2022.

Guidelines
Local Roads Design
(GLRD)

2. PAVEMENT STRUCTURES

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PAVEMENT STRUCTURES

1 General

One of the specific characteristics of local roads is the wide range of all types of pavement construction, starting from roads without pavement, to roads with modern flexible or rigid pavements.

The basic characteristics of local roads that influence design of pavement structures are:

- Low volume of traffic and possible occurrence of vehicles with heavy axle load
- Great influence of climatic factors
- Greater tolerance of structural and functional defects
- Financial constraints during construction and maintenance

The quality of materials and construction, the choice of the appropriate thickness of the layers of the structure and regular maintenance have a decisive influence on the sustainability of the performance of the pavement structure. The prerequisite for the sustainability of the structural and functional characteristics of the pavement construction of local roads is the application of approved design procedures, adequate technical specifications for materials and execution of works, regular monitoring of pavement condition and timely implementation of maintenance and rehabilitation measures.

2 Traffic Load

Traffic load is the load expressed by the number of vehicles (PGDS-average annual daily traffic) or by the number of crossings of the nominal axle load of 82kN or 100kN, which will pass through the selected cross-section of the road in a defined period of time.

The pavement structure is exposed to moving traffic load, which causes stress in the upper and lower layers of the pavement structure. Repeated loading causes fatigue distress to the materials in the layers which finally deform and crack, leading to permanent deformation of the pavement surface. Heavy trucks increase pavement wear and thus contribute to premature pavement fatigue. A pavement reaches the end of its life when the extent of distress and/or permanent deformation of the surface exceeds acceptable levels for safety, comfort and economy of transportation.

Fatigue of pavement construction materials depends on:

- characteristic of the motor vehicle:
- axle load,
- arrangement of axles on the vehicle,
- arrangement of wheels on the axle of the vehicle, i
- the number of load repetitions, i.e. crossing of the vehicle through the cross section of the roadway.

The traffic of different vehicles and loads is converted to the total number of passes of the loaded reference axle, i.e. equivalent traffic that would produce the same amount of distress as the actual combination of different traffic loads. Based on the equivalent number of standard axles, the allowable stress and deformation of the layers of the pavement structure are defined in order to reach the design life of the structure.

2.1 Relevant design traffic load

Calculation of the traffic load for the purposes of design pavement structures on roads in Serbia is carried out in accordance with:

- Standard SRPS U.C4.010 - Determination of the total equivalent traffic load for the dimensioning of asphalt pavement structures (1981) and
- Manual for designing roads in the Republic of Serbia (Guidelines - "Roads of Serbia" 2012)

By applying the methodology prescribed in these documents, the relevant traffic load for the dimensioning of pavement structures is calculated in relation to the standard axle and vehicle category.

The relevant traffic load is a characteristic value for the traffic load of the pavement structure in the planned project period, which is determined on the basis of the average annual daily traffic expressed through the number of crossings of the nominal axle load, traffic growth during the project period and other influencing factors (number and width of traffic lanes, longitudinal slope.

2.2 Traffic load according to the standard SRPS U.C4.010

According to the standard SRPS U.C4.010 (1981), the total equivalent traffic load is the calculated value of the total number of standard axles in the design period on the relevant traffic lane for design the pavement structure. The term standard axle means a single axle with a load of 82 kN. The standard axle has two double wheels, each of which transmits a load of 20.5 kN.

When analysing the traffic load, the following parameters are taken into account:

• Average annual daily number of heavy vehicles in the initial year of road exploitation
• Average annual growth rate of the number of heavy vehicles in the design pavement life
• Axle loads of representative types of vehicles
• Average capacity utilization of heavy goods vehicles
• Distribution of traffic load by traffic lanes

If there is no data on the number of vehicles for local roads (IV and V traffic class), the average annual daily number of heavy vehicles can be predicted approximately based on an estimate. Also, if there is no detailed data on the utilization of the vehicle's carrying capacity, it is adopted in the calculation for all vehicles that the average utilization of the vehicle's carrying capacity is 70%.

The axle loads of individual analysed heavy vehicles are converted into standard axle loads using the appropriate equivalence factors f_e (given within the standard).

The average daily equivalent traffic load on the relevant traffic lane (Td) is determined according to the following formula:

$$\text{Td} = \sum_{i=1}^{i} Fe \; x \; ni$$

where is:

Fe – the total number of standard axles for certain types of heavy vehicles (obtained by summing the equivalence factor for all vehicle axles)

ni – average annual daily number of individual heavy vehicles in the initial year of operation on the busiest traffic lane

When design asphalt pavement for local roads (IV and V traffic class), an approximate determination of the total equivalent traffic load can be applied. According to this procedure, the average annual daily number of heavy vehicles in one direction in the initial year of exploitation is estimated from the average daily annual traffic (PGDS) of all motor vehicles for the considered traffic class.

The average annual daily equivalent traffic load of heavy vehicles is roughly determined according to the expression:

$$Td = k \times n$$

where is:

k – average number of standard axles for one heavy vehicle
n – estimated average annual daily number of all heavy vehicles in the busiest traffic lane in the initial year of road exploitation

The average number of standard axles k is determined depending on the estimated average annual daily number of all heavy vehicles in one traffic direction of the road, according to the following table:

Table 1: The average number of standard axles for a heavy goods vehicle

Average annual number of heavy vehicles in one traffic direction of the road	Average number of standard axles of 82 kN for one heavy vehicle
>500	1,2
100-500	0,75
<100	0,45

The total equivalent traffic load of heavy vehicles in the initial year of operation (Tg) is obtained from the expression:

$$Tg = Td \times 365$$

The total equivalent traffic load of heavy vehicles in the project designed period (Tu) is determined on the basis of the total equivalent traffic load in the initial year of exploitation (Tg), taking into account the average annual growth rate of the number of heavy vehicles.

The total equivalent traffic load of heavy vehicles in the design period for the design of asphalt pavement structures of non-urban public roads is:

$$Tu = Tg \times \sum_{i=1}^{p}(1+\frac{r}{100})^{i}$$

where is:
p – the design period of pavement structure in years
r – average annual growth rate of the number of heavy vehicles

Within this standard, depending on the size of the total equivalent traffic load in the project design period, the traffic load is divided into groups.

Table 2: Traffic load groups

Traffic load group	Total equivalent axle load of 82kN (Tu) in the project period
very heavy	$>7 \times 10^6$
heavy	$2 \times 10^6 - 7 \times 10^6$
medium	$7 \times 10^5 - 2 \times 10^6$
light	$2 \times 10^5 - 7 \times 10^5$
veri light	$<2 \times 10^5$

2.3 Manual for road design in the Republic of Serbia

(Guidelines –„Roads of Serbia“2012)

In Serbia, the procedure described in the Road Design Manual from 2012 is also in use. According to this procedure, the traffic load is expressed through the nominal axle load of the single axle of the vehicle of 100 kN, which is transmitted by the wheels to the pavement surface.

For the quantitative evaluation of the influence of different axle loads of motor vehicles on the fatigue of the pavement structure material, the updated equation of the ASSHO test is applied:

$$FE_i = f_{o,i} \times (f_{k,I} \times L_{stat,i})^4 \times 10^{-8}$$

where is:

$f_{o,I}$ – a factor that depends on the type of axle (single axle $f_{o,1}$=1.0, double and triple axle $f_{o,2}$=0.7156)
$f_{k,i}$ – tire type (single tire f_{k1}=1.0, double tire f_{k2}=0.9, super single f_{k3}=0.97)

The evaluation of the utilization of the vehicle's carrying capacity is carried out through equivalence factors, so that they are calculated with the estimated load of the vehicle's axles.

The calculation of the equivalence factor Fev of a representative motor vehicle is performed using the equation:

$$FE_v = \sum FEi$$

If the characteristics of representative vehicles are not known, the average values of the equivalence factor FE_v from the following table can be used:

Table 3: Average values of equivalence factors for representative vehicles

Representative vehicle	Equivalence factor FE_v
• passenger vehicle	0.00003
• bus	0.55
• truck:	
o light	0.004
o medium	0.10
o heavy	0.50
o heavy with trailer	0.90

In case the spectrum of heavy trucks is not known, average values of the equivalence factor can be applied depending on the average number of heavy trucks per day.

Table 4: Average values of equivalence factors for trucks

Average number of heavy trucks per day	Average equivalence factor FE_v
< 200	0.40
200 - 1 000	0.60
> 1 000	0.80

By reviewing the attachment in which the calculation of the equivalence factor of the relevant vehicles (eg the relevant towing vehicle with a semi-trailer - TPP) is given, calculation errors were observed, which should be corrected.

After determining the equivalence factor for representative vehicles, the daily traffic load is calculated according to:

$$Td = \Sigma FE_{v,i} \times n_{v,i}$$

where is:

Td – daily traffic load
FE_v – equivalence factor for representative vehicle i
n_v – number of reperesentative vehicle i per day

The relevant traffic load according to which the pavement structure is designed is defined on the basis of:

- projected equivalent daily traffic load Td,
- additional impacts arising as a result of road characteristics, i
- the design life of the pavement and the annual increase in traffic.

The relevant traffic load is calculated using to the following formula:

$$Tn = 365 \times Td \times f_{pp} \times f_{št} \times f_{pn} \times f_{du} \times f_{po}$$

where is:

Tn – relevant traffic load for a period of n years
Td – equivalent daily traffic
f_{pp} – pavement cross-section factor (number of traffic lanes)
$f_{št}$ – traffic lane width factor
f_{pn} – factor of longitudinal inclination of the pavement level
f_{du} – factor of additional dynamic influences
f_{po} – traffic load increase factor in a period of n years

In the Rulebook for road design, the traffic load was categorized depending on the number of nominal axle load crossings per day and for a period of 20 years, which is relevant for determining the materials quality for the construction of pavement structures.

Table 5: Categorization of traffic load

Traffic load group	Number of repetitions of the nominal axle load of 100 kN	
	per day	for 20 years
extremly heavy	preko 3.000	preko 2×10^7
very heavy	800 – 3.000	$6 \times 10^6 – 2 \times 10^7$
heavy	300 – 800	$2 \times 10^6 – 6 \times 10^6$
medium	80 – 300	$6 \times 10^5 – 2 \times 10^6$
light	30 – 80	$2 \times 10^5 – 6 \times 10^5$
very light	do 30	do 2×10^5

2.4 EU Practice

Current EU law (Directive 96/53/EC) limits the maximum permissible vehicle weight to 40 tons, except for intermodal transport using 40-foot containers that have a maximum weight of 44 tons. The maximum axle loads are: 10t for one axle and 11.5t for the drive axle, 11.5t to 19t depending on the wheelbase for the tandem axle and 11t to 24t for the tridem axle.

Although each member of the EU has specifics in determining the equivalent traffic load, it is common that the axle load of 100 kN (exceptionally 115 kN for highways) is used as the standard load.

Due to the traditional practice that the regulation of the road industry in Serbia is most often based on the corresponding regulation in Germany and Austria, the analysis of determining the relevant traffic load is limited to the procedures applicable in these two European countries. The relevant traffic load in both countries is determined very similar to the procedure described in the Rulebook for road design in the Republic of Serbia, with the application of specific corrective factors.

Based on the cumulative traffic load, the load class is defined as the basic parameter for the design of pavement structures.

In Germany, the so-called construction classes (Bk - Bau klasse) that correspond to the intensity of the traffic load and range from Bk0.3 to Bk100, where the Bk value is expressed in millions of equivalent axles of 10t (e.g. Bk0.3 corresponds to a traffic load of less than 3×10^5 equivalent axle). Construction classes Bk are classified into 7 classes according to which the type of pavement construction is selected. It is recommended that the traffic load be calculated on the basis of actual recorded axle loads in the field (measurement of the axle load in motion).

When the designer does not know the data on the actual traffic load, tables are available from which he can define the traffic load depending on the specific purpose of the road, respectively according to the specific type of traffic.

Austria for the design of pavement structures divides it into load classes according to the cumulative traffic load in the design period, i.e. design standard load (BNLW). In the event that data on the characteristics of representative vehicles are not known, average equivalent factors can be applied, i.e. the ratio of the relative degradation of the pavement due to the passage of vehicles of category (i) in relation to the degradation due to the passage of a standard axle (100 kN).

Table 6: Average equivalent factor for different vehicle categories i

Vehicle category	A_i
Truck (LKW)	0.80
Truck with trailer	1.25*
Towing track (semi-trailer)	2.00*
Bus	0.60
Public bus	0.80
Articulated bus	1.40

**If it is not possible to distinguish between trucks with trailers and towing trains, an equivalent value of 1.75 is applied.*

Based on traffic load, the roads are classified into 10 classes (LK163 - LK0.05), according to which the type of pavement structure is selected.

If heavy vehicle traffic data is not available, in exceptional cases on the road network with lower traffic intensity, the load class is assigned according to the assessment of the relevant heavy vehicle traffic in accordance with the Table 7.

Table 7: Allocation of traffic load class based on heavy vehicle traffic for roads on the traffic network with lower intensity *)

Load class	Relevant heavy traffic
LK0,4 ($1x10^5$-$4x10^5$)	80 heavy vehicles per 24 h
LK0,1 ($5x10^4$-$1x10^5$)	20 heavy vehicles per 24 h
LK0,05 (< $5x10^4$)	10 heavy vehicles per 24 h

**) Period procene od 20 godina, maksimalna širina trake 3.50 m*

Based on the analysis carried out, it is noticeable that the procedure given in the Road Design Manual in the Republic of Serbia does not deviate significantly from the practice in Germany and Austria (probably the methodology from the relevant documents of the mentioned countries was used for Manual preparation).

The existing SRPS U.C4.010 standard, in use since 1981, has been surpassed primarily due to the use of a normative axle load of 82 kN, so it should be innovated as soon as possible. The main problem is its connection with the standards that have as their subject the design of pavement structures in Serbia, which means that these standards should also be harmonized with the new standard for determining the traffic load.

2.5 Traffic load on local roads

Local roads have a number of specificities regarding the traffic load. This primarily refers to the great diversity regarding the spectrum of vehicles that use these roads. The participation of characteristic types of vehicles largely depends on the economic activity of the area it serves and connects with roads of a higher category, as consequence so all types of vehicles can appear on local roads.

Intensity of traffic on local roads is generally characterized by a small volume of traffic, except in the case when local roads have the function of connecting local traffic centers (SP IV). This has the effect that light and very light traffic loads prevail on local roads, although heavy and medium traffic loads may also occur depending on the connection function.

Based on the above, it can be concluded that defining the traffic load is extremely important for the pavement design on local roads. Unfortunately, there is currently no systematized collection of data on traffic counts on local roads (except for the city of Belgrade), although the companies that take care of public roads have an obligation to count vehicles (Law on Roads, Article 9 and 10 - "Official Gazette of RS", no. 41/2018 and 95/2018). As soon as possible, it is necessary to carry out the action of installing traffic counters on local roads with the possibility of categorizing vehicles and to form appropriate databases.

Until the conditions for obtaining reliable data on the traffic load on local roads are met, estimates based on data from local roads of similar functional purpose can be used, with a mandatory check of assumed input data through traffic counting with vehicle categorization in a limited time interval. In the absence of reliable data for local roads in Serbia, an average share of heavy vehicles of about 10% can be assumed. By analyzing the traffic counting database in Slovenia, where 70% of state road sections are covered by traffic counters, and based on the good correlation of the participation of heavy vehicles on high-ranking roads with the database of Serbia, it can be assumed that the average participation of heavy vehicles on low-ranking roads is similar to the participation of these vehicles on roads of the same class in Slovenia. As mentioned earlier, the participation of heavy vehicles directly depends on the functional role of the local road, so this should be taken into account in case there is no reliable data on the counting and categorization of vehicles.

In accordance with the practice of EU countries, a further growth trend of vehicles with a triple axel and with the so-called super-single tires. The increased number of axles on the vehicle and single tires lead to faster structural fatigue and a greater risk of permanent deformations, i.e. the participation of vehicles with these characteristics significantly increases the stresses and deformations in the pavement structure, which has a great impact on the life of the structure.

When determining the traffic load, it is preferable to determine the traffic load according to the seasons, in order to control the influence of the traffic load in critical conditions of the soil during pavement design.

Axle overload and high pressure in the tires of heavy vehicles represent a particular risk during the exploitation of the pavement structure of local roads. An overload of 5% results in a 22% increase in the fatigue of the pavement structure, and an overload of 20% doubles the fatigue of the structure. Bearing this in mind, special attention should be paid to axle load control, especially in the period of intensive harvesting of agricultural products (e.g. sugar beet transport period).

Traffic load is extremely important for the design of new and reconstruction of existing pavement structures on local roads. On the most local roads, the traffic load is light or very light, but depending on the function of the local road, medium and heavy traffic loads could be expected. The absence of reliable data on traffic counting and categorization of vehicles increases the risk of using unreliable traffic load.

3 Climate and hydrological conditions

Climate and hydrological conditions of the area where the road is located have a significant influence on design of the pavement structure as a whole. This especially applies to the air temperature, which significantly affects the characteristics of the flexible layers of the pavement structure, the hydrological conditions at freezing temperatures and the characteristics of the road foundation.

When defining the climatic conditions for the design of pavement structures, special attention should be paid to the impact of climate change on the sustainability of the functional and structural characteristics of the road. Climatic changes can significantly reduce the projected life of the pavement structure, reduce resistance to the appearance of permanent deformations and cracks.

3.1 Climate conditions

Climate conditions make up a set of meteorological phenomena that characterize the average state of the atmosphere and its changes in a specific location or area through which the road passes, in a specific period of time. The most significant of climate conditions is the air temperature which affects the temperature of the pavement.

Temperature significantly affects the characteristics of the bituminous binder, on a way that at high temperatures it reduces stiffness and increases the risk of plastic deformation of asphalt layers, while at low temperatures it increases stiffness and the risk of cracking in these layers. Also, in the case of rigid pavement, it significantly affects the stress state due to the bending and expansion of the concrete slabs. In addition to the impact on the upper pavement`s layers, low temperatures can cause serious damage to the structure due to the effect of frost and swelling of the soil in the road foundation, so when design the pavement structure, special attention should be paid to protection against the effects of frost.

According to the available climate maps, the territory of Serbia can be divided into three basic climate zones. The first zone covers the largest area with 60-90 days with temperatures below freezing. The second zone with a greater number of days (90 - 120) extends over a narrow strip along the eastern border with Romania and Bulgaria and southeast in the zone of Kosovo and the border with Montenegro. The third zone with the highest number of days with temperatures below freezing (120-200) is located in the small territory of Sandžak. These are only indicative data until the final definition of climate zones. For this, it is necessary to collect and process the data of the Hydrometeorological Institute and conduct additional research with the precise measurement of the depth of soil freezing, with the aim of determining the thickness of the unbound subbase layer for freesing protection subgrade sensitive to the harmful effects of frost. For this purpose, the data collected from the Road Weather Information System (RWIS), which is in the phase of expanding the number of measuring stations in Serbia, should be included, as well as the monitoring of climate changes through monitoring.

Climate changes that have been registered in the last few years can affect the accelerated degradation of pavement structures. An increase in air temperature affects the characteristics of bituminous binders, which results in increased stress on the pavement sublayers and fondation and the damage, most often in the form of permanent deformations and cracks. The consequence of these impacts is the need for more frequent interventions as part of maintenance and the shortening of the designed life of pavement structures

The global phenomenon of rising air temperatures has been registered in Serbia, so that since the 1980s, a constant trend of increasing periods of high air temperatures, as well as increasingly frequent occurrences of extreme precipitation intensities, has been observed.

Based on the measured air temperatures in the period from 1960 to 2010, the increase in the average annual air temperature in the largest part of the territory of Serbia is 0.04°C per year, while in the eastern and southeastern parts it is up to 0.05°C per year.

Climate conditions in a certain environment can be determined based on:

- freezing depth h_m, or
- frost index I_m.

The protection of the pavement structure against the effects of frost in the Republic of Serbia is carried out in accordance with SRPS U.B9.012 - Assessment of the sensitivity of the pavement structure to the effects of frost and technical measures to prevent damage.

The following data are used in the process of checking the sensitivity to the effects of frost:

- Climate and hydrological conditions SRPS U.C4.016
- Sensitivity of the subgrade material SRPS U.E1.012
- The depth of freezing, determined by direct measurement according to SRPS U.B9.010
- Total thickness of the pavement structure

The effect of low temperatures is presented through the value of the frost index, i.e. duration of frost intensity. The frost index is the absolute value of the difference between the maximum and minimum of the cumulative graph of mean daily air temperatures in the coldest period (cold wave) at one selected place or meteorological station for the observed winter (°C x days).

Depending on the level at which measurements are made, there are the following types of frost indexes :

- Environmental frost index - to check the pavement structure. The frost index determined at a height of 1.2 m with three measurements per day: 7, 14, 21h
- Road surface frost index
- Frost index at subgrade level

Design of pavement structures and its protection against the harmful effects of freezing is done on the basis of the relevant frost index, according to the following:

- 20-year project period - the average value of the frost index for the 3 coldest winters in the past 30-year period
- 10-year project period - the average value of the frost index for the 3 coldest winters in the past 15-year period

Freezing depth is the maximum depth below the pavement surface to which pore water turns into ice during the freezing period.

The depth of freezing is calculated based on:

- the thickness of the pavement structure
- volumetric mass of dry marial
- relevant frost index (from the diagram given in SRPS U.B9.012)

The depth of frost penetration into the road surface depends on the thermal properties of the materials, especially on their compactness and moisture content.

Because the moisture content of unbound base layer materials is generally low, frost penetrates such materials relatively quickly. In fine-grained materials that contain a larger amount of water, frost penetrates more slowly. This means that when the thickness of the pavement structure is increased in order to protect against changes in the properties of materials that are not resistant to frost, it causes a deeper penetration of the frost.

In the absence of systematized measurements, data on measured maximum freezing depths at several measuring points in the Republic of Serbia can be temporarily used as informative values (Report of the Institute for Roads and Geotechnics of the Faculty of Civil Engineering in Belgrade, no. 53076-2/1992).

Table 8: Measured maximum freezing depths on the territory of the Republic of Serbia

Location	Winter	Freezing depth h_m(cm)
Sjenica	1974/75	70
	1977/78	74
	1988/89	77
	1989/90	82
Divčibare	1975/76	69
	1984/85	107
Majdanpek	1976/77	56
Prokuplje	1978/79	81
Užice	1979/80	87
	1987/88	63
Niš	1983/84	50
	1985/86	75
Zlatibor	1986/87	72
	1988/89	76
Čumić	1988/89	77
Požega	1989/90	81
	1991/92	83
Novi Pazar	1990/91	70

3.2 Hydrological conditions

Recognition of hydrological conditions in a certain environment are necessary for assessing the sensitivity of the pavement structure and the materials in its composition to freezing, as well as for determining measures to prevent damage.

Hydrological conditions are determined based on

- Underground water level,
- Frost penetration depth,
- The material's sensitivity to freezing.

Based on the mentioned factors, the hydrological conditions are divided into

- Favourable, and
- Unfavourable.

Hydrological conditions are favourable, if

- the height of the road embankment is at least 1.5 m,
- the level of underground water is constantly below the depth of penetration of frost, hm,
- shallow cut with good drainage conditions,
- when there is no surface water inflow above the groundwater level

Hydrological conditions are unfavourable, if

- the height of the road embankment is less than 1.5 m,
- the level of underground water is in the area of frost penetration depth hm,
- good drainage of the shallow cut is not provided,
- the cut is deep,
- when there is a possibility of capillary rise of underground water or water coming in from the side as well as water penetration from the surface.

Moisture is the most important factor affecting pavement performance and long-term maintenance costs. Therefore, one of the significant challenges faced by the designer is to provide a pavement construction in which the harmful effects of water will be reduced to acceptable limits in relation to the traffic load, the characteristics of the materials used, the conditions for construction and maintenance, and the degree of isolation.

This challenge is emphasized by the fact that most local roads will be built from locally sourced, lower quality materials that are usually sensitive to moisture. This induce additional emphasis on drainage conditions and moisture control to achieve satisfactory pavement life. Effective drainage is a basic requirement in the design and construction of pavement structures of local roads.

Road drainage elements that are most closely related to pavement design are:

- the permeability of pavement
- finished road levels in relation to the surrounding terrain
- transverse slope of the pavement surface
- lateral drainage

For materials that are less sensitive to freezing, the transverse slope of the subgrade should be at least 2.5%, while for more sensitive materials (cohesive soil), the transverse slope should be at least 4%.

It is impossible to guarantee that pavement surface will remain watertight during the design period, so it is important to ensure that if any pavement layer, including the subgrade, consists of materials that are sensitive to the presence of water, then it must be ensured that water is drained from the structure as soon as possible. To facilitate this the correct grade should be maintained on all layers that are impervious and a suitable path for water to escape must be provided, either by extending the permeable layer of the pavement through the embankment or by including a water-permeable permeable layer in the construction of the shoulder.

The design and maintenance of drainage systems becomes even more important due to climate change, because an increase in the intensity of precipitation and a rise in the level of underground water, in soils sensitive to an increase in humidity, can lead to a decrease in carrying capacity.

3.3 Pavement protection measures

The risk of road damage due to freezing and thawing depends on the following factors:
• depth of frost penetration, hm,
• hydrological conditions,
• the material's sensitivity to freezing and
• the thickness of the pavement structure, which is resistant to freezing.

In order to protect the road pavement structure from the harmful effects of freezing or damage, it needs to be made of resistant materials to a certain depth.
Experiences gained on roads with high traffic loads, where no damage due to freezing and thawing was recorded, showed that the minimum required thickness of the pavement structure h_{min} (i.e. the thickness of resistant materials) is not equal to the measured maximum depth of frost penetration h_m, but that, according to the rule, sufficient is smaller total depth of h_{min} layers of frost-resistant materials.

Table 9: The minimum required thickness of the pavement structure h_{min}

Sensitivity of the material under the pavement structure to the effects of freezing and thawing	Hydrological conditions	Thickness of pavement h_{min}
resistant	favourable	≥ 0,6 h_m
	unfavourable	≥ 0,7 h_m
unresistant	favourable	≥ 0,7 h_m
	unfavourable	≥ 0,8 h_m

The sensitivity of the material to the effects of frost is determined by the standard SRPS U.E1.012 (1981). This standard determines the types of subgrade materials in terms of their sensitivity to the effects of frost. The classification of materials in terms of their sensitivity to the effects of frost is used in the selection of materials in the design and construction of pavement structures, as well as in the determination of protective measures against the harmful effects of frost.
In order to determine the thickness and type of unbound lower layers for protection against the harmful effects of frost, it is necessary to establish categories of subgrade soil in combination with three complementary data, according to sensitivity to the impact of frost:

1. Climatic zone and corresponding freezing depth (0.8m, 1.0m, 1.2m and more than 1.2m)
2. Groundwater level in relation to the subgrade and the impact on the sugrade soil
3. Type of soil at the sugrade level in relation to water permeability and sensitivity to the influence of freezing (swelling)

As a rule, the classification of such soil is defined by three levels of gradation:

G1 - very low sensitive
G2 – low to medium sensitivity
G3 – medium sensitivity
G4 – very sensitive

Table 10: Categorization of materials based on their sensitivity to frost

Category	Materijal	Particle content to 0,02mm (%)	Clasification per SRPS U.E8.010
G1 – very low sensitive	gravel	3 -10	GW,GP,GM,GC
G2- low to medium sensitivity	gravel	10 - 20	GM,GC-GL,GM-GC,GM-ML
	sand	3 - 15	SW,SP,SM,SC
G3 - medium sensitivity	gravel	>20	GS-CL,GM-GC,GM-ML
	sand	>15	SC,SM-SC,SM-ML
	clay (IP>12)	-	CL, CH
G4- very sensitive	silt	-	ML, MH
	silty sand	>15	SM-ML
	Lean clay (IP>12)		CL,CL-ML,
	layered clay and other sediments with small particles		In layers: CL, ML CL, ML, SM CL, CH, ML CL, CH, ML, SM

In the case that silty materials are used, which are generally more sensitive to freezing, the rise of the groundwater level can be very significant. Therefore, in the most cases, it is necessary to consider unfavourable hydrological conditions, regardless of the fact that the groundwater level is several meters below the formation level.

