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Improving roadside safety on old roads

The following recommendation has been reached based on the studies carried out in the Finnish National Road Administration's strategic project S12 on "Solutions for Improving Highways" ("Pääteiden parantamisratkaisut”):

The following measures should be considered in order to improve the run-off safety of the current main roads:

1. Modifying old guardrails to correspond to the current standard (EN 1317-2, N2)
2. Replacing existing sloped guardrail ends with an energy absorbing ends on the busiest roads
3. Building a guardrail in a rock cut
4. Converting old lighting columns to break-away type on public roads, independent of the owner
5. Reducing the number of dangerous utility poles of electric power and telephone companies

In addition, the following measures should be carried out in an experimental manner:

6. Piping of oversized side ditches by a field
7. Building a game fence on the slope of an embankment without guard-rail
8. Systematic inspection of the run-off safety of old highways

The following pages contain preliminary instructions on the selection of targets and assessment of expected accident reductions.

Efficiency of measures

The primary targets, the quantities and the costs of the measures and the estimated annual reduction of personal injury accidents (PIA, including fatal accidents) attained through them are as follows:

1. Modifying old guardrails to correspond to the current standard (EN 1317-2 class N2) on busy highways (ADT > 3000 vehicles/d and v > 80 km/h).

   The measure will cost approximately EUR 16,000 per guardrail kilometre when the guardrail is at the same time extended, if necessary. EUR 1.6 million is needed when 100 guardrail kilometres is repaired, whereby, the repair achieves

   a) An annual reduction of 2.3 (1.8) PIA when ADT > 6000 vehicles/d and

   b) An annual reduction of 0.7 (0.5) PIA when ADT = 3000 ... 6000 vehicles/d. Outmoded guardrails total about 2000 km and of these 700 km are on such busy roads that repairing the guardrails pays off. The figures in the parentheses take into account that guardrail side accidents are 20 per cent less severe compared to the average cost of a PIA (EUR 0.12 million/PIA).

   In the modification the height and length of a guardrail are adjusted, pole screws are replaced, the poles are weakened and rail joints are improved. The guardrails are repaired in summertime when it is light. Priority is given to guardrails that are too low.

2. Replacing the existing sloped guardrail ends with energy absorbing ends on the busiest roads (ADT > 12 000 vehicles/d and v > 100 km/h) on highways.

   The measure will cost about EUR 2,500 per guardrail end. EUR 1.6 million is needed when 700 guardrail ends are repaired, whereby, the repair achieves an annual reduction of 1 (2) PIA when ADT > 12,000 vehicles/d. There are 31,000 guardrail ends of which about 700 are apparently in places where replacement is cost-effective. The greater than average severity of motorway guardrail end accidents (EUR 0.33 million/PIA) is taken into account in the figures in parentheses.

3. Building a guardrail in a rock cut on busy highways (ADT > 3000 vehicles/d and v > 80 km/h).

   The measure which includes also slope adjustment will cost EUR 27,000 per guardrail kilometre, about EUR 37,000 per rock cut kilometre since the guardrail is longer than the rock cutting and there are guardrails on both sides of the road. In addition, there will be maintenance costs with a current value of about 20 per cent of the investment.

   When 50 kilometres of rock strip is handled, the investment requires EUR 1,6 million, whereby, the repair achieves

   a) An annual reduction of 3 PIA when ADT > 6000 vehicles/d and

   b) An annual reduction of 1.1 PIA when ADT = 3000…6000 vehicles/d. Rock cutting slopes along the aforementioned roads total about 250 km.

   The width of the hard shoulder between the guardrail and the driveway is increased by 0.25 ... 0.75 m. The guardrail is not needed if there is a land slope at least 1 m high in front of the rock slope. The guardrails are made in summertime.

