PRODUCTIVITY IN RAIL CONSTRUCTION
LESSONS LEARNED FROM THE DEVELOPMENT OF THE RHEDA 2000 TRACK CONSTRUCTION SYSTEM

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Abstract:
Between Amsterdam and Antwerp a new High Speed Rail link with the length of 96 KM is under construction and will be opened in April 2007. Based on the existing Rheda Ballastless Track construction system a new and improved construction method has been developed. New equipment was designed. After two years of construction this new system called RHEDA 2000 NL is evaluated. The production is measured during the whole construction period.
In this paper the improvements and changes of the construction method RHEDA 2000 NL will be explained. Figures will be shown about: productivity, construction speed, labour hours and quality of the rail structure.
These results will be compared with the figures of the original used systems. The sometimes huge differences will be elaborated on. The paper will end with lessons learned from the RHEDA 2000 NL Ballastless Track construction system.

Keywords: speed rail, construction method, productivity, quality

1. INTRODUCTION

1.1 Short Introduction into the project (HSL ZUID High speed Line)

The EPC works which are described in this article have been carried out by the Rheda 2000. This VOF (general partnership) has constructed a concrete railway track (slabtrack), a Design, Build, Finance & Maintain (DBFM) contract with the 'Staat der Nederlanden' (Dutch State) for the superstructure of the Hoge Snelheidslijn Zuid (HSL Zuid – High Speed Railway Line South). This contract is of the PPP (Public Private Partnership) type with a 25-year maintenance period. The HSL Zuid will provide a high speed link (speeds of 300 kph) between the Belgian Border and Amsterdam, thus effectively linking Amsterdam (and it's main airport Schiphol) to Paris and further.

Due to the fact that the engineering and construction costs are funded by the partners and investors of the consortium itself together with a large consortium of banks, and repayment of those funds will only take place by the Dutch State on a yearly basis if an availability of a minimum of 99% is reached, one can easily imagine that the quality of the final product plays a very important role. Thus many decisions both in the engineering as well in the construction phase have been taking by using the tools of Total Life Cycle Costing analyses.

The scope of the Rheda 2000 VOF consisted of approximately 80 km's of double track and 4 major switch complexes. In this paper the latter are not described. This 80 km of double track is roughly divided in 43 km's in the Northern part and 37 km's in the South. In between use is made of the present infrastructure. One could thus describe the building site as being 80.000 meters long and thus 12 meters wide. A very linear building method is thus needed. This is even more so due to the very limited access to this building site since on many places physical boundaries (easiest recognisable at the locations of the tunnels, bridges and Viaducts) as well as local permit impossibilities prohibit the access to the track or the usage of construction roads parallel to the track. Further more a lot of different type of substructures were encountered also causing limitations on both design as well as on constructional possibilities. The main substructure types as encountered vary from Embankment (Settlement poor structure) through Settlement Free Plates (piled concrete plates) and various types of short and long span viaducts and Bridges (as the Bridge Hollandsch Diep) to Tunnels (two sunken tunnels of each approx. 2 km's in length and a bored tunnel of 8 km's).

1.2 Short Introduction into the product (Rheda 2000 nl Slabtrack)

The Rheda 2000 NL slabtrack type is basically a concrete in situ poured plate, in which high quality prefabricated sleepers are embedded.

1.2.1 Rheda Original

The Rheda Original system was based on the structure of the slab at two tracks:

1. Neubaustrecke Köln-Rhein/Main, System Rheda Berlin in 1999-02, ca. 86.000m (figure 1)
2. Neubaustrecke Erfurt-Halle/Leibzig, first time Rheda 2000 was built, ca. 7.000m

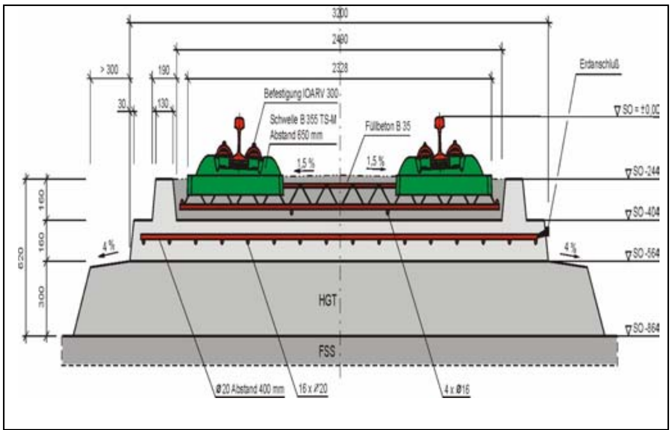


Figure 1: RHEDA Berlin with modified Bi-block Sleepers (reduced concrete blocks)

Structure of the slab track:

- Endless track construction without joints
- Cant is built in the substructure (in Frost Protection Layer)
- Hydraulic bounded layer brought in with special equipment on Frost Protection Layer
- Concrete trough brought in with special equipment without shuttering (heavy concreting unit)
- Filling concrete brought in by hand

1.2.2 Rheda 2000 NL

An important structure was designed for the track Amsterdam to the Belgium Border.

