VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

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FAKULTA STAVEBNÍ

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INSTITUTE OF ROAD STRUCTURES

Návrh okružní křižovatky v Horsens (Dánsko) a porovnání dánského a českého přístupu k návrhu

DESIGN OF ROUNDABOUT IN HORSENS (DENMARK)
AND COMPARISON OF DANISH AND CZECH APPROACH TO DESIGN

BAKALÁŘSKÁ PRÁCE

BACHELOR'S THESIS

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VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ
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ANOTACE:

Cílem této bakalářské práce je návrh okružní křižovatky v Dánsku ve spolupráci s dánskou univerzitou VIA University College v Horsens a porovnání různých přístupů k řešení jednotlivých prvků okružních křižovatek v České republice a Dánsku.

První část práce se zabývá vlastním návrhem okružní křižovatky a je zpracována vesměs v angličtině. Výkresová dokumentace je dvoujazyčná a je doplněna technickou zprávou v češtině.

Druhou část práce tvoří porovnání dánského a českého přístupu k návrhu okružních křižovatek a zaobírá se nejdůležitějšími rozdíly, které byly zjištěny při vytváření projektu.

ANNOTATION:

The aim of this bachelor's thesis is design of roundabout in Denmark in cooperation with Danish university VIA University College in Horsens and comparison of different approaches to specific project solutions for roundabouts in Czech Republic and Denmark.

The first part of thesis is dealing with whole roundabout design and is made generally in English. All drawings are bilingual with added technical report in Czech.

The second part of this thesis consist of comparison of Danish and Czech approach to roundabout design and is dealing with the most important differences, which were found during project.

KLÍČOVÁ SLOVA:

okružní křižovatka, návrh, Dánsko, porovnání návrhů

KEYWORDS:

roundabout, design, Denmark, design comparison

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PROHLÁŠENÍ:

Prohlašuji, že jsem tuto bakalářskou práci zpracoval samostatně, a že jsem uvedl všechny použité informační zdroje.

V Brně dne 25. 5. 2012

Martin Pěknica

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PODĚKOVÁNÍ:

Především bych chtěl poděkovat svému vedoucímu bakalářské práce panu Ing. Martinu Smělému za odborné vedení a vůbec možnost vzniku této bakalářské práce. Rád bych také poděkoval mému vedoucímu projektu na VIA University College, Horsens v Dánsku panu Niels Leo Christensenovi za veškerou pomoc a odborné rady. Zvláštní poděkování patří slečně Alici Nevrlé za korekturu anglických i českých textů.

V Brně dne 25. 5. 2012

Martin Pěknica

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OBSAH:

1. Introduction

This interdisciplinary civil engineering project provide description and guide for establishing a roundabout with technical decisions about design and aesthetics, which will lead to safe and easy to usage of intersection. However, volume of this project is limited, it is not completely dealt with water treatment and with proper connections to surrounding infrastructure.

For the purposes of project the specialized software was used. *Novapoint 18.00, Autodesk Civil 3D 2010* for designing process and *DanKap,* the Danish software for traffic calculations.

2. Overview

The area, where the roundabout is situated in the town Horsens in Denmark at the east side of Nørrestrand bay. This intersection will arrange connection between main streets Oddervej and Brådhusvej with residential areas at Sundsgårdsvej and along Ulfeldtsvej *(Figure 2.1 and 2.2)*.

The design of connecting roads is preliminary and the road geometry used in this project is there to mostly ensure roundabout's best position, horizontally and vertically.

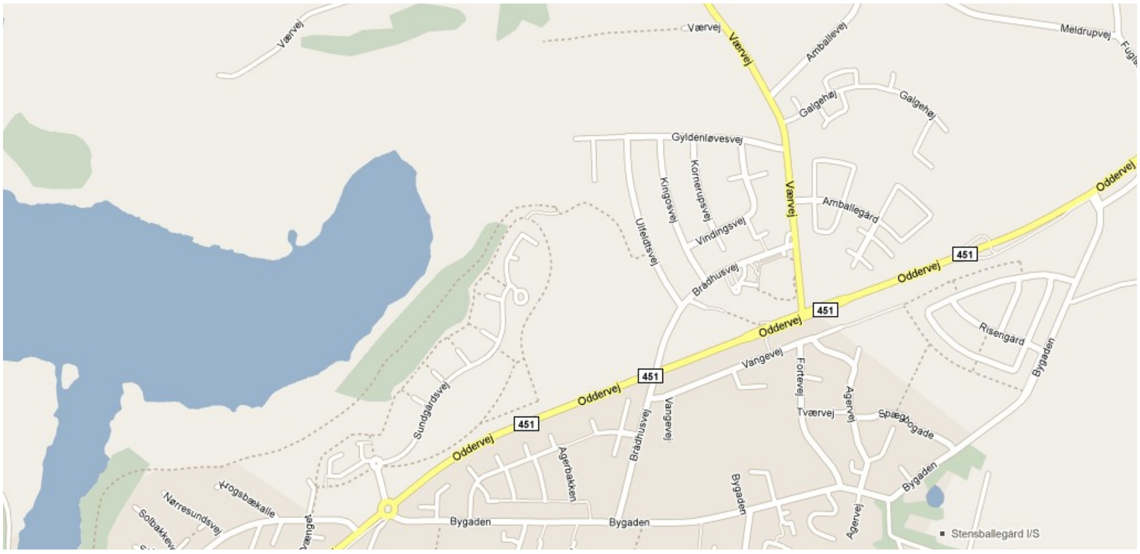

Figure 2.1 - Area map

Figure 2.2 - Roundabout position

The stationing for west/east road starts at connection with Sundsgårdsvej and the roundabout center is in stationing 381,38m. For south/north road the stationing starts near Oddervej and position of roundabout center is in stationing 243,88m.

