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Roundabout Mondsee in Upper Austria: A Case Study

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ABSTRACT

The first roundabouts as traffic engineering facilities were not built until the beginning of the 20th century, although there were islands in the middle of the streets and marketplaces long before that time. Even in Roman times, people admired the water fountains and statues in marketplaces. A long time ago in England there were also traffic islands as pedestrian oases and in France there were also the imposing buildings in the middle of market squares. However, it was only the "planning border" of all these objects that turned them into traffic roundabouts. The circular roadways at roundabouts are exposed to special traffic loads due to cornering, namely friction and shear stresses, and in smaller roundabouts (mini roundabouts) also torsional stresses (turning of tyres on the spot). Especially due to the high proportion of heavy traffic, damage to the asphalt pavement is often found, such as cracks, unevenness (indentations, ruts), etc. This article introduces the roundabout on the B 154 highway access and exit A1 Mondsee (Upper Austria). This roundabout was completed and opened to traffic in 2012. The photos of the roundabout's road pavement were taken by the author in 2020.

Keywords: aggregate loss, asphalt, bitumen, circular lane, circular roadway, crack, damage, pavement, plucking, roundabout, ruts, torsional stress, unevenness

INTRODUCTION

Description of the Roundabout

The roundabout on the B 154 highway access and exit A1 Mondsee (Upper Austria), was built as a four-armed, 2-lane roundabout on the A1 West highway with the B154 Mondsee Strasse. The relevant roundabout data are shown in Table 1.

Table 1. The relevant roundabout data in accordance with (Amt der OÖ. Landesregierung 2012)

ADT* (2012)	13.100 vehicle/day
Outer diameter *D*	70,0 m
Curve radius *R*	70,0/2 – 9,0/2 = 30,5 m
Circular lane width B_K	9,0 m
Max. cross gradient q_{max}	3,67 %
Asphalt surface layer	AC11 deck PmB 45/80-65, A2, G1, 3.0 cm
Asphalt binder layer	AC32 binder PmB 25/55-65, H1, G4, 11.0 cm
Asphalt base layer	AC32 binder PmB 25/55-65, H1, G4, 11.0 cm
Skid resistance value *μ*	0,35
Upper unbound TS	Unbound base course ($C_{50/30}$), 20.0 cm
Lower unbound TS	frost protection layer $C_{90/3}$, 30,0 cm
Opening	2012
Special feature	first Upper Austrian 2-lane roundabout

*ADT - Average daily traffic [vehicle/day]

Since Mondseeland is a holiday and excursion destination for many people, as well as an important economic area and workplace in Upper Austria, the construction of the new roundabout also had to provide sufficient capacity for the traffic volumes to be accommodated. To achieve this, the first 2-lane roundabout in the Upper Austrian provincial road network was built. The ramps of the A1 West highway were connected to the B154 Mondsee road at the Mondsee junction via two T-junctions (Figure 1). Due to the high traffic load of about 13,100 vehicles per 24 hours with a share of heavy goods vehicles of 7%, the junction was partly overloaded during peak hours and especially the western T-junction was an accident black spot. For this reason, it was decided to redesign this dangerous T-junction into a 2-lane, 4-arm roundabout with a diameter of 70 m (Hrapović 2018).

Figure 1. Old intersection of the highway ramp with the B154 (Hrapović 2018)

By reconstructing this extremely dangerous T-junction into the 2-lane roundabout in 2012, the number of traffic accidents with injured persons has even been reduced by 80 % after the opening in 2012. The aerial view of this roundabout in July 2012 is shown in Figure 2 and a photo of the author in October 2015 in Figure 6.

Figure 2. Aerial photograph of the B 154 roundabout / highway A1 Mondsee in July 2012 (Amt der OÖ. Landesregierung 2012)

Calculation of the Centrifugal Force Acting on the Roundabout Pavement

Correctly, for reasons of driving dynamics, the transverse gradient in a road bend is always inclined inwards so that the vehicle does not fly out of the bend in the tangential direction (tangential path) at a certain speed due to the effect of centrifugal force (from Latin "*centrum*" = centre and "*fugere*" = to flee, hence also called "*flee force*") (Figure 3).