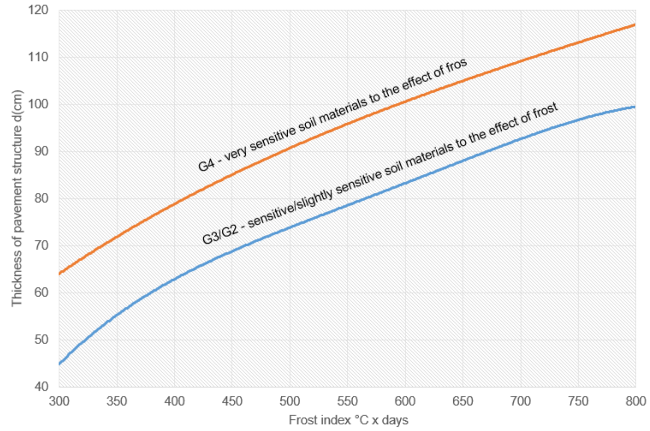
If it is determined that the pavement structure is sensitive to the effects of frost, measures must be taken to prevent the harmful effects of frost. The aim of applying these measures is to:

- prevent freezing of frost-sensitive material in the subgrade
- limit the effects of heaving of the structure due to the swelling of the material due to freezing
- limit the effect of reducing the bearing capacity of the pavement structure during thawing

In that case, the following technical measures are applied in practice:

- complete replacement of subgrade material - soil sensitive to the effect of frost with materials insensitive to freezing to the required depth, so that the effect of frost can only reach the materials insensitive to frost
- partial replacement of subgrade material - replacement of materials sensitive to the effect of frost with materials insensitive to freezing to a depth less than the depth of the effect of frost. The thickness of the pavement structure is determined depending on the frost index and the sensitivity of the subgrade material (Figure 1). In this case, it should be taken into account that the thickness of the structure determined in this way is valid only if it is greater than the thickness of the structure obtained from the load-bearing conditions. In the case of favourable hydrological conditions, the thickness of the structures shown in Figure 1 can be reduced by 10%. For concrete pavement structures and materials G3 or G4, the thickness can be reduced by 15%
- application of bonded layers - instead of replacing materials, it is possible to reduce the risk of a drop in the bearing capacity of the subgrade during thawing using hydraulic or bituminous bonded layers.
- thermal insulation – frost on the subgrade is prevented or reduced by installing thermal insulation materials, for example Expanded Polystyrene (EPS)

Figure 1: Partial replacement of subgrade material sensitive to the effects of frost



4 Pavement Foundation

The basic requirement for the development of a sustainable pavement design is the provision of realistic and comprehensive data on the bearing capacity of the soil as a base for the new pavement structure. The term carrying capacity also includes changes in carrying capacity during seasonal changes in temperature and hydrological conditions.

The bearing capacity represents the mechanical resistance of the pavement structure to the load. For the design of the pavement structure, it is extremely important to determine the bearing capacity of the subgrade and to define the requirements for the bearing capacity of the subgrade and bearing layers. During construction, it is necessary to control the load capacity, and during exploitation measure the load capacity of the pavement structure as a whole.

4.1 Subgrade bearing capacity

Subgrade is the final layer of an embankment or foundation soil up to 50 cm thick with a uniform load-bearing capacity, with special properties achieved by the application of appropriate construction and technical measures.

The bearing capacity of subgrade and foundation in the process of designing flexible pavement structures is most often determined by the value of the California Bearing Index (CBR), i.e. characteristic values of material deformability.

Table 11: Subgrade classification in relation to the CBR value

CBR (%)	Subgrade quality
2 – 5	very bad
5 – 8	bad
8 – 20	medium
20 – 30	good
30 - 100	very good

The CBR value can be determined by:

- direct measurement in the laboratory or in the field
- indirectly by means of correlation with the values of deformation modulus measurements
- assessment of the CBR value based on material characteristic (only in exceptional cases)

CBR values obtained by standard laboratory testing (SRPS U.B1.042) on samples prepared in the laboratory after soaking in water until saturation, for 4 days, are most often used for the design of pavement structures. To check the bearing capacity of existing pavement, for the purposes of monitoring or preparing a reconstruction project, a field CBR is also carried out. In this case, the test should be performed in the most unfavorable conditions of the subgrade (most often spring).

The CBR value represents the ratio between the load F required to drive a cylindrical piston with a circular cross-section of 20 cm^2 at a constant speed into the soil material to a depth of S1 (2.54 mm) or S2 (5.08 mm) and the standard load Fs required to drive the same piston at the same speed to the same depth into the standard material (mechanically compacted crushed stone mix).

$$CBR = F / F_s \ (\%)$$

Design value of CBR is a value less than or equal to 90% of the individual values tested on a homogeneous section with a minimum length of 500 m.

When designing pavement construction on roads with low traffic load, the estimated CBR values from Table 12 can be exceptionally used, depending on the type of material and hydrological conditions.

Table 12: Estimated CBR values

USCS soil classification	Material description	Volumetric mass in dry state γ_d (kg/m^3)	CBR (%)	
			Favorable hydrological conditions	Unfavorable hydrological conditions
GW	Well-graded gravels	2000–2250	30	30
GP	Poor-graded gravels	1750–2100	20	20
GM	Silty gravels	2100–2300	20	15
GC	Clayey gravels	1900–2250	7	5
SW	Well-graded sands or gravelly sands	1750–2100	15	15
SP	Poorly graded sands or gravelly sands	1650–1900	10	10
SM	Silty sands	1900–2150	10	7
SC	Clayey sands	1700–2100	5	3
ML	Inorganic silts and very fine sands	1600–1800	3	2
CL	Inorganic clays of low to medium plasticity	1600–1800	5	3

Additionaly CBR value is possible to optain from the results of other tests. Tests that measure the static and dynamic deformation modules (Ev2 and Evd), as well as the compressibility module (ME) are most often used for this.

The settlement of the soil as a homogeneous elastic isotropic half-space under the circular plate is defined by the following function:

$$s = \frac{\pi}{2} * (1 - \mu^2) * \frac{F+r}{E}$$

where is:

μ – Poisson's number
F – uniform vertical load
r – radius of the circular plate
E – modulus of elasticity of the material

Depending on the testing method, the characteristic values of soil deformation and built-in materials have the following form:

- Compression modulus

$$M_E = \frac{\Delta F}{\Delta s} * D \text{ (MN/m}^2\text{)}$$

- Static deformation modulus (strain modulus)

$$E_{vs} = 0.75 * \frac{\Delta F}{\Delta s} * D \text{ (MN/m}^2\text{)}$$

- Dynamic deformation modulus

$$E_{vd} = 1.5 * r * \frac{\sigma}{s} \quad \text{(MN/m}^2\text{)}$$

where is:

ΔF – difference between the two vertical load levels (MN/m2)
Δs – difference between the two settlements of the plate when load changes by ΔF (mm)
s – deflection caused by impulse load
D – diameter of circular plate (mm)
σ – normal stress under the circular plate loaded with the maximum force Fs

$$\sigma = \frac{Fs}{\pi + r^2} \quad \text{(MN/m2)}$$

Table 13 shows the approximate correlation of CBR and the basic parameters of soil bearing capacity and deformability.

Table 13: Approximate correlation of the basic parameters of bearing capacity and soil deformability

CBR (%)	Drformation module (German regulations) E_{v2} (MPa)		Compression modulus (Swiss regulations) (Mpa)	Resilient modulus (dynamic modulus) (MPa)		Dynamic deformation modulus E_{vd} (Mpa)
	Coherent soil	Noncoherent soil	M_s	M_R (AI)	M_R (TRL)	k
3	15	-	4	31	36	-
5	20	-	8	52	49	10
7	(30)	45	13	72	61	20
10	-	60	20	103	77	25
15	-	80	35	155	100	35
20	-	100	50	207	120	45

Note: values are indicative

The resilient modulus are calculated from the expression :

M_R = 10,342 CBR Asphalt Institute (AI)
$M_R = 17{,}61 \times CBR^{0{,}64}$ Transportation Research Laboratory (TRL)

The bearing capacity of the subgrade and road foundation in the process of design rigid pavement structures is the most often determined by the value of the modulus of soil reaction - k. Due to the complexity of the test, for roads with medium and low traffic loads, the soil reaction modulus is usualy determined from the correlation with the values of deformation modules and CBR measurements. Table 14 shows the estimated values of soil reaction modulus depending on the material and hydrological conditions.

Table 14: Estimated values of soil reaction modulus

USCS soil classification	Material description	Volumetric mass in dry state γ_d (kg/m^3)	k (MN/m3)	
			Favorable hydrological conditions	Unfavorable hydrological conditions
GW	Well-graded gravels	2000–2250	90	90
GP	Poor-graded gravels	1750–2100	70	70
GM	Silty gravels	2100–2300	70	60
GC	Clayey gravels	1900–2250	40	30
SW	Well-graded sands or gravelly sands	1750–2100	60	60
SP	Poorly graded sands or gravelly sands	1650–1900	50	50
SM	Silty sands	1900–2150	50	40
SC	Clayey sands	1700–2100	30	20
ML	Inorganic silts and very fine sands	1600–1800	20	15
CL	Inorganic clays of low to medium plasticity	1600–1800	30	20

4.2 Quality of subgrade materials

According to SPRS U.E8.010, all types of materials that meet the conditions listed in Table 15 can be used for subgrade construction.

Table 15: Requirements for the quality of subgrade materials

Characteristic	value or range
Maximum volumetric mass standard Proctor's test	≥1,6 t/m^3
Liquid Limit LL	<50% (<35%)*
Plasticity index I_P	<20 (<12)*
Coefficient of unevenness Cu=D60/D10	>9 (>6)*
CBR bearing capacity	>3%
CBR swelling	<3%
Content of organic materials	<6%

*) Recommendation SRCS - Technical conditions for road construction in the Republic of Serbia - Requirements for the quality of subgrade materials

The criteria listed in Table 16 are used to assess the quality of build-up subgrade.

Table 16: Criteria for assessing subgrade quality

Material	Criteria		
	Compaction (%)	Compression modulus M_s (N/mm^2)	Deformation modulus E_{v2} (N/mm^2)
Fine-grained coherent material and fine-grained sand	100	20	30 (20)*
Mixed stone and soil (clay gravel, clay rubble, marl, clay shale, etc.)	100	30	45 (40)*
Stone material (crushed stone, gravel, etc.)	100	40	60 (80)*

*) Recommendation SRCS - Technical conditions for road construction in the Republic of Serbia - Requirements for the quality of subgrade materials

4.3 Subgrade testing (field and laboratory)

Assesment of the bearing capacity of pavement subgrade is carried out by testing the soil in laboratory conditions or in the field. Before starting the test, it is necessary to carry out a program of investigative works, which must be based on the analysis of local conditions, the applicability of certain tests and the availability of appropriate testing equipment.

In general, the methods of testing the road foundation and pavement subgrade can be divided into:

Laboratory methods:

- laboratory CBR test (SRPS U.B1.042)
- resilient modulus MR (AASHTO T 307) - for mechanistic-empirical design procedure (MEPDG)

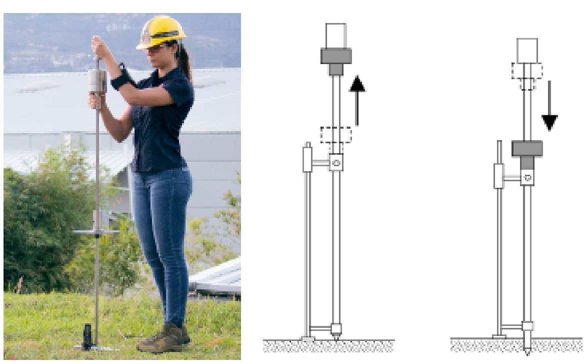
Field methods:

- field CBR
- plate test
  - modulus of compressibility (Swiss method) - SRPS U.B1.046/1968
  - deformation modulus (German method) - SRPS U.B1.047/1997
  - dynamic deformation module (light deflectometer)
  - subgrade reaction modulus K (for rigid pavements)
- dynamic cone penetrometer DCP (Dynamic Cone Penetrometer)
- nuclear probe (Troxler)

The procedure, depending on the test method, is described in detail in the corresponding standards.

For local roads with low traffic load, test method with dynamic cone penetrometer (DCP) is very applicable for testing the soil as a base for pavement construction.

Figure 2: Dynamic cone penetrometer



DCP is a simple device used for field testing of soil characteristics and aggregate layers. Unlike the plate test, it does not require a counter load, so it is easy to perform test. The test result gives a continuous strength profile throughout the tested depth. Numerous correlations can be found in the literature between DCP and CBR, resilient modulus and plate static load test values that should be used with due care depending on the material characteristics. This note applies in particular to the natural moisture of the soil during the test and the granulometric composition, the variations of which can affect the test result. The DCP test mostly will not provide adequate data for project purposes if it is conducted during a period with lower soil moisture than the critical moisture that usually occurs in the spring.

Regardless of certain risks, this method, due to its easy application, remains one of the basic methods for determining the bearing capacity of granular layers and road foundation with light traffic loads.

To check the bearing capacity of the subgrade and the subbase layers of the pavement structure, instead of standard tests with a circular plate, which are time-consuming and expensive because it is necessary to provide a counterweight (most often a heavy vehicle), it can be done by measuring the dynamic deformation modulus with a low-weight deflectometer (Low Drop Weight Tester - LDWT).

A light-weight deflectometer allows determination of the bearing capacity of soil and unbound layers at individual points, similar to a slab load test. The measurement results are immediately available, so the device is particularly suitable as an alternative for compaction control with intensive measurement point coverage. Various application possibilities, low cost per trial and direct availability of results make this device particularly suitable for testing the quality of performed works on local roads.

The conditional correlation of E_{v2}, E_{vd} and CBR based on test data in laboratory conditions, with optimal material characteristics (optimal validity), is given by the following expressions:

$$E_{v2} = 2 * E_{vd}$$

$$CBR_d = 24.26 * p/s^{0.59}$$

where is:

Evd – dynamic deformation modulus (MN/m2)
Ev2 – static deformation modulus (MN/m2)
CBRd – "dynamic" CBR (%)
s – measured deflection (mm)
p – impulse load (N/mm2)

Note: In practical application, it is necessary to check correlations for specific conditions and material.

Figure 3 : Correlation between E_{v2}, E_{vd} and CBR

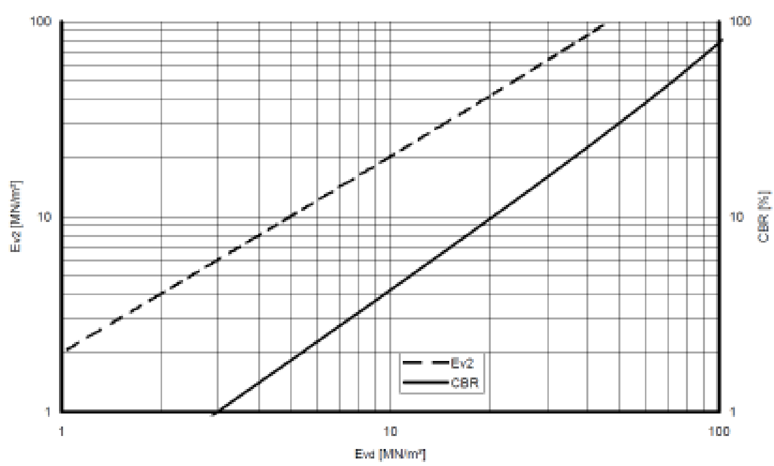


Figure 4 ︰ Light weight deflectometer (Low Drop Weight Tester – LDWT)

4.4 Measures to improve subgrade mechanical characteristics

If the subgrade of the pavement structure does not meet the conditions for achieving and sustaining the designed performance, it is necessary to improve the mechanical characteristics of the ground of the road foundation, primarily to improve the bearing capacity by modifying the material in the subgrade. Material replacement can be applied in the case of sustainability of that solution, i.e. if the thickness of the soil layer, which is replaced by material with a higher load capacity, is limited and if economic justification is proven. In some cases, adequate measures to improve the drainage of the subgrade can significantly contribute to the improvement of the mechanical characteristics of the soil and remove the need for the application of other measures. Also, constraints in the road geometry can limit the levels of intervention and dictate certain solutions.

The application of measures to improve the mechanical characteristics of the road foundation is considered in the event that:

• soil is sensitive to frost in critical climatic and hydrological conditions

• expansive soil / soil subject to swelling in critical hydrological conditions

• weak bearing / collapsible soil

• high level of underground water

Figure 5: The process of selecting a solution to eliminate/reduce the impact of problematic soil on the performance of the pavement structure

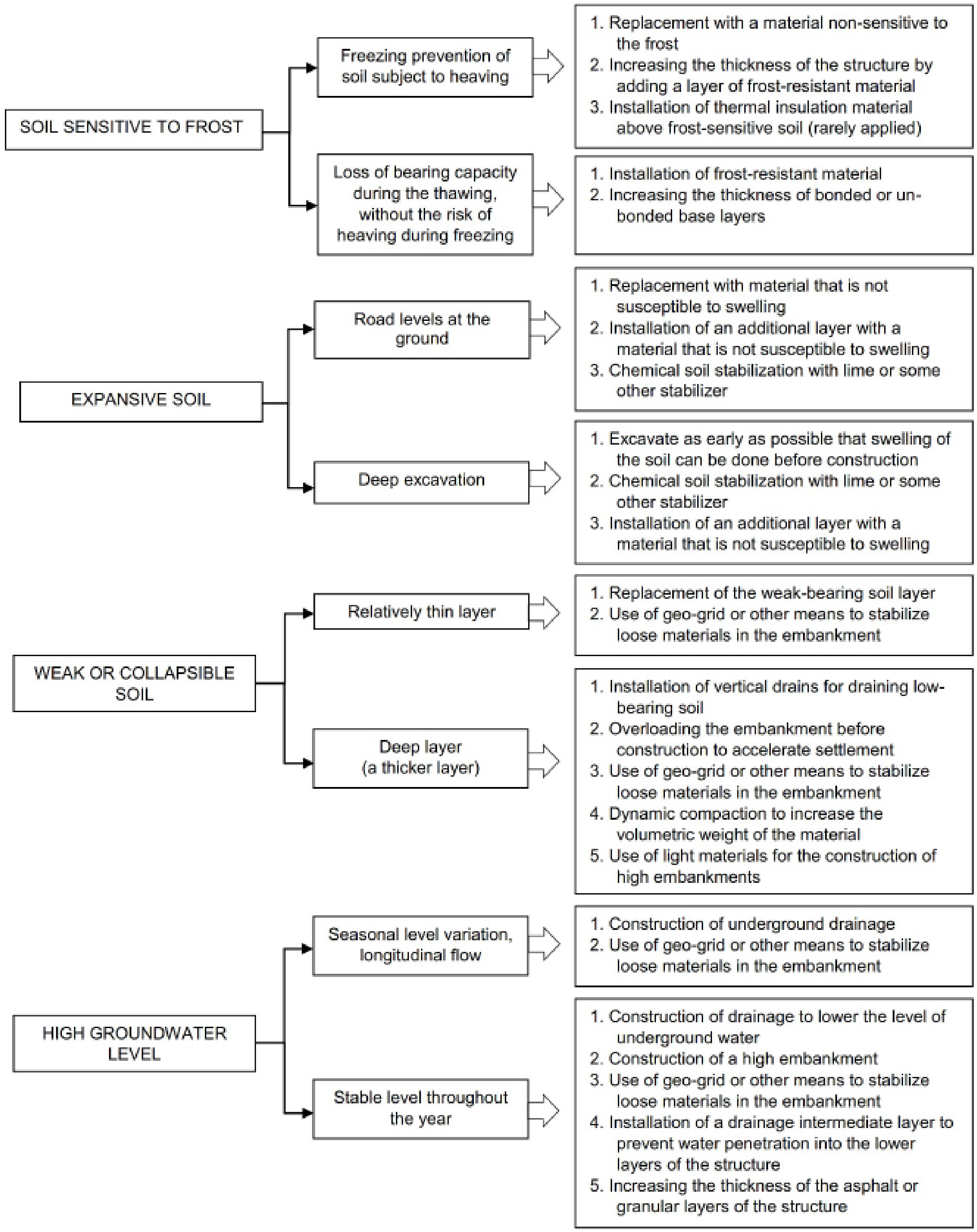


Table 17: Minimum bearing capacity of the subgrade

Country	subgrade bearing capacity	document
Serbia	CBR ≥ 3%	SPRS U.E8.010
Germany	$E_{v2} \geq 45$ MN/m^2	RStO 12
Austrija	$E_{v1} \geq 35$ MN/m^2	RVS 03.08.63

If the sugrade does not have a satisfactory bearing capacity, its stabilization or replacement can be applied.

Subgrade stabilization covers a wide spectrum of inteventions and in the context of the materials found in the subgrade and non-bonded layers, several types of interventions are available:

- Mechanical stabilization – additional compaction
- Physical stabilization – mixing the existing material with a certain percentage (30%) of crushed aggregate
- Chemical stabilization – stabilization with a hydraulic binder
    - Lime - primarily for stabilizing the subgrade made of coherent soil (clay)
    - Cement – for non-coherent materials
    - Mixture of cement and lime - collapsible soils with specious high strengths - loess

Complete replacement of material, as the most drastic type of intervention, represents the replacement of material in the subgrade in a certain thickness in order to achieve the required load capacity. Most often, material replacement is carried out in thicknesses from 20 cm to 50 cm, non-bonded materials, nominal grains up to 100 mm.

4.5 Subgrade bearing capacity of local roads

The bearing capacity of the subgrade and its sustainability are extremely important for the design, construction and exploitation of roads. Bearing in mind that on local roads, smaller thicknesses of upper pavement layers are usually designed, this emphasizes even more the importance of ensuring the bearing capacity of the subgrade for these roads.

The structure of the pavement structure, and especially the thickness and quality of the designed layers, depend to a large extent on the bearing capacity of the subgrade. A soil with a lower load-bearing capacity requires a thicker pavement construction and vice versa. If the bearing capacity of the subgrade is underestimated, it will result in an oversized pavement structure, and in case the bearing capacity of the subgrade is overestimated, the consequence will be structural distress to the structure before the end of its designed life.

The recommendation that during the construction of new roads one should attempt to increase the bearing capacity of the subgrade as much as possible, within local conditions, because in the long term it is much more profitable compared to increasing the thickness or quality of the upper pavement layers, also applies in the case of local roads.

When the load-bearing capacity of the subgrade is low or problematic, it is necessary to consider replacing the weakly load-bearing soil, if the thickness of this layer is less than 1.5 m. Although the costs of transporting materials should be limited during the construction of local roads, in the case of replacement of low-bearing soil with material of higher bearing capacity (CBR >15% in high humidity conditions), significant savings in the costs of making the upper layers of the structure can be achieved. An alternative solution is the application of mechanical, physical or chemical soil stabilization.

5 Pavement Materials

The choice of type and quality of materials for the construction of pavement layers is influenced by a number of factors, among others, local conditions, traffic load, functional requirements, position of materials in the construction structure, availability of a certain type of material, economy of application.

Mixtures of crushed stone aggregates and mixtures of natural or mixed stone aggregates are used for the production of unbound bearing layers. The application of a mixture of natural stone aggregate is limited to bearing layers in pavement constructions for lighter traffic loads.

Mixtures of crushed stone aggregate are mainly used for the production of bonded layers of pavement construction. Natural or mixed stone aggregates can also be used in cement-concrete mixtures, and asphalt granulate can be used in appropriate amounts in the composition of materials for bound asphalt layers. The bituminous and/or cement binder for the designed bonded layers in pavement constructions should be adapted to traffic loads and climate conditions.

5.1 Binders

The binder is an active component of the mixture with the role of binding and stabilizing granules of the mineral mixture that it forms a monolithic unit with appropriate physical and mechanical characteristics.

Two groups of binders are used for the production of modern pavement constructions:

- Bituminous and
- Hydraulic

The most commonly applicable types of bituminous binder are:

- Bitumen – it is used as the most common binder in asphalt layers of pavement construction (asphalt-concrete, bitumen base layer, mastic asphalt...). Classification into types according to the depth of penetration. Characteristics according to SRPS EN12591
- Modified bitumen - in order to improve rheological characteristics, especially thermostability (increasing resistance to rutting, cracking at low temperatures, fatigue resistance), bitumen is modified by adding modifiers (elastomers, plastomers, antioxidants, natural asphalts...). It is used in asphalt layers exposed to heavy traffic (asphalt-concrete, stone mastix asphalt-SMA, mastic asphalt, drainage asphalt...) and harsh climatic conditions. Classification into types according to penetration depth and softening point. Characteristics according to SRPS EN 14023
- Cutback bitumen – bitumen with an instantly reduced viscosity with the addition of thinning agents (petroleum derivatives) that evaporate after incorporation. It is used for spraying the base to improve the bond between the layers, making cold asphalt mixtures of open and closed type and surface treatment. Characteristics according to SRPS EN 15322
- Bitumen emulsions – a dispersion system composed of a bituminous binder dispersed in the form of small particles in water containing a suitable emulsifying agent. Bitumen emulsions can be divided by type into anionic and cationic, according to the time of decomposition into unstable, semi-stable and stable and according to the type of bitumen into ordinary bitumen or polymer modified bitumen (PmB KN ..). Application for spraying the base, surface treatment, production of asphalt cold mixes, cold recycling, stabilization of the subgrade, slurry seal ..). Characteristics according to SRPS U.M3.022 Anionic Bituminous Emulsion and SRPS EN 13808 Framework for Creating Specifications for Cationic Bitumen Emulsions

- Foamed bitumen - obtained by injecting a small amount of cold water (~2%) into hot bitumen with a penetration of 80 to 200. During this process, a sudden expansion of the volume of bitumen occurs and foam is created, which is sprayed with special nozzles during the installation phase of the bituminized layer using special machinery . It is most often used for the production of stabilized base layers using the cold recycling process.

For the purposes of dimensioning the asphalt layers of the pavement structure, the bitumen stiffness modulus can be calculated from the following expression (Shell – Van der Poel):

$$S_{bit} = 1{,}157 \times 10^{-7} \times t_w^{-0{,}368} \times e^{-IP} \times (T_{800} - T)^5$$

where is:

S_{bit} – bitumen stifness modulus (MPa)
t_w – duration of load (t_w=0,02 sec for v=50-60 km/h)
T_{800} – the temperature at which penetration is 800pen°(1 pen° = 0,1 mm), corresponds approximately to T_{PK}
T – relevant temperatures for dimensioning the pavement structure
pen_{25}° – penetration of aged binder (~ 65% penetration of original binder)

$$IP = \frac{1951{,}55 - 500 \cdot \log(pen_{25}^{o}) - 20 \cdot T_{pk}}{50 \cdot \log(pen_{25}^{o}) - T_{pk} - 120{,}15}$$

The penetration index (IP) is an indicator of the bitumen's sensitivity to temperature changes. The higher the IP, the less sensitive the bitumen is to temperature changes. (standard bitumen IP -1.5 to +0.7, PmB IP>4)

Hydraulic binders (Portland cement, Lafarge cement, hydraulic lime, etc.) are mainly used for construction rigid pavements (road with concrete slabs) and for making stabilizations. In order to prevent the appearance of cracks when applying stabilization in constructions with flexible upper layers, it is necessary to limit the strength of the layers made with cement as a binder.

The basic properties of cement for concrete mixtures are specified in SRPS EN 197-1.

CEM I (Portland cement) strength class 32.5 is particularly suitable for cement concrete mixtures. For cement stabilization CEM II/B-P or CEM II/B-S (2 - 6 % cement in the mixture).

For cements used for cement concrete, the start of setting at 20°C is limited to less than 1 hour, the start of setting at 30°C is limited to less than 45 minutes, and the end of setting is limited to 10 hours.

5.2 Stone Aggregates

In the Republic of Serbia, there are two types of natural stone aggregate used in road construction, primarily according to origin:

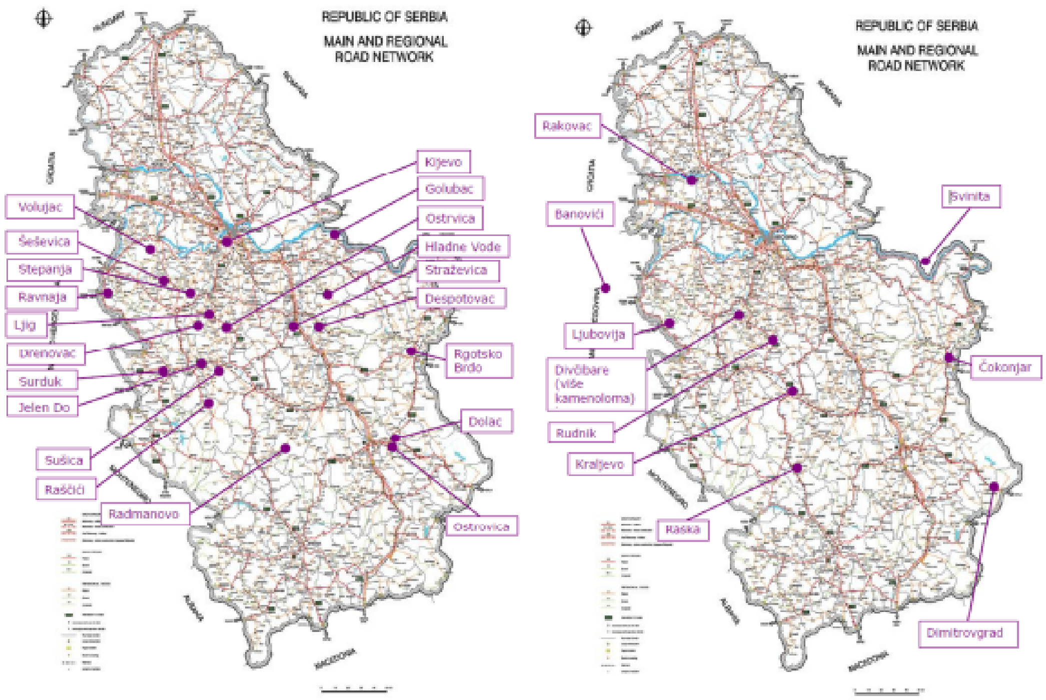
Eruptive (Magmatic) that are formed by cooling magma, silicate composition. Among the characteristic ones present on the market are: diabases, dacites, andesites. The main characteristic of these stone aggregates is their exceptional resistance to wear and, accordingly, they are mainly used for pavement wearing layers.

