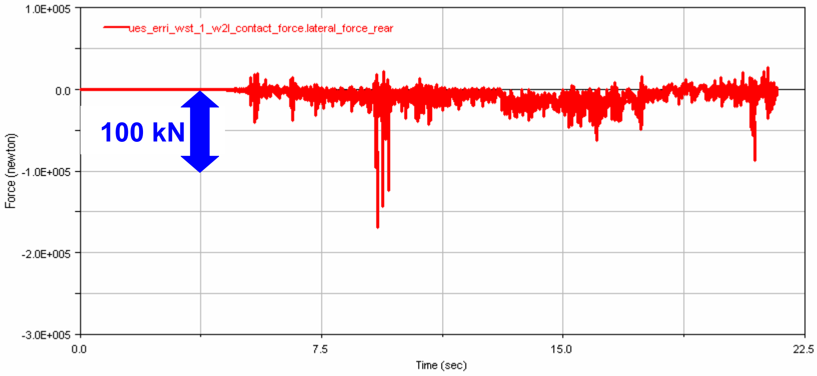



d) Vertical wheel displacement

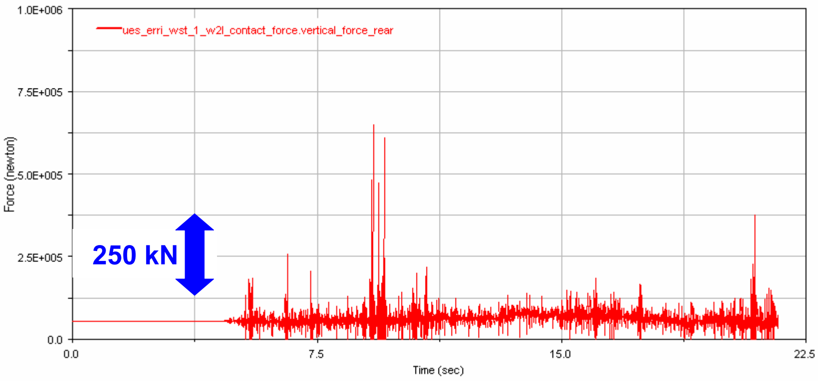
Figure B.10. Results for speed V=22m/s (80km/h). 1st wheelset, right wheel



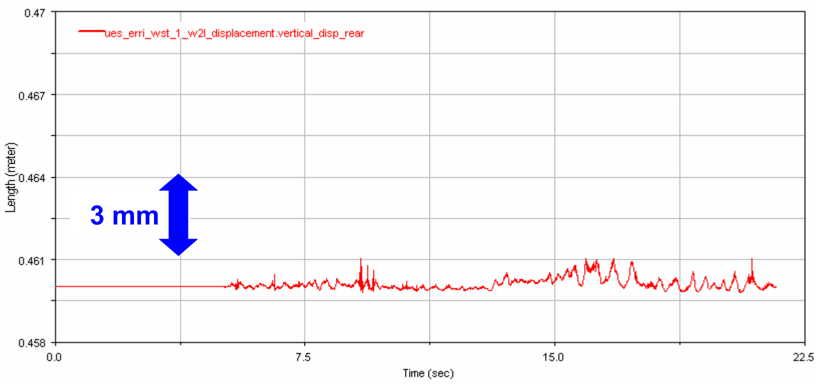

a) Derailment coefficient




b) Lateral contact force

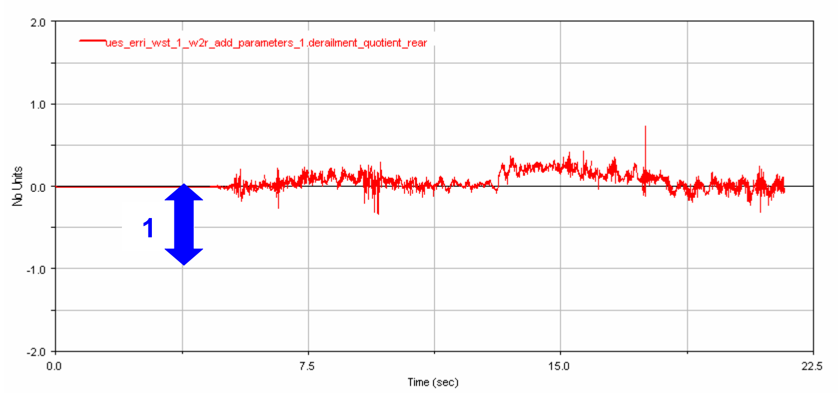



c) Vertical contact force

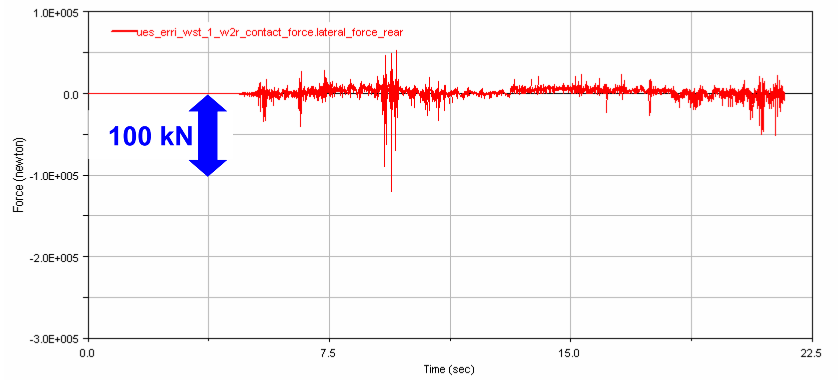



d) Vertical wheel displacement

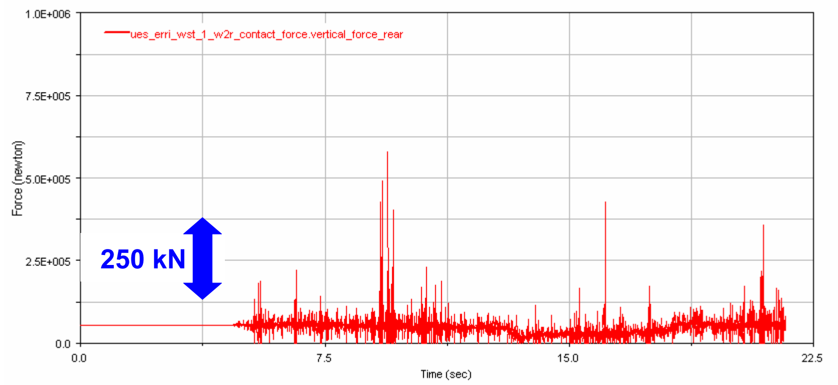
Figure B.11. Results for speed V=22m/s (80km/h). 4th wheelset, left wheel



