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ИЗВЕСТИЯ

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ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ

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СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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ASSESSMENT OF DEFECTSIN MOUNTAIN ROADWAY TUNNEL DUE TO VARIOUS NATURAL AND OPERATIONAL FACTORS – ISTIQLOL (REPUBLIC OF TAJIKISTAN)

Abstract. The present article analyses the defects in a mountain roadway tunnel (Istiqlol) recorded between 2013 and 2017. The defect analysis of the mountain tunnel is vital as it deals with the safety of the passengers using the tunnel. The factors causing the deterioration of tunnel is discussed in this present work. Deterioration of the tunnel lining is due to continuous maintenance of the tunnel is the biggest threat to the durability of the tunnel. Infiltration of groundwater through seismic (deformation) seams, cracks through the tunnel lining have a special role in deteriorating the state of the tunnel construction, which leads to minor surface corrosion to major ones. The defects in the tunnel were noted personally in a regular basis between the years 2013 and 2017. Defects were categorized into 6 different types with respect to their nature. Probability plots were plotted with help of MINITAB software to analyse the probability at which a particular value of Technical condition severity occurs. The final observations states the main reason for the defects in the tunnel.

Keywords: Mountain tunnels, Tunnel defects, Defect assessment, Tunnel safety, Ventilation tunnel, Probability distribution.

Introduction. Mountain road tunnels play vital role in the road transportation system throughout the world as it is expected to reduce the transportation time as well as the distance makes travelling easy. Most of the countries, irrespective of its economic status allocate funds to construct the road tunnels. Road tunnel's safety operation is vital as tunnels are specific engineering structures, which are built to minimise the transport routes and improve road safety. At the same time, transport of dangerous goods through the tunnel affects the safety of the tunnel overall.

The technology of construction of tunnels for various purposes is considered as a complex of interrelated production processes and technical means used for the purpose of forming a cavity in an array of rocks that ensures the performance for a specified period of functions of a special purpose. The technological process is understood as the most essential arrangement of operations and operations, determined by their composition and sequence of execution in time and space. The type and composition of technical means are determined by the purpose and form of production, the way of tunneling and fixing the tunnel and are characterized by the design and type of lining.

Construction of "Istiqlol" tunnel was carried out in rocks of strong and medium strength by mining method [1]. When constructing tunnels in strong, resistant rocks, the continuous face pattern is most often used.The Istiqlol tunnel, built in 2006, is a two-way transport development on the Dushanbe-Khujand highway, is 4,996 m long, a width of 10.20 m and a height of 8.10 m, and a ventilation tunnel with a width of 6.24 m and a height of 5.5 m was constructed parallel to a distance of 27 m. The area of the Istiqlol tunnel is located on a site bounded in latitude from N39º03.42 'to N39º06.30' and in longitude from E68º42.01 'to E68º41.14'. The tunnel is located at an altitude of 2670m above sea level. The tunnel cross-

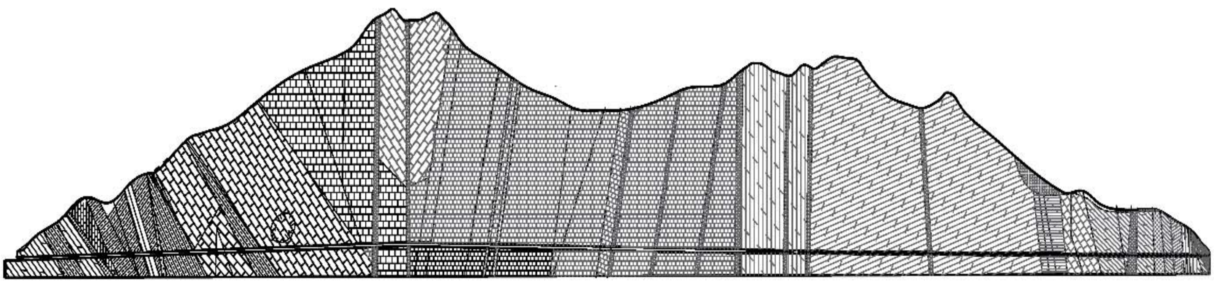

Figure 1 – Geological section of the transport route in tunnel "Istiqlol"

section has a horseshoe shape with lining of monolithic concrete and reinforced concrete.The tunnel is passed in a rocky massif, composed of granites, quartz, sandstones, dolomites, etc. Coefficient of rock strength varies from 2 to 20 (figure 1). Plicative and disjunctive dislocations, which cause a strong fracture to the rocks, are developed. Cracks are oriented along the strike of the rocks and parallel to each other. Cracks are gaping, partially "healed" by clay material and hair, developed in the middle part of the tunnel. The size of open cracks varies from 0.5 to 7-8 mm.

