COMPARATIVE ANALYSIS OF FLEXIBLE AND RIGID PAVEMENT DESIGN

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Summary: *Very often in civil engineering, during the design of pavements designed for traffic flow of heavy vehicles, the question of choosing between two types of pavements - flexible and rigid pavement comes to the fore. This paper presents the results of pavement (plateau) dimensioning, designed for traffic of heavy vehicles (dump trucks) exclusively with a weight of 2,350 kN, ie. 775.5 kN + 1574.5 kN. Design was carried out for two case studies, ie. two variant solutions for flexible and rigid pavement are given, as well as the results comparison regarding the complexity of construction technology as well as the cost price of the construction works included in the priced bill of quantities*.

Keywords: *Design, pavement, flexible and rigid, heavy vehicles*

1. INTRODUCTION

The development of a country depends on the connection of various places within those countries with adequate road network. Roads are the main channel for the transport of goods and passengers. The benefits of investment in the road sector are indirect, long-term and not immediately visible. Roads are an essential asset for any nation. However, the creation of these assets alone is not enough - they must be carefully planned, as pavement that is not well-designed and constructed quickly collapse. There are various types of pavement structures that differ in their suitability in different environments [1].
Pavement structure is part of the road with the traffic flow, and serves to provide a safe, comfortable and economical movement of vehicles within the foreseen period of exploitation. In order to accomplish this, it is necessary to pavement structure meets the following requirements:

- it is sufficiently resistant to the impact of moving load and to provide load transfer on the placenta and the groundbasis (subsoil),
- it is usable for traffic in all weather conditions,
- the pavement surface characteristics, especially evenness and roughness, provide a comfortable and safe driving,

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- to ensure the designed service life (or estimated number of passages of standard axle), with easy maintenance and reasonable cost [2].

Very often in civil engineering, during the design of pavements aimed for traffic flow of heavy vehicles, the question of choosing between two types of pavements - flexible and rigid pavement comes to the fore. Flexible pavements carries such name, because the entire pavement has the elastic deflection under load. The pavement structure consists of the bitumen bound materials, hence they are more elastic than rigid and more deformable. On the other hand, rigid pavements consist of portland cement based materials, they transfer the load over a larger area of the placenta, lower compression streesses can occur and lower deformations then in the case of the flexible pavements (Figure 1).

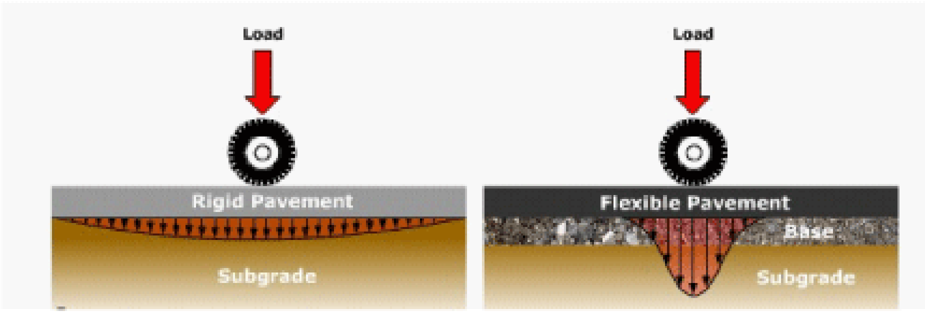

Figure 1 - Basic types of pavements

This paper presents the results of pavement (plateau) of overhaul workshop in Gacko dimensioning, designed for traffic of heavy vehicles (dump trucks), exclusively, with a weight of 2,350 kN, ie. 775.5 kN + 1574.5 kN. Dimensions of the plateau are 115.80m 25.31m x x 33.64m. After reviewing of situation and conditions of pavement support, traffic loads and climatichydrologic conditions, design was carried out for two case studies, ie. two variant solutions for:

1. flexible pavement
2. pavement

In addition, the results comparison regarding the complexity of construction technology as well as the cost price of the construction works included in the priced bill of quantities is given.

In the variant solution 1, with rigid pavement, finishing layer is derived from RC plates with the class C 30/37, with dimensions 5x5m with separate expansion joints and reinforced mesh reinforcement ± Q257, supported on the a layer of cement stabilization and unbound crushed aggregate. In the case of flexible pavement, the final layer of asphalt-concrete mixture covers layers of unbound crushed aggregate. Dimensioning of pavement structure was carried out according to standars SRPS U.C4.014 and SRPS U.C4.012.

