Comparison of operating costs of reinforced concrete bridges and overpasses with different static schemes

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Abstract. The article considers two options for the design of an overpass with a beam-cut and a beam-continuous static scheme. An inspection of the technical condition of beam-cut reinforced concrete bridges in operation in Tashkent built in 1970-90 was conducted. Estimating the maintenance costs of overpasses with different static schemes operating for the last 50 years shows that the continuous reinforced concrete option drastically reduces the cost of repair work in operation. This, in turn, has a cumulative effect on the development of the bridge-building industry in the Republic of Uzbekistan. The predicted operating costs of overpasses with different static schemes during operation for 50 years showed that in a continuous reinforced concrete option, 435,803,803 soums are saved annually. The most important thing is that the proposed solution dramatically reduces the cost of repair work. This, in turn, has a cumulative effect on the development of the bridge-building industry in the Republic of Uzbekistan.

1 Introduction

In modern cities, the design and construction of transport structures (bridges, overpasses, and trestles) are developing rapidly. This is primarily due to the constant increase in the number of cars, especially in metropolitan areas, which creates serious problems for traffic and pedestrians, and causes traffic jams, making it difficult for people to reach their destination [1, 2].

At present, to improve the transport infrastructure of the Republic of Uzbekistan, Decrees of the President of the Republic of Uzbekistan dated October 4, 2017, No. PP-3309 "On improving the system for organizing the construction and operation of road bridges, overpasses, and other artificial structures", dated March 29, 2018, No. PP- 3632 "On approval of the program for the construction, reconstruction, and overhaul of road bridges, overpasses, and other artificial structures in the Republic of Karakalpakstan, regions and the city of Tashkent for 2018-2022" and dated December 9, 2019, No. PP-4545 "On

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measures to further improve road industry management systems" [3-5] are important program steps in raising the construction in this sphere to a new level.

New modern design and construction methods are being studied in the Uzbek bridge-building, and new techniques and technologies are being applied, gradually abandoning the principles of typical design and construction [6-9]. The method of monolithic construction is one of the well-known and non-traditional methods. This method is widespread in constructing unique facilities in major cities worldwide [10].

2 Objects and methods of research

The object of research is a monolithic bridge. A monolithic method of building bridges and overpasses is widely used for developing and improving the road and transport infrastructure of the large historic city of Samarkand. One of the clearest examples of this is the new overpass, which is being built on the 1083rd km of the M-39 highway passing through the city of Samarkand (Fig. 1).

Based on the foregoing, it can be noted that the development of technical solutions (design and calculation) for monolithic reinforced concrete bridges and overpasses is an urgent issue. It has a cumulative effect on the development of the bridge-building industry in the Republic of Uzbekistan.

Fig. 1. Monolithic overpass on the 1083rd km of the highway M-39 passing through the city of Samarkand

The purpose of the study is to substantiate the technical, economic, and operational indices of reinforced concrete overpasses with different static schemes during their operation in the conditions of the Republic of Uzbekistan.

The cost of the beam-cut and continuous reinforced concrete options of overpasses and their performance are analyzed and predicted in the article.

It should be noted that in paragraphs 192-197 of the Decree of the President of the Republic of Uzbekistan, No. UP-60 "On the Development Strategy of New Uzbekistan for 2022-2026" dated January 28, 2022, a road program for the next 5 years was planned to rapidly develop the road network between Tashkent and major cities of the republic. As a result, it is planned to build, reconstruct, and repair roads with a total length of 57.8 thousand kilometers, and stage-by-stage reconstruct and repair 1512 existing bridges and other artificial structures. It should be noted that no more than 5% (about 300-400) of bridges are inspected during the year.

Analysis of the technical and operational state of city bridges and overpasses. The operation of bridges is a set of organizational and technical measures that ensure the safety and operation in good condition during the entire estimated service life of bridges, regulatory structures, and territories adjacent directly to them. The safety of road and rail transport and the uninterrupted operation of their work largely depend on their condition and reliability [11].

According to regulatory documents, diagnostics should be performed at least once every five years. Currently, the total number of bridge structures in Tashkent exceeds 300, and about 70% of them are under the jurisdiction of the "Special Directorate for the operation, maintenance, and repair of artificial structures." The department has 216 bridge structures at its disposal; most of these structures were built between the 60s and 90s of the last century, and relatively new structures were built in the middle and end of the 20th century and the beginning of the 21st century. It should be noted that the technical and operational condition of most of these bridge structures is unsatisfactory; they are not given due maintenance [12-16].

