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Calculation of the Load-Carrying Capacity of spans when reinforced with a14 (vehicle load) and NK100 (wheel load) loads

Saatova Nodira Ziyayevna

Tashkent State Transport University, doctor of philosophy (PhD), docent of the department "Artificial structures on highways", 100067, 1, Adilkhodjaev st., Uzbekistan

ABSTRACT. The paper presents the calculations of the spans, taking into account the strengthening of the supporting sections of the beams, checked their carrying capacity, whether it is sufficient to pass the modern load A14 (vehicle load) and NK100 (Wheel load) by ShNK (Urban planning rules and regulations) 2.05.03-12. "Bridges and pipes".It has been shown that reinforced concrete structures with an emergency risk more than 0.1 should be replaced, and structures with an emergency risk less than 0.1 are repairable and can be restored. It is practically impossible to reinforce the supporting elements of the overpass to the level which meets the requirements of passing the modern loads A14 and NK100 and requires enormous material expenses which are probably commensurable with the cost of erecting new overpass.

I. INTRODUCTION

Increase of traffic intensity on the highways and growth of load intensity creates threat to the reliability of bridge constructions. The main tasks of regular inspections of operating bridges and overpasses are to detect the technical condition and to check their compliance with the established requirements.

II. SYSTEM ANALYSIS

Road overpass for the entrance to Gulistan from the highway on the 117+150 km of the M34 highway " Tashkent-Dushanbe".
The 22.16 m long spans are installed in the middle of the overpass over the railroad tracks and roads.
The 22.16 m long spans consist of precast reinforced concrete prestressed beams made according to the typical project of Soyuzdorproekt, issue 122-62, inv. №172. The girders of the 16.76 m long spans are made of conventional reinforced concrete according to the typical project of Soyuzdorproekt, issue 56, inv. No 147/2.

Covering of the overpass roadway - asphalt.
There are 9 beams with the distance between the axes of 1.65-1.70 m in all the spans of the overpass. The girder joint at the level of the slabs is made with monolithic concrete (photo 1).

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Photo 1. General view of the spans from below

Defects and damages of beams found during the inspection are shown in photos 2 - 5.

Photo 2. Span №1. Damage to the supporting sections of the beams

Photo 3. Span №2. Damage to the supporting sections of the beams

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Photo 4. Corrosion of bare reinforcement at the sites of destruction of the protective layer of concrete in the beams of the span with L=16.76 m: (a) section of the beam near the drainage tube; b) section of the slab near the expansion joint

Photo 5. Fracture of concrete and corrosion of reinforcement at the ends of beams with L=22.16 m

16.76 m long beams

According to the results of selective dissection of the reinforcement, it was found that the ribs of the beams in the middle are reinforced with 12Ø32AIII. The actual concrete class in the undamaged sections of the beams is B30, in the monolithic sections - B20. In all spans of the bridge, bridged by beams L=16.76 m, the support sections of ribs and slabs are damaged:
the protective layer of concrete has been lost,
the concrete and the reinforcement are corroded,
the reinforcement lost its bond with the concrete,
the concrete of the slabs has deteriorated,
the reinforcement of the plates is torn and deformed in some places.

There are vertical and inclined cracks up to 0.3 mm wide in the beam ribs. Longitudinal cracks have formed on the supporting sections of the beams on the lower surface of the ribs. There are traces of leaching on the surface of the beams.

The length of the damaged support sections of the beams is mainly up to 0.5 m, in some beams - up to 1.0 m. The depth of the carbonized layer of concrete in these sections is 30-50 mm. The degree of lamellar corrosion of the reinforcement is up to 15%. Unacceptable deflections of the beams were not detected.

22.16 m long beams

The actual concrete class on the undestroyed sections of the beams is B30, the monolithic sections is B25. In the bridge spans overlapped by beams L=22.16 m, the support sections of ribs and slabs are damaged:

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The protective layer of concrete has peeled off and bulged,
The concrete and reinforcement are corroded,
Concrete of the plates is destroyed,
There are traces of leaching on the surface of the beams,
The length of damaged support sections of the beams ranges from 0.3 to 0.8 m,
The depth of carbonized layer of concrete in these sections is 30-50 mm,
The bare reinforcement in the ends of the beams is corroded,
The degree of corrosion is up to 10%.