2. RIGID PAVEMENT DESIGN

2.1 Traffic load

In determining the traffic load of the pavement, it is necessary to perform the following:

- Determine the average annual daily traffic,
- Determine the weight of individual axle of vehicles,
- Determine assessment rate of utilization of vehicles [3].

Designed traffic load is:

$$T_n = 365 * T_d * f_{pp} * f_{st} * f_{nn} * f_{du} * f_{po}\text{, where:}$$

T_n – designed traffic load for a period of n years,
T_d – equivalent daily traffic load,
f_{pp} – factor of the average cross section of pavement,
f_{st} – factor of width of traffic lanes,
f_{nn} – factor of longitudinal finish grade slope ,
f_{du} – factor of additional dynamic impacts,
f_{po} – factor of increasing traffic load due to the growth of traffic in a given period.

Designed traffic load of heavy vehicles exclusively (amps) contains weights of 2350 kN ie. 775.5 kN +1574.5 kN, each axle, hence the factor of equivalence is:

$F_e=\Sigma f_i$

$f_e=2.44 * 10^{-8} * L_1^4$, where:

f_e – equivalence factor for the single axle,
L_1 – single axle load [kN]

F_e= 158779.89 kN
$T_d = F_e * n$, where:

n – assumed daily number of vehicles (n=5)

As the future traffic frequency was not assessed, following equivalent traffic load will be assumed:

$T_d \approx 793899.44$ kN

$T_n = 28*10^7$ kN

In accordance with the analysis given above, the load on the structure can be considered as very heavy.

2.2 The composition of cement-concrete pavement

Cement-concrete pavement are composed of the following layers:

- cement-concrete layer,
- interlayer of cement stabilization and

- unbound base layer.

The required thickness of cement-concrete layer and unbound layer of stone aggregate for the applicable traffic load during the service life of pavement, and a certain CBR value should be determined based on the nomogram presented in Figure 2 and diagram presented in Figure 3.

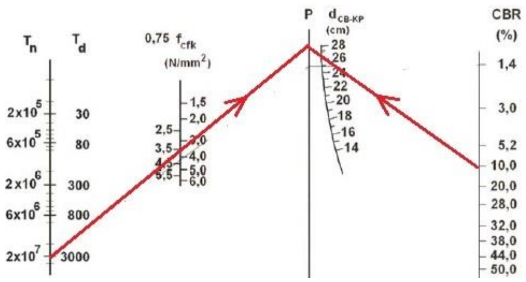

Figure 2 - The nomogram for the determination of thickness of cement-concrete layer

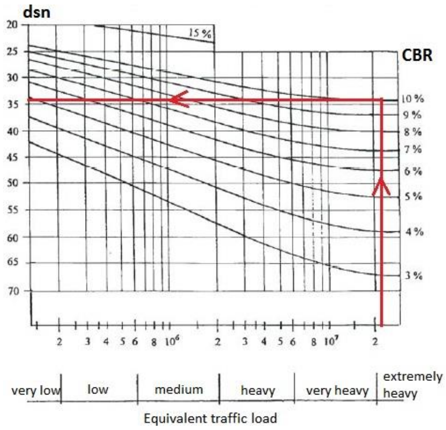

Figure 3 - Graph for the determination of thickness of unbound layers

The thickness of cement-concrete layer $d_{CB,KP}$, which is shown in nomogram in Figure 2, is determined by the average quality of cement-concrete mixtures and class C30/37. Thicknesses of pavement layers are determined based on an assumed value of CBR of 10%: [3]

- Cement-concrete layer, class C30/37: d = 26 cm,
- Interlayer (cement stabilization): d = 15 cm,
- Unbound crushed stone: d = 35 cm.

For the new cement concrete pavement, the thickness of an unbound supporting layer of gravel grain mixture should amount:

- heavy traffic load, min 25 cm,
- medium or low traffic load, min 20 cm.

