Appendix 1

Prerequisites for Electrification of the Swedish Main Road Network

TRAFIKVERKET

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1. Road Network

1.1 Prerequisites for Electrification of the Road Network

Is electrifying roads different from electrifying railroads? Yes, the greatest difference is probably that whereas the road is public, the railroad is not, and that all traffic on the railroad is guided along the tracks, which does not apply to road traffic. These differences need to be taken into consideration in connection with the electrification of roads. The electrical installation needs to be protected from vehicles which drive off the roadway. Additional study is needed of what the consequences will be if a vehicle tears down the overhead line or if the overhead line penetrates the space reserved for traffic (the free space). What are suitable measures for reducing, for example, the direct risk that a vehicle will get caught in the torn-down overhead line? What is an acceptable time period for restoration of the electrical installation after it is torn down and blocks, in whole or in part, the road traffic? The answers to these questions affect the design of the installation.

Electrification of parts of the road network means designing vehicles so that they are capable of moving both along stretches of the road which are electrified and stretches of the road which are not. This is an advantage from the point of view of road electrification as road sections which are technologically difficult (expensive) then do not need to be electrified. Examples of such places are road intersections and traffic circles (roundabouts). Other obstacles can be viaducts or tunnels where overhead lines should be installed without infringing on the road's loading gauge. Building an overhead line system in an urban environment, which presumably also exists, naturally poses a greater technological and financial challenge than electrifying a main road. The question is what would be a comprehensive optimum solution. And this is where vehicle design becomes an important aspect. Vehicles need more output (tractive force / speed) on a main road than in an urban environment and the same can apply to power. Road electrification should probably concentrate on main roads and major routes in urban environments.

1.2 Sections Possible to Electrify

Since road electrification should concentrate on road networks outside urban environments, the focus in the initial stage of electrification should be placed, for example, on businesses which currently use vehicles for large-scale goods transport, where the goods are reloaded on to existing railroads and/or where it is not economically justified to extend the railroad network.

In a long-term perspective, it should be possible to electrify longer national sections of the state road network. Possible sections include Södertälje – Jönköping – Malmö and Helsingborg – Gothenburg – Jönköping. A summary of some of the obstacles which may be of importance for the electrification of the suggested sections follows below. Note that the data provided below has been borrowed from the Swedish Transport Administration's traffic data. In this state, however, the data constitutes only a rough estimate. Nevertheless, it can be viewed as an indication of the obstacles that will need to be overcome.

Total stretch: approx. 1,000 km

Södertälje - Jönköping	Jönköping - Gothenburg	Gothenburg – Malmö	Malmö - Jönköping
291 km (E4)	147 km (Rv 40)	270 km (E6)	292 km (E4)

Number of Bridges: 150 (Bridge – traffic passes on top of a structure – bridge)
Number of Gateways: 120 (Gateway – traffic passes under a structure – e.g., bridge, foot and bicycle path, etc.) Number of Branches (Ramps): 1,880

An overall geographic distribution of vehicles and heavy transport in the respective subsection:

Subsection/Interchange	AADT	
	Vehicles	Trucks
Södertälje – Jönköping (E4)		
Södertälje syd Interchange	18,090	2,023
Hölö Interchange	13,860	1,843
Åby Interchange	11,721	1,540
Ryd Interchange	7,213	397
Gränna Interchange	8,062	1,892
Ryhov Interchange	19,064	2,483
Jönköping – Gothenburg (Rv 40)		
Hulta Interchange	11,186	1,053
Gothenburg – Malmö (E6)		
Lindomemotet Interchange	23,566	2,249
Varberg Interchange	10,781	1,854
Halmstad Interchange	12,300	2,359
Väla Interchange	18,578	1,171
Sege Interchange	22,108	1,456
Malmö – Jönköping (E4)		
Landskrona Interchange	17,710	3,014
Markaryd Interchange	5,699	1,606
Ljungby Interchange	5,810	1,860
Värnamo Interchange	5,564	1,762
Vaggeryd Interchange	6,436	1,576

AADT – Annual average daily traffic, data from measurements conducted in 2006 and 2010.

1.3 Standard Cross-Sections

Designations: V = Shoulder, K = Traffic lane, M = Median strip

1.3.1 Freeway

1.3.1.1 <u>TV124 1975</u>

Older freeways had broader shoulders and somewhat narrower traffic lanes than freeways of later times. Narrow median strips (0.8 m) were fitted with double barriers with crossbeams. Broader median strips were fitted with single barriers on both sides. When the median strip was ≥ 12 meters, it was possible to dispense with the crash barrier. Roadside barriers were often older barrier types (Kolsva type) on concrete posts which were placed at the edge of the asphalt. In many places, these have been replaced with the more modern European barriers (EU barriers) on steel posts. The hard strip was 0.25 m and the inner slope 1:3.

V3.0+K3.5+K3.5+V1.5+ M 0.8 - ≥12.0+V1.5+K3.5+K3.5+V3.0 = 23.8 - ≥35
On and off-ramps
V1.0+K4..0+V3.0 = 8.0

1.3.1.2 <u>Road Design – 94 (VU94)</u>

VU94 introduced two new types of freeway cross-sections: one for urban environments where the speed limit was 70 km/h and one for rural environments where the speed limit was 90 km/h. These are not particularly frequent. Most freeways are designed according to the standard cross-section for a speed of 110 km/h. The width of the median strip was increased to at least 2 meters or more, including the median barrier, and when the median strip was ≥ 13 meters, it was possible to dispense with the median barrier. Barriers were predominantly EU barriers. Roadside barriers were placed in direct connection with the edge of the asphalt but could also be placed closer to the object of protection if the inner slope was 1:6. The inner slope in certain cases was “broken”, i.e., a slope of 1:6 for a width of at least 6 m which then becomes 1:3 in the toe of the fill slope or drain. The inner slope behind the roadside barriers was 1:2. Under certain circumstances (less traffic load and good side area), a speed limit of 120 km/h was allowed.

Urban 70 km/h
V2.0+K3.5+K3.5+V0.25+M2.0 - ≥13.0+V0.25+K3.5+K3.5+V2.0 = 20.5 - ≥31.5
On and off-ramps
V1.0+K4.0 +V1.0 = 6.0

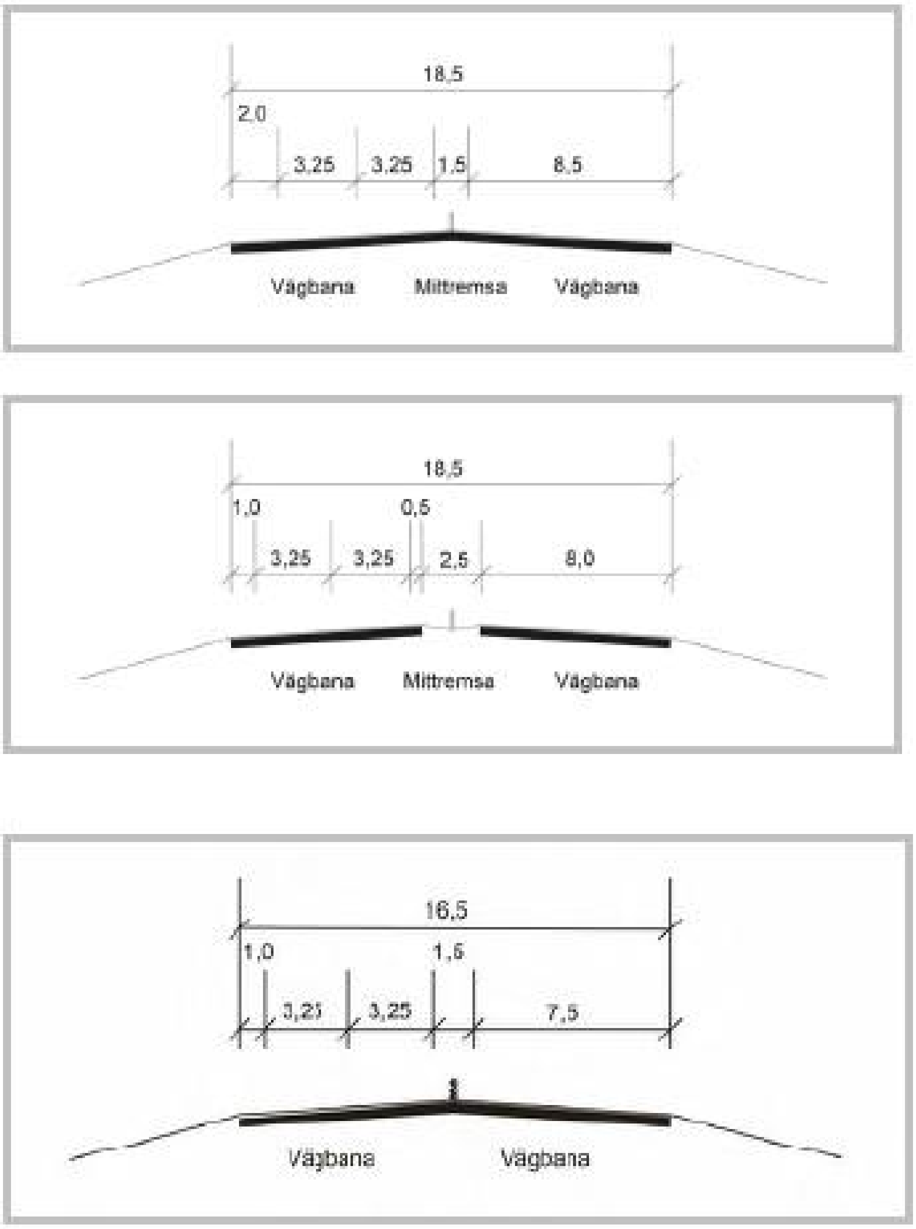
Rural 90 km/h
V2.0+K3.75+K3.75+V0.5+M2.0 - ≥13.0+V0.5+K3.75+K3.75+V2.0 = 22.0 - ≥33.0
On and off-ramps
V2.0+K4.0+V1.0 = 7.0

