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ABSTRACT

The Danish Guidelines for Geometric design of roads in rural areas were forwarded to formal enquiry in 2010 and finished in 2013.
The wish of designing the roads as selfexplaining roads, and the need to ensure a more efficient management of the roads including traffic safety and a high degree of passability during road works lead to a reduction of the 17 road types to 6 basic road types.
The new basic road types has been developed on the basis of comprehensive research and development.
The Guidelines for roundabouts has been revised due to an extensive international literature study - a detailed before-after safety evaluation and models of safety effects of converting intersection to roundabouts.

The evaluation shows how central island size and height, circulating lane width and shape, design of splitter islands, width of entry and exit lanes, angle and distance between arms, sight distance to the roundabout, bicycle facilities, pre-warning, direction signs and road markings influence safety effects.

In the aim to keep the low speed at roadwork zones (80km/h on motorways and 50km/h on other roads) speed reducing measures has been developed and tested. Accidents at roadwork zones are often caused by high speed and inattention.
To keep the passability during the road works narrow lanes has been developed, and surprisingly with higher capacity than calculated on the basis of the known reduction factors based on the HCM.

PREFACE
The Danish standards and guidelines for roads are prepared under the responsibility of the Minister for Transport by the Danish Road Directorate in cooperation with, municipalities, universities, consultants and road user organisations (vehicle owners, cyclists, professional drivers and disabled peoples organisations. The standards and guidelines are valid for all roads and paths in urban areas and all public roads in rural areas.

The new Danish guidelines for geometric design of roads in rural areas were completed in 2013.

The guidelines are based on a holistic philosophy that incorporates all the disciplines relating to road construction and traffic into a single whole. Thus, in the recommendations, the expertise of traffic engineers, traffic psychologists and road design engineers are integrated in total solutions that - with the current knowledge - ensure that road users are guided safely and comfortably through the road system during normal traffic conditions as well as road works.

FIGURE 1 The motorway is a self-explaining road

In the long term, these guidelines are intended to create "the self-explaining road" through which the information provided by the road, the road equipment and the surroundings, road users are made aware of possible other categories of road users they may encounter on the road and which road safety behaviour will be most appropriate.

Design requirements are not only taking the construction of the new road into account, but must also prepare for rebuilding and maintaining the road. Basic cross sections are designed to enable passability during the rebuilding or maintenance work.
Comprehensive research has been carried out to ensure traffic safety and passability through road works.

GUIDELINES
The guidelines consist of the following volumes:

- Road planning in rural areas
- Premises for the geometric design
- Alignment
- Cross sections
- Planning of road junctions
- Yield controlled junctions
- Roundabouts
- Signal-controlled junctions
- Grade separated junctions and interchanges
- Rest areas

The draft guidelines were introduced at the 2010 Symposium. Since then, the regulations on cross sections and roundabouts have changed because of recent research.

The most significant research that led to the change of the cross sections regulations was a Nordic study of the safety of different designs of roadside areas.

The Main objective of this study was to evaluate the safety of different roadside ditch and slope profiles. For this purpose, a number of simulated tests were conducted. The analyses in the report are based on data from these simulations together with results of full-scale tests performed in Finland and Sweden. As background data for the analysis, detailed statistics of single vehicle accidents and applicable results of earlier research were collected.

The analyses of roadside areas include several ditch profiles with up to 4 m high backslopes. In most cases, risk analysis was used to evaluate the safety of tested roadside profiles. In the analysis, the likelihoods and severities were defined for the following incidents:

- Crash into the backslope
- Rollover
- Collision with another vehicle when re-entering the roadway

The results are presented in the report: *Safety of roadside area. Analysis of full-scale crash tests and simulations.*

On the basis of the findings of the report, the Danish Road Directorate decided to implement ditches designed as shown in Figure 2. Usually, Type 1 is the preferred choice. If conditions allow vehicles to continue out into a field, Type 2 may be selected. Type 3 is implemented when conditions do not allow room for a complete backslope setup 1V:3H.
FIGURE 2 Three types of ditches (A = 2 is 1V:2H and A=3 is 1V:3H)

