

The rehabilitation of the Antwerp Ring Road in CRCP

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Abstract.

The rehabilitation of the Ring Road of the city of Antwerp is, without doubt, the largest and most discussed road construction project undertaken in Belgium in recent years. The Antwerp Ring Road is one of the most trafficked freeways of European importance. Six radial freeways are tying into it and traffic volumes on its busiest sections are nearing 200000 vehicles per day, 25% of which are heavy trucks.

The dual carriageway of the Ring is 14.2 kilometers long. The number of lanes varies from four to seven in each direction. Along with 30 kilometers of access and exit ramps on the interchanges, the project comprises a total of 100 hectares of pavement requiring renewal and full recycling.

Considering the economic importance of the Ring for the Port of Antwerp, the rehabilitation works envisaged a safe, modern and efficient Ring Road, having a low maintenance pavement with a service life of at least 35 years. Based on a Life Cycle Cost Analysis and a Multi Criteria Analysis, a continuously reinforced concrete pavement has been chosen for the main part of the Ring Road.

The complete pavement structure is being renewed and consists of 23 cm of CRCP, a 5 cm thick bituminous inter-layer, 25 cm cement stabilized granulated asphalt rubble and 15 cm granulated lean concrete rubble. A fine exposed aggregate surface combines a good skid resistance with a low level of rolling noise.

The paper describes the presently applied common practice for the construction of CRCP in Belgium (longitudinal and transverse reinforcement steel, tie bars, anchoring abutments...) and highlights the details of execution as they have been applied for the rehabilitation works. Some particular aspects are the use of a new type of terminal joint and the design and construction of CRCP with variable width on the auxiliary lanes. By the latter method of construction, only short transverse transition joints occurred between the CRCP on the auxiliary lanes and the asphalt pavement on the ramps.

The experience in designing and constructing this ambitious project will certainly contribute to a further development of the technique of CRCP in Belgium and in other countries.

Introduction

General description of the R1. On May 31, 1969 the Ring Road “R1” around the city of Antwerp was opened to traffic.

The R1 is an urban freeway located at approximately 3 km from the centre of the city.

The most recent rehabilitation works were executed between 1976 and 1977. At that occasion some areas of the ring road were widened up to 7 traffic lanes.

Today, after 35 years of service, the maximum traffic intensity on the R1 is nearing 200000 vehicles per day, which makes it to one of the most trafficked freeway links in Europe.

As depicted on Figure 1 the ring road comprises the J.F. Kennedy tunnel in the southwest and the Merksem viaduct in the northeast.

Several fully directional interchanges provide the link with 6 radial freeways tying into the R1. Due to the vicinity of the ring with regard to the city centre local access and exit ramps are provided as well.

The Kennedy tunnel, named after the late American President J.F. Kennedy, connects the left and right bank of the river Schelde. The tunnel is 690 m long and comprises amongst others 2 tubes for automobile traffic, each tube having 3 lanes of 3.75 m wide.

The Merksem viaduct has a total length of 1700 m and a maximum height of 15.13 m and accommodates 2 x 4 lanes plus a shoulder.

Surrounding area. From the Kennedy tunnel up to the approach to the viaduct, the ring road has been designed in a wide open cut below the general natural ground level. At the time of the original design this choice was made in order to maintain the crossing radial urban arteries and roads at the natural terrain level. Furthermore urban planning considerations pertaining to the densely built-up urban area reinforced this concept as well.

Given the fact that the natural ground water level varied between 2 and 4 m below the natural terrain level, an extensive and permanent sub-surface drainage system was realised in order to ensure that the groundwater level in the wide open cut is lowered well below the sub grade of the ring road pavement. This drainage system along with the storm water network has a total length of around 170 km.

