THE INFLUENCE OF DIFFERENT TYPES OF BLOCK PAVEMENT ON THE (UN)EVENNESS OF THE SURFACE OF WORLDS LARGEST CONTAINER TERMINAL

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0. Summary

The port of Rotterdam, although already the largest in the world, is still expanding at a rapid pace. In view of developments in the near future a test track of 600 meter length was made with six different types of mechanically laid concrete block pavements. The purpose was to investigate the performance, especially the effect on the evenness, under traffic conditions. This evenness is of paramount importance for the Automatic Guided Vehicles (AGV), that handle the growing stream of containers on the quayside. Wheel suspension with these vehicles is non-existent, so the evenness has a great effect on the behaviour of the vehicles and the electronic equipment on board.
In a subsection within each section profiles were measured in longitudinal and transversal direction with a stationary recording straightedge. Also the rideability has been established by testruns with an AGV. Moreover creep and general condition of the pavement were monitored.
From the monitoring of the test track until October 1993 (nine months under traffic) the tentative conclusion may be drawn that the sections with 100 mm thick dovetailed elements in stretcher bond, the 100 mm thick elements in herring bone bond and the double elements in stretcher bond behaved most favourably.

1. Introduction

Spring 1993 saw the opening of the ECT-Sealand terminal, an extension of the existing container terminal within the Rotterdam Harbour. Over 424 000 m² (17,8 millions block paving elements with a total weight of 106 000 ton) were mechanically laid.
The transport of the containers on these (and future) terminals is being done by so called Automatic Guided Vehicles (AGV - without driver). These AGV's are moving around in restricted area's and are guided by wires, placed in the sand cement subbase, and transponders in the elements. The maximum wheel load is 15 ton (150 kN), tyres are airplane tyres. Further details may be taken from figure 1. These AGV's have no suspension, so the evenness of the pavement is very important for the behaviour of the vehicle. Heavy vibrations may cause damage to the (electronic) equipment on board the AGV and limit the speed. This even may interfere with the programmed route and trigger off an emergency stop.

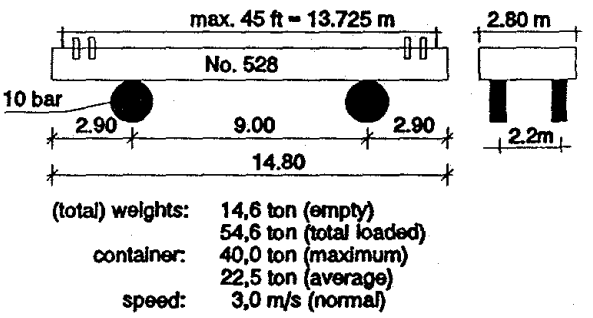


Figure 1: AGV characteristics

In view of future expansion of the terminal ECT, as well as the manufacturer of all elements and the pavement contractor were interested in the performance of different types of mechanically laid block pavements, the main points of interest being the initial unevenness, the behaviour in time and the effect on an AGV.

2. Test track

For that reason in December 1992 a test track was chosen in a supply road to the Delta terminal, provided with different types of mechanically laid block pavements. The following types of pavement were selected (elements' sizes: length and width):

-E12 120 mm thick concrete paving element in elbow bond (el. size: 220 x 110 mm)
-S10 100 mm thick concrete paving element in stretcher bond (el. size: 220 x 110 mm)
-E10 100 mm thick concrete paving element in elbow bond (el. size: 220 x 110 mm)
-H10 100 mm thick concrete paving element in herring bone bond (el. size: 220 x 110 mm)
-DV10 100 mm thick concrete paving element (dovetailed) in stretcher bond (el. size: 218 x 106 mm)
-DC12 120 mm thick double concrete paving element in stretcher bond (el. size: 220 x 220 mm)

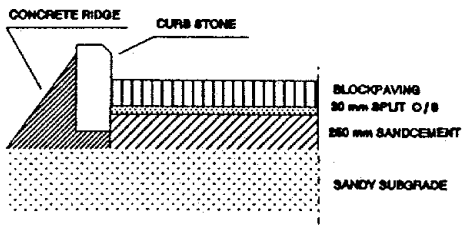


Figure 2: Cross section of pavement

On the test track all elements were laid in a 30 mm interlayer of crushed stone 0/8 mm on a 250 mm thick sand cement base on a sandy subgrade. Each section has a length of 100 meter.