According to the results of the survey conducted by the authors, it was determined that in more than 10 city bridge structures, the main damage to the spans and supports of reinforced concrete bridges and overpasses was caused primarily by the poor state of waterproofing and expansion joints and the absence of drainage pipes. Figures 2 and 3 show the general defects and damages to bridges in Tashkent by years (in percent, Fig. 3).

a) *b)*

Fig. 2. Defects and damage to bridges and overpasses in Tashkent: *a* is defects and damage in the lower part of the slab span; *b* is roadway defects and cracks in the expansion joint constructions

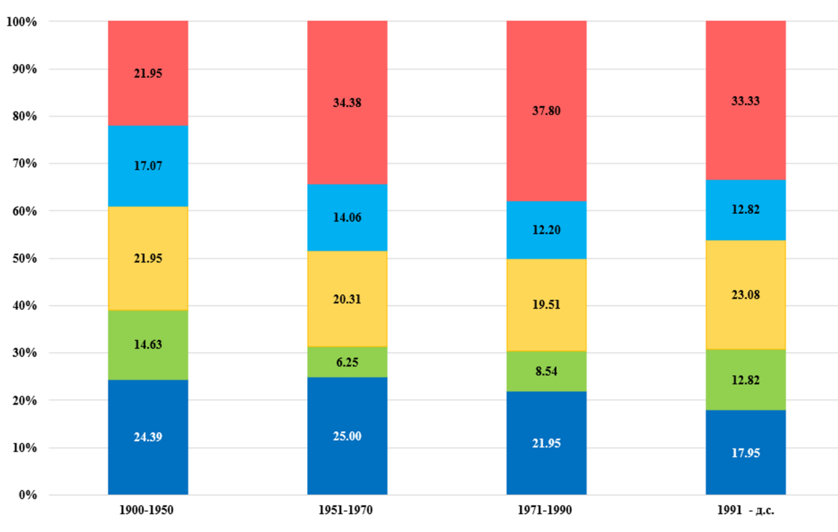

Fig. 3. General defects and damage to bridges in Tashkent by years (in percent)

As seen from the graph, according to the inspection results, the technical condition of some bridges in operation in Tashkent in the last 25-50 years (built in 1970-90) was unsatisfactory. For example, in waterproofing and expansion joints, cracks and damage are often observed, which account for 38% [1, 12, 13].

Thus, in modern bridge management, the structure's functional performance is paramount. It should be remembered that a bridge (an overpass) is designed and built relatively quickly, and it has operated for decades. Therefore, the design and construction of bridges and overpasses with the best performance is an urgent issue of domestic bridge building.

Based on the capabilities of the bridge-building industry of the Republic of Uzbekistan, the possibility of designing and building continuous reinforced concrete monolithic bridges and overpasses in cities requires a new approach to design, specific research, and the development of a rational solution.

It should be noted that in recent years, various new techniques and technologies have been used to construct bridges. The construction of monolithic structures is one of the well-known and unconventional methods. The main feature of monolithic construction is that the construction site is the place to produce materials for monolithic bridges and other engineering structures. The use of monolithic reinforced concrete makes it possible to realize various architectural forms and reduce steel consumption by 7–20% and concrete by 12% [9, 10]. In addition, there are some advantages of this method:

first, in the bridge-building of our country, the maximum length of typical spans is 33 m; the monolithic method will make it possible to increase the length of spans using high-class concrete and high-strength reinforcement;

second, *the duration (rapidity) of construction.* This method allows us to quickly install supports and move on to the next stage of construction;

third, *reliability*. The monolithic reinforced concrete structure, made in strict accordance with the "*post tension*" technology, has increased strength and resistance to the strongest loads (Fig. 4). In addition, the use of modern bearings [16] and expansion joints [20] provides maximum seismic protection for bridges and overpasses (Fig. 5);

fourth, the price. Because the technological process of monolithic construction is quite fast and economical in resources, the cost of work on this technology is much lower than that of other analogs. Based on this, we can say that the most important reserve for reducing the cost of construction (in a monolithic way) is the *constant improvement of the technology of works;*

fifth, unique opportunities for creating complex geometric shapes, i.e., superstructures made of prestressed monolithic reinforced concrete, along with undeniable technical and economic advantages, also have *aesthetic appeal.* Continuous bridges can be used in complex conditions in plan and profile, which are common to urban structures.

Considering the above positive characteristics of monolithic reinforced concrete continuous bridges and overpasses, a forecast was made in the article for the operating costs of beam-cut (prefabricated) and beam-continuous (monolithic) schemes during bridge operation.