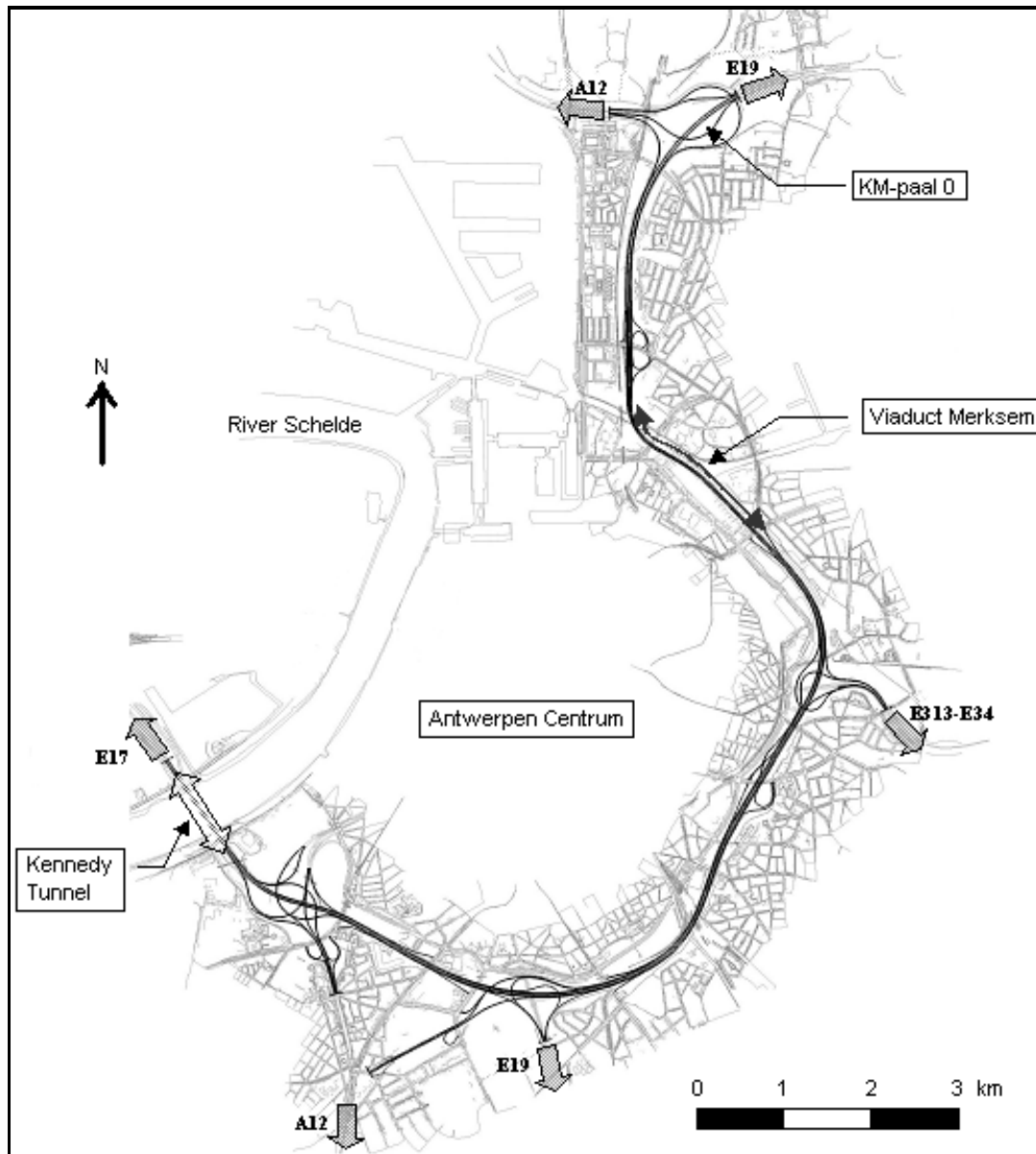


Figure 1 – General ground plan of Ring round Antwerp.

Structural rehabilitation of the R1. The project “Structural Rehabilitation of the Antwerp Ring Road”, called hereinafter the “R1” project comprises the comprehensive renovation of the freeway starting at the western end of the Kennedy tunnel up to and including the interchange with the A12/E19 freeways in the north. It also includes the rehabilitation of all ramps and loops of all interchanges with the radial freeways and of all local entrances and exits.

The subject paper covers the rehabilitation of the pavement of the R1 in general and the most important innovative techniques or approaches with regard to the execution of the CRCP-pavement in particular.

This project is unique due to its size (total construction cost of approximately 100 million Euros) the extremely short execution period (2 x 5 months) and considering the large scale of alleviating mobility measures within the city of Antwerp and its surroundings.

The construction period was split up into two main periods. In the beginning of November 2004 the first main period (rehabilitation of the outer ring) was completed. The works of the second main period (rehabilitation of the inner ring) are being executed from April 2005 till September 2005.

Study and design.

Testing programme. Considering the large scale of the project and taking into account the international importance of this transport facility the technical study was started by an extensive testing programme (by means of visual inspection, falling weight deflectometer, and research of drilled cores) in order to determine to what degree the rehabilitation works were needed.

Based on this test programme and considering the required minimum lifetime of 35 years it was concluded that it was necessary to renew the existing pavement structure over its full depth.

Traffic regulation during the rehabilitation works. Considering the fact that the traffic intensity can rise up to 200000 vehicles per day, which is nearing the full capacity of the R1, a thorough traffic study was made of several possible scenarios for the traffic regulation during construction of the works. In this study the most important preconditions were accounted for i.e. an as short as possible construction period along with a realistic guarantee of the mobility without jeopardizing the quality and thoroughness of the rehabilitation works.

Because of the international importance for the through traffic on the R1 and the radial freeways tying into it, several multi-modal traffic regulation measures are implemented both in the immediate vicinity of the project and at long distance.

On the R1 itself all traffic is prohibited on the carriageway that is being rehabilitated. All local entrances and exits are closed. Local traffic has to use the at grade city ring which is temporarily equipped with prefabricated fly-over structures.

Furthermore all through traffic is detoured by means of minimum 2 x 2 lanes on that carriageway on which the rehabilitation works are not in progress. From and to this carriageway a thoroughfare with a minimum width of 1 lane has to be provided for the through traffic to and from the interchanges with the radial freeways.

As a result of this regulation the carriageway being rehabilitated becomes available for construction over its full width and length with the exception of the at grade thoroughfares to the interchanges.

Choice of type of pavement. An important part of the study pertained to the choice of the type of pavement material.

Considering the limited space because of the requirement to maintain traffic on at least 1 lane and due to the relatively small radii of the alignment curves it was immediately decided to use asphalt for the pavement of the ramps of the interchanges.

For the new pavement on the actual Ring Road a thorough comparative study was made of the type of new pavement structure to be used, i.e. asphalt pavement versus continuously reinforced concrete pavement (CRCP).

At first a Life Cycle Cost Analysis was made. This involves a economic appraisal. Subsequently a Multi Criteria Analysis was made in order to take into account in the appraisal the non-budgetary aspects as well.

In the Life Cycle Cost Analysis the Constant Value Method over infinite horizon is used, i.e. it is determined how much money one has to reserve now for the construction today and the maintenance and the re-construction in the future.

The comparison indicated that, at the moment of initial construction, an asphalt pavement is less expensive than a CRCP. On the long term, taking also into account future rehabilitation and re-construction costs a CRCP is less expensive.

Upon performing the Multi Criteria Analysis besides economical aspects other aspects were considered as well such as amongst others noise, recycling, comfort, safety etc.

This analysis resulted in a score of CRCP that was slightly better than that of an asphalt pavement.

Based on this comparative study the decision was made to renew the pavement on the actual Ring Road using CRCP with the exception of the asphalt pavement on the viaduct and in a short zone between the Kennedy tunnel and the first under-bridge.

Unlike the pavement on the Ring plain concrete was used in the Kennedy tunnel. This choice was made because of the difficult circumstances regarding the supply of fresh concrete. Furthermore a CRCP would have required relatively expensive terminal systems at both ends of the tunnel shaft.

Number of lanes and cross fall. The number of traffic lanes on the 7 km long section of the R1, which is being executed in CRCP varies according to the location from 4 up to a maximum of 5 to 7.