Transport tunnel "Istiqlol" refer to be heavily watered and under this factor the construction conditions are considered difficult. The maximum water flow in the tunnel reaches 250-300 m^3/ h and depends on the season. The main drainage tray is located in the central part of the ventilation tunnel, which serves to collect incoming water through the galleries. At the walls of the main tunnel, there are catchments [1].

During the construction of the tunnel, a number of water manifestations were revealed in the form of concentrated outcrops of intensive capes, associated with zones of severe weathering and tectonic crushing. The temperature of groundwater in the tunnel construction area is 3-5 °C.

During the construction of the tunnel, the drilling and blasting method (BVR) is applied. The lining was built in a parallel scheme using telescopic formwork. The section of the tunnel, where concrete works were produced, was separated from the rest by a bridge to provide the required temperature regime for hardening concrete. The air temperature in the winter period at the place where the concrete was laid was at least +4 °C. Concrete delivery for the formwork was made by the PN-500 concrete pumping unit, installed within the construction site of the permanent lining.

Tunnels were developed from two sides with an average speed of 60-80 meters per month. The exit of the face for the cycle was 1.3-2.0 m with a depth of 1.5-2.3 m. The cycle time varied from 1.0 to 1.5 days, depending on the stability of the rocks. Depending on the nature and water content of the rocks, which vary both in the individual tunnels and in each of them, the designs provide horseshoe and vaulted shapes (figure 2).

Concrete of class B15 is used in tunnel constructions of "Istiqlol". The concrete grade for frost resistance for the construction area was applied not less than Mpз200. The thickness of the lining is calculated for the possible load from the vertical rock pressure determined according to the require-

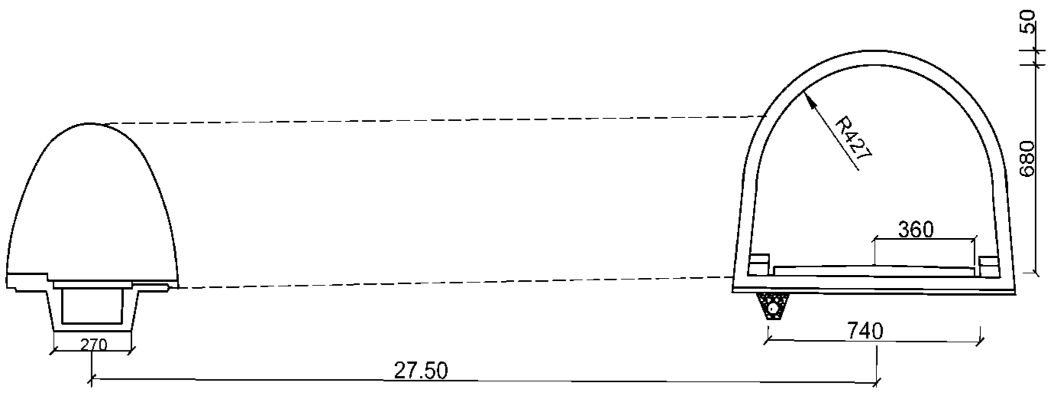

Figure 2 – Section of the transport tunnel "Istiklol"

ments [2]. The load-bearing structures are designed for a disadvantageous combination of impacts from the rock pressure and the load from the self-weight of the lining, according to the limiting state of group 1 (according to bearing capacity). According to the project, taking into account mining, hydrogeological and climatic conditions, the thickness of the lining is 500 mm.

Regular inspection was conducted personally between years 2013-2017. Regular inspections of the tunnel condition revealed a number of violations of lining in the form of dumps, caverns, cracks, leaching sites, ice sheets and infiltration of water. The disturbances are distributed randomly on the surface of the tunnel, the areas of the disturbed lining amount to 60-80% of the total length of the tunnel. In addition to the above-mentioned, so-called obvious defects, in the lining of tunnels, there are hidden violations that were not established by external examination (figures 3.1 and 3.2).

Figure 3.1 – Infiltration of water and leaching of the lining of the tunnel "Istiqlol"

Figure 3.2 – Rust formation inside the tunnel and formation of ice on the lining of the tunnel "Istiqlol"

The presence of cracks, wet spots and ice on the surface of the tunnel leads to the formation of leaching areas of concrete lining, shells and piles. The danger to the stability of the lining is the opening of cracks, especially when they are combined with wet spots, areas of dripping and leaking water. Entering on the cracks and pores water interacts with cement and destroys it.

