The Austrian Journal of Technical and Natural Sciences, No 11–12
ISSN 2310-5607

PREMIER Publishing
ppublishing.org

DOI:10.29013/AJT-23-11.12-56-62

CALCULATION METHOD FOR DETERMINING THE REMAINING RESOURCE

Saatova Nodira Ziyayevna [1]

[1] Tashkent State Transport University, "Artificial structures on highways", Uzbekistan

Cite: *Saatova, N.Z. (2023). Calculation Method for Determining the Remaining Resource. Austrian Journal of Technical and Natural Sciences 2023, No 11-12*. https://doi.org/10.29013/AJT-23-11.12-56-62

Abstract

The paper presents calculated method for determining the measure of damage to concrete and reinforcement, based on the basic provisions of the linear theory of damage accumulation. The proposed dependences of the damage measure are convenient for using them in predicting the resource of superstructure structures.

Practical method for calculating the residual resource of the operated superstructures has been developed. It is shown that parameters determined during technical diagnostics are the main initial data for calculating the residual resource. It is established that the residual resource of superstructures subject to salt corrosion is up to 3 times less than the residual resource of the same structures under normal operating conditions.

Keywords and expressions: *operated bridge structures, damage, resource forecasting, critical values, damage measures*

Introduction

Currently operated bridge structures in the Republic of Uzbekistan operate under different force loads with simultaneous unfavorable environmental impact.

Therefore, it is practically impossible to develop a calculation method of bearing capacity and durability of bridge spans with simultaneous consideration of all influencing factors. In the presented work, the authors have limited themselves to the investigation of the part of this problem – prediction of service life of reinforced concrete bridge superstructures in accordance with slab durability. The main attention here is paid to probabilistic calculations of determined resource using modern methods of probability theory and calculations.

Improvement of questions devoted to the problems of increasing durability of bridge structures under conditions of corrosion of their concrete and reinforcement is closely connected with researches in the field of reliability of building structures (Bolotin, V.V., Iosilevskiy, L.I., Chirkov, V.P., Osipov, V.O., Potapkin, A.A., Ashrabov, A.A. and others), prognostication of service life of reinforced concrete bridge spans, (Antonov, E.A., Gordon S.S., Iosilevskiy L.I., Chirkov, V.P., Mamazhanov, R.K., Mukumov, T., Nizamutdinova, R.Z., Urmanov, I.A., Shesterikov, V.I.), corrosion processes in concrete and reinforcement of reinforced concrete spans (Alekseyev, S.N., Moskvin, V.M., Kildeyeva, O.I.). However, based on the results of these data it is difficult to quantify the carrying capacity of operational bridge spans and to predict the residual life for planning the time between repairs. Thus, the research aimed at the development of effective ways to take into account the influence of concrete and reinforcement corrosion in bridge superstructures calculations is an actual problem, which has an important national economic importance. The results of this work will be used to improve the regulatory documents for the calculation of bridge structures in the regional conditions of the Republic of Uzbekistan.

Researching method

When predicting the service life of stressed elements of machines and structures (Bolotin, V.V., 1990; Iosilevsky, L.I., Shcherbakov, E.N., Mamajanov, R.T., 1989) as well as metal bridge spans, the main provisions of the linear theory of damage accumulation are currently used (Chirkov, V.P. 1990).

In this case, the damage caused by external action at a given moment of time does not depend on the loading history, and it can be summed up with the previous damage. The magnitude of the damage is evaluated by the value 0 ≤ Ψ ≤ 1at the beginning of loading $\Psi = 0$; at the moment of exhaustion of the load-carrying capacity of the structure $\Psi = 1$. The accumulation of damage over time is described by the expression

$$\sum_{t=v}^{T} \frac{t_i}{T_i} \qquad (1)$$

For constructions subjected to cyclic loads,

$$\sum_{t=1}^{K} \frac{n_i}{N_i} = 1 \qquad (2)$$

Where n_i – is the number of cycles under uniform loading; Ni is the number of cycles before failure.

Damage measure by any point in time

$$\Psi_i = \sum_{t=0}^{T} \frac{t_i}{T_i} \qquad (3)$$

In the case of non-linear voltage loading σ

$$\Psi_i = \int_0^T \frac{dt}{T(\sigma)} \qquad (4)$$

Based on (3) in (Osipov, V.O. 1999), dependences for determining the resource of metal bridge elements have been proposed.