The largest number of lanes occurs in the weaving sections of the exits and entrances of the interchanges. In an attempt to accommodate the ever-increasing traffic flows the R1 was widened in certain areas. This is the reason why at present no shoulders are available along certain parts.

Where compatible with the geometry a crowned cross section is applied in order to ensure an adequate surface run-off. The minimum cross slope is 2.5%. Where geometrically required a superelevation is introduced.

On the interchanges the number of traffic lanes varies from 1 to 2.

Basic design options. The basic technical options mentioned hereinafter were of direct influence on the design and concept of the new CRCP.

1. A densely built-up area adjoins the R1 on both sides. Although the R1 is mostly situated in a deep open cut it was nevertheless decided to take extra measures to abate the noise produced by the intense traffic. Therefore a noise-reducing concrete pavement surface was opted for.
2. In order to abate the detrimental influence of the edge effect the width of the concrete pavement is increased beyond the edge of the outer traffic lane
3. Longitudinal joints between concrete pavement and asphalt pavement are avoided as much as possible. Such joints, which are discontinuities in material as well as in method of execution, are often subject to premature deterioration especially when they are intensely trafficked by heavy vehicles.
4. Irregardless of the changing number of traffic lanes on the R1, it is purposely opted for to construct the pavement in CRCP over the full width of the carriageway, i.e. from the median up to and including the auxiliary lanes and/or the shoulders. This allows to permanently transform the paved shoulder into an additional traffic lane in the future or to use it as a temporary lane during accidents or works. Furthermore this option helps to comply with basic design options N°s 2 and 3 above.

On Figure 2 a schematic ground plan of the varying number of traffic lanes is depicted.

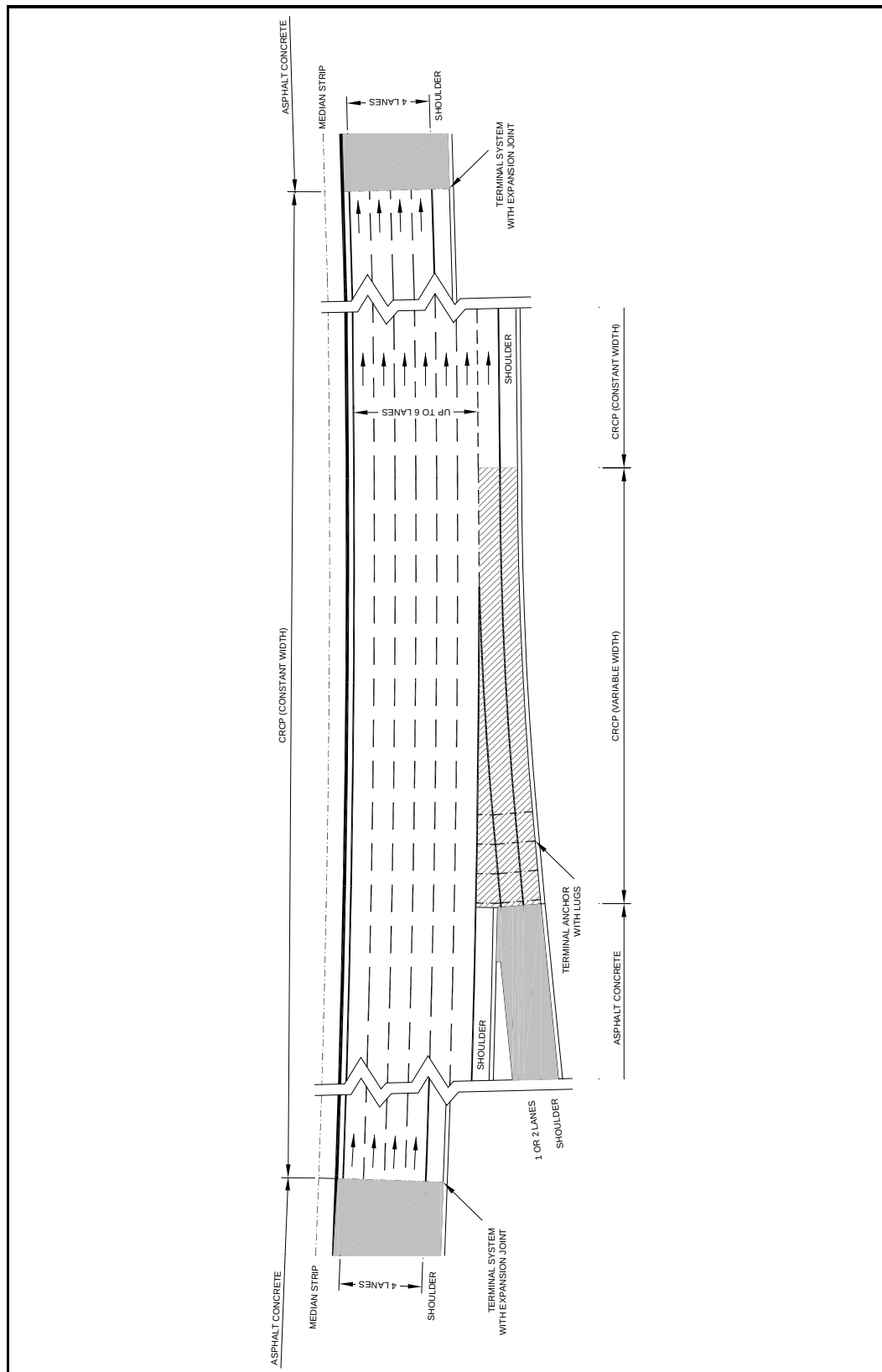


Figure 2 – Schematic ground plan main lanes and auxiliary lanes in CRCP.

Recycling. It was a major purpose of the rehabilitation project to apply recycling of broken-up materials to the maximum possible. This was a logical consequence of the very large quantities of broken-up and recyclable materials, of the envisaged short construction period, and last but not least, of the decision not to create additional traffic flows by hauling broken-up materials and by supplying new materials.