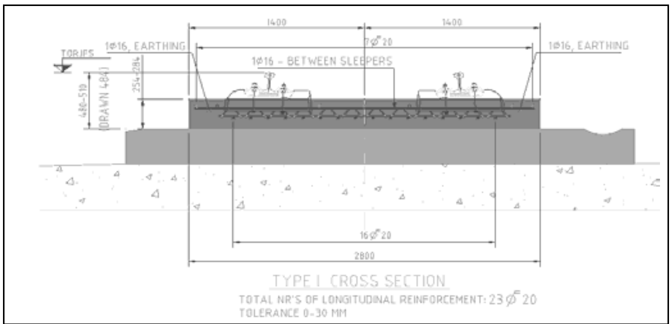


Figure 2: RHEDA 2000 NL on Embankment

Structure Rheda NL on embankment:

- Endless track construction without joints (figure 2)
- Cant is built in the substructure hydraulic bounded layer
- Special shuttering system fixed on hydraulic bounded layer and transported with special equipment
- Concrete brought in with concreting unit (light, small and therefore flexible unit)

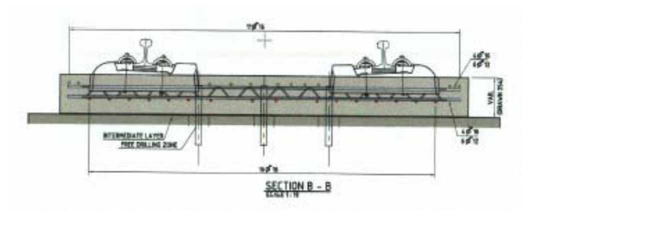


Figure 3: RHEDA 2000 NL on SFP (cant = 0-40mm)

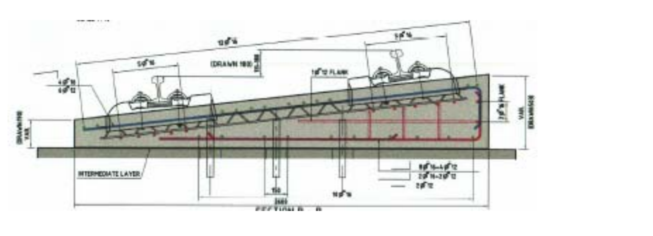


Figure 4: RHEDA 2000 NL on SFP (cant = 111-180mm)

Structure Rheda NL on SFP (see also attached building method) (figure 3 and 4):

- Building a plate construction with a joint every 5-7 m (comparable to Rheda original on viaducts)
- Substructure/superstructure connection built with dowels
- Special shuttering system transported with special equipment
- Cant is built in concrete layer of the superstructure (as a trapezium while building with a cant)
- Concrete brought in with concreting unit (light, small and therefore flexible unit)

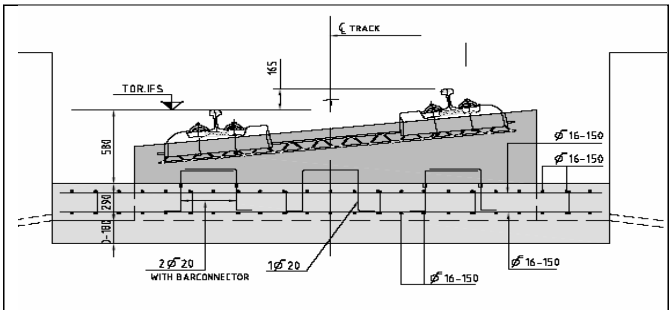


Figure 5.: RHEDA 2000 NL in tunnel

Structure Rheda NL in tunnel (figure 5):

- Endless track construction without joints
- Special shuttering system transported with special equipment
- Cant is built in concrete layer of the superstructure (as a trapezium while building with a cant)
- Concrete manually brought in with special concrete transport equipment

2. RESEARCH QUESTIONS

The aim of the mechanisation of the Rheda 2000 track system is the reduction of the cost of man-hours and to improve productivity and quality of track construction. The mechanisation mainly focuses on the installation of the separation layer, the adjustment of the track, the (dis-) assembling of the shuttering and the concrete pouring.