3. Traffic Analysis

The original traffic data *(Figure 3.1, 3.2)* for this area in year 2011 are incomplete and inaccurate. The connecting roads will be established after roundabout construction so there is not any original traffic data for this intersection, there is only probable estimate of traffic related to this area.

vehicles 100%					12% AADT	10% AADT	AADT
from/to	north	south	west	east	sum		
north		180	100	200	**480**	400	4000
south	180		100	80	**360**	300	3000
west	80	50		110	**240**	200	2000
east	100	100	100		**300**	250	2500

Figure 3.1 - Peak hour traffic, sum of vehicles

bikes					30% AADT	AADT
from/to	north	south	west	east	sum	
north		3	15	3	**21**	70
south	-3		3	15	**15**	50
west	1	10		-2	**9**	30
east	5	2	5		**12**	40

Figure 3.2 - Peak hour bicycle traffic

Peak hour values for every roundabout leg is accordingly to *Danish Road rules: Capacity and service-level* set to 12% of Annual average daily traffic (AADT). Although these values had to be changed for bicycle traffic to 30% of AADT because of probable very high bicycle peak hour traffic in this mostly residential area. In *Figure 3.2* the bicycle traffic from south to north and from west to east has negative values. This problem is caused by inaccurate difference between low assumptions of AADT and quite high assumptions for peak hour. To avoid any other problems with calculations the bicycle traffic in these directions was set to 0.

Assumption of vehicle type split is as follows:

Cars/Vans	85%	ST/TT	5%
Lorry/BUS	8%	MC	2%

For peak hour values for every type of vehicles from all directions see *Figure 3.3*

cars, vans 85%

from/to	north	south	west	east	sum
north		153	85	170	**408**
south	153		85	68	**306**
west	68	43		94	**204**
east	85	85	85		**255**

lorry, bus 8%

from/to	north	south	west	east	sum
north		14	8	16	**38**
south	14		8	6	**29**
west	6	4		9	**19**
east	8	8	8		**24**

ST, TT 5%

from/to	north	south	west	east	sum
north		9	5	10	**24**
south	9		5	4	**18**
west	4	3		6	**12**
east	5	5	5		**15**

MC 2%

from/to	north	south	west	east	sum
north		4	2	4	**10**
south	4		2	2	**7**
west	2	1		2	**5**
east	2	2	2		**6**

Figure 3.3 - Peak hour traffic split to vehicle types

3.1 Traffic Increase

The annual increase of traffic was set to 1,5 % per year. This value is the most common and the most probable accordingly to previous development. In the actual designing process I am counting with traffic size twenty years in to the future, which means that total increase of traffic up to year 2031 is 30 % *(Figure 3.1.1, 3.1.2)*. We expect that split of vehicles types will remain the same, for every vehicle and direction peak hour values in 2031 see *Figure 3.1.3*.

vehicles 100%					12% AADT	10% AADT	AADT
from/to	north	south	west	east	sum		
north		234	130	260	**624**	520	5200
south	234		130	104	**468**	390	3900
west	104	65		143	**312**	260	2600
east	130	130	130		**390**	325	3250

Figure 3.1.1 - Peak hour traffic, sum of vehicles for year 2031

bikes					30% AADT	AADT
from/to	north	south	west	east	sum	
north		4	20	4	**27**	91
south	-4		4	20	**20**	65
west	1	13		-3	**12**	39
east	7	3	7		**16**	52

Figure 3.1.2 - Peak hour bicycle traffic for year 2031

cars, vans 85%

from/to	north	south	west	east	sum
north		199	111	221	**530**
south	199		111	88	**398**
west	88	55		122	**265**
east	111	111	111		**332**

lorry, bus 8%

from/to	north	south	west	east	sum
north		19	10	21	**50**
south	19		10	8	**37**
west	8	5		11	**25**
east	10	10	10		**31**

ST, TT 5%

from/to	north	south	west	east	sum
north		12	7	13	**31**
south	12		7	5	**23**
west	5	3		7	**16**
east	7	7	7		**20**

MC 2%

from/to	north	south	west	east	sum
north		5	3	5	**12**
south	5		3	2	**9**
west	2	1		3	**6**
east	3	3	3		**8**

Figure 3.1.3 - Peak hour traffic split to vehicle types for year 2031

3.2 Capacity Calculation (DanKap)

For the calculation of capacity the Danish software DanKap was used. It works accordingly to Danish road rules. Both traffic data from 2011 and 2031 were used to see the difference and make a conclusion for following design.

According to results *(Figures 3.2.1 - 3.2.6)* it is not possible to use one-lane roundabout. The capacity values from north direction and south are way above 70 % limit so in those directions two-lane entrances has to be established, which leads to two-lane entrances which leads to two-lane circulatory area. In this solution it is not possible to accommodate bicycle path in front of two-lane entrances. Bicycles are in this case excluded from motorized traffic *(see 4.5 Bicycle paths)*. The split between two lanes is set to 66 % of traffic in the right lane and 34 % in the left lane.

For final solution of calculation excluding bicycle traffic see *Figures 3.2.7 - 3.2.9*.

Rundkørsel, Skema A

Fastsættelse af trafikmængderne i rundkørslen

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2011

Beregningsperiodens længde: T = 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Trafikmangderne i rundkorslen i beregningsperioden														
	Pv/Vv		LB/Busser		St-v/Ph.v-tog		Mc		$N_{M,Kt}$	N_M	of	N_{ud}	H_M	$H_{c/k}$	H_{fod}
	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	Pe/T		Pe/T	Pe/T	Pe/T	Pe/T
South	306	1,0	28	1,5	18	2,0	8	0,5	360	388	0,93	358	423	4	
East	255	1,0	24	1,5	15	2,0	6	0,5	300	324	0,93	423	388	4	
North	408	1,0	38	1,5	24	2,0	10	0,5	480	518	0,93	388	324	5	
West	205	1,0	19	1,5	13	2,0	5	0,5	242	262	0,92	324	518	5	

Figure 3.2.1 - Traffic quantity in calculated period for year 2011

Rundkørsel, Skema B

Fastsættelse af middelforsinkelsen og belysning af kødannelserne i rundkørslens tilfartsspor