Due to these circumstances a detailed study was made of the opportunities for recycling. The envisaged service lifetime of the new pavement structure, the very large quantities of recyclable materials and the experiences in Belgium and abroad were taken into account in this study.

Recycling in itself is not new but the large scale that was at stake was new and unique in Belgium.

As a result of the recycling study the existing asphalt pavement was recycled

- partly in the new bituminous pavement mixes
- partly in the new cement bound coarse granular base. In order to arrive at a continuous gradation and at a maximum density of the base after compaction, it was necessary to add 15 % to 20 % sand.

The existing road base, which consisted either of lean concrete or of coarse aggregate, was broken-up and recycled in the granular new sub-base.

Dimensioning of CRCP. The thickness design of the pavement was made according to the standard “Wegstructuren, Version 2” (Ref.) of the Ministry of Public Works of Flanders, Belgium. This method is based on the determination of the traffic expected to use the pavement, expressed in terms of cumulative 100 kN equivalent standard-axle load applications during the design period.

From this the Pavement Class and the corresponding slab thickness design are derived. The main variables in the method concern the CBR-value of the sub grade, the lane distribution factor, the traffic volume and the percentage of heavy trucks (up to 25 % for the R1), the design speed and the design period.

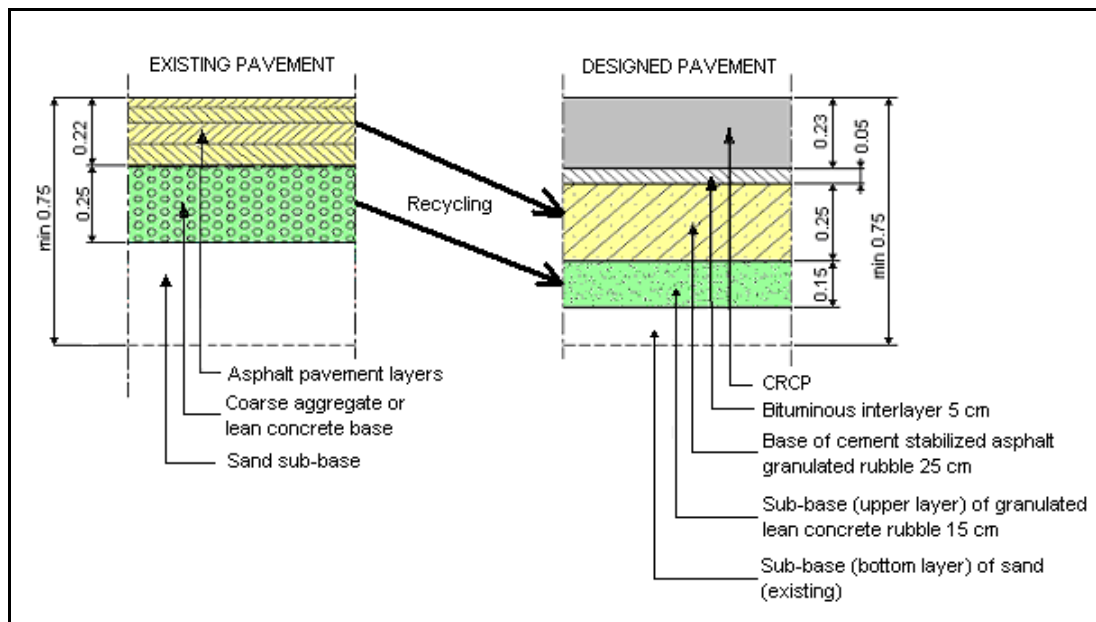


Figure 3 – Existing versus designed pavement structure.

Characteristics of the concrete. A fine texture of the pavement surface renders good results with regard to noise abatement. The best abatement result is attained when the exposed aggregate granules are spaced at 5 to maximum 10 mm. In order to comply with Design option 1, two measures were taken. As surface finish an exposed aggregate concrete was applied. In addition to this a fine concrete mix was utilized. This mix complies with the following specifications:

- The stone grading to be used is 4/7, 7/14 and 14/20 mm. The amount of 4/7 aggregate has to be at least 20% of the total granular mix (sand and coarse aggregate). The percentage of sand was kept as low as possible for as far compatible with an adequate workability.
- The water/cement ratio is less than 0.45
- The minimum amount of cement is 400 kg/m³
- The use of an air-entraining agent is compulsory

Standard concept for CRCP in Belgium. The concept of the CRCP for the R1 is based on the standard practice in Belgium.

A bituminous interlayer is always placed between the base and the CRCP (Figure 3).

The position as well as the diameters of the reinforcing steel is dependent on the thickness of the CRCP to be constructed. The longitudinal reinforcing steel and the transverse steel amount to a total percentage of reinforcing steel of 0.74 %. A schematic arrangement of the steel is shown in Figure 4.

For the pavement of the R1 the longitudinal steel (BE 500 S) consists of deformed bars diameter 20 mm spaced at 0.18 m c.t.c. They have a minimum length

of 14 m and are placed on top of the transverse reinforcing steel. When splicing longitudinal steel the minimum lap is 35 bar diameters ($35 \times 20 = 700$ mm or 0.70 m) with a skewed splice pattern as depicted on Figure 4 and whereby having more than one splice in the same transverse plane is kept to a minimum.

The transverse reinforcement (BE 500 S) consists of diameter 12 mm deformed bars. They are spaced at 0.70 m and are supported on steel chairs, which are placed on the bituminous interlayer.

The transverse reinforcing bars are placed at an angle of 60 degrees to the longitudinal steel. When placed at a right angle it is expected that the bars could be crack-inducing and could thus influence the crack pattern.

Tie bars diameter 16 mm are placed across each longitudinal construction joint. These tie bars have to be placed by drilling holes at a right angle to the longitudinal joint at half the thickness of the CRCP and by subsequently chemically anchoring the tie bars. The spacing can vary from 0.80 m to 0.85 m so as to avoid interference with the transverse steel bars.