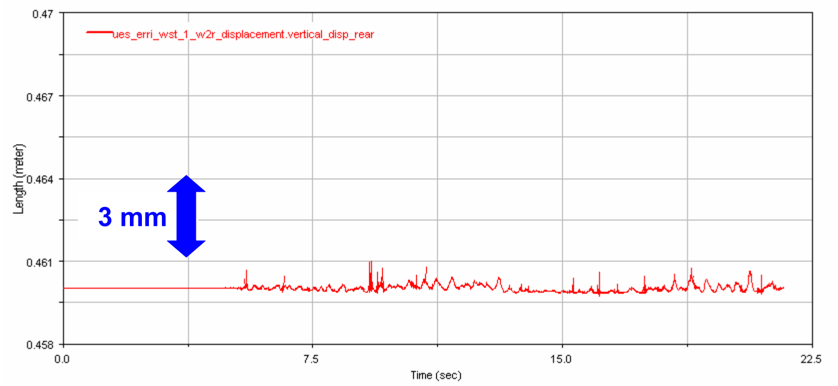

a) Derailment coefficient




b) Lateral contact force

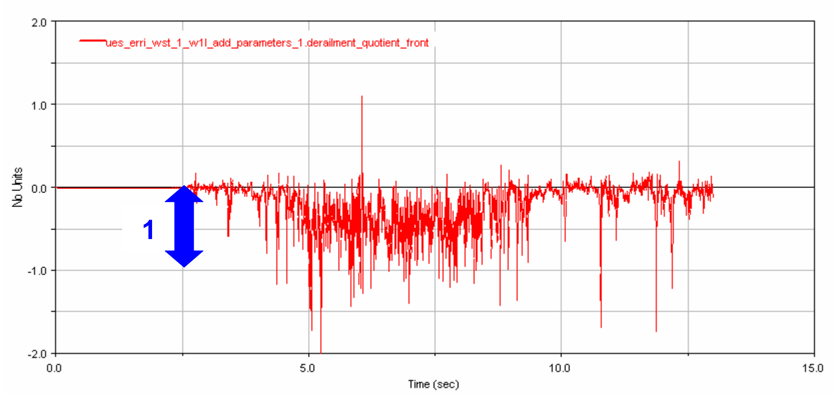



c) Vertical contact force

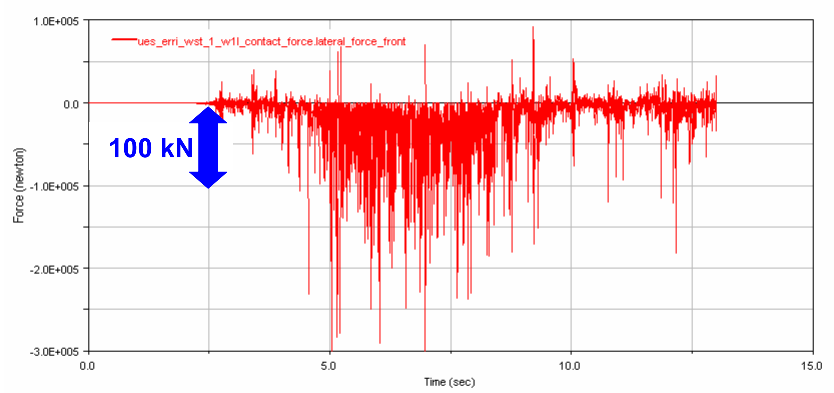



d) Vertical wheel displacement

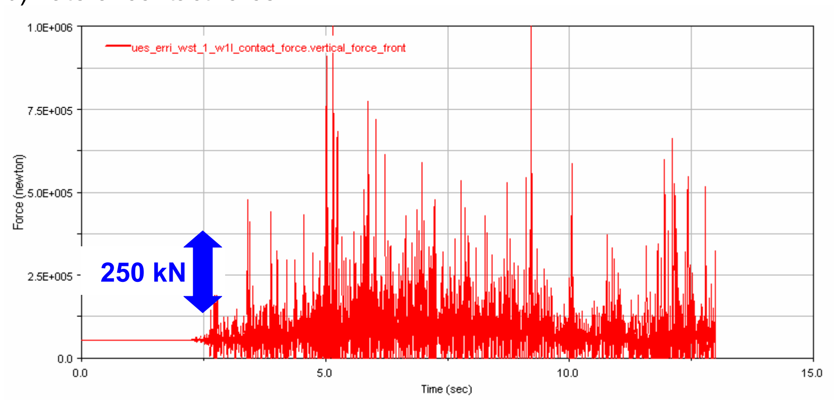
Figure B.12. Results for speed V=22m/s (80km/h). 4th wheelset, right wheel