Fig. 4. "Post tension"

a) *b)*

Fig. 5. Modern bridge devices used in monolithic bridge building: a is expansion joints; b is seismic protection bearing parts

3 Research methods

In the field of the construction industry and, in particular, in bridge-building, a research methodology based on the theory of correlation can be recommended [16]:

- to identify scientifically based technical and economic indices of the construction of bridges of various systems, depending on the span length, bridge width, support height, method of work, and other design and technological factors;

- to determine the effect of prefabrication, the level of mechanization, and other factors on the duration of construction;

- to determine the laws of weight and the laws of cost of reinforced concrete structures for various purposes based on such factors as:

• congestion with reinforcement;

• span size;

• complexity of the profile, etc.;

• to study various problems associated with choosing optimal options for the organization of production.

The total cost of the structure is determined as the sum of the actual cost of manufacturing and installation of the superstructure (beam-cut system) or manufacturing in a monolithic way with the estimated cost of temporary structures.

The choice of option is realized according to the minimum annual reduced construction and operating costs:

$$P_{CE} = E_N K + C_Э - E_N (E_{TR} + E_E - P_0) \qquad (1)$$

where E_H is the normative coefficient of efficiency of capital investments, $E_N = 0.1$;

K is the estimated cost of the bridge construction; C_E is the annual operating costs; E_{TR} is the effect of reducing overhead costs for options with less labor intensity of work; E_E is the effect of early commissioning of the option with a shorter construction period; P_0 is the losses from non-functioning capital investments in the calculation of comparative efficiency.

A unified methodology makes it possible to identify comparable indices characterizing the spans of beam-cut and beam-continuous (monolithic) bridges and overpasses and to assess and compare with sufficient accuracy various technologies of their construction [15, 16].

4 Results and discussion

3.1 Forecasting the maintenance costs of bridges and overpasses with different static schemes during operation

The task of this stage is to find a solution that would allow, at rational costs, to build of an easy-to-use, reliable, durable, and beautiful structure.

When determining the maintenance costs of reinforced concrete bridges and overpasses, the following inspections should be done: current; periodic; surveys and tests; special observations, and examinations [21, 22]. The service life and the period until the bridge's first repair are determined per the Interstate Standard GOST 33178-2014, app. B (Table B.1) [25].

The growth of operating costs is determined by the following formulas in ascending years for two options of overpasses (Table 1).

Table 1. Calculation of growth in operating costs by years

Years	Operating cost formulas		Prefabricate, million soum	Monolithi, million soum	Amount saved, in million soum
	Prefabricated	Monolithic			
5th year	$E_{ex(5)}= n^* E_y + E_d$,	$E_{ex(5)}= n^* E_y$,	676.29 (0.06)	350.00 (0.031)	326.29 (0.029)
10th year	$E_{ex(10)}= n^* E_y + E_d + E_{da}$,	$E_{ex(10)}= n^* E_y + E_{da}$,	2 191.33 (0.19)	1 607.49 (0.14)	583.84 (0.052)
20th year	$E_{ex(20)}= n^* E_y + 2^*E_d + E_{da} + E_k$	$E_{ex(20)}= n^* E_y + 2^*E_{da}$	9 224.89 (0.81)	3 214.98 (0.28)	6 009.91 (0.53)
50th year	$E_{ex(50)}= n^* E_y + 5^*E_d +2^*E_{da} + 2^*E_k + E_r$	$E_{ex(50)}= n^* E_y + 5^*E_{da}$	30 735.12 (2.71)	8 944.93 (0.79)	21 790.19 (1.92)

Note. 1 USD = 11330.69 Uzbek soum (CBR 21/02/2023).
In parentheses, the costs are given in million rubles.

where E_{ex} is operating costs; n is period of operation, year; E_y is annual seasonal repair; E_d is repair of expansion joints; E_{da} is repair of expansion joints and asphalt-concrete pavement; E_k is overhaul; E_r is reconstruction.

Figures 6 and 7 show the graphs of the growth in operating costs of overpasses of various static schemes over 15 and 50 years.

The amounts were obtained from calculating expenses for the maintenance of road bridges, overpasses, and other artificial structures at the expense of the budget of the Republic of Uzbekistan. Costs for the seasonal repair of prefabricated and cast-in-place bridges are roughly derived from the reports of enterprises on the maintenance of bridges and overpasses in Tashkent (for overpasses with a length of approximately 100 m).