III. RESULTS

In all the beams, the bending from prestressing was preserved, which shows the absence of sliding of prestressed reinforcement in the concrete body.
Since the overall reliability of the span is the sum of the reliability of the individual beams, the failure rate of the beams can be used to determine the failure rate of the spans. The reliability of the supports is also determined. As a result, it is possible to determine the operational reliability of the entire overpass.
Table 1 shows the results of the reliability calculation and the degree of failure of the spans.

Table 1.
The results of instrumental studies and calculations of the degree of reliability and emergency risk of girders of span structures

No. of span	No. of beams	Actual strength MPa	Fittings corrosion degree, %	Reliability	Accidental risk level	Recommendations
1	2	3	4	5	6	7
1	1,2,3,8,9	18	8	0,76	0,240,1	Replacing girders
	4,5,6,7	21	3	0,91	0,090,1	Girder operability restoration
2	2,3,8	19	7	0,78	0,220,1	Replacing girders
	1,4,5,6,7,9	22	2	0,92	0,080,1	Girder operability restoration
3	2,3,4, 5,6,7,8	14	17	0,72	0,28	Replacing girders
	1,9	23	2	0,90	0,10,1	Girder operability restoration
4	2,3,6,7,8	20	11	0,79	0,21	Replacing girders
	1,4,5,9	20	2	0,9	0,10,1	Girder operability restoration
5	2,3,4,5,7,9	13	8	0,68	0,32	Replacing girders
	1,6,8	21	3	0,92	0,080,1	Girder operability restoration
6	2,8	17	9	0,76	0,240,1	Replacing girders
	1,3,4,5, 6,7,9	26	-	0,96	0,040,1	Girder operability restoration

Recommendations on the results of the calculations of the spans in visual form are shown in Table 2.

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Table 2
Recommendations on the results of calculations of the operational suitability of superstructures

Number span	Girder number of the span (counting beams from left to right on the Gulistan side)								
	1	2	3	4	5	6	7	8	9
1	Replacing	Replacing	Replacing	Major repairs.	Major repairs.	Major repairs.	Major repairs.	Replacing	Replacing
2	Major repairs.	Replacing	Replacing	Major repairs.	Major repairs.	Major repairs.	Major repairs.	Replacing	Major repairs.
3	Major repairs.	Replacing	Replacing	Replacing	Replacing	Replacing	Replacing	Replacing	Major repairs.
4	Major repairs.	Replacing	Replacing	Major repairs.	Major repairs.	Replacing	Replacing	Replacing	Major repairs.
5	Major repairs.	Replacing	Replacing	Replacing	Replacing	Major repairs.	Replacing	Major repairs.	Replacing
6	Major repairs.	Replacing	Major repairs.	Major repairs.	Major repairs.	Major repairs.	Major repairs.	Replacing	Major repairs.

Verification calculations of the load-carrying capacity of the spans for loads A14 And NK100P are made taking into account the rehabilitation of the beams of the spans, reinforcement of supports and rearrangement of the carriageway.

Spans - L=16.76 m

The cross-section of the span consists of 9 beams.
The reinforced concrete beams of the overpass were manufactured in 1972 according to typical project of Soyuzdorproekt, inv.No.147/2.

Input data

The main data for the calculation are taken from the results of the survey:
- total length of the beam l = 16.76 m;
- calculated length lp = 16.16 m;
- beam height h = 100 cm;
- the width of the rib at the bottom of the beam b = 16.4 cm;
- actual concrete strength of the beam Rbf = 16.0 MPa;
- calculated width of the slab bf = 100cm;
- Unstressed reinforcement, working bars 14Ø32AII +2 Ø16AII.

Loads

Collection of permanent loads per 1m length of the span is made in Table 3.
Constant load on 1 girder:
Regulatory

$$q_n = \frac{205{,}9}{9} = 22{,}9 \text{ кН/м};$$

Calculated

$$.q_r = \frac{247{,}8}{9} = 27{,}5 \text{ кН/м}$$

Temporary loads.