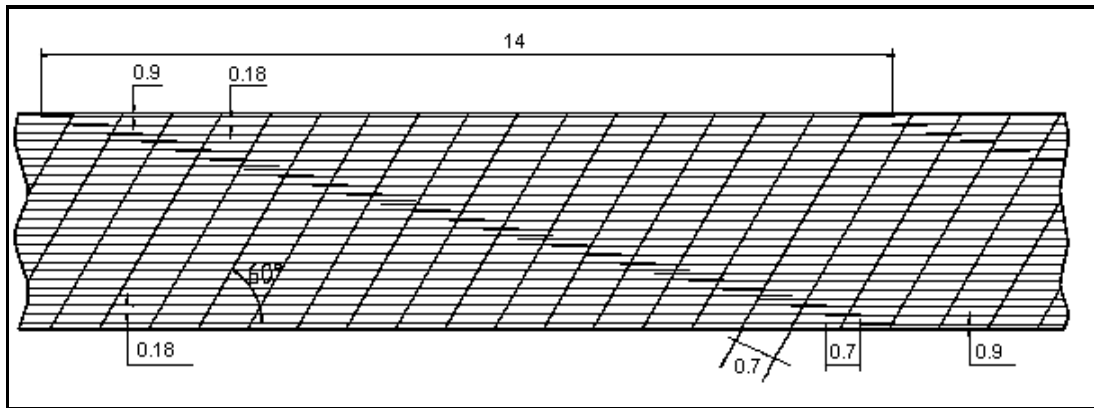


Figure 4 – General arrangement of reinforcing steel.

Over width of the outer traffic lane. The stresses in a concrete slab are increased considerably when the load is located near the edge of the slab. This so called edge effect has become even more critical due to the increased loads of the truck traffic (especially trucks with triple axles and overloaded vehicles).

One of the detrimental consequences of the edge effect is that it increases the potential of punch-outs along the edge of the outer traffic lane.

These high stresses can be decreased by constructing the CRCP with an extra width (see Design Option N° 2) where the shoulder consists of asphalt pavement or where no shoulder is available. By this measure the distance between the wheel track and the edge of the pavement is increased.

The edge effect in the outer traffic lane can also be avoided by executing the shoulder pavement in concrete as well.

On the R1 the latter solution has been adopted with the exception of a few isolated areas where a narrow shoulder was paved in asphalt. In these areas the CRCP on the mainline was executed with an extra width of 0.70 m (including the edge striping).

CRCP lanes with variable width. The ends of the auxiliary lanes to and from the ramps of the interchanges and the local ramps have mostly a variable width. A pavement of variable width can more easily be constructed in asphalt than in CRCP. However, because it was opted for to avoid longitudinal joints between asphalt and concrete in the traveled way, the auxiliary lanes were executed in CRCP for as far as they were adjacent to the CRCP of the mainline of the R1. In this way basic design options N°s 3 and 4 were complied with in that only transverse joints occur between the asphalt pavement on the ramps on the one hand and the CRCP along the mainline on the other hand. Furthermore these joints are kept as short as possible.

As a consequence of this decision the CRCP had a variable width at the ends of the entrance and exit lanes. Both straight and curved variations of width occur.

For short and transversally small variations in width, it is possible to construct the CRCP with a constant width while indicating the varying width of the traveled way by traffic striping. This method is also used for asphalt pavements.

For long and transversally large variations in width, the solution of constructing the CRCP with a variable width was chosen.

This solution is perfectly realizable in practice provided the phasing and the placement of the reinforcement and the concrete are well prepared in advance and are given the needed attention during execution.

In Figure 5 the principles are shown of the placement of the reinforcement and of the phasing of the concrete.

Considering the function of the longitudinal steel the alignment of the longitudinal bars of the ramp lane(s) deviating from the mainline was kept parallel to the horizontal geometry of these lanes. When the width of the CRCP slab becomes too large (± 5 m) a spontaneous shrinkage-bending crack will originate in a longitudinal direction. Therefore, a longitudinal saw cut was made from a width of more than 5 m on. The saw cut is stopped where the width becomes less than 5 m. At this location additional transverse reinforcement bars were placed (at half the normal spacing, i.e. 0.35 m in lieu of 0.70 m) in order to minimize the risk of a spontaneous developing of a longitudinal crack beyond the end of the saw cut.

Additional tie bars (at half the normal spacing i.e. 0.40 m in lieu of 0.80 m) along the longitudinal construction joint between the CRCP of the mainline and the CRCP with variable width, were deemed necessary to limit the risk of opening of the longitudinal joint.

The alignment of the longitudinal reinforcement bars of the triangular area between the main lanes and the ramp was taken parallel to that of the main lanes.

Consequently these bars abut the joint with the ramp at an angle. In order to avoid that this situation would induce cracks, 2 additional longitudinal bars are placed along this joint with the CRCP on the ramp.