Rural 110 km/h
V2.75+K3.75+K3.75+V1.0+M2.0 - ≥13.0+V1.0+K3.75+K3.75+V2.75 = 24.5 – ≥35.5
On and off-ramps
V2.0+K4.0+V2.0 = 8.0

1.3.1.3 VGU 2004

The 2004 Road and Street Design (VGU) abolished the urban and rural freeway cross-sections with a speed limit of 70 and 90 km/h, respectively, and replaced them with divided highways with a speed limit of 90 to 110 km/h. These often employed a simple type of interchange. The traffic lanes were reduced to 3.25 meters and the shoulders to 1 meter – even if 2-meter shoulders also occurred. This cross-section exists in urban environments but rarely in rural environments. There are short rural stretches with this cross-section on E6 in Bohuslän. The cross-section was subsequently abolished as it turned out that the number of accidents in rural environments was high. The freeway cross-sections were divided into two types: normal standard and low standard. The change compared to VU94 was a reduction in traffic lane width to 3.5 meters and in shoulder width to 2 meters for the normal standard and in traffic lane width to 3.25 meters and in shoulder width to 2 meters for the low standard. The median strip was reduced to a narrow median strip with median barrier. The shoulders and median strip could be extended on roads with a heavy traffic. After a bus accident outside Arboga, broken slopes have been abolished and replaced by a slope of 1:4. Slopes of 1:6 or less are executed only in places with good overall conditions or for aesthetic reasons.

1.3.1.4 Divided Highway Cross-Sections, 90 – 110 km/h

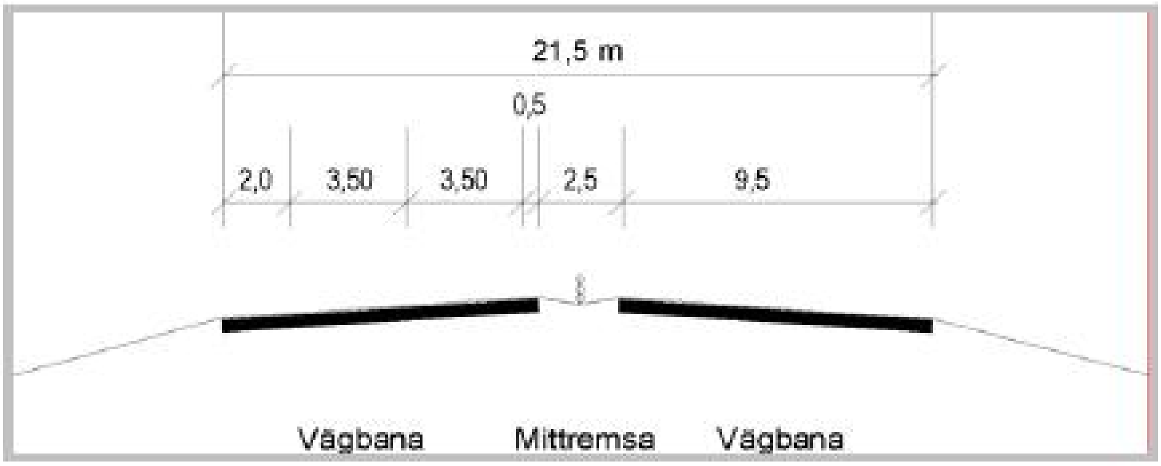


FIGUR 5-3 **Exempel på typsektioner för fyrfältsväg som inte är motorväg. I ett framtida hastighetssystem kan denna vägtyp komma att få lägre tillåten hastighet än motorväg.**

V1.0 – 2.0+K3.25+K3.25+M1.5 – 2.5+K3.25+K3.25+V1.0 – 2.0 = 16.5 – 18.5
On and off-ramps
V1.0+K4.0 +V1.0 = 6.0

1.3.1.5 Freeway Cross-Sections, 110 – 120 km/h

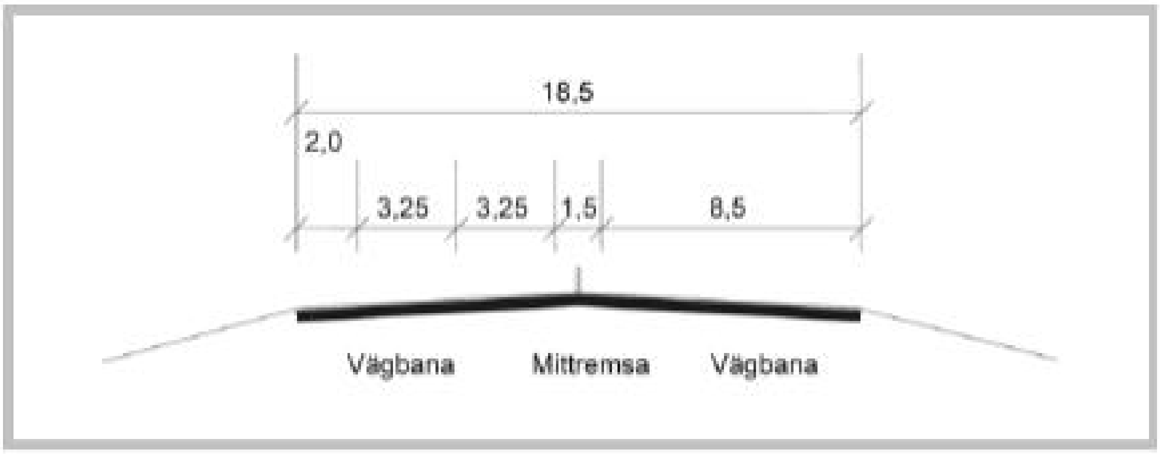
Normal standard



FIGUR 5-1 **Typsektion för motorväg med normal standard**

V2.0 - 2.75+K3.5+K3.5+V0.5+M2.5+V0.5+K3.5+K3.5+V2.0 – 2.75 = 21.5 – 23
On and off-ramps
V1.0+K4.0 +V1.0 = 6.0

1.3.1.6 Low Standard Cross-Section, 110 km/h

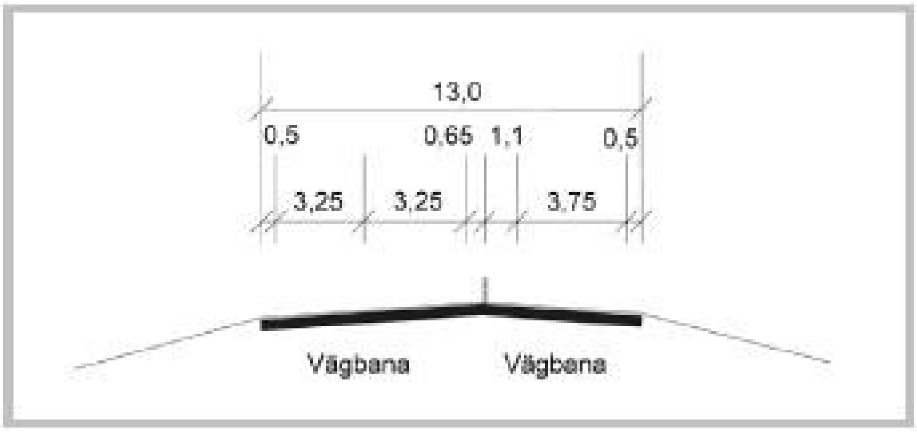


FIGUR 5-2 **Typsektion för motorväg med låg standard**

V2.0+K3.25+K3.25+M1.5+K3.25+K3.25+V2.0 = 18.5
On and off-ramps
V1.0+K4.0 +V1.0 = 6.0

1.3.2 2+1 Roads

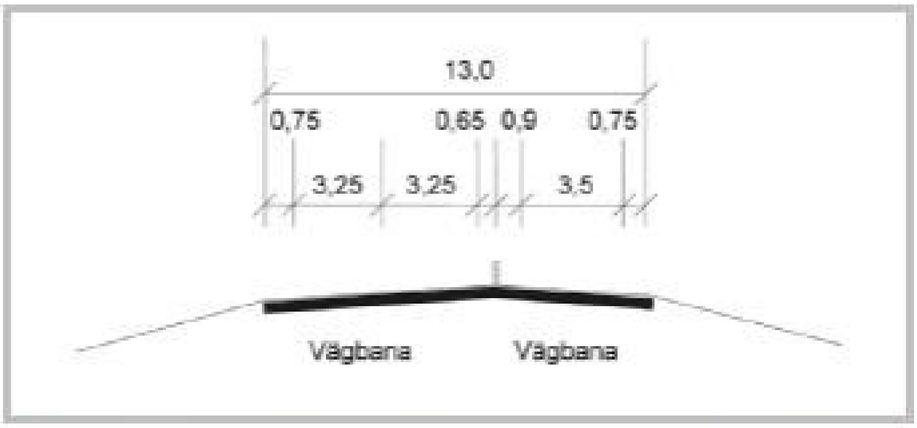
A later version of VU94 (S2) introduced a cross-section for 2+1 expressway. The cross-section was applied first to existing expressways on a trial basis but after good results with a reduced number of deaths and heavily injured, it was also applied to roads with broad shoulders (13-meter roads).
Conversion of existing 13-meter roads, 100 km/h. Vulnerable road users and slow-moving vehicles are forbidden (expressways with grade-separated junctions).