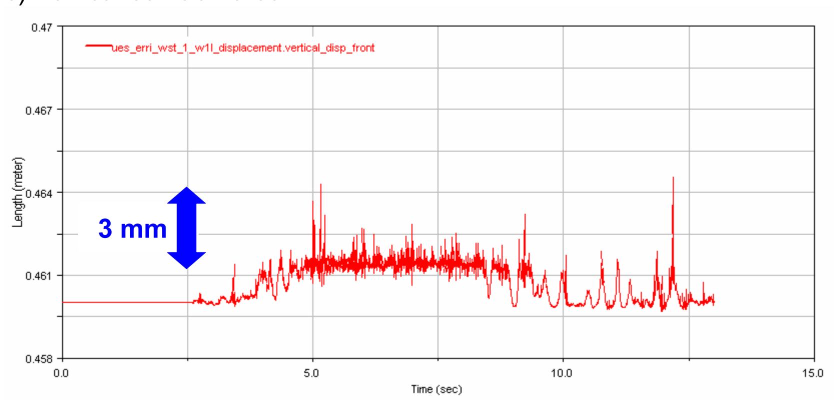

a) Derailment coefficient




b) Lateral contact force

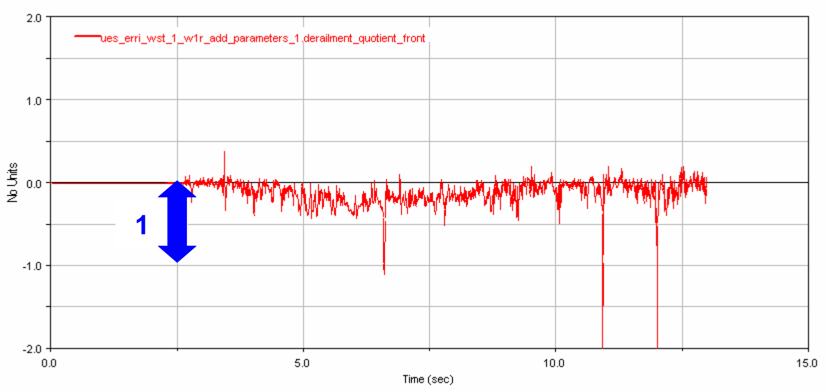



c) Vertical contact force

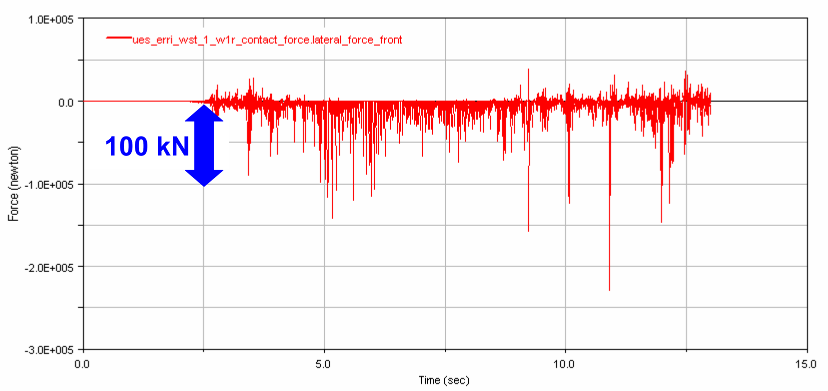



d) Vertical wheel displacement

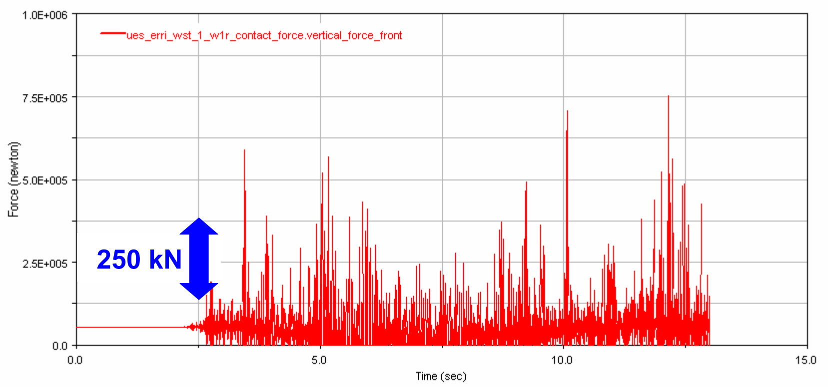
Figure B.13. Results for speed V=36m/s (130km/h). 1st wheelset, left wheel



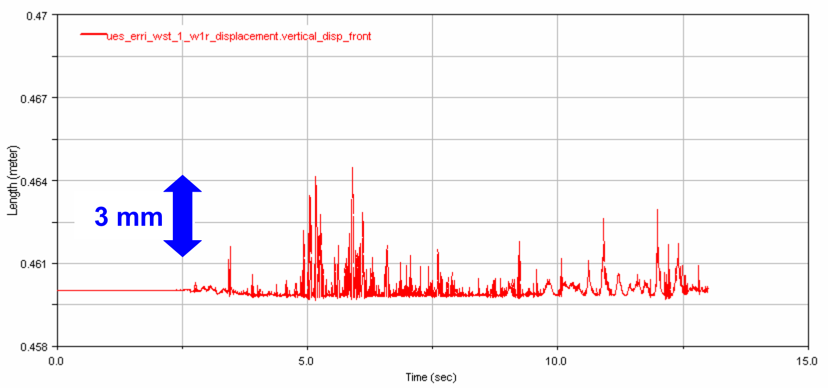

a) Derailment coefficient




b) Lateral contact force

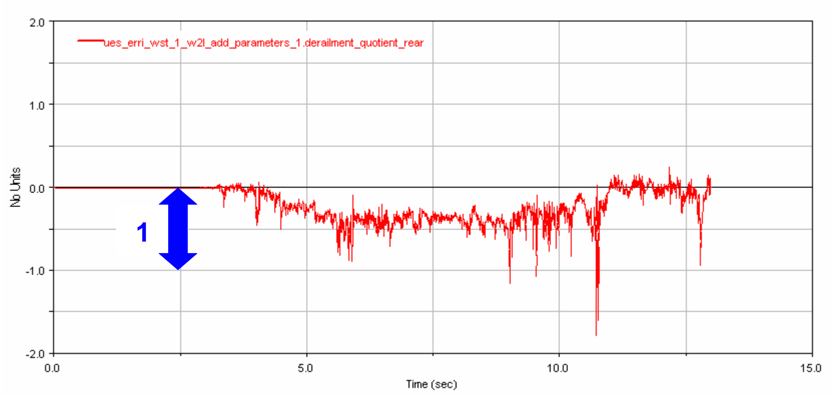



c) Vertical contact force

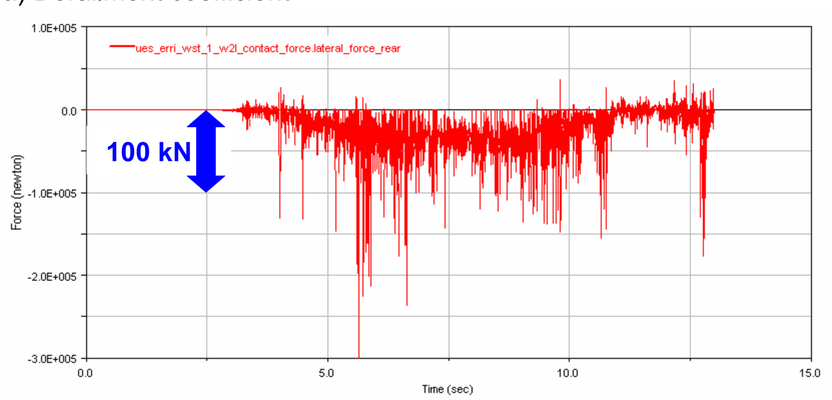



d) Vertical wheel displacement

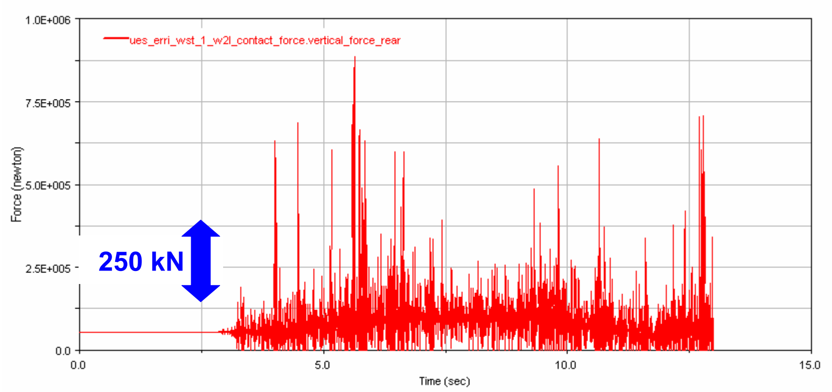
Figure B.14. Results for speed V=36m/s (130km/h). 1st wheelset, right wheel