V.P. Chirkov has proposed mathematical models to predict the service life of reinforced concrete bridge spans on the basis of the above-mentioned provisions. A change in the transverse strain factor V was taken as a measure of concrete damage under repeated loading and dependences for determining the life of spans were obtained with this in mind.

In R. Mamajanov's work the main parameter of fracture mechanics – stress intensity coefficient K – was used to describe the process of degradation and development of cracking in concrete of compressed zone of span structures. Dependences for description of K in time under repeated loading have been proposed.

In the above-mentioned works the loading history, characteristics of loads and their statistical scatterings have been taken into account.

However, it should be noted that the use of these dependences to estimate the damage measure for practical calculations is difficult and large statistical data are required.

Results and the analyze of them

Based on the analysis of the above studies, it can be concluded that it is more promising to take the actual values of concrete strength, reinforcement corrosion degree as a damage measure. Knowing actual values of the mentioned parameters, it is possible to determine values of damage measure and to determine service life of span structures by concrete strength at salt corrosion and reinforcement corrosion.

Considering the above, the concrete damage measure is assumed to be

$$\Psi = \frac{R_b - R_{t\exp}}{R_b - R_{cr}} \qquad (5)$$

Where R_b – is the design value of the concrete strength;

R_{texp} – meaning of concrete strength at the time of technical diagnosis;

R_{cr} – is the maximum permissible value of reduction of concrete strength during salt corrosion.

For (5) the prerequisites fulfilled:

$$R_b = R_{texp}; \quad \Psi=0; \tag{6}$$

$$R_{texp} = R_{cr}; \quad \Psi=1 \tag{7}$$

Thus, $\Psi = 0$ corresponds to the case where there is no salt corrosion and strength is not reduced, and $\Psi = 1$ corresponds to the time when the limit state is reached.

From (5) we have

$$\Psi_b = a - bR_{t\exp}; \tag{8}$$

$$a = \frac{R_b}{R_b - R_{cr}} \tag{9}$$

$$b = \frac{1}{R_b - R_{cr}} \tag{10}$$

By substituting $R_{bt} = 0{,}9R_b e^{-0{,}01t}$ into (8), we obtain

$$\Psi_b = a - 0{,}9bR_b e^{-0{,}01t} \tag{11}$$

According to (11) it is possible to determine the value of the concrete damage measure at any time t of the technical diagnosis from actual measurements of the concrete strength.

Similarly, the reduction of the cross-sectional area of the reinforcement can also be expressed in terms of the damage measure

$$\Psi_s = a_s - b_s A_{st} \tag{12}$$

$$a_s = \frac{A_s}{A_s - A_{cr}} \tag{13}$$

$$b_s = \frac{1}{A_s - A_{cr}} \tag{14}$$

Where A_S – is the cross-sectional area of the reinforcement as designed;

A_{st} – sectional area of the reinforcement after corrosion;

A_{cr} – maximum permissible value of reduction of reinforcement cross-sectional area

Given A_{st}=A_s0 e^0,015t, expression (12) is written as

$$\Psi_s = a_s - 0{,}7b_s A_{so} e^{-0{,}015t} \tag{15}$$

The obtained dependences for description of damage measure in time allow determining residual life of span structures according to the results of technical diagnostics.

Differential equation for damage accumulation measure according to (Chirkov, V. P. 1998, Osipov, V. O. 1999) with regard to (13) is written as

$$\frac{d}{dt} = ce^{-\alpha t}; \tag{17}$$

Where $c = 0{,}9R_b \times b$.

The dependence obtained describes the rate of deterioration of concrete strength over time under salt corrosion conditions.

From (17) dividing the variables is can be written

$$\int_0^{\Psi} d\Psi = c\int_0^t e^{-at}dt \tag{18}$$

The accumulated damage measure Ψ_1 at time t is determined by integrating the equation

$$\int_0^{\Psi_1} d\Psi c\int_0^{t1} e^{-at}dt \tag{19}$$

$$\Psi_1 = -c \times e^{-\alpha tI} \tag{20}$$

The resource T_{res} of the span when the load-bearing capacity $\Psi = 1$ is exhausted is determined from the equation

$$\int_0^1 d\Psi = -c\int_0^{T_{res}} e^{-\alpha T}dt \tag{21}$$

From here, by integration we get

$$e^{-T_{res}} = 1/c \tag{22}$$

$$T_{res} =_h \frac{en\, 1/c}{\alpha} \tag{23}$$

Suppose that by the time of technical diagnosis *t1* the damage accumulation is $\Psi = \Psi_1$. The permissible value of the damage measure is taken as $\Psi = \Psi_{cr}$. then to determine the time for damage to reach critical values Ψ_{cr} (20) is written as

$$\int_{\Psi_1}^{\Psi_{cr}} d\Psi = c\int_{T_1}^{T_{res}} e^{-\alpha t}dt \tag{24}$$