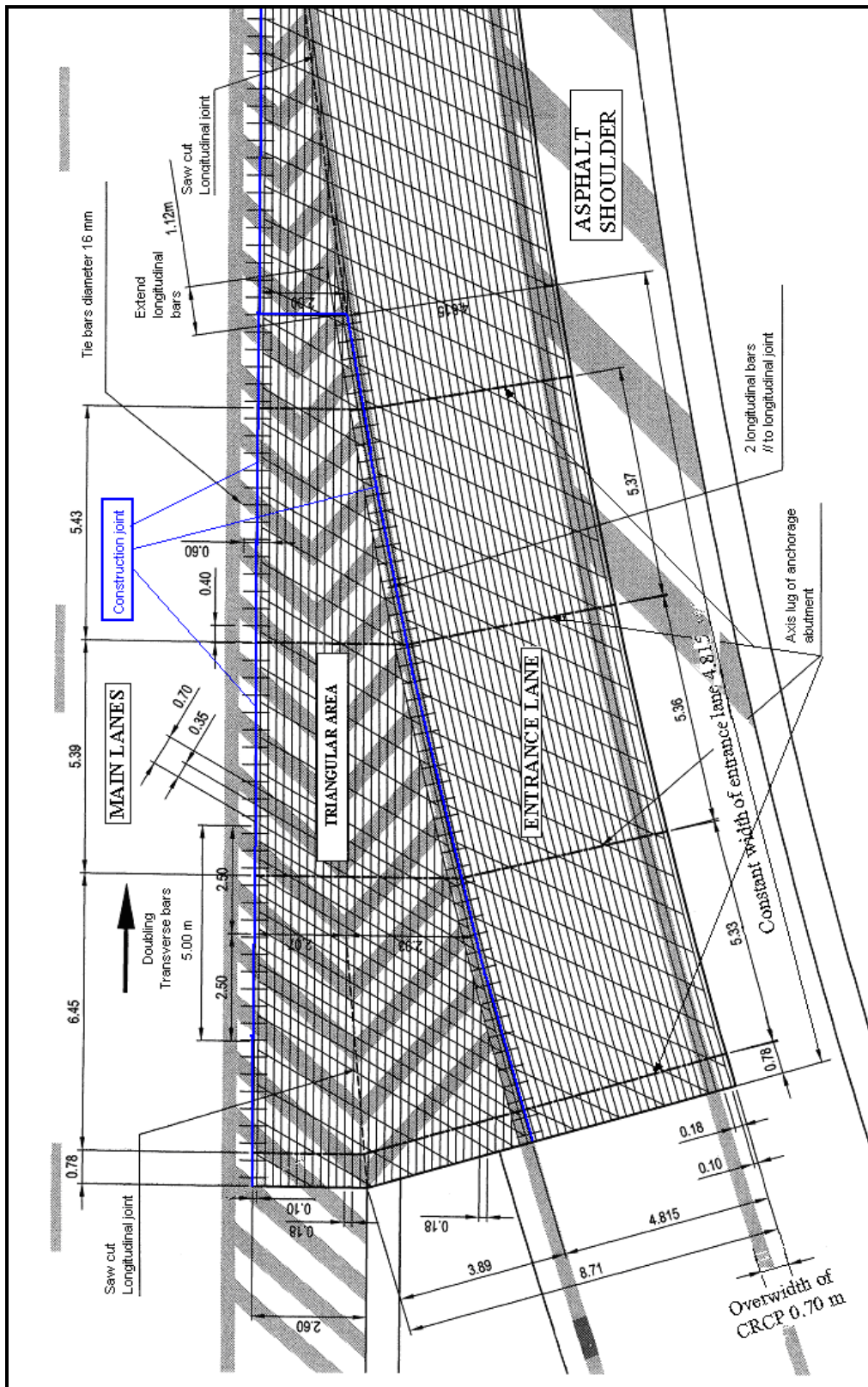


Figure 5 – Detailed layout reinforcement of entrance ramp in CRCP and shoulder in asphalt

Terminals for CRCP. The ends of the CRCP slabs are subjected to changes in length mainly as a result of changes in temperature. The length over which the movement at the ends occurs, the so-called active length is dependent on the friction between the slab and the underlying bituminous layer, on the temperature changes, etc. and amounts to about 125 m.

Where the continuity of the CRCP has to be permanently interrupted there are two possible solutions to cope with these terminal movements:

- the movement of the end is restrained by using end anchorages
- the movement of the end is accommodated by using a terminal joint

Anchorage abutment. An anchorage abutment is designed so that it can resist the forces that result from restraining the movement of the active length of the concrete. For this purpose the end of the concrete slab is equipped with transverse or longitudinal lugs, which are anchored in the sub grade. The degree to which the anchorage abutment resists the forces depends on the number and the dimensions of the lugs. Consequently it is possible to design the abutment such that the residual movement is practically nil.

The lugs are realized by excavating their shape in the sub grade and by placing the reinforcement and the concrete without the use of any side forms.

Figures 6 and 7 depict the dimensions and reinforcement of a longitudinal section of the standard type end anchorage abutment used in Belgium.

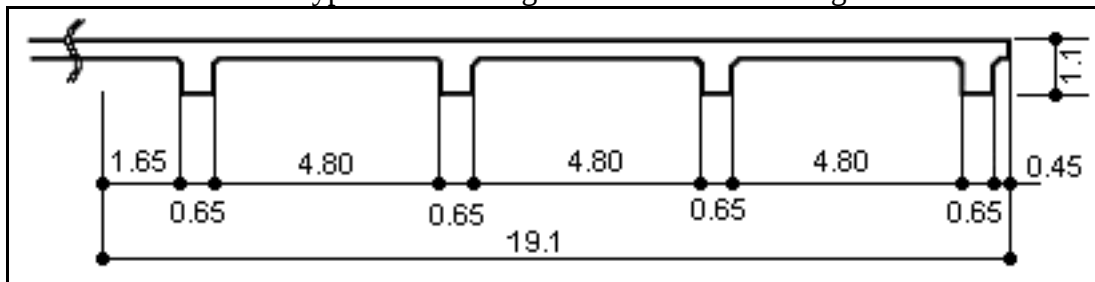


Figure 6 – Longitudinal section anchorage abutment.

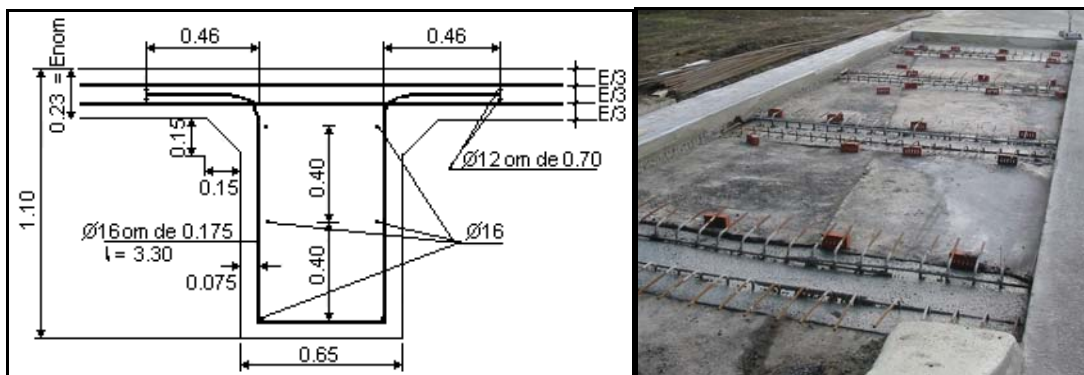


Figure 7 – Anchorage lugs.