3. Measurements

3.1 Longitudinal and transverse evenness

Within each test section a representative subsection has been closely monitored. The longitudinal evenness has been measured along three lines, positioned near the edges and in the centre of the road. The road being 8.0 m across there is no canalized traffic, so the exact location of the wheel paths is difficult to define.
The longitudinal as well as the transverse profile has been measured by a stationary recording straightedge. The total length of this straightedge is 4.0 meter. The subsection is divided into four parts with five levelling points in each measuring line, so creating a longitudinal profile of 16 m[1]. The transverse profile is measured on the cross section through the levelling points 2 and 4 (see figure 3). The main advantage of determining the true profile is that it allows one to simulate by computer different types of evenness measurements.

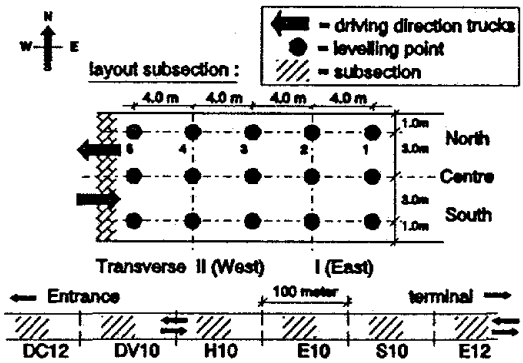


Figure 3: Layout testtrack in supply-road and subsections

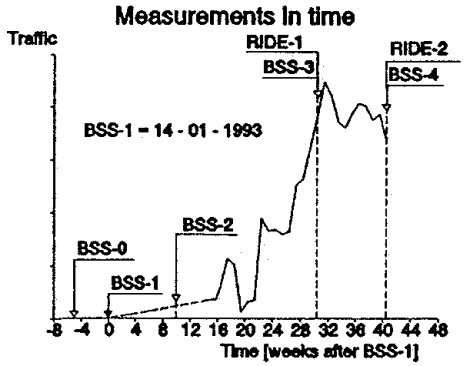


Figure 4: Time of measurements

3.2 Creep

Two saw cuts were made across the pavement to measure the creep of the elements, situated at the outermost rows of levelling points. Also the transverse displacement of the curb stones was measured.

3.3 Visual inspection

During the final series of measurements a detailed condition rating has been performed, according

to [7], to cover all additional aspects.

3.4 Vertical acceleration (rideability)

Vertical acceleration is of major importance for the life expectancy of the AGV's electronic and electric components. To measure these accelerations a special device was used, a so called ridemeter ("Ride-Indexer II") developed by the Technical University of Delft's Mechanical Engineering Department [1,2,3]. Both the vertical and horizontal accelerations are measured and cumulated over an adjustable period of time and stored in a K value. In this test program only the relative results on the different sections of block pavement have been taken into account.
On the northern side of the road testruns were made with an AGV, travelling at its normal speed of 10 km/h. The accelerometer was placed in four positions (Left Front, Right Front, Left Rear, Right Rear) and held firmly in place by a screw clamp. The measurements were made in two different loading conditions; loaded with an "average" 40 ft. container and unloaded (total weight respectively 37,1 and 14,6 ton).
The measuring time on each section was approximately 28 sec at a travelling speed of 10 km/h. The measurement was started when the rear axle arrived on the relevant section and ended just before the front wheel passed into the next section. Unfortunately the wheeltracks of the AGV didn't coincide with the longitudinal lines of the levelling points, because of the necessary free space around the AGV and the fact that freight traffic at the supply road should not be disturbed.