Figure 3. Racing cars driving through an inwardly inclined curve (Dabarti 2020)

For drainage reasons, however, the opposite is the case for the roundabout, because the transverse gradient of the circular roadway is designed to be inclined outwards, in order to avoid complicated drainage systems for the internal gradient around the circular island and to make drainage easier (Figure 4).

Figure 4. Bending in the circular roadway (Hrapović 2016)

The driving dynamics and driving geometry when driving in an arc are shown in Figure 5 by means of a disc model and this is applied analogously to the circular roadway of a roundabout. The rigid disc model represents a strong two-dimensional simplification of the real three-dimensional vehicle.

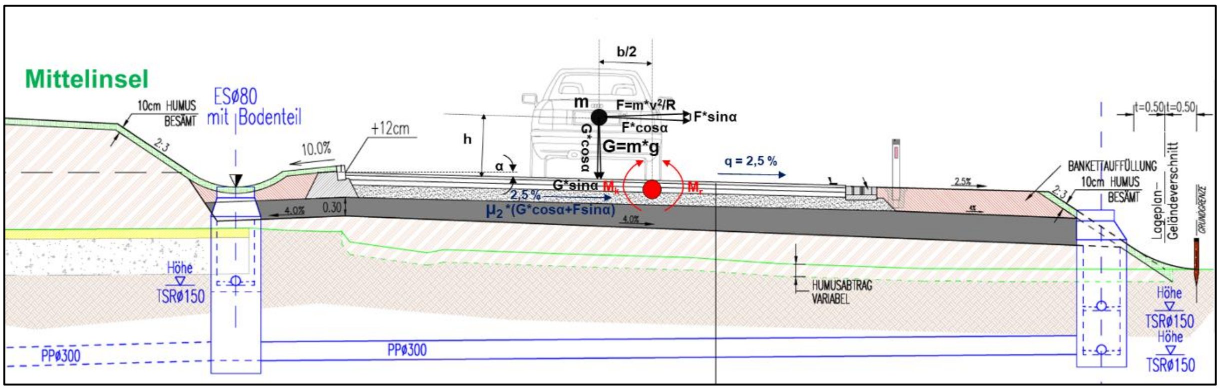

Figure 5. Driving dynamics and driving geometry when driving in the circular roadway of a roundabout (Amt der OÖ. Landesregierung 2016) (edited by author)

According to the following formulas apply (Hoffmann 2010):

$$F \cdot \cos\alpha - G \cdot \sin\alpha - \mu_2 (G \cdot \cos\alpha + F \cdot \sin\alpha) = 0 \quad [1]$$

$$(m \cdot v^2 / R) \cos\alpha - m \cdot g \cdot \sin\alpha - \mu_2 (m \cdot g \cdot \cos\alpha + (m \cdot v^2 / R) \cdot \sin\alpha) = 0 \quad [2]$$

mit $\sin\alpha \sim \tan\alpha \sim q$ and $\cos\alpha \sim 1$ for cross slope << q

$$m \cdot v^2 / R - m \cdot g \cdot q - \mu_2 \cdot m \cdot g + \mu_2 \cdot q \cdot m \cdot v^2 / R = 0 \quad [3]$$

for v, q

$$v_{zul} = \sqrt{\frac{R * g(\mu_2 + q)}{1 - \mu_2 * q}} \quad [4]$$

$$\mu_{2erf} = \frac{v^2 - g * q * R}{g * R + q * v^2} \quad [5]$$

$$R_{erf} = \frac{v^2(1+\mu_{2*}q)}{g*(q+\mu_2)} \qquad [6]$$

mean in it:

F - centrifugal force [KN]
G - vehicle weight [KN]
m - vehicle mass [kg]
μ - skid resistance value (friction value) of the road surface [-]
α - angle of inclination of the carriageway [°]
g - acceleration due to gravity [m/s^2]
q - transverse gradient of the carriageway [%]
R - curve radius [m]
v_{zul} - permissible speed of the vehicle when cornering [m/s]
b - vehicle width [m]
h - vehicle height [m]