Terminal joints. Unlike an end anchorage treatment terminal joints allow the free movement of the ends of the concrete. Figure 8 shows the details of the terminal joint designed for the R1 project. This design is an improvement of a formerly applied concept in Willebroek, Belgium.

The free expansion and contraction of the CRCP end is accommodated by means of a standard expansion joint used for bridges. The neoprene joint strap is attached to the metal clamps, which are anchored to a reinforced concrete beam on each side of the joint.

The concrete beam on the asphalt pavement side is supported on steel beams driven vertically in the ground. This support system is intended to ensure a proper load transfer across the joint and to avoid possible differential settlements or movements as a result of braking and acceleration forces.

The concrete heel beam on the concrete pavement side is anchored to the CRCP and is supported on a concrete foundation. The top surface of this foundation is to be finished smooth and covered with a bond breaker to allow free movement of the heel beam over the top surface of the foundation.

Upon contraction of the concrete pavement the movement of the heel beam should not be hindered. Therefore a void is foreseen on the backside of the heel beam to accommodate contraction.

In principle the terminal joint should be watertight. Water that might have infiltrated in the joint accidentally is discharged to the storm water network by means of a drain at the lowest points of the cross section of the carriageway.

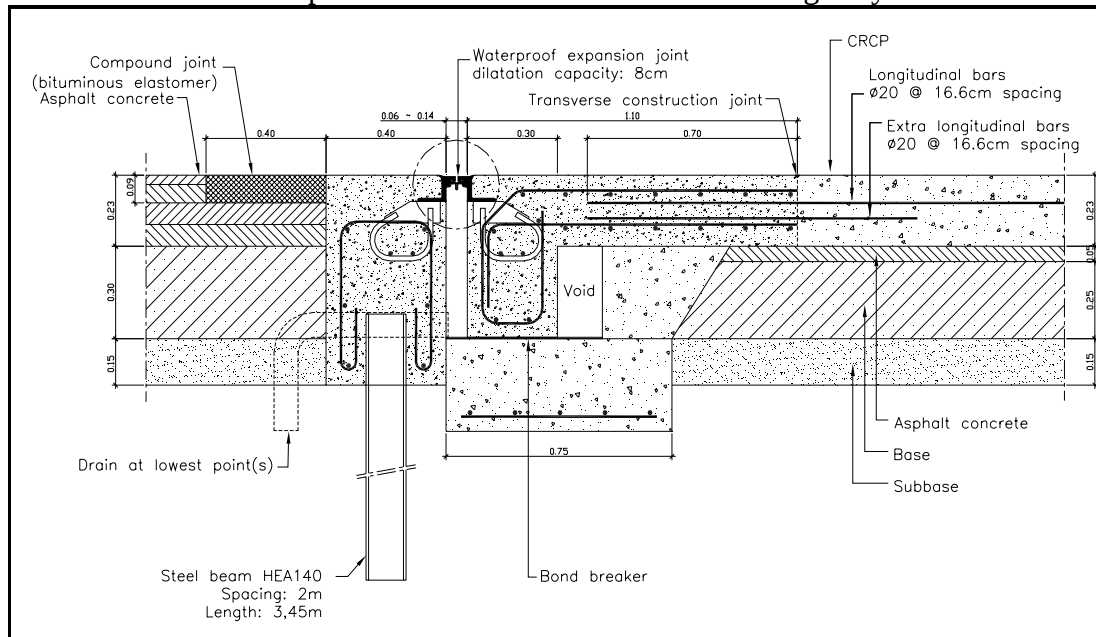


Figure 8 – Cross-section terminal joint.

Types of terminal systems used for the R1. In the USA both the terminal joint solution (e.g. wide flange beam) and the terminal treatment using anchorage abutments are used throughout various states.

In Belgium the Standard SB 250 specifies only the anchorage abutments. Notwithstanding this specification the terminal joint treatment detailed in Figure 8

was used at both ends of the CRCP on the mainline (4 through traffic lanes plus a shoulder) of the R1, mainly because of the substantially lower price.

As opposed to the terminal treatment of the CRCP on the main lanes one has no choice regarding the type of treatment of the ends of the CRCP of the auxiliary lanes. Indeed, it is necessary that the behavior of the CRCP on the auxiliary lanes be as much as possible the same as that of the adjoining CRCP on the mainline.

As the CRCP of the main lanes is not subjected to longitudinal cyclic movements at the location of the intermediate auxiliary lanes, it was necessary to utilize anchorage abutments to restrain their ends. The number of transverse lugs was designed so that the residual movement was limited to 4 mm. This was considered acceptable and resulted in terminal anchor abutments having 4 lugs each. This solution is shown on Figures 2, 5, 6, and 7.

In addition to these anchor abutments the doubling of the number of tie bars in the longitudinal joints between the mainline CRCP and the CRCP on the entrance and exit lanes help to avoid opening up of these joints.

Construction

Time schedule. The international importance of the R1 along with the extremely high average daily traffic volumes necessitated to keep the construction period as short as possible. This construction period was limited to 140 calendar days during construction period 1 for the Outer Ring and to 150 calendar days during construction period 2 for the Inner Ring.

In addition to these short construction periods a working time of 16 hours per day, 7 days a week was imposed for the rehabilitation works on the mainline. The rehabilitation works in the Kennedy tunnel had to be carried out continuously, 24 hours a day, 7 days a week.