4. Results

4.1 Longitudinal and transverse evenness

4.1.1 Plots

The profile measurements were presented in figures [4], one for each measuring line. Two examples are given in figure 5 and 6.
In the figures 8 to 13 the differences between the last (BSS-4) and the first (BSS-1) transverse profiles are shown to detect possible rutting. The upper part shows the western transverse plot and the lower part the eastern transverse plot (see also figure 5). From these plots may be concluded that the sections show only minor settlements, although not all sections to the same degree. Rutting is only slight and mostly concentrated in the central area of the road.

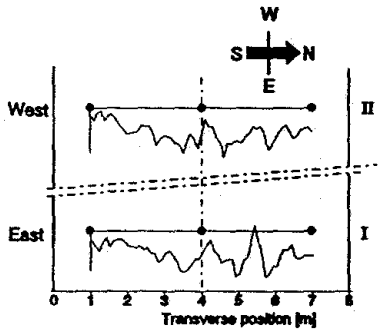


Figure 5: Explanation transverse plots

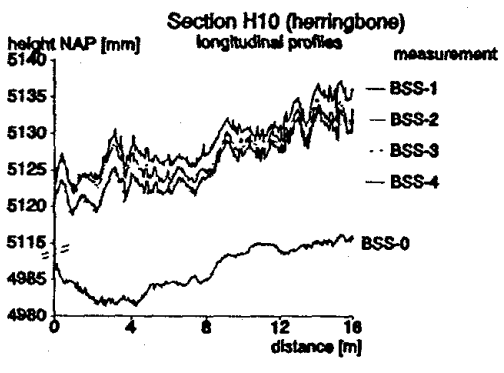


Figure 6: Longitudinal profile (example)

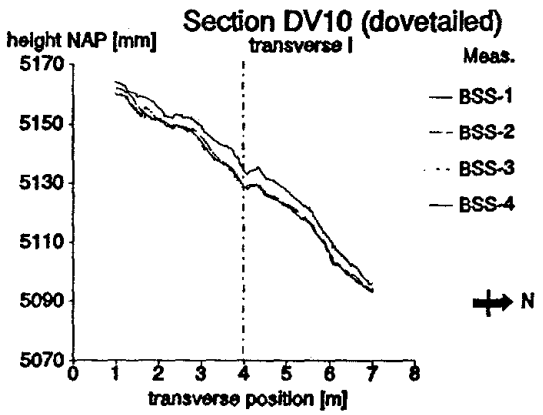
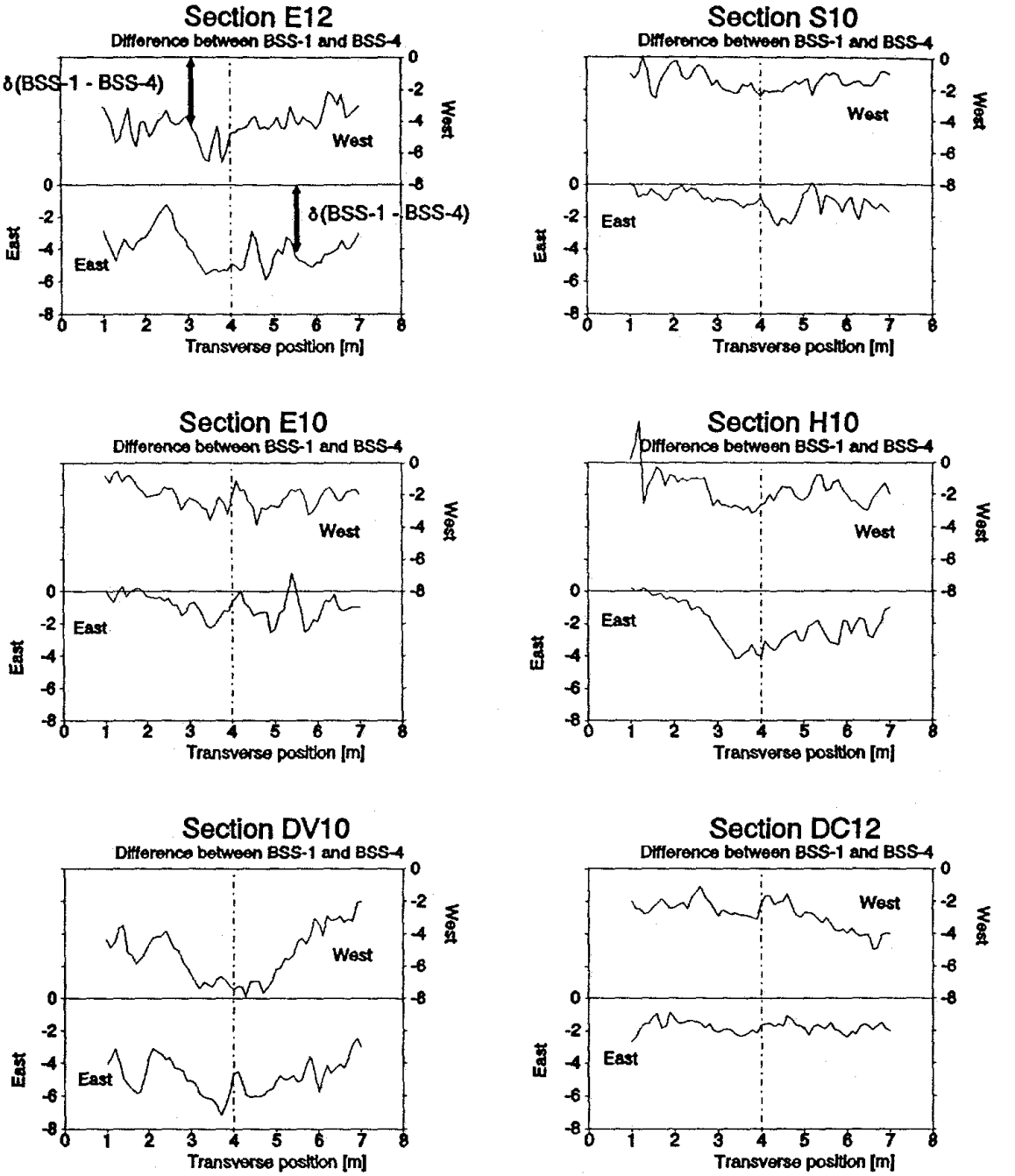