FIGUR 5-5 **Typsektion för mötesfri motortrafikled och landsväg utan GC-trafik vid ombyggnad av befintlig 13 m väg**

V0.5+K3.25+K3.25+M1.75(0.65+1.1)+K3.75+V0.5 = 13 (width of the roadway of the 1-lane part – 5.3 m) On and off-ramps: V0.5+K3.25+V1.0 = 4.75

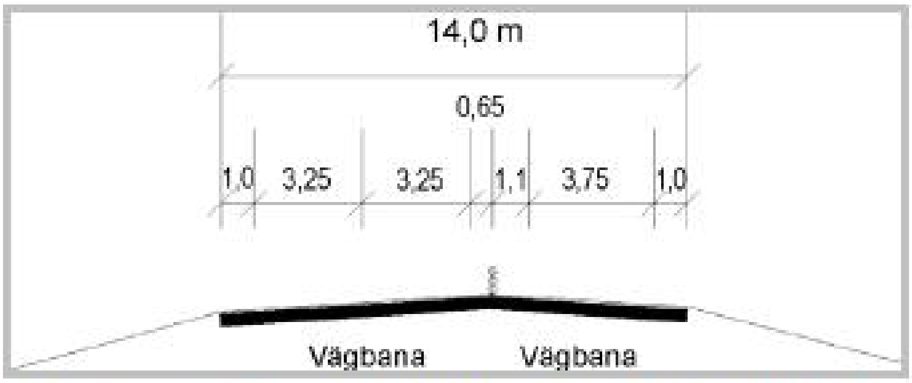
Conversion of existing 13-meter roads, 100 km/h. Vulnerable road users and slow-moving vehicles occur.



FIGUR 5-4 **Typsektion för mötesfri landsväg med GC-trafik vid ombyggnad av befintlig 13 m väg**

V0.75+K3.25+3.25+M1.55(0.65+0.9)+K3.5+V0.75 =13 (width of the roadway of the 1-lane part –≈5 m) On and off-ramps occur seldom. Most often simpler at-grade intersections.

New construction



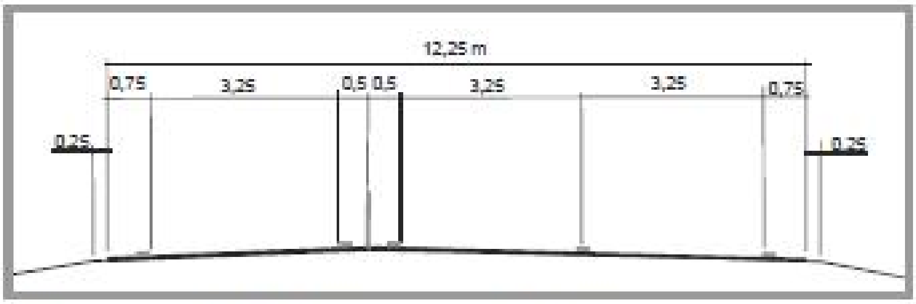
FIGUR 5-6 **Typsektion för mötesfri landsväg vid nybyggnad och breddning**

V1.0+K3.25+K3.25+M1.75(0.65+1.1)+K3.75+V1.0 = 14 (width of the roadway of the 1-lane part – 5.8 m)
1+1 stretches

V1.0+K3.75+M2.2(1.1+1.1)+K3.75+V1.0 = 11.7 (width of the roadway of the 1-lane part – 5.8 m) On and off-ramps
V1.0+K3.25+V1.0 = 5.25

VGU Supplement "Safe Access" which replaces previous standard cross-sections for 2+1 roads.

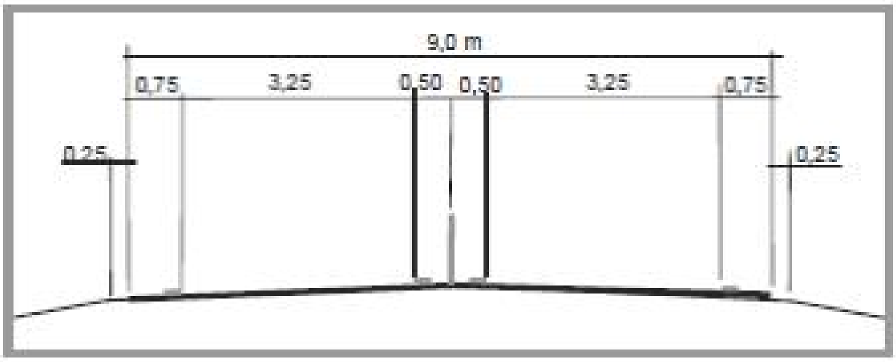
Conversion of existing road, 2+1 with median barrier



FIGUR 4-2 **Sektion för 2+1 sträcka på befintlig väg**

V0.75+K3.25+K3.25+M1.0(0,5+0.5)+K3.25+V0.75 = 12.25 (width of the roadway of the 1-lane part – 4.5m)

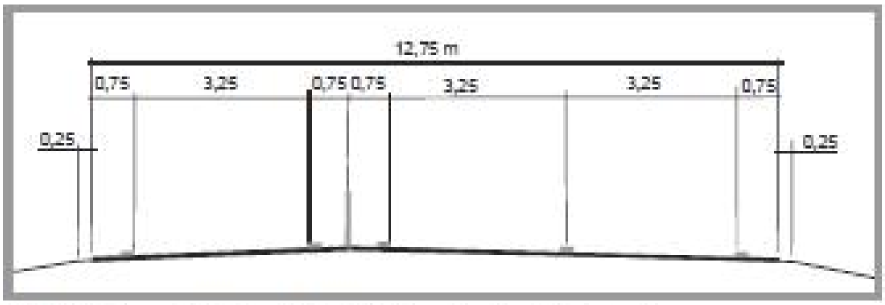
Conversion of existing road, 1+1 with median barrier



FIGUR 4-1 **Sektion för 2-fältssträcka för befintlig väg**

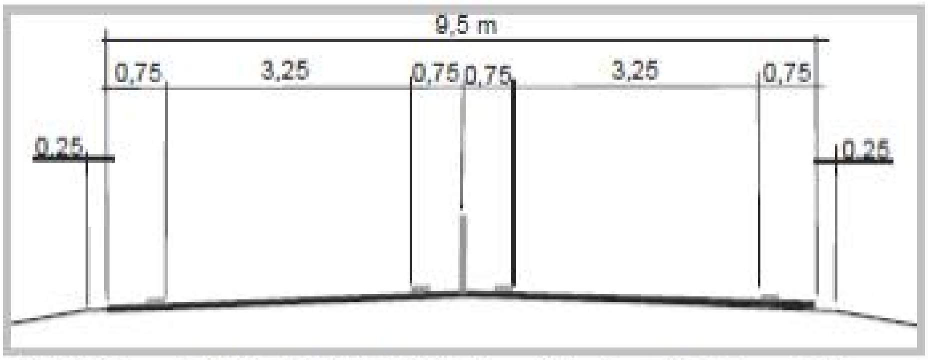
V0.75+K3.25+M1.0(0.5+0.5)+K3.25+V0.75 = 9.0 (width of the roadway of the 1-lane part –4.5 m) On and off-ramps:
V1.0+K3.25+V1.0 = 5.25

New construction of 2+1 road with median barrier



FIGUR 4-2 **Sektion för 2+1 sträcka på nybygdnad av väg**

V0.75+K3.25+K3.25+M1.5(0.75+0.75)+K3.25+V0.75 = 12.75 (width of the roadway of the 1-lane part – 4.75m) New road 1 +1 with median barrier