4. It cost-effective to continue converting old lighting columns to breakaway. The Finnish Road Administration also pays for the change of posts owned by municipalities on public roads. Choosing a break-away column instead of a traditional rigid one, or sawing or carving old wooden poles hollow costs so little (EUR 120 per pole) that converting them break-away is recommended already at a relatively low traffic volumes:

   * 1000 vehicles/d, when the speeds used on the road (or street) are about 60 km/h (which can also appear in an area of 50 km/h), and
   * 700 vehicles/d when the speeds used on the road are generally at least 80 km/h.

   Exceptions are constituted by cases in which the poles

   a) are behind a guardrail
   b) are behind a side ditch in the midst of thick trees or sufficiently far
   c) are partly decayed and the interval between posts is short
   d) carry heavy transfer lines or the overhead cable angle of a self supported pole is wide.

   Equipping old metal poles with a slip base is more expensive in which case the traffic volume limit of profitability is slightly higher. Completely outmoded lighting systems must be rebuilt. Profitability is calculated case by case whereby also saving of energy is taken into account. The profitability limit of rebuilding is apparently 3,000 ... 6,000 vehicles/d, depending on the case.

5. Reducing the number of the dangerous utility poles of electric power and telephone companies

   Rigid utility poles in the inner slope are as dangerous as lighting columns. Pole owners are responsible for changing them to become flexible or replacing them with a ground cable. Part of the telephone wires are unused and may be dismantled. Road districts should assess the urgency order of measures. Consideration is focused on whether the Finnish National Road Administration could also support the alteration work financially.

6. Piping of oversized side ditches by a field.

   Dangerously deep side ditches by a field should be piped along the busiest roads. The objective is to provide a gently featured run-off area for a car running off the road. The targets are selected according to accident statistics.

7. Building a game fence in the slope of an embankment without a guardrail

   A game fence may be erected at a distance of 7 m from the edge of a road in the inner slope with moderate gradient (1:2,5... 3) observed to be dangerous. It is hoped that the fence will prevent a passenger car from running off to a ditch, against a tree or other rigid obstacle located beside the embankment. The advantage is that a fence at least will not bounce the car against an oncoming vehicle, as can be the case with a guardrail on a slippery road. On the other hand, it has not been possible to verify the efficiency of a fence. A fence is not suitable for steep slopes. A fence will have 100 mm wooden poles and a net on both sides. The height is 1.8…2.1 m. Because of elks a fence will be built on both sides of a road and the fence ends shall be designed in accordance with instructions.

8. Systematic audit of the run-off safety of old highways

   The audit charts out guardrails requiring mending, unprotected bridge pillars, overhead sign supports, dangerous vertical signs, rock cuts, and the inspection classifies ditches, embankments, forest sections etc. with regard to dangerousness. The costs and efficiency of various improvement alternatives of the roadside environment are investigated in the audit.

   Instructions on the audit and choice of measures will be given in the course of the year 1999 or 2000. The cost of the audit is not known (EUR/km). About 400 road kilometres of highways should be inspected in the whole country in the course of the year 1999. The audit should also include a couple of fairly new roads. All highways should be audited in the future. Based on the audit efficient improvement work can be implemented and lessons can be learned for design of new roads and broadening of existing roads.

   The accident data on which the recommendations of points 1 and 2 above are based is reviewed in the following.

Crashes against guardrail

Table 1: The hitting point of crashes against guardrails in crashes leading to death on the main roads of the whole country according to TKK98 (sample 6 years, speed limit   80 km/h, incl. also motorways, incl. also bridge railings):

Crash target and type		Accidents Number in 6 years	Total
Guardrail end	Over sloped end	5	
	From sloped end back to road	1	
	Crash against other type of guardrail end	2	8
Road guardrail	Over guardrail	1	
	Through guardrail	1	
	Into guardrail	3	
	From guardrail back to road	3	8
Bridge railing	Over / through / into railing / to the road	-	0
Transition structure	Over or through	-	
	Crash against main pillar etc.	2	
	Back to road	-	2

According to the table 50 per cent of fatal crashes against road guardrails are guardrail end accidents and 50 per cent other crashes against guardrails.

Next, results from following studies are reviewed.

Studies focusing on road guardrails

Kk/1990: (Roine, Mäkinen, Lehtonen) Collisions with Road Structures and Appurtenances), Finnra Reports 29/1991 in English.