Integration gives

$$\Delta T_{resb} = \frac{\ln\left[\frac{\Psi_{cr} - \Psi_{1b}}{c}\right]}{\alpha} \tag{25}$$

Where $\Delta T_{res} = T_{res} - t_1$ – residual life – estimated service life since technical diagnosis;

T_{res} – the design life of the span.

The corrosion life of the span is determined using a similar methodology

$$\frac{d_3}{dt} = c_3 e^{-\beta t}; \tag{26}$$

$$\int_0^1 d_3 = c_3 \int_0^{T_{res}} e^{-\beta t} dt \quad (27)$$

$$T_{res} = \frac{\ln \frac{1}{c_3}}{\beta} \quad (28)$$

Residual life by valve corrosion

$$\int_{\Psi_1}^{\Psi cr} d\Psi = c_3 \int_{t_1}^{T_{res}} e^{-\beta t} dt \quad (29)$$

$$\Delta T_{ress} = \frac{\ln\left[\frac{\Psi_{c3} - \Psi_{is}}{c_3}\right]}{\beta} \quad (30)$$

Thus, it is possible to determine the residual life of the reinforced concrete superstructures subject to salt spray corrosion using the obtained dependencies. The main input data are the results of technical diagnostics.

It should be noted that an important point in determining the residual life is the correct assignment of the limit values of the damage measure $\Psi_{cr.}$

Research on the assignment of Ψ_{cr} in practical tasks has been devoted to (Tynkov, I.B., Nizamutdinova, R.Z., 1990).

From the analysis of these works, it is clear that the normalized value Ψ_{cr} is a random variable, and its precise determination is a difficult task and presents mathematical difficulties. Therefore, (Osipov, V.O., 1999) provides evidence for the practical use of simple mathematical models to assign Ψ_{cr} when justifying assumptions.

In the works of V.O. Osipov, the value of $\Psi_{cr..}$ is substantiated for predicting the residual life of metal spans.

In works (Tynkov, I.B., Nizamutdinova, R.Z. 1990) the normalized value $\Psi_{cr.}$ is set separately for different types of span resource exhaustion – by endurance of concrete and reinforcement, by deflection and other attributes. The probability of non-destruction at any value of accumulated damage measure is given as

$$P(\Psi) = 1 - \frac{1}{\sigma\sqrt{2\tau}} \int_0^{cr} exp\left[-\frac{\left(-\overline{\Psi}\right)^2}{2\sigma^2}\right] d \quad (31)$$

Or

$$P(\Psi) = 1 - \left[\frac{\overline{\Psi} - \Psi_{cr}}{\sigma}\right] \quad (32)$$

Table 1 records the values Yc_r calculated according to (32) from the results of the repeated loading tests of the test specimens.

Table 1.– *Changing the meaning of a* Ψ_{cr}

Meaning of the Ψ_{cr}	0.35	0.4	0.45	0.5	0.55	0.6	0.65
Probability of non-destruction	0.999	0.996	0.989	0.971	0.934	0.864	0.722

As it can be seen from table 1, the probability of non-destruction decreases with increasing tolerance values Ψ_{cr}. Here, one of the main tasks is to establish the level of non-destruction *P (Ψ)* – the level of reliability of the span structure operation according to the characteristic under consideration.

In works (Nizamutdinova, R.Z., 1994) for reinforced concrete structures with failure due to brittle failure, loss of stability it is proposed to take *P(Ψ)* = 0.999, and with failure without loss of load-bearing capacity *P(Ψ)* = 0.99.

In recommendations (Recommendation on Evaluation and Reliability of Transport Structures 1989) reliability level of *P (Ψ)* is proposed to be assigned depending on the category of road on which the bridge structures are located.

As can be seen, there are currently no sufficiently well-founded suggestions for assigning *P(Ψ)*. Therefore, following the results of studies (Shesterikov, V.I. 1991), (Kildeeva, O.I., 1998) (*P (Ψ)* = 0.95 can be taken with some caution for resource calculations).