FIGUR 4-3 **Sektion för 2-fältssträcka för ny "9-meters väg" bör vara ≥ 9,5 m**

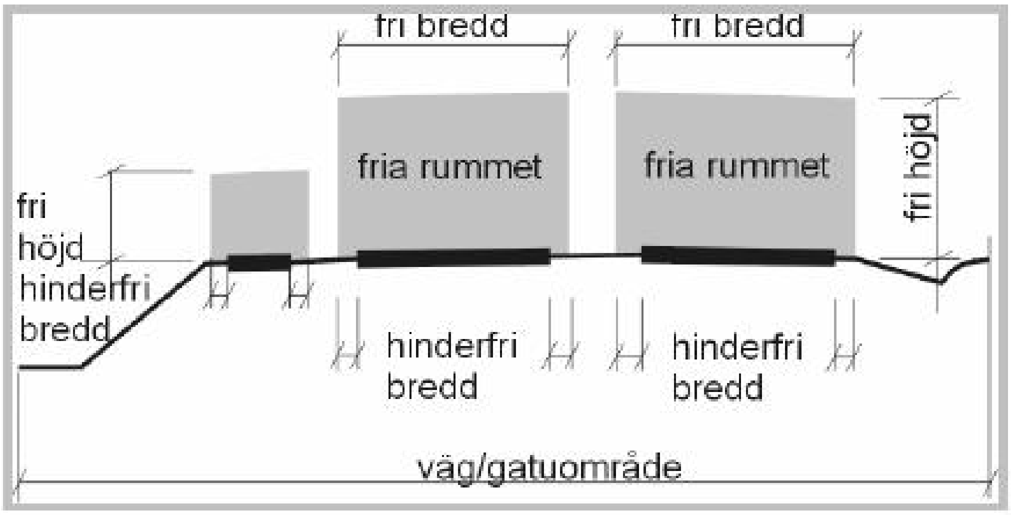
V0.75+K3.25+M1.5(0.75+0.75)+K3.25+V0.75 = 9.5 (width of the roadway of the 1-lane part – 4.75 m) On and off-ramps:
V1.0+K3.25+V1.0 = 5.25

1.3.3 Entrances to and Exits from Freeways/Expressways

Exits can be designed in two variants: tapered exits or parallel exits
Tapered exits vary in length depending on whether they constitute right-hand or left-hand curves and on the main road's horizontal geometry. The length of the exit itself (from the point where the roadside begins to shift outwards until the beginning of the ramp) can, on average, be from 200 to 300 meters. The outer shoulder is the same as on the main road, most often 2 to 3 meters. Exits are often signposted with two preparatory information signs (1,000 and 500 m before the exit, respectively) and an exit sign. In the event of high traffic volumes, the signs are often places on gateways.
Parallel exits on a straight stretch have a minimum length of 500 meters from the beginning of the increase in width until the beginning of the ramp. The outer shoulder is most often one meter. Signposting for parallel exits is most often placed on gateways.
The minimum length of entrances is 350 meters. The outer shoulder is most often one meter.

1.4 Rules and Standards for Road Space

1.4.1 Free Space



FIGUR 2-1 **Fria rummet, beträffande skyltars placering se del "Vägmärken"**

1.4.1.1 Free Height

TABELL 2-1 **Dimensionerande höjd**

	HINDERTYP	DIMENSIONERANDE HÖJD (M)
Bana för biltrafik	Vägport och vägmärken. Tunneltak utan installationer	4,7[1]
	Skyltportalbalk utan elledning	4,9[2]
	Vägport i lättkonstruktion (stål, prefabricerade betongelement, aluminium eller trä), se ATB BRO Tunnel med takinstallationer	5,1
	Luftledning för svagström Skyltportalbalk med elledning	5,1[3]
	Luftledning för starkström	6,0 m , för fasledare 7,0 + S (spänningstillägg) m [4]

[1] Måttet är bestämt med hänsyn till fordon med 4,5 m dimensionerande höjd (4,3 m samt körmån 0,2 m) och 0,2 m för snö och is, tjällyftning, underhållsbeläggning m.m. Där snö, is och tjällyftning kan antas vara större än 0,1 m bör totalmåttet ökas med motsvarande mått. Lägre fri höjd än 4,7 m kan accepteras endast om dimensionerande fordons höjd är mindre än 4,5 m (inkl. körmån 0,2 m) eller alternativ färdväg finns.

[2] Fri höjd under vägmärke på balk blir 4,7 m.

[3] Vägmärkets fria höjd blir 4,9 m för att minska underhållskostnader.

[4] Se närmare Elsäkerhetsverkets föreskrifter ELSÄK FS 2004:1

[5] Kontroll av erforderlig höjd för brandfordon och fordon för drift och underhåll måste göras i det enskilda fallet.

1.4.1.2 Obstacle-Free Width

The obstacle free width is 1.5 m from a lane with a speed limit of 90 km/h and 2.0 m from a lane with a speed limit of 110 km/h.
As regards freeways, the shoulder is wide enough to provide obstacle-free width but objects (collision-friendly) taller than 0.2 m must be placed at a distance of 0.5 meters from the edge of the asphalt. An exception is the crash barrier which can be placed directly at the edge of the asphalt.
The same distance from the lane applies to 2+1 roads, which can mean that collision-friendly objects must be placed at least one meter from the edge of the asphalt at 90 km/h if the shoulder is 0.5 m and 1.5 m from the edge of the asphalt at 110 km/h. The barrier can be placed at the edge of the asphalt but is often placed one meter from it in the one-lane half of the road in order to meet the requirements for broad exemption transport.

1.4.1.3 Safety Zone

The safety zone can be different depending on the side area’s design of the slopes. As a rule, a distance of 9 to 11 meters from the roadside can be estimated for a speed limit of 90 km/h and 11 to 13 meters for a speed limit of 110 km/h.
Fixed objects may not be present within the safety zone unless they are protected with a barrier. Fixed objects are non-collision-friendly objects such as, for example, trees, electric, telecommunications and lamp posts, stones with a height of over 0.3 m which are fixed to the ground.

1.4.1.4 Crash Barriers

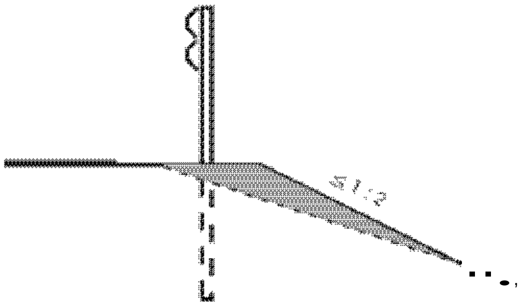
1.4.1.4.1 Capacity and Working Width

The most common roadside barriers are EU barriers and steel cable barriers. Crash barriers can protect passenger cars from driving into the side area. The barriers are not stiff but deflect in the event of a collision to approx. 1.5 meters. This is why fixed objects must be placed outside the barrier's working width.

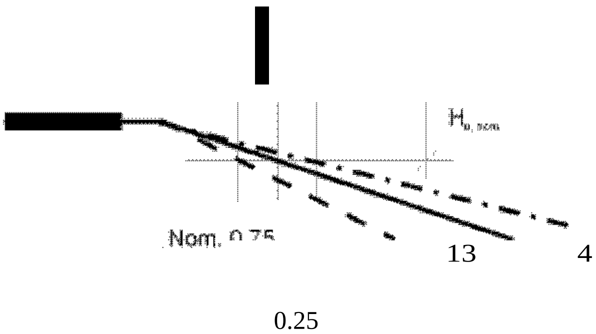
For specific risk objects such as electric installations, railroads, water catchments, underlying public roads, bridges or major water courses, the barrier must be able to prevent heavy vehicles from driving off the road. These barriers have a higher capacity. The barrier's working width then is between 1.7 and 2 meters. In order to reduce the working width, another type of barrier must be used, for example, concrete elements which have a working width of approx. 0.6 meters.

1.4.1.4.2 Placement

Crash barriers on freeways are normally placed at the edge of the asphalt, with a hard strip of 0.35 to 0.5 meters behind the barrier. Barriers on 2+1 roads cannot always be placed at the edge of the asphalt as the width of the 1-lane half of the road then limits accessibility for wider means of transport. The barrier is then usually placed at a distance of one meter from the edge of the asphalt. Where the crash barrier is placed at a distance of one meter from the edge of the asphalt, the hard strip is widened accordingly or the barrier is placed on the inner slope.



Förflyttning av slänträcke i sidled vid släntlutning mellan 1:2 och 1:4



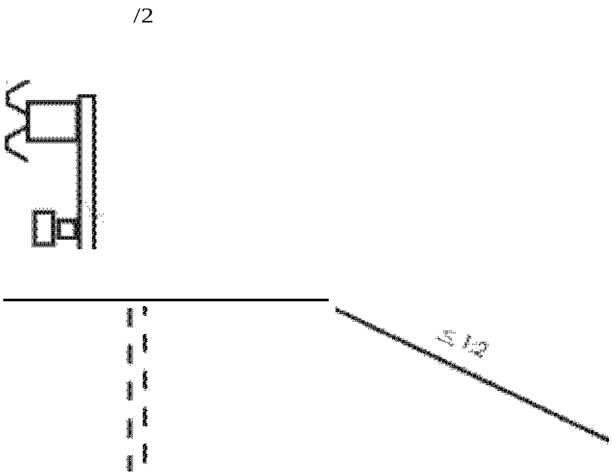


FIGURE 2-14 **Stödremsa bakom högkapacitetsräcke vid slänt**

The normal slope behind a crash barrier is 1:2 but, in extreme cases, can be 1:1.5 when the road embankment is made up of sorted blast rock. In the latter case, the crash barrier tends to be a high-capacity barrier as the road embankment is often extra high so that it can pay off to make the effort to have a steep slope.