TKK96: (Salmela) Törmäysonnettomuudet kaiteisiin ja liikenteen ohjauslaitteisiin (Crashes against guardrails and traffic control devices). In Finnish.

VALT: Hautala: Yksittäiset kuolemaan johtaneet suistumisonnettomuudet vuosina 1991-94 (Fatal single-vehicle run-of-the-road accidents in 1991-94). In Finnish.

46/1993: (Kallberg, Lehtonen) Tien reunaympäristön pehmentämisen turvallisuusvaikutukset. Tielaitoksen selvityksiä 46/1993 (Potential safety benefits of road side improvements). In Finnish.

TKK tielaboratorio/98: (Kelkka) Kaideonnettomuudet valta- ja kantateillä (Crashes against guardrails on main roads). In Finnish.

Source	years	dead/yr./ sample	dead/yr./ 1000 guardrail km	PIA/yr./	accident cost/ guardrail metre (EUR)[1] curr.value
All roads:					
Kk/1990	84-86	2,7 [2]			
Kk/1990 [3]					36
TKK96	91-94	4,5 [4]			
VALT	91-94	2,7 [2]			
Only main roads with a speed limit of 80 or 100 km/h (not including motorway or bridge railing accidents, includes guardrail ends):					
46/1993:	88-90	2, 0 [2]	1,3 [5]	10…30 [6]	20…55 [6]
46/1993 [7]	87-91				43
TKK98	91-96	2,0 [2]	1,2 [5]		
TKK98 [8]	94-96			25	33

It can be observed that the results are fairly compatible. The accident cost per guardrail metre, for example varied between EUR 20 and 55.

1. Current value for 20 years, 6% discount rate.
2. This figure does not include cases in which a car first crashed into a car and only thereafter against a guardrail.
3. Sample of 266 guardrail kilometres, 4 years, included also property damage only accidents.
4. This figure also includes cases in which a car first crashed into a car and only thereafter against a guardrail.
5. According to samples, of the main roads of the 60's and 70's 7 per cent have a guardrail from the edge of the road. The same result has been obtained for newer roads, as well. Highways and main roads with a speed limit of 80 or 100 km/h covered 10,900 km in 1990 and 11,850 km in 1995.
6. It has been assumed that for each person dying due to a guardrail 7 ... 20 persons get injured. This ratio has been established in research on crashes against guardrails and lighting columns (Kk/1990). The average accident costs per personal injury accident is about EUR 0.16 million.
7. Sample of 800 road km, included also property damage only accidents.
8. Sample from 5 road districts, included all personal injury accidents.

Profitability of modifying old guardrails

The following table presents the distribution of guardrail accidents leading to personal injuries among all main roads according to ADT (average daily traffic) and the accident costs corresponding to them.

Table 2: Costs of crashes against the side of a guardrail (excluding guardrail end accidents). The documentation contains main roads with a speed limit of at least 80 km/h, including motorways. In the table it has been assumed that guardrails amount to 7 per cent of the edge lengths of roads (ADT < 12,000) or 10 per cent (AIDT > 12,000). The average cost of a guardrail side injury accident (excl. guardrail ends) leading to a personal injury amounts to EUR 134,000 (TKK98).

ADT	Length of guard-rail (km)	Number of PIA's against guardrail sides per year and current values of costs and savings (EUR, 20 yrs, 6 %), per guardrail metre					
		According to sample			Computational [1]		
		PIA/yr. sample[2]	Cost/m 20yrs	Saving/m 20 yrs [3]	PIA/yr. per 100km	Cost/m 20 yrs	Saving/m 20 yrs[3]
< 1500	668	0,2	0.5		0,4	5	
> 1500	443	2,6	10	(3)	1,0	16	(5)
> 3000	410	4,8	18	(6)	2,0	32	(11)
> 6000	129	2,6	33	(11)	3,4	53	(18)
> 9000	62	4,1	103	(34)	4,7	75	(25)
> 12000	106	13,5	203	(68)	11,2	180	(60)
Total	1818	28	25				

1. Computational accident costs are derived from the formula:

$\text{Costs}(ADT_X) = (ADT_X/3{,}430) \times$ EUR 24,

where 3,430 is the mean ADT of highways and main roads (yr. 1995) and EUR 25 is the average cost (current value for 20 years) per guardrail metre of a guardrail accident leading to personal injury (not incl. guardrail ends).