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2011

Beregningsperiodens længde: T 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Kritisk interval / Passagetid				Tilfartssporets kapacitet								Middelforsinkelsen og kolangden i tilfartssporet		
	t_M	$t_{c/k}$	$t_{vægtet}$	d	$H_M+H_{c/k}$	tf	G_{time}	G	kf_{Nud}	kf_{fod}	N_{Max}	$N_{Max,kt}$	B	t	$n_{5\%}$
	sek	sek	sek	sek	Pe/T		Pe/time	Pe/T			Pe/T	Kt/T		sek/Kt	Kt
South	5,1	2,5	5,1	3,0	427	1,00	781	781	1,00	1,00	781	725	0,50	10	3
East	5,1	2,5	5,1	3,0	392	1,00	810	810	0,90	1,00	729	675	0,44	10	2
North	5,1	2,5	5,1	3,0	329	1,00	864	864	1,00	1,00	864	801	0,60	11	4
West	5,1	2,5	5,1	3,0	523	1,00	708	708	1,00	1,00	708	654	0,37	9	1

Figure 3.2.2 - Capacity, waiting times and queue lengths for year 2011

Rundkørsel, Skema C

Beregning af mængden af cirkulerende trafik foran en vejgren

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2011

Beregningsperiodens længde: T =3600 sekunder — Parametre: Vejregler

Trafik fra vejgren:	Cirkulerende trafik i enheden Pe/T foran vejgren:							
	West		South		East		North	
	M	C	M	C	M	C	M	C
South			194	0	108	3		
			108	3				
East					108	0	108	2
					108	2		
North	216	3					194	0
							216	3
West	121	0	86	1				
	86	1						
Total (Pe/T)	423	4	388	4	324	5	518	5

Figure 3.2.3 - Circulating traffic in front of entering roads for year 2011

Rundkørsel, Skema A

Fastsættelse af trafikmængderne i rundkørslen

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T = 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Trafikmangderne i rundkorslen i beregningsperioden																
	Pv/Vv		LB/Busser		St-v/Ph.v-tog		Mc		$N_{M,Kt}$	N_M	of	N_{ud}	H_M	$H_{c/k}$	H_{fod}
	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	Pe/T		Pe/T	Pe/T	Pe/T	Pe/T
South	398	1,0	37	1,5	24	2,0	10	0,5	469	507	0,93	465	546	5	
East	333	1,0	30	1,5	21	2,0	9	0,5	393	425	0,93	546	507	5	
North	531	1,0	50	1,5	32	2,0	13	0,5	626	677	0,93	507	425	7	
West	265	1,0	24	1,5	15	2,0	6	0,5	310	334	0,93	425	677	7	

Figure 3.2.4 - Traffic quantity in calculated period for year 2031

Rundkørsel, Skema B

Fastsættelse af middelforsinkelsen og belysning af kødannelserne i rundkørslens tilfartsspor

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Kritisk interval / Passagetid				Tilfartssporets kapacitet								Middelforsinkelsen og kolangden i tilfartssporet		
	t_M	$t_{c/k}$	$t_{vægtet}$	d	$H_M+H_{c/k}$	tf	G_{time}	G	kf_{Nud}	kf_{fod}	N_{Max}	$N_{Max,kt}$	B	t	$n_{5\%}$
	sek	sek	sek	sek	Pe/T		Pe/time	Pe/T			Pe/T	Kt/T		sek/Kt	Kt
South	5,1	2,5	5,1	3,0	551	1,00	688	688	0,90	1,00	619	573	0,82	32	11
East	5,1	2,5	5,1	3,0	512	1,00	717	717	0,90	1,00	645	597	0,66	17	5
North	5,1	2,5	5,1	3,0	432	1,00	779	779	0,90	1,00	701	649	0,96	77	24
West	5,1	2,5	5,1	3,0	684	1,00	601	601	0,90	1,00	541	502	0,62	19	4

Figure 3.2.5- Capacity, waiting times and queue lengths for year 2031

Rundkørsel, Skema C

Beregning af mængden af cirkulerende trafik foran en vejgren

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T =3600 sekunder — Parametre: Vejregler

Trafik fra vejgren:	Cirkulerende trafik i enheden Pe/T foran vejgren:							
	West		South		East		North	
	M	C	M	C	M	C	M	C
South			254	0	142	4		
			142	4				
East					142	0	142	3
					142	3		
North	281	4					254	0
							281	4
West	154	0	111	1				
	111	1						
Total (Pe/T)	546	5	507	5	425	7	677	7

Figure 3.2.6 - Circulating traffic in front of entering roads for year 2031

Rundkørsel, Skema A

Fastsættelse af trafikmængderne i rundkørslen

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T = 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Trafikmangderne i rundkorslen i beregningsperioden														
	Pv/Vv		LB/Busser		St-v/Ph.v-tog		Mc		$N_{M,Kt}$	N_M	of	N_{ud}	H_M	$H_{c/k}$	H_{fod}
	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	APe	Kt/T	Pe/T		Pe/T	Pe/T	Pe/T	Pe/T
South	398	1,0	37	1,5	24	2,0	10	0,5	469	507	0,93	465	546		
East	333	1,0	30	1,5	21	2,0	9	0,5	393	425	0,93	546	507		
North	531	1,0	50	1,5	32	2,0	13	0,5	626	677	0,93	507	425		
West	265	1,0	24	1,5	15	2,0	6	0,5	310	334	0,93	425	677		

Figure 3.2.7 - Traffic quantity in calculated period for year 2031,

two-lane entrance south/north

Rundkørsel, Skema B

Fastsættelse af middelforsinkelsen og belysning af kødannelserne i rundkørslens tilfartsspor

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T 3600 sekunder — Parametre: Vejregler