1.4.2 Bridges

As regards bridges and viaducts where there is enough room, the Swedish Transport Administration does not see any obstacles to the continuation of the overhead line under the bridge, even if it will have to be at a height of less than 5.5 m. However, the overhead line may not be under power in such sections. Nevertheless, it is possible not to have to take the current collector down when a vehicle passes. As regards bridges and viaducts where there is not enough room because some of it is allocated, for example, for future asphalt layers, the overhead line must terminate before the viaduct and the current collector must be taken down. Overhead line posts may need to be placed so far from the actual roadway on exits and entrances in major junctions and at-grade intersections that it will not be a reasonable solution to continue with the overhead line across the intersection. There is also a risk that the overhead line posts will block out signs. All in all, the most probable solution for interchanges is therefore to terminate the overhead line for approx. 1,500 m across the junction. There has been no study of how many interchanges will end up in the different categories at this stage but approx. half the existing bridges today have a height lower than the guaranteed 4.5 m to the ceiling of the bridge (4.7 m).

Vehicle passage over bridges (a bit longer) is also problematic as the Swedish Transport Administration has not designed the edge beams which are supposed to hold the electric posts.

1.4.3 Exemption Transport

Exemption is not needed for free height but it is up to the carrier to make sure that the height will not lead to any problems. The exemption applications the Swedish Transport Administration receives, however, specify the height of the transport. The Swedish Transport Administration approved approx. 100 exemptions indicating a height of at least 5 m within a year between August 2010 and August 2011. High transport occurs in the Malmö-Gothenburg-Stockholm triangle, however, most often, along short stretches. High transport vehicles avoid even now roads with grade-separated junctions and this is why an introduction of overhead lines should not affect such transport to a significant extent. Individual vehicles may, however, come to be affected.

1.4.4 Prerequisites/Requirements Regarding Electric/Power Supply

A parallel network for 50 Hz will probably be needed along the road and the overhead line. The reason for this is that there could quite simply be no suitable 50 Hz high voltage network to receive supply from and that the supply must be strong enough for the current load. The load may not reduce the voltage in the supply network too much and the generation of harmonics by the load may not interfere with other loads. Stronger networks and better (more expensive) static converters reduce the risk of interferences with other electric equipment.

1.5 Prerequisites for Electrification Depending on Frost Heaving

The new construction regulations applicable to frost heaving are 10 to 50 mm for the type of roads that make up the Södertälje – Jönköping – Malmö and Helsingborg – Gothenburg – Jönköping triangles. Frost heaving higher than 50 mm should therefore not be relevant for an early stage of a national construction of electrified roads. Frost heaving of 100 mm is, however, allowed on smaller roads with design speed of 80 km/h, which may be relevant in minor demonstration projects for electrified roads.

1.6 Experiences from Railroad Catenaries

Experiences from railroad catenaries are predominantly good. The overhead catenary system has been developed successively throughout the years for higher speeds and lower operating and maintenance costs. The main challenges railroads face with regard to overhead catenary systems today concern the aging of the installations and the maintenance of the catenary and the vehicles' current collectors. The latter may become an even greater challenge along roads since current collectors there will be more advanced (they should be capable of finding an overhead line "themselves" and automatically connect to and disconnect from it) and the number of vehicles there will be greater than that on the railroad. Maintenance of current collectors will be important for ensuring a well-functioning traffic along the electrified road.

Railroad overhead catenary systems are designed in such a way as to stretch the catenary in a zigzagging shape between the carrying posts. Zigzag is used in order to ensure even wear of the current collector and thereby better current collection. It also increases the lateral stability of the contact wire (stretched laterally at 70 to 900 Newton). Above all, the lateral traction entailed by the zigzagging provides greater vertical stability (elasticity). If the zigzag is not used, it can be replaced with, e.g., springs for achieving the right elasticity.

1.7 Traffic Safety

1.7.1 Safety Zone

In order to reduce harmful consequences in connection with driving off the road, the road's side area should be so designed as to prevent a passenger car that drives off the road from colliding with dangerous objects such as stones, large trees and posts or other hazards such as precipices and deep water in the road's safety zone by eliminating these from it. If such hazards exist and cannot be eliminated or made less hazardous to collide with at a reasonable cost, a common solution is to install barriers at the roadside. Ordinary crash barriers are designed to hold back passenger cars.

The sought-after extent of the safety zone can be said to correspond roughly to as many meters as are obtained by dividing the speed limit by ten, e.g., 90 km/h gives 9 m. Certain slopes are considered to be so steep that they may not be included. There may be certain compensation for sharp curves. Road fixtures such as lamp and road sign posts which are placed in the safety zone without being shielded by a barrier should have such characteristics as not to expose the road users to hazardous strain (they should be flexible) in the event of a collision with a passenger car. A corresponding effect can be achieved by impact attenuators before a hazardous object, e.g., a bridge pillar.

1.7.2 Functional Requirements to Posts

1.7.2.1 Flexible Posts

The flexibility of posts is tested according to SS-EN 12767 whose latest edition is from 2007. The standard is a supporting standard to product standards for lamp posts according to the EN 40 series and road signs. Even “utility posts” can be tested according to the standard.

The function of the flexible posts is determined through collision testing with a small car at a low speed (35 km/h) and at the rated speed for the speed class, typically 100 km/h in rural environments. The risk of injuries (acceleration and impact speed for the road users) and initial velocity (energy absorption) are measured during the tests.

Flexible posts can be divided into three types from a functional perspective:

Energy-absorbing posts which should significantly reduce the colliding vehicle's speed in a collision, often executed as a thin plate shell, possibly with inner reinforcements. In a collision, they are flattened by the front of the car and run over. Relatively long posts are required for higher speeds. In addition to thin plate, the posts can also be made of weaker framework structures. They are common as lamp posts and have two degrees of energy absorption – high and low energy absorption, respectively, HE/LE. Designations can be, e.g., 100HE2, where 2 designates impact severity level.

Non-energy-absorbing posts should let the colliding vehicle through without any appreciable speed reduction. They are often manufactured as relatively rigid posts (steel pipes, framework structures with rigid frame poles) mounted on break hinges straight above the ground. In a collision, the post is pushed out of its hinge and rotates around its center of gravity or center of inertia allowing the car to pass underneath. Posts which break at ground surface or are splintered in a collision are also part of this group. This is the alternative to flexible lamp posts. The design with break hinges is dominant for flexible road sign posts and is classified as Non-Energy-Absorbing, NE.

Posts with break hinges may be sensitive to the position of the point of impact during a collision and their use on steep slopes is not recommended (there is a great probability that if vehicle drives off the road, it will fly over them).

Typical materials include steel and aluminum but plastic composites also occur.

Framework structure posts with break hinges are the most practical way for bearing a big load using only one post.

A flexible post is most often somewhat more expensive than a corresponding non-flexible post.

1.7.2.2 Flexible Posts and Overhead Lines

Where the power supply for lighting installations with flexible posts is provided by overhead lines, the mode of operation of the lamp post is taken into consideration from a flexibility perspective. There are two principally different solutions with one common point – that they should be fastened to one end and sit loose at the other. As regards posts which are designed to deform during energy absorption, the cable is connected in such a way as to loosen from the post during a collision. The root of the post remains fixed to the foundation, whereas the top of the post with its arms and fittings can move freely. Posts with break hinges had better be fixed to the overhead line since they let loose from the foundation when the break hinges release their grip.

As regards an overhead line placed in the middle of the traffic lane, with a holder in the form of a post with a long single arm (comparable to an L-shaped portal), none of the two alternatives seems to be good. If the post loosens from the foundation (break hinge) during a collision but remains attached to the overhead line, it is going to hang down in the middle of the traffic lane. If it remains attached to the foundation but is yanked from the overhead line, the arm is highly likely to fall on the roadway.

An alternative could be to draw a strong wire between the tops of the posts and to hope that disconnected posts will remain hanging to it. Posts which should have wires/cables should undergo collision testing with such a design. If the overhead lines should be kept stretched using counterweights hanging along the side of the post, in practice, it will be completely impossible to make such a post flexible. It seems to be difficult to ensure traffic safety using flexible posts.

1.7.2.3 Design of Posts

Posts should be designed to carry their own weight, the wind load on the arm and lines of the post and the load of the lines, including the pressure in the system. An ice cover should possibly be assumed on the lines; the load it generates consists of the weight of the ice itself and a greater wind load in the form of a larger surface of the line. The wind's return period should be set to 50 years. It should be noted that when a post is placed on a bridge, the exposure factor is determined based on the height above the underlying water/ground. If an ice load should be taken into consideration, the typical ice load is assumed to be the weight of a 10-mm thick ice cover with a weight of 9 kN/m^3 on all surfaces. As regards cables with a diameter of up to 30 mm, a characteristic ice load of 10 N/m can be assumed.