Example of calculating the residual lifetime of a reinforced concrete structure subject to salt spray corrosion

Input data. The 16.76 m long reinforced concrete span of the overpass. The year of construction of the overpass is 1967. The girder design was developed for H30 and NK80 load.

The overpass was repeatedly examined by bridge departments of TashIIT and TADI.

The scheme of the span is shown in Figure 2.1. The main beam is reinforced with periodic profile reinforcement ø 14 mm of A-II class. The carriageway slab is reinforced with A-II class reinforcement ø 12 mm with 10 cm spacing. The distance between the main beams is 56 cm. The design class of concrete is B25 (M300).

The survey found that salt corrosion had reduced the original diameter of the reinforcement to 5.9 mm. The depth of salt penetration determined by the method specified in clause 2.3 is up to 12–17 mm. The actual strength of the concrete layer of the corroded slab is Rb = 12.0 MPa.

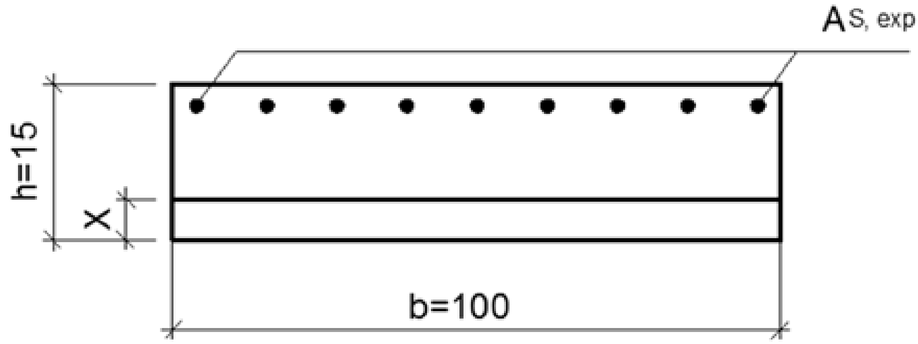
It is required to determine the residual life of the span in terms of slab strength.

Calculation of the slab load-bearing capacity at the time of the technical diagnosis.

Calculation diagram of the external cantilever slab

h1 – height of compression zone not subject to salt corrosion.

Figure 1.



The height of the concrete compression zone, taking into account the actual condition of the slab, is determined according to the following expression

$$x = \frac{R_s A_{Sexp}}{R_{bexp}} = \frac{240 \cdot 5{,}9}{12 \cdot 100} = 2{,}36\ sm$$

Where A_{sexp} – actual cross-sectional area of the reinforcement;

R_{bexp} – actual design resistance of concrete.

Checking the load-bearing capacity of the section

$$R_{b\exp} bx\left[h_0 - \frac{x}{2}\right] = 12 \cdot 100 \cdot 2{,}36\left[12 - \frac{2{,}36}{2}\right] = 15{,}3\ кНм > M = 14{,}1\ kNm$$

Where M – the calculated bending moment in the considered cross-section, at the moment of diagnostics the bearing capacity of the cross-section is provided with a small reserve. Exhaustion of the resource can take place at reduction of concrete strength up to R_{crb} = 8.0 MPa and reduction of actual reinforcement area up to A_{scr} = 5.5 cm^2.

Determine the measure of damage accumulation in concrete and reinforcement by the time of technical diagnostics by formulas

$$\Psi_{1b} = \frac{R_b - R_{bexp}}{R_b - R_{cr}} = \frac{35-12}{35-8} = 0{,}85$$

$$\Delta T_{resb} = \frac{\ln\left[\frac{\Psi_{cr} - \Psi_{1b}}{c}\right]}{\alpha} = \frac{\ln\left[\frac{1{,}92-0{,}85}{1{,}18}\right]}{0{,}01} = 9{,}8\ years$$

$$C = 0{,}9\,Rbb = 0{,}9\frac{35}{35-8{,}5} = 1{,}18$$

$$\Psi_{cr} = \frac{1}{[\Psi_{cr}]} = \frac{1}{0{,}52} = 1{,}92$$

Where $[\Psi_{cr}]$ =0,5 for reliability level 0,95 by table 1.