Figure 7: Transverse profile (example)



Figures 8 to 13: Difference between first and last transverse measurements

4.1.2 Geometric characteristics of the longitudinal profiles

From the longitudinal profiles the following parameters have been calculated: the Present Serviceability Index (PSI), the standard deviation, the settlement (difference between first and following measurements), the deviation area and the number of deviations > 3 mm under a moving 3 meter edge. The results are given in figures 14 to 17.

4.1.3 IRI (International Roughness Index, longitudinal profiles)

To try and compare the profile characteristics, as measured with the straightedge to the rideability measurements, the IRI-value of each longitudinal profile has been calculated according to

Sayers [6]. The International Roughness Index (IRI) basically is the accumulated vertical movement per unit of distance of a "quarter car" on a measured true longitudinal surface profile at a speed of 80 km/h. As an AGV has totally different characteristics (suspension, tyre pressure and dimensions, speed) an attempt has been made to adjust for these differences. Within the boundary conditions of the IRI computer code the parameters for speed and tyre baselength were adjusted (v=10 km/h, b = 600 mm).

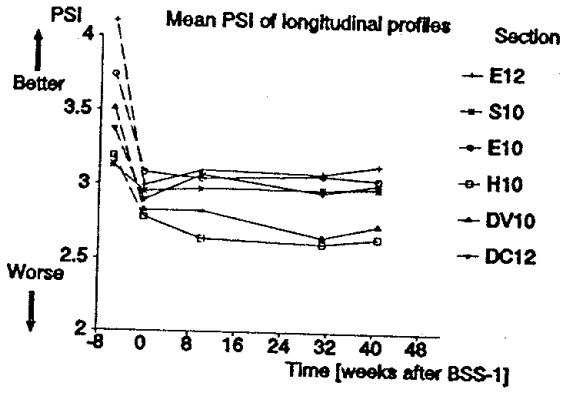


Figure 14: Time history of PSI

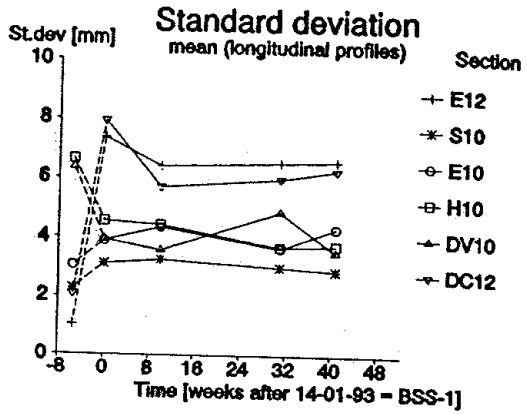


Figure 15: Time history of standard deviation

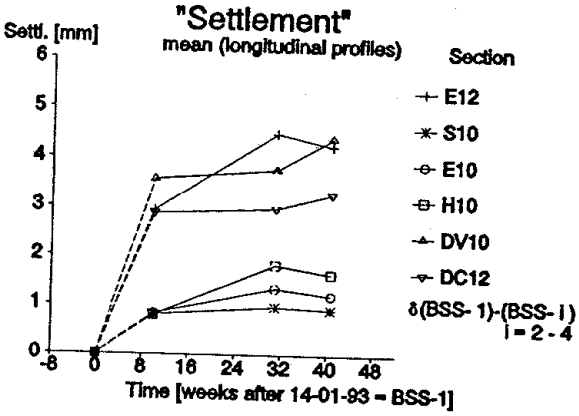


Figure 16: Time series of 'settlements'

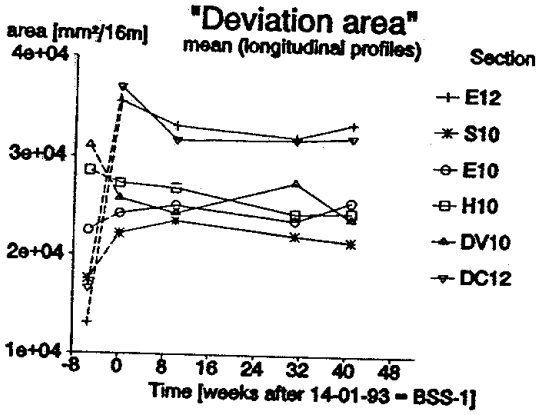


Figure 17: Development of deviation area

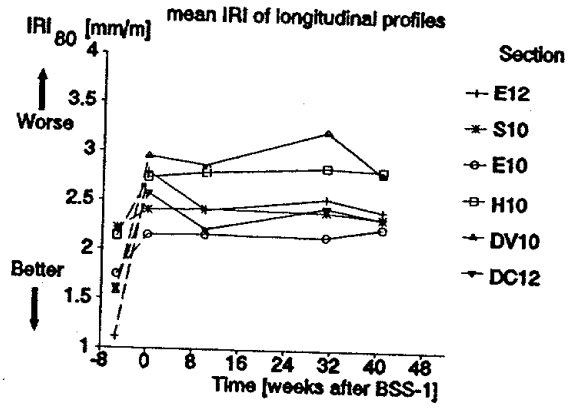


Figure 18: Time history of IRI

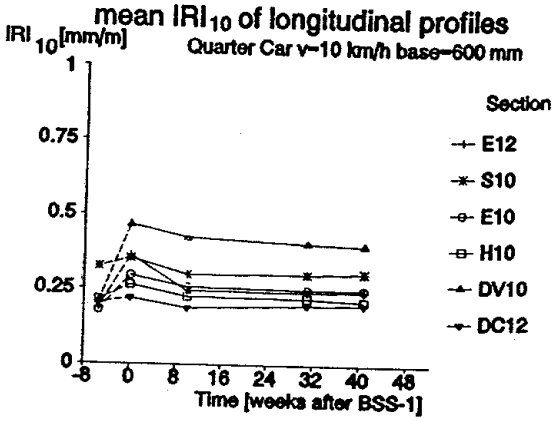


Figure 19: Adjusted IRI (IRI_{10})

In the majority of cases the evenness of the cement stabilised base (BSS-0) is better than the evenness of the overlaying block pavement. Also the ranking in initial evenness generally doesn't change over the period of observation.