- ➢ What are the differences in philosophies between Rheda original and Rheda 2000 NL?
- ➢ What is the impact of the mechanisation on need of man-hours?
- ➢ What is the impact of the mechanisation of the quality of the Rail Track?
- ➢ Which activities in the construction process of the Rail Track can be mechanised?

3. RESEARCH METHOD

3.1 Research limitations

The research was carried out between 2002 and 2006 and limited to one project: the High Speed Rail link between Amsterdam and Antwerp.

3.2 Research approach

The study was conducted by collecting data from the Rheda original system from several German projects. By collecting and processing data from the HSL project the actual performance of Rheda 2000 NL System became clear.
The data of the Rheda 2000 NL System were collected by using all the accounting figures of the project management system of the HSL project.

4. THE RESULTS

4.1 Reasons for introducing mechanisation in the Rheda 2000 vof

The main objectives have always been 1st Safety and 2nd Quality and 3rd Constructional Speed. Since the time schedule as imposed was very tight and the quality requirements were extremely high (both following the High Speed Line design requirements as well as the commercial influences of 25 years maintenance responsibility as well as the absolute need for a 99% availability of the line) the human risk element to both processes was felt to be needed to be eliminated as much as reasonably possible. By introducing mechanisation the first goal (Safety of the Workers) could at the same time also be supported by introducing labour friendly tools and reducing the exposure to the weather as much as possible.

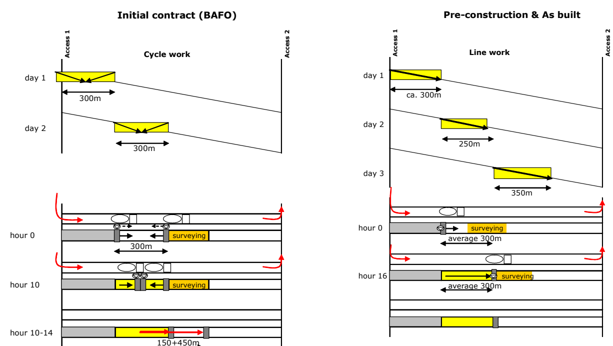
4.2 Differences in philosophies between Rheda Original and Rheda 2000 NL.

Please see figure 6 for the main differences between the 3 separate stages on main parameters and assumptions.

	Rheda Original	Rheda 2000 NL
Track construction (engineering)	Endless track construction without joints	Building a joint every 5-7 m A lot of delays (changed access dates) and additional works, e.g. filling layer viaducts at Brabant zuid, BHD, filling layer TDK & TOM etc.
Concrete amount	0,7m³/m as average	0,56-0,79m³/m
Concreting speed (per meter track)	300m/day minimum, 2 teams doing this 300m/day parallel, also in limiting conditions such as tunnels	Rheda on embankment 300m/day average (peaks up to 400m/day – max. 499m/day), Rheda in Tunnels average 140m/day (dictated by door to door distance), Rheda on SFP/viaducts varying due to cant and local circumstances, average 200m/day
Concreting process	Step by step working - 2 shifts concreting parallel (10 h for 300 m/d).	Line working - 1 shift concreting (8-10h for **200** m/d *(obstructions, delayed access dates, etc.)* →*up to 14h for 300m/d*) *More machines than pre-construction*
Working time	10 h day and 8-10 h night (not economical)	8-10 h/d concreting and transports running parallel *No night hours!*
Access points/roads	Every 1.500 - 2.000 m access points	Distances in many situations longer (up to 6.000 m) – more construction roads than assumed in pre-construction stage – less rail logistics needed and more flexibility achieved

Figure 6 Comparison of main parameters in different planning stages of the HSL Zuid project

One of the major changes was the change from "step by step" working to "line working". It was believed that by introducing mechanisation in the concreting process the total concreting time for 300 meters could be lowered from 20 hours shifts doing 150 meters in 10 hours) to a maximum of 16 hours (maximum of 2 shifts working on the same machine after each other) with the target set at 12 hours of concreting. In this way the flexibility was raised tremendously (see figure 7 below) and the construction organization could then cope easier with the limitations on access points. The main differences between both methods are shown graphically in the following table:



