ABSTRACT
In Belgium, as in many European countries, traffic at major junctions is managed increasingly by constructing right-of-way roundabouts, which allow safer and smoother traffic flow. The intense heavy traffic at these roundabouts induces extreme stresses in the pavement, both as a result of centrifugal forces as well as the overloading exerted by the offside wheels of tilting vehicles. The effects of such stresses include rut formation, the sideways displacement of the wearing course, the loss of surface aggregate, and cracking as a result of insufficient bearing capacity in the road structure beneath the offside wheels.

These findings encourage designers to think of ways of using continuously reinforced concrete for the construction of roundabouts, with the result that the first such roundabouts were built in 1995 and are still in excellent condition today. There can be no better demonstration of the suitability of this technique for application on a larger scale.

This paper deals with the design and construction specifications of roundabouts in continuously reinforced concrete.

KEY WORDS
ROUNDABOUTS / CONTINUOUSLY REINFORCED CONCRETE / DESIGN / CONSTRUCTION SPECIFICATIONS

1. INTRODUCTION
In Belgium, as in many other European countries, traffic at major junctions is managed increasingly by constructing right-of-way roundabouts, which allow safer and smoother traffic flow. The intense heavy traffic at these roundabouts induces extreme stresses in the pavement, both as a result of centrifugal forces as well as the overloading exerted by the offside wheels of tilting vehicles. The effects of such stresses include rut formation, the sideways displacement of the wearing course, the loss of surface aggregate, and cracking as a result of insufficient bearing capacity in the road structure beneath the offside wheels. These observations led to continuous reinforced concrete (CRC) being considered for use for the construction of roundabouts. The first such roundabouts were built in 1995.

2. WHY SPECIFY A PAVEMENT IN CONCRETE OR IN CONTINUOUS REINFORCED CONCRETE?
Two reasons in particular justify the choice of a concrete pavement for roundabouts, namely:

- the elimination of the risk of deformation due to the loads imposed by heavy goods vehicles moving at a moderate speed;
- the elimination of the slippage of the wearing course as a result of loads caused by centrifugal forces.
When designing a concrete slab pavement for a roundabout, special attention must be given to the positioning of the contraction and construction joints. Indeed if the slabs are too large or are sharply angled the finished pavement may quickly develop unpredictable and undesirable cracks. The project designer must therefore carefully define the location of all the joints during the project design phase. When it is expected that the roundabout will have to bear higher volumes of traffic, the joints will of course be dowelled. Here too the satisfactory positioning of the dowels during the construction work is vital if the joints are not to become locked up.

Continuous reinforced concrete offers several important advantages:

- the presence of transverse reinforcement makes it possible to distribute the outward thrust due to radial loads;
- the presence of continuous longitudinal reinforcement makes it possible to eliminate the conventional contraction joints required in unreinforced concrete pavement and thus avoid loading at the corner of the slab.

Nonetheless the edge effects are still large and the dimensions of the structure and reinforcing must take this into account. One solution might be the provision of extra thickness in the lean concrete base on the outer perimeter of the roundabout, which would make it possible to reinforce the road structure in the most heavily loaded area (Figure 1).

![Figure 1 - Example of a standard transverse profile](image)

3. CONSTRUCTION OF ROUNDABOUTS IN CONTINUOUS REINFORCED CONCRETE

All the rules of the art applicable to conventional continuous reinforced concrete (CRC) pavements apply with equal force to roundabouts. The recommendations of the standard sets of specifications applicable to CRC must be complied with.

Various aspects will be discussed in the following, including formwork, steel reinforcement, manual concreting, or by using a slipform paver, as well as a number of more specific details.

3.1. Formwork

If the concrete is laid with the help of a slipform paver, the concrete pavement is laid prior to the other linear elements. On the other hand if the concrete is laid with a vibrating beam, the linear elements may be used as formwork, both on the inside and the outside of the roundabout. The formwork at the approach arms to the roundabout is provided by sturdy wooden planks which are as high as the thickness of the concrete to be used. These wooden elements may linked firmly together using fastenings embedded in the wood, so that the vibrating beam can slide over them without hindrance (Figure 2). They are held in place on the outer side by stabilized sand.
3.2. The reinforcing steel

Further to CCT RW 99, the longitudinal and transverse reinforcement use in roads should be installed in accordance with the principles illustrated in Figure 3 below. The arrangement of the reinforcement for a roundabout should comply with these principles with the exception of the various points indicated in the following. Moreover the reinforcement should comply with the specifications given in Table 1.