Cross sections
Based on the functional road classification (through roads, distributor roads and local roads) and supplementary speed classification, this Volume defines 5 types of roads:

- 6-lane roads
- 4-lane roads
- 2 + 1 roads ("Two plus one")
• 2-lane roads
• 2 -1 roads ( “Two minus one”)

The previous version of the guidelines defined 17 different types of roads, which caused a great deal of problems in pursuing the concept of the self-explaining road. As it turned out, problems occurred also in connection with ensuring a clear and uniform strategy for operations and maintenance, both in terms of traffic flow through roadworks and in the provision of operations and maintenance tasks.

For each type of road, a basic cross section profile has been determined, ensuring satisfactory road safety and excellent passability during normal operation and during roadworks.

The cross section profile for a 6-lane motorway is 35m wide allowing a planned speed of 130 km/h. This enables traffic in 5 lanes on one side of the motorway while performing roadworks in the opposite side of the motorway. The 5 lanes compose of 3 lanes in one direction and 2 lanes in the other direction. If necessary, reversible lanes are an option. The speed is reduced to 80 km/h through roadworks.

The basic cross section profile for a 4-lane motorway is 29m wide allowing a planned speed of 130 km/h. The table below shows the design of one-half of the cross section profile. The width of the inner shoulder is based partly on traffic safety studies and partly on the consideration of short-term mobile roadworks, during which robotic vehicles with traffic signs may be used.

![Cross section profile for 4-lane motorway, one lane](image)

Through long-term roadworks, traffic runs with a speed of 80 km/h on one side of the motorway as shown in the figures below.
Narrow lanes are established based on extensive studies in terms of speed, capacity and traffic safety, and applied successfully in practice tests for 3 years. A sub-study on speed reducing measures is summarised in the following section.

FIGURE 4 Lanes at the roadwork

FIGURE 5 Example from the Vejle motorway (Vejlemotorvejen)

The basic cross section profile for a 2+1 road is 16m wide allowing a planned speed of 90 km/h. The profile is designed to allow for 2-lane driving through roadworks.
In connection with the decision between establishment of traffic barriers or center lines as a means of traffic separation, a number of accident studies of Danish 2+1 roads and comparative Swedish and German accident studies have been completed. In addition, conditions for operation and maintenance in relation to the application of traffic barriers have been assessed. As a result of this work, it was decided not to establish traffic barriers as separations.

Rumble strips shaped as sinus shaped grooves in the asphalt are a standard centerline separation. Rumble strips are usually established in the driving lane right up to the centerline.
The basic cross section profile for 2-1 roads is 7.9m wide allowing a planned speed of 60 km/h. 2-1 roads are local roads with two-way traffic and bicycle traffic in the road space. The width of 3.5m is determined on the basis of behavioural studies showing, that wider driving lanes cause misunderstandings, in the sense that road users do not give way to each other by crossing the broken line as assumed. This behaviour leads to the risk of side mirrors colliding when passing.

**Roundabouts**

The Guidelines for roundabouts has been revised due to an extensive international literature study - a detailed before-after safety evaluation and models of safety effects of converting intersection to roundabouts.

The evaluation shows how central island size and height, circulating lane width and shape, design of splitter islands, width of entry and exit lanes, angle and distance between arms, sight distance to the roundabout, bicycle facilities, pre-warning, direction signs and road markings influence safety effects.

The main results of this study will be presented during this symposium.

**Designing roadwork zones**

Design and construction of the road space and the road marking in connection with roadworks on a motorway is of vital importance for road safety and passability. The narrow cross section profiles for motorways through roadworks require low speed traffic, a constant velocity profile without stops and good guidance through the roadwork area. Hence, the Danish Road Directorate has developed a coherent strategy to ensure a sensible flow of traffic during roadwork. The strategy is summarised in the following:
The basic philosophy for traffic management in roadwork zones on motorways:

- Keep the number of lanes
- Reduce the speed to 80 km/h
- Keep the traffic on the motorway
- No increase in personal injury accidents
- No accidents between workers and the traffic
- Good passability, delays only caused by reduced speed

How do we fulfil our requirements?