Sedimentary (carbonates) that are formed by the consolidation of sedimentary materials that have hardened from the pressure of the masses above the layers due to the presence of silicate or carbonate minerals, carbonate composition. Among the characteristic ones present on the market are: limestones, dolomites. Due to the good reaction to bitumen, and due to less wear resistance, they are used in base and wearing layers, when the level of service does not require higher criteria for traffic flow.

Quarries of stone material are spread mainly in the western territory of Serbia. The quality of the stone material tested and determined so far varies, especially due to inadequately applied control of production in quarries. The standard quality of eruptive material is especially critical, which often leads to the occurrence of distress in the road exploitation before the end of the design life, i.e. preventive measures in roadway maintenance.

Figure 6: Querries of stone materials in the Republic of Serbia

Querries of stone of carbonate origin Querries of stone of eruptive origin



Sorce: Prof. G. Mladenovic – Pavement structures, Faculty of Civil Engineering, Belgrade

Mineral material - stone aggregate by origin and geometric characteristics is divided into:

- Sand - natural or crushed, 0.09 (0.063) - 2 mm
- Course aggregate - crushed stone aggregate 2 - 63 mm, obtained by crushing rock, rubble or gravel, separated into fractions
- Crushed stone - naturally crushed rock mass with angular grain
- Gravel - natural stone aggregate with a rounded shape, grain size 2 - 63 mm

The basic fractions of stone aggregate are:

- 0/4 mm
- 4/8 mm
- 8/16 mm
- 16/32 mm (16/31.5)
- 32/63 mm (31.5/63)
- 63/125 mm

The most common application according to the type of aggregate:

- Silicate origin aggregates (of eruptive origin)
    - They can be used in all asphalt mixtures and all categories of roads (due to the high price, they are mainly used for wearing layers)
- Carbonate origin aggregates
    - For wearing course - medium, light and very light traffic load
    - For base layers
- Gravel
    - For base layers - medium (with 30% crushed stone), light and very light traffic load

Mineral material - aggregate, which is used for the construction of pavement structures must meet the criteria specified in the Rulebook on technical requirements for fractionated aggregate for concrete and asphalt ("Official Gazette of RS", no. 78/2020) and the SRPS EN 13043/2007 standard .

The quality of the rock used for the production of aggregates, the resistance of the aggregates to crushing and water absorption have a special influence on the durability and functional properties of the pavement structure, so the following tables list the requirements in relation to these characteristics.

Technical requirements for rock for the production of aggregates to be used in asphalt mixtures for wearing course and base layers

Table 18 : Technical requirements for rock for the production of aggregates to be used in asphalt mixtures for wearing course and base course

no.	Characteristic	Technical requirements for the traffic load group		
		Highway, very heavy and heavy	Medium	Light and very light
1.	Dry compressive strength	Min 160 MPa	Min 140 MPa	Min 120 MPa
2.	Water absorbing	Max 0,75%	Max 0,75%	Max 1,00%
3.	Wear	Max 12 cm³/50 cm²	Max 18 cm³/50 cm²	Max 35 cm³/50 cm²
4.	Frost resistance	Max 5%	Max 5%	Max 5%

Table 19: Crushing resistance requirements for natural aggregate to be used in asphalt mixtures for the lower and upper bearing layers of pavement structures

Traffic load	„ Los Angeles", %	
	Upper bearing layers	Lower bearing layers
Very heavy and Highway – section with binding course – section without binding course	max. 28 max. 25	max. 40
Heavy	max. 28	
Medium	max. 30	
Light and very light	max. 35[a)]	
[a)] for wearing/bider course maximum „Los Angeles" is 28%		

Table 20: Crushing resistance requirements for crushed aggregate to be used in asphalt mixtures for wearing course

Traffic load	„ Los Angeles", %	
	eruptive and/or metamorphic origin, and silicate composition	sedimentary and/or metamorphic origin, and carbonate composition
Very heavy and Highway	max. 16	–
Heavy	max. 18	–
Medium	max. 22	max. 25
Light	max. 22	max. 28
Very light	max. 22	max. 30

In the case of the 4/8 mm natural aggregate fraction, which is used for the production of asphalt mixtures for the bearing layers of road constructions, water absorption must not exceed 1.2%, except in the case that the aggregate is resistant to frost.

In the case of the 4/8 mm fraction of natural aggregate, which is used for the production of asphalt mixtures for wearing and binder course, water absorption must not exceed 1.6%.

The water absorption of the aggregate fraction is determined in accordance with SRPS ISO 6783 and SRPS ISO 7033 on the 4-8 mm aggregate fraction.

5.3 Recicled Materials

In addition to the increasing use of recycled materials in the construction of roads of all categories, the use of recycled materials is of particular importance in the construction of local roads. The use of recycled bricks, concrete, and asphalt has been in general use in the countries of the European Union for years. The use of suitable recycled materials achieves the required structural and functional characteristics of the pavement construction where this material is installed, and at the same time significant material savings and positive environmental protection effects are achieved (avoidance of depositing construction waste and less exploitation of natural resources).

On local roads with low and very low traffic load, it is possible to build a pavement structure with the participation of recycled material up to 50%.

Manufactured or recycled aggregates that are used for production concrete and/or asphalt mixtures must meet the technical requirements established by:

- standard SRPS EN 12620:2010 - Aggregates for concrete, for use as an ingredient for production concrete;
- standard SRPS EN 13043:2007 - Aggregates for bituminous mixtures and surface treatment of roadways, airports and other traffic surfaces, for use as an ingredient for bituminous mixtures and surface treatment of road pavements, airports and other traffic surfaces

For all raw materials for the production of manufactured and recycled aggregates, information related to the prevention of adverse effects on human health and the environment must be additionally provided, in accordance with the regulations governing waste management.

5.4 Material selection for the construction of local roads

The use of locally available materials should be a basic requirement when designing a local road and during its construction.

When choosing a local source of material, special attention should be paid to:

- material location, quality and quantity
- uniformity of quality
- material characteristics
- usability
- workability;
- quality control;
- impacts of exploitation on the environment

The shortage of suitable local materials can be overcome by:

- Adapting the technical specifications and design of the pavement structure of the road, in order to match the local materials; or
- Adapting or modifying local materials to suit technical specifications.

Materials for the structural layers of local roads usually consist of gravel from a local quarry or materials that have been transported by some natural force (eg water, wind, gravity). The use of expensive aggregate obtained by crushing stone for the construction of bearing layers of local roads with low traffic load should be minimized. Such materials are usually used exclusively for wearing asphalt course or concrete structures with high strength requirements.

The advantages of using locally available materials come from:

- decreasing transport costs
- less distress to existing roads due to transportation of materials
- stimulation of the local economy and local companies
- creating road projects compatible with local maintenance possibilities
- reduced costs of road exploitation

Standard technical specifications tend to limit the use of many locally sourced materials in favor of more expensive crushed stone or other processed materials. However, research shows that "non-standard" materials can often be used successfully and cost-effectively in the construction of local roads with light traffic loads provided appropriate precautions are taken. These precautions include effective drainage of the pavement structure, good construction practice and regular maintenance.

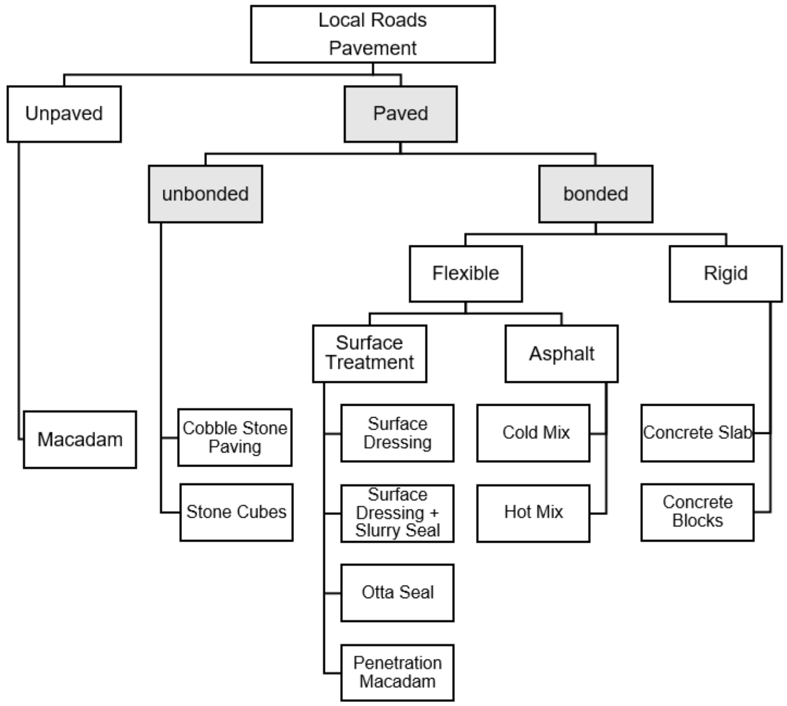
6 Pavement Construction Types

For local roads, there is a wide range of application of pavement construction types. Each type has its advantages and disadvantages depending on the specific circumstances in which it will be used. The choice of pavement construction type is usually made based on local climatic conditions, traffic load, availability of local materials, contractor's equipment and financing possibilities. In addition to the mentioned criteria, sometimes other criteria have a significant influence, such as the possibility of phased execution, environmental impacts, etc.

Within this chapter, the basic characteristics of the most commonly applied types of pavement structures on local roads are given. The basic classification was made into unpaved roads and paved roads. Today, local unpaved roads are very rarely built, so only a macadam road is shown as a typical example of a unpaved road. From the aspect of exploitation characteristics and traffic safety, unpaved roads without can exist only as a temporary solution.

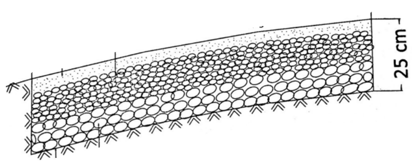
Paved roads are divided into roads where the material in the pavement is not bonded and roads where some type of binder has been applied to stabilize the material in the pavement. The binder can be bitumen-based, in which case it is flexible pavement type, or cement-based for rigid pavements type.

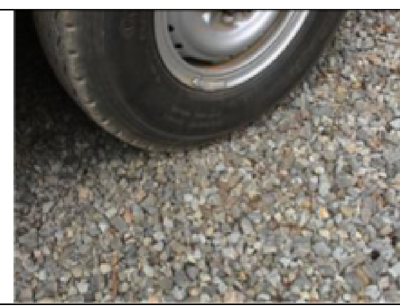
Figure 7: Types of pavement construction on local roads



6.1 Unpaved Roads

Macadam



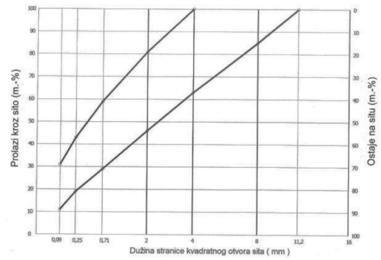


General Description

Although back in 1820, John MacAdam first applied then revolutionary method of road construction with multiple layers of unbound stone aggregate, this construction method of building roads is still used today with minor or major modifications. The structure is usually three-layered with a total thickness depending on the bearing capacity of the soil, traffic load and climatic conditions, usually around 25 cm. A layer of stone with a maximum grain size of up to 50 mm, usually 10 cm thick, is first laid on the subgrade, and over it a layer of crushed stone with a maximum grain size of up to 36 mm, usually 10 cm thick. The top is made of clean crushed aggregate of size 10-20 mm, which is mechanically stabilized by interlocking the grains. For better locking and connection of the grains, the layer is subsequently filled with fine granules moistened with water. On the top of the unbounded surface layer, the required min. value of the deformation modulus is $E_{v2} \geq 100$ MN/m^2 ($E_{vd} \geq 45$ MN/m^2).
Macadam is suitable for use on roads with low traffic volumes and low speeds; where there is a need to avoid dust problems. However, it is not recommended to use it where bicycle or motorcycle traffic is common due to the unstable surface.

Key Resource Requirements

Separated coarse stone aggregate of appropriate strength. Mechanized crushing and screening at the source of the stone material. Transportation by truck and mechanical spreading and rolling with a light roller. For shorter sections, spreading with communal equipment is possible. Local semi-skilled and unskilled labor to work on site.



Granulometric composition of aggregates 0/8 mm for sealing and strengthening unbound wearing layer

Principal Advantages

- Does not require expensive equipment and qualified personnel for construction.
- Significantly reduced occurrence of dust compared to the untreated roads
- There is no retention of water on the road surface because it is drained through the layers of the structure via the appropriate transverse slope (min. 2.5%)Loss of stone from the surface is usually small.
- Easy to maintain with occasional reshaping and addition of stone material.

Principal Concerns

- Only suitable for light traffic.
- Requires quality stone. The grain shape is angular, not rounded.
- Not suitable for bicycles and motorcycles or fast traffic, due to unstable surface and risk of accidents.
- Not suitable for medium or high speed traffic due to risk of flying stones and stability.
- Not suitable on steep slopes.
- Not suitable directly over moisture sensitive subgrade, such as expansive clay. Since the layers of the structure are water-permeable, this can lead to a drop in bearing capacity and deformation of the subgrade in the case of soils sensitive to increased moisture.
- In dry periods, noticable occurrence of dust

6.2 Unbound Pavement

Cobble Stone Paving	

General Description

Irregular cobble
stones consist of a layer of irregular, roughly cube-shaped stone about 100-120 mm thick, laid on a base of sand or fine aggregate 50-100 mm thick. Individual stones should have at least one face that is smooth and flat that is placed flush with the surface of the pavement. Coarse sand is inserted into the spaces between the stones. When a sufficient area of stones has been placed, the layer is compacted with a vibrating or non-vibrating roller. Additional sand is added to the surface if necessary. A curb or curb made of (for example) stone or concrete improves durability.

Key Resource Requirements

A durable and crushed stone made of hard and tough rock with at least one bright face used on the face of the pavement. Uniaxial wet crushing strength min. 75 Mpa. Medium to coarse sand or fine aggregate.
Skilled and unskilled workforce; heavy non-vibrating or vibrating roller.

Principal Advantages:

- Does not require expensive equipment to build or maintain.

• Suitable for construction by small contractors or in remote areas with access problems for crushing equipment or heavy plant. • Can be constructed on any slope. • Easy maintenance, easy to repair. • Can be upgraded later by using a thin regulation layer and a suitable bituminous seal in the construction phase strategy.
Principal Concerns: • Only suitable for light traffic loads and low speeds. • Requires strong stone to be available locally. • Requires skill in laying to achieve a smooth finish. • Not suitable for moisture-sensitive subgrade in areas with moderate to heavy rainfall. • Smooth to medium surface roughness. • Stones prone to polishing under traffic or slippery when wet should not be used.

Stone Cube	

General Description
A stone cube pavement consists of a layer of cube-shaped stone approximately 80 - 100 mm in size laid on a thin layer of sand (20 - 50 mm). Cubes are produced by mechanical processing of suitable hard stone such as granite or basalt. The space between the cubes is filled with sand, and the entire pavement is compacted using a vibrating plate or a light roller. For the stability of the structure, it is necessary to make a curb next to the road shoulder, which can also be made of stone or concrete. To improve durability and prevent water penetration to the lower layers of the structure and bedding, the space between the stone blocks (joints) can be filled with cement mortar. The stone cubes is usually laid over the lower bearing layers made of unbound mineral material.

Key Resource Requirements:
A hard and durable sound stone that can be cut into an almost cube shape. Uniaxial wet crushing strength min. 75 Mpa. Medium to coarse sand as a subbase and joint filler.
Skilled and unskilled workforce; vibrating plate or lighter roller.

Principal Advantages:
- Suitable for all climatic conditions and for light to medium traffic loads in rural and urban areas.
- Does not require heavy compaction equipment or any other expensive construction or maintenance equipment.
- Suitable for construction by small contractors, or in remote areas with difficult access to crushing equipment or heavy plant.
- Can be constructed on any slope.
- Minimal maintenance required, easy to repair.
- High residual value; the materials can be recycled into other types of paving or covered with another surface.
- Erosion resistant, durable.

Principal Concerns:
- Requires the use of quality stone, preferably from local sources.
- The stone must be suitable for forming a stone cube.
- Requires skill in stonework and laying to achieve a smooth finish.
- Not suitable for moisture sensitive sub-base/sub-grade in moderate to high rainfall areas unless cement mortar is used as joint filler.
- Smooth to medium surface roughness.
- Stone subject to polishing due to traffic or slippery when wet should not be used.

6.3 Flexible Pavement

Surface Dressing

General Description

Although in Serbia, surface dressing is mostly used as a measure of preventive maintenance, it can also be used to create pavement for local roads with very low traffic. The surface dressing primarily acts as a waterproof membrane and driving surface created by applying a layer of bituminous emulsion binder on which a layer of stone chips with a grain diameter of no more than 25 mm is sprinkled and gently rolled onto the previously prepared base.
Double surface dressing is most often used for construction local road pavements by means of a double application. The first layer is usually with 14-19 mm fine stone, and the second layer with 6-10 mm fine stone. For environmental and safety reasons, it is recommended to use bitumen emulsion, which contains bitumen dispersed in water.

Key Resource Requirements

Requires the application of aggregates of uniform gradation, suitable shape with adequate bitumen adhesion properties. The binder is usually a quick setting unstabile bituminous emulsion.

Approximate values of the amount of binder and aggregate for single surface dressing

average annual daily number of vehicles	Aggregate size [mm]	Amount of aggregate [kg/m^3]	Amount of binder [lit/m^2]	Binder type
2000 - 4000	19.0 - 9.5	21.7 - 27.1	1.58 - 2.03	Bitumen
			1.81 - 2.26	A-RS, C-RS
1000 - 2000	12.5 - 4.75	13.6 - 16.3	1.58 - 2.03	Bitumen
			1.81 - 2.26	A-RS, C-RS
200 - 1000	9.5 - 2.36	10.9 - 13.6	1.58 - 2.03	Bitumen
			1.81 - 2.26	A-RS, C-RS
20 - 200	6.3 - 1.18	8.1 - 10.9	1.58 - 2.03	A-RS, C-MS
			1.81 - 2.26	C-RS, C-MS
< 20	Sand	5.4 - 8.1	1.58 - 2.03	A-RS, C-MS
			1.81 - 2.26	C-RS, C-MS

Multiple surface dressing consists of a series of single surface dressings with the same nominal grain sizes per layer. However, it is more common for the top layer to be made of aggregate whose grain size is twice as small as that of the bottom layer. The most commonly used multiple surface dressing is the double surface dressing. The thickness of the layers is from 16 mm to 19 mm, and the lifetime of the multiple surface tdressing is about 3 times longer than the single surface dressing, while the costs are 1.5 times higher. In double surface dressing, the second layer fills the voids on the surface of the first layer of aggregate. The filling of the voids of the layer represents the texture of the surface dressing.
The binder is applied using a trailed/self-propelled spreader. Stone fines are applied with a spreader - a self-propelled vehicle on which there is a basket for loading aggregates, a conveyor belt from the loading basket to the basket above the spreading device and the spreading device. After spreading, the surface is compacted with a light static roller,

preferably with tires.

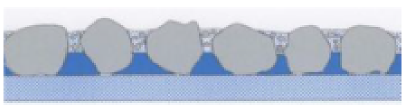
Principal Advantages:

- Proven performance in all climates, suitable for rural and urban environments.
- Suitable for low traffic volumes
- Construction does not require expensive equipment.
- Suitable for construction by small contractors.
- Easier quality control compared to hot bitumen pavements.

Principal Concerns:

- The surface dressing does not increase the bearing capacity of the structure, so it is necessary that the layers under the surface treatment provide the required load capacity.
- Requires the application of stone aggregate of appropriate granulation and grain shape.
- The emulsion (anionic or cationic) should be compatible with the type of stone material.
- Special attention is needed to control the amount of binder and aggregate application.

Surface Dressing + Slurry Seal



General Description

Surface Dressing & Slurry Seal is a multiple surface treatment consisting of the application of one layer of surface dressing over which a single or double bituminous suspension seal (Slurry Seal) is applied. Usually, surface dressing with stone fineness up to 13 mm is done with one application of bitumen spraying, and in the case of surface dressing with stone fineness up to 19 mm with double bitumen spraying. When finished the tops of the stone chips are just exposed above the mass that fills the interstices between the stones.
Bituminous suspension (Slurry Seal) is a mixture of fine aggregate of good quality, bitumen emulsion, filler (usually Portland cement) and additional water. It is mixed in a concrete mixer or dedicated equipment, and applied to a pre-prepared surface using special equipment. When freshly mixed, the sealant can be applied to a thickness of 1.5 – 5 mm. After application, the water in the emulsion separates from the emulsion and evaporates, leaving the remaining bitumen in place to adhere to the pavement surface and aggregates.

Key Resource Requirements

Stone chips and classified, fine aggregate, of appropriate shape with adequate bitumen adhesion properties and fast setting (RS) bitumen emulsion, cement or lime filler, water. Emulsion mixing and spreading equipment or concrete mixer, wheelbarrow and hand spreading tool. For compaction roller with pneumatic tires is required. Skilled and semi-skilled workforce.

Principal Advantages:

- Proven performance in all climates, suitable for rural and urban locations.
- Construction does not require expensive equipment.
- Suitable for construction by small contractors or community groups.
- Easier quality control than with hot bitumen.
- Safer for construction and maintenance personnel than hot bitumen.
- Simple and cheap maintenance.

Principal Concerns:

- Only suitable for low to medium traffic load
- Requires proper emulsion sources.
- Requires the use of high-quality stone aggregate - stone chips
- The emulsion (anionic or cationic) should be compatible with the materials.
- The emulsion should harden after application and before opening to traffic.

OTTA Seal

General Description

Otta Seal consists of a relatively thick layer of bituminous binder into which the aggregate is embedded using a roller with heavy pneumatic tires or loaded trucks. Compared to single-fraction stone fill material used in surface treatments, graded gravel or crushed aggregate is used. The quality of the resulting layer depends on whether the binder is sufficiently pushed through the aggregate by the action of extensive rolling with rollers with pneumatic tires during construction and later under traffic. Variants with one or two layers can be used, depending on the traffic load of the road.

After applying the binder, intensive rolling should continue for the next two days in order to cover all aggregate grains with the binder. If it is constructed in two layers, 8-12 weeks must pass between layers.

Key Resource Requirements

Separated natural or processed fine aggregate. Soft bitumen (MC3000 cut-back-thinner kerosene or 150/200 degree of penetration). Cut-back bitumen or soft bitumen 150/200 is applied in an approximate amount of 1.7-1.8 l/m2. Recommended addition of dop to improve binding of bitumen to aggregate.

Equipment for spraying hot bitumen; 10-12 ton pneumatic tire roller or suitably loaded trucks. Skilled and semi-skilled workforce.

Aggregate strength requirements	Vehicles per day	
	< 100	> 100
Min. Dry	90 k N	110 k N
Min. Wet/Dry strength ratio	0.60	0,75

Grading Envelopes		
Sieve sizes (mm)	Open grading (% passing)	Medium grading (% passing)
19	100	100
16	80 - 100	84 - 100
13.2	52 - 82	68 - 94
9.5	36 - 58	44 - 73
6.7	20 - 40	29 - 54
4.75	10 - 30	19 - 42
2.00	0 - 8	3 - 18
1.18	0 - 5	1 - 14
0.425	0 - 2	0 - 6
0.075	0 - 1	0 - 2

Principal Advantages:

- Suitable for local roads with traffic volume PDGS < 500
- Proven technology in numerous roads in the Scandinavian countries
- A wide range of natural or processed aggregates can be used

Principal Concerns:

- Occurrence of bleeding during the first weeks after constructionb
- Require special types of soft bitumen that may not be readily available in some regions

- Higher amounts of bitumen than standard crushed stone pavements
- Requires extensive heavy duty pneumatic rolling, therefore not suitable for small contractors/utilities
- Requires significant traffic immediately after construction to cover all stone grains with binder
- Relatively low skid resistance

Penetration Macadam

General Description

Constructed in three layers, first applying a layer of rolled coarse aggregate (eg 40/60 mm) followed by the application of an bitumen emulsion or penetrating binder (usually 5-6 kg/m2). After spraying the binder, the voids in the coarse aggregate layer are filled with finer aggregate (e.g. 10/20 mm) to stabilize the layer, followed by an additional application of bitumen emulsion (2-3 kg/m2) which is then covered with fine aggregate (e.g. 5/ 10 mm) and rolls. The finish line is to achieve a structure of a layer of cubic stone and filling covered with bitumen to a depth of about 60-80 mm.

Key Resource Requirements

Crushed hard and tough aggregate fractions 40 mm, 10-20 mm and 5-10 mm.
Bitumen, bitumen emulsion, heater-distributor and roller with capacity of 8-10 tons. Skilled and unskilled workforce.

Principal Advantages:

- Proven application in all climatic conditions, suitable for local roads.
- Gives a stable and solid layer after compaction, but the price is relatively high due to the very high bitumen application rate (7-9 kg/m²).
- Low initial maintenance

Principal Concerns:

- Requires a good quality control of the materials and the distribution of the bitumen in the layers during construction
- Expensive due high bitumen use (around 7-9 kg/m2)
- In case of application of hot bitumen instead of bitumen emulsion, special safety measures should be taken at work.

Asphalt – Cold Mix	

General Description

Cold asphalt mix is a mixture of mineral aggregate and bitumen emulsion. The mineral mixture is open type, with very little filler, aggregates 0-8, 0-11 and 0-16 mm. Asphalt mix by cold process is used to create a wearing layer on roads with medium, light and very light traffic, as well as for the repair of potholes in the winter period.

An essential ingredient of any asphalt mixture is aggregate, which can be of stone or mineral origin, with coarser or finer grain granulations. In addition to the dosage of binders and fillers, which dictates the strength of the mixture and its "behavior" during use, the overall quality of the asphalt will largely depend on the correct choice of the type of aggregate and its quality.

These compounds are more flexible than traditional hot-process compounds and are very suitable for local roads.

Key Resource Requirements:

Cold mix asphalt can be produced and applied using a specialized paver. Aggregates are mixed with bitumen emulsion and spread in the paver. The layer is then compacted and opened to traffic after reaching the required strength.

In the event that a special paver is not available, the mixture can be prepared in a mixer of suitable capacity, and then transported to the site and installed with standard machinery.

Principal Advantages:

- Cold mix asphalt is economical compared to hot mix asphalt because this method eliminates the need to heat the aggregate.
- No special high-tech machines are required as standard equipment can be used for construction
- The mixture can be used even when the ambient temperature drops, thus reducing the need to maintain the asphalt temperature.

Principal Concerns:

- Applicable if the outside temperature is above 10ºC.
- Requires proper emulsion sources.
- Requires the use of high-quality stone aggregate - stone chips
- The emulsion (anionic or cationic) should be compatible with the materials.
- The emulsion should harden after application and before opening to traffic.

Thin Surfaced Asphalt

General Description:
Thin asphalt pavements are often used on roads with low traffic loads. These pavements usually consist of a top thin bituminous layer (10 mm to 40 mm thick) over one or more unbound granular layers over a well-compacted sub-base. The bearing capacity of thin asphalt pavements is largely provided by unbound granular materials with the upper bituminous surface acting as a waterproofing layer with little contribution to the bearing capacity. The main disadvantage associated with the use of thin asphalt wearing courses is the susceptibility to damage, especially from frost and cracking. Therefore, mixtures with high resistance to plastic deformation and sufficient flexibility to withstand large elastic deformations without cracking must be used. Mixtures are prepared with high-quality aggregates with high resistance to fragmentation, wear and polishing.

Key Resource Requirements:
Preparation of asphalt mixture in a plant for mixing stone aggregate, filler and hot bitumen, transport in closed containers, spreading and initial compaction with a paver. Final compaction with a tire roller. Stone aggregate - crushed stone fractions 0/4 mm and 4/8 mm. Qualified labor and special equipment are required for the preparation of the mixture and its installation.

