Research of cost aspects of cement pavements construction

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Abstract. The tendency to increasing traffic volume on public roads and to increased axle loads of vehicles makes the road scientists to develop scientifically justified methods for preserving the existing and developing the new transport network of Ukraine. One of the options for solving such issues is the construction of roads with rigid (cement concrete) pavement. However, any solution must be justified considering technical and economic components. This paper presents the results of the research of cost aspects of cement pavements construction.

1. General instructions

The dynamic growth of traffic volume on public roads and increased axle loads of vehicles that has been observed in Ukraine over the past decade requires continuous development of the road network and upgrading the road pavement designs. Unavailability of highways to traffic flow demands results in speed reduction, increased wear of motor vehicles and growth of repair costs, causes increased fuel consumption and reduced traffic safety level, as well as an increased number of traffic accidents.

Modern road design and construction technologies are based on two alternative competing pavement types - asphalt and cement pavements.

Significant reduction in service life of asphalt pavements which is caused by the dynamic growth of traffic volume on major trunk roads stimulates a constant search for an alternative to the construction of highways with asphalt pavement. One of the alternatives to solve such issue is the construction of roads with rigid (cement concrete) pavement.

In order to determine the feasibility of using a particular type of pavement for the construction of the highway a feasibility comparison study of different design options was fulfilled.

1.1. Calculation of pavement design

Regardless of the type, road pavement is to be calculated considering the composition of traffic flow, predicted traffic volume by the end of its service life, as well as geological and climatic conditions.

Non-rigid type of pavement (asphalt concrete) is designed considering the reliability of pavement structure.

Design and calculation of non-rigid pavement type is fulfilled in accordance with the Departmental Construction Norms VBN V.2.3-218-186 [1].
Design of rigid pavement type (cement concrete) is fulfilled in accordance with VBN V.2.3-218-008 [2]. The calculation includes the definition of design and standard loads, the size of basic structural elements (thickness and length of slabs, thickness of foundation layers, reinforcement plates and layers, distance between expansion joints) for different types of pavement, road categories, for any traffic loads, soil and climatic conditions.

1.2. Methodology of pavement designs comparing assessment

Defining the effectiveness of different pavement design options is carried out by comparing labor and material costs incurred throughout the comparative period \( T \).

Pavement design options under consideration are distinguished by the design type and by their operating maintenance methods during the period \( T \) (the distinctive features of operating maintenance of rigid and non-rigid pavement types are taken into account).

Evaluation of the effectiveness of placement and operation of road pavement designs is fulfilled per 1 running km based on the parameters and operation conditions of a certain road category.

As a criterion for assessing the comparative effectiveness of placement and operation of various road pavement types the minimum value of integrated costs \( B_{\text{gen}} \) is used which includes:

- The cost of new construction of road pavement
- Costs for capital and current repairs of road pavement
- Costs for operational maintenance of road pavement

Calculation of reduced costs in the \( i \)-th year starting with the next year following the beginning of the new pavement construction is carried out considering the risk-free discount rate \( E \) (in relative units).

For comparison of the costs for the new construction, repair and operational maintenance of pavement designs of various types the following formula is used:

\[
B_{\text{gen}} = B_{\text{con}} + B_{\text{Mj}} \times (1 + E)^i + \sum_{j=1}^{n} \left[ B_{\text{Mid}} \times (1 + E)^j \right] \times n \\
+ \sum_{j=1}^{m} \left[ B_{\text{Mid+Op}} \times (1 + E)^j \right] \times m + \sum B_{\text{User}} \times (1 + E)^j
\]

\( B_{\text{con}} \) – the cost of new construction of 1 km of pavement;
\( B_{\text{Mj}} \) – the costs for major repairs of pavement;
\( B_{\text{Mid}} \) – the costs for current mid-life repairs of pavement;
\( n \) – the number of current mid-life repairs performed during the comparative period \( T \);
\( B_{\text{Mid+Op}} \) – the costs for current mid-life repairs and operating maintenance of pavement;
\( B_{\text{User}} \) – the losses of road users when performing repair works.
\( m \) – the number of years of operating maintenance of pavement of the highway when using the selected option of works fulfillment;
\( E \) – the risk-free discount rate in relative units;
\( (1 + E) \) – the discount rate costs.
Table 1. Initial data.

| №  | Initial data                                    | Road pavement design type |
|----|------------------------------------------------|---------------------------|
|    |                                                | Non-rigid | Rigid |
| 1  | Beginning of works fulfillment, year           | 2014      | 2014  |
| 2  | Road category                                 | II        | II    |
| 3  | Initial traffic volume on the section, vehicles/day | 5000      | 5000  |
| 4  | Road-climatic zone                            | Y-II      | Y-II  |
| 5  | Interrepair time for roads (year):            |           |       |
|    | - current mid-life repair after construction  | 6 (17)    | 9 (18) |
|    | (second current repair)                       |           |       |
| 6  | - capital repair                              | 12        | 21    |
| 7  | Growth of traffic volume, %                   | 4         | 4     |
| 8  | Discount rate, %                              | 5         | 5     |

Considering the initial traffic volume, the alternative options of non-rigid and rigid pavements design types were calculated.