Tilfartsspor	Kritisk interval / Passagetid				Tilfartssporets kapacitet								Middelforsinkelsen og kolangden i tilfartssporet		
	t_M	$t_{c/k}$	$t_{vægtet}$	d	$H_M+H_{c/k}$	tf	G_{time}	G	kf_{Nud}	kf_{fod}	N_{Max}	$N_{Max,kt}$	B	t	$n_{5\%}$
	sek	sek	sek	sek	Pe/T		Pe/time	Pe/T			Pe/T	Kt/T		sek/Kt	Kt
South Spor H	4,2	0,0	4,2	2,8	546	1,00	835	835	0,95	1,00	793	734	0,42	8	1
South Spor V	4,2	0,0	4,2	2,8	546	1,00	835	835	0,95	1,00	793	734	0,22	6	1
East	5,1	0,0	5,1	3,0	507	1,00	718	718	0,90	1,00	646	598	0,66	17	5
North Spor H	4,2	0,0	4,2	2,8	425	1,00	920	920	0,95	1,00	874	809	0,51	9	2
North Spor V	4,2	0,0	4,2	2,8	425	1,00	920	920	0,95	1,00	874	809	0,26	6	1
West	5,1	0,0	5,1	3,0	677	1,00	602	602	0,90	1,00	542	503	0,62	18	4

Figure 3.2.8- Capacity, waiting times and queue lengths for year 2031,

two-lane entrance south/north

Rundkørsel, Skema C

Beregning af mængden af cirkulerende trafik foran en vejgren

Project — Tid på dagen:

Trafik: PROJECT Roundabout 2031

Beregningsperiodens længde: T =3600 sekunder — Parametre: Vejregler

Trafik fra vejgren:	Cirkulerende trafik i enheden Pe/T foran vejgren:							
	West		South		East		North	
	M	C	M	C	M	C	M	C
South			254	0	142	0		
			142	0				
East					142	0	142	0
					142	0		
North	281	0					254	0
							281	0
West	154	0	111	0				
	111	0						
Total (Pe/T)	546	0	507	0	425	0	677	0

Figure 3.2.9 - Circulating traffic in front of entering roads for year 2031,

two-lane entrance south/north

4. Horizontal Alignment

4.1 Dimensioning Vehicles

According to [2] the normally used dimension-giving vehicle is semi-trailer road train (SVT) and SK22 as accessibility-demanding vehicle. These demands are for this area unnecessarily high, it is not probable that this intersection has to handle such a big transport as SK22. Most of the traffic are personal cars, vans (85%), buses and small trucks.

In accordance to this it was decided to use as dimension-giving vehicle **12m BUS** and as accessibility-demanding vehicle **16,5m SVT**, for both of these vehicles speed 15 km/h is assumed when passing through roundabout.

4.2 Central Area

4.2.1 Central Island

Dependent on the number of road branches, the central island in a two-lane roundabout should have a layout with a large diameter (40 - 60 m) [2]. In regards to localization of this roundabout it is not economical and aesthetic to use 40m diameter, also with larger diameter there is a probability of higher circulating speeds *(see 4.4)*.

To ensure enough space for dimensioning vehicles, better displacement curve and diameter of **30 m** is used to ensure lower speed and not very small lengths between road branches

The drainage wells for proper water disposal are established around central island outer area in every connecting road center-lines (distance ±21 m) *(for details see 6.2)*.

4.2.2 Circulatory Area

The width of circulatory area is starting from inner side with 0,5 m shoulder, inner 3 m lane, outer 4,5 m lane and ending with 0,5 m shoulder *(see Figure 4.2.1)*.

The larger width of outer lane is used to accommodate space requirements for dimensioning vehicle (BUS), it is assumed that inner lane will be used only by cars so the width does not need to be so large.

The apron area is not necessary in two-lane roundabouts, the accessibility-demanding vehicle can use both lanes to safely pass the roundabout.

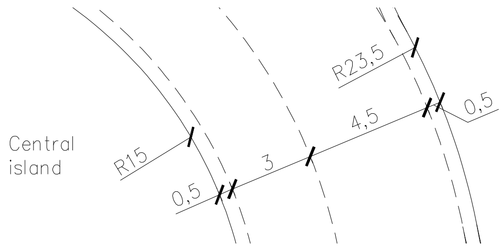

Figure 4.2.1 - Circulatory area width

4.3 Road Branch Connections

4.3.1 East/West Approaches and Exits

For east/west roads are accordingly to traffic *(3.2)* one lane approaches and exits are established. The width and radius of connecting edges varies.

A driving lane width of 3,0 m is normally recommended and an outer edge strip of 0,9 m can be established if there is a need for a drive-over area with its largest width smaller than 1,0 m.

The recommendation *Booklet 4.2, p84* [2] can't be fulfilled because of area demands for dimension-giving vehicle *(Drawing no. 15)*, also there is no need for 0,9 m edge strip, the drive-over areas (aprons) have largest width 1,0 m on both sides.

In approach the width of lane is 3,75 m with 0,5 m outer shoulder and the connecting radius 12,5 m. In the exit the width of lane is 4,5 m with 0,5 m outer shoulder and the connecting radius 14,5 m. The radiuses for connecting edges to original road are 49,5 m *(Drawings no. 10 and 11)*.

4.3.2 South/North Approaches and Exits

In these two-lane approaches and exits are used widths recommended in *Booklet 4.2* [2], 3,0 m in right lane and 2,75 m in left lane with 0,5 m shoulders on the outer edges. The outer connecting radius is the same in both directions, 17,5 m. The radiuses for connecting edges to original road are 49,5 m *(Drawings no. 12 and 13)*.

Angular shift in direction on exiting lanes at both sides is modified. The connecting roads are turning left so there is not possible to connect extended lanes to original road. For this reason there is an additional angular shift of 1:10 with edge rounding radius of 50 m. With this solution it is possible to accommodate desired types of vehicles in desired speeds.

4.3.3 Secondary (Splitter) Islands

For whole roundabout triangular splitter islands are used. This type is used because of its good ratio between area demands and speed reduction. Also for separated bicycle paths there is a demand of safe one-level crossing through the splitter island *(4.5)*.

The maximum width (nearest to circulatory area) 5 m is the same in all islands. The total length varies, in one-lane approaches/exits (east/west) it is 28 m from edge of circulatory area and in two-lane approaches/exits (south/north) it is 40 m for better speed reduction and higher offset for bicycle crossing *(4.5)*.

The curb delimited areas lengths from edge of circulatory area in east/west are 14,5 m with 2,2 m gap for bicycle crossing, in south/north it is 20 m with 2,2 m gap. The curb is executed with an edge of 0,3 m including road marking *(8.1)* [2].