Principal Advantages:

- Smooth and closed road surface
- Good functional properties
- No separation of aggregate grains
- Can be used for traffic in a short time after application and compaction
- Can be recycled.
- Can be used in phased construction.
- Low maintenance

Principal Concerns:

- Complicated asphalt mixture production
- Special equipment for production and installation of asphalt mixture
- Does not contribute to the bearing capacity of the structure
- Tendency to damage
- Application at lower air temperatures is not possible

Asphalt – Hot Mix (HMA)

General Description:

Asphalt mixtures produced by the hot process are the most commonly used material for the production of upper bearing and wearing layers on roads. Various types of these mixtures are in use, which differ in composition and method of installation, and all of them have in common that thermal energy is used during production. Some of the most commonly applied types are: asphalt concretes, hot rolled asphalts, SMA, mastic asphalts, porous asphalts, asphalt mixtures for ultra-thin layers, etc. In these mixtures, the granulometric composition of the mineral material has a key influence on the characteristics of the asphalt mixture. Depending on the maximum grain size in the mineral mixture, coarse-grained mixtures differ (higher load capacity,
greater skid resistance, greater resistance to rutting) and fine-grained mixtures (lower noise level, less tire wear). By weight composition, the mixture is a combination of approximately 95% fractions of stone aggregate, sand and stone filler bounded by a bituminous binder. The optimal composition of the asphalt mixture is obtained on the basis of pre-testing during which the design of the mineral mixture is carried out (participation of certain fractions of stone aggregate, sand and stone flour) and the determination of the optimal binder content depending on the requirements of the technical specifications – Job Mix Formula. For the production of asphalt mixture, standard fractions of stone aggregate are usually used: 0/4 mm, 4/8 mm, 8/16 mm and 16/32 mm. The production of asphalt mixtures is carried out in a stationary or mobile plant where fractions of mineral aggregate and mineral filler are dosed, heated, hot bitumen added and mixed. The hot mix is transported to the site where it is installed with appropriate equipment (usually pavers) and compacted with smooth and pneumatic rollers. The structure is ready for traffic immediately after cooling.

Key Resource Requirements:
The production of the mixture requires stone aggregates of high quality, which often cannot be obtained from local quarries. Production of asphalt mixture in stationary or mobile plants of appropriate capacity (Asphalt Plant). Means of transport and pavers for installing asphalt mixes and sets of rollers. Skilled labor is required for mixture preparation and execution.

Principal Advantages:
- Suitable for all levels of traffic load
- Smooth and sealed pavement surface (except porous asphalt)
- Good functional properties
- Resistance to climatic influences
- No separation of aggregate grains
- Noise reduction
- Can be used for traffic in a short time after application and compaction
- Great durability
- Can be recycled
- Can be used in phased construction

Principal Concerns:
- High construction cost
- Complicated asphalt mixture production
- Application of special equipment for production and installation of asphalt mixture
- Construction restrictions at low air temperatures

6.4 Rigid Pavement

Interlocking Blocks	

General Description

Pavements made of concrete blocks are widely used, from manipulative platforms for heavy traffic loads to local roads. The application is based on the ability of concrete blocks to effectively spread the load laterally to adjacent blocks. Depending on the expected traffic load, interlocking blocks or blocks with straight edges are used. The blocks used for local roads are rectangular in shape, usually 6-8 cm thick and stacked in a herringbone or other shape. The blocks are stacked over a layer of crushed sand up to 3 cm thick. Depending on the traffic load, the lower bearing layers can be a combination of bound (usually with cement) and unbound layers for higher traffic load or only unbound layers of total thickness according to the soil's bearing capacity and the depth of frost penetration. In the case of blocks that are not connected to each other, the space between the blocks is filled with cement mortar, so that the pavement is waterproof. Special attention should be paid to the surface texture of the concrete cube in order to obtain the required skid resistance values.

Key Resource Requirements:

Availability of quality-made concrete blocks with a minimum 28-day cube strength of 20-25MPa. In case of local production of blocks, concrete mixer, suitable steel molds, vibratin table. Sand for the base and joint filling. Lightweight compactor plate. Skilled and unskilled workforce.

Principal Advantages:

- Suitable for rural or urban applications in all climates.
- Social and economic benefits for communities through local block production.
- Centralized block production can facilitate good quality control.
- Employment of local workforce in both construction and ongoing maintenance.
- Suitable for construction by small contractor communities.
- Good durability, load bearing and load spreading characteristics.
- Inexpensive maintenance procedures.

Principal Concerns:

- Mortarless joint option may be susceptible to erosion in high rainfall areas without maintenance.
- It requires continuous production of blocks and control of the required quality.
- Danger of a slippery surface in case of inadequate selection of stone aggregate.

Portland Cement Concrete PCC (slabs)

General Description:

Concrete pavements are usually made in the form of non-reinforced concrete slabs with a ratio of width to slab length usually 1:1 to 1:1.2. The thickness of the concrete slab depends on the traffic load and the bearing capacity of the subgrade, and for local roads it ranges from 15 cm to 20 cm. Concrete slabs are poured on a previously prepared and compacted base. After installation, it is necessary to care concrete, by applying a membrane to avoid the sudden loss of moisture and maintaining the humidity until the primary strength is reached, for at least 7 days. Thanks to its rigidity, the PCC pavement transfers the load to a much larger area of the subgrade, causing significantly less compressive stresses and deformations in the subsoil, compared to flexible pavement constructions. They are suitable for construction on roads with steep slopes and on roads that are subject to seasonal flooding and other major climatic influences.

Key Resource Requirements:

High-quality stone aggregate and cement and a mixing plant with adequate capacity for concrete production. Equipment for mechanized installation in the case of larger areas or suitable equipment for installation and compaction in the case of smaller areas (vibro beams and vibro pins). Equipment and material for concrete care and a cutter with a diamond disc for cutting joints. Equipment for installation of sealant in pavement joints. Skilled and unskilled workforce.

Principal Advantages:

- Suitable for all climates and rural or urban applications
- Suitable for regions with high rainfall and flooding.
- Use of a standard concrete production plant
- Application of standard concreting technology applied by local small contractors.
- Long service life
- Resistant to high temperatures
- Applicable for roads with large gradients

Principal Concerns:

- High initial construction cost compared to the most other options.
- Typically requires expansion and contraction joints with dowel bars for load transfer.
- May be susceptible to shrinkage cracking unless properly made and cured.
- Tendency of workers/contractors to add too much water to the concrete mix to facilitate construction; thus weakening the slab and risking shrinkage cracks.
- A minimum of 7-14 days of curing is required after construction.
- Requires a good base and shoulers protected from erosion
- The problem of the pumping due to the deflection of the slab.
- Necessary regular maintenance of joints
- Danger of a slippery surface in case of inadequate selection of stone aggregate and treatment of the surface of the concrete slab.
- Increased maintenance costs for utility instalations if they exist in the road body

6.5 Pavement Type Selection

In order to choose the most suitable type of pavement structure under the given conditions, it is necessary to evaluate possible options.

Options of construction types that meet structural requirements for specific conditions are compared using life cycle cost analysis to find the most economical pavement type. The pavement type selection process should also focus on other criteria such as functionality, usability, durability, driver comfort, environmental impact and safety.

It is usual to evaluate possible options based on the following three criteria:

1. Technical assessments
2. Financial estimates
3. Economic assessments

1. The technical assessment is based on the analysis of:

- Traffic load
- Local restrictions
- Construction deadlines
- Design life of the structure
- Frequency of maintenance interventions
- Traffic safety
- Local availability of materials and equipment for execution
- Suitability for phased construction
- Sustainability of the environment
- Suitability for carrying out rehabilitation and reconstruction

2. The financial assessment is based on the analysis of:

- Construction costs
- Annual costs of maintenance
- Total costs in the designed life of the structure

3. The economic assessment is based on the analysis of:

- Road managment cost estimation
- Assessment of road user costs

The final choice of pavement type is approved by the organization that manages the local roads, so care should be taken to ensure that the choice is made on the basis of a balanced ratio of criteria used for evaluation. When proposing the optimal variant, the designer must provide evidence that the proposed solution is optimal from the aspect of technical requirements, duration, financial costs and economic profitability.

The following figures illustrate the relationship between three technical evaluation criteria: construction cost, maintenance cost and design life of the structure, for four characteristic types of pavement construction on local roads.

Figure 8 : Pavement type selection criteria – Construction Cost

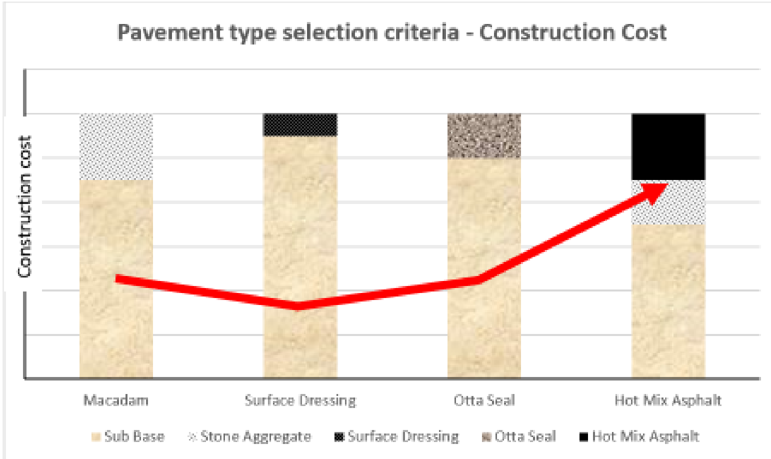


Figure 9 : Pavement type selection criteria – Maintenance Cost

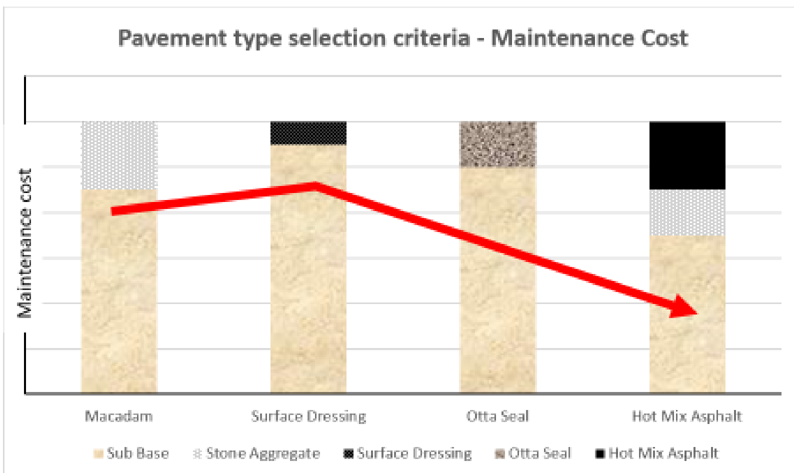
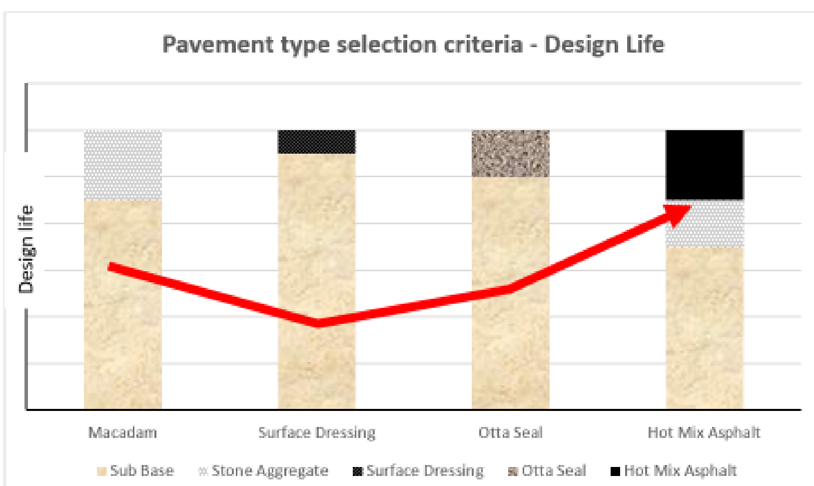


Figure 10 : Pavement type selection criteria – Design Life



7 Pavement Design

The design of pavement structures has long been based on empirical methods, i.e. based on scientific facts gathered through empirical observation of the behavior of the structure during exploitation. With the development of mechanics, computer technology, equipment for testing materials and structures, the analytical-empirical calculation procedure of pavement structures is increasingly being applied. Unlike the empirical procedure, where the thickness of the structure is obtained depending on the influencing parameters, the analytical-empirical procedure is an iterative process in which the thickness of the pavement is obtained indirectly, by analyzing the stresses and deformations in the structure. Based on the forecast volume of traffic, climatic conditions, bearing capacity of the soil, the condition of the existing pavement structure (in the case of rehabilitation), designer first assumes the pavement structure on the basis of experience data and technological requirements. The next step is the verification of the assumed pavement structure by checking stresses and deformations, i.e. by checking the structure's resistance to fatigue due to traffic and climatic influences. In the event that the assumed pavement structure does not meet the given conditions, the structure is corrected and re-checked until all conditions are met.

The design process can be divided into four basic phases:

- Data collection (input data)

    a. New construction - traffic load forecast, design life, climate influence, investigation works in order to determine the structure, bearing capacity and drainage properties of the soil, availability of building materials

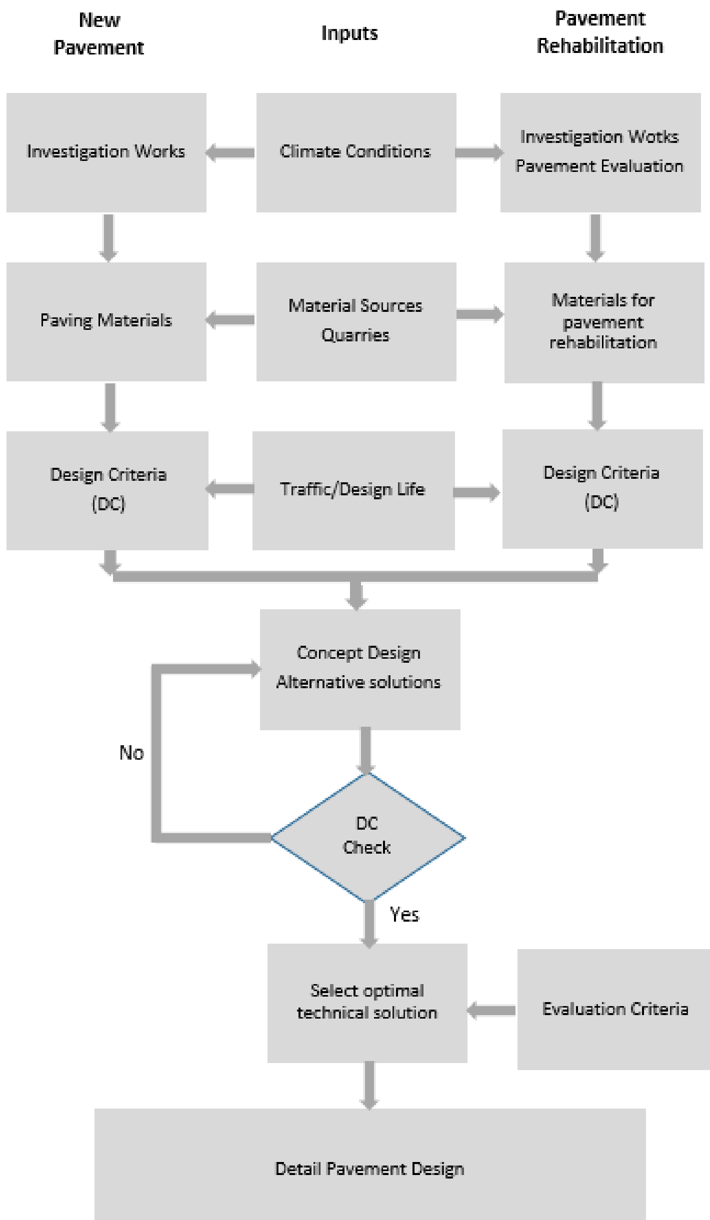
    b. Reconstruction/rehabilitation - past and forecast traffic load, design life, climate impacts, investigative work and evaluation of the existing structural and functional condition of the pavement, condition of the drainage system and drainage characteristics of the structure, availability of building materials and equipment for the application of specific technological procedures for the execution of rehabilitation and reconstruction works

- Analysis of collected data and development of variant solutions
  Comprehensive analysis of the collected data, selection of the values of all relevant parameters for construction design, proposal of variants of the conceptual solution of the new construction/reconstruction/rehabilitation

- Selection of the optimal technical solution
  Selection of the optimal technical solution by applying multi-criteria analysis

- Development of the pavement project

Figure 11: Pavement standard design process

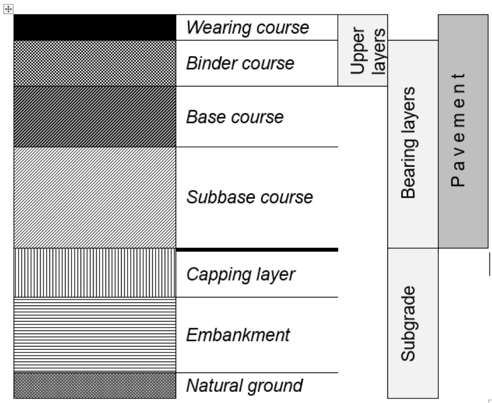


7.1 Pavement Structure

The general structure of the pavement in the case of a new construction is presented in Figure 12

In relation to the different conditions of use, all the shown layers are required in pavement structures as a rule, primarily for extremely heavy traffic loads.

Figure 12 : Pavement structure



Flexible Pavement

- Surface layer. Layer in direct contact with the loaded wheel and is exposed to the direct effect of all ambient influences.

- Upper supporting layer. This layer (or layers) is immediately below the surface layer and usually consists of crushed aggregate bound with bitumen or only mechanically stabilized.

- Lower bearing layer. This is the layer (or layers) below the upper bearing layer, it is not always necessary (for example, in the case of bedding in rock material, it is replaced by a leveling layer of stone chips).

The surface layer is in contact with traffic and is usually made of the highest quality materials. It provides surface characteristics such as friction, flatness, noise control and protection from atmospheric impacts. The pavement surface is sometimes divided into two layers: a wearing course and a binder course.

- The wearing course is usually made of asphalt concrete (AB). Tand he layer has increased stiffness, high density, wear-resistant and waterproof. (unless drainage asphalt is applied).
- The binder course is directly below the wearing layer and has the role of increasing the load capacity in the upper part of the pavement structure, by distributing the still quite concentrated load over a larger area. It is made of asphalt concrete, where the quality criteria are lower than those of the wearing course

Base layer/s usually consists of:

- Crushed stone aggregate. This is a classic Base layer, made of well-granulated and high-quality crushed stone, resistant to moisture and frost.

- Bituminized base layer – asphalt similar to asphalt concrete, but with less strict quality requirements for materials and the finished mixture. It can also contain a small part of natural sandy gravel, but only for light traffic loads.

Base layer must be used in situations where a large load capacity is necessary, i.e. when the pavement is loaded with heavy traffic.

Sub Base

Sub Base is between the Base layer/s and the subgrade. First of all, it serves as a bearing layer of the pavement structure, whose role is largely in strengthening the insufficiently load-bearing subgrade, so its thickness and the choice of the type of material are closely related to the quality of the subgrade (in addition to the traffic load).

In addition to the requirement to form a good, load-bearing foundation for Base layer/s, the role of Sub Base is to:

- reduce the penetration of subgade material into the pavement structure
- improve drainage
- reduce the impact of freezing
- provide a platform for work

Rigid Pavement

A typical modern rigid pavement construction consists of a top layer, an upper (base) and lower (sub base) bearing layer and a subgrade.

The top layer is made of cement concrete and has a high stiffness (due to a high modulus of elasticity) and provides the largest part of the bearing capacity of the pavement. The top layer is in contact with the moving load and is made of concrete. It has the role of enabling friction, flatness, does not create noise and ensures the drainage of atmospheric water and prevents the penetration of water into the lower layers. The thickness of the top concrete layer can vary from 150mm to 300mm.

The upper supporting layer (base) can be made of:

- unbound aggregate - a simple material that can be easily installed, commomly used in rigid pavement construction
- stabilized aggregate - stabilization (cement, bitumen); the basic material is crushed stone aggregate, sandy gravel or a mixture of these materials, which is usually bound with about 4% to 7% of cement and thus obtains a strength that is about 20% to 25% of the strength of a concrete pavement.
- thick asphalt mixes by hot process - form a well-bearing and waterproof base for concrete pavement
- water-permeable asphalt (discontinuous hot asphalt mixture) - used in situations where good drainage is required
- lean concrete - has properties similar to concrete pavement, but due to the lower binder content, its strength is generally less than 50% of the strength of concrete pavement; however, it must have expansion joints.

Sub Base

Located between the base and the subgrade, it has less stiffness, but also contributes to the bearing capacity of the pavement and serves to protect against frost and to drain water that may penetrate the pavement.

The primary role of this layer is to: prevent the mixing of pavement uper layer`s materials and subgrade, improve water drainage, serve as protection against frost penetration into the subsoil and provide a working surface for the construction of the upper layers. The lower supporting layers are generally made of materials of lower quality than the upper layers.

7.2 Design Process

Empirical and analytical-empirical procedures are used for the design of pavement structures in Serbia.

For empirical design procedures, the standards SRPS U.C4.012/1981, SRPS U.C4.014/1994 and SRPS U.C4.015/1994 are applied. Empirical design methods are based on relationships between site conditions, traffic load, structure of the pavement structure and level of service. These relationships are based on experience and experimental research. The methods were primarily developed for roads with a higher volume of traffic, so when applying them to local roads with a low traffic load, care should be taken to avoid dimensioning errors.

Analytical-empirical design is widely used when designing new pavement structures, especially for reconstructions and rehabilitations. There is no binding procedure for the design of pavement structures using the analytical-empirical procedure in Serbia, but designers apply generally accepted procedures at their own discretion and experience.

In recent years, design of pavement typical structures has been increasingly used. Unfortunately, due to the absence of a suitable rulebook for the application design of typical pavement structures, this procedure is still not applied in Serbia. Bearing in mind that most European countries apply this procedure for design pavement structures of local roads, within these guidelines a brief overview of typical pavement structures applied for roads in Austria is presented.

7.2.1 Pavement design using the SRPS standard

Design of new asphalt pavement structures according to SRPS U.C4.012

Design using the SRPS U.C4.012 standard according to the bearing capacity criterion is based on: design life, planned level of service (driving capability at the end of the project period), traffic load, climatic and hydrological conditions, subgrade quality (CBR) and material quality in the layers of pavement structure. Climatic-hydrological conditions are defined by the environmental factor R, which is a function of the depth and duration of freezing, the length of the period of soil saturation with water and the length of the dry period during the year. Evaluation of the material in the layers of the pavement structure is carried out through replacement coefficients, i.e. substitute thicknesses of individual materials in relation to the standard material.

The design life is the time period expressed in years for which the pavement structure is designed. The length of the project period depends on the method of maintenance of the pavement and, as a rule, it is 20 years, except in the case of phased construction, when the project period can be shorter (at least 5 years).

The drivability of the pavement surface is defined by the drivability index, whose value for new and perfectly level pavements is p=5, and for completely degraded pavements p=0. Usually, the lowest value of the drivability index value at the end of the project life p=2.5 is adopted.

The traffic load is determined according to the SRPS U.C4.010 standard.

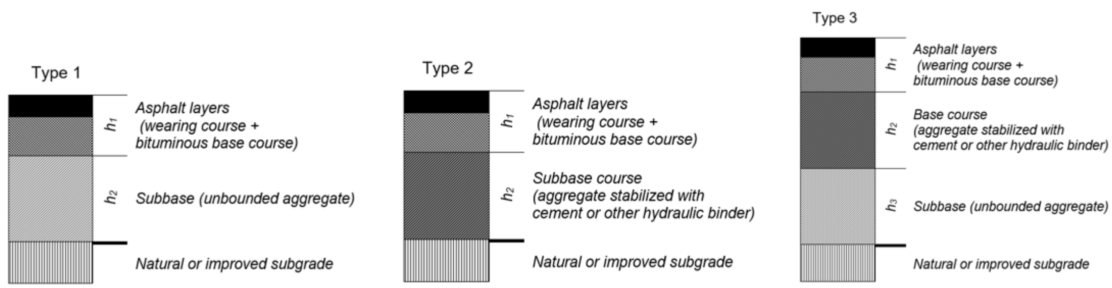
The bearing capacity of the subgade is expressed through the value of the California Bearing index CBR, which is determined according to the SRPS U.E8.010 standard.

When selecting the type of material in the pavement construction, the function of individual layers, the economy of construction and the requested quality criteria of the materials and mixtures to be installed must be taken into account. When design, the applied materials are evaluated through material replacement coefficients, i.e. substitute thicknesses of individual materials in relation to the standard material.

Table 21: Average values of material replacement coefficients

Material type	Replacement coefficient ai	Standard SRPS
Asphalt-Concrete	0.42	U.E4.014
Bituminous crushed stone	0.35	U.E9.021
Bituminous gravel with the addition of small stone (30%)	0.33	U.E9.021
Bituminous gravel	0.28	U.E9.021
Subbase bituminous layer	0.24	U.E9.028
Stabilization with cement	0.20	U.E9.024
Stabilization with lime	0.17	U.E9.026
Breakstone	0.14	U.E9.020
Crushed stone material	0.14	U.E9.020
Granulated gravel	0.11	U.E9.020
Crushed natural gravel	0.11	U.E9.020
Natural gravelly sand	0.07	U.E9.020

Dimensioning using this standard is done by choosing one of three types of construction, depending on the type of bearing base under the asphalt layers.



Design of pavement structure consisting of asphalt layers and load-bearing layers of unbound aggregate (Type 1) is performed using the diagram in the Figure 13.

Design of pavement structure consisting of asphalt layers and bearing layers of cement-stabilized granular stone material (Type 2) or asphalt layers and bearing layers of cement-stabilized granular stone material and unbound aggregate (Type 3) is performed using the diagram in Figure 14.

The total thickness of asphalt layers and load-bearing layers is determined from the diagram depending on the total equivalent traffic load in the design period and the reference value of the bearing capacity of the subgrade expressed through the CBR value.

The thickness of the load-bearing layer of unbound aggregate determined from the diagram (Figure 13) refers to gravel of standard quality with a calculation coefficient of replacement ar = 0.11. The gravel layer can be partially or completely replaced with appropriate mineral materials by recalculating the required thickness using the coefficients from Table 21.

The thickness of the bearing layer of cement-stabilized granular stone material determined from the diagram (Fig. 14) refers to a mixture of cement-stabilized gravel of a quality standard with a calculation coefficient of replacement ar = 0.20. The total thickness of this layer can be partially or completely replaced by suitable materials stabilized with hydraulic or bituminous binder by recalculating the required thickness using the coefficients from Table 21.

The total thickness of the asphalt layers from the diagram refers to the selected asphalt mixture with an average quality between asphalt concrete mixture and bituminized crushed stone, with a calculation coefficient of replacement ar = 0.38. Determination of the thickness for certain selected asphalt mixtures is performed by recalculating the total thickness of the asphalt layers using the replacement coefficients from table Table 21. When determining the thickness of the layers, the limits of the technological thickness of the layers must be taken into account.