Along with the pavement rehabilitation works, 170 km of storm water sewers and drainage pipes, 9 utility tunnels under the R1 and many bridges had to be rehabilitated within the same construction periods mentioned above. This comprehensive programme of rehabilitation works required an integrated organization and coordination in order to realize both qualitatively and quantitatively the works within the requirements of the specifications.

Construction site. A separate temporary haul road was built over the entire length of the project. This road was also intended for use by emergency vehicles and crossed the ramps of the interchanges by means of temporary grade separations.

In order not to overload needlessly the surrounding roadway network the provision of two construction plants on the construction site itself had to be foreseen. These plants were utilized to recycle the broken up materials and to supply the concrete.

A continuous blinding screen on the median ensured a visual separation between all through traffic detoured on one carriageway and the construction operations on the other carriageway.

Fragmented construction of the CRCP. The selected regulation of traffic during execution along with the envisaged basic design options necessitated a well thought-out phasing and organization of the works and resulted in a construction phasing of the CRCP, which was fragmented both longitudinally and transversally.

The placement of the CRCP for the R1 had to be split-up in a number of phases, which is more than usual for CRCP. Several circumstances mentioned above caused this situation. The main aspects and difficulties of this method of construction are described hereinafter.

Zones of constant width. It was impossible to execute the pavement at once over its full width. Not only the great total width of the carriageway but also the presence of reinforcement inherent to casting CRC made this impossible.

In principle the 4 through lanes were cast (from the median towards the outer edge) in widths of 2 lanes (2 x 3.75 m) or 1 lane plus a shoulder. Subsequently the adjoining entrance and exit lanes were cast. The casting widths varied according to the number of lanes, the presence of a shoulder in CRC and/or the necessity to foresee an overwidth of the outer lane at those locations where no shoulder was available or where the shoulder pavement was of asphalt.

Zones of variable width. As described above the R1 has many entrance and exit lanes. At the ends of these lanes the CRCP had to be placed with variable widths from narrow to wide. This required not only a well prepared sequence of supply and placement of the concrete but also a detailed plan of construction joints with all related special arrangements of reinforcing bars and tie bars.

All sections having a variable width were also cast by slip-form paver.

Longitudinal leave-outs. Due to the requirement that all ramps of the interchanges had to remain open to traffic at all times, it was inevitable that the traffic had to cross at grade the carriageway where the rehabilitation works were in progress. As a result of this the execution of the CRCP could not be realized in one continuous operation from the beginning to the end of the mainline pavement. It was necessary to leave a gap of about 300 m long and to temporarily end the newly placed CRCP by a transverse construction joint at both ends of the gap. Four suchlike leave-outs spread over a distance of about 7 km had to be realized.

The leave-outs were paved after detouring the traffic. This too required a detailed scheduling and coordination of the placement of the reinforcing steel and the concrete. The traffic on the leave-outs could only be briefly interrupted outside peak hours to allow the passage of the slip-form paver across the leave-out.



Figure 9 - Photograph of leave-out.

Precautions at leave-outs. At the leave-outs a period of 7 days on the average elapsed between the pours of the concrete. It was necessary to restrain the movement of the free ends of the newly placed CRC on both sides of the leave-outs in order not to distress the bond between the bituminous interlayer and the CRCP. This restraining precaution is necessary until the moment of paving the leave-outs.

Restraining could have been realized by means of anchor lugs. Because of the high construction cost of anchor lugs a cheaper solution (which was temporary anyhow) was chosen. The solution consisted placing over the full width of the concrete a moist layer of sand, 0.50 m thick and 50 m long insulating on both ends of the CRCP adjoining the leave-outs. This layer insulates the concrete and restrains the temperature changes and thus the movements too. A length of 50 m was considered adequate because of the limited variation of the temperature that could be expected within this temporary situation. A plastic foil is placed under the sand to protect the newly placed concrete. The sand layer has to be kept moist and should be kept in place until 1 day or less before paving the leave-out. Removal of the sand shall be done with care in order not to damage the pavement surface.

Once the paving of the leave-outs had begun it was sometimes necessary to remove the sand in order to allow the passage of the slip-form paver and the supply of the concrete. It was therefore in such circumstances permitted, as an exceptional measure, to remove the sand over a limited width and during a short period provided meanwhile the concrete surface was moistened regularly in order to limit the temperature changes as much as possible.

Placement of the concrete. Subsequent to the placement of the bituminous interlayer and the reinforcing steel the concrete was cast using a CMI Model HVW 2000 slip-form paver capable of placing CRC widths of up to about 10 m.

The paver was equipped to cast concrete slabs with variable width. The casting was done from narrow to wide because the reverse would have caused heaping of the concrete in front of the paver.

Considering the fact that the surface regularity of the track for the caterpillar of the slip-form paver is of great influence on the surface regularity of the finished concrete, stringent requirements were applicable for the quality of this track. The track needs to have an adequate bearing capacity, has to be sufficiently rough and has to comply with the same surface finish tolerances as the CRCP surface itself.

Open bin trucks were used to transport the concrete from the site plants to the paver. Tarpaulins are required upon warm weather conditions.

After application of the surface retarder, the concrete is protected against drying out or rain by means of a plastic sheet. The next day the surface mortar layer is washed out. Subsequently the longitudinal joints are saw cut and chamfered. Then the joint sealant is placed.

The concrete is finally protected against drying by application of a curing compound.

Conclusion. The rehabilitation works of the outer Ring of Antwerp in 2004 have been successful both in the technical field and in the field of traffic alleviating measures. This pioneering experience will certainly be useful for the inner Ring and for the future comparable rehabilitation project.

On the pure technical level, very useful experience has been gained with the large-scale execution of CRCP with variable widths. The same applies to the design and construction of a new type terminal joint accommodating the movement of the CRCP ends.

The findings in the design and execution of this ambitious project will certainly contribute to the further development of the CRCP technique in Belgium and elsewhere.

Last but not least the experience with the rehabilitation of the pavement of the outer ring has proven that a high quality of CRCP can be obtained under difficult circumstances provided that the phasing and important details of construction are well studied beforehand and are continuously monitored during construction.

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