Stability and reliability of tunnels. The operational reliability of underground structures and the degree of stability of the lining of the tunnel depends on the impact produced by the natural and man-made factors. The problem of predicting the condition of the rock contour and the lining of underground structures is reduced by calculating the stability of the rocks on the outline and nearly within the zones of inelastic deformations. The task of determining the stability of the lining is multifactor, which includes the correct choice of the type and parameters of the pillars (bearing walls) at the design stage, the rational technology of construction of underground structures, the erection of it, the implementation of measures for water trapping and water suppression in the tunnel, increasing the frost resistance of the lining, which will ensure its high quality and minimum costs during further operation.

In case of railway and road tunnels internal lining, there are many requirements for their stability, associated with the long life of underground structures and the dependence of the effective work performance on the reliability of the condition of the pillar. The failure of individual elements of the lining leads to a decrease in the overall reliability of the underground structure, the suspension of the tunnel for rehabilitation work for a long time, which affects the rhythm of the operation of the transport main as a whole.

According to the literature sources, the failures of structure as a whole are complete and partial, sudden and gradual, operational and technological, constructive, preventive, dependent and independent, dangerous and safe. Over time, hidden defects to the lining under the influence of unfavorable factors pass into the category of obvious ones, which leads to emergencies that require immediate action to prevent the destruction of the lining.

The main type of failure (95%) is the gradual increase in displacements (gradual failure), which ultimately lead to an unacceptable reduction in the cross section, the failure of the weakest or heaviest loads (partial failure), and then to a complete collapse of the pillar (complete failure).The collapse of the pillar, or the complete failure, which is usually of a sudden nature, occurs quite infrequently (no more than 5% of all failures), due to the fact that, as a rule, the development is timely repaired at the stage of the appearance of partial failures, a greater danger and most often caused by the collapse of the roof rocks along the slip planes.

Table 1 – Representation of categorizing the defects and no. of defects between 2013 and 2017

Defect Index (type)	Description of the defect (events)	Criticality category	Coefficient of ranking k_p	Number of defects ($S_{criticality}$)					Category of repair-fitness
				2013	2014	2015	2016	2017	
1	Portals								
1.1	Exfoliation of finishing plaster coatings on the surface of the portal	C	0.6	2	2	2	2	3	4
1.2	Violated waterproofing of portal sections of tunnels with increasing their watering after heavy rains and during the thawing of snow	D	1	2	2	2	2	2	4
2	Tunnel lining made of monolithic concrete or reinforced concrete (perception of external loads and impacts from a soil massif)								
2.1	Separate parts, lining, elements of communications and ice on the walls and arch come into the outline of the dimensions of approaching buildings by 50 mm and more	B	1	34	34	36	40	45	2
2.2	Transverse cracks in cold and expansion joints, opening more than 0.2 mm.	D	1	13	13	15	17	20	4
2.3	Destructive concrete lining - defrosted or leached, manually disassembled, more than 20 mm deep.	D	0.65	12	12	14	17	22	4
2.4	Exfoliation of coverings of concrete lining.	D	0.55	10	10	13	16	15	4
2.5	Shells and caverns on the surface of the lining more than 20 mm deep.	D	0.3	34	35	38	42	50	4
3	Intra-tunnel arrangements (providing specified parameters for the functioning of the facility)								
3.1	Malfunctions of ventilation systems	B	1	2	2	2	2	1	2
3.2	Malfunctions of the security signal system (traffic lights, barriers)	B	0.5	2	2	2	2	2	3
3.3	Malfunctionsofpowersupplysystems	C	1	1	1	1	1	1	3
3.4	Absence of a system of electroheating of drainage trays	D	1	0	0	0	0	0	4
3.5	Littered, silted out issues from the isolation drainage, interruptions from drainage tunnels and intraband drainage trays	D	0.95	3	4	5	7	5	4
3.6	Lack of lighting in the section of the tunnel	D	0.5	12	12	12	14	12	4
4	Watering of the facilities of the tunnel construction								

