Evaluation of the Automobile Tunnels Water-Logging Risk

Boris Ksenofontov, *Member, IAENG*, Roberto Revetria, *Member, IAENG*, Mikhail Ivanov, *Member, IAENG*, Olga Ivanova, *Member, IAENG*, Evgeniy Yusipov, *Member, IAENG*, Ksenia Zykova, *Member, IAENG*, Ekaterina Zherebtsova, *Member, IAENG*

***Abstract*— The paper researches the aspects of automobile tunnels water-logging for both ordinary tunnels located at different level above and below surface and Winchester type tunnels. Integrated assessment of vulnerability and risk of the tunnels maintenance was carried out. The assessment included consideration of such parameters as the amount of precipitation and its duration, the level of the territory and ground water quality, as well as capacity of water drainage system. Evaluation of risk is performed with an easy-to-use technique developed and presented in current research. Results of modelling demonstrated higher water-logging risk of Winchester type tunnels compared to the classical types of tunnels. A set of recommendations to prevent possible floods in tunnels is provided basing on the performed research.**

***Index Terms*— land runoff, monthly norm of precipitation, risk evaluation, water-logging of tunnel.**

I. Introduction

SCIENTIFIC substantiation of various systems of water drainage from the surface of motor roads is an inherent part of motor roads improvement [1]. Following this requirement the results of studies and systematization of schematic diagrams of roadway drainage and sewage water treatment is presented in terms of its expediency and applicability in different climatic, geological and hydrological conditions. During operation motor roads and artificial structures located on the roads are exposed to destructive effect of atmospheric precipitates and land runoff that have a negative influence on transportation and roads operational characteristics [2].

Rainfall has a determinative impact on the changes of water-and-thermal regime of earth roadbed and road toppings [3]. The results of numerous experimental studies held in different countries have proved that moisture of earth roadbed soil increases in case of reduction of distance from ground water table and in case of the reduction of distance from filtering bed as well as when average precipitation increases during 15 days [4, 5, 6, 7].

Over time expansion joints and small cracks in roadway paving pass water through in the amount, which is more than enough to cause damage [8]. Due to dynamic loads and deformations of roadway paving there appear fatigue cracks in asphalt-concrete pavement while it is in operation. Cement concrete pavement always has cracks in the places of junction with roadsides and expansion joints loose water-resisting properties.

Free water that is inside the pavement layers brings the most harm to the road structure durability. Pressure created by wheels of vehicles causes this water to move inside the pavement layers, which leads to pavement destruction. Under dynamic loads free water situated in the granular layer of roadbed may reduce pavement durability of the layer by 25% and more [6].

Due to low air humidity and considerable evaporation heavy occasional summer rains do not increase moisture in earth roadbed soil much. However, drop of air temperature contributes to migration of free water located in different depths of roadbed soil freezing to the pavement surface.

Rains falling during summer, when air humidity is insufficient, directly influence the condition of pavement and traffic safety. The water remaining on road pavement causes the appearance of water wedge in the contact zone between the wheel and the pavement, which increases when the vehicle speed grows. Hydroplaning effect occurs when the wheel loses longitudinal and lateral grip [9].

Most traffic accidents caused by low grip properties of road pavements happen when the pavement is wet and there is no water drainage [10]. Hydroplaning effect occurs under certain vehicle speeds and under certain thickness of water film on the pavement, which depends on the rain intensity, longitudinal and lateral slope, non-skid properties of road surface and length of water drainage section.

All of these highlight the need in a set of preliminary studies of hydrological, geological and climatic conditions of motor way construction in order to make the correct choice and implement the plan for water drainage from the road surface.

Evaluation of risk of water-logging and flooding of territories including both residential areas and structures related to roads including motor ways, overhead roads, tunnels, etc. is of high importance at the initial stage of

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Dr. M.V. Ivanov is with the Bauman Moscow State Technical University, Moscow, 105005 Russia (corresponding author phone +79153303469; e-mail: mivanov@bmstu.ru).

Prof. B.S. Ksenofontov is with the Bauman Moscow State Technical University, Moscow, 105005 Russia (e-mail: ksenofontov@bmstu.ru).

Prof. R. Revetria is with University of Genoa, Genoa, 16145 Italy (email: roberto.revetria@unige.it)

O.A. Ivanova is with the Bauman Moscow State Technical University, Moscow, 105005 Russia and University of Genoa, Genoa, 16145 Italy (e-mail: olgaivanova@bmstu.ru).

E.A. Yusipov is with the Bauman Moscow State Technical University, Moscow, 105005 Russia (e-mail: yusipovea@bmstu.ru).

K.I. Zykova is with the Bauman Moscow State Technical University, Moscow, 105005 Russia (e-mail: zykova.ki@bmstu.ru).

E.O. Zherebtsova is with the Bauman Moscow State Technical University, Moscow, 105005 Russia (e-mail: zherebtsovaeo@bmstu.ru).

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studies.