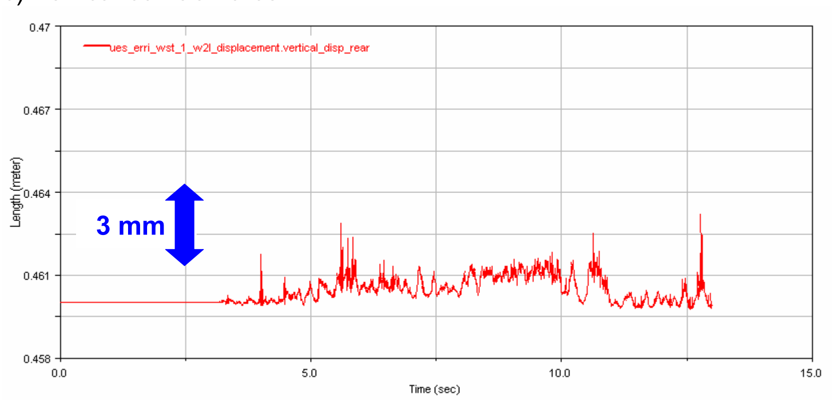

a) Derailment coefficient




b) Lateral contact force

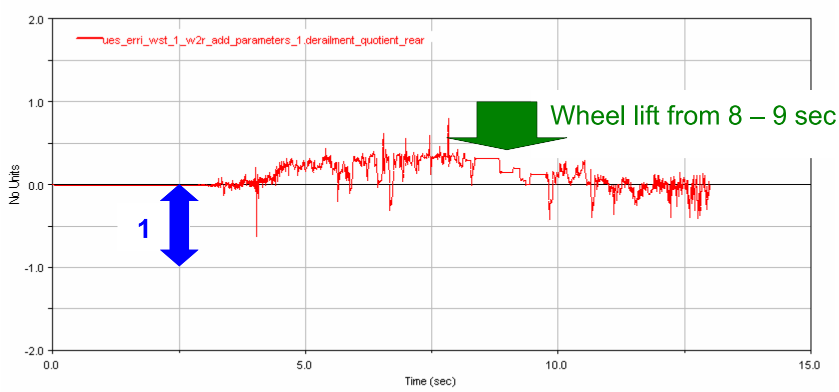



c) Vertical contact force

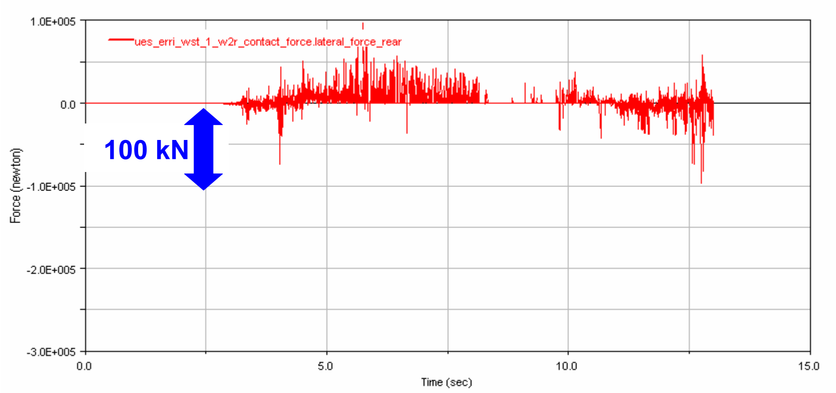



d) Vertical wheel displacement

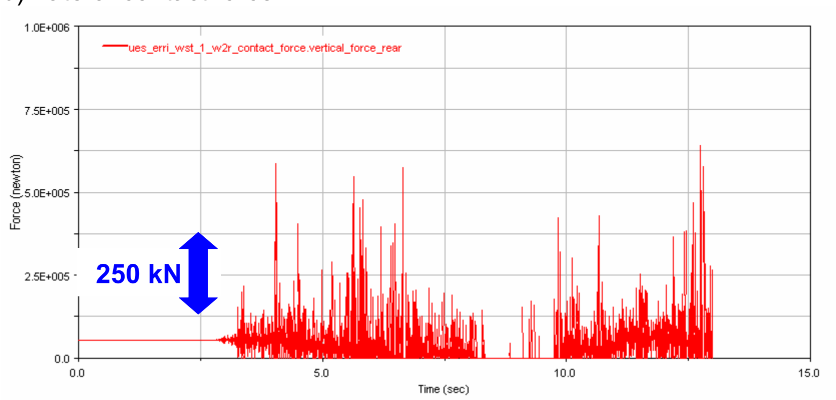
Figure B.15. Results for speed V=36m/s (130km/h). 4th wheelset, left wheel