Out of formula [2] $F \cdot \cos\alpha - G \cdot \sin\alpha - \mu_2(G \cdot \cos\alpha + F \cdot \sin\alpha) = 0$ follows:
$F \cdot \cos\alpha - \mu_2 \cdot F \cdot \sin\alpha = G \cdot \sin\alpha + \mu_2 \cdot G \cdot \cos\alpha$
$F (\cos\alpha - \mu_2 \cdot \sin\alpha) = G (\sin\alpha + \mu_2 \cdot \cos\alpha)$

Centrifugal force [KN]:

$$F = G \cdot \frac{(\sin\alpha + \mu \cdot \cos\alpha)}{\cos\alpha - \mu \cdot \sin\alpha} \qquad [7]$$

In the case of roundabout pavement, the transverse gradient is usually $q = 2.5$ %.

For the selected roundabout installations, the calculated dimensions of the centrifugal forces acting on the roundabout pavement (centrifugal forces) at the points with maximum transverse gradient of the roundabout pavement are calculated using formula [7].

The maximum transverse gradient of this roundabout was calculated using the source (Land of Upper Austria 2, 2016) is determined: $q_{max} = 3,67$ %.

$\sin\alpha \sim \tan\alpha \sim q$
$q = 3,67/100 = 0,0367 \Rightarrow \sin\alpha = 0,0367$
$\sin^2\alpha + \cos^2\alpha = 1 \Rightarrow \cos^2\alpha = 1 - \sin^2\alpha \Rightarrow \cos\alpha = \sqrt{1 - sin^2\alpha}$
$\cos\alpha = \sqrt{1 - 0,037^2} = 0,999326 \Rightarrow \alpha = \arccos\alpha = 2,1$ °

For the vehicle mass *m* [kg], or the vehicle weight [KN] of the relevant vehicle, the mass of a truck with trailer fully loaded. The legally permissible gross vehicle weight in Austria is 44 tonnes.

m = 44,000 [kg] - the total weight legally permitted in Austria
$G = m \cdot g = 44{,}000 \cdot 9.81 = 431{,}640$ [kg m/s^2] = 431,640 [N]
$G \sim 432$ KN

Where *g* is the acceleration of gravity: $g = 9.81$ [m/s^2].

The centrifugal force [KN] at the point with maximum transverse gradient of the roundabout pavement of the roundabout B 154 / highway A1 in Mondsee is calculated from formula [7] as follows:

$$F = 432 \cdot \frac{(0{,}037 + 0{,}35 \cdot 0{,}999326)}{(0{,}999326 - 0{,}35 \cdot 0{,}037)} = 169 \text{ KN}$$

F = 169 KN - centrifugal force (flee force) at the point with maximum transverse gradient q_{max} = 3.67 % of the roundabout pavement of the roundabout B 154 / highway A1 in Mondsee, which acts on a semi-trailer combination fully loaded with wood during cornering.

The permissible speed of the vehicle when cornering [m/s] was determined for all seven roundabouts according to formula [4] is then:

$$v_{zul} = \sqrt[2]{\frac{30{,}50 \cdot 9{,}81\,(0{,}35 - 0{,}037)}{1 + 0{,}35 \cdot 0{,}037}} = 9.61 \text{ m/s} \cdot 3.6 = 34.62 \text{ km/h}$$

Figure 6. Two-lane roundabout B 154 / highway A1 Mondsee in October 2015 (Hrapović 2020)

The site plan with four roundabout arms can be seen on Figure 7 and the standard cross-section with a 9.0 m wide, two-lane circular roadway on Figure 8.