II. Modelling Approach

TABLE I
EVALUATION OF RISK FACTOR OF TERRITORY WATER-LOGGING (λ_M) UNDER DIFFERENT PRECIPITATION INTENSITY

Code	λ_M	Code	λ_M
00	0.0	20	0.0
01	0.2	21	0.0
02	0.8	22	0.5
03	1.0	23	0.8
10	0.0	30	0.0
11	0.2	31	0.0
12	0.7	32	0.0
13	1.0	33	0.7

The approach to the evaluation of the risks of residential areas water-logging and flooding, was presented earlier in papers [11, 12, 13]. Let us consider the risks for residential areas in accordance with this approach and assign the following codes: code 0 – low risk, code 1 – medium risk, code 2 – high risk, code 3 – very high risk.

1. Duration of precipitation:
- 1 rain – code 0;
- 1 day – code 1;
- 1 week – code 2;
- 1 month – code 3.

2. Amount of precipitation in fractions of monthly norm of precipitation:
- 0.1•norm - code 0;
- 0.5•norm – code 1;
- 1.0•norm – code 2;
- >1.0•norm – code 3.

It is possible to standardize vulnerability factor in the same way as risk factor; vulnerability factor values change within the range between 0 and 1, i.e. $0 \le \nu_y \le 1$.

Definition of vulnerability factor reflects sensibility of the territory with all the facilities located in it to the hazardous effect of water-logging. It is therefore necessary to evaluate this value for the territories with various functional purposes (residential or industrial areas, recreation zones, road, power transmission lines, etc.) taking various aspects into consideration [4]. Let us consider the vulnerability aspect for residential area and assign the following codes: code 1 – low vulnerability, code 2 – medium vulnerability, and code 3 – high vulnerability.

1. Level of the territory under consideration (terrain):
- above zero – code 1;
- zero – code 2;
- below zero – code 3.

2. Ground water table:
- low hazard – code 1;
- medium hazard – code 2;
- high hazard – code 3.

3. Ground water quality indices:
- low hazard – code 1;
- medium hazard – code 2;
- high hazard – code 3.

4. Water drainage system capacity:
- low – 3 [4];
- medium – 2 [4];
- high – 1 (designed with enhanced water drainage).

The evaluation of vulnerability factor of residential area with allowances made for the aspects mentioned above is presented in table 2.

Further risk factor of the territory water-logging is calculated based on the obtained results.

Risk factor of the territory water-logging (R_n) is defined in accordance with the following equation [11].

$$R_n = \frac{\sum_{i=1}^{k} \nu_{yi} \cdot \lambda_{Mi} \cdot S_i}{S_0}, \qquad (1)$$

Zoning of the territory in accordance with water-logging risk is provided in table 3.

III. Object of Modelling

Let us consider the examples of risk calculation method application for such important case as water-logging of a road tunnel. Arbatskiy, Taganskiy, Varshavskiy and Volokolamskiy tunnels in Moscow are among the most risky in terms of water-logging [12]. Water drainage in these tunnels has ineffectual design and in the Volokolamskiy tunnel there is no drainage system at all. In heavy rain periods the tunnel in Kuntsevo collects up to 70 cm of water, which can only be drained to the open underground railway line. Quite frequent water-logging and flooding of Alabyano-Baltiyskiy and Mikhalkovskiy road tunnels in Moscow that are not-commissioned up to now confirm the necessity of risk evaluation based on the proposed method.

Experts suppose that in the Alabyano-Baltiyskiy tunnel either waterproofing finish was damaged during the tunnel building or, which is more likely, the soil moved during the actual tunnel operation [14]. Due of these factors regular water-logging is often the case in the Alabyano-Baltiyskiy tunnel. In such a way, due to a heavy rain at the beginning of July 2009 part of the tunnel construction site was completely flooded including the machines. And on May 29, 2014 the tunnel was flooded after a heavy rain [15].

The Mikhalkovskiy tunnel being under construction at the crossing of Mikhalkovskaya and Bolshaya Akademicheskaya streets in the north of Moscow was flooded even at the groundbreaking stage [14]. Taking this

TABLE II
EVALUATION OF VULNERABILITY FACTOR ν_Y FOR RESIDENTIAL AREAS

Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M	Code	λ_M
1211	0.05	1211	0.05	1311	0.15	2111	0.05	2211	0.15	2311	0.25	3111	0.15	3211	0.25	3311	0.40
1212	0.15	1212	0.15	1312	0.25	2112	0.30	2212	0.35	2312	0.45	3112	0.55	3212	0.60	3312	0.75
1213	0.25	1213	0.25	1313	0.35	2113	0.40	2213	0.45	2313	0.55	3113	0.65	3213	0.70	3313	0.85
1221	0.10	1221	0.10	1321	0.20	2121	0.15	2221	0.20	2321	0.40	3121	0.25	3221	0.30	3321	0.55
1222	0.20	1222	0.20	1322	0.30	2122	0.35	2222	0.40	2322	0.50	3122	0.60	3222	0.65	3322	0.75
1223	0.30	1223	0.30	1323	0.40	2123	0.45	2223	0.50	2323	0.60	3123	0.70	3223	0.75	3323	0.90
1231	0.20	1231	0.20	1331	0.30	2131	0.20	2231	0.30	2331	0.40	3131	0.30	3231	0.40	3331	0.60
1232	0.30	1232	0.30	1332	0.40	2132	0.40	2232	0.50	2332	0.60	3132	0.65	3232	0.75	3332	0.90
1233	0.40	1233	0.40	1333	0.50	2133	0.60	2233	0.60	2333	0.70	3133	0.85	3233	0.85	3333	1