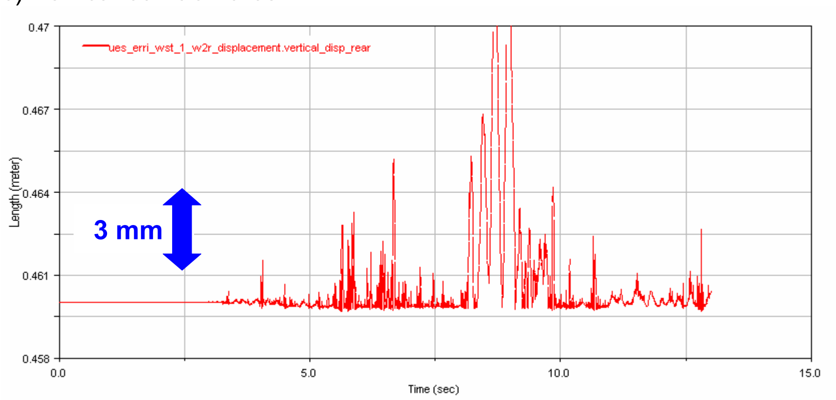

a) Derailment coefficient




b) Lateral contact force




c) Vertical contact force




d) Vertical wheel displacement

Figure B.16. Results for speed V=36m/s (130km/h). 4th wheelset, right wheel

# APPENDIX C.

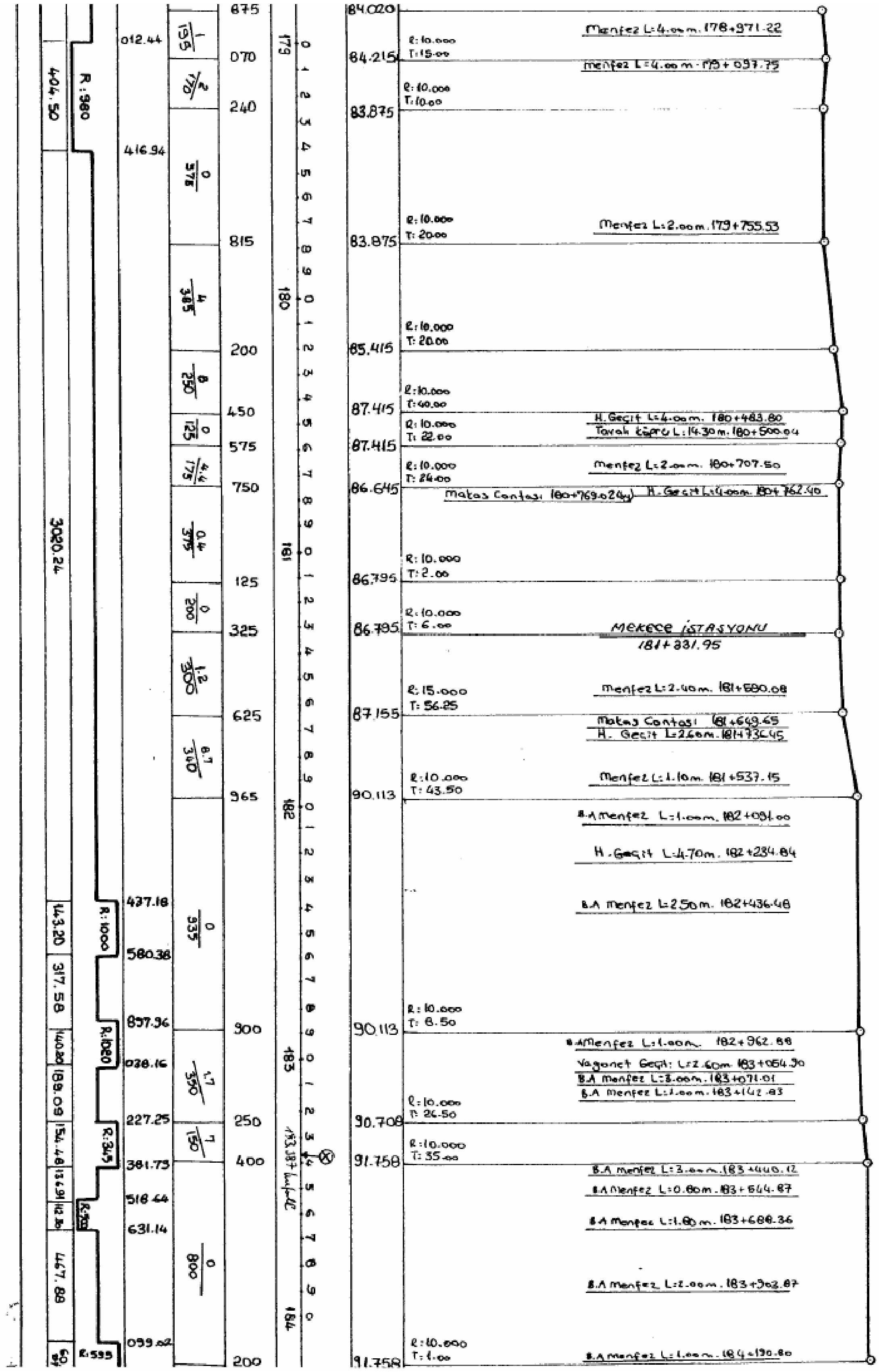



Figure C.1 Route information near the accident

ARİFİYE — ESKİŞEHİR Hattı Kurp Bilgileri

| [illegible] KLM'si | [illegible] KLM'si | Radius YARIÇAP (m) | Länge Development (m) | PARABOLLER L1 (m) | PARABOLLER L2 (m) | DEVER (mm) | YÖNÜ | DÜŞÜNCELER |
|---|---|---|---|---|---|---|---|---|
| $167 + 837^{48}$ | $167 + 945^{28}$ | 2000 | 107.50 | 80.00 | 45.00 | 30 | Sağ | |
| $167 + 945^{28}$ | $168 + 067^{78}$ | 550 | 122.50 | 45.00 | 90.00 | 65 | Sağ | |
| $169 + 062^{99}$ | $169 + 738^{75}$ | 1925 | 675.76 | 80.00 | 80.00 | 60 | Sol | |
| $171 + 115^{11}$ | $171 + 750^{81}$ | 1425 | 635.70 | 110.00 | 110.00 | 80 | Sağ | |
| $173 + 247^{50}$ | $173 + 962^{50}$ | 980 | 715.00 | 105.00 | 115.00 | 115 | Sol | |
| $175 + 427^{83}$ | $175 + 755^{13}$ | 1350 | 327.30 | 80.00 | 80.00 | 85 | Sağ | |
| $176 + 525^{51}$ | $177 + 240^{41}$ | 980 | 714.90 | 120.00 | 100.00 | 115 | Sol | |
| $179 + 012^{44}$ | $179 + 416^{94}$ | 980 | 404.50 | 110.00 | 110.00 | 115 | Sol | |
| $182 + 437^{18}$ | $182 + 580^{38}$ | 1000 | 143.20 | 100.00 | 100.00 | 115 | Sağ | |
| $182 + 897^{96}$ | $183 + 038^{16}$ | 1020 | 140.20 | 100.00 | 100.00 | 115 | Sağ | |
| ⇒ $183 + 227^{25}$ | $183 + 381^{73}$ | 345 | 154.48 | 90.00 | 90.00 | 130 | Sağ | |
| $183 + 518^{64}$ | $183 + 631^{14}$ | 500 | 112.50 | 100.00 | 100.00 | 130 | Sol | |
| $184 + 099^{02}$ | $184 + 196^{62}$ | 595 | 97.60 | 90.00 | 90.00 | 125 | Sağ | |
| $184 + 363^{73}$ | $184 + 513^{89}$ | 390 | 150.16 | 90.00 | 90.00 | 130 | Sol | |
| $185 + 259^{86}$ | $185 + 622^{64}$ | 495 | 362.78 | 100.00 | 100.00 | 130 | Sağ | |
| $185 + 816^{01}$ | $186 + 030^{36}$ | 390 | 214.35 | 90.00 | 63.29 | 130 | Sol | |

Anlage 3

| ID | Station | From KM | To KM | Length | Gradient | R | Cant | Direction | Velocity Old | Velocity New | Date of Ins. | Rail Length | Rail Type | Sleeper Type | Fasten Type | Passenger Gt | Freight Gt | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 222 | Makasa | 181,125 | 181,325 | 200 | 0.000 | | | | 120 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 223 | | 181,325 | 181,625 | 300 | 1.200 | | | | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 224 | | 181,625 | 181,965 | 340 | 8.700 | | | | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 225 | | 181,965 | 182,437 | 472 | 0.000 | | | | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 226 | | 182,437 | 182,580 | 143 | 0.000 | 1,000 | 115 | R | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 227 | | 182,580 | 182,898 | 318 | 0.000 | | | | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 228 | | 182,898 | 183,038 | 140 | 1.700 | 1,020 | 115 | R | 70 | 130 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 229 | | 183,038 | 183,227 | 189 | 1.700 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 230 | | 183,227 | 183,381 | 154 | 7.500 | 345 | 130 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 231 | | 183,381 | 183,518 | 137 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 232 | | 183,518 | 183,631 | 113 | 0.000 | 500 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 233 | | 183,631 | 184,099 | 468 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 234 | | 184,099 | 184,197 | 98 | 0.000 | 595 | 125 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 235 | | 184,197 | 184,364 | 167 | 0.310 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 236 | | 184,364 | 184,514 | 150 | 0.310 | 390 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 237 | | 184,514 | 185,260 | 746 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 238 | | 185,260 | 185,500 | 240 | 0.000 | 495 | 130 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 239 | | 185,500 | 185,623 | 123 | 0.000 | 495 | 130 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 240 | | 185,623 | 185,816 | 193 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 241 | | 185,816 | 186,030 | 214 | 0.600 | 390 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 242 | | 186,030 | 186,115 | 85 | [illegible] | 7,300 | 45 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 243 | | 186,115 | 186,249 | 134 | 0.000 | 500 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 244 | | 186,249 | 186,545 | 296 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 245 | | 186,545 | 186,800 | 255 | 0.000 | 500 | 125 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 246 | | 186,800 | 187,018 | 218 | 1.400 | 590 | 125 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 247 | | 187,018 | 187,148 | 130 | 1.400 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 248 | | 187,148 | 187,549 | 402 | 0.000 | 395 | 130 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 249 | | 187,549 | 187,875 | 326 | 4.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 250 | | 187,875 | 188,285 | 410 | 6.310 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 251 | | 188,285 | 188,500 | 215 | 0.000 | 285 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 252 | | 188,500 | 188,654 | 154 | 7.500 | 285 | 130 | L | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 253 | | 188,654 | 188,849 | 195 | 0.000 | | | | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |
| 254 | Kapısa | 188,849 | 189,040 | 191 | 1.290 | 1,160 | 95 | R | 70 | 80 | 1988 | CWR | 49,050 | Concrete | K | 36,128,115 | 33,525,834 | 69,653,949 |