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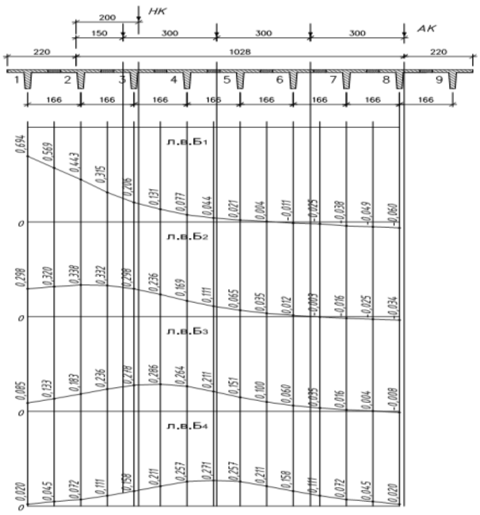
Table 3
Constant load per 1 m of span length

№ n.a.	Type of load	Normative, kN/m	Reliability factor	Design load, kN/m
1	Asphalt driveway	25,8	1,5	38,64
2	Additional reinforced concrete layer for roadway leveling	35,0	1,3	45,5
3	Waterproofing	4,65	1,3	6,1
4	Alignment layer	16,3	1,3	21,15
5	Sidewalk railings	3,0	1,1	3,3
6	Sidewalk barrier	5,6	1,1	6,2
	Total	99,35		130,8
7	Tare weight of 9 main beams	106,5	1,1	130,8
	Total	205,9		247,8

The lines of influence of pressures on the beams are plotted as lines of influence of support reactions on elastic supports [7, 9] and are shown in Pic. 1.



Pic. 1. Scheme of loading of span structures

Loading is done for three circuits:
1) the two A14 loading lanes are as close to the safety barrier as possible;
2) the two A14 load lanes are as close to the edge of the roadway as possible and combine with the crowd on the sidewalk;
3) NK100 load at the edge of the roadway.

The results of calculations of transverse installation coefficients (TIC) for different girders of the span are given in Table 4.

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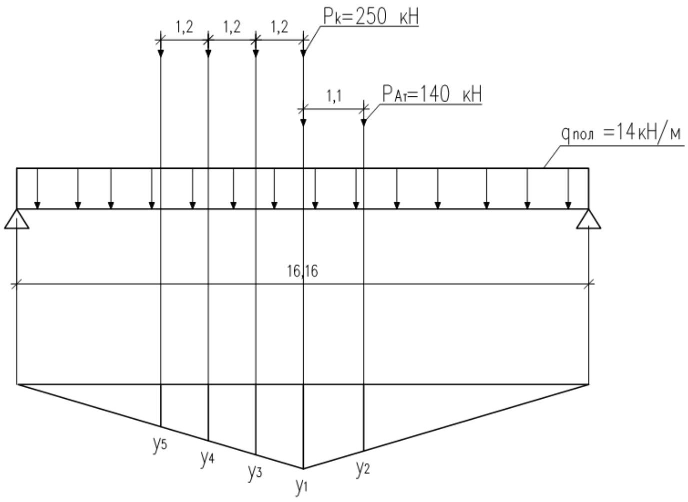
Table 4
Transverse Installation Coefficients (TIC) for different loading patterns

Load circuit number	Girder number of the span	TIC values		
		TIC $_A$	TIC $_{A,,T}$	TIC $_T$
1	0 1 2	0,42 0,56 0,63	0,41 0,52 0,56	- - -
2	0 1 2	0,15 0,43 0,63	0,15 0,36 0,56	0,88 0,26 0
3	0 1 2	- - -	0,15 0,28 0,245	- - -

Determination of the maximum bending moments in the middle of the span.
The construction of the influence line is shown in Pic. 2.