![Figure 2 - Fixed formwork made of sturdy planks installed on the access roads](image)

**Table 1 - Recommendations for reinforcement**

<table>
<thead>
<tr>
<th>Pavement thickness (mm)</th>
<th>200</th>
<th>230</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal diameter of the longitudinal reinforcement (mm)</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Nominal diameter of the transverse reinforcement (mm)</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Spacing (e) of the centrelines of the longitudinal reinforcement (mm)</td>
<td>130</td>
<td>180</td>
</tr>
<tr>
<td>Distance between the upper surface longitudinal reinforcement and the surface of the finished pavement (mm)</td>
<td>70 to 90</td>
<td>80 to 100</td>
</tr>
<tr>
<td>Height of the support (mm)</td>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>

The longitudinal reinforcement in a roundabout should exactly follow the curve of the roundabout. The length of overlap of the reinforcing elements should be at least 35 times the nominal diameter of the reinforcing steel, although it is difficult to maintain a constant angle of splicing $\alpha$ (to the perpendicular of the tangent of the axis of the road (the radius)). This means that the length of overlap should be varied as a function of the radius of the circle formed by the longitudinal reinforcement or that in other words the length of the longitudinal reinforcement should be reduced towards the inner edge of the roundabout ring. It is important, to avoid a concentration of splices in the same radial section, so that not all the splices lie on the same radial line.

The transverse reinforcement makes an angle of 60° to the tangent of the centreline of the road. Various configurations are possible halfway between the transverse bars. The first possibility for avoiding excessive spacing at the outer edge of the ring, is to leave a space of 70 cm between two transverse bars one third of the way across the width of the circulatory carriageways measuring from the outer edge. Additionally when building roundabouts with an internal radius of more than 20 m, an extra transverse bar is provided on the outer half of the circulatory carriageway in order to avoid any sudden changes in the thickness of the steel. These additional bars are staggered by one metre. A second alternative is to allow a space (orthogonal between two transverse bars) of no more than 70 cm at the outside edge of the circulatory carriageway and at least 20 cm at the inside edge. The length of the bars may thus be reduced in order to achieve this spacing of at least 20 cm at the inside edge.
Figure 3 - Road reinforcing steel plan in accordance with CCT RW 99

Figure 4 - When the roundabout has a diameter of more than 20 m, additional transverse bars are placed in the outer half of the ring, these are staggered by one metre

3.3. Concreting

3.3.1. Concreting using a vibrating beam

This technique has most often been used because of the possibility of adapting the vibrating beam to the width of the concreting work. The beam slides round on the inside of the ring on the edge of half-batter kerb or on the inner edge of the roundabout. In order to absorb any differences in the level of these edges, the vibrating beam bears on the kerb via an articulated intermediate beam with a length of at least 2m. It has to be possible to adjust the height of the beam with respect to the kerb in order to overcome the height of the upstand of the kerb.

After pouring and levelling the concrete using a crane (Figure 5a), and prior to the passage of the vibrating beam (Figure 5b), the concrete is vibrated by means of poker vibrators (Figure 5c). The
provision of one poker vibrator for every 1.50 m of width of the concrete is recommended. A smoothing rail can be used to get rid of any small differences in level due to stops made by the beam (Figure 5d).

3.3.2. Concreting using a slip-form paver

There are several obstacles in using this technique. A machine capable of concreting widths of least 8 m or even as much as 10 m is needed for large roundabouts. It is difficult to construct the onsets of access and exit roads as part of the same operation. If the concrete of the roundabout is laid all in one day, the cleaning of the machine after completing the concreting work must be done on pavement that has not completely hardened and the machine will be stuck on the roundabout for several days, i.e. during the time required for the concrete to become sufficiently hard for it to bear traffic.

Figure 5 - Concreting with a vibrating beam

Figure 6 - Concreting with a slip-form paver
3.4. Special Measures

3.4.1. Concreting carried out as single operation in one day

Because the completion of the concreting of the pavement of the roundabout has to be carried out on concrete which has not yet hardened, it will be necessary to provide a catwalk so that the joint can be finished without walking on the concrete. Moreover if the volume of concrete is more than 150 m³, two gangs will be required, with one relieving the other after about 10 hours of work.

Figure 7 - Working over unhardened concrete to complete the roundabout

3.4.2. Concreting carried out as single operation in two days

When the volume of concrete is greater than 150 m³, the provision of an end-of-day joint may be considered. Like the initial joint this joint should be realized close to one of the traffic islands of the access roads to avoid greater stresses at the entry and exit zones.

3.4.3. Concreting in two operations

If the junction cannot be isolated for traffic reasons, concreting in two separate operations may be considered. Generally speaking shifting at the extremities due to contraction and temperature variations are limited. Consequently no precautions need be taken in this respect unless the radius of the roundabout is extremely large. In these latter cases, however, the problems posed by traffic requirements will not usually arise. Problems may occur though when the time between the two concreting operations is extremely long (a year or more). In such cases the two ends of the pavement must be loaded (with wet sand for example) in order to prevent the ends from moving. The recommended load should be spread over the entire width of the pavement. Its thickness should be at least 50 cm and it should extend 15 m. Should insufficient length be available, this distance may be reduced by increasing the thickness in the same proportion as the reduction in length. An anchoring beam (or thrust block) may be used as an alternative to loading.