4.1.4 Characteristics transverse profiles

Apart from the settlements (in figures 8 to 13) the standard deviation and the deviation under a 1.20 m edge (used in [7] to measure rutting) has been calculated.

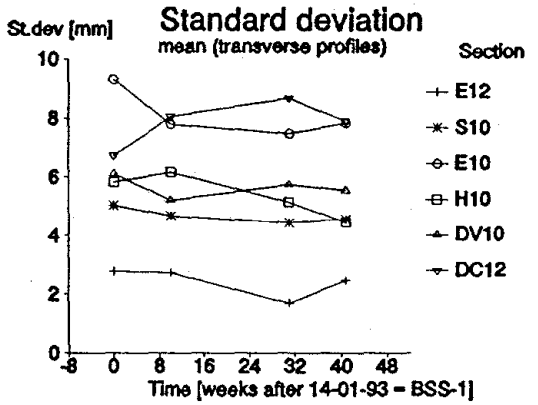


Figure 20: Standard deviation

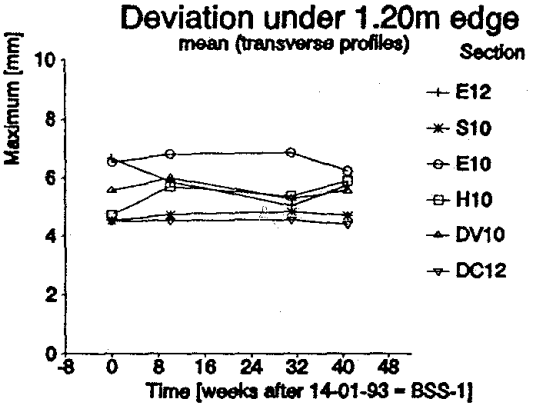


Figure 21: Deviation under 1.20 m edge (rutting)

4.2 Creep

In the two saw cuts per section have been no displacements measured except for the western cut in section H10. At the centre of the road a shift of 10 to 15 mm has been observed.

4.3 Visual inspection

The detailed condition rating brought to the fore that sections E12, E10 and H10 were slightly worse in comparison to the other three sections.In those sections 3 - 4 percent of the total area showed joint widths between 5 and 10 mm.

4.4 Rideability

As mentioned before, vertical acceleration has the most effect on the behaviour of vehicles. Therefore in the comparison of the K-values between the sections the K(horizontal) values have been left out. Vertical acceleration of an unloaded AGV is significantly greater than of a loaded AGV (see figures 23 and 24). This result was not unexpected, because the AGV and the tyre pressure (1.0 MPa) are adjusted to a loaded vehicle. In figure 22 the two rideability measurements are compared.