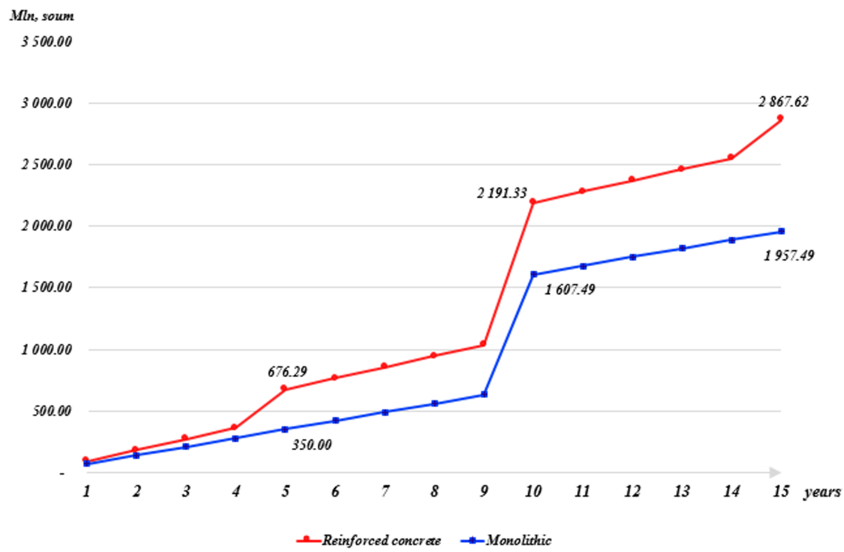

Fig. 6. Graph of growth in the operating costs of overpasses over 15 years

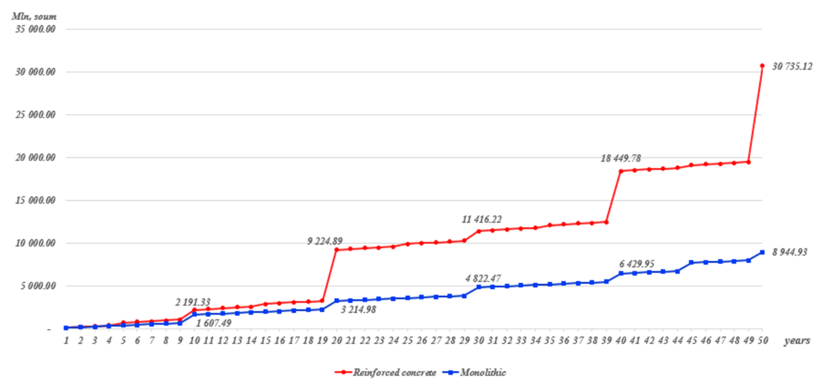

Fig. 7. Graph of growth in the operating costs of overpasses over 50 years

Experience in the operation and maintenance of prefabricated reinforced concrete bridge structures (Figs. 2 and 3) shows that a significant proportion of defects and damage are observed in the bridge deck (pavement), waterproofing, and expansion joints, which lead to premature damage to the structural parts of bridges. Therefore, expansion joints (EJ) in prefabricated structures are repaired once every 5 years (Figs. 6 and 7, red line), the replacement of asphalt-concrete pavement with the replacement of EJ is done after 10 years, and a major overhaul of the structure is carried out in the 20th year of operation. Following GOST 33178-2014 and IKN 140-21, the bridge is reconstructed with the replacement of span structures in the 50th year of operation.

Figure 7 shows that continuous (monolithic) reinforced concrete bridges (blue line), unlike prefabricated ones, are overhauled every 10 years. The operating costs of overpasses built with different static schemes during operation (over 50 years) show that 435,803,803 soums are saved every year in the option of a continuous reinforced concrete bridge. The practice of monolithic bridges shows that operating costs are much lower (71%) than prefabricated ones since a monolithic structure does not have expansion joints between spans.

5 Conclusion

The results of the inspection of the technical condition of some beam-cut reinforced concrete bridges in operation in the city of Tashkent erected in1970-90 show that a significant proportion of defects and damages are observed in the bridge deck (pavement), waterproofing, and expansion joints, which account for 38% of the volume of defects and damage to the entire structure. Monolithic bridge structures are especially appropriate in the design and construction of urban transport facilities, providing unobstructed movement around the city and improving the architectural and aesthetic appearance of urban development. Two design options for an overpass with a beam-cut and a beam-continuous static scheme were developed; they were compared according to scientifically substantiated technical, economic, and operational indices based on the correlation theory, and an overpass of a beam-continuous (monolithic) scheme was chosen. The predicted operating costs of overpasses with different static schemes during operation for 50 years showed that in a continuous reinforced concrete option, 435,803,803 soums are saved annually. The most important thing is that the proposed solution dramatically reduces the cost of repair work. This, in turn, has a cumulative effect on the development of the bridge-building industry in the Republic of Uzbekistan.

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