Figure 13: Diagram for dimensioning pavement structures made of asphalt layers and load-bearing layers made of unbound aggregate

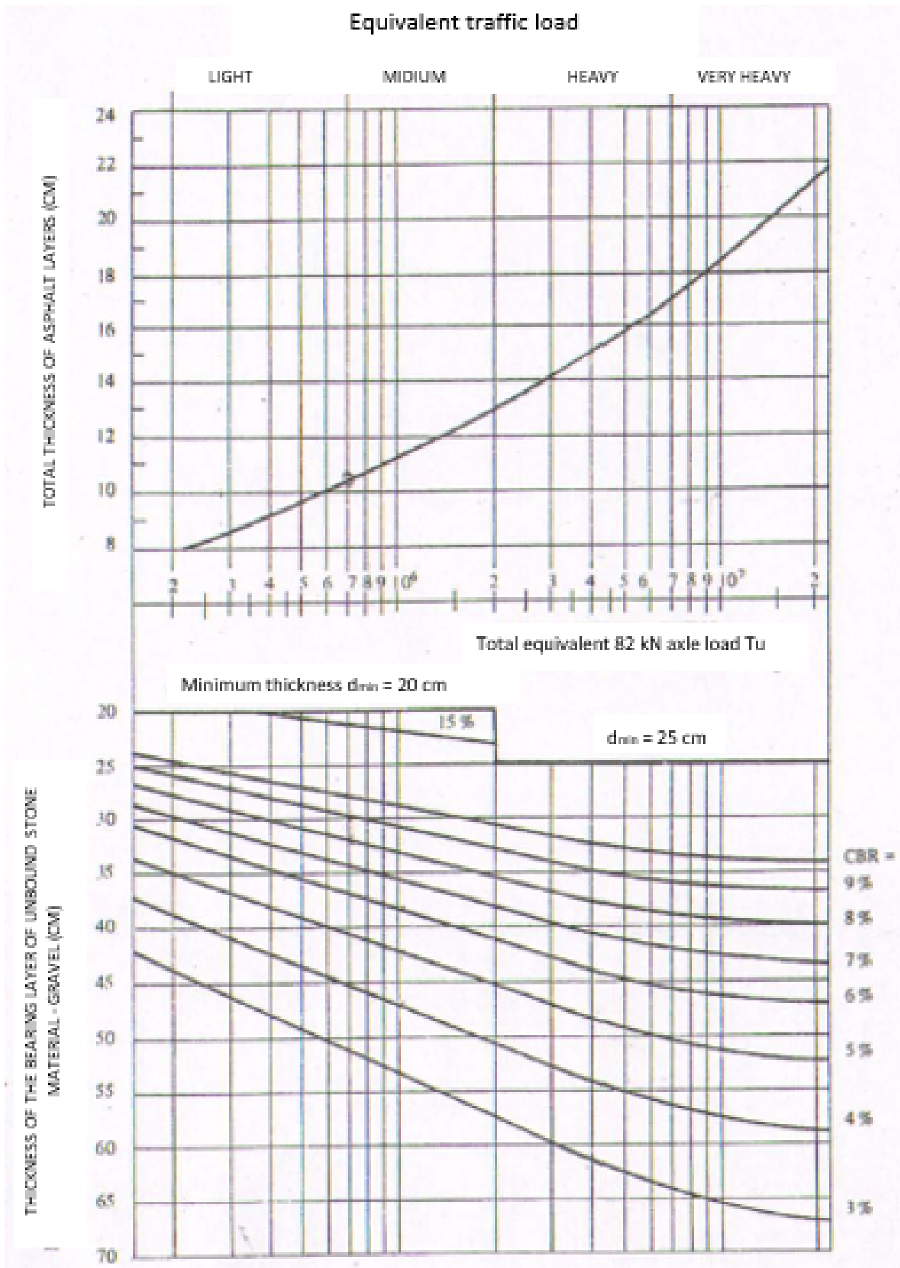
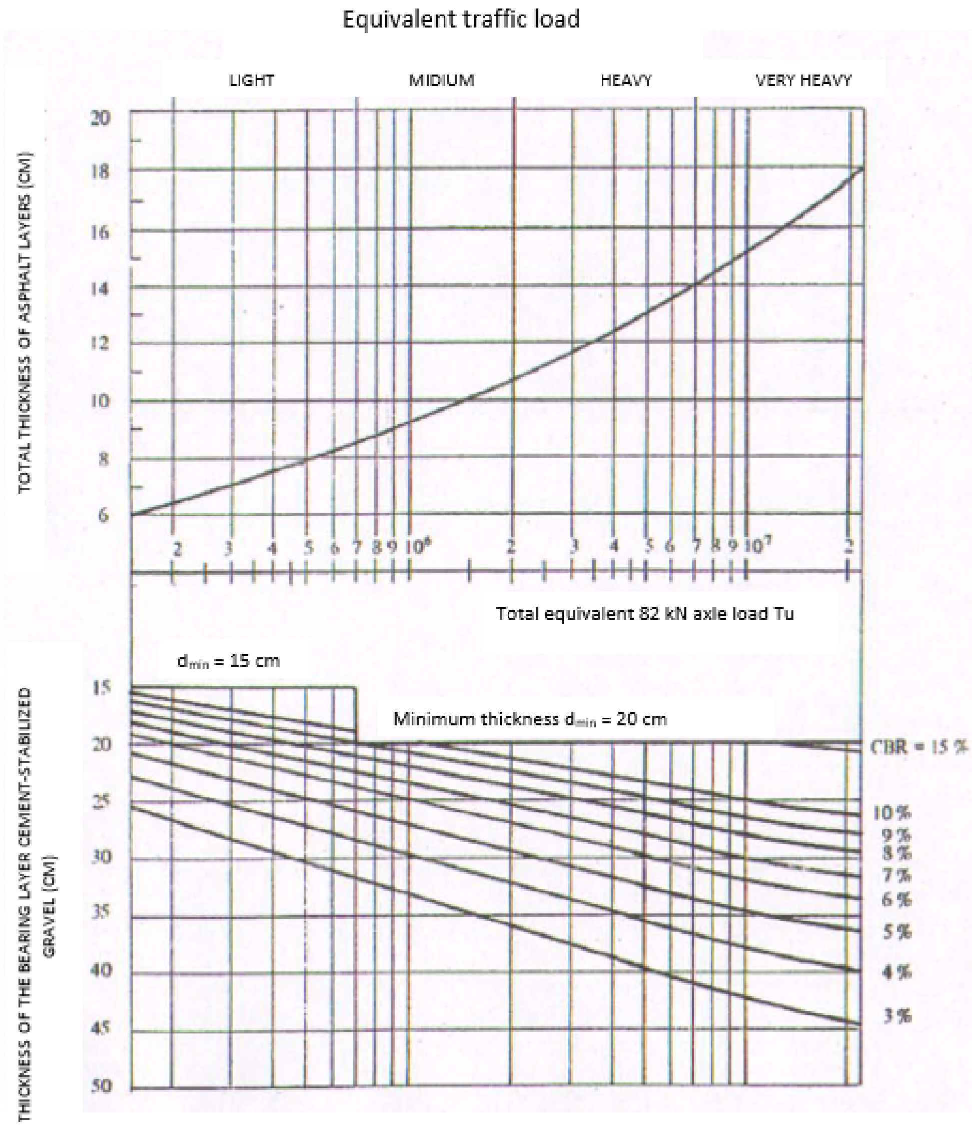


Figure 14: Diagram for the dimensioning of pavement structures made of asphalt layers and load-bearing layers of cement-stabilized granular stone materijala



After dimensioning of the pavement structure according to the bearing capacity criterion, depending on the climatic and hydrological conditions and the depth of frost penetration, the structure should be checked for the influence of freezing.

Design of new asphalt pavement structures according to SRPS U.C4.015

In Serbia, is also used pavement design procedure in accordance with the SRPS U.C4.015 standard, which is based on AASHTO Guide for Design of Pavement Structures from 1986. In relation to the procedure according to the SRPS U.C4.012 standard, it differs, because instead of the soil bearing index, the resilient modulus of the soil MR is used, the material replacement coefficients are a function of the layer modulus, and a safety factor is introduced over the reliability level, which controls the influence of the variation of individual parameters. This dimensioning procedure is also applicable for phased construction.

Basic parameters for dimensioning are:

- Duration of period until the first reinforcement
- Design pavement life
- Traffic load
- The influence of the environment
- Quality criteria
- Material properties
- Road construction characteristics
- Economy

The procedure is based on an empirical equation in which the relationship between the measurable characteristics of the pavement and the performance of the pavement is established, from which the structural number of the pavement is determined. The structural number is an abstract number that expresses the structural strength of the pavement required for a given combination of soil bearing capacity (MR), total traffic load, serviceability and environmental impact.

The equation has the following form:

$$\log ESO_{80} = Z_R \cdot S_o + 9.36 \cdot \log(SN + 2.54) + \frac{G_t}{0.40 + \dfrac{138071.59}{(SN + 2.54)^{5.19}}} + 2.32 \cdot \log M_R - 7.045$$

where is:

ESO_{80} – total equivalent traffic load in the project period
Z_R – standard normal deviation for the corresponding level of design reliability
S_o – standard deviation (0,3-0,5)
G_t $\quad G_t = \log(\Delta p / (4{,}2 - 1{,}5)) = \log[(p_o - p_t) / (4{,}2 - 1{,}5)]$
Δp – loss of usability during the project period
p_o – initial usability index
p_t – ultimate usability index
M_R – subgrade resilient modulus (Mpa)
SN – structural number of the pavement structure (cm)

Basic input data for design:

• Traffic load. Equivalent traffic load ESO_{80} – the number of crossings of standard axles of 80 kN during the project period. Equivalence coefficients (factors) depend on the structural number of the pavement structure (SN) and the ultimate serviceability index (pt).

• Reliability. The reliability of the pavement design process and performance is the probability that the section of pavement designed using this process will be at a satisfactory level for the forecased traffic and environmental conditions during the design period. The variables ZR and So explain reliability.

• Road construction. The pavement structure is characterized by a structural number (SN). The structural number is converted to actual layer thicknesses using the layer coefficient (ai) which represents the relative strength of the building materials in that layer. Additionally, all layers below the HMA layer are assigned a drainage coefficient (m) that represents the relative loss of strength in the layer due to its drainage characteristics and the total time it is exposed to near-saturated moisture conditions. In general, rapidly draining layers that almost never become saturated can have coefficients of up to 1.4, while slowly draining layers that are often saturated can have drainage coefficients of up to 0.40.

$$SN = a_1 \cdot d_1 + m_2 \cdot a_2 \cdot d_2 + m_3 \cdot a_3 \cdot d_3$$

where is:
a_i – replacement coefficient of the i-th layer
d_i – thickness of the i-th layer (cm)
m_i – drainage coefficient of the ith layer

• Lifetime. The time period covered by the economic analysis of the construction and maintenance costs of the pavement structure. For local roads 15-25 years. If phased construction is planned, the minimum period between phases is 5 years.

• Level of service. The difference between the initial and final structural serviceability index (PSI). Typical values are p_0=4,2 immediately after construction and p=1.5 for the end of life. The lowest permissible value of the usability index for local roads is pt = 2.0.

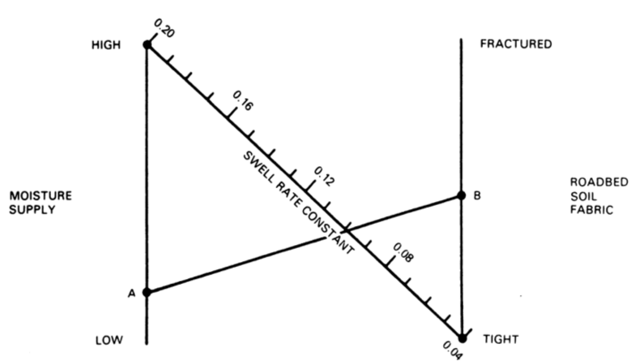
• Subgrade bearing capacity. The bearing capacity of the subgrade is defined by the weighted value of the resilient modulus of the soil (M_R), which includes the seasonal influence of the change in the soil bearing capacity due to the change in humidity. The weighted value of M_R is calculated from the average value of the relative damage factor Uf, based on data on the seasonal value of M_R (for each month of the year).

$$U_{fi} = (1128{,}03 \cdot M_{Ri})^{-2{,}32}$$

• Enviroment influence. Under the influence of the environment is understood the effect of frost and swelling.

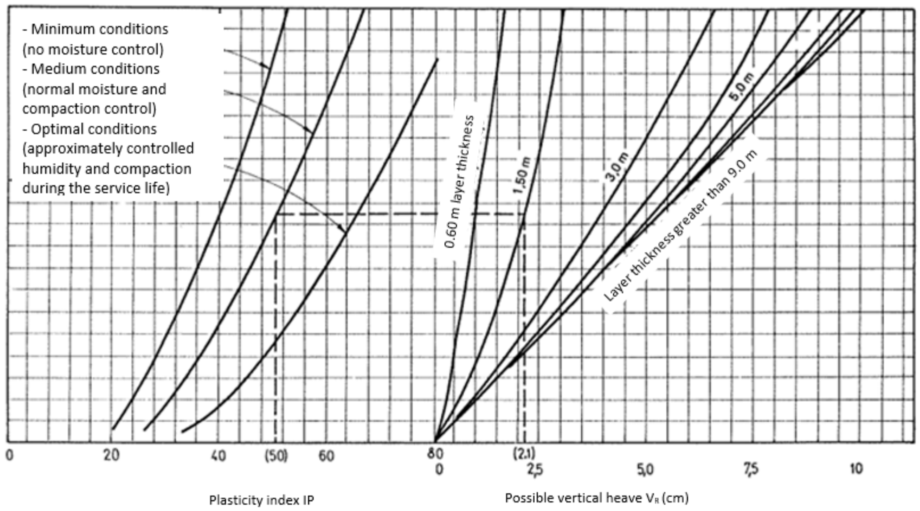
The effect of swelling on serviceability decline is determined by swelling constant, possible vertical rise and swelling probability. The value of the swelling constant θ_s depends on the composition of the soil and the rating of the water level. It is determined from the diagram in the Figure 15.

Figure 13: Diagram for determining the swelling constant



Possible vertical heave V_R represents the possible vertical heave of the soil in the sugrade, which occurs during high swelling. The value can be obtained in the laboratory or by reading from the diagram in Figure 16.

Figure 16: Determination of vertical heave due to swelling



The loss of serviceability due to swelling of the soil is calculated from the following formula:

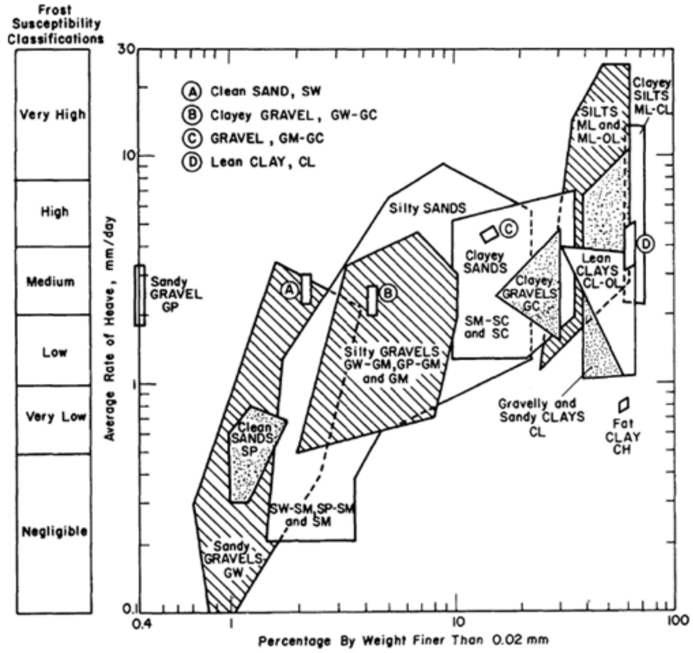
$$P_{sw} = 0.00132 * V_R * Ps * (1\text{-}e\text{^}\text{-}(\Theta s * t))$$

where is:

V_R - possible vertical heave cm
t – time (years)
Ps - probability of swelling %
Ɵs - swelling constant

Soil heave due to the effect of frost is similar in effect to the effect of swelling. It is caused by the formation of ice lenses in the ground. The loss of serviceability due to soil heave due to the effect of frost is determined by the heave constant, the heave probability and the maximum possible loss of serviceability.The heave constant θ_F represents the unit daily heave due to the effect of frost (mm/day) and depends on the sensitivity of the soil to the effect of frost.

Figure 14: Diagram for estimating the frost heave constant



The maximum possible loss of usability due to frost heave (Δp) depends on the quality of drainage and the depth of frost penetration. For frost penetration depth up to 1.5m and poor drainage quality, it ranges from 1.8 - 2.0.

The probability of pavement heave p_F due to frost is the percentage of the observed area where this damage can occur. It depends on the sensitivity of the soil to frost, moisture, drainage conditions, the duration of the freezing temperature and the number of freezing and thawing cycles.

The loss of usability due to soil heaving in the subgarde is calculated from the following formula:

$$\Delta p_{FH} = 0.01 * p_F * (\max\Delta p) * (1 - e^{-0,02*\theta f*t})$$

where is:

max Δp – maximum possible loss of usability
t - time (years)
p_F – heave probability %
θ_f - heave constant

The total serviceability loss due to the influence of the environment $\Delta\ p_{SWFH}$ is the sum of the serviceability loss due to swelling (p_{SW}) and due to frost heave (p_{FH}).

• Material properties. The mechanical properties of the material are defined by the resilient modulus of the soil in the subgrade, the resilient modulus of unbound materials, the modulus of stiffness/elasticity for bounded materials, and the layer coefficients.

The resilient modulus of the soil can be determined experimentally or from the correlation between M_R and the California bearing capacity index CBR.

$$M_R = 10,342 * CBR \quad (MPa)$$

The resilient modulus for the subbase made of unbound material E_1 depending on the module on the subgrade M_R and the thickness of the lower subbase h_1 is calculated from the ratio:

$$E_1 = M_R * 0,58 * (h_1)^{0,45}$$

where is:
E_1 – subbase resilient modulus (Mpa)
M_R – subgrade resilient modulus (Mpa)
h_1 – subbase thickness (cm)

The properties of bitumen-bonded materials are characterized by the dynamic stiffness modulus, which is calculated from the following expression:

Svojstva bitumenom vezanih materijala karakteriše dinamički modul krutosti koji se izračunava iz sledećeg izraza:

$$\text{Log } E = -1{,}607535 + 0{,}028829 \text{ x } \frac{P_{200}}{f^{0{,}17033}} - 0{,}03476\, V_v + 0{,}70377 \text{ x } (\eta_{21°C,\ 10^6}) +$$
$$+ 0{,}000005 \text{ x } \left[(1{,}8\, t_p + 32)^{(1{,}3+0{,}49825 \log f)} \; x\, P_{ac}^{0{,}5} \right] -$$
$$- 0{,}00189 \text{ x } \left[(1{,}8\, t_p + 32)^{(1{,}3+0{,}49825 \log f)} \; x\, \frac{P_{ac}^{0{,}5}}{f^{1{,}1}} \right] + 0{,}931757 \text{ x } \frac{1}{f^{0{,}02774}}$$

where is:
E - stiffness modulus of asphalt concrete (Mpa)
P_{200}- % passage of aggregates through sieve No200 (size 0.074 mm) approximately 2%-10%
f- frequency in Hz - approximately 10 Hz
Vv- percentage of voids filled with air - approximately 0%-15%
$\eta_{21°C,\ 10^6}$- absolute viscosity at 21°C in Nsec/cm2 - approximate 0.13 Ns/cm2 - 0.44 Ns/cm2
Pac- the amount of binder in % of the mass of the mixture - approximately 3.5% - 10%
tp- temperature in °C - approximate 25°C

The modulus of elasticity for cement-bonded materials is calculated from the following expressions:

-cement-stabilized crushed aggregate

$E = 8 * \sigma_b + 3\ 500$ (Mpa)

$E = 4{,}16 * \sigma_a^{0{,}88} + 3\ 485$ (Mpa)

- cement-stabilized gravel

$E = 10 * \sigma_b + 1\ 000$ (Mpa)

$E = 5{,}13 * \sigma_a^{0{,}88} + 1\ 098$ (Mpa)

where is:
σ_a – compressive strength with free lateral expansion
σ_b – bending strength

Layer coefficients

The characteristics of the material in the layers are shown through the construction coefficients of the layers a_i.

Table 22: Correlation coeficients for different layers and materials are :

Pavement layer material	Layer construction coefficient a_i
Asphalt concrete or binder layer	$a_1 = 0{,}40 \log E_1 – 0{,}951$
Bito gravel and binder subbase	$a_2 = 0{,}30 \log E_2 -0{,}713$
Cement stabilization	$a_2 = 0{,}52 \log E_2 – 1{,}728$
Crushed concrete	$a_2 = 0{,}27 \log E_2 – 0{,}589$
Unbound aggregate in the base layer	$a_2 = 0{,}249 \log E_2 – 0{,}439$
Unbound aggregate in the subbase layer	$a_3 = 0{,}227 \log E_3 – 0{,}348$

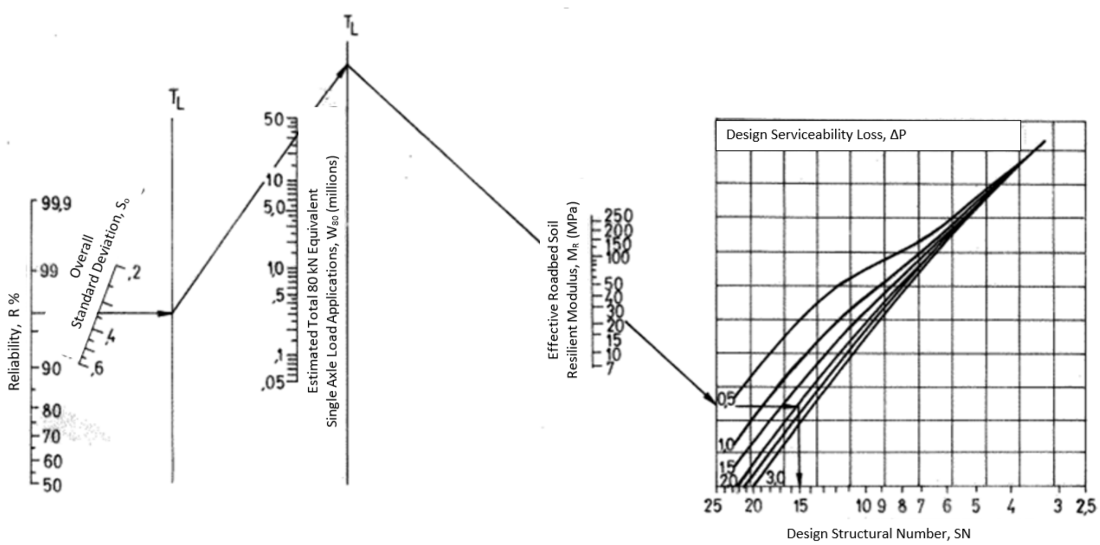
Flexible pavement design

Dimensioning the required thickness of the pavement structure is done in five steps using the basic equation:

$$\log ESO_{80} = Z_R \cdot S_o + 9.36 \cdot \log(SN + 2.54) + \frac{G_t}{0.40 + \frac{138071.59}{(SN + 2.54)^{5.19}}} + 2.32 \cdot \log M_R - 7.045$$

or the diagram given in Figure 18, and based on the input data on:
- design traffic load ESO_{80}
- the reliability of R
- average standard deviation s_0
- the actual resilient modulus of the subgrade M_R
- designed loss of usability $\Delta p = p_0 - p_t$

Figure 18: Diagram for determining pavement structural number SN



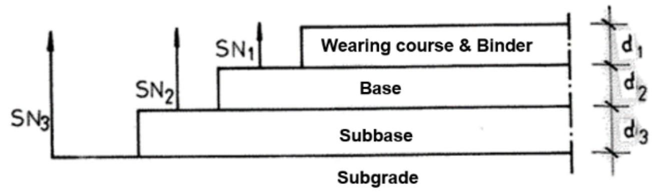
Based on structural number SN, calculated or read from the diagram (Figure 18), the thickness of the upper layers and lower bearing layers is determined.

$$SN = a_1 \cdot d_1 + m_2 \cdot a_2 \cdot d_2 + m_3 \cdot a_3 \cdot d_3$$

where is:
a_i – replacement coefficient of the i-th layer
d_i – thickness of the i-th layer (cm)
m_i – drainage coefficient of the i-th layer

The thickness of the layers is determined by testing, as follows, taking into account the minimum technological layer thicknesses, environmental conditions and costs:

$d_1 \geq SN_1 / a_1$
$SN_1' = a_1 * d_1 \geq SN_1$
$d_2 \geq (SN_2 - SN_1') / (a_2 * m_2)$
$SN_2' = a_2 * d_2 * m_2 \geq SN_1$
$d_3 \geq [SN_3 - (SN_1' - SN_2')] / (a_3 * m_3)$



If the pavement structure is exposed to swelling and/or heaving due to frost, it is necessary to check the design life of the structure for loss of serviceability due to these influences (p_{SW} and p_{FH}). If the calculated life of the structure differs from the designed life until the first reinforcement by more than 1 year, it is necessary to correct the assumed thicknesses and repeat the calculation.

When determining the thickness of the layers, you should take into account the choice of asphalt mixture and the minimum technological thickness of the asphalt layers.

Table 23 : Selection of asphalt mixture depending on the traffic load group

Traffic load group	Type of asphalt concrete						
	AB4	AB8	AB 11	AB 11s	AB 16	AB 16s	AB 22s
Highway&very heavy	-	-	-	+	-	+	+
Heavy	-	-	-	+	-	+	+
Midium	-	+	+	+	+	-	-
Light	-	+	+	-	-	-	-
Veri light	+	+	+	-	-	-	-

Table 24: Limiting layer thicknesses of bitumenized mixtures for asphalt wearing cours

Technological thickness (mm)	Type of asphalt						
	AB4	AB8	AB 11	AB 11s	AB 16	AB 16s	AB 22s
minimum	20	30	35	40	50	60	70
maximum	30	40	50	60	60	75	85

Table 25: Limiting layer thicknesses of bitumenized mixtures for asphalt binder course

Technological thickness (mm)	Type of asphalt				
	AB16 bin	AB22 bin	AB 16 base	AB 22 base	AB 32 base
minimum	50	60	50	60	80
maximum	80	100	70	100	140

Design of rigid pavement structures according to SRPS U.C4.014

Although cement concrete pavements (rigid pavement) are rarely used on local roads, in specific conditions it can be shown that the application of this type of pavement is economically profitable, and for this reason a brief description of the design procedure is given.

For the dimensioning of rigid pavement structures in Serbia, the SRPS U.C4.014 standard is applied, which was prepared in accordance with the AASHTO Guide for Design of Pavement Structures from 1986. Dimensioning is carried out according to the load-bearing criterion in order to determine the optimal thickness of the layers of the structure, based on the analysis of the following parameters:

- Design life
- Level of service (driving ability at the end of the project period)
- Traffic load

- Subgrade bearing capacity (subgrade reaction modulus activity and drainage coefficient)
- Concrete modulus of elasticity and flexural strenght
- Load transfer on joints
- Reliability levels
- Environmental influences (swelling of the soil and the effect of frost)

Dimensioning according to this standard is methodologically similar to the procedure for dimensioning flexible pavement structures using the SRPS U.C4.015 standard.

The procedure is based on an empirical equation in which the relationship between the measurable characteristics of the pavement and the performance of the pavement is established, from which the thickness of the concrete slab is determined.

The equation has the following form:

$$\log \mathrm{ESO80} = \mathrm{ZR} \cdot \mathrm{So} - 3{,}0355 + 7{,}35 \cdot \log(\mathrm{D} + 2{,}54) + \frac{G_t}{1 + \frac{4{,}32 \cdot 10^{10}}{(D + 2{,}54)^{8{,}46}}} + (4{,}22 - 0{,}32 \cdot \mathrm{pt}) \cdot \log \frac{0{,}673 \cdot f_{ZC} \cdot C_d \cdot (D^{0{,}75} - 2{,}278)}{J \cdot [D^{0{,}75} - \frac{14{,}796}{\left(\frac{E_c}{K}\right)^{0{,}25}}]}$$

where is:

ESO_{80} – total equivalent traffic load in the designe life

Z_R – standard normal deviation for the corresponding level of design reliability
S_o – standard deviation (0,3-0,5)
G_t $G_t = \log(\Delta p / (4{,}5 - 1{,}5)) = \log[(p_o - p_t) / (4{,}5 - 1{,}5)]$
Δp – loss of usability during the designe period
p_o – initial usability index
p_t – ultimate usability index
D– thickness of the concrete slab
f_{ZC} – bending tensile strength of concrete slab (Mpa)
C_d – drainage coefficient
E_c – modulus of elasticity of the concrete slab (Mpa)
K – module of reaction of the slab foundation (MN/m^3)

Basic input data for dimensioning:

• Traffic load. Equivalent traffic load ESO_{80} – the number of application of standard axles of 80 kN during the design life. Equivalence coefficients (factors) depend on the thickness of the concrete slab (D) and the ultimate serviceability index (p_t).

The determination of the following input data is performed in the same way as the procedure for design flexible pavement structures using the SRPS U.C4.015 standard (see the chapter related to flexible pavement design using this standard):

- Realibility level
- Design life
- Level of service
- Subgrade load capacity
- Environmental influence (swelling and heaving due to frost)

• Material properties. Within the material properties, the effective modulus of the subgrade reaction K, material characteristics in the pavement layers, concrete modulus of rupture and coefficients of the layers are defined.

The basic indicator of the bearing capacity of layers made of non-bonded materials are the elastic or resilient modulus M_R, the modulus of the subgrade reaction K and the California index of bearing capacity CBR.

The modulus of subgrade reaction K is derived from Winkler's theory of a plate on an elastic base. According to this theory, the reaction force at any support point is proportional to the deflection at that point and does not depend on the deflection at the surrounding points. The proportionality coefficient is the soil reaction modulus K (MN/m3).

The modulus of soil reaction depends on:

- Subgrade quality (M_R)
- Quality and thickness of the sub-base
- Possible loss of bearing capacity (LS) due to material erosion in the sub-base
- Depth to a solid, non-deformable layer

If the concrete slab is laid directly on the subgrade, the soil reaction modulus is calculated from the following expression:

$$K = M_R / 0{,}477$$

The resilient modulus of soil M_R can be determined experimentally or from the correlation between M_R and the California Bearing Index CBR. ($M_R = 10{,}342 * CBR$ (MPa)).

If the concrete slab is laid over the sub-base, the complex modulus of the sub-base reaction is used for the calculation, which depends on the bearing capacity of the sub-base, the modulus of elasticity of the sub-base, the thickness of the sub-base and the designed thickness of the cement-concrete slab.