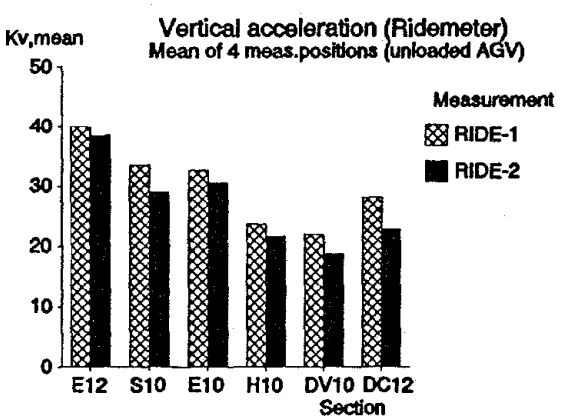


Figure 22: Kv-values Ride-1 and Ride-2 unloaded AGV

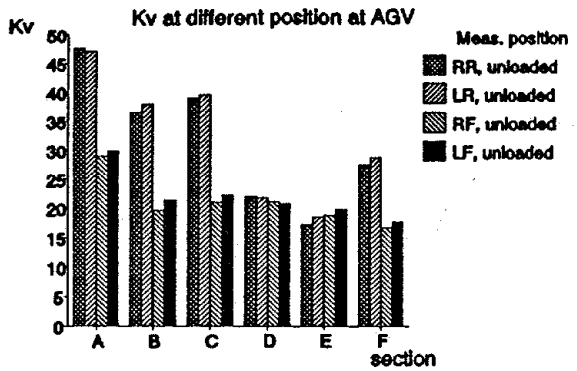


Figure 23: Unloaded AGV

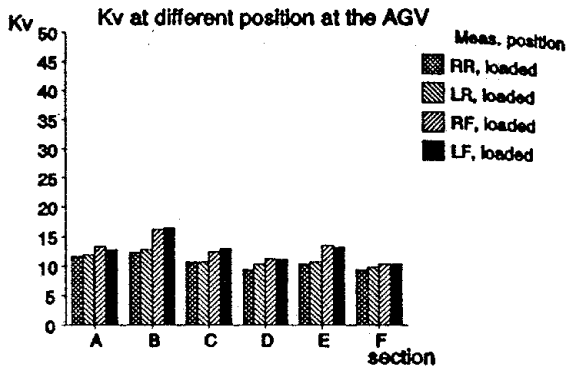


Figure 24: Loaded AGV

5 Evaluation

The sections show no great changes within the observation period. The absolute height above sealevel of the levelling points in some sections has diminished so a general settlement has taken place between the measurements BSS-1 (just for opening of the supply-road) and BSS-2 (two months later) and BSS-3 (seven months later). The northern side and the centre of the pavement show more of this settlement than the southern side (north side is from and south side is to the terminal). An overview of the performance of all sections in all aspects investigated is given in table 1.

Table 1: Results of evenness and rideability measurements

Measurement		test section					
		E12	S10	E10	H10	DV10	DC12
longitudinal evenness	IRI_{80}	0	0	0/+	-	-	0
longitudinal evenness	PSI	0/+	0	0	-	-	0
longitudinal evenness	adjusted IRI (IRI_{10})	0	0/-	0	+	-	+
longitudinal evenness	st.dev.	-	+	0	0	0	-
longitudinal evenness	dev. area	-	+	0	0	0	-
transverse evenness	rutting	0	0/+	0/-	0	0	+
transverse evenness	st.dev.	+	0/+	-	0/+	0	-
settlements		-	0/+	0	0	-	-
rideability (vert. acceleration)		-	0/-	0/-	+	+	0/+
visual condition		-	0	-	-	0	0/+
total weighted rating		0/-	0/-	0	+	0/+	0/+

In the comparison of the different types of block pavement the Ridemeter and the calculated (adjusted) IRI (IRI_{10}) are the most important aspects, since these aspects have a bearing on the behaviour of the AGV's. The other calculated quantities are more important for passenger cars

and are of lesser importance in this project.

6 Conclusions

From this test it would appear, that the type of block paving has an effect on the rideability (of AGV's) and that herringbone bond would be the favourite, followed by dovetailed and double element, both in stretcher bond. However the initial ranking of the different sections was maintained throughout the test, which could mean that this test has shown which type of paving can be mechanically laid most evenly rather than showing what type of block pavement performs best in the long run.
To answer the last question the test must be followed up for some considerable time or the pavement must be loaded by accelerated trafficking.
An investigation in the UK [9] concluded that for pavements on stabilised bases, the type of block does not affect the performance of the pavement, which is another reason to continue the test.

References

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[9]. Knapton J., A review of concrete block pavements at ports in the UK, proceeding 3rd International Conference Block Paving, Roma, 1988.

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