Pic. 2. Influence line of the determination of *Mmax*

$$\omega_{м} = 0{,}125l^2 = 0{,}125 \cdot 16{,}16^2 = 32{,}64 \text{ м}^2;$$

$$y_1 = \frac{l}{4} = \frac{16{,}16}{4} = 4{,}04 \text{ м};$$

$$y_2 = y_1 \frac{0{,}5l - 1{,}5}{0{,}5l} = 4{,}04 \frac{0{,}5 \cdot 16{,}16 - 1{,}5}{0{,}5 \cdot 16{,}16} = 3{,}29 \text{ м};$$

$$y_3 = y_4 = y_1 \frac{0{,}5l - 1{,}2}{0{,}5l} = 4{,}04 \frac{0{,}5 \cdot 16{,}16 - 1{,}2}{0{,}5 \cdot 16{,}16} = 3{,}44 \text{ м};$$

$$y_5 = y_1 \frac{0{,}5l - 1{,}2 - 1{,}2}{0{,}5l} = 4{,}04 \frac{0{,}5 \cdot 16{,}16 - 1{,}2 - 1{,}2}{0{,}5 \cdot 16{,}16} = 4{,}94 \text{ м}.$$

Normative temporary load on sidewalks

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$$P_T = 4 - 0{,}02\lambda = 4 - 0{,}02 \cdot 16{,}16 = 3{,}67 \text{ кПа} > 2 \text{ кПа}.$$

Reliability coefficients of loading:
for vehicle A14

$$\gamma_{fA_t} = 1{,}5 - \frac{0{,}3 \cdot 16{,}16}{30} = 1{,}34\,;$$

For bandwidth

$$\gamma_{fA} = 1{,}2\,;$$

for NK100 load

$$\gamma_{fK} = 1{,}0\,.$$

Dynamic coefficients:
for load A14

$$(1+\mu)_A = 1 + \frac{45 - l}{135} = 1 + \frac{45 - 16{,}16}{135} = 1{,}215\,;$$

for NK100 load

$$(1+\mu)_K = 1{,}1\,.$$

Bending moment in the beam №1 from the load A14

$$M_1 = q\omega_M + (1+\mu)_A\left[\gamma_{fA} q_{\text{пол}} \text{КПУ}_A \omega_M + \gamma_{fA_T} P_{A_T} \text{КПУ}_{A_T} (y_1 + y_{2)}\right] +$$
$$+\gamma_{fT} P_T \text{КПУ}_T \omega_M = 27{,}5 \cdot 32{,}64 + 1{,}215 \times$$
$$= \times\, [1{,}2 \cdot 14 \cdot 0{,}49 \cdot 32{,}64 + 1{,}34 \cdot 140 \cdot 0{,}36(4{,}04 + 3{,}29)] +$$
$$+1{,}2 \cdot 3{,}67 \cdot 0{,}26 \cdot 32{,}64 = 1825{,}5 \text{ кНм}.$$

Bending moment in girder No. 2 from load A14 and crowd on the sidewalk

$$M_2 = 27{,}5 \cdot 32{,}64 + 1{,}215[1{,}2 \cdot 14 \cdot 0{,}63 \cdot 32{,}64 +$$
$$+1{,}34 \cdot 140 \cdot 0{,}56(4{,}04 + 3{,}29)] + 1{,}4 \cdot 1.5 \cdot 2 \cdot 3{,}67 \cdot 0{,}88 \cdot 32{,}64 = 2695{,}3 \text{ кНм}.$$

Bending moment in girder No. 1 from load A14 and crowd on the sidewalk

$$M_1 = 27{,}5 \cdot 32{,}64 + 1{,}215[1{,}2 \cdot 14 \cdot 0{,}56 \cdot 32{,}64 +$$
$$+1{,}34 \cdot 140 \cdot 0{,}52(4{,}04 + 3{,}29)] + 1{,}4 \cdot 1.5 \cdot 2 \cdot 3{,}67 \cdot 0{,}88 \cdot 32{,}64 = 2582{,}2 \text{ кНм}.$$

Bending moment in girder No. 2 from load A14

$$M_2 = 27{,}5 \cdot 32{,}64 + 1{,}215[1{,}2 \cdot 14 \cdot 0{,}63 \cdot 32{,}64 +$$
$$+1{,}34 \cdot 140 \cdot 0{,}56(4{,}04 + 3{,}29)] = 2253{,}0 \text{ кНм}.$$

Bending moment in the beam №1 from the load NK100

$$M_2 = 27{,}5 \cdot 32{,}64 + 1{,}1 \cdot 1 \cdot 250 \cdot 0{,}28(4{,}04 + 2 \cdot 3{,}44 + 4{,}94) = 2119{,}0 \text{ кНм}.$$

Thus, the greatest bending moment occurs in the beam No. 2 when loaded with load A14 and the crowd on the sidewalk.