Rounding of edges is the same in all splitter islands, tip is rounded with 1,0 m radius, the edges near circulatory area are rounded with 0,5 m radius and the edges of the gap are rounded with radius 0,25 m.

(Drawings no. 2, 10 - 13)

4.4 Entering/Exiting Speed

The entering/exiting speed is calculated accordingly to *Booklet 4.2, section 1.3* [2]. The maximum speed for entering/exiting roundabout without bicycle traffic past the road branch is 35 km/h. This desired speed must correspond to the maximal speed of an ordinary car. The speed is calculated according to Dutch model as

$$V = 7.4 \cdot \sqrt{R_{kk}} \qquad (4.4.1)$$

where the radius R_{kk} corresponds to circle arc of displacement curve calculated as

$$R_{kk} = \frac{L^2 + F^2}{4F} \qquad (4.4.2)$$

where F is a displacement and L is a displacement stretch length in meters.

The displacement curve starts at the approach lane, at the point where a car changes direction by turning right onto the circulatory roadway area. This is in the tangential point between the connecting edge and the right delimitation line for the approach lane. It is assumed that car is going in the distance of 0,5 m from the right roadway edge line. The curve ends in the tangential point at left delimitation of the lane. Same as in the beginning, car is going in the distance of 0,5 m from the left lane edge line.

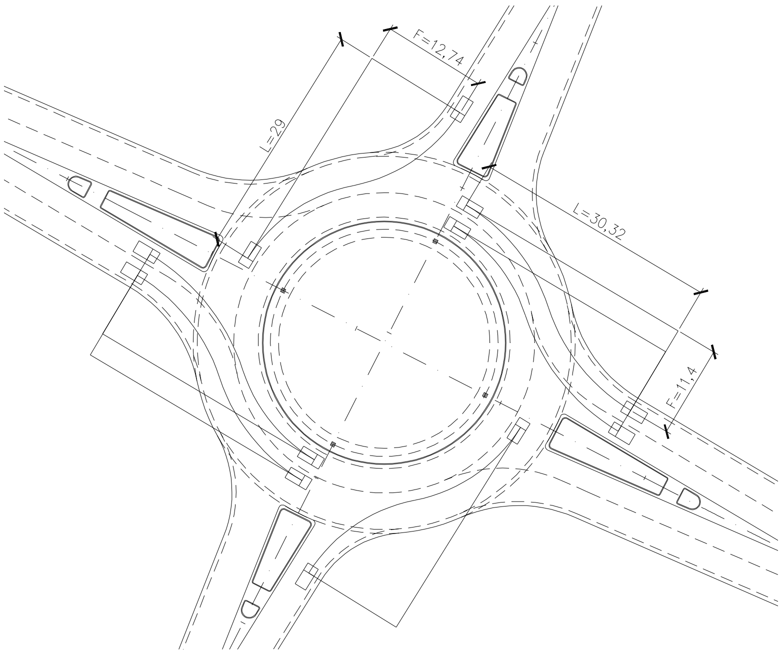

Figure 4.4.3 - Displacement

Calculated speeds are as follows:

south/north both lanes	R_{kk} = 23,0 m	**V = 35,5 km/h**
west/east	R_{kk} = 19,7 m	**V = 32.8 km/h**

The speed in south/north branch is slightly higher than maximum of 35 km/h, but in accordance to area demands for dimensioning vehicles and not much possibility of improving geometry to achieve lower speed is this solution adequate.

4.5 Bicycle Paths

Because of two-lane approaches/exits it is not possible to accommodate bicycle traffic past the road branches. This leads to exclusion bicycle traffic from motorized traffic *(Drawings no. 1-5)*. The width of separated bicycle path is common 2,2m [2]. The separation of bicycle paths starts at the point, where the angular shift of connecting road branches starts and ends in the middle of them, all with rounding radiuses of 20m. The final offset from connecting road edge is 2,2m and the angular shift varies from 1:13 to 1:17.

The bicycle path's offset from roundabout circulating area is 4,5 m and the outer connecting radiuses to straight bicycle lanes are 5,8 m. Connecting edges for crossing the road branches are rounded with radius of 1,5 m. The width of crossing gap in splitter island is 3 m.

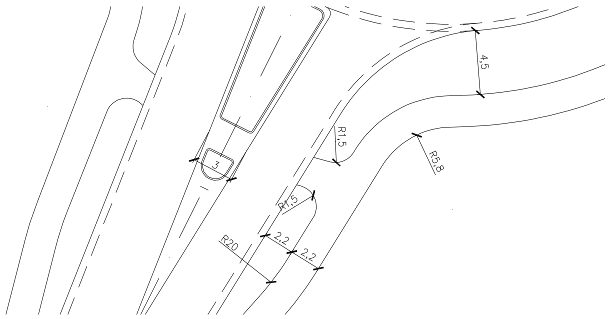

Figure 4.5.1 - Bicycle connection geometry

Pull-backs from circulatory area for crossings road branches varies *(4.3.3)*. For west/east the pull-back is 10 m and for south/north it is 15 m. The bigger pull-back for two-lane branches should ensure more time for cyclists to cross both lanes, although this solution according to [2] is not recommended.

There is possibility to use greater pull-back (20 - 40 m), but that results in greater detours for cyclists with the added danger, that some cyclists might take a short-cut via the carriageway. The safest solution is 2-level crossing, but there is a big economical aspect. This problem needs better examination and consultation with municipality. The probable changes in bicycle paths geometry do not effect motorized traffic, so it can be done additionally.

The road marking suggests bi-directional bicycle traffic and yielding lines in roundabout area and ensures faster passing through roundabout *(Drawing 9)*.

5. Vertical Alignment

(Drawings 4, 5, 6)

In this case all road branches shall adapt to roundabout vertical alignment, so there is no need for any vertical slopes to accommodate existing roads. The roundabout is leveled (slope 0 ‰) in a height of 18,74 m above the sea level *(Figure 5.2)*. This height is used to optimize earthworks so there is not big difference between cut and fill *(7)*.

The stationing starts at south road center-line and goes around outer edge of circulatory area counter-clockwise *(Figure 5.1)*.