2. Accidents per guardrail length for the traffic volume in question

3. The saving generated by modification of guardrail has been estimated at 33 per cent. Lifting the rail, weakening of poles and screws does not help when crashing against an end, but does reduce penetration through the fence, crash injuries and bouncing against oncoming vehicle, each by an estimated 33 per cent.

Modifying an old guardrail costs about EUR 15 per metre. It is cost-effective (period of 20 years, 6% discount rate) when the traffic volume exceeds 3,000 ... 6,000 vehicles/d when the speed limit is 80 or 100 km/h.

Crashes against guardrail ends

In the years 1991-96 a total of 8 people died on main roads in Finland as a result of hitting a guardrail end.

- 5 against the sloped end a guardrail and from there to a land slope, bridge pillar, subway or corresponding
- 1 to the sloped end of a guardrail and from there back to the driveway
- 2 against a non-sloped, rigid end of a guardrail

In the years 1994-96 guardrail end accidents on main roads leading to injury numbered 24, totalling 9 personal injury accidents (including fatal) per year. The average personal injury cost amounts to EUR 277,000 in guardrail end accidents. Accident costs will then make EUR 2.5 million per year, representing a current value of EUR 30 million in 20 years with a 6 per cent interest.

There were 12,760 kilometres of main roads at the time of the accident documentation (1995) and of these 390 km were motorways.

The following table shows the distribution of guardrail end accidents leading to personal injuries among all main roads according to ADT and the accident costs corresponding to them.

Table 3: Costs of crashes against end of guardrail. Main roads with a speed limit of at least 80 km/h, including motorways. It has been assumed that guardrail ends on motorways number 3.0 and on other roads 2.4 per kilometre. The average cost of a guardrail end accident leading to personal injury amounts to EUR 280,000 (TKK98).

ADT	Number of guardrail ends	Number of PIA's against guardrail ends per year and current values of costs and savings (EUR, 20 yrs, 6 %), per guardrail end [1]		
		According to sample		Computational [2]
		PIA sample/ yr.	Cost/ end 20 yrs	Cost/ end 20 yrs
< 1 500	11 453	0,2	70	280
1 500…3 000	7 596	0,5	216	530
3 000…6 000	7 025	3,7	1 750	1 260
6 000…9 000	2 206	0,2	370	2 100
9 000…12 000	1 070	0,8	2 600	3 000
> 12000	1 593	3,5	7 600	7 100
Total	30 945	9	960	

1. Accident costs and savings for 20 years, 6% discount rate.
2. Computational accident costs are derived from the formula

Costs(ADTX) = (ADTX/3,430) x EUR 970 ,

where 3,430 is the mean ADT of highways and main roads and EUR 970 the average cost of a personal injury accident per guardrail end (current value for 20 years).

Existing guardrail ends sloped to the ground may be replaced with an energy absorbing end. The total cost of the replacement is over EUR 2,500 per head of guardrail. The measure reduces accident costs by an estimated 67 per cent. The measure would then be profitable if the original accident costs exceeded EUR 3,900. According to Table 3 the replacement is profitable on roads where traffic volumes exceed 12,000 vehicles/d.

Is it cost-effective to build guardrails in rock cuttings?

Studies on rock cutting accidents

Here we compare the results produced by different studies.