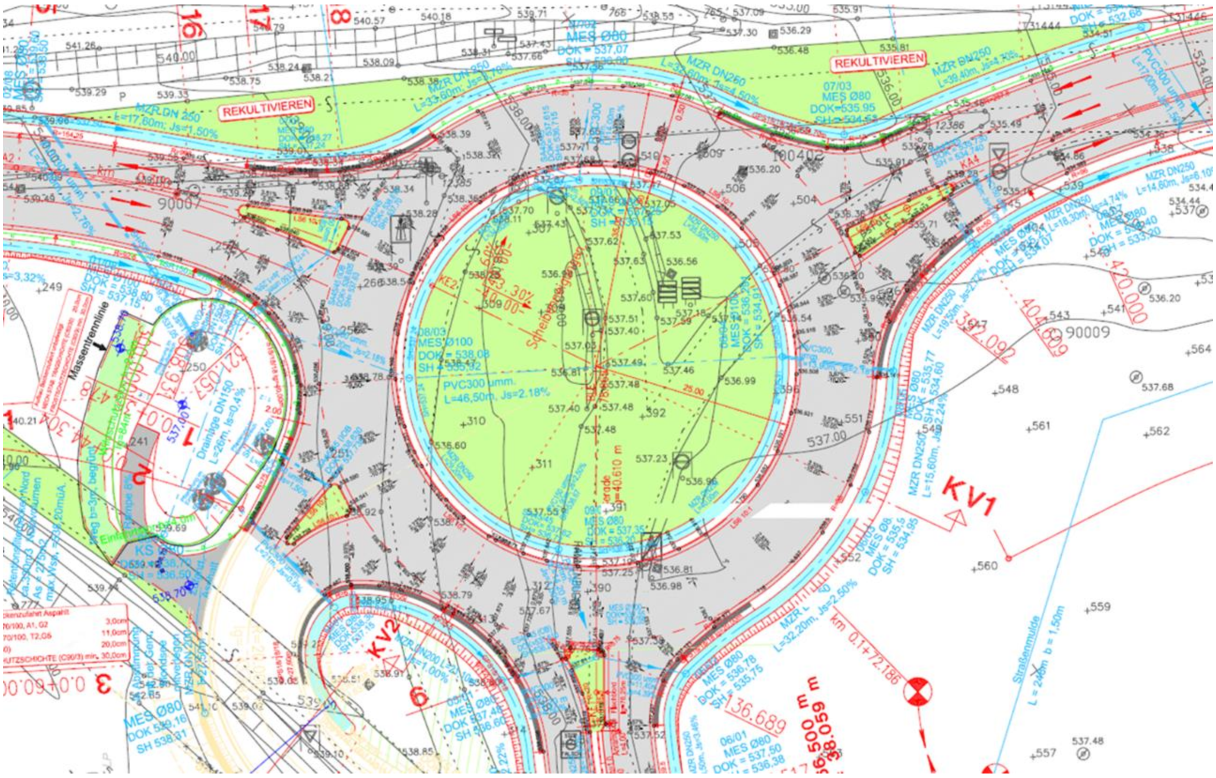

Figure 7. Site plan with four arms of the B 154 roundabout / A1 highway (Hrapović 2018)

Figure 8 shows the standard cross-section of the B 154 roundabout / A1 highway with 9.0 m wide, 2-lane circular road. This road construction is made up of:

- Asphalt surface layer AC11 deck PmB 45/80-65, A2, G1, 3.0 cm
- Asphalt binder layerAC32 binder PmB 25/55-65, H1, G4, 11.0 cm

- Asphalt base layer AC32 binder PmB 25/55-65, H1, G4, 11.0 cm
- Upper unbound TS Unbound base course (C50/30), 20.0 cm
- Lower unbound TS Frost protection layer C90/3, 30,0 cm

The surface course of this roundabout is Asphalt Concrete **AC11 deck PmB 45/80-65, A2, G1, 3.0 cm**. The above mix designation is:

AC11 – Asphalt Concrete with maximum grain size 11 mm according to OENORM EN 13108-1 (ASI 2008).

11 - maximum particle size 11 mm

deck - name for the top layer, here is surface course.

PmB 45/80-65 – Polymer modified bitumen, penetration of the bitumen at +25 °C is between 45 and 80 $x10^{-1}$ mm according to EN 1426 (CEN 2007) and with +65 °C softening point of ring and ball is +65 °C according to EN 1427 (CEN 2015).