Prestressed beam L=22.16 m

Prestressed beams 22.16 m long are installed on spans 9-16. The beams were made according to the standard project No.122-62 of Soyuzdorproekt, inv.No.172.

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Loads
Collection of permanent loads per 1 m of the span length is made in Table 6.3.
Constant load on 1 girder:
regulatory

$$q_n = \frac{213,35}{9} = 23,7\ кН/м\,;$$

estimated

$$q = \frac{255,8}{9} = 28,4\ кН/м\,.$$

Temporary loads are calculated similarly to the calculation of beams of length L=16.76m.

Table 5
Constant load per 1 m of span length

№	Type of load	Normative, kN/m	Reliability factor	Design load, kN/m
1	Asphalt driveway	25,8	1,5	38,64
2	Additional reinforced concrete layer for roadway leveling	35,0	1,3	45,5
3	Waterproofing	4,65	1,3	6,1
4	Alignment layer	16,3	1,3	21,15
5	Sidewalk railings	3,0	1,1	3,3
6	Sidewalk barrier	5,6	1,1	6,2
	Total	99,35		130,8
7	Tare weight of 9 main beams	114,0	1,1	125,0
	Total	213,35		255,8

Calculations are made similarly to the beam =16,76 м.
The results of the calculations of the beams =16.76 m and l=22.16 m are recorded in Table 6.

Table 6
Calculation results for girders of span structures

No. item	Type of calculation	Parameters		Ratio of design parameters to load capacity
		from design loads	load-bearing capacity	
Span *l*=16.76 m				
1	Bending moment strength calculation, kNm	2695,3	2515	1,07
2	Calculation of shear force strength, kN	705	540	1,30
Span *l*=22.16 m				
3	Bending moment strength calculation, kNm	3850	3105	1,24
4	Calculation of shear force strength, kN	745	585	1,27

Table 6 shows that the load-carrying capacity of the spans after the restoration and repair is insufficient to absorb the modern design loads A14 and NK100 according to ShNK 2.05.03-12.

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IV. CONCLUSIONS

As a result of the lack of a proper level of operational process in the supporting structures of the overpass there was damage affecting the carrying capacity of the structure:
Span structures - supporting sections of ribs and plates of all spans of the overpass are damaged by salt corrosion: the protective layer of concrete is lost, the armature is corroded and has lost its bond with the concrete, concrete plates are destroyed, plate armature is torn off and deformed in some places. The length of the damaged support sections of the beams is 0.4-1.0 m. The depth of carbonized concrete is up to 5 cm, the degree of corrosion of the reinforcement on the supporting sections is from 10 to 95%;
Based on the actually measured mechanical parameters of concrete and reinforcement, the degree of reliability and emergency risk of load-bearing structures has been evaluated and established:
- Of the total number of girders of spans - 216 pcs., 74 pcs. are to be replaced. The remaining beams must be repaired;
- all supports must be reinforced;
- all single-roller bearing parts must be replaced.

Calculations of span structures taking into account the reinforcement of supporting sections of beams showed that their carrying capacity is insufficient to pass the modern load A14 and NK100 according to ShNK 2.05.03-12. "Bridges and pipes".
Experience from the reconstruction of reinforced concrete bridges shows that the removal of individual intermediate beams in the cross-section of the span is a technologically complex process that requires special equipment and technology to incorporate the new beam into the operation of the span. Therefore, the replacement of one girder may necessitate the replacement of all girders in the span.
Technologically complex is also the device of reinforced concrete jackets for the supports, because the increase in the cross section of the transom on top requires the removal of all the beams in the span and will lead to an increase in the proportion of permanent loads on the foundation.
Strengthening the supporting elements of the overpass to a level that meets the requirements for passing modern loads A14 and NK100 is practically impossible and requires enormous material costs, probably commensurate with the cost of erecting a new overpass.
Given the above, it is recommended that the overpass be dismantled.

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