4.1	Leaks with the removal of soil because of the lining.	B	1	4	5	4	4	5	2
4.2	Operating (increasing in volume) ice on the surface of the lining, in niches and chambers.	B	0.7	23	23	27	31	22	4/2
4.3	Leaks and drops with water on the lighting and electromechanical equipment	B	0.6	15	15	17	21	12	3/2
4.4	Dampness and separate drinking, no leaks	D	1	88	90	92	95	96	4/2
4.5	Inactive ice thickness of up to 50 mm on the surface of the lining	D	0.65	12	12	13	16	15	4/2
4.6	Leaks following the rust removal	D	0.45	12	12	12	15	10	4/2
5	The carriageway in the tunnel (ensuring the safe and smooth movement of vehicles in the tunnel)								
5.1	Cross cracks with a distance between them from 1 to 40 m in the presence of splashes of water from cracks	B	0.65	1	1	1	1	2	2
5.2	Cracks longitudinal along the axis and edges of the roadway, in the presence of a splash of water	B	0.6	40	41	43	47	45	3/2
5.3	Large (over an area of more than 1 m^2) potholes with a depth of more than 50 mm with damage to the protective layer and exposure of the reinforcement	C	1	3	3	5	5	5	3
5.4	Single hollows (up to 0.5 m^2) of potholes with a depth of 50 mm with damage to the protective layer and exposure of the reinforcement	C	0.7	5	5	5	5	3	3
6	Other elements (information, shielding and protective functions)								
6.1	Violation of security barriers and pedestrian sidewalks	C	1	6	7	6	6	5	4
6.2	Availability of free access to hazardous objects and electromechanical equipment	C	0.85	15	15	15	13	15	4
6.3	Absence of signal coloring of niches and chambers, their numbering	D	0.4	20	20	20	20	20	4
6.4	Cluttering of niches, chambers and security zones	D	0.2	16	15	15	15	15	4

Root causes of the listed failures are: non-correspondence between the load-bearing capacity of the pillar or its individual components to the current load (structural failure), the violation of the support system technology (absence or poor-quality backstopping of the fixed space, poor attachment of the clamping jaws, etc.), violation of operating conditions unforeseen operating time and part-time, watering of production, etc.).Almost all types of failures depend on the duration of production exploitation, and this factor must be taken into account when investigating the reliability of the support.

Calculation and discussion: technical condition assessment of structures and facilities of transport tunnel (istiqlol). We will calculate the absolute assessment of the technical condition of the transport tunnel Istiqlol, more than 5 km long, with approaches to the tunnel of 150 m. The lining of a tunnel made of reinforced concrete. The tunnel is located on the second category road, and the estimated speed of the transports is 50 km/h. This methodology for estimating tunnels was carried out in accordance with the methodology for assessing the transport-operational condition of mountain road tunnels designed by the Federal Road Agency (Rosavtodor) of the Ministry of Transport of the Russian Federation [3, 4].

Based on the results of surveys for the reporting period 2014-2017, defects and identification of which are carried out according to the classification of defects in structures and structures of Istiqlol mountain road tunnels (see table 1) in tunnel junction structures and facilities. The ranking factor of the criticality categories in (table 1) was obtained using the quantitative (in points) characteristics of reliability indicators determined by the group of experts in GOST 27.310-95 and grouped in groups corresponding to the classification of criticality categories. Ranking factors are the weighting factors (severity) of the defects of the subsystem (element) within one criterion category [3, 4].

In accordance with the classification of works on the overhaul, repair and maintenance of public roads and artificial structures, the following categories for maintainability are recommended:

- A - reconstruction or new construction;
- B - overhaul;
- C - repair;
- D - repair needed with insignificant importance.

Σ (A), Σ (B), Σ(C), Σ (D) - the sum of defects with the corresponding category of criticality.

Based on the results of analysis and identification of defects, an absolute estimate of the technical state of the tunnel transition is calculated by the formula 1. The absolute estimate $|T_C|$ is the sum of all structural defects and tunnel transition arrangements, taking into account their ranking according to the severity of the consequences, which characterizes the state of the tunnel structure at a certain point in its operation. In this regard, the increase in the number of defects for a fixed period of observations indicates the development of destructive processes and deterioration of the technical state, and vice versa, a decrease in the absolute estimate characterizes the improvement of the technical state in comparison with the previous period. Improvement or deterioration of the technical condition can be associated with both changes in external influences and as a result of repair measures.

$$| T_C | = k_a\Sigma(A) + k_b\, \Sigma(B) + k_c\, \Sigma(C)+ k_d\, \Sigma(D), \quad (1)$$

where $| T_c |$ – an absolute assessment of the technical condition or state of the tunnel transition; k_A, k_B, k_C, k_D are the coefficients of defect ranking in the corresponding criticality categories A, B, C and D. The evaluation of the technical state (T_C) for the previous reporting periods is shown in figure 1. According to the estimates given, it is possible to judge the deterioration of the technical state of the tunnel transition due to the increase in the number of defects in categories B and D. This may indicate a low efficiency of the maintenance of the structure.