A2 – There are the following asphalt types: A1, A2, A3, A4, A5, A6 and A7. Simplified, it can be said: Type A1 is to be produced with conventional binder, type A2 with modified binder and type A3 for thin-layer pavements. For types A1, A5, A6 and A7 all binders are permitted, for types A2, A3 and A4 modified binders according to 5.9 (ASI 2018). Types A2, A3 and A4 may also be produced with road bitumen using binder modifying additives. As far as the particle size distribution is concerned, a distinction is made between seven types (A1, A2, A3, A4, A5, A6 and A7). Type A2 shall be produced with a maximum grain size of 8 mm, 11 mm and 16 mm respectively.

G1 - Aggregate class of the asphalt mix according to Austrian standard OENORM B 3580-1 (ASI 2018) – see Table 2.

3,0 cm - Asphalt layer thickness.

Table 2. Combinations between mix types and aggregate classes (extract from OENORM EN 3580-1) (ASI 2018)

	G1	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**
deck, A1	X	X	X	–	–	–	X
deck, A2	X	X	–	–	–	–	–
deck, A3	X	X	X	–	–	–	–
SMA	X	X	X	–	–	–	–
binder, H1	–	–	–	X	X	–	–
trag, T1	–	–	–	X	X	X	–
trag, T2	–	–	–	X	X	X	–
trag, T3	–	–	–	X	X	X	–
It means: X Permitted combination – Impermissible combination							

The asphalt binder layer and asphalt base layer was made from the asphalt mix:

AC32 binder PmB 25/55-65, H1, G4, 11.0 cm.

11,0 cm - Asphalt layer thickness.

AC32 - Asphalt Concrete with a maximum.

particle size 32 mm

binder - binder

PmB 25/55-65 - Polymer modified bitumen, penetration of the bitumen at +25 °C is between 25 and 55 $x10^{-1}$ mm according to EN 1426 (CEN 2007) and with +65 °C softening point of ring and ball is +65 °C according to EN 1427 (CEN 2015).

H1 - highly stable base layer (binder)

G4 - aggregate class of the asphalt mix according to Austrian standard OENORM B 3580-1 (ASI 2018) for binder and base courses as well as base and surface courses with low requirements or no requirements for skid resistance.

Upper unbound TS - Unbound base course (C50/30), 20.0 cm: C50/30 = Categories for the percentage of crushed particle surfaces (including the percentage of totally crushed (50 %) and totally rounded (30 %) particles) (ASI 2014).

Lower unbound TS - Frost protection layer C90/3, 30,0 cm: C90/3 = Categories for the percentage of crushed particle surfaces (including the percentage of totally crushed (90 %) and totally rounded (3 %) particles) (ASI 2014).