- We respect the driver’s skills and behaviour
- We alert the driver through signs and road markings
- We guide the driver through the roadwork zone
- We protect the driver and the worker when accidents happen

Respecting the driver’s skills and behaviour:

- The driver does not always respect the law
- The driver does not think like a civil engineer
- The driver uses the information that suits him best
- The driver cannot read more than four pieces of information at a time
- The driver cannot read information placed after a bridge until he has passed the bridge
- The driver cannot see the road environment in darkness
- The driver can only solve one problem at a time
- The driver’s focus is far ahead of his vehicle
- The driver acts on the basis of experience and expectations
- The driver is inattentive

Alerting the driver, and how?

- Through an “alert signal” caused by 1cm high rumble strips
- By constructing a visual gate
- By applying warning signs for roadwork zones
- By applying visual speed reducing measures

Guiding the driver, and how?

- By applying a road design which is speed harmonised for 80 km/h:
  - Uniform horizontal curves
  - Recognisable ramp geometry at entries to the motorway, both in length and connection angle
  - Recognisable exit geometry
  - Lane drop 1:30
  - Narrow lanes 2,75m (min. 2,2m) in lane 2 and 3, and 2,9m in lane 1. Road markings are not included in these measures
  - Lane 2 and 3 are restricted to max 2,0m wide vehicles
- By use of white road markings, removing all existing road markings
- By use of 1,45m high delineator panels; however, in sight areas 0,75m
- Emergency shoulders each 800m
- By applying alerting measures such as rumble strips
By applying speed reducing measures
By Use of lane guidance signs
By installing reflective devises on guard rails

This strategy has led to a significant drop in accidents at motorway roadworks and passability far better than the expected passability based on capacity calculations with applied reduction factors for road geometry.

Extensive traffic evaluations of a number of large-scale road construction works in operation are being performed. The evaluations are expected to be concluded by mid-2015.

SPEED REDUCING MEASURES AT ROADWORK ZONES
In 2011-2014, the Danish Road Directorate completed a project on development and testing a variety of methods to reduce speed at motorway roadworks. The tested instruments are described in a small catalogue (4), which in future can be updated with new knowledge and examples as needed.

Narrow lanes
In connection with major roadworks in 2011, an experiment with reduced left lane width on a 1100m long stretch was conducted.
The experiment was evaluated on the basis of measurements on three different setups; A Basic setup, which is the original cross section, as well as two setups (Marking1 and Marking2) both of which have a reduced left lane width. In addition, N42 delineator panels have been placed along the Marking2 left shoulder line at 30m intervals. Similarly, N42 delineator panels have been placed along the right shoulder line at a distance of approximately 1m from the line. The three setups are shown in Figures 9.

![Basic](image1)
![Marking1](image2)
![Marking2](image3)

FIGURE 9 The three experimental setups: Basic (left), Marking1 (in the middle) and Marking2 (right). Marking1 and Marking2 have reduced left lanes of 2,20m. In Basic, the left lane is 2,75m
The evaluation results showed as follows:

- During low traffic intensity, the speed is reduced by 0-2 km/h at *Marking1* compared to *Basic*, and the speed reduction is slightly larger at *Marking2* (especially in the left lane).
- During high traffic intensity, the speed is slightly reduced at *Marking1* compared to *Basic*, but the speed is reduced by 5-10 km/h at *Marking2* compared to *Basic*.
- The speed difference between right and left lane is reduced from an average of 9 km/h in *Basic* to 8 km/h in *Marking1* and 5 km/h in *Marking2*.
- Traffic flows are estimated from the maximum flow measured during peak hours and calculated capacity based on speed-flow curves. Compared to *Basic*, a 1-2% reduction in capacity has been measured at *Marking1* and a 5-6% at *Marking2*.
- At *Marking1* and *Marking2* an increased use of the right lane was registered. This increase corresponds to approximately 2-5% compared to *Basic* and is the largest at *Marking2*.
- The lateral placement of vehicles is affected by the reduced lane widths. At high traffic intensity, the distance between vehicles in the left and right lanes is reduced by 9cm at *Marking1* and 14cm at *Marking2* compared to the *Basic* setup.
- The number of vehicles running on or beyond the left shoulder line in *Marking1* is significantly increased compared to *Basic*. At *Marking2*, which also involves N42 delineator panels close to the shoulder line, no overruns were observed, and the number of vehicles running on the shoulder line is at the same level as that of the *Basic* setup.