*Yellow cells shows the accidents location

Figure C.2 Curve information

Berechnung Schotter

# BALAST YÜKSEKLİĞİ HESABI

Dingil Basıncı : 20 ton

Mıntıka Hızı : 80 km/saat

Dinamik Katsayı : 1.211

Traverse İntikal Eden Yük (S) = 1.211 X 0.42 X 10.000 = 5086.2 kg

l = Travers Uzunluğu

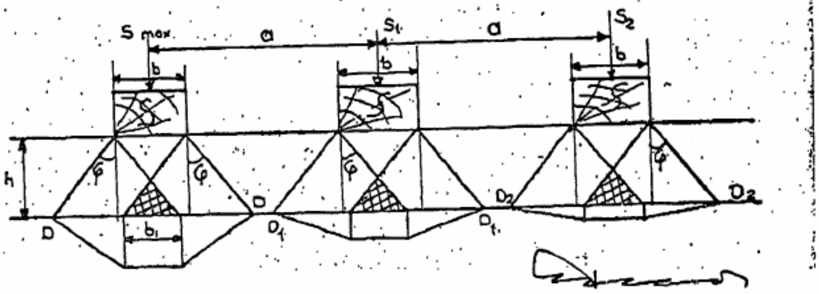
e= Ray Eksenleri Arası Mesafe

$$h = \frac{S}{2.18 \times (l-e) \times Tg\varphi \times q}$$

$$h = \frac{5086.2}{2.18 \times (240-150) \times 0.727 \times 1.36} = \frac{5086.2}{193.986864} = 26{,}2 \text{ cm.}$$

$$h > \frac{b}{2 \times tg\varphi} \quad \frac{30}{2 \times 0.727} \quad \frac{30}{1.454} = 20.632 \text{ cm.}$$

26.2 cm > 20.63 cm. olduğundan üniform olduğu kabul edilen $q$ gerilmeleri, $b_1=2\, htg\varphi - b$ genişliğindeki bir alanda tesir eder. Bundan sonra gerilmeler, travers kenarından dışa doğru $\varphi$ açısı ile çizilen doğrunun altyapıyı kestiği d noktasına kadar azalarak gider ve bu noktada değeri sıfır olur.




Ferhat DEMIRTAŞ
Yol Dairesi Başkan V.

KAYNAK : Üstyapı Ve Demiryolu Mekaniği (Yüksek Mühendis Feridun KUMBASAR)

Figure C.3 Ballast information

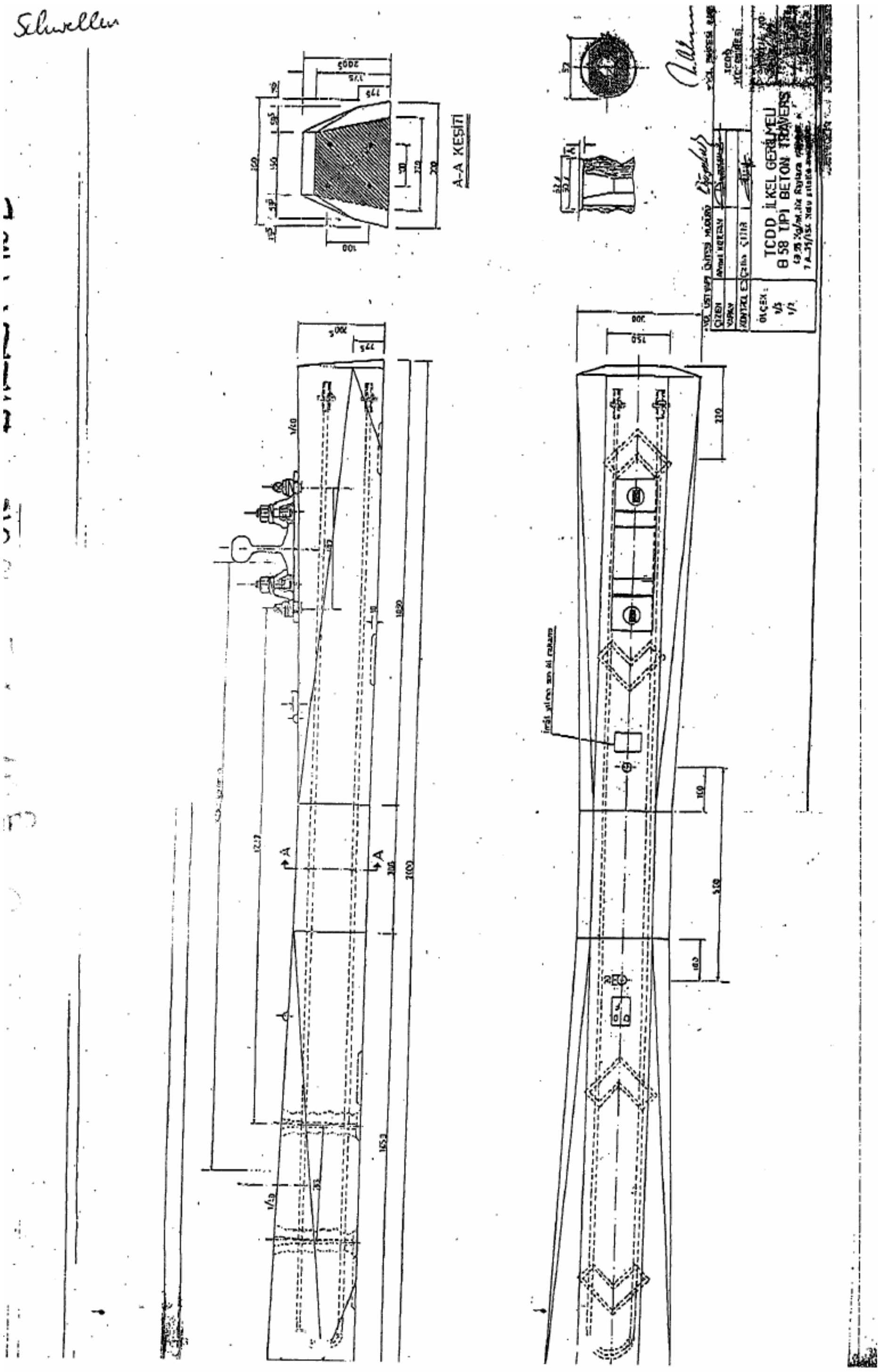


Figure C.4 Sleeper information

Berechung Schienenprofil

## RAY PROFİLİNİN SEÇİLMESİ

Şimdiye kadar edinilen tecrübelere göre P dingil ağırlığındaki arabaların işletmeciliği mutat yollarda kullanılacak rayın minimum m. tul ağırlığı : G=2 P ile belirtilir.

Bu formülde G Kg. P ise ton cinsindendir. Bu şekilde yapılan ilk tahminden sonra K=0,29 alınarak, M= 0,29 X G X L Xα ile moment bulunarak;

M=0,29 X G XLXα

M= 0,29X10.000X62X1.470

M= 268569

W = 239 cm³ 49.050

$$G = \frac{M}{W} = \frac{268569}{240} = 1119 \text{ kg/cm}^2$$

1. sınıf yollarda emniyet gerilmesi 1500 cm² olup

1119>1500 kg/cm² 2. sınıf yollarda 1400 kg/cm² dir.

## 2- RAY PROFİLİ HESABI

P = 20 ton

V = 140 km/saat

L = 63 cm.