- Every day 300m (+/- 0m), different speed not possible, every day 300m a must (>=10h?) - Logistics difficult, both teams have to work exactly with the same speed, if not the other team stands still for this time - Machines have to move out after the regular working time (thus at night!) to the next starting points (150m and 450m every night!). Machines have to drive over the formwork of a freshly concreted area - Surveying more then 300 m before concrete	+ speed can be variable (Weather, failure...), higher/lower speed always possible + logistic is easy and independent, only one team + machinery starts at the same location the next day (end point), no transport necessary + surveying works closer in front of the concreting, lower risk of temperature and damage

Figure 7 Comparison of "step by step" working to "line working"

4.3 Mechanisation results on man-hours

In this paragraph the results are shown of the implementing of the mechanisation into the construction process.

It is clear that the mechanisation process has paid out. Not only the total amount of hours has decreased, also the number of actual night shift hours has virtually been eliminated, thus not only resulting in a much lower average rate (Rheda Original 30% of total hours for night rates, as built virtually 0%) (figure 8).

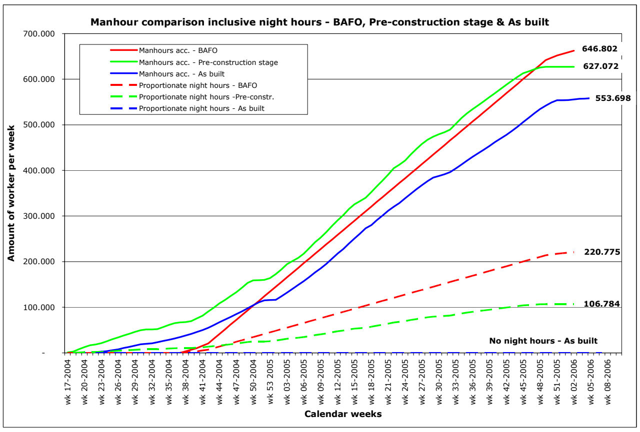


Figure 8

Apart from the overall man-hour figures it also very interesting to follow the development of the "learning curve" within this project with regard to the amount of man-hours needed to operate the machines etc. Theoretically in each mechanised process of repeating actions this learning curve is present. In order to already reap the benefits of the learning curves as much as possible a "Trial Track" was introduced which was part of the real to be build end product, however during which the pressure of the to be achieved final speeds was lowered. The latter due to the fact that it was carried out before the actual start of construction date. It was also still in time to make the final decision whether or not the assumptions of the Pre Construction phase were feasible or that more teams would need to be added. In the following figures the learning curves are presented for the Tunnel team and the SFP team. Firstly the needed man-hours per meter are given in figures 9 and 10. Both display a certain learning curve however the effect is much larger for the Tunnel team. The explanation is that the Tunnel Team really had the same activities with the same boundary conditions (8km bored tunnel) for the latter 2/3rd of their project whereas the SFP team encountered many obstructions by (third parties) and difficulties in the execution of the work (large cants up to 180 mm and different substructure types such as a Tunnel (TRN) and a very long and high viaduct (DSV) in the last part of their project (see also specifically Figure 10). Secondly the production ratios are given (note that the tunnel team could not go any faster from a certain moment in time onwards since the boundary condition is the distance between doors to the adjecent tube) in Figure 11