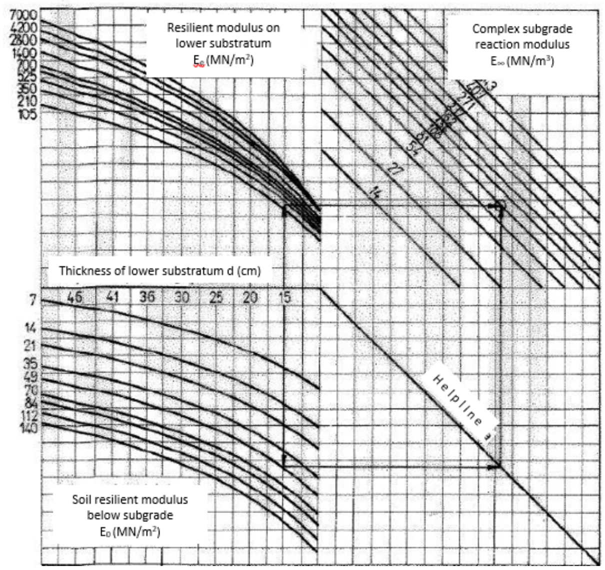
The modulus of elasticity for the sub-base made of unbound material E_1 is calculated from the ratio:

$$E_1 = M_R * 0{,}58 * (h_1)^{0{,}45}$$

where is:
E_1 – sub-base resilient modulus (Mpa)
M_R – subgrade resilient modulus (Mpa)
h_1 – sub-base thickness (cm)

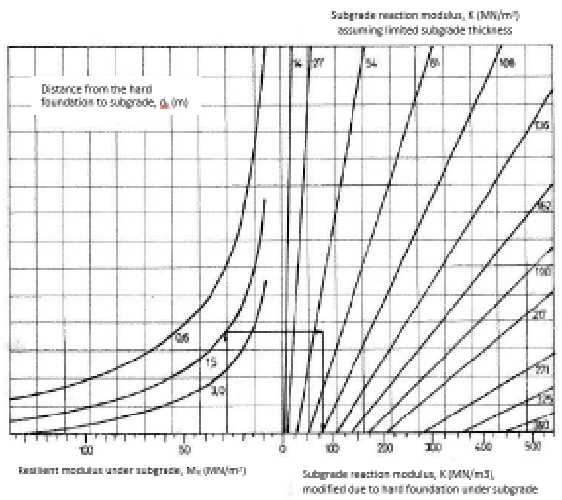
The complex modulus of the subgrade reaction is determined from the diagram in Figure 19

Figure 19: Diagram for estimating the complex modulus of subgrade reaction assuming that the thickness of the subgrade soil layer is greater than 3 meters



In the event that there is a rigid foundation under the subgrade at a depth of up to 3 meters, the correction of the modulus of the reaction of the subgrade is carried out according to the diagram in Figure 20.

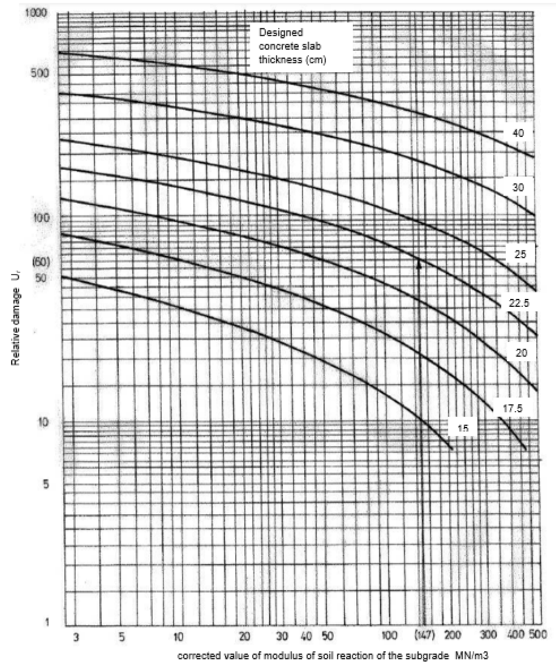
Figure 20 : Diagram for correction of modulus of reaction for non-deformable foundation



The modulus of soil reaction changes during the annual seasons, primarily depending on the state of moisture. In order to obtain a representative value, which includes seasonal changes in the stiffness modulus, the effective soil reaction modulus K_{eff} is calculated. It is determined through a weighted value based on n=12 or n=24 seasonal values, through the relative damage factor U_r. For each season/month of the year, U_{ri} i = 1.....12 (24) is determined, and based on the average value $\overline{U}_r$ from the same expression, the weighted (design) value of the base reaction module $K_{eff.}$ is determined.

$$\overline{U}r = \frac{\sum_i^n U_{ri}}{n} \quad \Rightarrow \quad K_{eff}$$

Figure 21 : Diagram for the assessment of relative damage based on the thickness of the slab and the bearing capacity of the subgrade



Properties of bonded materials. The basic indicator of the bearing capacity of layers made of materials bound with cement is the modulus of elasticity, or the modulus of stiffness of those bound with bitumen.

The modulus of elasticity of cement concrete E_C represents the ratio of stress and elastic return deformation during short-term loading and unloading. The approximate value of E_C is 20,000Mpa to 40,000Mpa. In addition to laboratory testing, the modulus of elasticity of cement concrete can be determined from the following expression (PBAB87):

$$E_c = 9250 \cdot \sqrt[3]{f_{bk} + 10} \quad \text{(MPa)}$$

f_{bk} – characteristic compressive strength of concrete (MPa)

Tensile strength of cement concrete when bending f_{ZS} is laboratory determined on prisms, or from the following expression (PBAB 87):

$$f_{zm} = 0{,}25 \cdot \sqrt[3]{f_{bk}^2}$$

where is:
f_{zm} – mean value of pure tensile strength (MPa)
f_{bk} – characteristic compressive strength of concrete (MPa)

The ratio of bending tensile strength f_{zs} and axial tensile strength f_z according to PBAB 87 is:

$$\frac{f_{zs}}{f_z} = \left(0{,}6 + \frac{0{,}4}{\sqrt[4]{h}}\right) \geq 1$$

h – cross-sectional height

The allowable tensile stress during bending is calculated using the expression:

$$\sigma_{zsdop} = \frac{f_{zs}}{F_s}$$

The safety factor F_s depends on the number of load repetitions and ranges from 1.33 (5,000 repetitions to failure) to 2.00 (100,000 or more repetitions to failure). F_s = 1.33 is usually adopted.

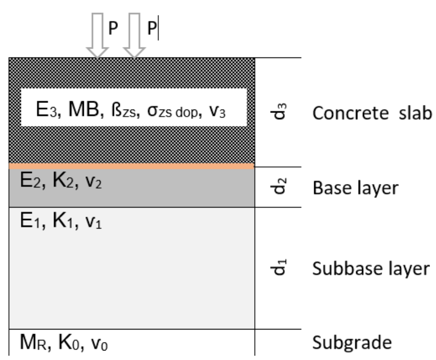
According to the specifications for the production of cement concrete pavement SRPS U.E3.020 for the traffic load expected on local roads (medium, light and very light), concrete MB30 (class C25/30) with f_{bk} ≥ 30 Mpa, f_{zs} ≥ 4.0 Mpa is used for the production of cement concrete slabs.

The modulus of elasticity for a cement-stabilized base and the stiffness modulus for bitumen-bonded materials are determined according to the procedure described in the section related to the dimensioning of new asphalt pavement structures according to SRPS U.C4.015.

Characteristics of pavement construction. Within the characteristics of the pavement structure, the assumed cross section, drainage, load transfer and loss of bearing capacity are defined.

In order to adopt the relevant design parameters, it is necessary to assume the structure of the pavement based on experience.

Figure 22: Cross section of the assumed pavement structure



The quality of drainage and the percentage of time during the year when the foundation of the structure and the subgrade are exposed to moisture close to saturation, are defined by the drainage coefficient C_d, with the values listed in Table 26.

Table 26: Drainage coefficients Cd

Drainage quality	The percentage of time during the year when the pavement structure is exposed to moisture levels close to saturation			
	< 1,5%	1 – 5 %	5 – 25 %	> 25 %
Excelent	1,25 - 1,20	1,20 – 1,15	1,15 – 1,10	1,10
Good	1,20 – 1,15	1,15 – 1,10	1,10 – 1,00	1,00
Medium	1,15 – 1,10	1,10 – 1,00	1,00 – 0,90	0,90
Poor	1,10 – 1,00	1,00 – 0,90	0,90 – 0,80	0,80
Very poor	1,00 – 0,90	0,90 – 0,80	0,80 – 0,70	0,70

Load transfer through a joint or a crack in a concrete pavement is defined by the load transfer coefficient J. This coefficient depends on the bearing capacity of the subgrade and thermal conditions, so the value of J is higher at lower values of the modulus of soil reaction K, higher thermal coefficients and larger temperature changes. In the case of the application of dowels on joints, the value J=3.2 is adopted. In case there is no dowels J= 3.8 to 4.4.

Loss of carrying capacity

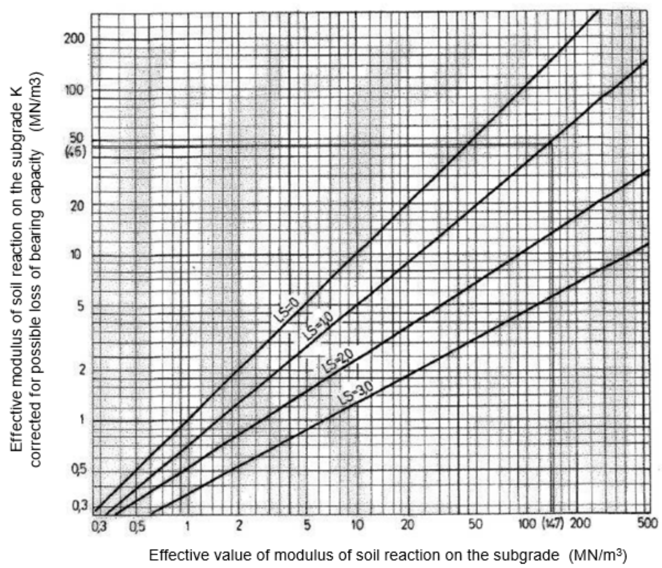
The coefficient of loss of bearing capacity LS, includes the possible loss of bearing capacity due to erosion of the subgrade or different vertical movements in the foundation soil.

Table 27: Correction Keff due to loss of load capacity LS

Type of material in the pavement structure	LS
Gravel stabilized with cement (E = 7000 - 14000 MPa)	0,0 – 1,0
Local material stabilized with cement (E = 3500 - 7000 MPa)	0,0 – 1,0
Bitumenized gravel or crushed aggregate (E = 2500 - 7000 MPa)	0,0 – 1,0
Aggregate stabilized with bitumen (E = 300 - 2100 MPa)	0,0 – 1,0
Stabilization with lime (E = 150 - 500 MPa)	1,0 – 3,0
Unbonded gravel (E = 100 - 200 MPa)	1,0 – 3,0
Fine-grained natural material in subgrade (E = 20 - 300 MPa)	2,0 – 3,0

The influence of the LS value on the reduction of subgrade reaction modulus K is shown in figure 23.

Figure 23: Correction of the effective modulus of the pavement reaction due to the loss of bearing capacity in the subgrade



Determining the required thickness of the cement concrete slab

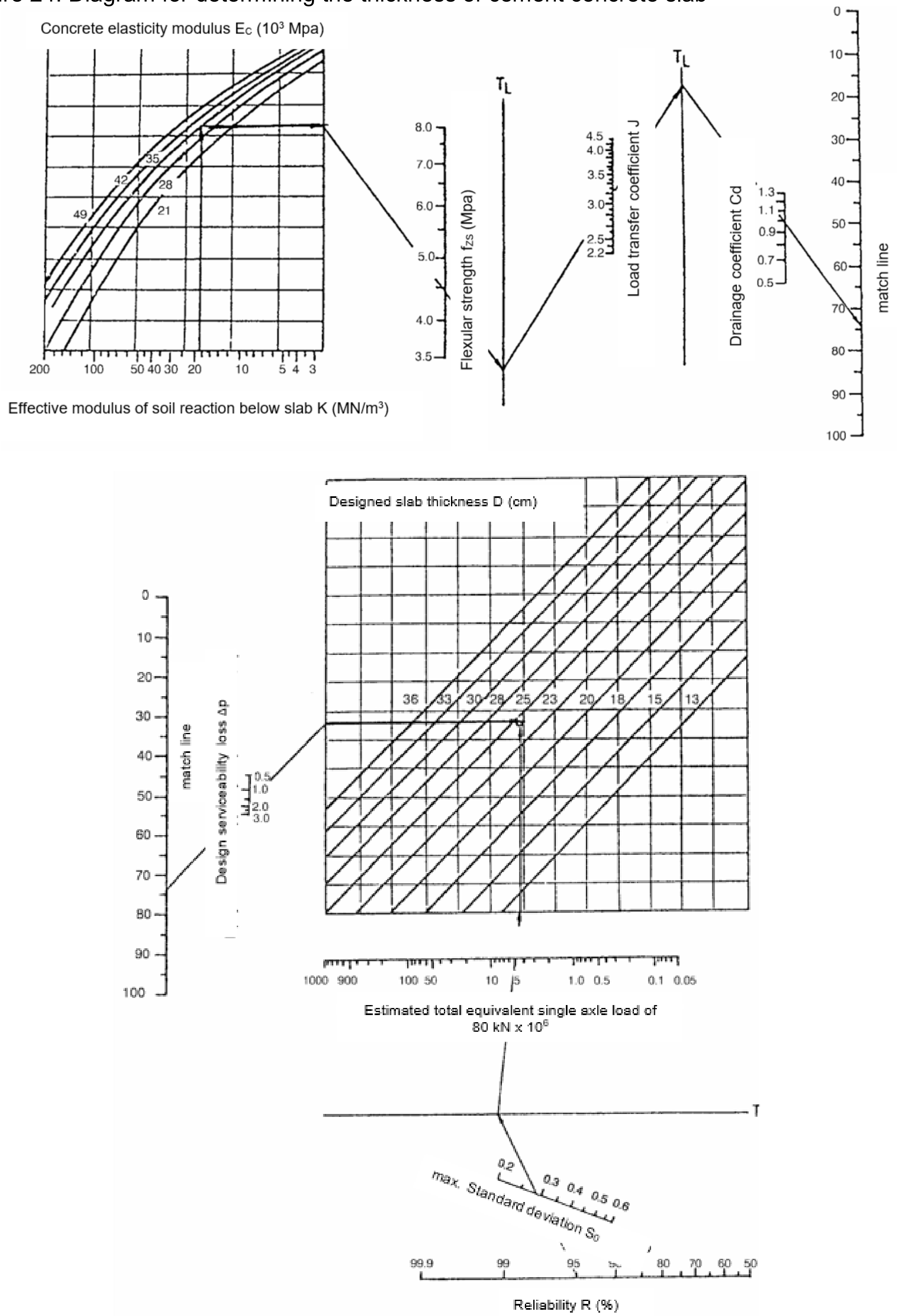
The thickness of the cement concrete slab is calculated from the basic equation:

$$\log \mathrm{ESO80} = \mathrm{ZR} \cdot \mathrm{So} - 3{,}0355 + 7{,}35 \cdot \log(\mathrm{D} + 2{,}54) + \frac{G_t}{1 + \frac{4{,}32 \cdot 10^{10}}{(D + 2{,}54)^{8{,}46}}} + (4{,}22 - 0{,}32 \cdot \mathrm{pt}) \cdot \log \frac{0{,}673 \cdot f_{ZC} \cdot C_d \cdot (D^{0{,}75} - 2{,}278)}{J \cdot \left[D^{0{,}75} - \frac{14{,}796}{\left(\frac{E_c}{K}\right)^{0{,}25}}\right]}$$

or graphically from the diagram in Figure 24 based on the following data: the effective modulus of reaction K on the base under the slab, the forecasted total equivalent traffic load in the design period, the reliability R, the largest standard deviation S_0, the designed loss of serviceability, the modulus of elasticity of concrete Ec, the allowable flexural strenght f_{zs}, load transfer coefficient J and drainage coefficient C_d.

The optimal combination of the thickness of the cement concrete slab and the type and thickness of the sub-base is chosen by the designer based on economic and other parameters.

Figure 24: Diagram for determining the thickness of cement concrete slab



Before the final acceptance of the pavement structure, stresses due to load and thermal effects must be checked.

After adopting the layers of the pavement structure and their thickness, the second phase of dimensioning is carried out during which is performed:

- Determination of slab dimensions
- Determining the joints dimnsions
- Dowel arangement and dimension
- For reinforced slabs transverse and longitudinal reinforcement

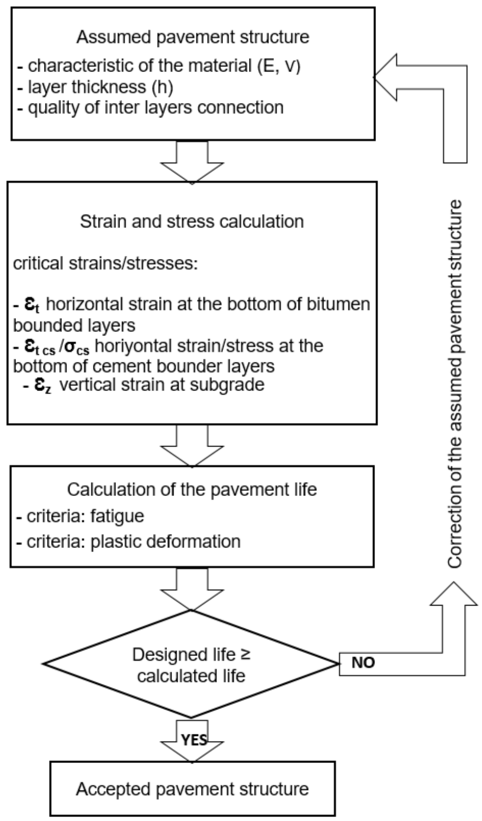
The preferred ratio between length and width of the slab is (L/B) ≤ 1.25, and the maximum dimension of the slab should not exceed 25 x h where h is the thickness of the slab in cm. For non-reinforced concrete slab without dowels L < 4.5 m, with dowels L < 6.0 m.

7.2.2 Mechanistic-Empirical Pavement Design

Since the beginning of the application of standards for empirical procedures for the design of pavement structures (SRPS U.C4.012 - 41 years ago; SRPS U.C4.014 and SRPS U.C4.015 - 28 years ago) there has been significant progress in the design methodology. For example, the AASHTO Design Manual, which was the basis for the creation of the SRPS U.C4.015 standard, has been innovated several times, so that first in the edition of 2008, and later in 2015, the concept of an empirical procedure was abandoned and an mechanistic-empirical procedure (MEPDG) was introduced for dimensioning pavement structures. This procedure is a combination of an analytical procedure for the calculation of stress, dilatation, deflection and an empirical procedure for evaluating the cumulative damage of the structure. It was shown that there are significant differences in the analysis of structures according to the earlier and innovative ASSHTO dimensioning procedures, especially in the domain of defining the condition of the pavement, as well as in the significantly smaller total thickness of the structure calculated according to the MEPDG procedure. This is logical because with purely empirical methods, with very limited influential data, higher safety coefficients are applied. The application of the mechanistic-empirical procedure allows for a more precise assessment of the structure's behavior, and therefore potential savings in material and construction/rehabilitation costs. This primarily applies to local roads with low traffic. Due to a number of specificities, and especially in the domain of conditions for composite materials and mixtures, direct application of AASHTO procedures is not possible, but a series of modifications must be made in order to adapt to local conditions.

Design is carried out by calculating the stress and deformations for the assumed pavement structure, using a mechanical model of a multi-layer elastic system or the finite element method. Based on the calculated values of the critical horisontal strain at the bottom of the bitumen-bound layers or the tensile stress in the cement-bound layers and the vertical strain on the top of subgrade, it is checked whether the design life of the assumed structure is sustainable in relation to fatigue and permanent deformation. If the assumed construction does not meet the given condition, correction and recalculation is performed until the condition is met.

Figure 25: Design procedure using mechanistic-empirical method



The first step in the dimensioning procedure is the formation of the pavement construction structure based on all influencing factors. The designer, based on all the influencing factors (predicted volume of traffic, climatic conditions, bearing capacity of the soil, availability of materials, technological conditions of construcyion, etc.), based on experience or with the help of one of the empirical methods, forms a proposal for the pavement structure. By this it is understood that the type of material for each of the layers and the subgrade, the characteristics of the material through modulus and Poisson's coefficient, the characteristics of connection between the layers and the assumption of the thickness of the layers are assumed.

The modulus of elasticity is most often calculated using formulas obtained as a result of research and laboratory tests, and verified during application on projects.

The resilient modulus of elasticity for the subgrade can be determined experimentally or from the correlation between M_R and the California bearing capacity index CBR, according to the following formula:

$$E = M_R = 10,342 * CBR \quad (MPa)$$

Poisson's coefficient for the soil in the subgrade is μ = 0.3 – 0.5

The modulus of elasticity for the sub-base made of unbound material E_1, depending on the module on the subgrade M_R and the thickness of the sub-base h_1, is calculated from the ratio:

$$E_1 = M_R * 0,58 * (h_1)^{0,45}$$

where is:
E_1 – sub-base resilient modulus (Mpa)
M_R – subgrade resilient modulus (Mpa)
h_1 – sub-base thickness (cm)

Poisson's coefficient for sub-base made of natural or crushed aggregate is μ = 0.35 - 0.40

For cement stabilization, the modulus of elasticity depends on compressive strength, so the modulus of elasticity for lean concrete and mixtures with crushed aggregate can be calculated from the formula:

$$E_{cs} = 4733 \cdot \sqrt{f_{b,28}}$$

and for mixtures with crushed and natural aggregate from the formula:

$$E_{cs} = k \cdot f_{b,28} \quad (k = 1000 - 1250)$$

where is:
E_{cs} – modulus of elasticity of lean concrete/cement stabilization (Mpa)
$F_{b,28}$ - compressive strength after 28 days (Mpa)

According to the standard SRPS U.E9.024 - Construction of bearing layers of road pavement structures from materials stabilized with cement and similar binders, the design value of compressive strength after 28 days for use in the lower bearing layers of roads with low traffic load is $f_{b,28}$ = 2.5 – 6.0 MPa.

Bitumen bound layers are characterized by a stiffness modulus which, for design purposes, is calculated from the stiffness modulus of the binder and the volume concentration of the binder and aggregates in the mixture.

The stiffness modulus of bitumen can be calculated from the following expression (Shell – Van der Poel):

$$S_{bit} = 1{,}157 \times 10^{-7} \times t_w^{-0{,}368} \times e^{-IP} \times (T_{800} - T)^5$$

where is:

S_{bit} – bitumen stiffness modulus (MPa)
t_w – load duration time (t_w=0,02 sec – corresponds for V=50-60 km/h)
T_{800} – the temperature at which penetration is 800pen° (1 pen° = 0,1 mm), approximately T_{PK}
T – representative temperatures for dimensioning the pavement structure
$pen_{25}°$ – penetration of aged binder (~ 65% penetration of the original binder)

$$IP = \frac{1951{,}55 - 500 \cdot \log(pen_{25}°) - 20 \cdot T_{pk}}{50 \cdot \log(pen_{25}°) - T_{pk} - 120{,}15}$$

The penetration index (IP) is an indicator of the bitumen's sensitivity to temperature changes. The higher the IP, the less sensitive the bitumen is to temperature changes. (standard bitumen IP -1.5 to +0.7, PmB IP>4)

Bitumen-bonded layers are thermosensitive, at low temperatures the layer becomes brittle and fragile, while at higher temperatures it is subject to plastic deformation, so special attention must be paid to determining the relevant temperature for pavement design. The temperature for design pavement structure (T) is determined from the weighted mean annual pavement temperature (WMAPT) according to the Shell Pavement Design Manual - Asphalt pavement and overlays for road traffic.

WMAPT is calculated from the reference air temperature (WMAAT) at a given location based on mean monthly air temperatures. For each mean monthly air temperature, the weighting factor WF is calculated from the following expression:

$$WF_i = 10^{\left(-1{,}224+0{,}06508 \cdot T_{air} - 0{,}000145 \cdot T_{air,i}^2\right)} \qquad i = 1 \ldots..12$$

The relevant air temperature is calculated from the following expression:

$$WMAAT = 19{,}66 + 16{,}91 \cdot \log(WF_{av} + 0{,}3117 \cdot (\log(WF_{av}))^2$$

where is:

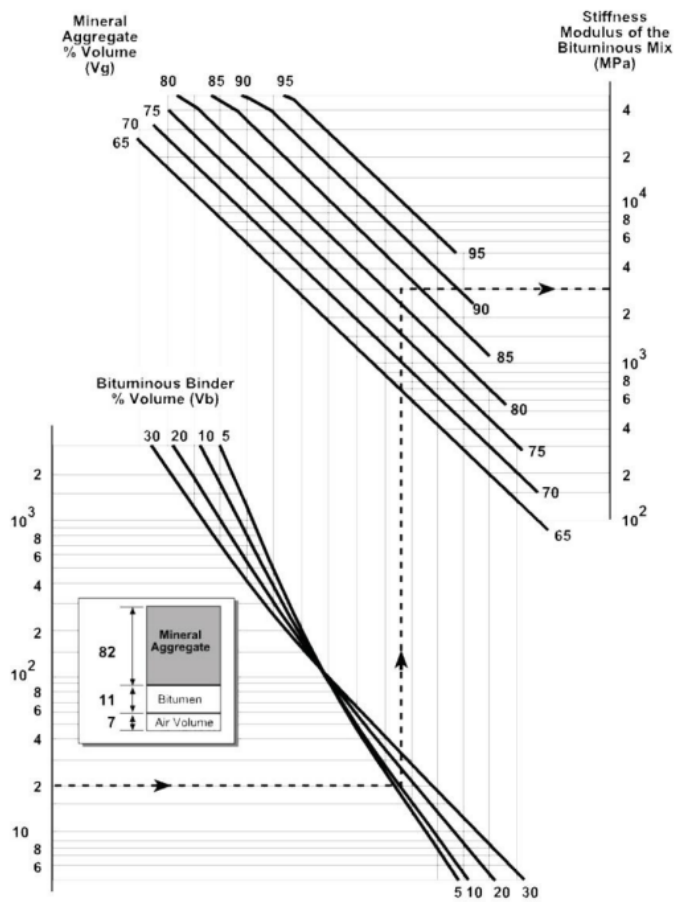
WF_{av} - the mean annual value of the weighting factor obtained from : $WF_{av} = \frac{\sum_1^{12} WF}{12}$

The relevant temperature of the layer at the depth h (cm) is:

$$WMAPT = WMAAT \cdot \left(1 + \frac{2{,}54}{h + 10{,}16}\right) - \left(\frac{2{,}778}{h + 10{,}16}\right) + 3{,}333$$

The stiffness modulus of the asphalt mixture is determined from the modulus of stiffness of the binder and the volume share of the components in the mixture. To calculate the stiffness modulus of bitumen at the relevant temperature of the layer and the ratio of the volume share of binder (V_b) and aggregate (V_a), the stiffness modulus of the bitumen mixture is obtained from the nomogram in Figure 26.

Figure 26: Nomogram for determining the stiffness modulus of bituminous mixture



The second step of the pavement structure design is the stress analysis, during which the deformations and stresses at certain points are calculated. Usually, during dimensioning, the risk of damage due to i) fatigue cracking in the asphalt mixture and ii) permanent deformation of the pavement due to exceeding the bearing capacity of the subgrade is considered. The analysis of the mentioned risks is carried out by controlling the horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the base. Pavement life prediction is done through fatigue laws developed in the laboratory and calibrated with on-site results. To consider bottom-up fatigue cracking, the fatigue law relates the horizontal tensile strain at the bottom of the asphalt mixture to the number of cycles to failure. Permanent deformation due to a drop in soil bearing capacity is controlled using fatigue laws, which relate the vertical strain at the top of the subgrade to the number of cycles leading to permanent deformation. Typically, pavement fatigue is defined as the ratio between the expected traffic and the number of standard axle load applications that the pavement structure can withstand.

The calculation of stresses and deformations is based on the assumption that the pavement structure can be represented as a multi-layered elastic system. When calculating stress, deformation and expansion in an elastic multi-layer system, the following assumptions are used:

1. The system consists of horizontal layers of uniform thickness resting on a semi-infinite foundation or half-space
2. Layers extend infinitely in horizontal directions.
3. The material of each layer is homogeneous and isotropic.
4. Materials are elastic and have a linear stress-strain relationship.

The system is loaded at the top of the structure by one or more circular loads, with an even distribution of stress over the loaded surface.

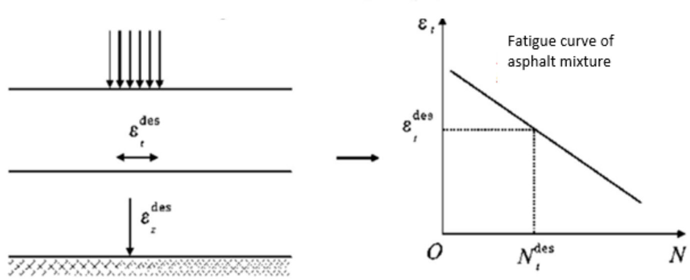
Due to the complexity, the calculation is performed using reference software tools (BISAR, CIRCLY, ELSYM5, CHEVPC...). Input data for calculating stress, dilatation and deformation using computer programs are the most common:

- number of layers
- elasticity modulus of layers
- poisson coefficients of layers
- layer thickness (except semi-infinite subgrade layer)
- the quality of the connection at the contact of each layer
- number of loads
- coordinates of the position of the load center
- vertical load component
- coordinates of the points for which the calculation is performed

The software calculates characteristic values and vectors of stress and strain tensors, principal stresses and strains, and corresponding principal directions. With the calculated stresses and dilatations, the structure is controlled for fatigue.