Source	time	dead/ sample/yr.	dead/yr./ 1000 edge km	PIA/yr./ km	accident cost per meter of edge (EUR) [1]
Only main roads with a speed limit of 80 or 100 km/h Rock cuttings					
46/1993	88 - 90	2,7	2,3	18…48 [2]	37…95
46/1993 [3]	87 - 91				57
Old-fashioned guardrails on hilltop [4]					
46/1993	88 - 90	1,8	1,2	10…25[2]	20…50
46/1993 [3]	87 - 91				40
Main roads with a speed limit of 80 - 120 km/h Rock cuttings					
TKK98	91 - 96	2,2 (1,8 acc.)		15…40[2]	
TKK98 [5]	94 - 96			21	73 [6]
Modern guardrails (side and heads)					
TKK98	91 - 96	2,7			
TKK98[5]	94 - 96			38	35 [7]
Difference					
46/1993	88-90 Whole country, fatal			8… 23	16…45
46/1993 [3]	87-91 Sample, injuries included				16
TKK98	91-96 Whole country, fatal				30
TKK98[5]	94-96 Sample, injuries included				38

Further observations are made based on documentation TKK98. There rock slope accident costs are higher compared to older documentation because motorways are included.

1. Accident costs and savings for 20 years, 6% discount rate.

2. It has been assumed that for one person dead due to a guardrail 7 ... 20 persons are injured. The ratio was established in study Kk/1 990 on crashes against guardrails and lighting columns. The accident costs per personal injury accident are about FIM 1 mil-lion. The current value for 20 years at 6 per cent interest is 12 times the costs of one year.

3. Sample of 800 road kilometres.

4. The accident risk of guardrails has been clarified on the basis of embankments. The result is here multiplied by 0.9 since rock cuttings are often at the top of a hill and the risk of accident is smaller compared to an embankment, which often comes after a downward slope.

5. Sample of 5 road districts.

6. Accident costs on all main roads when crashing against a rock cutting are EUR 188,000 per personal injury accident, amount of rock cuttings 2.5 per cent per edge kilometre.

7. The price of a personal injury accident in a guardrail crash is EUR 170,000, guardrails constitute 7 per cent of a road's edge length. (10 %, when ADT > 12,000). New guardrail 17 per cent safer compared to an old one.

Profitability of building guardrails

The following table shows by ADT categories the current values for 20 years of accident costs per rock cutting and guardrail metre.

Table 4: Costs of crashing against a rock cutting and the side and ends of a guardrail. Main roads with a speed limit of at least 80 km/h, including motorways. It has been assumed that 2.5 per cent of the edge lengths of roads are rock cuts and 7 per cent (AIDT < 12,000) or 10 per cent (AIDT > 12,000) are guardrails. In the documentation the average cost of a rock cutting accident leading to personal injury is EUR188,000 (TKK98).

ADT		Number of PIA's against rock cuttings and guardrails per year and current values of costs and savings (EUR, 20 yrs, 6 %), per rock cutting metre					
		According to sample		Computational			
	Rock cuttings (km)	PIA/yr. sample	Cost/ Rock slope m,20 yrs	Cost/ Rock slope m,20 yrs	Cost/ Guardrail m,20 yrs	Difference m,20 yrs
< 1 500	239	1,0	8	17	10	7
>1 500	158	1,9	27	40	22	18
> 3 000	146	7,6	116	87	45	42
>6 000	46	2,3	113	153	76	77
> 9 000	22	2,8	279	222	106	116
> 12 000	27	5,2	440	576	250	326
Total	638	21	74			

Guardrail crash cost (ADT_x) = (ADT_x/3,430) x EUR 35,

Rock crash cost (ADT_x) = (ADT_x/3,430) x EUR 74,

where 3,430 is the mean ADT of main roads.

The costs of crashing against an old-fashioned guardrail are on an average EUR 33/guardrail metre in 20 years. Modern guardrails are 17 per cent safer than old-fashioned guardrails (as regards the side 33 %, as regards the head 0 %), but the guardrail is 20 per cent longer than the rock slope. Guardrail accident costs will then make EUR 35 per rock slope metre in 20 years.