2.3 Execution of cement-concrete slabs and joints

Basic conditions, the base under the concrete pavement must meet, are the mechanical properties of the soil, which should be more uniform, to thereby achieve uniform load load-bearing capacity. If adequate bearing capacity can not be achieved by using natural materials, it is necessary to introduce appropriate methods for improvement, consolidation and/or stabilization. Given that these procedures do not require more

investment, it is necessary to achieve the maximum possible load-bearing capacity, which must not be less than the CBR = 10%.[3]
Road section with the uniform load-bearing capacity should be as long as possible. According to the rules, bearing capacity of the base under the pavement (the placenta) should be uniform across the entire section of a certain new road, with the condition that sections shall not be shorter than 500m. [3]

The minimum designed thickness of the concrete slab in a pavement layer for medium to heavy traffic load must be 20 cm. Length of concrete slabs must not exceed 6m. In order to prevent damages due to operation processes and stresses that occur in them, concrete slabs in the pavement structures must be divided as follows:

- At the point of contact with other solid structural elements (curbs, manholes, connections to the bridges) - spatial joints,
- locations (temporary) interruption of incorporation, ie. the already hardened cement concrete, compressed (working) joints, and
- in order to prevent not controlled cracks due to exceeding the tensile strength of cement concrete slabs (in certain places) - the apparent transverse joints.

Cement-concrete slabs should be divided with transversal joints per square shapes. If the width of cement-concrete pavement is greater than 4m, the slabs are divided to such size with longitudinal joints. According to the rules, cement-concrete slabs with joints must be reinforced with smooth dowels (diameter 20 to 25 mm, length 500 mm) and ribbed anchors (diameter 16 to 20 mm, length 800 mm).

In order to ensure height of concrete slabs and transfer of traffic and temperature changes caused by load, disposition of dowels in the transverse joints should be as follows:

- in the rutting area at 25 cm (4 or 5 x25 cm),
- from the edge of the slab 25 cm, and
- between ruttings 50 cm.

In order to to prevent spacing of cement-concrete slab, anchors in the longitudinal joints must be built:

- on a flat road sections 5 anchors in each slab, and
- on curve sections with radius of ≤ 600m in the middle third of each plate - 3 anchors.

In cement-concrete mixtures, an admixture for the creation of air micropores, for wearing layers, should be implemented, or their composition should be amended, to ensure their needed degree of resistance to freezing and thawing in the presence of salt to prevent ice formation.

2.4 Influence of freezing

Based on the environment conditions, the present structure is exposed, its necessary thickness in relation to the depth of frost penetration is:

$h \geq 0.7 * 80cm \approx 56cm$
The total thickness of the structure is 56 cm. [3]

3. FLEXIBLE PAVEMENT DESIGN

3.1 Traffic load

The traffic load is determined in the same way as in the case of the rigid pavement, given in Section 2.1.

3.2 Asphalt overlay

Required thickness of asphalt overlay, ie. asphalt wearing course and superstructure is determined by the average quality of asphalt mix with the designed equivalency factor of 0:38. The selection of asphalt mix for wearing course and superstructure depends on the specific usage conditions, mainly on the scheduled traffic load, weather conditions and the course of the route, which adjusts the composition of the stone aggregates and type of bitumen. [3]
The quality of asphalt mixture must be chosen according to the requirements specified in the technical regulations for the manufacture and disposition of asphalt mixtures. Very hard and heavy traffic load should contain modified bituminous binder.
For the upper layers of the asphalt pavement, which are exposed to very heavy and extremely heavy traffic load, it is needed to use crushed stone aggregate. In addition, it is also recommended to use modified bituminous binder. Especially for light and very easy traffic loads, a bituminous asphalt mixture of gravel may be proposed. [3]

3.3 Unbound load-bearing layers

For new asphalt pavement, designed thickness of unbound supporting layer should be:

- heavy traffic load min. 25 cm,
- medium or light traffic load min. 20 cm

If the unbound gravel layer, thicker than 40 cm, is required, due to the weak capacity of sub-structure and a heavy traffic load, load-bearing capacity of sub-structure should be increased.

Part or whole thickness of unbound gravel layer can be replaced by crushed stone aggregates, taking into account the designed equivalency factor 0.14. Since the thickness of the layer of unbound crushed stone is also limited to 40 cm, it can replace an equivalent layer of the designd gravel, which is up to:
$40 \times 0.14/0.11 \cong 50$ cm.