Figure 8 - Concreting in 2 separate operations

The length of the waiting longitudinal reinforcing steel calls for some attention. It is important to vary their length in order to avoid any significant concentration of splices in the same radial sector.
Repeatedly extending the longitudinal reinforcing steel by 1, 2, 3, 4 and 5 metres (see Figure 9) offers a solution.

Figure 9 - Illustration of varying the length of the longitudinal reinforcement in a construction joint in order to avoid a significant concentration of splices in the same radial line

3.4.4. Concreting the starting points

To prevent a corner of a slab in the approach area from being particularly loaded, the starting points of the accesses and exits are shuttered, provided with reinforcing steel and concreted at the same time as the actual pavement of the roundabout. The starting point must be such that the dimension of its smallest side is at least 1 m.

3.4.5. Concreting the approach arms

The approach arms of a roundabout crossing are always subject to particularly large stresses (braking, acceleration, tangential forces). For this reason it is desirable for the pavement of the approach arm to be in concrete, and in that case the arm should be anchored to the circulatory carriageway to ensure continuity with the concrete pavement. Anchoring is achieved using 1 m lengths of 16 mm diameter reinforcing steel located every 40 cm at half the height of the construction joint. The transverse joints are then provided, although these use conventional dowelling. The slabs are unreinforced or reinforced if their shape is complex. The reinforcement in the reinforced slabs is usually with 10 mm – 150 x 150 mesh, which is placed in the upper third of the concrete slab (Figure 10).

If no variable width vibrating beam is available, one of the access sides will have to be provided with formwork so that the beam can stretch over the formwork in the confined area. On the other hand if the concreting is done using a variable width beam, the concreting may be carried out between linear elements.

The approach to the roundabout junction may also be highlighted by adjusting the colour of the concrete.
Figure 10 - Diagram showing the layout of the slabs on the approach arms: reinforced slabs, unreinforced slabs, anchored joints and dowelled joints.
Figure 11 - Concreting the starting points
3.4.6. Protecting gulleys

Any gulleys should be protected to prevent concrete or laitance, should the surface of the concrete be stripped, from getting in the water drainage system.

When a vibrating beam is used, the formwork should be raised to the correct height using a plank attached to the edge of the gulley to ensure that the rolling path is uninterrupted.

3.4.7. Delivering the concrete

Regardless of whether the concreting work is carried out in one or two stages, the space available outside the circulatory carriageway does not often permit access to cranes and concrete delivery vehicles. This is why the concrete is sometimes supplied from the centre of the roundabout. In that case a way through the reinforcement must be left open. This way is closed when the concreting works are finished and the crane left at the centre of the roundabout for the completion of the works will only be able to leave after several days have gone by.
The starting joint of the day must be provided with shuttering to ensure its evenness and that it is perpendicular. This joint must be cleaned immediately afterwards to avoid having to use a jack hammer, which could crack the concrete, at a later stage.

3.4.8. Integrating a roundabout in the middle of an existing carriageway in CRC

Increasingly roundabouts have to be installed at an existing junction where the main carriageway already exists and is made of CRC. The installation of the roundabout will thus break the continuity of the longitudinal reinforcement. To prevent any significant movement due to contraction or temperature variation at the ends of the pavement which has been cut through, loads must be placed on them. The recommended load should be spread over the entire width of the pavement. Its thickness should be at least 50 cm and it should extend 15 m. Should insufficient length be available, this distance may be reduced by increasing the thickness in the same proportion as the reduction in length. Afterwards the pavement will be anchored to the new roundabout in CRC.

4. CONCLUSIONS

Since the first roundabout in continuous reinforced concrete was built in May 1995 at the end of the N52, at the junction of an access road to the CCB quarries and a road serving an industrial zone, no fewer than 80 circulatory carriageways in CRC have been built in Belgium.

The difficulties and constraints encountered on each of these sites have made it possible to refine and develop the installation and construction of such roundabouts.

Concrete roundabouts offer:

- sufficient strength to stand up to the stresses;
- a range of different solutions, such as slabs in concrete or in continuous reinforced concrete, small or large radii of curvature, a multiple choice of textures and colours, satisfactory integration into all kinds of environments;
- rapid execution and low maintenance.

In all cases, concrete roundabouts require detailed preliminary study and careful construction that takes account of local constraints. Even so there are still improvements to be made, in particular with respect to:

- access to the centre of the roundabout for the delivery of the concrete;
- the correct unrolling of the plastic to avoid pleats at the inner edge;
- the replacement of reinforcing steel by cables in circulatory carriageways of limited diameter;
- the concreting of wide circulatory carriageways as two concentric rings, which would make it possible to do the concreting works with normal slipform pavers.