**Corridor of N42**

With the aim of enhancing the speed reducing effect in connection with roadworks with lane reductions from 2 to 1, a series of tests were conducted in 2013 with narrowing of the road space in addition to the standard marking (DRI-261) at motorway roadworks (see Figure 10).

The narrowing was established as a corridor by use of 2m high N42 delineator panels. The narrowing was tested on a stretch WITHOUT cross-over (stage 1) and on a stretch WITH crossover of traffic to the opposite half of the lane (stage 2). On the stretch WITHOUT crossover, the speed limit was 80 km/h, while this was “signed down” on the stretch WITH crossover from 80 km/h to 50 km/h approximately halfway on the stretch before the crossover. At both stages, the road users’ speed was measured at two different N42 delineator panel setups (15m and 7,5m) as well as on a reference stretch.

The width of the corridor was 3,65m, which is the minimum for the sake of wide vehicles. The length of the corridor was 160 m (stage 1 WITHOUT cross-over) and 150 m (stage 2 WITH cross-over). The first 15m of the corridor were funnel-shaped. The distance between the two truck mounted attenuators at the entrance to the corridor (stage 2) was 4,5m (see Figure 11).

Speeds were measured in five selected sections for each of the two corridor setups, WITH and WITHOUT crossover of traffic respectively, as well as for the associated reference setups.
FIGURE 10 The corridor stretch with the 2m high N42 delineator panels each 7,5m at stage 1 (bottom) and corresponding reference stretch with a standard DRI-261 marking (top).

FIGURE 11 The corridor stretch on stage 2. In this case, the entrance to the corridor is marked with two truck mounted attenuators placed by 4,5m. At the bottom, the 2m high N42 delineator panels are shown on the middle of the stretch of the 3,65m wide corridor.
Results of the test of corridors WITHOUT cross-over (stage 1) showed that:

- The two corridor setups (distances 15m and 7.5m respectively) had a reducing effect on the average speed of about 4-6 km/h before, during and after passing the test stretch – whatever the time of day.
- Whether the N42 distance in the corridor was 15m or 7.5m had no great significance in the daytime, whilst the effect during night hours was larger through the 15m distance stretches.

Results of the test of corridors WITH cross-over (stage 2) showed that:

- The average speed was reduced by approximately 3-4 km/hour in all measurements before the crossover –in daytime. After passing the crossover - and generally during night hours - the effect of the corridor setups was less significant.
- Whether the N42 distance in the corridor was 15m or 7.5m, the average speeds and 85% percentiles were generally very much alike for both corridor setups both day and night. The only exception was at the crossover, where the 85% percentile during night hours was 4 km/h lower at the 15m distance compared to the 7.5m distance.

"Port & Cone”

In connection with maintenance of traffic barriers in the centre strip of a 4-lane motorway in the night hours, a new marking concept called Port & Cone” has been tested.

The speed limit on the motorway is gradually ”signed down” to 70/80 km over a distance of 200m before the lane reduction forewarned on a E16.2 sign at a distance of 400m.

Two truck mounted attenuators are placed at the lane reduction, one on each side of the right lane, thereby forming a gate to the work area (see Figure 12). The truck mounted attenuator on the right side is placed in the emergency shoulder right up to the shoulder line.