The stationings of road branches are as follows:

South 0,00m

East 37,22m

North 73,84m

West 111,03m

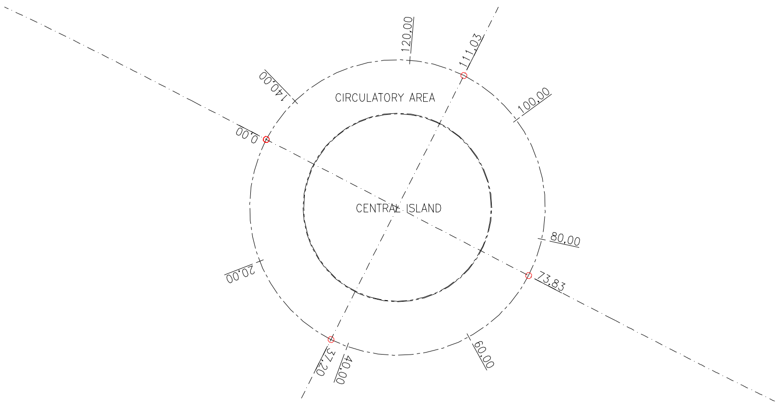

Figure 5.1 - Stationing

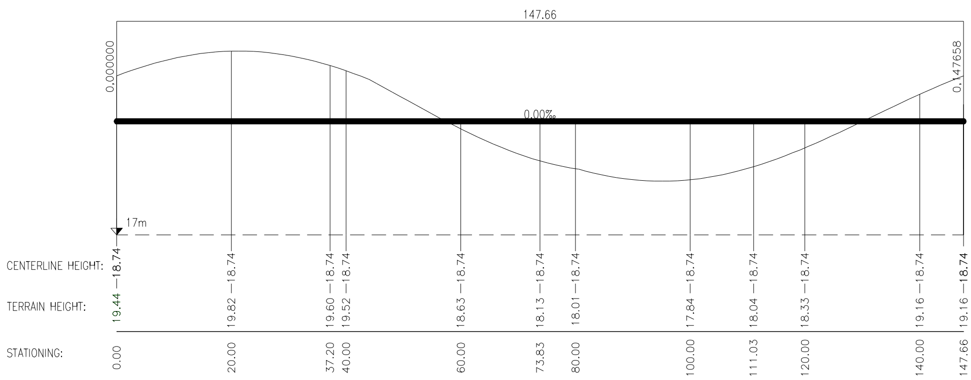

Figure 5.2 - Vertical alignment

6. Cross-Sectional Profiles

(Drawing 7)

6.1 Pavement Layers

For pavement dimensioning catalog method described in *Road rule: Dimensioning of fortification and reinforcement of surfacing (2007)* [2] was used. There are eight types of traffic classes (T0 - T7) with distinction of trucks number on the road per day in both directions [5].

For roundabout pavement design is crucial a number of trucks passing through per day. The amount of trucks for this traffic is 5 % out of all, for actual numbers see *section 3.2*. The sum of AADT from all directions is 14950 vehicles, of which are 747 trucks. This value corresponds to T5 type of traffic (600 to 1400 trucks per day).

The corresponding flexible surfacing layers widths and types are chosen from catalog in regards to traffic type T5 [2]. For circulatory area and road branches most common type Asphalt + SG (stabilized gravel) is used with following layers:

	30 mm AB 70/10	*Asphalt concrete*
	60 mm ABB 40/60	*Asphalt concrete*
	65 mm GAB I 40/60	*Gravel asphalt concrete*
	215 mm SG	*Stabilized gravel*
	350 mm BL	*Sub-base layer (sand)*
sum	*720 mm*	

For bicycle paths are used layers for traffic type T0 (only light traffic):

	30 mm PA 250/330	*Powder asphalt*
	120 mm SG	*Stabilized gravel*
	150 mm BL	*Sub-base layer (sand)*
sum	*300 mm*	

There are not any data available in this area concerning composition of sub-soil, but assumption is that the moraine clay is most probable in this area as it is in whole Denmark. Moraine clay is considered frost questionable and for traffic type T5 is the minimum total paving thickness, taking into account the added risk of frost, 700 mm - which is less than sum of used layers [5].

6.2 Central Roundabout Cross-Section

Starting in the middle of roundabout with outward down slope of 100 ‰ to ensure visibility of roundabout and proper water disposal, 2 m before circulatory area the small ditch is established with slopes 200 ‰ from both sides to drain dirty water through wells to drainage system at the bottom layer *(Drawing 7, Detail 2)*. The surface of central island is grass covered, so for proper growth and aesthetics the layer of 0,2 m top-soil is used.

When the central island is changing to circulatory area the concrete curb is established with height 0,1m above road to ensure visibility and safety. The curb with skewed outer edge is used, and is fixed in concrete bed of 0,1 m. The whole circulatory area is in the slope 25 ‰ including both lanes and 0,5 m shoulders on both sides. The layers for circulatory area are described in *section 6.1*.

The separation part between circulatory area and bicycle path is grass-covered with 0,2 m top-soil layer and slope of 30 ‰ for slow water disposal and not large soiling of bicycle path. Slope for bicycle path is also common 25 ‰ with layers described in *section 6.1*.

The layer connection between bicycle road and 1m outer verge is stepped *(Drawing 7, Detail 1)*. Outer verge is in the slope of 75 ‰ and is continuing to the trapeze ditch with slope of 1:2 on both sides and 0,35 m wide bottom.

All the cuttings and fillings of layers are in triangular shapes with slope 1:1 on both sides, with underground drainage systems on both sides of circulatory area.

6.3 Connecting Roads Cross-Sections

Splitter islands curb delimited part in all directions are covered with granite setts with slope 100 ‰ on both sides into roadway and rounded with radius 20 m on top. Granite setts are laid into concrete 0,1 m layer. Splitter islands curbs with skewed outer edge are 0,1 m above road.

Roadways are in slope 25‰ outwards including splitter island's non-curb part. In south/north branches slopes continue symmetrically on both sides same as in central roundabout cross-section, 30 ‰ slope for separation part with grass surface, 25 % slope for bicycle path and 75 ‰ slope for outer verge continuing into ditch.