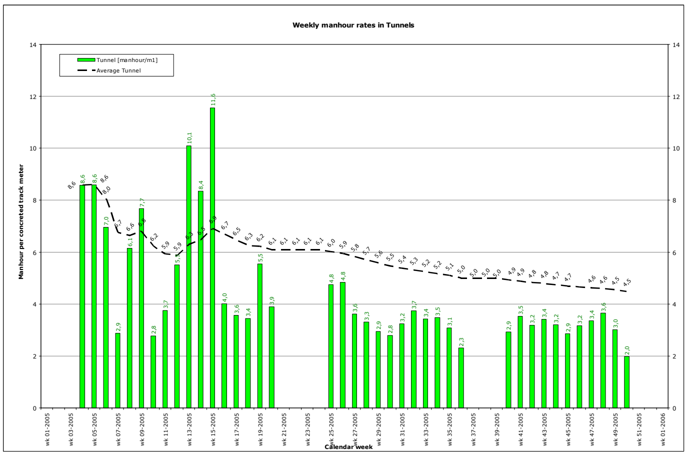


Figure 9: Learning curve for Rheda in Tunnels

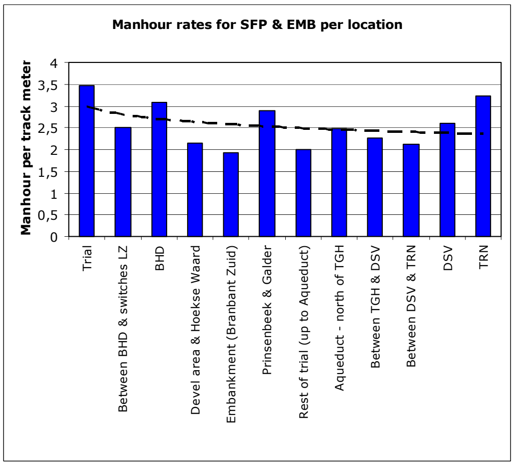


Figure 10: Learning curve for Rheda for SFP and Embankment

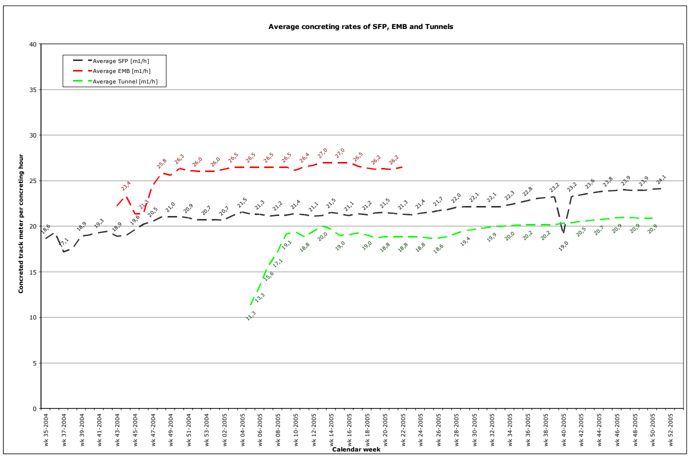
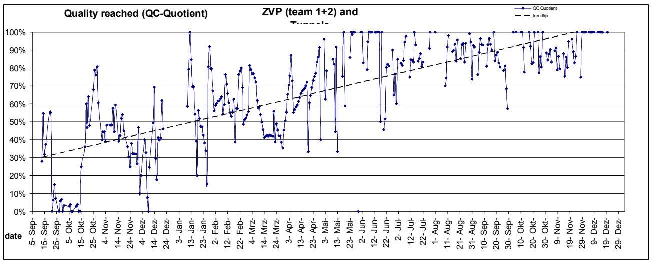


Figure 11: Comparison of concreting rates

4.4 Mechanisation results on quality

The mechanisation process allowed for a continuous controlled and monitored improvement of the quality by tweaking various parameters in the process one at a time, and sticking to those which proved to be effective. This is shown in figures 12 and 13, in which two specific Key Performance Parameters were monitored. Note that these figures give the result of “first checks”. All mentioned (small) faults were auditable and proven corrected before concreting was allowed to take place.



QC Quotient = Percentage right plates in first check

$$\text{QC Quotient} = \frac{\text{Number of plates “OK” in first check}}{\text{Total number checked plates (first check)}}$$

e.g. $QC_{quotient} = \frac{80 \text{ plates “OK”}}{100 \text{ plates checked}} = 0.8$ (Target R2V 0.8)

ZVP (Team 1+2) and Tunnels

Figure 12 Percentage of R2V plates right in the first check

FpS –Index = Number of Findings per (one) R2V Slab (plate)

$$\text{FpS} = \frac{\text{Number of findings}}{\text{Total number of checked plates}}$$

e.g. 16 findings in 16 plates → FpS = 1; 9 findings in 3 plates → FpS = 3

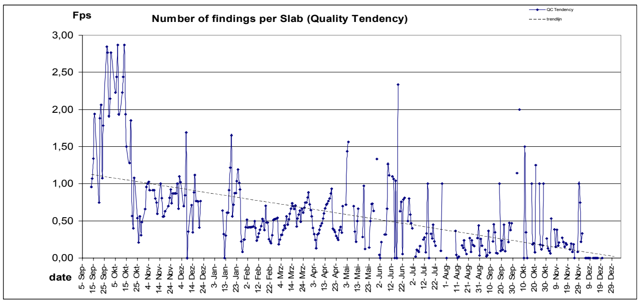


Figure13 Number of findings per R2V slab

Another interesting figure is the following. There you can see that the inset of the concreting machines directly result in quality improvement of the concreted track. The Southern Section of the HSL was built by only partly using the concreting machines until week 24 in 2005. From week 24-2005 on, the northern HSL was built with a 100% concreting machines inset by all teams. As can be seen in the figure 14, the average crack amount per concreted track decreased enormously from week 24-2005. This underlines the improved concrete quality while making use of the machines.