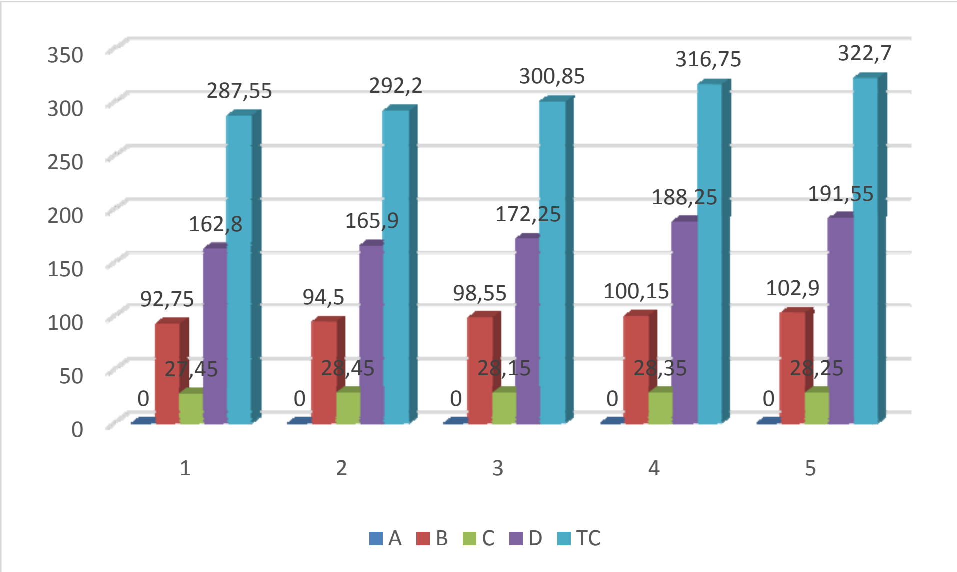

Figure 4 – Assessment of the technical condition of the Istiklol transport tunnel
in terms of criticality for the duration between 2013 and 2017:
A - high risk, B - significant risk, C - slightly significant risk, D - insignificant risk, T_C - technical condition

The analysis of the detected defects by the categories of maintainability of the tunnel “Istiqlol” shows that at the time of inspection of the design and arrangement of the tunnel transition, it is required:

- Overhaul (category B for maintainability) in 20 cases;
- Repair (category C) in 30 cases;
- Repair at the maintenance (category D) in 85 cases.

During the assessment of the technical condition, there were no defects of category A(1^{st} category for maintainability) in the tunnel “Istiqlol” for the entire 5 years.

The probability plot [5] for the events (defects) of various types occurred between 2013 and 2017 have been plotted and examined by using MINITAB 2017 software as with the help of this plots, the probability of recording a particular value of defect can be analyzed and by which the repairs can be conducted first on a type of a defects whose probability of occurrence is higher than rest of others. The mean and the standard deviation were shown. By determining the p-value [5], the normal probability

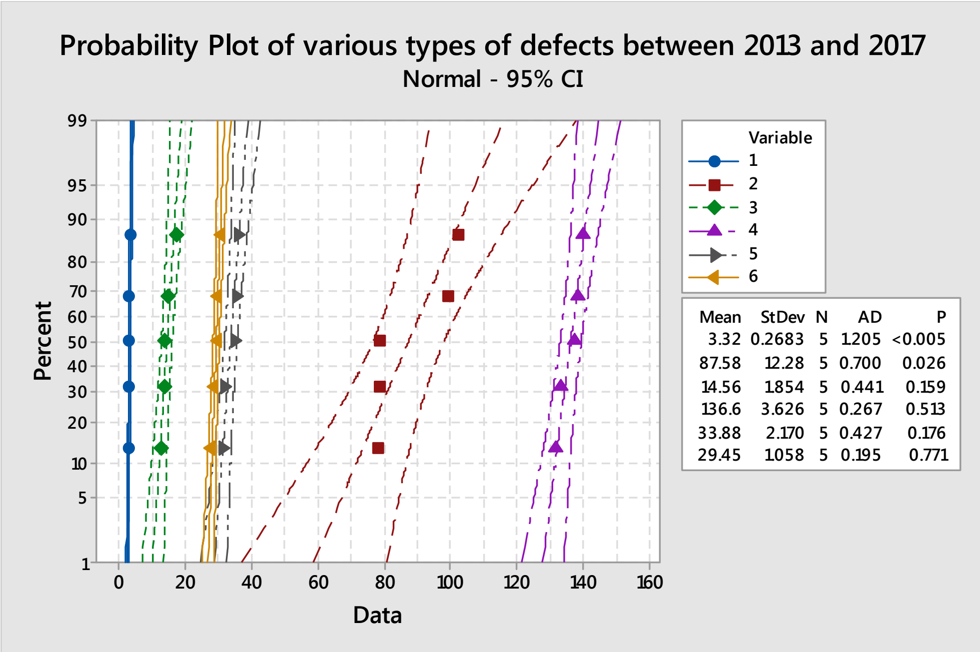

Figure 5 – Probability plot for different types of defect severity.