$\sigma_e$ = 1200 kg/cm² 0.20 aşınmış ray için

$$W = \frac{0,29 \times 10.000 \times 63 \times 1.470}{1200} = 223,80 \text{ cm}^3$$

$$W = 5.2\,H - 533$$

$$H = \frac{W}{5,2} + 102,5 = 145.53 \text{ mm.}$$

$$6 = 156 - \frac{16000}{145,53} = 46 \text{ kg./m}$$

Ferhat DEMİRTAŞ
Yol Dairesi Başkan V.

Figure C.5 Rail calculations

**TURKISH STATE RAILWAYS**
**Foreign Relations Department**

No: B.11.2.DDY.0.67.00.06/65/ 10769
Subject: Train Accident in Turkey

Dear Sir,

As you know a tragic train accident occurred on 22nd of July 2004 in Turkey taking so many lives of passengers.

In order to overcome the consequences of this sad event, we would be very glad to receive experts from your Company(ECS) for helping us to investigate the actual causes of this severe accident. All the costs of experts will be borne by our Railway Administration.

We would appreciate your confirmation as soon as possible.

Thank you in advance for your kind assistance.

Ali Kemal ERGÜLEÇ
Acting Director General of
Turkish State Railways

Adress:TCDD Genel Müdürlüğü 06330 GAR/ANKARA
Tel: 90 312 3098257 Fax: 90 312 312 50 42

23/07/2004 19:07 90-312-3125042 DIS ILISGILER PAGE 01

Figure C.6 Invitation to investigate the railway accident

11-AUG-2004 16:06 FROM:TCDD OZEL KALEM 03123103727 TO:0031152783443 P:1/1

**TURKISH STATE RAILWAYS GENERAL DIRECTORATE (TCDD)**
**PERMANENT WAY DEPARTMENT**

**No:** B.11.2.DDY.0.10.00.09/410-19/
**Subject:** The train Accident in Pamukova

Dear Mr. Esveld,

Thank you very much for your e-mail and your interest related to this train accident.

The questions you have asked are answered as follows:

1- The locomotives speed recording device measures with respect to max. 180 km/h and speed graph measures according to max. 150 km/h. Therefore, the graph value should be multiplied by (180/150) = 1.2 . Hence, the real speed is 1.2x110 = 132 km/h and this value is the definite.
2- As far as It is known, the brake is not applied. However, in Coach 2 one emergency brake, in Coach 5 two emergency brakes are drawn.
3- Deviation value seen in right hand side rail for 80-140 km/h (in joint) is 16.5 mm. This value is within limit our maintenance tolerances. The graph's scale is 1/1.

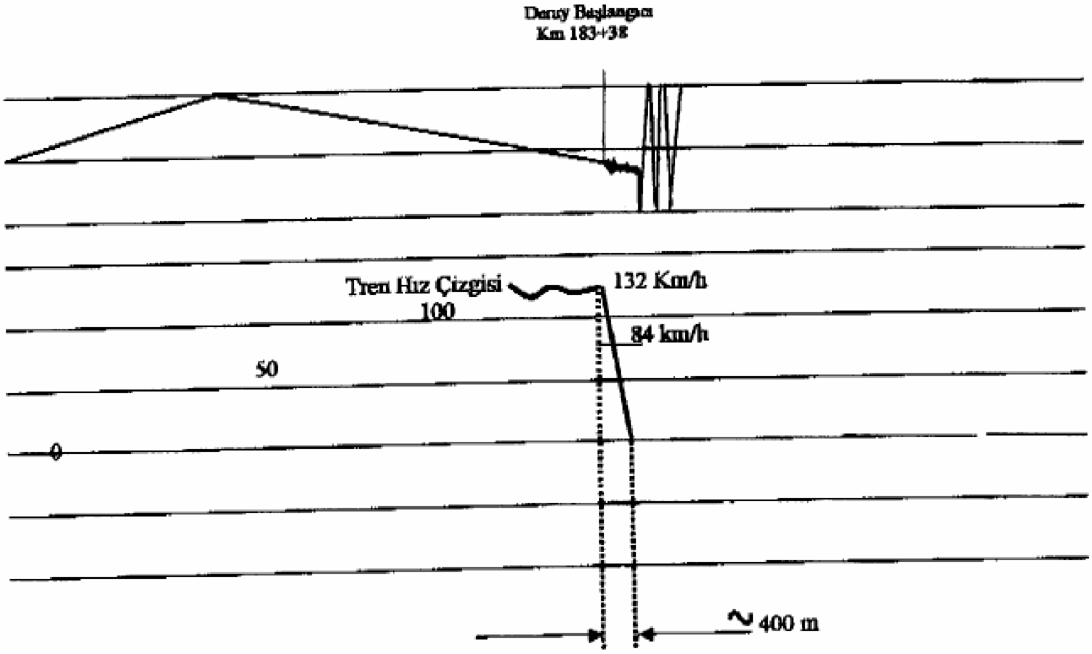
Yours Sincerely,

TURKISH STTATE RAILWAYS

Ferhat DEMİRTAŞ
Acting Head of Permanent Way Department

Erol İNAL
Deputy Director General

Figure C.7 Additional questions and answers




BANDIN TETKİKİNDE ;

1) Deray Başlangıç noktasına kadar fren yapıldığına dair herhangi bir hız düşürümü görülmemektedir. Ancak yaklaşık 160-200 mt.lik bir mesafede %07 lik eğimin başlaması ve R= 345 mt lik kurba girmesi nedeniyle yaklaşık 1-3 km/h hız azalması olduğu,
2) Deray Başlangıç noktasındaki ani hız düşümünün ise ;
   a- Makinist tarafından ani fren yapılması,
   b- Yolcu Vagonlarındaki imdat freninin çekilmesi,

   Sonucunun meydana geldiği,

Kanaatine varılmıştır.

Ancak, Livrelerde izin verilen hızın üstünde aşırı bir hızla kurba girilmesi halinde ani fren veya imdat freni çekilmesi derayın meydana gelmesine artı bir etken olabilir.

Figure C.8 Additional information about speed

Coenraad Esveld 00803123103727

**From:** Coenraad Esveld [coenraad@esveld.com]
**Sent:** woensdag 4 augustus 2004 17:10
**To:** Erol Inal (erolinal@tcdd.gov.tr)
**Cc:** Hulya Cilgi (hulyacilgi@hotmail.com)
**Subject:** Some questions

Dear Mr. Inal,

I am still busy with my investigations for which I would like to receive the following information:

1. What was the precise train speed at the moment the axle of the second coach derailed. According to the graph it was 110 km/h, whereas the information given orally in Turkey said it was 130 km/h.
2. During my visit to Turkey several suggestions were made that just before the derailment of the axle of the second coach the train was braked. Is this information correct and if so was the braking light, medium, or heavy.
3. Just before the point of derailment a geometrical defect in the right hand rail is visible on the recording car trace for the level of the right hand rail. What is the maximum deviation in terms of zero to maximum. Please also see the file attached with the defect circled in blue.

We intend to make an analysis of the train dynamics with the ADAMS/Rail package and see whether an explanation can be given for the conditions under which the axle derailed. Our ADAMS specialist will return from holidays on Monday.

I am looking forward to receiving your answer.