FIGURE 12 Together, the two truck mounted attenuators form a ”port” continuing in a corridor established by two rows of marker cones

The two truck mounted attenuators are both equipped with flashing arrows and 2 flashes on the beam. The flash frequency of the two vehicles must be synchronised. The 0.75m high cones fitted with a fluorescent surface are positioned in the extension of the two attenuators
by 15m. As such, the "gate" formed by the two truck mounted attenuators at the beginning of the work area, continues into a "cone corridor" over the entire work area.

The new marking concept (DRI-254) has been tested in relation to the old concept (DRI-253), at which there were no markings on the right side of the driving lane past the work area and the left side barrier was made with the ordinary cylinder cone. Speeds were measured in 5 cross sections through the process.

*Result of the test:*
- The speed is generally lower at the new marking (DRI-254) compared to the old (DRI-253). The average speed at the gate (measuring point at the TMA) is reduced by 18 km/h from 62 km/h to 44 km/h (see Figure 13).
- The percentage of road users exceeding the posted speed limit has been reduced to 1/4 (from 36% to 9%). Speed reduction through the last 200m before the gate is 15 km/h for the "old" and 30 km/h for the "new" marking.
- When using the old concept, crossings of the right shoulder line could regularly be recorded with driving of one set of wheels in the emergency shoulder. This does not occur with the new "Port & Cone" concept (DRI-254).

Based on the results, the new marking concept has been implemented in the road standards for road marking at roadworks on motorways in the October 2013.

**FIGURE 13** Speed profiles of "the old" DRI-253 and the new "Port & Cone" concept DRI-254
Mobile road quakes combined with “SLOW DOWN” signs

In September 2012, mobile rumble strips were tested in connection with roadworks on a motorway (route 16). The test included installation of mobile road quakes – both alone and in combination with a message to ”SLOW DOWN” - provided by a VMS sign when overspeeding (see Figure 14). The test was carried out along a 600m long stretch during which the speed was “signed down” prior to the roadworks from 90 km/h to initially 70 km/h and finally 50 km/h.

Mobile road quakes are an American product (Road Quake) manufactured of a heavy plastic. The single piece of strip is 1.8cm high and 1m long. The pieces are snapped together in appropriate lengths. They are not fixed to the road surface but attach themselves through their own weight.

In the test, the rumble strips were initially zoned with 3 strips of each 3m in each driving lane. It quickly became apparent that they did not remain in position. Therefore, they were placed as 3 rumble strips instead, each 6m in length, across both lanes and a spacing of only 1.5m in a first set-up and 4m in a second set-up.

Results of observations during the test:

- The road quakes were dislocated by the traffic, primarily in the right lane where most of the heavy vehicles are driving. Moreover, this lane was the busiest.
- When heavy vehicles ran over the road quakes, a slight movement of these could be observed for each wheel passage in the driving direction.
- The road quakes were dislocated, primarily in the area around the 70 km speed limit sign and a little less around the 50 km/h speed limit sign.
- Passenger vehicles from the right lane were repeatedly observed driving into the emergency shoulder to avoid crossing the road quakes.
Results of speed measurements

- Speed changes due to mobile road quakes, were generally small, regardless of setup.
- Regardless of the road quakes being placed with 1.5m or 4m spacing, no difference in speed behaviour could be documented.
- Regardless of the VMS sign with “SLOW DOWN” being placed before or after the road quakes, no difference in speed behaviour could be documented.
- Regardless of the road quakes being placed at the 70 km/h or the 50 km/h speed limit signs, no clear difference in speed could be documented.
- Generally, the “SLOW DOWN” signs had a positive effect, since the speed was reduced by 5-10 km/h when signs were part of the setup.

The tested mobile road quakes are only suitable for use during very short-term roadworks and at relatively low speeds of around 50 km/h or less. Hence, these are not well suited for use related to motorway roadworks.

Rumble strips before entry to interim motorway

In connection with construction work on Highway E20 at Slagelse, an interim stretch of road was established to lead the motorway traffic around the work area.

At the entry to this interim stretch solid rumble strips in combination with a “Your speed” sign were established to reduce the speeds. The signed speed limit on the road was 80 km/h.