The fatigue strength of an asphalt mixture refers to its ability to withstand repeated bending without breaking. Fatigue is most often manifested in the form of cracking due to repeated traffic loads. Fatigue characteristics of asphalt mixtures are usually expressed as ratios between the initial stress or strain and the number of loading repetitions to failure, which are determined using repeated bending or direct tension tests. Fatigue tests are carried out in two ways, dilation control and stress control. In controlled dilation mode, the strain is kept constant by decreasing the stress during the test, while in controlled stress, the stress is kept constant which increases the dilation during the test. For the fatigue analysis of thinner flexible structures, the controlled dilation test is more often used. The fatigue behavior of a specific asphalt mixture can be characterized by the slope and the relative level of stress or deformation in relation to the number of load repetitions until failure.

Figure 27: Fatigue diagram of asphalt mixture



Many fatigue laws have been developed over recent years. In Serbia, fatigue calculation based on the Shell model is most often used, created as a result of an extensive laboratory testing program.

Shell's fatigue law for bitumen-bonded layers is defined by an equation that relates the service life, i.e. the number of repetitions of the load from a standard axle of 80 kN (N) with the value of tensile strain at the bottom of the bitumen-bonded layers (ε_t), the dynamic modulus of stiffness of the bitumen-bonded materials in Pa (S_{mix}) and by the volumetric share of bitumen in the mixture (V_b).

$$\varepsilon_t = (0{,}856 \cdot V_b + 1{,}08) \cdot S_{mix}^{-0{,}36} \cdot N^{-0{,}2}$$

or

$$N = (0{,}856 \cdot V_b + 1{,}08)^5 \cdot \varepsilon_t^{-5} \cdot S_{mix}^{-1{,}8}$$

Construction is checked for the appearance of permanent deformation by applying the fatigue law that connects the service life, i.e. the number of repetitions of the load from a standard axle of 80 kN (N) with the value of vertical strain on the top of subgrade (ε_z)..

$$\varepsilon_z = a \cdot N^{-0{,}25}$$

or

$$N = b \cdot \varepsilon_z^4$$

where is:

Confidence level	a	b
50%	2.8×10^{-2}	$6{,}15 \times 10^{-7}$
85%	2.1×10^{-2}	$1{,}94 \times 10^{-7}$
95%	1.8×10^{-2}	$1{,}05 \times 10^{-7}$

The verification of the preliminary pavement structure is performed by comparing the permitted number of load repetitions of the pavement structure according to both criteria, with the predicted number of load repetitions. If the permitted number of repetitions of the load is equal to or greater than the predicted one - the proposed structure meets the conditions and is adopted as a design solution. If it is not satisfactory, the proposed structure is corrected by changing the type of material in the layers of the structure or by increasing the thickness of the layers. For the modified construction, the critical stresses and strains are recalculated and the permitted number of load repetitions is calculated, ie. expected life of the structure. The procedure is repeated until the permitted number of load repetitions is equal to or greater than the forecast for the analyzed structure.

In the case of phased construction, mixed traffic loading (multiple types of loads) or calculations with changing layer properties due to seasonal influences (temperature and humidity), Miner's law of fatigue accumulation is applied. The sum of damage to the layers of the pavement structure in various stages, under different loads or seasonal changes in the modulus of the layers must be less than 1.

$$IO = \sum(\Delta IO) = \sum_{i=1}^{n} \frac{N_{st,i}}{N_{v,i}} = \frac{N_{st,1}}{N_{v,1}} + \frac{N_{st,2}}{N_{v,2}} + \cdots \ldots + \frac{N_{st,n}}{N_{v,n}} \leq 1$$

where is:

IO – damage index

N_{st} – actual traffic load (in the i-th phase of construction, for a certain type of load or in a certain climatic season)

N_v – allowed number of load repetitions (in the i-th phase of construction, for a certain type of load or in a certain climatic season)

7.2.3 Pavement Design Catalogue

The process of pavement design is a complex procedure in terms of time duration and costs. In order to simplify the procedure, reduce costs and shorten the time needed for design, for standard conditions of road exploitation, and especially for new pavement structures, catalogue design is increasingly applied. The application of this method is possible only under the condition of the existence of procedures and standards that define all the data essential for the construction of the pavement structure. Dimensioning according to this procedure still requires activities to collect input data, but significantly reduces time and costs in other design phases, because it offers already defined construction solutions depending on predefined local conditions (traffic load, soil bearing capacity, soil drainage conditions, frost effect, etc.).

Recognizing the convenience of catalogue design, the road directorates of most European countries have developed procedures for the application of this design method. The introduction of catalogue design of pavement constructions in Serbia is justified considering the existing practice and experience in countries where this procedure has been in practice for many years. It certainly implies the prior preparation of a number of procedures and standards, especially the standardization of the quality of composite materials, the development of standard technical specifications for the execution of works, the standardization of traffic loads, mapping of climate impacts, etc. The convenience of applying this design method is the shortening of project development deadlines, the reduction of costs and the reduction of the risk of applying economically and technically inadequate project solutions. Although in 2020 preparatory activities were initiated for the introduction of catalogue design of pavement structures in Serbia and the document " Instraction for preparation of guidelines for asphalt pavement design on state roads of I and II category" was prepared, up to date no basic studies and procedures have been carried out that would enable the application of this dimensioning procedure of pavement structures in Serbia. Bearing in mind the very easy applicability of this dimensioning method to pavement constructions of local roads, below is given as an example a brief overview of the catalogue design process in Austria.

The process of catalogue design of pavement structures of public roads in Austria is described in document RVS 03.08.63 (edition 2016). Within this document, typical solutions are given with the thickness of each layer of the pavement structure, depending on the traffic load and the applied materials, with the condition of the minimum bearing capacity of the pavement. Application of the catalog requires prior familiarization and application of the reference documents listed in the catalog, which refer to the quality of composite materials and mixtures for the production of pavement construction layers.

The catalogue applies to the construction of new and reconstruction of existing pavement structures on public roads. Reconstruction means investment works on the renewal of the pavement structure, from the replacement of the entire structure to the replacement of certain layers of the pavement structure. The catalogue offers the possibility of choosing within four basic types of construction depending on the type of pavement top layer: with asphalt, with concrete, with concrete block and with stone cube.

Traffic load is classified within 10 groups depending on the number of load repetitions expressed over an equivalent axle load of 100 kN.

Table 22: Austrian catalogue - classification groups according to traffic load

Class	LK185	LK89	LK40	LK21	LK18	LK6,5	LK2,1	LK0,6	LK0,15	LK0,075
BNWL (millions)	> 89 ≤185	>40 ≤89	>21 ≤40	>18 ≤21	>6,5 ≤18	>2,1 ≤6,5	>0,6 ≤2,1	>0,15 ≤ 0,6	>0,075 ≤0,15	≤0,075

The total number of repetitions of the load expressed through the equivalent axle load of 100kN (BNWL) during the designed operational life of the structure is calculated using the formula:

$$BNLW = NLW_{daily} * R * V * S * 365 * n * z$$

where is:

NLW_{daily}- estimated average daily number of of the equivalent axle load of 100kN over road profile during the first year of exploitation. It is calculated from the sum of the average daily traffic of individual groups of vehicles multiplied by the equivalence factor for each group of vehicles to convert into an axle load of 100 kN. In case it is not possible to estimate the traffic by vehicle groups, the average daily number of all vehicle categories multiplied by the mean equivalence factor specified depending on the road category is used.R – faktor raspodele obima saobraćaja po smerovima

V – the influence factor of the number of traffic lanes per direction
S – traffic lane width factor
n – design life of pavement (usually 20 years for flexible and 30 years for rigid pavement constructions)
z – traffic growth factor

The typical pavement construction in the catalogue are based on the application of standard materials in the construction layers. For each type of structure, the thicknesses of the layers are determined from the stress and deformation analysis and the fatigue check of the structure in relation to the traffic load class.

The calculation of typical flexible and semi-rigid pavement structures was performed using the theory of a multi-layer elastic system. When modeling the soil as the base of the structure, four different bearing periods were taken into account, in accordance with the seasons. The stiffness of the unbound lower bearing layers is determined depending on the type of material of the lower layers and their thickness. For mixtures stabilized with cement, a constant stiffness over the year was assumed. In contrast, a stiffness model is used for bituminous layers, which contains a total of twelve different stiffness levels. Each level refers to the characteristic temperature distribution on the pavement, considering the corresponding seasonal period, the temperature difference between day and night and the thickness of the layer.

For all types of constructions from the catalogue, the minimum bearing capacity of the subgrade is required, expressed through the deformation modulus E_{v1}≥35MN/m^2 (German procedure). If the bearing capacity of the soil is lower, it is necessary to take appropriate measures to reach the required bearing capacity (improvement of the soil, replacement of the soil, etc.).

In the event that the soil layer immediately below the pavement is of sufficient thickness and insensitive to the effects of frost, as well as meeting the requirements for unbound mixtures of the sub-base (deformation modulus and compaction), it is possible to omit the production of the sub-base layer.

According to Austrian regulations, the material used for the production of unbound layers of pavement construction is classified depending on its physical and mechanical properties, granulometric composition and the ratio of crushed and rounded grains. There are 10 categories in total, from U1 to U10.

Unbound mixtures of classes U6, U7 and U8 are used for the sub-base layers with the condition of the minimum value of deformation modules on the upper surface of the layer, for U6 and U7 (E_{v1}≥72MN/m^2), and for U8 (E_{v1}≥60MN/m^2). Application of the appropriate mix class in construction depends on the type of construction and traffic load. When applying the mixture of class U8, for a lower rank of the road and smaller layer thickness, slightly lower values of the deformation modules are acceptable (layer thickness 15 cm - E_{v1}≥51MN/m^2, layer thickness 20 cm - E_{v1}≥55MN/m^2).

In typical pavement construction, unbound mineral mixtures or mineral mixtures with a binder are used for the base layers. For unbound mixtures, a mineral mixture of classes U1 to U5 is used (U1 and U2 for all traffic load classes, and U3, U4 and U5 for lower classes LK4-LK0.05). The following table specifies the class of unbound mineral mixture for base layer and the required value of the deformation modulus on the upper surface of the layer, depending on the catalogue type of construction and traffic load class.

Table 29: Austrian catalogue - unbound mixtures for base layers

Pavement type	Class of unbound mixture (RVS 08.15.01)	Traffic load class	E_{V1}
AS1	U2	LK10, LK25, LK42, LK82, LK163	E_{V1}≥90 MN/m2
	U3 i U4	LK0,05, LK0,1, LK0,4, LK1,3, LK4	E_{V1}≥90 MN/m2
	U5	LK0,05, LK0,1, LK0,4, LK1,3, LK4	E_{V1}≥75 MN/m2
AS2	U1	Sve klase	E_{V1}≥120 MN/m2
AS3	RA		
AS5	U2	LK10, LK25	E_{V1}≥90 MN/m2
	U3 i U4	LK0,05, LK0,1, LK0,4, LK1,3, LK4	EV1≥90 MN/m2
PF1-PF4	U3 i U4	LK0,05, LK0,1, LK0,4, LK1,3, LK4	E_{V1}≥90 MN/m2
PF1-PF2	U5	LK0,1	E_{V1}≥75 MN/m2
PF3	U5	LK0,05	E_{V1}≥75 MN/m2

RA - mixture with recycled asphalt granules (for traffic load classes LK4, LK10, LK25, LK42, LK82, LK163 - max 5%, and for classes LK0.1, LK0.4, LK1.3 - max 50% of recycled asphalt granules .

In the typical constructions given in the catalogue for base layers, in addition to unbound mixtures, binder mixtures are also used.

Mixtures with a bitumen binder are used for the construction of the binding layer and the wearing course in typical constructions with a flexible pavement and in rigid constructions as a base under a concrete slab (except for low traffic loads LK0.6, LK0.15 and LK0.075). Bitumen with increased resistance to rutting is used for the mixtures applied in the binding layer, and bitumen with increased resistance to fatigue-dilation is used for the mixtures in the base layer.

Bituminous mixtures for the upper layers of the structure are made in accordance with a set of regulations related to this area. In the catalogue type constructions, the total thickness of the asphalt layers is indicated (upper bearing layer if it is made of an asphalt mixture + binding layer + wear layer). The thickness of the wear layer is determined depending on the type of asphalt mixture in accordance with the relevant document.

In the case when the top layer is done as a surface treatment (most often in order to improve the functional characteristics of the pavement), the thickness of this layer is not included in the total thickness of asphalt layers for flexible pavement types from AS1 to AS4.

If the surface pavement layer is made with drainage asphalt, the thickness of this layer is included in the total thickness of the asphalt layers with 50% of the thickness for pavement types from AS1 to AS4.

AS5 type constructions have a top layer of semi-rigid mixture (asphalt mixture with 25-30% voids filled with special mortar) with optimal properties of high strength mortar and flexibility of bitumen bound mineral mixture. This type of construction can be used for medium heavy and light traffic loads (LK25-LK0.075).

In type constructions BE1 and BE2, the pavement is made of concrete slabs, with the fact that in type BE1 the lower layer is made of unbound mineral mixture, and in type BE2 it is made of a mixture with hydraulic binder (stabilization).

For a traffic load of less than 1.3 mil. standard axles of 100kN, it is possible to apply pavement with stone blocks or concrete blocks.

Catalog types of construction PF1-PF3 are made with a pavement of stone cubes on supporting layers of unbound mineral mixture. Constructions of type PF5-PF7 are also covered with stone blocks, but in the base is a layer of drainage concrete. Due to the low shear resistance, construction types PF3 and PF7 are not performed in places where horizontal forces are expected to occur.

Similar to the stone block pavement, there are two types of pavement construction with a concrete blocks. Construction type PF4 with supporting layers of unbound mineral mixture and construction type PF8 with a layer of drainage concrete.

Depending on the traffic load and dimensions, minimum thicknesses of concrete blocks are prescribed.

The process of pavement design using the typical pavement catalogue

Based on the category of traffic load and the type of pavement, the catalogue construction type is selected, depending on the applicability of the material for making the upper and lower bearing layers.

Depending on the pavement type, the construction types are indicated in the catalog, AS1-AS5 with asphalt top layers, BE1-BE2 with concrete slabs, PF1-PF8 with concrete blocks/stone blocks.

The choice of construction type is made from the following tables, which are an integral part of the catalog:

Table 30 - typical pavement constructions with an asphalt layers

Table 31 - typical pavement constructions with concrete slabs/

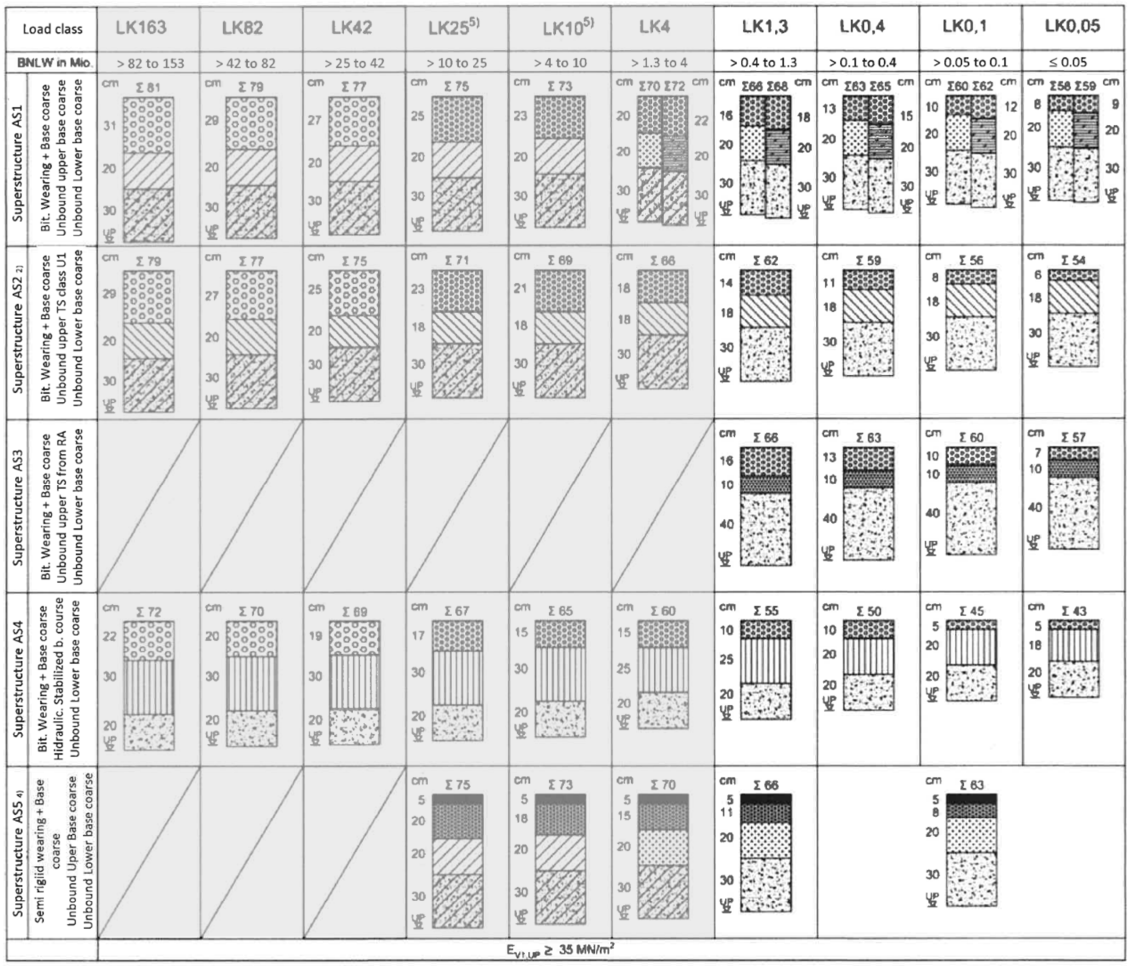
Table 32 - typical pavement structures with concrete blocks/stone blocks with bearing layers of unbound mineral mixture

Table 33 - typical pavement structures with concrete blocks/stone blocks over drain base layer

In the tables, the types of pavement structures that are rarely used on local roads are shaded.

The thicknesses of the construction layers listed in the tables represent minimum thicknesses. After choosing type of pavement structure from catalogue, the resistance of the structure to local conditions is checked and the quality requirements of each layer of the structure are defined in accordance with the specifications in the relevant documents.

Table 30: Typical pavement constructions with an asphalt layers



1) For higher loads, according to RVS 03.08.68, a separate calculation for dimensioning is required.
2) Specified thickness for the asphalt layers package apply only if the higher value of Ev1 ≥ 120 MN / m2 is achieved for the upper base course of class U1 according to RVS 08.15.01. Otherwise the corresponding value of the thickness should be in accordance with construction type AS1.
3) For lower loads, dimensioning should be carried out in accordance to RVS 03.03.81.
4) For loads over 25 million BNLW separate calculation for dimensioning is required in accordance to RVS 03.08.88.
5) If all bituminous base layers are made with polymer-modified binders in accordance with ÖNORN EN 14023, the upper load class limit can be increased by 10%

- Bituminous base and wearing course according to RVS 08.16.01 or RVS 08.16.04, RVS 08.16.05, RVS 08.16.06, whereby the bituminous base layer AC D is made with road construction bitumen in accordance with ONORM EN 12591
- Bituminous base and wearing course according to RVS 08.16.01 or RVS 08.16.04, RVS 08.16.05, RVS 08.16.06, whereby all bituminous base layers are made with polymer-modified binders in accordance with ONORM EN 14023.
- semi-rigid wearing course according to RVS 08.16.03
- bituminous base course according to RV 08.16.01 or RVS 08.16.06
- Hydraulically stabilized base layer (ST-Z, ST-T) according to RVS 08.17.01
- Unbound base course with asphalt granulate according to RVS 08.15.02
- U1 unbound upper base course of class U1 aggregate according to RVS 08.15.01
- U2 unbound upper base course of class U2 aggregate according to RVS 08.15.01
- U3, U4 unbound upper base course class U3 or U4 aggregate according to RVS 08.15.01
- U5 unbound upper base course of class U5 aggregate according to RVS 08.15.01
- U6, U7 unbound lower base course class U6 or U7 aggregate according to RVS 08.15.01
- U8 unbound lower base course of class U8 aggregate according to RVS 08.15.01

Table 31: Typical pavement constructions with concrete slabs

Load class 3)	LK185	LK89	LK40	LK21	LK18	LK6,5	LK2,1	LK0,6	LK0,15	LK0,075
BNLW in Mio.	> 89 to 185 2)	> 40 to 89	> 18 to 40	> 18 to 21	> 6.5 to 18	> 2.1 to 6.5	> 0.6 to 2.1	> 0.15 to 0.4	> 0.075 to 0.15	≤ 0.075
	concrete slab with dowels							concrete slab without dowels		
Superstructure BE1 Concrete slab - wearing course Bituminous base course Unbound base course	cm Σ 79 29 5 45 UP	cm Σ 77 27 5 45 UP	cm Σ 75 25 5 45 UP	cm Σ 73 23 5 45 UP	cm Σ 72 22 5 45 UP	cm Σ 70 20 5 45 UP	cm Σ 55 20 5 30 UP	cm Σ 50 20 30 UP	cm Σ 48 18 20 UP	cm Σ 36 16 20 UP
	concrete slab with dowels							concrete slab without dowels		
Superstructure BE2 Concrete slab - wearing course Bituminous base course hydraulically stabilized base course Unbound lower base course	cm Σ 74 29 5 20 20 UP	cm Σ 72 27 5 20 20 UP	cm Σ 70 25 5 20 20 UP	cm Σ 69 23 5 20 20 UP	cm Σ 68 22 5 20 20 UP	cm Σ 65 20 5 20 20 UP	cm Σ 61 18 5 18 20 UP	cm Σ 56 18 18 20 UP		cm Σ 54 16 18 20 UP
	The cross slope of the substructure surface is to be carried out in the same way as the roadway.									
	$E_{V1,UP} \geq 35$ MN/m²									

Comments (regarding the definition of the concrete slab geometry, see also RVS 08.17.02):

1) In the case of constant traffic close to the edge (wheelspin center closer than 80 cm to the edge of the concrete slab), frequent crossings over the free concrete slab edge or frequent load repetition, the concrete slab thickness should be increased to the next higher load class.
2) Separate dimensioning is required for loads over 185 million BNLW.
3) With low loads, dimensioning according to RVS 03.03.81 can be carried out.

Concrete slab – wearing course according to RVS 08.17.02

bituminous base layer according to RVS 18.16.01

hydraulically stabilized base course (ST-Z, ST-T) according to RVS 08.17.01

U6,U7 unbound lower base course with aggregate class U6 or U7 according to RVS 08.15.01

U8 unbound lower base course with aggregate class U8 according to RVS 08.15.01

Table 32: Typical pavement structures with concrete blocks/stone blocks with bearing layers of unbound mineral mixture

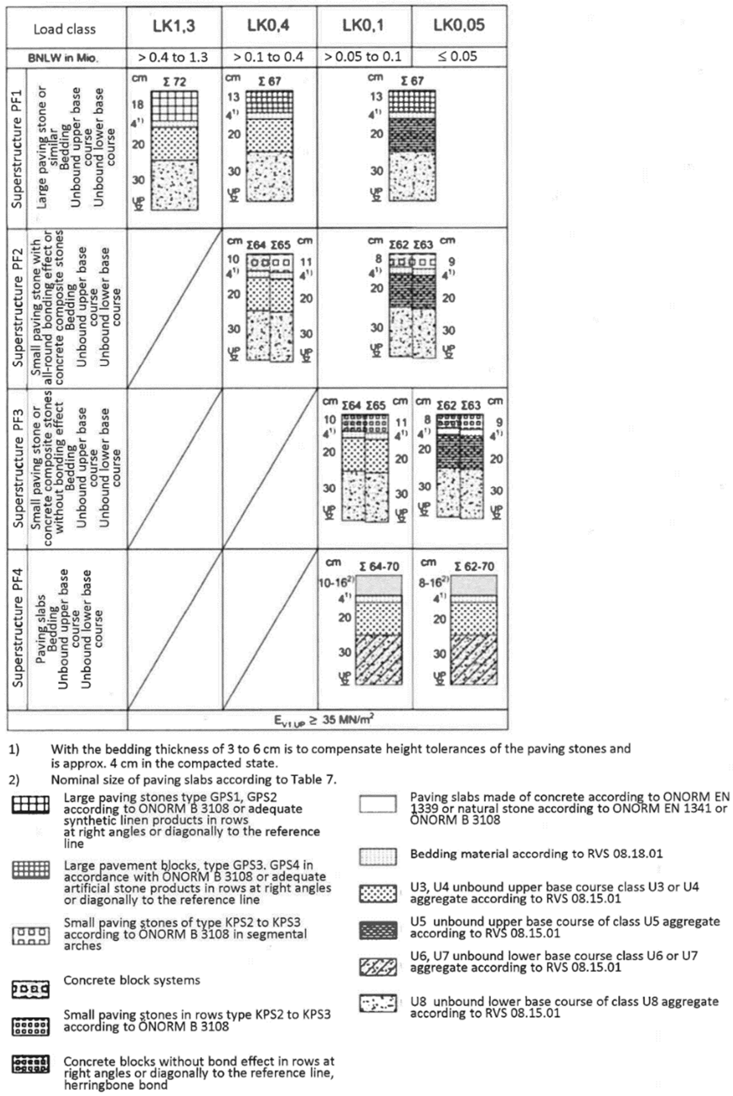
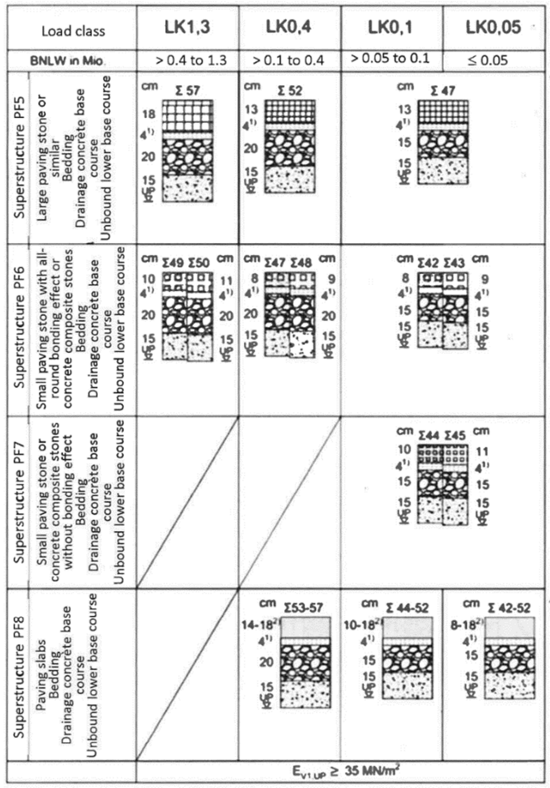
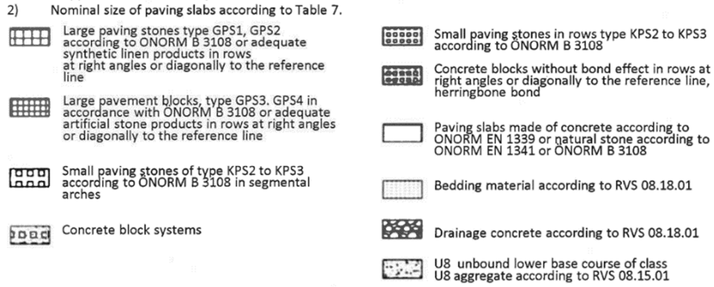


Table 33: Typical pavement structures with concrete blocks/stone blocks over drain base layer a layer



1) With the bedding thickness of 3 to 6 cm is to compensate height tolerances of the paving stones and is approx. 4 cm in the compacted state.

2) Nominal size of paving slabs according to Table 7.



8 Evaluation of the functional and structural condition of pavement structures

For quality road management and planning of corrective measures, the assessment of the condition of the pavement structure is of crucial importance. The assessment is carried out through the procedure for assessing the structural and functional characteristics of the road. Structural conditions focus on the structural integrity of the structure; while functional condition refers to skid resistance, surface texture and roughness of the pavement and the overall rating of pavement quality.

The assessment of the pavement quality should enable the local road manager to make a decision on proper maintenance, rehabilitation or reconstruction measures of the road or a certain road section.

The process of assessing the condition of the pavement structure is carried out through several steps, starting with data collection, visual recording of the pavement distress, laboratory and field tests and measurements, and ending with the analysis of the collected data. If the road manager has established a pavement management system (Pavement Management System), data is entered into this system, which should help in deciding what to do. Until the establishment of this system, the manager makes a decision on taking certain measures based on internal criteria.

Data collection is the first and most important step in pavement evaluation. An up-to-date database on the condition of the structure after construction and during exploitation is of great help in assessing the condition and defining the program of investigation works, so special attention should be paid to the regular updating and maintenance of these databases.

The assessment of the condition of the pavement structure is carried out through the assessment of functional characteristics and structural characteristics (bearing capacity).