As regards posts along major roads in the countryside, the load of plow snow against the post itself should be assumed. When the plow snow load is determined, a high plow speed should be assumed and the load set to 4 kN/m^2 (assume that the post is within three meters of the roadside) and the plow snow load should be placed in the most unfavorable position. Framework type posts should, in this context, be considered as a structure with a whole surface. The design should be carried out in accordance with the relevant parts of Eurocode, whereas national choices regarding, e.g., wind load and temperatures should be performed according to the Swedish National Board of Housing, Building and Planning's Regulations, EKS. Equipment which, in the event of a breakdown, falls on the roadway is classified in safety class 2; see Chapter 2 of the Swedish National Road Administration's Regulation 2004:31 on Carrying Capacity, Stability and Resistance in Construction Work in the Construction of Roads and Streets.

1.7.3 Collision Protection

1.7.3.1 Impact Attenuators

Impact attenuators are protective devices (akin to barriers) which reduce the speed of a colliding passenger car coming from the front by dealing with the kinetic energy through deformation. There are different speed classes, straight and conical designs (broader at the back), as well as designs which work or do not work as barriers (directional/redirective) in the event of a lateral collision. For permanent use, an impact attenuator needs to be directional. Impact attenuators along the main road network should meet the requirements for speed class 110. The requirements for vehicle business class and deformation depend on the placement and traffic situation. Speed class 110 impact attenuators are tested with a 1500-kg passenger car for determining their energy-absorbing capacity and with a small car for determining the risk of injuries.

Impact attenuators are relatively costly; they should be placed on level ground which can hamper their use in those cases where posts are placed on a slope and they require certain supervision, e.g., cleaning in order to preserve their function. Impact attenuators are tested according to SS-EN 1317-3 (current edition from 2010). Impact attenuators are covered by the requirements for CE marking according to SS-EN 1317-5.

Impact attenuators can presumably not be used as a general solution in connection with electrified roads but may be used for posts placed, e.g., in ramp noses.

1.7.3.2 Barriers

The posts can still be protected using longitudinal barriers. If only road users in passenger cars driving off the road are taken into consideration, barriers with N2 performance class should probably be sufficient. If the installation owners consider the installation to be some form of a protected object and desires to protect the posts from being run over by heavy vehicles, they should probably opt for H2 or a higher performance class. In the event of high volumes of trucks with trailers, e.g., more than 1,000 per day, the option of barriers with H4 performance class can be considered if running over posts is considered to be completely unacceptable.

The posts should be placed outside the barrier's working width or, to formulate it in another way, the barrier should be specified with such a working width as not to come into conflict with the posts. Common working widths are between 1 and 2 meters and are measured from the barrier's traffic side to their maximum deflection during type testing aimed at determining their performance class. The working width includes the barrier's own width.

The latest edition of the testing standard, SS-EN 1317-2 from 2010, has introduced a concept called vehicle penetration for H-classified barriers (H1 through H4). It specifies how much a heavy vehicle leans over the barrier during type testing. Vehicle penetration for trucks is measured at a height of 4 m above the ground.

The barrier's price level varies strongly depending, in part, on barrier type (concrete barriers are most expensive, steel cable barriers cheapest) and, in part, on performance class (a lot more material is consumed in order to hold back heavy vehicles), from a couple of hundred of SEK to may be SEK 2,000 per meter.

1.8 Technical Solutions

1.8.1 Wear of the Road Structure

Electrified roads will probably affect channelization and thereby wear to a small extent as the vehicles are not laterally fixed. Barriers placed next to the roadway will affect channelization to a higher extent.

1.8.2 Effect from Operation and Maintenance

Overhead lines may stand in the way during asphalting works but since these are planned and most often relatively extensive on these roads, it should not be any problem to turn off the power on such occasions and adapt the work so that the platforms do not interfere with the cable. Certain caution will be needed and certain trucks will be more unsuitable than others. Cost increase? Yes, possibly, but by a very small margin.

Reinforced roads structures will not be needed.

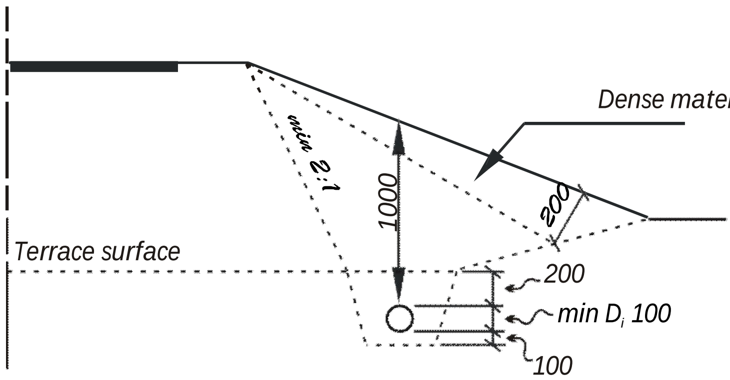
1.8.3 Foundation-Laying of Posts

When new foundations for overhead line posts must be built along an existing road, the Swedish Transport Administration tries to avoid poking in the roadbed as much as possible. The reason for this is that this reduces the risk of undesired movements in the roadbed and the track's position. Methods which are used then include drilled holes or vibrated/compressed pipes as a foundation. When a hole is drilled, a pipe is inserted simultaneously with the drilling and is subsequently filled with concrete so as to produce a prefabricated foundation in the ready hole.

Attention during erection of overhead line posts and their foundations in a road structure should be paid to ensuring that there are generally different types of ducting placed in the inner slope.

1.8.3.1 Drain Pipe

Pipes for draining of the superstructure may occur in a road structure and should lie at least 0.3 m below the terrace level, see the figure.



Depending on the thickness of the superstructure, the drain can be estimated to be placed at a distance of between 0.5 and 1.0 m from the edge of the cover in the inner slope.

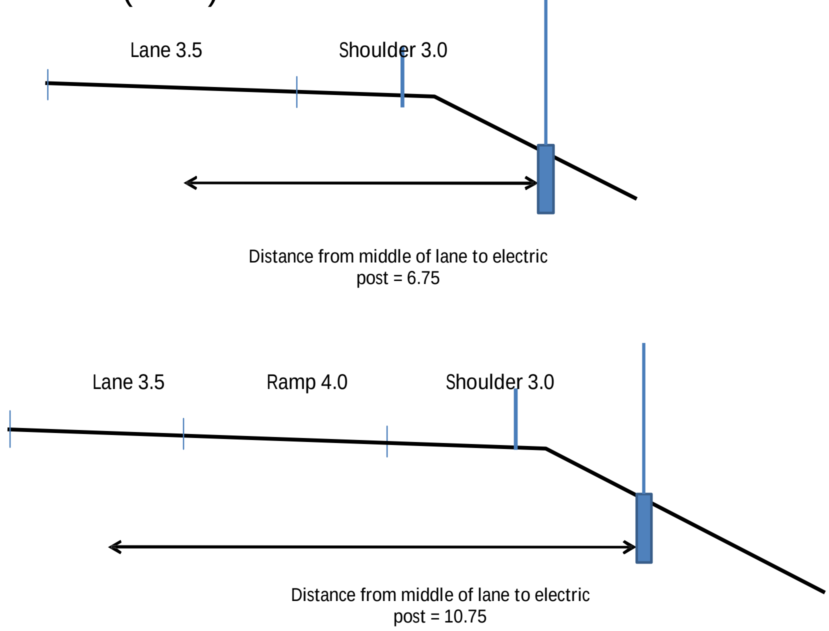
1.8.3.2 Optical Fiber and the Like

Different types of optical fiber (opto-cable, broadband cable, etc.) may also be placed in the inner and outer slope. A check should be made to determine where these are located in relation to the edge of the cover during the foundation-laying of overhead line posts.