Kind regards,

Coenraad Esveld

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*Prof.dr.ir. C. Esveld*

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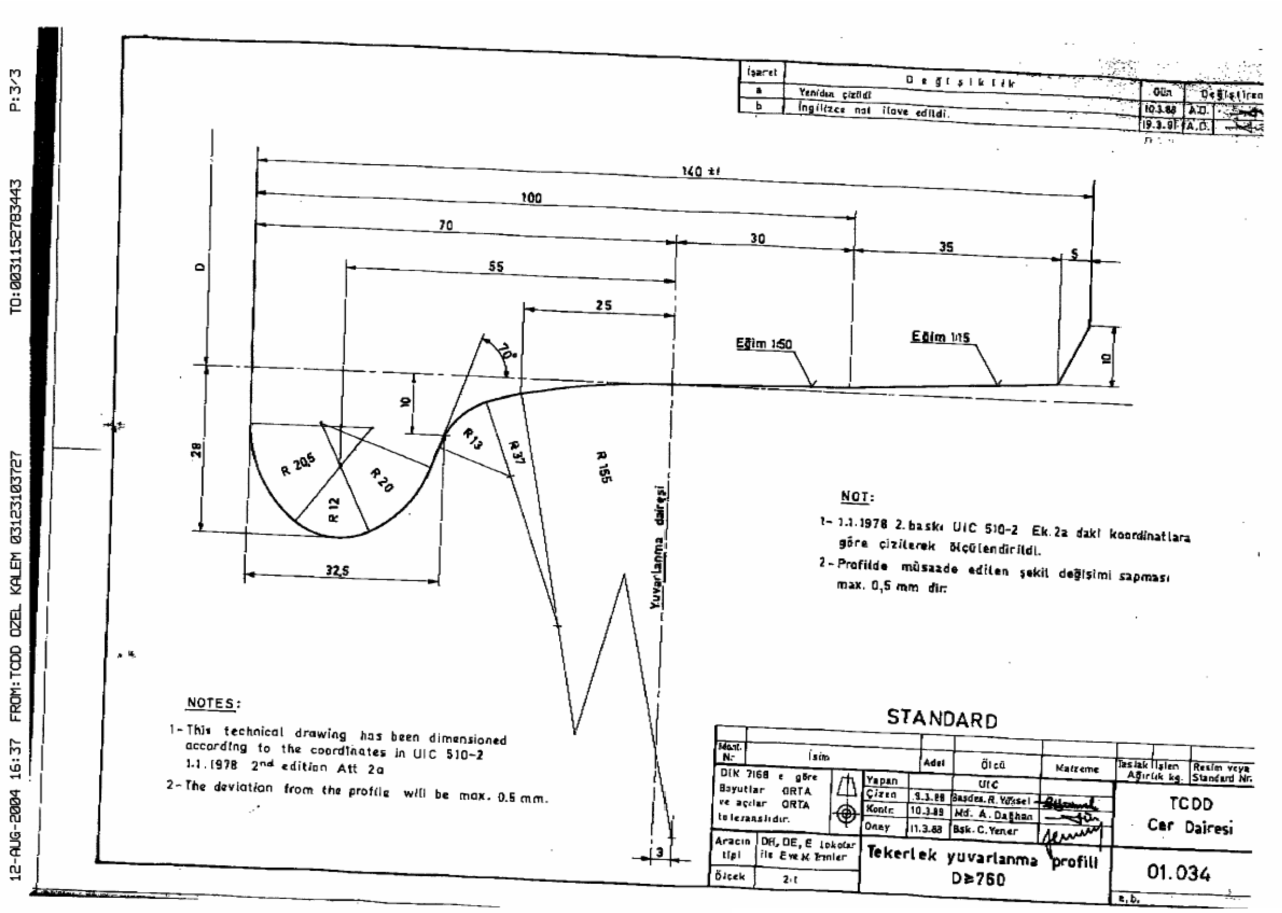
*Internet: http://www.esveld.com, Email: coenraad@esveld.com*

Figure C.9 Additional questions




**TEKERLEK YUVARLANMA PROFİLİ İLE İLGİLİ NOT:**

11.08.2004 tarihinde tarafınızca fakslanan "Tekerlek Yuvarlanma Profili" resmi, 1960'lı yıllarda yazılmış olan "TCDD Teknik Umumi Emirler-5" Yönergesinin ekinden alınmış bir resimdir. Söz konusu "Tekerlek Yuvarlanma Profili", vagonlar için 1984 yılından itibaren değiştirilmiş olup, ekte gönderilen 02.029 nolu resimde belirtilen profil kullanılmaktadır. Lokomotifler için ise, ekte gönderilen 01.034 nolu resimde belirtilen profil 1988 yılından beri kullanılmaktadır.

Bilgilerinize saygılarımla arz ederim.

EK:
1- 02.029 nolu resim
2- 01.034 nolu resim

**NOTE RELATED TO ROLLING WHEEL PROFILE**

The drawing about "Rolling Wheel Profile" that you faxed on 11th August 2004 was taken from annex of "TCDD General Technical Regulations-5" Directives which was written in 1960s. The mentioned "Rolling Wheel Profile" has been changed since 1984 and the profile given in enclosed 02.029 drawing is used for wagons. And for locomotives, the profile given in enclosed 01.034 drawing has been used since 1988.

Best Regards,

ENC:
1- 02.029 no. drawing
2- 01.034 no. drawing

Ahmet SEVİM
Cer Dairesi Başkan Yrd.

Figure C. 10 Information about the wheels

# APPENDIX D

# DISCUSSION OF SOME FINDINGS FROM OTHER EXPERTS

### 1. Wheel climb and turn over

If a simple calculation is made based on the quasi-static forces it can be shown that vehicle turn over will not occur at 130 km/h, but at a much higher speed. Also When Nadal's derailment ratio Y/Q < 1.2 is applied with just the quasi-static loads the value of 1.2 will not be exceeded. However the physics of a derailment is much more complicated and simple hand calculations are absolutely insufficient. Also track irregularities should be considered. For such analyses advanced vehicle dynamics packages like ADAMS/Rail, as we used, VAMPIRE and NUCARS are inevitable. In my analysis I have shown that at 130 km/h wheel unloading and exceedence of the limit Y/Q indeed occurs. For a derailment the bottom line is whether a wheel is lifted over a sufficient height so that it can step over the rail. Our ADAMS/Rail analyses revealed that under certain conditions wheel lift of a sufficient magnitude could be observed at 130 km/h and so the axle could derail.

### 2. Safety under static and dynamic loads

Under the static and dynamic loads our ADAMS/Rail analyses showed that a derailment could occur. However, under the actual loads at 130 km/h there was no risk for track shifts or damage to track components. This was also confirmed during the inspection at the site of the accident, where no abnormalities, track shifts, or damage to the track could be found.

### 3. Braking

In the analyses with ADAMS/Rail it was found that the system became more or less instable at a speed of 130 km/h. With a lateral force of 20 kN and a vertical lifting force of 20 kN applied to the buffers the rear axle of the coach derailed. This set of forces could very well represent the vertical and lateral component of a braking force due to the angle between the coaches in the curve and other excentricities and imperfections in the system. It can be concluded that according to our analyses the braking forces could cause a derailment at 130 km/h, whereas it should be emphasized that at 80 km/h, under the same conditions as mentioned before, no derailment would occur.

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