Non-rigid pavement design type (Figure 1) is adopted on the basis of the requirements of VBN V.2.3-218-186 [1]. Rigid pavement design type (Figure 2) is adopted on the basis of the requirements of VBN V.2.3-218-008 [2].

The costs for the construction and maintenance of subgrade, placing and arrangement of road equipment elements during the feasibility comparison study were not taken into account because they are the same for both options.

Process sequence of works performance, the associated machines and mechanisms were adopted to meet the requirements of existing standards and regulations [3] and flow charts.

1.3. Calculation of costs for capital and current repairs of pavement design

1.3.1. Non-rigid pavement design type. According to Table 2 VBN G.1-218-050 [4], the first current mid-life repair after the new construction is carried out after 6 years of the highway operation.

According to Table 1 VBN G.1-218-050 [4], capital repair of pavement design is performed after 12 years of the highway operation.
The next current mid-life repair is performed after 5 years of operation after capital repair, according to Table 2 VBN G.1-218-050 [4], that is the 17th year of the highway operation.

1.3.2. Rigid pavement design type. Process sequence of works performance is adopted to meet the requirements of the Guidelines MR V.3.2-218-03449261-674 [5].

According to Table 2 VBN G.1-218-050 [4], the first current mid-life repair after the new building is to be performed during the 9th year of the highway operation.

The next current mid-life repair is to be performed in 7 years, according to Table 2 VBN G.1-218-050 [4] after the first current mid-life repair- that is the 16th year of the highway operation.

Major repair of pavement is not taken into account, as a comparative term is 20 years.

Based on the initial data, consolidated construction costs for the construction and functioning of different road pavement design types are defined. The calculation results for non-rigid and rigid pavement types are shown in Tables 2 and 3.

**Table 2. Total cost of the construction and maintenance of 1 km of non-rigid pavement design type.**

| Year | Discount rate | B_con | B_Mid+Op | Total for the year | Accumulation of costs |
|------|---------------|-------|-----------|--------------------|----------------------|
| 0    | 1.0           | 9325.495 | -         | 9325.495           | 9325.495              |
| 1    | 1.05          | -      | -         | 19.04              | 19.04 9344.535       |
| 2    | 1.103         | -      | -         | 21.001             | 21.001 9365.536      |
| 3    | 1.158         | -      | -         | 46.787             | 46.787 9412.323      |
| 4    | 1.216         | -      | -         | 49.13              | 49.13 9461.453       |
| 5    | 1.276         | -      | -         | 51.555             | 51.555 9513.008      |
| 6    | 1.34          | -      | 1221.744  | 25.513             | 25.513 10760.265     |
| 7    | 1.407         | -      | -         | 26.789             | 26.789 10787.054     |
| 8    | 1.477         | -      | -         | 59.676             | 59.676 10846.73      |
| 9    | 1.551         | -      | -         | 62.666             | 62.666 10909.396     |
| 10   | 1.629         | -      | -         | 65.817             | 65.817 10975.213     |
| 11   | 1.71          | -      | -         | 69.09              | 69.09 11044.303      |
| 12   | 1.796         | -      | 4474.087  | 34.195             | 34.195 15552.585     |
| 13   | 1.886         | -      | -         | 35.909             | 35.909 15588.494     |
| 14   | 1.98          | -      | -         | 79.999             | 79.999 15668.493     |
| 15   | 2.079         | -      | -         | 83.999             | 83.999 15752.492     |
| 16   | 2.183         | -      | -         | 88.2               | 88.2 15860.692      |
| 17   | 2.292         | -      | 2089.729  | 43.64              | 43.64 17974.061      |
| 18   | 2.407         | -      | -         | 45.828             | 45.828 18019.889     |
| 19   | 2.527         | -      | -         | 102.099            | 102.099 18121.988    |
| 20   | 2.653         | -      | -         | 107.19             | 107.19 18229.178     |