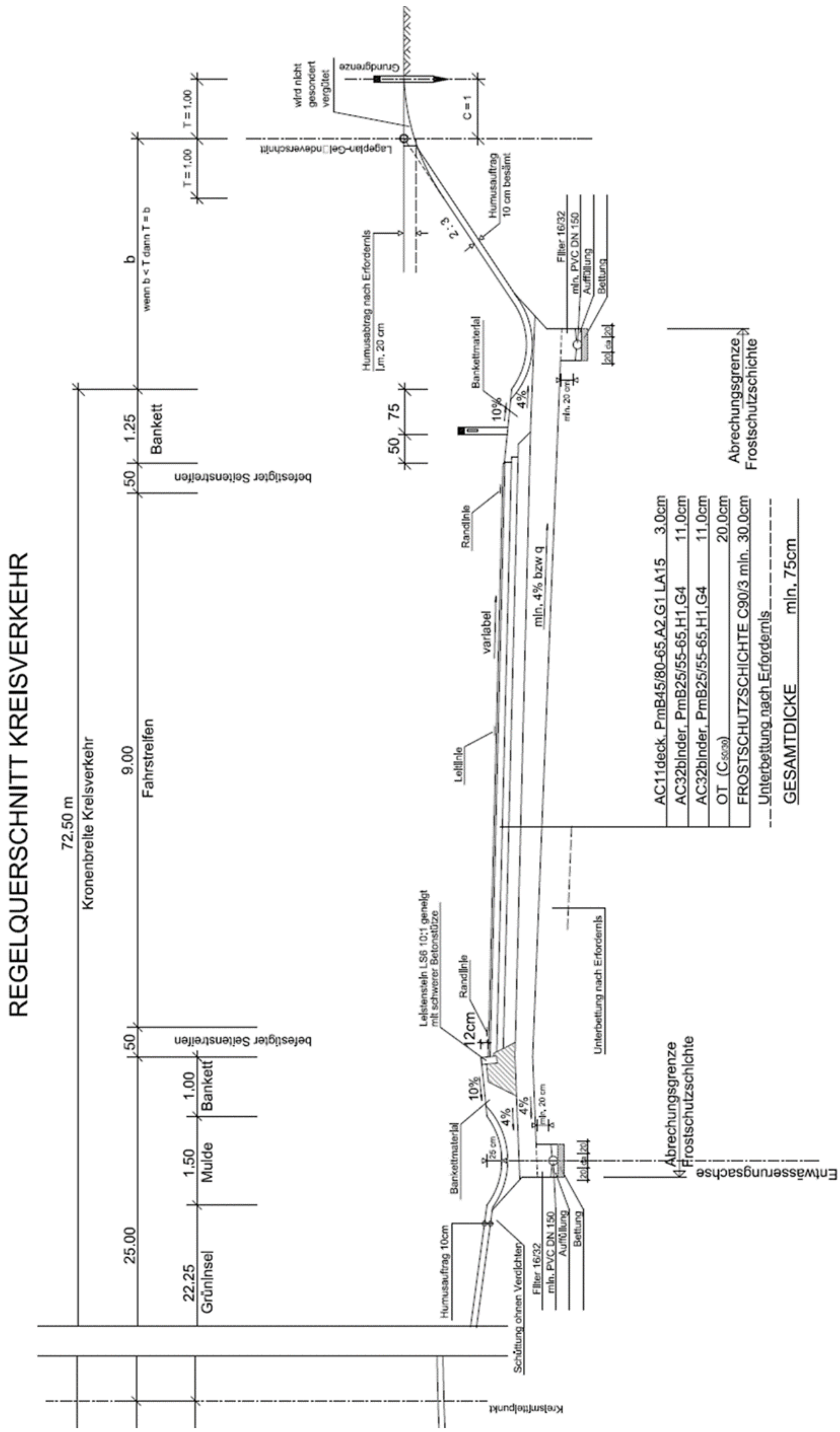

Figure 8. Standard cross-section of the B 154 roundabout / A1 highway with 9.0 m wide, 2-lane circular road (Hrapović 2018)

Description of the Condition of the Roundabout

The roundabout on the A1 / B 154 in Mondsee, eight years after its opening in September 2012. Figure 9 shows the irregular longitudinal and transverse cracks repaired with hot bitumen compound, area of roundabout pavement, exit on B154 Oberhofen. Figure 10 shows the plucking (fretting), transverse crack repaired with hot bitumen compound, Mondsee access and exit area.

Figure 9. Irregular longitudinal and transverse cracks (Hrapović 2020)

Figure 10. Plucking, transverse crack (Hrapović 2020)

Figure 11 shows the detailed view of the area from Figure 9. Figure 12 shows the alligator cracks partially repaired with hot bitumen compound, exit area on B154 Mondsee.

Figure 11. Detailed view of the area from Figure 9 (Hrapović 2020)

Figure 12. Alligator cracks partially repaired with hot bitumen compound, exit area on B154 Mondsee (Hrapović 2020)

Figure 13 shows the longitudinal and transverse cracks repaired with hot bitumen compound, area of roundabout pavement between Mondsee access and exit and A1 access and exit. Figure 14 shows the transverse crack across the entire width of the roundabout pavement, longitudinal cracks, longitudinal and transverse working seam crack, area of the A1 access and exit.