Type of stone aggregate for unbound bearing layers can be adjusted to traffic load and economical conditions. When creating a new asphalt pavements that are exposed to heavy and very heavy traffic load, it is necessary, as a rule, to use crushed stone aggregates for unbound bearing layer. [3]
Quality of stone aggregates, used for unbound bearing layers, must meet the requirements of the applicable technical regulations for manufactured and built stone aggregates. [3]

3.4 Calculation of layers thicness

According to the diagram in Figure 3, for the estimated traffic load and bearing capacity of the substrate and the CBR = 10% calculation of pavement was carried out:

- Bitumen-bound layers thickness of 23 cm
- Unbound gravel layer thickness of 35 cm

Average values of equivalency factors of materials are given in Table 1
Thickness index of the road structure is:

$D = 23*a_{pz} + 35*a_s = 23*0.38 + 35*0.14 = 13.64$ cm

Table 1: Average values of equivalency factors of materials

Type of material	Equivalency factor a_i
Wearing course	
Bitumen concrete	a_0=0.42
Fine crushed stone with bitumen mastiks SMA	a_0=0.42
Upper bearing layers	
Bitumenized crushed stone	a_{zv}=0.35
Bituminized gravel	a_{zv}=0.28
Bounded lower layers	
Stone aggregate stabilized with bitumen	a_{sv}=0.24
Stone aggregate stabilized with cement	a_{sv}=0.20
Unbounded lower layers	
Crushed stone aggregate	a_{sn}=0.14
Gravel	a_{sn}=0.11

To take a specific traffic load Tn, pavement structure could be built from layers:

- bituminous concrete BB 8s or BB 11 s (according to specific technical terms)
- bituminized crushed stone AGNS 22s (according to specific technical terms)
- unbounded crushed stone DK according to specific technical terms with thickness:

$$h_d = \frac{D - a_0 * h_0 - a_{zv} * h_{zv} * 2}{a_d} = \frac{13.64 - 0.42 * 5 - 0.35 * 10 * 2}{0.14} \approx 37cm$$

Where:
BB – Bituminized asphalt concrete
AGNS – Asphalt upper bounded layer
BB with “s” contain grains of sand from silicate rocks

The pavement with the following layers was adopted:

- BB 11s (AB 11c) 5cm,
- AGNS 22s (BNS 22) 9cm,
- AGNS 22s (BNS 22) 9cm,

- CS 0/32 15cm, (CRUSHED STONE)
- CS 0/64 25cm. (CRUSHED STONE)

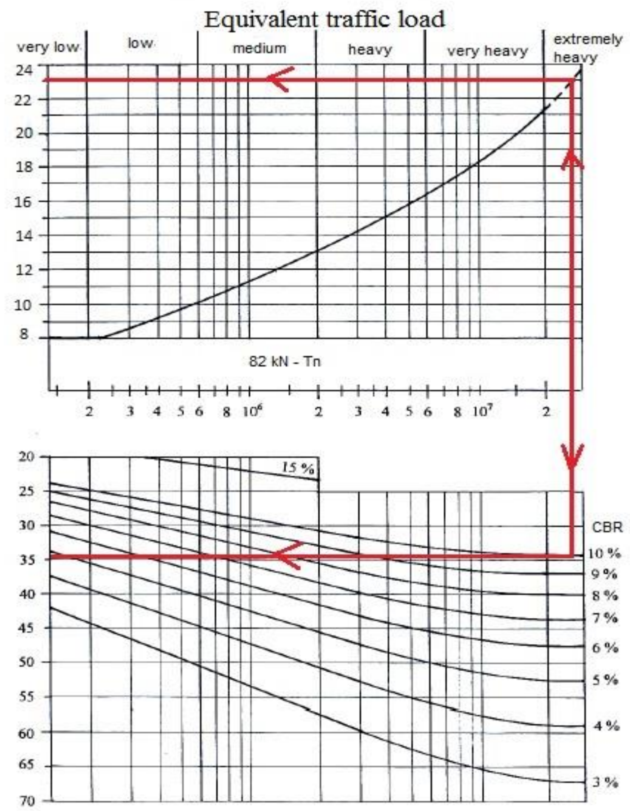

Figure 4 - Graph for determining the thickness of pavement layers

4. BILL OF QUANTITIES

Table 2 contains the bill of quantities for the plateau area of 3,283.00 m^2 while Figure 5 illustrates differences in prices of construction works for the pavement.