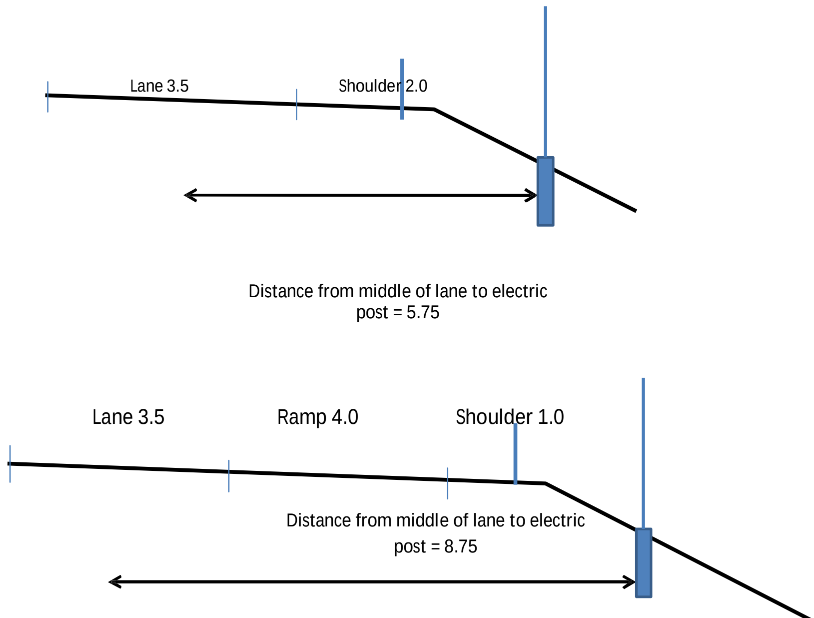
1.8.4 Placement of Posts

	Traffic lane	Shoulder	Middle of lane to el. post
Freeways max and min	3.75-3.25	3.0-2.0	6.75-5.63
2+1 road	3.75-3.25	1.0-0.5	5.13-4.13
Divided highway	3.25	2.0	5.63

TV124 (1975)



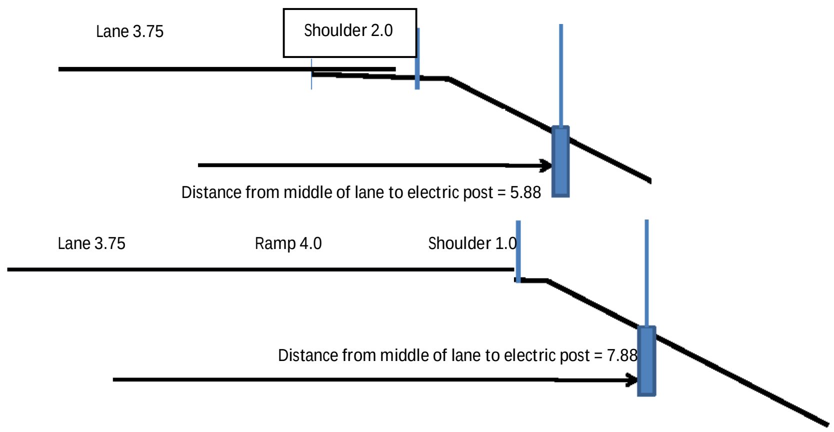
VU 94 70 km/h



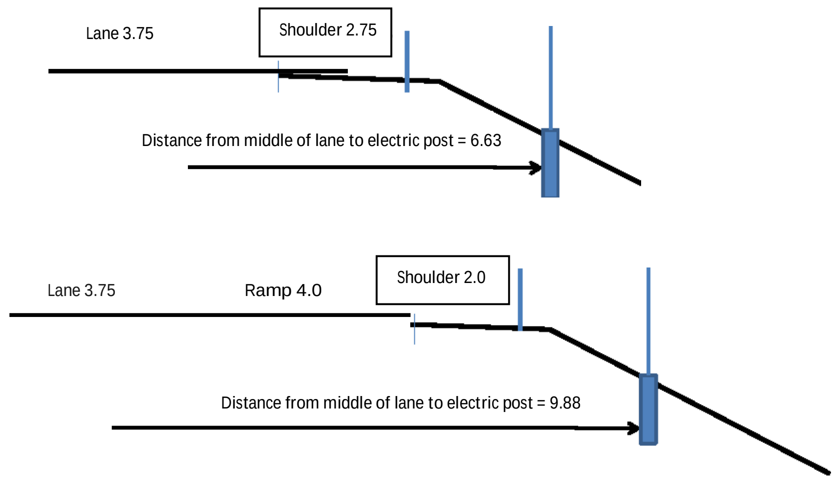
Appendix 1

Prerequisites for Electrification of the Swedish Main Road Network – Swedish Transport Administration