The organization that manages the road has the obligation to prepare annual and five-year reports on the control and assessment of the condition of public roads, i.e. comprehensive inspection and technical assessment of the state of public road elements (Rule book on the content and form of reports on the performed control and assessment of the state of public roads - "Official Gazette of RS", number 34 of May 17, 2019).

8.1 Evaluation of the functional condition of pavement structures

Within the functional condition assessment procedure, the condition of the surface characteristics of the pavement and the level of pavement distress are determined.

The assessment of functional characteristics of the pavement is carried out by checking the longitudinal roughness, texture and skid resistance the pavement surface.

Longitudinal roughness is expressed through the International Roughness Index (IRI) and is a deviation from an ideally flat surface with characteristic values of wavelengths that affect vehicle oscillations and driving comfort. Roughness measurement is carried out in accordance with the SRPS EN 13036-6 standard. Depending on the IRI value, the pavement roughness is classified into five groups:

Roughness condition	very good	good	satisfactory	poor	very poor
IRI (m/km)	< 1,0	1,0 do 2,5	2,5 do 3,5	3,5 do 5,5	> 5,5

For local roads with a speed limit of up to 50 km/h, an acceptable value of IRI < 5 m/km can be considered.

The roughness and skid resistance of the pavement surface depend on the texture of the pavement and have a crucial impact on traffic safety. Depending on the wavelength, microtexture (<0.5mm), macrotexture (0.5-50mm) and megatexture (50-500mm) are distinguished. Microtexture depends on the type of aggregate and has a key influence on tire-pavement contact, macrotexture depends on the type of mixture and has an impact on pavement surface drainage, and megastructure depends on the quality of construction and affects comfort and driving speed.

Microtexture is most often measured with a device with a pendulum (Portable Skid Resistance Tester -SRT) in accordance with the SRPS EN 13036-4 standard. Limit values are from SRT=65 (very good friction) to SRT=45 (low friction).

The macrotexture is measured with a laser profilometer or, in the case of local roads, most often by volumetric methods. The mean texture depth is measured in accordance with the SRPS EN 13036-1 standard.

Distress assessment of the pavement surface on local roads is done by visual inspection of the distress. When recording the distress, a pavement distress catalog is used, on the basis of which the type of distress is identified and classified in relation to the intensity and affected area.

Distresss are classified according to the cause of occurrence, into distresss caused by:

- traffic load
- aging of materials (oxidation of bitumen binders)
- thermal influences
- inadequate material
- mistakes in the construction

As a consequence of the mentioned causes, distress occurs in the form of:

- Fatigue crack (most commonly aligator cracks)
- Ruting (as a permanent deformation of the pavement structure)
- Thermal cracks (most often in the form of longitudinal and transverse cracks due to thermal shrinkage and increase in stiffness of bitumen-bonded materials at low temperatures)
- Block cracks (due to bitumen aging)
- Pavement blowup (due to the effects of frost)
- Potholes (degradation of distress most often due to the effects of frost)
- Pavement raveling (due to loss of bond between bitumen and aggregate)
- Bleeding bitumen (for mixtures with excess bitumen)
- Aggregate polishing (decrease in roughness, typical for limestone aggregate)

On the basis of recording with identification, intensity and surface area of the distress, the sides of the distress are indexed, most often using the following methodologies:

- Present Serviceability Index (PSI) i
- Pavement Condition Index (PCI)

The serviceability index (PSI) is used in pavement design according to the 1993 AASHTO method and is calculated from the following formula:

$$PSI = 5.03 - 1.91 \cdot \log(1 + SV) - 0.01 \cdot \sqrt{C + P}\text{-}0.2139 \cdot RD^2$$

where is:

SV (slope variance) – slope change, mean value from two ruts
C,P – surface affected by cracks and patches (m2 /1000 m2)
RD – rut depth (cm)

The PSI value ranges from 5 to 0.

The lower value of the usability index for local roads is PSI_t = 2.0

The Pavement Condition Index (PCI) is calculated using a standard pavement distress catalog according to the methodology described in ASTM DS6433-18. Depending on the PCI value, the pavement condition is classified into 7 categories.

Figure 15: Standard PCI Rating Value

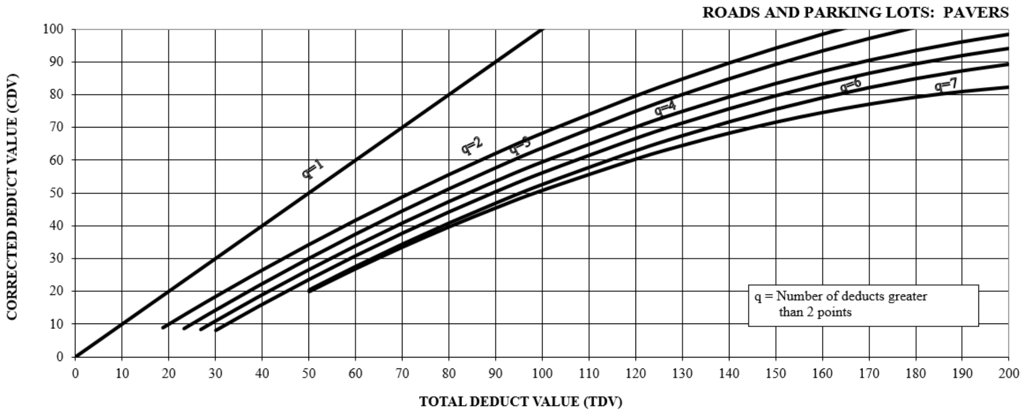
Determination of pavement condition index is carried out through several steps. Before starting the recording of the distress, it is necessary to divide road into sections of 150m2 - 300m2 and calculate the number of representative sections on which the recording will be performed, provided that a reliability level of 95% is achieved. During the recording, the type of distress, intensity and involvement are identified. Identification is done according to the catalog that includes 19 representative types of distress

After recording, the density of distress (%) is calculated, i.e. the ratio of the extent of distress in relation to the area of the section. The second step is the determination of negative points depending on the intensity and involvement, for each of the recorded distresses from the diagrams that are an integral part of ASTM DS6433-18. The third step is the determination of the sum of negative points (TDV), where only distress with values above 2 are taken into further processing, and the fourth step is the determination of the corrected sum of negative points.

The final value of PCI is equal to:

$$PCI = 100 – CDV$$

Figure 16: Determination of the corrected value of negative points



To calculate PCI, there are a number of programs that facilitate the calculation by avoiding the use of a series of diagrams to determine negative damage values.

8.2 Evaluation of the structural condition of pavement structures

The assessment of the structural condition of the pavement structure is determined based on visual inspection, field and laboratory testing and analysis of collected data.

The bearing capacity of the existing pavement structure is determined by measuring the vertical deformation (deflection) of the pavement surface. The aim of deflection measurement is to determine the condition of the existing pavement structure, to monitor the condition during exploitation and to plan interventions in a timely manner in order to maintain or increase the load capacity of the road.

The procedures for deflection measurement of pavement structures are based on the static or dynamic load of the measuring point on the pavement surface. The following deflection measurement procedures are most often used:

- Benkelman beam (under static load),
- Lacroix-deflectograph (under moving load),
- Falling weight deflectometer FWD (under dynamic load).

As part of the preparatory activities for recording deflections, it is necessary to determine the structure of the pavement that will be the subject of recording and analysis. Information about the structure of the pavement structure can be determined on the basis of:

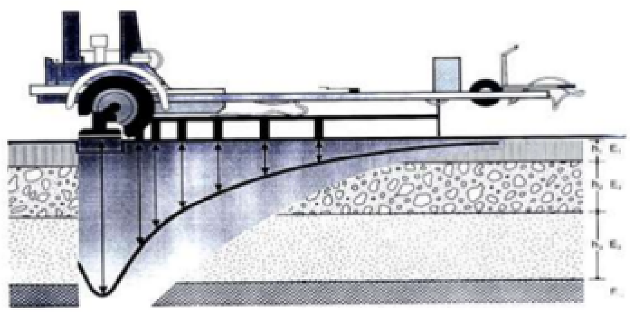
- Archive project/as-built project
- Sampling (core drill) with DCP test
- Excavation of testing pits
- Georadar screening

The sampling and laboratory test program should be based on the analysis of all relevant data collected by non-destructive testing. Data and results obtained by sampling and laboratory tests, in addition to the assessment of the condition layer to which they refer, should be used for calibration and verification of the results from the analysis of the pavement load capacity based on data obtained by measuring the deflection using non-destructive methods. In addition to standard laboratory tests, modern test methods based on real conditions of behavior in the exploitation of materials and mixtures in pavement construction should be included (for example, for asphalt mixtures set of standards SRPS EN 12697-1 to SRPS EN 12697-56).

In recent years, a device with falling weights (FWD) is mainly used to record deflections, so the following is a brief procedure for recording and analyzing data obtained by recording pavement with this device.

FWD is a device mounted on a trailer, in the central part of which there is a plate with a diameter of 300 mm through which the impulse load is transferred to the road surface. Above the plate is a weight that drops from a certain height to cause a load on the pavement similar to that exerted by a set of standard axle tires on the pavement. Most often, seven geophones, distant from the load plate at intervals of 30 cm, are used to measure the deflection of the pavement surface. In the case of local roads with a thinner pavement structure, the number of geophones can be reduced, provided that three external geophones must be placed at a greater distance than the equivalent thickness of the pavement structure.

Figure 17: FWD device

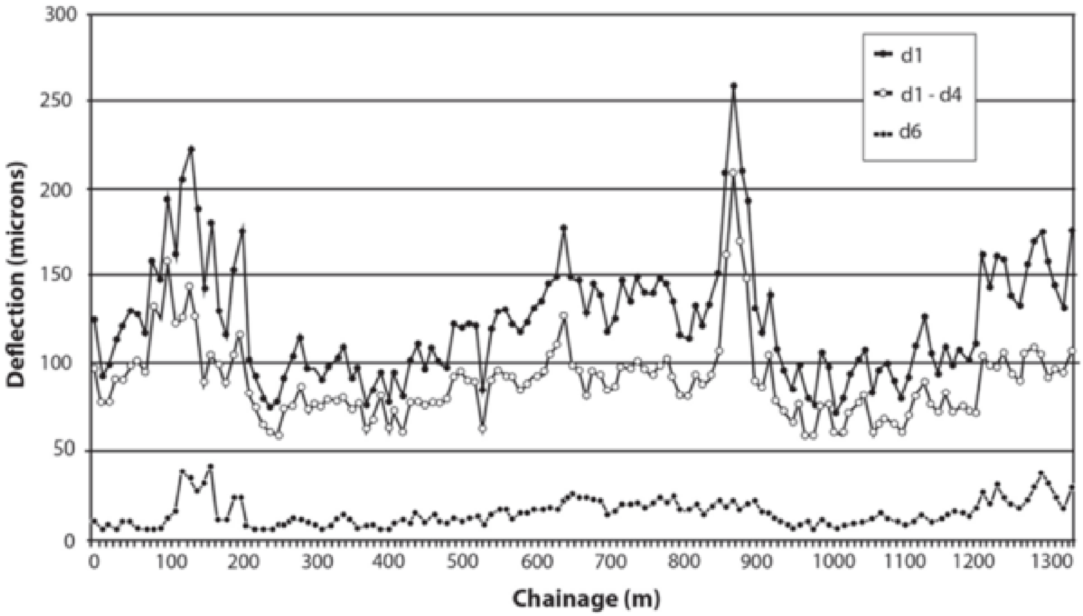


The distance between individual measuring points should be determined in relation to the purpose of the measurement. The distance should be up to 50 m for planning appropriate measures, and up to 200 m for roadway management. The entire procedure of measuring the deflection of the surface of the pavement structure using a deflectometer with a falling weight should be controlled electronically, via a computer. During the test, it is necessary to record data on the pavement temperature. Temperature has a significant effect on the stiffness modulus of asphalt layers, and therefore on the measured deflections. After the measurement, it is necessary to correct the deflections to some standard temperature in order to be able to compare them - typically 20^0C.

Deflections of the pavement structure depend on:

- Load
- Distances from load
- Characteristics of the pavement structure
  - layer thicknesses
  - modules of each layer

Figure 18: Graphical presentation of measured deflections



The data of the measured deflections are processed through the following steps:

a) Normalization of deflection (through normalization of load size and duration)
b) Correction of deflection (through correction of temperature and seasonal influences)
c) Calculation of homogeneous sections
d) Calculation of characteristic deflections and characteristic deflection basins within homogeneous sections

Deflection normalization is done for a certain standard load, in the case of local roads it is usually 40kN or 50kN. Normalization consists in the proportional change of the measured deflections in relation to the applied load.

The procedure for correcting the deflection with respect to temperature depends on the method used for the load-bearing analysis. Correction of only the maximum deflection, correction of the parameters of the deflection basin or correction of the modulus of the bitumen bound layers can be performed.

To define homogeneous sections, the method of cumulative differences is used based on deflections under load d_0, parameters of the deflection basin or other variables. This method determines the change of parameters along a certain section in relation to the average value of the parameters on the section.

When the homogeneous sections are defined and it is established that the coefficient of variation of the considered parameter is within the acceptable value (CV<30%) on the homogeneous section, the analysis of the parameters of the deflection basin and the calculation of the layer modulus is performed.

Figure 19: Deflection basin

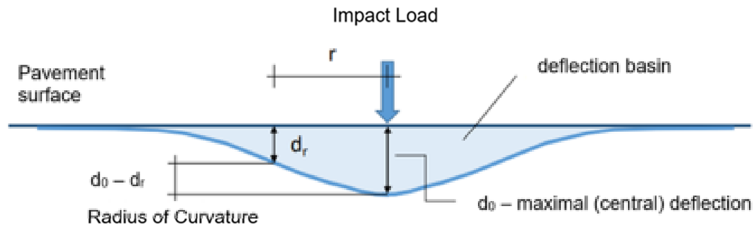


Table 23: Deflection basin parameters

Description	Label	Indication
Deflection under load	d_o	general condition of the pavement
Other deflections	d_r	condition of the layer at the equivalent depth r
Surface curvature index-SCI	$d_0 – d_{300}$	fatigue of bonded material layers
Base damage index - BDI	$D_{300} – d_{600}$	condition in the base layers
Subgrade curvature index - BCI	d_{n-1} - d_n	condition in the subgrade
Curvature basin factor - CBF	$(d_0 – d_r)/d_0$	condition of the layer at the equivalent depth r
Deflection factor - DF	d_0 / d_r	condition of the layer at the equivalent depth r

Table 24: Deflection criterion under load and SCI criterion for local road

Deflection under load d_0 (μm)	SCI300 = d_0-d_{300} (μm)	Ability to transfer loads
<300	<150	good
300-500	150-250	good to midium
501-800	251-400	midium to poor
>800	>400	poor

Note: the specified deflections refer to a load of 40kN

Table 25: Deflection criterion for defining the condition of the subgrade

Deflection at a distance of 2.1m from the load (μm)	Subgrade bearing capacity
<15	High
15-30	High to midium
31-45	Medium to low
>45	low

Note: the specified deflections refer to a load of 40kN

Table 26: Deflection limit values

Traffic load group	Number of repetitions of nominal axle load of 100 kN		Expected service life of rehabilitation (years)			
	per day	During the period of 20 years.	5	10	15	20
			maximum deflection (mm) under a load of 50 kN			
Heavy	300-800	$2x10^6$-$6x10^7$	1.2	1.0	0.9	0.6
Midium	80-300	$6x10^5$-$2x10^6$	1.5	1.2	1.1	0.8
Light	30-80	$2x10^5$-$6x10^5$	1.7	1.4	1.2	1.0
Very light	<30	< $2x10^5$	1.8	1.6	1.4	1.2

Source: Manual for road design in the Republic of Serbia, JP Putevi Srbije 2012.

Based on the results obtained by measuring the deflection of the surface of the pavement structure using a deflectometer with a falling weight, it is possible to determine:

- valid deflection,
- dynamic modulus of elasticity of the material layers of the pavement structure,
- the remaining service life of the pavement structure
- possibly necessary strengthening of the pavement structure.

The determination of the dynamic modulus of elasticity of the layers from the measured deflections is performed using an iterative procedure (Backcalculation), where the variation of the modulus of the layers is performed with the aim of obtaining the measured deflection basin by calculation. Iteration is performed until a satisfactory match between the calculated and measured deflection basin is obtained. This procedure requires the use of computer calculation software such as MODULUS 6.0, ELMOD 5.0 and EVERCALC 5.0.

Based on the results obtained by measuring the surface deflection of the pavement structure, and based on the determined dynamic modulus of elasticity of the pavement structure layers, the special program ELMOD also provides the possibility of calculating the remaining service life of the pavement structure for the predicted traffic load, i.e. the number of crossings of the nominal axle load, as well as determining the need for strengthening the existing pavement structure.

Table 38 presents a proposal for interventions that should be undertaken depending on the functional and structural condition of the pavement structure.

Table 27: Proposal of interventions based on the condition of the pavement

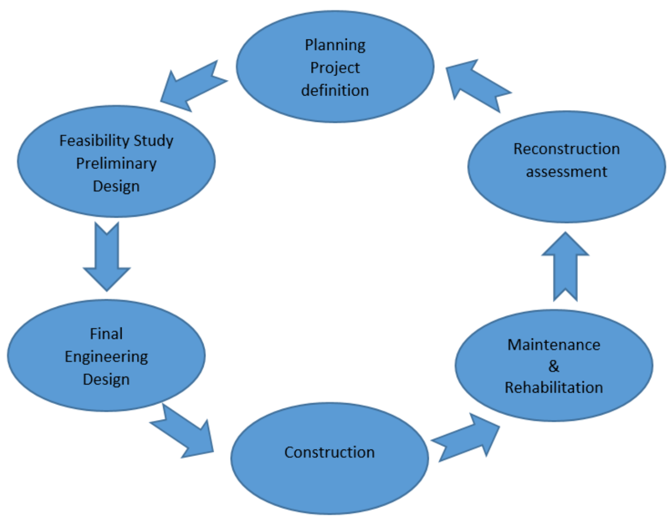
	Proposal of intervention	Functional condition	Structural condition
	Routine maintenance	excelent	excelent
		very good	very good
	Filling cracks and applying measures to improve functional characteristics (e.g. increasing skid resistance)	fair	good
		poor	
	Pavement restoration (local repairs and surface treatments or thin overlay)	fair	fair
		poor	
	Strengthen of the structure with a new layer (repair work before applying a new layer)	poor	poor
	Reconstruction	very poor	very poor
		failed	failed

9 Pavement Sustainability

9.1 Pavement Life Cycle

During lifetime, the pavement structure goes through several cyclical phases during which measures are implemented in order to maintain the usability of the pavement structure in relation to safety, comfort and economy of driving. Due to traffic load, fatigue of materials, climatic and hydrological influences over time, the functional and structural characteristics of the pavement structure decline. Therefore, immediately after construction, it is necessary to establish continuous monitoring of the condition of the pavement structure and adequate maintenance measures. After a certain period, if the extent and type of damage cannot be remedied by interventions within the framework of regular maintenance, roadway rehabilitation should be undertaken, and in case of significant degradation or requirements for increasing the load capacity, planning, design and implementation of the reconstruction of the pavement structure should be undertaken.

Figure 20: Pavement Life Cycle



According the Law on Roads, all construction interventions carried out after road construction are divided into two categories:

• **maintenance of a public road** - performing works and providing services within the existing road right –of-way that ensure the preservation of the characteristics of the road in the condition it was at the time of its construction or reconstruction and can be regular maintrenance, rehabilitation and urgent maintenance

• **reconstruction of a public road** - carrying out works on the existing road right –of-way (ROW) with associated road facilities, which can change the geometric elements, position or safety devices of the existing road with the aim of improving the functional and constructive characteristics of the road as a whole or its individual elements or facilities.

Works related to maintenance of public road are performed in accordance with the Law on Roads, accompanying regulations, approved procedures and technical specifications. Road rehabilitation works is a special subclass, within the framework of maintenance, which refers to works on public road and road facility within the road right–of-way (ROW), in order to preserve the characteristics of the public road in the same or approximately the same condition as it was at the time of its construction or last reconstruction.

Due to its specificity, the Rulebook on public road rehabilitation works (Official Gazette of RS, No. 23/19) was drawn up for these works, which lists the works that are subject to rehabilitation and the procedures for Reporting of Works works and Accepting the Works.

According to the aforementioned Rulebook, the following interventions on pavement structures are part of the rehabilitation works:

• restoration and replacement of worn out pavement layers, especially the application of a new asphalt layer of a required load capacity over the entire width of the existing road crosss section (overlay);

• installation of gravel, ie gravel cover on unpaved roads;

• pavement surface treatment or sealing;

The organization that manages the road is obliged 15 days before the start of the works to notify the competent body of the local self-government about the intention to carry out rehabilitation works, along with the submission of a technical description and cost estimate of the works, as well as a request for issuing decision on the technical regulation of traffic, which is an integral part of the project.

Upon completion of the works, the organization that manages the public road is obliged to estabish an independent commission that performs a technical review of the rehabilitation works.

The organization that manages the public road is obliged to submit to the competent body of the local self-government a report on the performed works on the rehabilitation of the public road certified by the expert supervision with a record of the performed technical inspection of the performed works, within 30 days from the date of completion of the works.

Construction and reconstruction of a public road, unlike maintenance work, is carried out in accordance with the Law governing planning and construction. The Law on Roads states that the reconstruction of a public road is the performance of construction works in the ROW, which can change the geometric elements, position or safety devices of the existing road, in order to maintain and improve the road value.

The reconstruction of a public road, according to definition from the aforementioned law is:

• works on the existing road and road facility that changes the position of the route of the public road in the zone of its basic direction;

• works on the modification of structural elements in order to improve the load capacity and stability of the road by widening the roadway and intersections, increasing the radius of the horizontal curves of the road and repairing landslides;

Based on the above, it is the road manager's obligation to continuously implement regular road maintenance measures, and depending on the condition of the road, to apply measures from the domain of urgent maintenance, rehabilitation or road reconstruction.

The key to successful road management is the establishment of a pavement management system (PMS), the implementation of which enables the road manager to make timely decisions on the type and scope of construction interventions in order to preserve the usability of the road or increase the traffic load. A significant advantage of applying the roadway management system is the possibility of analyzing life cycle costs in order to choose the optimal term and type of intervention on the pavement structure.

The level of intervention that will be applied depends on the condition of the pavement, and according to the extent of intervention, it can be divided into the following groups:

- **Re-sealing and restoration of skid resistance** - restoration of waterproofing of the pavement surface and improvement of skid resistance - applied in case of surface damage

- **Restoration of the road surface** - in addition to surface treatment, it can include, if necessary, improvement of drainage by correcting transverse and longitudinal slopes, patching of pot holes and local strengthening of weak road edges.
- **Pavement resurfacing** - includes leveling and applying a new layer of bounded material and, if necessary, correction of the slope of the pavement surface.
- **Pavement reconstruction** - complete or partial removal of existing pavement layers and their replacement with new bearing layers made of bounded or non-bounded material with provision of drainage, where necessary

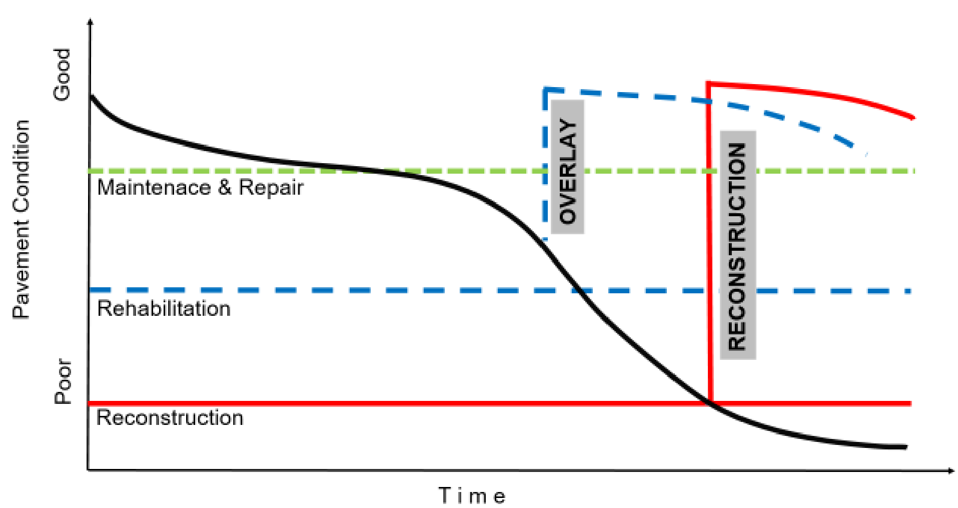
Table 39 shows the expected durability of the usual treatments for the renewal of the pavement structure.

Table 39: Pavement treatments expected life

Treatment	Expected Life (Years)
1) 50 mm overlay	7-10
2) 50 mm mill and overlay	10-15
3) Slurry seal	3-8
4) Chip seal	3-6
5) Microsurfacing	3-8
6) Micro mill (25mm)	1-4
7) Cold-in-place recycling and overlay	10-15
8) Hot-in-place recycling	5-7
9) Thin hot mix overlay (<50mm)	5-8
10) Patching	3-5
11) Thick overlay (125mm)	8-15
12) Full depth reclamation and 100 mm overlay	20+
13) Complete reconstruction	20+

Figure 34 shows an example of the application of two alternative solutions for the sustainability of the usability of the road pavement structure. The first alternative is the construction of a new surface layer of the pavement (resurfacing) and it is applicable in the event that it is performed before the total degradation of the pavement structure. If this solution is not applied in a timely manner and there is further degradation of the pavement structure, another alternative solution is applied, i.e. reconstruction of road construction, the implementation of which takes longer and costs more.

Figure 34: Choice of treatment v.s. condition of the pavement structure



As stated earlier, climate change has a significant impact on the sustainability of the functional and structural characteristics of pavement structure. Due to the increase in air temperature and the intensity of precipitation, which results in an increase in the temperature of the pavement structure and an increase in soil moisture, it is necessary to make appropriate modifications in the pavement design guidelines to prevent the negative effects of climate change. Until these modifications are made, it is necessary through Terms of References for the construction and reconstruction of local roads to emphasize the necessity of implementing measures in order to prevent the negative impact of climate change on roadway construction.

9.2 Modern technologies for pavement preservation and reconstruction

Modern technologies for pavement preservation and reconstruction are designed in accordance with the concept of sustainable development with the aim of protecting the environment and saving energy. The main characteristic of these procedures is the reuse of materials from the pavement being renewed.

Depending on the applied technology, these procedures are divided into procedures with:

• Recycling – the removed material is reused under the same functional conditions with previous processing/improvement

• Reuse – the material is reused without special processing/improvement under lower functional conditions

For both procedures, a number of technologies with their specific features have been developed, on the basis of which the appropriate technological procedure is selected, depending on the specific case.

When applying recycling, it is divided into the following:

- according to the place where the material is processed:
    - on-site recycling and
    - recycling in the central plant

- according to the processing on:
    - hot recycling and
    - cold recycling,

- according to the intensity of the intervention on:
    - surface recycling i
    - deep recycling

Within the recycling process, the material quality of the pavement structure is improved by adding additives and modifiers to regenerate the binder and by adding aggregates to repair the composition of the mineral mix.

The application of on-site recycling is possible if the intervention is carried out on a pavement with a homogeneous structure in terms of the quality and content of binders, granulometric composition, layer thickness, with limited repair areas. The advantage of applying on-site recycling is the complete use of materials from the existing construction and savings in material transportation.

Recycling in the central plant is applied when, due to the inhomogeneity of the material in the existing layers of the pavement structure, it is not possible to apply recycling on site or when deposited RAP (Reclaimed Asphalt Pavement) is available. In the technological process of cold recycling in the central plant, RAP is crushed and separated into fractions, new aggregate is added taking into account the ratio in the mixture and mixed (usually in a continuous plant) with the addition of a binder (bitumen emulsion or foamed bitumen). The material produced in this way is most often used for the production of stabilized subbase.

Surface hot recycling is most often used to repair the functional condition of the pavement structure, i.e. for the repair of surface characteristics. This procedure does not increase the bearing capacity of the pavement structure.

The on-site cold recycling process is particularly suitable for the processing of the upper layers of the pavement structure, provided that the materials on the treated layers are homogenous. By applying this procedure, load supporting layers are obtained whose characteristics depend on the characteristics of the recycled material and the binder used. Before making a decision on the application of this procedure, it is necessary to carry out preliminary tests of the characteristics of the materials being processed in order to confirm the suitability of the application of this procedure. It is most often used for the rehabilitation of the bearing layers of the pavement structure, so after application it is necessary to construct a wearing layer using a hot asphalt mix.

Deep cold recycling is used to increase the load capacity of the existing pavement structure by reworking the pavement base layers. Given that the application of recycling is to depths greater than 20 cm, by applying this procedure, it is possible to significantly increase the bearing capacity of the degraded pavement structure. It can be applied for:

- Rehabilitation of the upper bearing layer
- Rehabilitation of the lower bearing layer
- Improvement of the subgrade
- Surface leveling and rehabilitation of the upper bearing layer

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