Note: 1: Portals, 2: Tunnel lining made of monolithic concrete or reinforced concrete (perception of external loads and impacts from a soil massif), 3: Intra-tunnel arrangements (providing specified parameters for the functioning of the facility), 4: Watering of the facilities of the tunnel construction, 5: The carriageway in the tunnel (ensuring the safe and smooth movement of vehicles in the tunnel), 6: Other elements (information, shielding and protective functions).

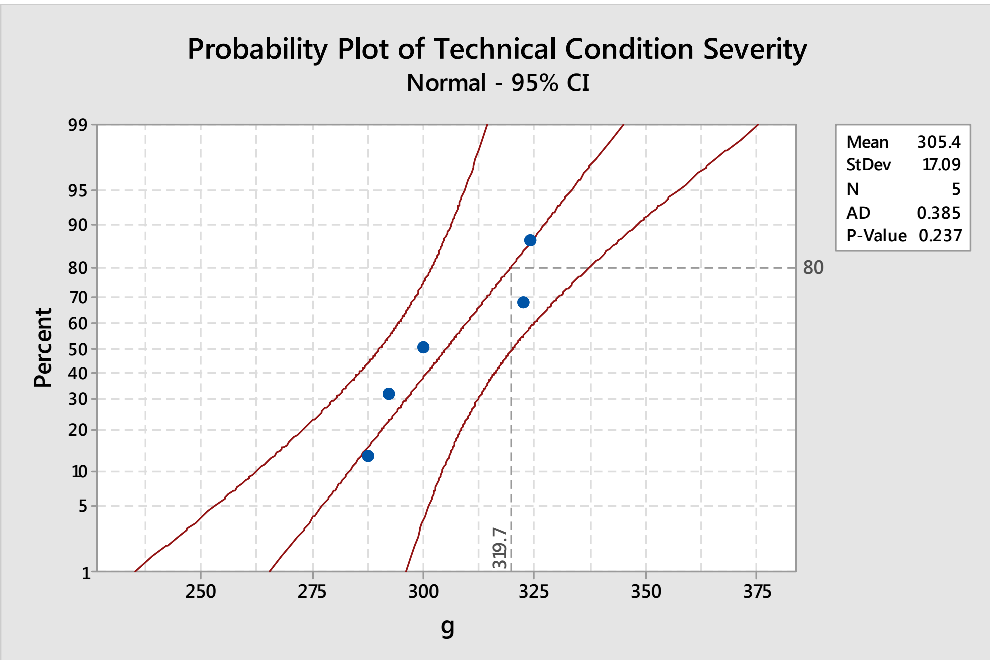

Figure 6 – Probability plot for total defect severity each year at Confidence interval of 95%

distribution can be evaluated. The analysis was carried out with 95% confidence interval. From figure 5 it can be observed that only in the case of data recorded for defects type 1 and type 2,p-value for the

Anderson-Darling test is below 0.05, which means that the mean value obtained to the data(defect type 1 and type 2) is not a true mean and cannot be used to determine the probability distribution which can help to predict the future values, but whereas all other type (3-6) as seen has p-value greater than 0.05for the Anderson-Darling test, which says that we are 95% confident that the mean values obtained for the defects(type 3-6) are true mean and can be used to determine the probability distribution for their respective cases. Also, the repairs show be first done on type 6 defect as it has highest p-value among all the defect types (as the high p-value means the highest probability of occurrence of that particular event). Finally the repair works can be carried out on type 2 and type 1 respectively as they have least p-value.