Total 9325.495 4474.087 3311.473 1118.123 18229.18 -
Table 3. Total cost of the construction and maintenance of 1 km of rigid pavement design type.

| Year | Discount rate | $B_{\text{cost}}$ | $B_M$ | $B_{\text{mid}}$ | $B_{\text{mid+op}}$ | Total for the year | Accumulation of costs |
|------|---------------|------------------|-------|-----------------|--------------------|---------------------|-----------------------|
| 0    | 1.0           | 9188.441         | -     | -               | -                  | 9188.441            | 9188.441              |
| 1    | 1.05          | -                | -     | -               | -                  | 17.033              | 9205.474              |
| 2    | 1.103         | -                | -     | -               | -                  | 17.893              | 9223.367              |
| 3    | 1.158         | -                | -     | -               | -                  | 22.048              | 9245.415              |
| 4    | 1.216         | -                | -     | -               | -                  | 23.152              | 9268.567              |
| 5    | 1.276         | -                | -     | -               | -                  | 24.295              | 9292.862              |
| 6    | 1.34          | -                | -     | -               | -                  | 60.632              | 9353.494              |
| 7    | 1.407         | -                | -     | -               | -                  | 63.663              | 9417.157              |
| 8    | 1.477         | -                | -     | -               | -                  | 66.831              | 9483.988              |
| 9    | 1.551         | -                | -     | 125             | 29.53              | 154.53              | 9638.518              |
| 10   | 1.629         | -                | -     | -               | 31.015             | 31.015              | 9669.533              |
| 11   | 1.71          | -                | -     | -               | 32.558             | 32.558              | 9702.091              |
| 12   | 1.796         | -                | -     | -               | 34.195             | 34.195              | 9736.286              |
| 13   | 1.886         | -                | -     | -               | 35.909             | 35.909              | 9772.195              |
| 14   | 1.98          | -                | -     | -               | 37.698             | 37.698              | 9809.893              |
| 15   | 2.079         | -                | -     | -               | 94.07              | 94.07               | 9903.963              |
| 16   | 2.183         | -                | -     | -               | 98.775             | 98.775              | 10002.738             |
| 17   | 2.292         | -                | -     | -               | 103.707            | 103.707             | 10106.445             |
| 18   | 2.407         | -                | -     | 2329.913        | 45.828             | 2375.741            | 12482.186             |
| 19   | 2.527         | -                | -     | -               | 48.113             | 48.113              | 12530.299             |
| 20   | 2.653         | -                | -     | -               | 50.512             | 50.512              | 12580.811             |
| Total|               | 9188.44          | -     | 2454.913        | 937.457            | 12580.8             | -                     |

Figure 3. Comparison of new construction and maintenance costs of 1 km of pavement of rigid and non-rigid design types.

Graph in the Figure 3 shows that considering the average prices of materials as of the third quarter 2016, the construction of cement pavements is economically sounder because savings at the end of the calculation period will make 45%.

Starting with the second quarter of 2012, DerzhdorNDI SE monitors changes in prices of basic road construction materials. Dynamics of price of asphalt and concrete mixes during the period from 2012 through the third quarter of 2016 are shown in Figures 4 and 5.
To compare the effects of the material component price on the final cost of construction and maintenance of pavement designs, 2 scenarios have been modeled that are shown in Figures 6 and 7.
Figure 6. Cost of construction and maintenance of 1 km of various pavement design types (cost of asphalt mix is reduced by 35%).

Figure 7. Cost of construction and maintenance of 1 km of various pavement design types (cost of concrete mix is increased by 30%).

With the reduced cost of asphalt mix by 35% (Figure 6), the situation changed dramatically. The efficiency of the construction and operation of cement pavements starts with the 12th year only. But at the end of the calculation period savings will make about 30%.

Increased cost of concrete mix by 30% results also in the growth of cement pavements construction costs compared to asphalt ones (Figure 7). But ultimately, there is saving due to lower repair and maintenance costs of cement pavements.
Conclusions

Thus, the following conclusions can be drawn on the basis of the conducted analysis and the results of calculation:

- The construction cost of any type of pavement design is too dependent on the cost of construction materials and the share of local materials used.
- In the long term (10 - 20 years) the construction of cement pavements is more expedient. It should also be taken into consideration that cement pavements can bear heavier loads than asphalt pavements which provides additional social and economic efficiency.
- Taking into account the fact that the price of bitumen is more tied to the exchange rate, the use of cement is the best solution.
- In each specific case, when choosing the type of pavement design, the pre-design feasibility and comparison study should be fulfilled which will allow proper assessment of the efficiency of the opted pavement design type.

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