![FIGURE 15 Rumble strips immediately before the entry to the interim motorway](image)

The study of the speed-reducing effect is based on observed speeds in a measuring cross section of around 100m and 200m respectively before the rumble strips, as well as 50m after the rumble strips (see Figure 16).

Speeds were measured over a whole day and night, during which the “Your speed” sign was active. In addition, speeds were measured over a whole day and night, during which the “Your speed” sign was deactivated (and dismantled). Approximately 15,000 vehicles were recorded during the active sign period and approximately 16,000 vehicles during the deactivation period. Overall, the traffic pattern was more or less the same during the two measurement days.
The results showed that the speed between the first and the last measuring point was reduced by 15 km/h during the active “Your Speed” sign period. During the deactivation period, the speed reduction was 12 km/h (see Figure 17).

The measurements show that the rumble strips alone do have a speed reducing effect, and that this effect is amplified when the strips are supplemented by a ”Your Speed” sign.

The number of road users exceeding the signed speed limit was measured to 65-70% in the first measuring point, whilst 18% and 34% were measured in the last measuring point during activation and deactivation respectively.
VMS for temporary speed reduction in work zones

Two different tests have been completed to compare the speed reducing effect of fixed speed signs and electronic VMS speed signs at roadworks on motorways.

In the first test, the fixed 90 km/h, 70 km/h and 50 km/h speed signs were supplemented by electronic VMS speed signs conveying the same messages. The electronic signs were positioned closest to the driving lane and in the same height as the fixed signs (see Figure 18). This setup was tested both during the day and at night.

The result of the first test showed that:

- Electronic VMS speed signs appear much clearer than the fixed signs
- The supplementary electronic VMS speed signs led to a reasonable speed reduction of 5-11 km/h in comparison to the fixed signs alone. This applied both in daylight and in darkness.

In the second test, the VMS signs were used for temporary reduction of the speed limit from 80 km/h to 50 km/h in connection with work-related driving in and out of the work zone in the motorway centre strip.

The stretch was “signed down” to 80 km/h with fixed signs each 1200m. Approximately 150m before the work zone entry, VMS signs had been positioned in both roadsides. The two VMS signs were only activated in connection with exits from the work zone in the centre strip. When activated, the signs showed 50 km/h (see Figure 19). When deactivated, the speed limit was 80 km/h as indicated on the fixed speed signs.
Speed measurements in the cross section by the VMS signs showed that the activated VMS signs reduced the average speed by approximately 13 km/h (from 75 km/h to 62 km/h). The 85% percentile was reduced by 9 km/h (from 83 km/h to 74 km/h).

Observations of the behaviour suggest that working vehicle manoeuvres in connection with entering and exiting the work zone affected other road users’ speed and choice of driving lane. However, behavioural observations also suggest that exiting the work zone apparently took place without any problematic consequences for the remainder motorway traffic. This experiment differs from the usual use of electronic VMS signs by the fact that the two signs placed before the work zone were the only ones on the entire stretch of roadwork – and that these were only active in connection with exiting the work zone.

Periodical “signing down” of the speed at work zone exits has moreover been tested on stretches with variable electronic signs (VMS) throughout the entire stretch of roadwork, in which case all VMS signs were constantly active. ”Signing down” the speed at work zone exits under these conditions shows reduced effect.

**PowerMoon used as mobile lighting**
A PowerMoon is a powerful light source which - due to its placement relatively high above ground level (e.g. 5-6m or more) – is able to illuminate a large area without causing a nuisance in terms of shading and blinding of road users.

The PowerMoon is visible from a relatively far distance alerting road users of the ongoing roadwork ahead (see Figure 20).

![FIGURE 20 Use of mobile lighting at roadworks in the dark](image)

The use of mobile lighting (PowerMoon) has been tested on two occasions in connection with motorway roadworks in the dark. In both cases, the speed before the roadworks was ”signed down” to 50 km/h and the mobile PowerMoons were located at the edge of the work area very close to the driving lane.

In both tests, the results show that the use of PowerMoons may provide a reducing effect on road speeds of up to 5 km/h.
REFERENCES
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