Figure 13. Longitudinal and transverse cracks (Hrapović 2020)

Figure 14. Transverse crack, longitudinal cracks, longitudinal and transverse working seam crack (Hrapović 2020)

Figure 15 shows the detailed view of the area from Figure 13: plucking (fretting), particle aggregate loss tending towards pothole. Figure 16 shows the irregular longitudinal and transverse cracks, access and exit areas of the industrial zone, repaired with hot bitumen compound.

Figure 15. Detailed view of the area from Figure 13 (Hrapović 2020)

Figure 16. Irregular longitudinal and transverse cracks (Hrapović 2020)

Figure 17 shows the rehabilitated with hot bitumen compound: continuous longitudinal seam, transverse crack, alligator cracks, area of access and exit of B154 Oberhofen. Figure 18 shows the continuous transverse seam crack (construction joint) repaired with hot bitumen compound.

Figure 17. Rehabilitated with hot bitumen compound (Hrapović 2020)

Figure 18. Continuous transverse seam crack (construction joint) (Hrapović 2020)

CONCLUSION

The surface course of this roundabout is Asphalt Concrete AC11 deck PmB 45/80-65, A2, G1, 3.0 cm and the photos show the pavement condition of this roundabout eight years after its opening. The above mix designation is:

AC11 – Asphalt Concrete with maximum grain size 11 mm according to OENORM EN 13108-1 (ASI 2008). Asphalt Concrete: asphalt in which the aggregate particles are continuously graded or gap-graded to form an interlocking structure.

PmB 45/80-65 – Polymer modified bitumen, penetration of the bitumen at +25 °C is between 45 and 80 x10^{-1} mm according to EN 1426 (CEN 2007) and with +65 °C softening point of ring and ball is +65 °C according to EN 1427 (CEN 2015).

A2 – There are the following asphalt types: A1, A2, A3, A4, A5, A6 and A7. Simplified, it can be said: Type A1 is to be produced with conventional binder, type A2 with modified binder and type A3 for thin-layer pavements. For types A1, A5, A6 and A7 all binders are permitted, for types A2, A3 and A4 modified binders according to 5.9 (ASI 2018). Types A2, A3 and A4 may also be produced with road bitumen using binder modifying additives. As far as the particle size distribution is concerned, a distinction is made between seven types (A1, A2, A3, A4, A5, A6 and A7):

- Type A1 is to be manufactured with a maximum grain size of 4 mm, 8 mm, 11 mm, 16 mm or 22 mm.
- Type A2 shall be produced with a maximum grain size of 8 mm, 11 mm and 16 mm respectively.
- Types A3 and A4 are to be manufactured with a maximum grain size of 4 mm and 8 mm respectively.
- Types A5 and A6 shall be produced with a maximum grain size of 11 mm, 16 mm and 22 mm respectively.
- Type A7 shall be produced with a maximum grain size of 4 mm, 5 mm, 8 mm, 11 mm, 16 mm and 22 mm respectively.

G1 - Aggregate class of the asphalt mix according to Austrian standard OENORM B 3580-1 (ASI 2018).

G4 - aggregate class of the asphalt mix according to Austrian standard OENORM B 3580-1 (ASI 2018) for binder and base courses as well as base and surface courses with low requirements or no requirements for skid resistance.

"The crack is the beginning of the end of the road". This well-known saying has lost none of its relevance to this day. Although it is generally known today that open cracks demonstrably lead to massive damage to the entire road superstructure and substructure, the rehabilitation of these is not yet generally recognised as the first important measure in road

maintenance. As the continuous damage to the road caused by un-repaired cracks cannot be visually monitored, the damage potential of cracks is often completely misjudged. Continuous ingress of surface water leads to constant washing out of fine particles in the deeper layers and, in combination with freeze/thaw cycles, to massive damage. This often leads to a sudden failure of the road with enormous damage. This damage could be prevented, or at least delayed by years, if the cracks were repaired in good time with comparatively little financial resources (Kurzmann 2013).

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