Building a guardrail of steel in a rock cutting costs EUR 23/m. In addition, redesign of the slope costs EUR 3/m. The guardrail will become about 20 per cent longer than the rock cutting, whereby, the guardrail price will be EUR 27 per guardrail metre i.e. EUR 32 per rock cutting metre. Building a guardrail in a rock cutting increases maintenance costs slightly: The current value for 20 years is about EUR 6.7/m. The reference price will be EUR 39 per rock cutting metre.

The difference between rock slope accident costs and guardrail accidents exceeds EUR 39 per rock cutting metre when ADT exceeds 3,000 vehicles/d.

Unit prices of personal injury accidents

Based on the accident data of the TKK98 study (accidents leading to death and injuries on main roads with a speed limit of at least 80 km/h) unit prices for different types of guardrail accidents and rock cut accidents have been calculated. The following assumptions are made in the calculations:

1. The price of an accident leading to death is EUR 1,593,000
2. The price of an accident leading to non-fatal injury is EUR 30,500
3. The non-reporting of accidents leading to injury is taken into account using the coefficient 2.0

Loss-adjusted unit prices of personal injury accidents:

Guardrail accidents (incl. all types of guardrail accidents):

– those occurring on all main roads:	EUR	170,400
– main roads, excluding motorways:	EUR	183,500
– motorways:	EUR	143,900

Guardrail end accidents:

– those occurring on all main roads:	EUR	280,000
– main roads, excluding motorways:	EUR	222,000
– motorways:	EUR	401,000

Other guardrail accidents (all except guardrail end accidents):

– those occurring on all main roads:	EUR	134,000
– main roads, excluding motorways:	EUR	170,000
– motorways:	EUR	61,000

Rock cutting accidents:

– those occurring on all main roads:	FIM	188,000
– main roads, excluding motorways:	FIM	177,000
– motorways:	FIM	231,000

More accurate instructions

The work specification concerning the modification of guardrails will be completed in April 1999. The work includes the following work phases:

1. Guardrail posts are pulled to the correct height
2. M16 8.8 screw between post and rail is replaced by M12 strength 4.6
3. Post base is weakened
4. Rail joints are improved
5. The guardrail is extended, if required
6. Additional post are added (to achieve 2 m), if required
7. The length of the end slope will be 12 m

The work specification concerning new guardrails will be completed in April 1999 and the type drawing was completed in February 1999. The difference compared to older work specifications is that:

1. Smaller clearance is allowed in the rail joints
2. The end anchorage of guardrails is improved.

The guideline concerning new types of guardrail ends will probably be completed in the year 2000. Energy absorbing ends are currently manufactured only in the United States where approximately 10 different products are on the market.

Instructions on the length of guardrails are given in the publication "Teiden suunnittelu V 2 Kaiteet" (Road Design V 2 Guardrails). A preliminary outline as regards the length of a guardrail will be completed in April 1999. 2 m should be added to the safety distances of the table in the old 1987 instruction, at least on busy roads. The guardrail lengths of tables 2 and 3 should be extended by 20 m before an obstacle and by 10 m after an obstacle. The minimum values of flexibility margins should not be used behind the guardrail.

An alternative where at the start of a rock cutting the guardrail ends are embedded in the outer slope of an earth cut preceding the rock should be studied. The prerequisite is a low-gradient (1:6) inner slope. Then, the risks related to a sloped guardrail end could be avoided without using an expensive energy absorbing end, and the guardrail will become shorter.

Instructions on the piping of side ditches are presented in the publication "Pellon kuivatus tien kohdalla, Tielaitoksen selvityksiä 64/1993" (Drainage of a Field by a Road, Studies by the Finnish Road Administration 64/1993).

There is no ready solution for the game fence used for the prevention of running-off-the-road accidents.

Previous numbers:

1. Break-away lighting columns, current practice in Finland in 1993
2. Foundations of luminare supports. The effect of backfill on the strains in foundations.
3. The need of space for snow remover from carriageways in Finland.
4. Acoustic performance of simple board and plywood fences.
5. Break-away lighting columns, current practice in Finland in 1996.
6. Break-away lighting columns, current practice in Finland in 1998.
7. The effect of openings on the insertion loss of a noise barrier

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