For west/east branches there is a drive-over area (apron) between roadway and grass separation part *(Drawing 16)*. The maximum width of apron is 1 m with 0,5 m wide concrete turning block with opposite slope 200 ‰ into roadway. Because of this, apron is making small barrier, which leads to accumulation of water, thus there must be established drainage wells in outer shoulder of road lane. Wells are connected to drainage system located at the end of bottom roadway layer under grass separation part.

Total apron width is reached outward from concrete turning blocks by granite setts with opposite slope of 100 ‰. Granite setts and concrete turning blocks are laid into concrete bed with minimum width 0,1m. From outer edge of apron the slopes and layers continue the same as in south/north branches.

As for central roundabout area, all the cuttings and fillings of layers are in triangular shapes with slope 1:1 same with stepped end layer connections *(Drawing 7, Detail 1)*.

7. Earthwork Calculations

The calculations of earthworks are made just for an circulatory area *(Figure 7.1)*. The earthworks for road branches should be calculated after establishing vertical alignment for both roadways which is not part of this project. However, preliminary solution was made with all branches with connection accordingly to *section 5* and the visible ratio between cut and fill seems low enough. This solution is also used in all drawings.

The final difference between cut and fill volumes for circulatory area with extend to bicycle paths is 9,7 m^3, for continuous results in 5 m stationing see *Figure 7.3*.

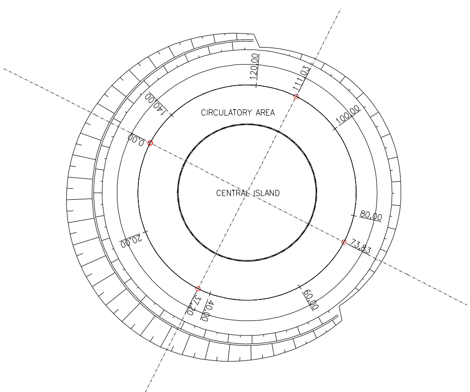

Figure 7.1 - Earthworks of circulatory area with bicycle extension

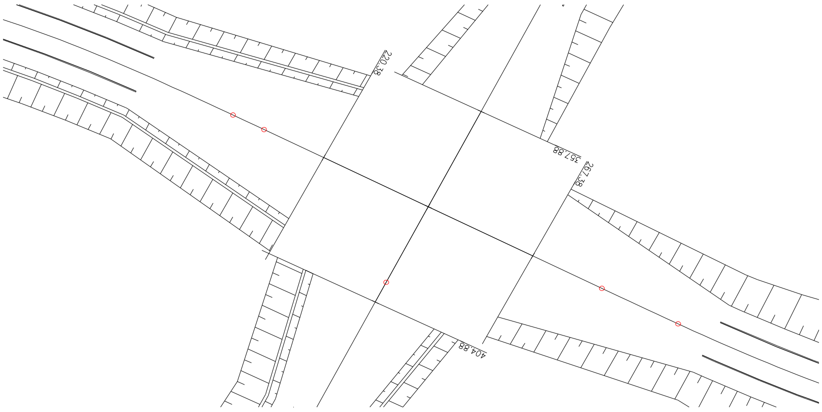

Figure 7.2 - Earthworks of road branches with bicycle extension

EARTHWORKS CUT AND FILL					
STATIONING INTERVAL	AREA OF CUT (m2) VOLUME OF CUT (m3)	AREA OF FILL (m2) VOLUME OF FILL (m3)	VOLUME SUM CUT (m3)	VOLUME SUM FILL (m3)	DIFFERENCE (m3)
0.000000 0.00	0.00 0.0	0.00 0.0	0.0	0.0	0.0
0.005000 5.00	34.12 85.3	8.88 22.2	85.3	22.2	63.1
0.010000 5.00	33.51 169.1	8.56 43.6	254.4	65.8	188.5
0.015000 5.00	35.73 173.1	8.36 42.3	427.5	108.1	319.3
0.020000 5.00	36.72 181.1	8.28 41.6	608.6	149.7	458.9
0.025000 5.00	35.69 181.0	8.31 41.5	789.6	191.2	598.4
0.030000 5.00	34.67 175.9	8.45 41.9	965.6	233.1	732.4
0.035000 5.00	35.12 174.5	8.71 42.9	1140.0	276.0	864.0
0.040000 5.00	31.41 166.3	9.10 44.5	1306.4	320.6	985.8
0.045000 5.00	25.75 142.9	9.63 46.8	1449.3	367.4	1081.9
0.050000 5.00	19.81 113.9	10.31 49.8	1563.2	417.2	1146.0
0.055000 5.00	14.16 84.9	11.16 53.7	1648.1	470.9	1177.2
0.060000 5.00	8.44 56.5	12.15 58.3	1704.6	529.2	1175.5
0.065000 5.00	1.23 24.2	14.30 66.1	1728.8	595.3	1133.5
0.070000 5.00	1.63 7.1	14.91 73.0	1735.9	668.3	1067.6
0.075000 5.00	0.01 4.1	21.30 90.5	1740.0	758.8	981.2
0.080000 5.00	0.01 0.1	23.21 111.3	1740.1	870.1	870.0
0.085000 5.00	0.00 0.0	25.12 120.8	1740.1	990.9	749.2
0.090000 5.00	0.00 0.0	22.59 119.3	1740.1	1110.2	629.9
0.095000 5.00	0.00 0.0	23.12 114.3	1740.1	1224.5	515.6
0.100000 5.00	0.00 0.0	27.31 126.1	1740.1	1350.6	389.6
0.105000 5.00	0.00 0.0	25.10 131.0	1740.1	1481.6	258.5
0.110000 5.00	0.01 0.0	22.66 119.4	1740.1	1601.0	139.1
0.115000 5.00	0.01 0.0	19.47 105.3	1740.2	1706.3	33.9
0.120000 5.00	1.13 2.9	16.44 89.8	1743.1	1796.1	−53.0
0.125000 5.00	3.63 11.9	13.20 74.1	1755.0	1870.2	−115.2
0.130000 5.00	12.21 39.6	12.17 63.4	1794.6	1933.6	−139.1
0.135000 5.00	12.64 62.1	11.18 58.4	1856.7	1992.0	−135.3
0.140000 5.00	22.62 88.1	10.32 53.8	1944.8	2045.7	−100.9
0.145000 5.00	23.37 115.0	9.64 49.9	2059.8	2095.6	−35.9
0.147658 2.66	29.90 70.8	9.34 25.2	2130.6	2120.9	9.7

Figure 7.3 - Cut and fill volumes of circulatory area with bicycle extension

8. Road Marking and Signs

(Drawings no. 8-10)

8.1 Road Marking

All road markings widths are used accordingly to *Booklet 4.2, section 7* [2].