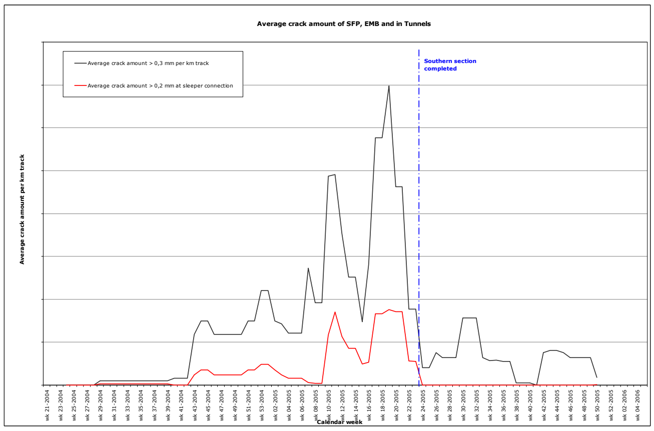


Figure 14

4.5 Final mechanisation applicable for which part of the construction process?

Some parts of the construction process are more influenced by mechanisation than others. Below an overview is shown (figure 15) about the construction activities and the effect of mechanism.

Mechanisation can have his origin in several reasons with different back grounds. Sometimes it is the reduction of man-hours or the increase of the production speed. At another moment it is related to dangerous and risk full work. Then the labour risks should be removed from the human beings.

Another reason for mechanisation can be to reach a constantly high production quality. And in this case it is important to focus on the activities, which quality depends of the execution of the work by the labour force.

In the project HSL Zuid, the track form Amsterdam to the Belgium border, the issue of the contract “Availability of the track” has been a very leading principle for the design of the track as well as for the design of the execution process.

High reliability was the most important design factor. And so: the designers looked for a working method, which should have as less as possible deviations and failures. The figures 12 and 13 show the result.

The constancy, certainty and reliability have been found in the mechanisation of the most delicate processes

Activity	Rheda 'original' Germany	Rheda 2000 NL	Effect of mechanisation* *(result in manhour savings)*
Material distribution	supplier	supplier	
Scanning substructure	*Not carried out*	manual work	0
Cleaning SFP	sweeper	sweeper	0
Installation separation layer	*Not carried out*	installing unit to unroll & fix layer	++
Drilling dowel holes	*Not carried out*	drilling unit	++
Position sleepers	excavator with hydraulic spreader	excavator with hydraulic spreader	0
Position+transport construction rails	rail transport trucks with crane	rail transport trucks with crane	0
Rail/sleeper/spindle block fixation	manual work	manual work	0
Rough track adjustment	manual work	Fassetta machine	++
Assembly of rebars	manual work	manual work	0
Earthing connections	manual work	Flash butt weld machine	+
Assembly shuttering	manual work	shuttering machines for transversal and longitudinal shuttering	+
Final track adjustment	surveying equipment	surveying equipment	0
Concreting	manual work & large conc. unit	concreting unit	+
Concrete finishing	manual work	manual work (plus tent)	0 execution was planned with finishing machine, unfortunately it didn't work properly
Disassembly shuttering	manual work	disassembly shuttering machines for transversal and longitudinal shuttering (incl. cleaning)	+
Disassembly spindle blocks & construction rails	manual work and transport trucks	manual work and transport trucks	0
Close spindle gaps	manual work	manual work	0

Figure 15

5. CONCLUSIONS

1. Raising the mechanisation level of the Rheda original system to the level of Rheda 2000 NL improves the total performance of the system.
2. The reduction of the cost of man-hours, as result of the higher productivity and avoiding the very expensive night shift is 24.6%.
3. The quality of the construction process improves tremendously as shown in figures 12 and 13.

6. REFERENCES

1. Modern Railway Track, 2nd edition 2001 by C. Essveld/TU Delft
2. RHEDA 2000®, Die Feste Fahrbahn für den Hochgeschwindigkeitsverkehr by Dr. Stephan Freudenstein
3. RHEDA 2000®, approved and certifidied according to European Council Directive for TSi, by Dr. Stephan Freudenstein
4. The planning process is of crucial importance to the successful control of linear construction sites, by Tanja Rickes and Carsten Lehmann
5. www.hslzuid.nl
6. www.infraspeed.nl