Table 2: Bill of quantities

Bill of quantities (€)		
	Flexible pavement	**Rigid pavement**
Preparation works	250.00	250.00
Substructure	8,062.00	8,062.00
Superstructure	143,481.00	183,779.00
Total	151,793.00	192,091.00

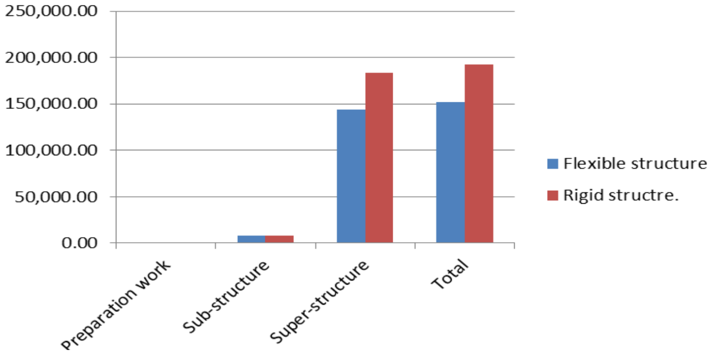

Figure 5 - Cost of work for pavement (plateu)

5. COMPARATIVE ANALYSIS OF FLEXIBLE AND RIGID PAVEMENT

Comparative analysis of the performance of flexible and rigid pavement is presented in Table 3.

Table 3: Characteristics of pavements[4]

	Flexible pavement	Rigid pavement
1	Deformation in the sub grade is transferred to the upper layers	Deformation in the subgrade is not transferred to subsequent layers
2	Design is based on load distributing characteristics of the component layers	Design is based on flexural strength or slab action
3	Low flexural strength	High flexural strength
4	Load is transferred by grain to grain contact	No such phenomenon of grain to grain load transfer exists
5	Low completion cost, high repair cost	Low repair cost, high completion cost
6	Short service life (High Maintenance Cost)	Longer service life (Low Maintenance Cost)
7	Surfacing cannot be laid directly on the sub grade but a sub base is needed	Surfacing can be directly laid on the sub grade
8	No thermal stresses are induced as the pavement have the ability to contract and expand freely	Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete
9	Expansion joints are not needed	Expansion joints are needed
10	Strength of the road is highly dependent on the strength of the sub grade	Strength of the road is less dependent on the strength of the sub grade
11	Rolling of the surfacing is needed	Rolling of the surfacing in not needed

12	Road can be used for traffic within 24 hours	Road cannot be used until 14 days of curing
13	Force of friction is low.	Force of friction is high

6. CONCLUSION

During the pavement design and construction, it is very important to analyze the present situation with all the factors that have an impact on future structure. Firstly, it is necessary to consider the needs of users and the environment which include features of the existing terrain, weather conditions, operating conditions and the traffic load. Based on that, techno-economic analysis can be carried out with the final selection of adequate pavement struture. The basic characteristics of both variants of pavement are listed in Table 3. Based on these general terms and perhaps some specific characteristics, it is necessary to determine the priorities and criteria for selecting the required pavement.

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КОМПАРАТИВНА АНАЛИЗА ПРОРАЧУНА ФЛЕКСИБИЛНЕ И КРУТЕ КОЛОВОЗНЕ КОНСТРУКЦИЈЕ

Резиме: *Веома често се у нискоградњи приликом димензионисања коловозних конструкција предвиђених за одвијање саобраћаја тешких теретних возила поставља питање избора између две врсте коловозних конструкција -*

флексибилне и круте коловозне конструкције. У раду је извршено димензионисање коловозне конструкције (платоа) на којем се предвиђа саобраћај искључиво тешких теретних возила (дампера) са тежинама од 2.350 kN, односно 775.5 kN + 1574.5 kN. Димензионисање је извршено за два случаја, тј. дата су варијантна решења за флексибилну и круту коловозну конструкцију, као и поређење резултата што укључује сложеност технологије извођења као и цене коштања извођења радова обухваћено предмером и предрачуном радова.

Кључне речи: *Димензионисање, коловоз, крути и флексибилни, тешка возила*