A 30 cm broad edge line is used to delimit the circulatory roadway area adjacent to the central island, also the 30 mm line is used on outer edge of circulatory area with dashed 1+1 m line in entering/exiting. The 10 mm 2+2 m lane separating line is used in circulatory area.

In two-lane approaches the 10mm lane separating line is dashed (3+3 m) from beginning of splitter island until bicycle crossing and then continuous until yielding line. From yielding line is used optimally curved dashed (1+1 m) connection to circulatory separating line. The dashed line between bicycle crossing and end of splitter island is in exits 2+2 m.

For all connecting roadways the outer delimitation line is 30 mm broad.

As a delimitation of splitter island is used 10 mm line, and specific hatching accordingly to *Figure 8.1.1*. The 20 m long warning line starting at the end of splitter islands is used.

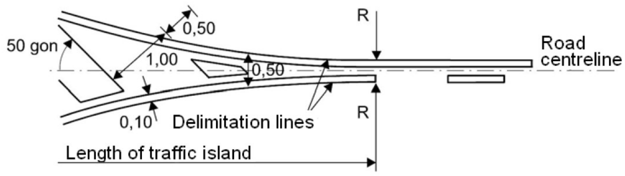

Figure 8.1.1 - The connection between the reservation area and the road markings [2]

The marking arrows suggesting right directions are positioned on outer circulatory lane and at bicycle paths accordingly to drawings. For bicycle crossings 0,5 m squares with 0,5 m gap and bicycle signs are used.

For roadway yielding lanes are used common triangles 0,5 m wide and 0,6 m long with 0,5 m gap, all yielding lines are pulled back from circulatory area for about 1m. The dimensions for bicycle yielding lines are the same but without a gap.

Bicycle path 10 mm 1+1 m separating lines are established with pull-back from bicycle crossings for about 10m to avoid unnecessary confusion with sudden change of lanes.

8.2 Signs

On all connecting roads 150 m before yielding line are used diagram orientation signs (G14) and bicycle warning sign 50 m before bicycle crossing.

On splitter islands three types of signs are used, near circulatory area directional sign (F11) with 120 mm capital letters is used and turned to be visible for drivers in both circulating lanes, mandatory driving direction sign (D11,3) at the tip of curb delimitation and yielding sign pulled back of 5 m from yielding line. The yielding sign is also used on the other side of the roadway.

On central island double mandatory driving direction signs (D11,3) are used in front of all entering roads.

The speed reduction signs recommended by *Booklet 4.2* [2] are not used. This area is in 50 km/h zone and the pull-backs 250 m from yielding lines are not, due to connecting road lengths, possible. However, pre-warning yielding sign with sub-sign (B11ug U1), 250 m before yielding line is used in all roadways except east, where this roadway is already connected to Brådhusvej.

9. Conclusion

The aim for this interdisciplinary project of intersection was accomplished with use of knowledge acquired from technical literature and related lessons at VIA University College.

Few solutions, mostly geometrical, had to be adjusted to meet demands for dimensioning vehicles and may lead to higher circulating speed, but there is always relation between these two criteria. Also redoing the bicycle paths to two-level crossings may lead to better, but expensive, solution.

All decisions regarding geometry and used materials made in this project should lead to safe, efficient and aesthetic roundabout.

10. List of Used Sources

[1] DANISH ROAD DIRECTORATE:
Capacity and service level, chapter 5 Roundabout, 2001

[2] DANISH ROAD DIRECTORATE:
Rules for roads and paths in rural areas, Booklet 4.2 - Roundabouts, 2001

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Cyclists in roundabouts - Different design solutions, Elsevier Ltd. 2010

11. List of Abbreviations

AADT Annual Average Daily Traffic
PRŮMĚRNÁ DENNÍ INTENZITA DOPRAVY (CELOROČNÍ PRŮMĚR)

ST/TT Semi-Trailer / Tow Trailer
NÁVĚS / TAHAČ

MC Motorcycle
MOTOCYKL

SVT Semi-Trailer Road Train
NÁVĚSOVÁ SOUPRAVA

SK22 Special 22m Long Vehicle
22M DLOUHÉ SPECIÁLNÍ VOZIDLO

AB Asphalt Concrete
ASFALTOVÝ BETON (OBRUSNÁ VRSTVA)

ABB Rust Resistant Asphalt Binder (Asphalt Concrete)
ASFALTOVÝ BETON PRO LOŽNÉ VRSTVY (OCHRANNÝ)

GAB I Asphalt Bound Base Layer (Gravel Asphalt Concrete)
ASFALTOVÝ BETON PRO PODKLADNÍ VRSTVY

SG Granular Base Layer (Stabilized Gravel)
STABILIZOVANÝ ŠTĚRK (ŠTĚRKODRŤ)

BL Granular Sub-Base Layer
PODKLADNÍ VRSTVA (ŠTĚRKOPÍSEK)

PA Powder Asphalt
LITÝ ASFALT

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   TECHNICKÁ ZPRÁVA

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5.	Longitudal Profiles of Roads (South, East) PODÉLNÉ PROFILY NAPOJENÍ (ODDERVEJ, BRÅDHUSVEJ)	1:500/50
6.	Longitudal Profiles of Roads (North, West) PODÉLNÉ PROFILY NAPOJENÍ (ULFELDTVEJ, SUNDSGÅRDSVEJ)	1:500/50
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18. Comparison of Danish and Czech Approach to Roundabout Design
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