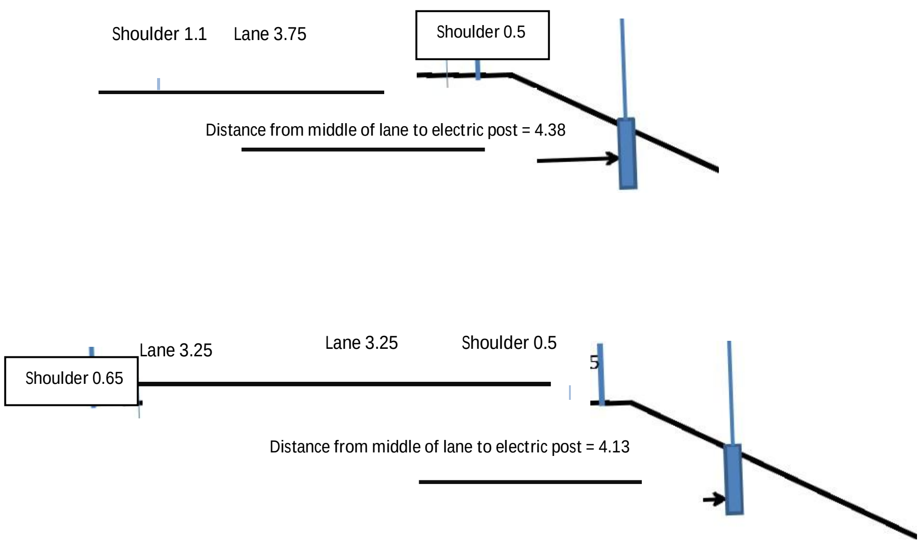
VU 94 90 km/h



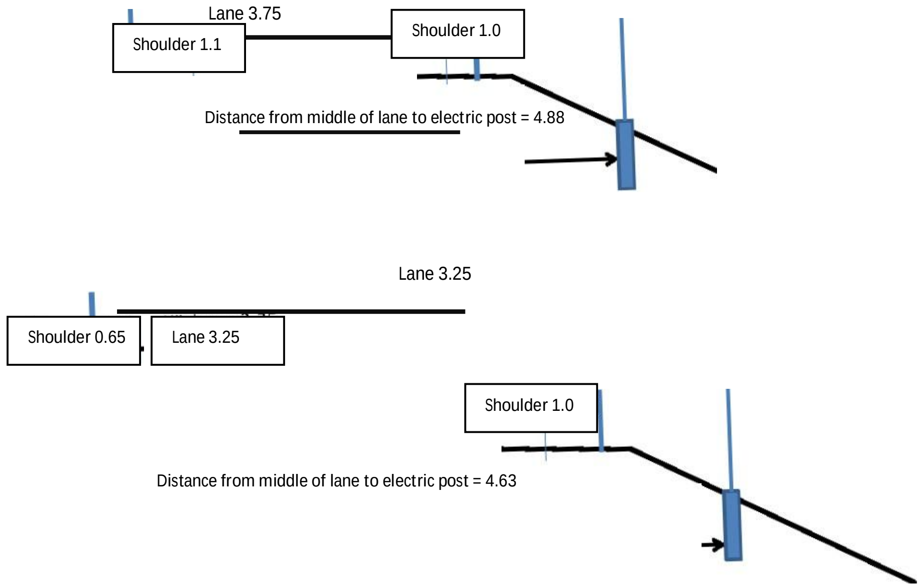
VU 94 110 km/h



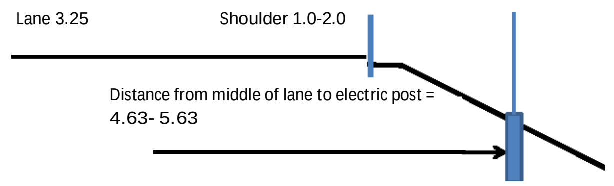
VU 94 2+1 Road existing 13 m 100 km/h

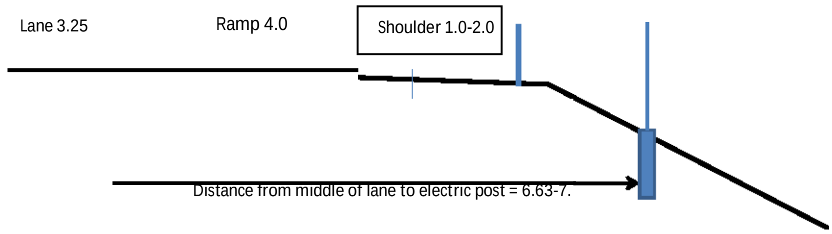


VU 94 2+1 Road New road 100 km/h

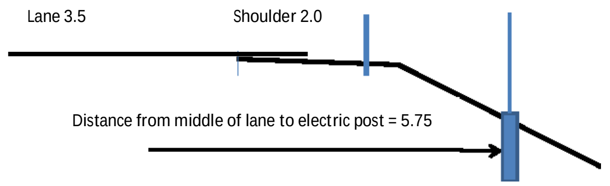


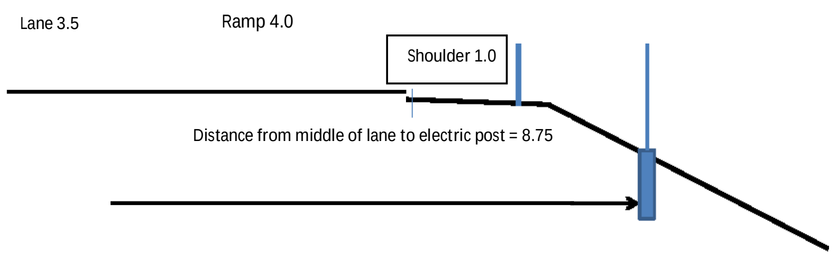
VGU Divided highway



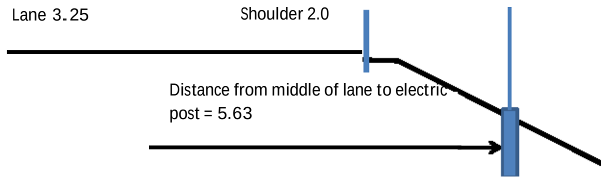


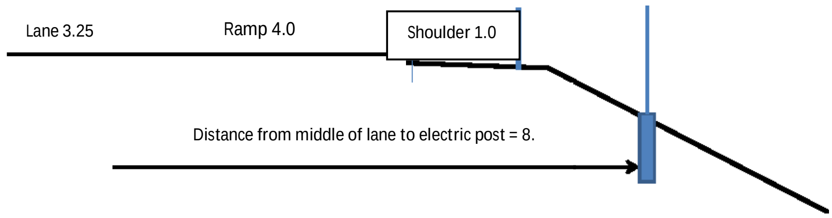
VGU Freeway, normal standard



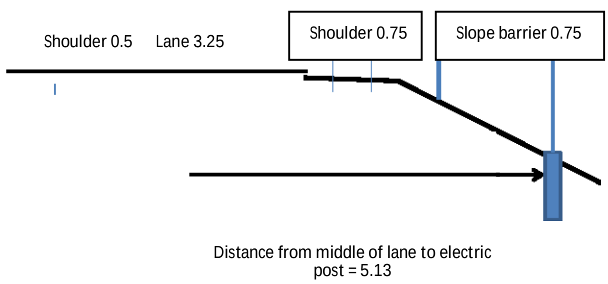


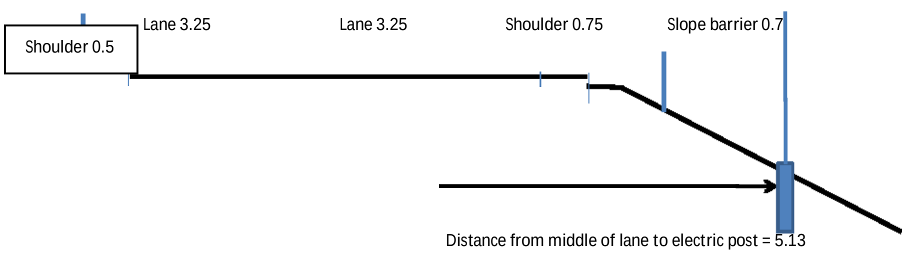
VGU Freeway, low standard





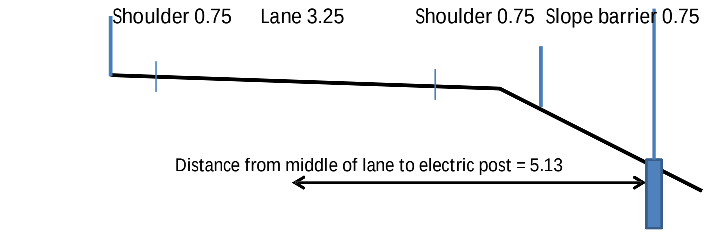
VGU 2+1 Road "Safe Access", existing 9 – 13 m 100 km/h

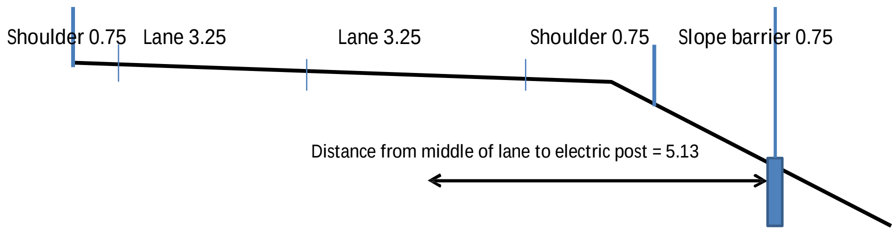




VGU 2+1 Road "Safe Access"

New road, 9 – 13 m/h 100 km/h





1.9 Construction Costs

1.9.1 Road Structure

The Swedish Transport Administration assesses that there will be no significant additional wear of the road on account of the overhead line and this is why there will be no additional road construction costs.

1.9.2 Posts and Installation

The cost of posts in railroad construction is approx. SEK 13,000 to 20,000/post, including foundation and their service life is 50 years.

1.10 Maintenance Needs

1.10.1 Road Structure

Electrified roads will probably affect channelization and thereby wear to a small extent as the vehicles are not laterally fixed. Barriers placed next to the roadway will affect channelization to a higher extent.

1.10.2 Posts and Installation

Railroad catenaries are replaced, on average, once every 50 to 60 years on ordinary lines and once every 30 to 40 years in big cities and surrounding areas. The replacement is caused by the ageing of the materials depending on the environment and, to a certain extent, on the number of passages of current collectors. There are approx. 30 passages of current collectors along the ordinary lines per day in Norrland and not less than 300 in Stockholm.

The average annual maintenance cost is approx. SEK 20,000/km.

1.11 Charging of Power Use

1.11.1 Load on the Power Network

Segment of section length		= A section of the overhead line where there is only one car at a time
Section	(m)	= The distance to the end of the current segment
Power (3-phase)	(kW)	= The power in the current segment
Current (3-phase)	(A)	= The current in the current segment
Voltage (3-phase)	(V)	= The voltage in the current segment
Sp fall	(V/section)	= The voltage drop in the current segment
Sp fall	(V total)	= Accumulated voltage drop along the line
Sp fall	(%)	= Voltage drop in per cent in relation to the supplied voltage
Loss/10 km	(kW)	= Power lost from the overhead line

Number of cars in a section	10		Distance between current collectors	120 m
Power/car	100 kW		Horsepower	137 hp
Conductor area, copper	260 mm^2		Corresponding area for aluminum	403 mm
Section length	1200 m		Total power per section	1.0 MW
Voltage, three-phase	1000 V		Total power per 10 km	8.3 MW
Voltage, single-phase/DC	1500 V		Loss/10 km, three-phase	259 kW
			Loss/10 km, single-phase/DC	230 kW

Three-phase

Segment of section length		1	2	3	4	5	6	7	8	9	10
Section	(m)	120	240	360	480	600	720	840	960	1080	1200
Power (3-phase cos⍰=1)	(kW)	1000	900	800	700	600	500	400	300	200	100
Current (3-phase)	(A)	578	520	462	405	347	239	231	173	116	58
Voltage (3-phase)	(V)	992	985	978	973	968	964	960	958	956	956
Loss/section	(kW)	8.1	6.5	5.2	4.0	2.9	2.0	1.3	0.7	0.3	0.1
Sp fall	(V/section)	8	7	6	6	5	4	3	2	2	1
Sp fall	(V total)	8	15	22	27	32	36	40	42	44	44
Sp fall	(%)	0.8%	1.5%	2.2%	2.7%	3.2%	3.6%	4.0%	4.2%	4.4%	4.4%

Single-phase/DC

Segment of section length		1	2	3	4	5	6	7	8	9	10
Section	(m)	120	240	360	480	600	720	840	960	1080	1200
Power (1-phase/DC)	(kW)	1000	900	800	700	600	500	400	300	200	100
Current (1-phase/DC)	(A)	667	600	533	467	400	333	267	200	133	67
Voltage (1-phase/DC)	(V)	1489	1480	1471	1463	1457	1452	1447	1444	1442	1441
Loss/section	(kW)	7.2	5.8	4.6	3.5	2.6	1.8	1.1	0.6	0.3	0.1
Sp fall	(V/section)	11	10	9	8	6	5	4	3	2	1
Sp fall	(V total)	11	20	29	37	43	48	53	56	58	59
Sp fall	(%)	0.7%	1.1%	1.9%	2.4%	2.9%	3.2%	3.5%	3.7%	3.9%	3.9%

1.11.2 Business and Payment Model

It should be possible to charge energy consumption in the same way as is already applied to railroads. Railroad companies which do not have electric meters installed are supposed to report performed transportation work per vehicle type on a monthly basis. This amount of energy is used as a basis for charging. Railroad companies which have electric meters installed in their vehicles send information about consumed energy per vehicle on a monthly basis. As regards railroad companies which have the Swedish Transport Administration's meters, the meters send all measurement data directly to the Swedish Transport Administration's settlement system. Loss surcharges for the transfer of electric power from the 50 Hz network to the vehicle are made per vehicle type. The main objective for a new system should be that all vehicles have power meters for direct transfer of measurement data to the Swedish Transport Administration's settlement system.

There should not be any greater risk for fare dodgers on the road than on the railroad, in particular, if there are requirements for power meters installed on all vehicles.

1.11.3 Means of Control

It should be possible to use similar means of control that exist and are under development for the railroads.

Amendments to the Swedish Railway Act entail the use of fees in the business management of the train traffic which, in turn, entails the introduction of quality fees by the Swedish Transport Administration and the railroad companies. The party to cause deviations from timetables and traffic agreements is supposed to pay in advance a certain quality fee to its counterparty. The fee should contribute to greater punctuality and raise the quality in the railroad system.