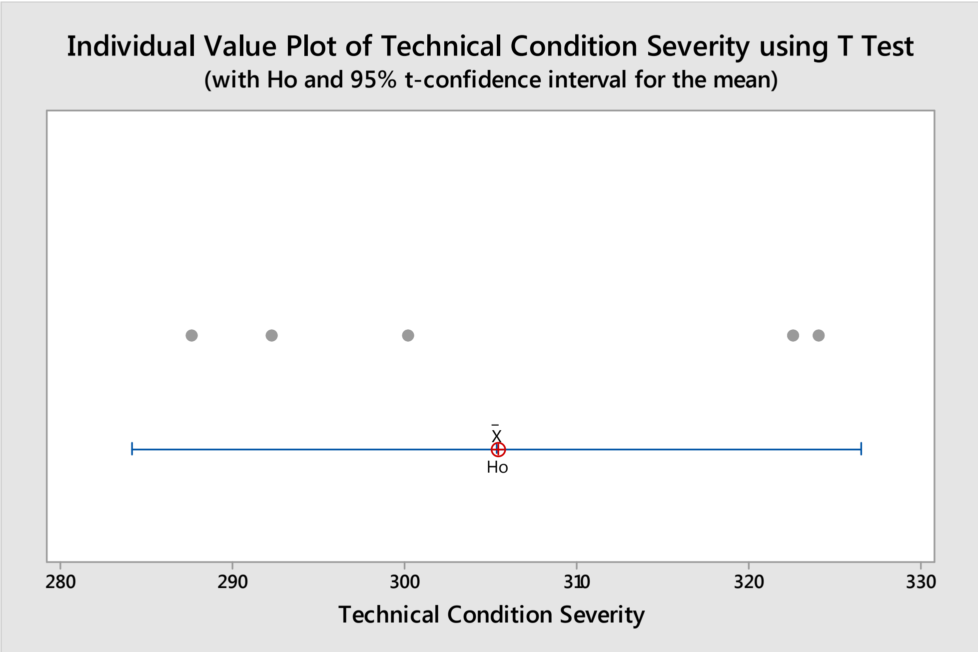

Figure 7 – T Test report of T_C to find the trueness of the hypothesis

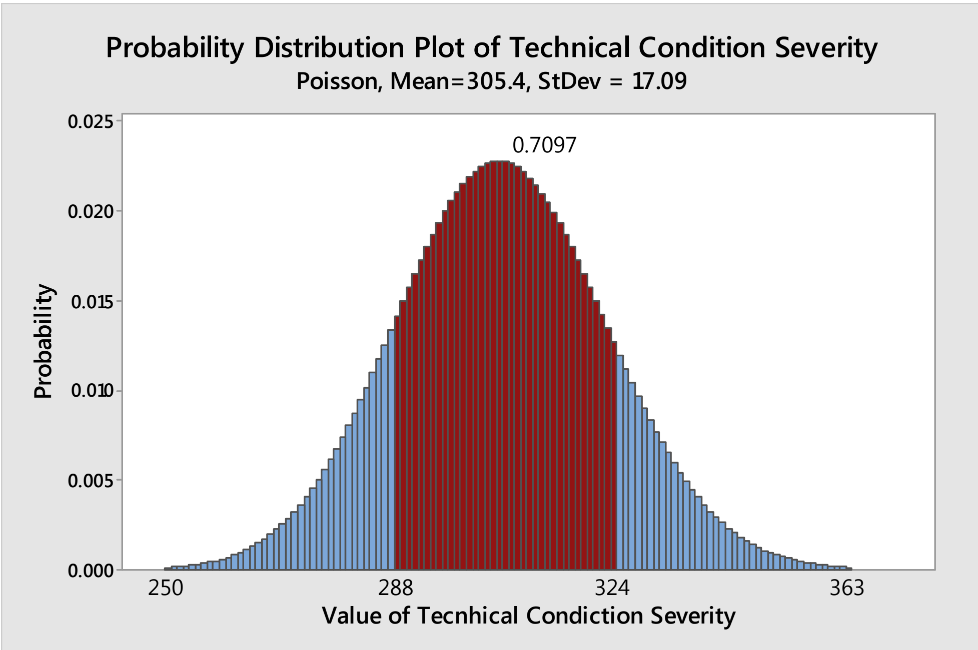

Figure 8 – Probability distribution plot of total technical defects condition

A probability plot[6] (figure 6) for the technical condition/state (the production defects and its severity) obtained was plotted with confidence interval of 95% and a technical state -mean value of 305.4

was obtained. The mean value of T_C can be used to plot the Probability distribution plot as the p-value for the Anderson-Darling test is greater than 0.05, and the mean value of T_C is a true mean of T_C.Also, the fitted line is used to estimate percentiles for the defects and it is estimated that for 80% percentile with 95% (confidence level) likely to record T_C value be between 301.932 and 337.546. In figure 7, a t-test [7] report can be seen and it can be noted that the p-value is said to be higher than that of 0.05, and as a result hypothesis H_0 (Target mean value = 305.4) cannot be false. It's was also determined that with 95% confidence, the future T_C value would be between 284.13 and 326.58.