$$\Psi_{1s} = \frac{A_S - A_{Sexp}}{A_S - A_{cr}} = \frac{11{,}3 - 5{,}9}{11{,}3 - 5{,}5} = 0{,}93$$

$$\Delta T_{ress} = \frac{\ln\left[\frac{\Psi_{c3} - \Psi_{1s}}{c_3}\right]}{\beta} =$$

$$= \frac{\ln\left[\frac{1{,}923 - 0{,}93}{1{,}42}\right]}{0{,}015} = 25{,}2 \ years$$

$$\Delta T_{ress} = \frac{\ln\left[\frac{\Psi_{c3} - \Psi_{1s}}{c_3}\right]}{\beta} =$$

$$= \frac{\ln\left[\frac{1{,}923 - 0{,}95}{1{,}42}\right]}{0{,}015} = 25{,}2 \ years$$

$$C_3 = 0{,}7 b_S A_{S0} = 0{,}7 \frac{1}{11{,}3 - 5{,}5} 11{,}3 = 1{,}42$$

Thus, the residual life of the span slab is $\Delta T_{res} = 9{,}8 \approx 10$ years on the basis of the bearing capacity of concrete corrosion.

Summary

The calculated method of determination of damage degree of concrete and reinforcement of bridge structures based on main provisions of linear theory of damage accumulation with regard for regional conditions of the Republic of Uzbekistan has been proposed. The proposed damage measure dependencies are convenient for their use in forecasting the service life of bridge superstructures.

The practical way of calculation estimation of residual resource of operating bridge spans has been developed. It is shown that the main initial data for residual resource calculation are the parameters, which are defined at technical diagnostics. It is established that the residual life of the spans that are exposed to salt corrosion is up to 3 times less than the residual life of the same structures which are under normal operation conditions.

References

Bolotin, V. V. (1990). Resource of machines and structures.– Moscow: Mashinostroenie.

Iosilevsky, L. I., Shcherbakov, E. N., Mamajanov, R. T. (1989). "Prediction of Service Life of Elements Subjected to Regime Loadings", Report of the Academy of Sciences of UzSSR.– № 12.– P. 18–20.

Mamajanov, R. T. T. (1993). Probabilistic prediction of lifetime of Reinforced Concrete Bridge spans.– Tashkent: Fan.– 156 p.

Ryazanov, Y. S. (2003). About estimation of technical state of bridges // Way and track facilities, 2003.– № 7.– P. 26–27.

Tynkov, I. B., Nizamutdinova, R. Z. T. (1990). The causes of damage in reinforced concrete spans operated in conditions of Central Asia // Operational reliability of engineering structures under complex loads and influences of external environment.– Tashkent, 1990.– 40 p.

Chirkov, V. P. (1990). Fundamentals of Theory of Calculation of Reinforced Concrete Structure Life //Concrete and Reinforced Concrete, 1990.– № 10.– P. 35–36.

Osipov, V. O. (1982). Durability of metal spans of railway bridges. Transport. 1982.– 287 p.

Osipov, V. O. (1999). Reserves of metal bridges load-carrying capacity // Railway transport. 1999.– № 8.– P. 42–45.

Chirkov, V. P. (1998). Theoretical basis of forecasting service life of reinforced concrete structures. Tutorial.– Moscow: MIIT, 1998.– 56 p.

Chirkov, V. P. (2000). et al. Service Life – the basis for designing of transport systems // Transport Construction – № 1.– 15 p.

Mamajanov, R. (1989). Practical method of calculation of reinforced concrete bridge spans // Transport construction.– № 3.– P. 19–20.

Nizamutdinova, R. Z. T. (1994). Resource of Reinforced Concrete Bridge spans on the railway lines of industrial enterprises / Tash IIT. Dissertation for the degree of Candidate of Technical Sciences 05.23.15.– Tashkent, 1994.

Shesterikov, V.I. (1991). Estimation of road bridges condition and forecasting of its changes by means of physical wear indicator.– P. 1–48. (Automobile Roads,– Vol. 4).
Recommendation on Evaluation and Reliability of Transport Structures.– Moscow: Central Research Institute of Railway Transport, 1989.– 71 p.
Kildeeva, O.I.T. (1998). Resource of Reinforced Concrete Bridge Spans by Armature Corrosion // Istedod.– № 7 (7).– P. 100–108.

submitted 14.12.2023;
accepted for publication 22.12.2023;
published 24.01.2024

Contact: general-Saatova-nsoatova@bk.ru