The probability distribution plot (figure 8) was obtained by using MINITAB 2017, and from the given data, it was observed that Probability is equal to 0.7097 to record the technical condition (T_C) between 287.9 and 322.65 (which are lowest and highest values recorded between 2013 and 2017)in the upcoming years. Also, P (T_C>323) = 0.1537 probability is obtained to have a technical condition (T_C) of more than 322.65 which is highest recorded value of T_C.

On the basis of the analysis of the technical condition of tunnels, a nomenclature of repairs of tunnel structures and facilities has been developed with reference to the tunnels in question (table 2).

Table 2 – Elaboration of Tunnel construction type and defects related and basic work required to eliminate the defect

Tunnelconstruction, arrangement	Defecttype	Basicwork
Lining of tunnels of monolithic concrete and reinforced concrete. Facingcoatings, includinginnon-ferroustunnels	Exfoliationofconcretelining	1. Fixing a flaking piece of concrete with picks on anchors.
		2. Collapse in the planned order with the subsequent friction of the cavity and the netting of the mesh on the anchors
	Cracks in the opening > 2 mm stabilized	Cutting with subsequent coining by special compounds
	Weak, leached, thawed concrete, shells, caverns	1. Weak concrete.
		2. Plastering with penetrating action materials (on large surfaces - on flat grids)
Watercut	Leaks, drips, dampness	Organized diversion through hoses and strobes
	Ice	1. Drawing and removal of ice from the tunnel
		2. Warming of ice-forming leaks
Drainage and water drainage devices	Inefficient dehumidification of lining and soil massif	1. Cleaning of the capturing wells.
		2. Replacement of drainage backfilling with drains
	Freezingofdrainagechutes	1. Warming of trays with heat-insulating materials.
		2. Installation or repair of electric heating
	Raising the water level in the trays	Cleaning trays from sediment and debris
	Destruction of paving of upland ditches and cuvettes	Repair or construction of paving
Approaches to the tunnel and portal gaps	Overhanging stones on slopes, sideways slopes	Assembling slopes from overhanging stones. Strengthening of slopes according to the state of soils
	Destruction of paving and waterproofing in the off-site zone	Restoration of paving and waterproofing
	Cracks in the construction of portals and walls. Destruction of the protective layer of reinforcement	Cutting of cracks and their chasing with special compounds. Plastering of places of exposure of reinforcement with materials of penetrating action. Solid coating of surfaces with waterproofing coatings or water repellents
Tunnel as a whole (in order of maintenance)	Littering of the passage, service passes, sidewalks, chambers and niches, etc. Absenceofsigns, inscriptions,etc.	Cleaning and removal of pollutants, painting of niches and chambers, portals, restoration of information and index signs and plates, inscriptions, road signs, etc.

The obtained actual picture of the state of the lining provides a correct approach to the design of the building, allows to predict possible violations of the lining, to choose the optimal technology and a set of equipment involved in the repair and restoration work of transport tunnels.

Conclusion. Based on the results of the analysis, it was revealed that groundwater is the main cause of the appearance of defects on these tunnels. Water in all its states is rightly considered one of the most important destructive factors that reduce the life of building structures from any material. Therefore, when constructing tunnels in any climatic zone, designers have to solve the problem of protecting underground structures from the harmful effects of moisture. The defects were observed and recorded personally in the respective years. The defects in the tunnel were characterized and was noted year by year between 2013 and 2017. A technical condition severity (T_C) was observed to be increasing year by year and more defect severity was observed in type 2: Tunnel lining made of monolithic concrete or reinforced concrete (perception of external loads and impacts from a soil massif). The probability distribution plot was obtained to predict the future values of T_C and it is observed that there are 70.97% chances to record a value of technical condition severity between the previously recorded values. Thep-value for the Anderson-Darling test was determined and was p-value greater than 0.05 was obtaining for all the types of defects except type 1 and type 2, which says thatall values (defects) are under specific normal distribution. Also, order of repair on type of defect is determined (repair work carried out on defect type with highest p-value to the lowest).Risk category analysis was done and was observed that the risk category (A) was not recorded between the years 2013-2017, mostly insignificant risk of category (D) was highest in every year. Defect reduction policy should be created and implemented in effective way to reduce the risk occurred to the passengers. This topic is especially relevant for the Republic of Tajikistan with its complex climate.

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