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TABLE III
ZONING OF TERRITORY IN ACCORDANCE WITH WATER-LOGGING RISK FOR THE TERRITORY

Zone	Risk
Low risk	$R_n < 0.1$
Moderate risk	$0.1 \le R_n < 0.25$
High risk	$0.25 \le R_n < 0.5$
Critical situation	$R_n \ge 0.5$

fact into consideration as well as the drawbacks of the Alabyano-Baltiyskiy tunnel construction, the tunnel design was modified to ensure double waterproofing: membrane waterproofing and metal insulation i.e. cofferdam [16].

IV. Results and Discussion

Let us consider some actual calculations of tunnel water-logging risk evaluation.

A. The territory of a road tunnel with the area of 6.82 ha received monthly norm of precipitation within 1 day.

The whole tunnel is located below zero level (fig. 1). Ground water is of medium risk for the territory water-logging, ground water quality indices indicate medium risk of the territory water-logging. Water drainage system is designed in accordance with the [4].

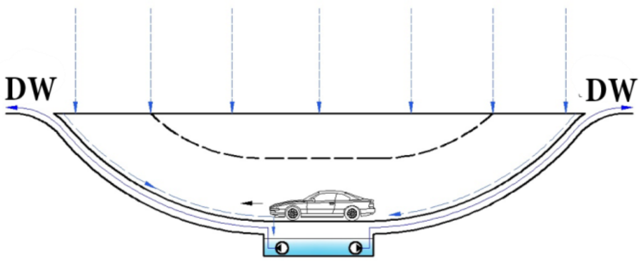

Fig. 1. The tunnel located below zero level. DW – drainage water for treatment.

Code of the territory for risk index is 12, risk factor λ_M = 0.7 (Table 1). Code of the territory in terms of vulnerability is 3222, the territory vulnerability factor ν_y =0.65 (Table 2).

Substituting the values in (1), we get:

$$R_n = \frac{0{,}65 \cdot 0{,}7 \cdot 6{,}82}{6{,}82} = 0{,}45$$

Hence, $0.25 \le R_n < 0.5$ that corresponds to high risk of water-logging of the tunnel.

B. The territory of a road tunnel with area of 6.82 ha received monthly norm of precipitation within 1 day.

The tunnel is located at zero level (fig. 2). Ground water is of medium risk for the territory water-logging, ground water quality indices indicate medium risk of the territory water-logging. Water drainage system is designed in accordance with [4].

Code of the territory for risk index is 12, risk factor λ_M = 0.7 (Table 1). Code of the territory in terms of vulnerability is 2222, the territory vulnerability factor ν_y =0.4 (Table 2).

Substituting the values in (1), we get:

$$R_n = \frac{0{,}2 \cdot 0{,}7 \cdot 6{,}82}{6{,}82} = 0{,}14$$

Hence, $0.25 \le R_n < 0.5$ that corresponds to high risk of water-logging of the tunnel.

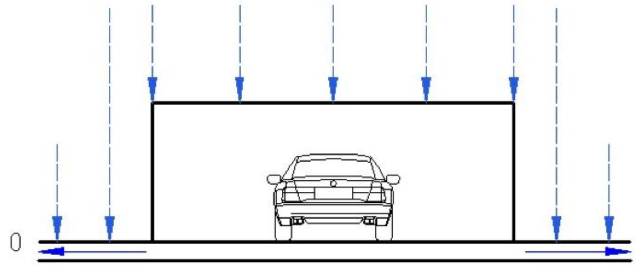

Fig. 2. The tunnel located at zero level

C. The territory of a road tunnel with area of 6.82 ha received monthly norm of precipitation within 1 day.

The tunnel is located above zero level (fig. 3). Ground water is of medium risk for the territory water-logging, ground water quality indices indicate medium risk of the territory water-logging. Water drainage system is designed in accordance with the [4].

Code of the territory for risk index is 12, risk factor λ_M = 0.7 (Table 1). Code of the territory in terms of vulnerability is 1222, the territory vulnerability factor ν_y =0.2 (Table 2).

Substituting the values in (1), we get:

$$R_n = \frac{0{,}2 \cdot 0{,}7 \cdot 6{,}82}{6{,}82} = 0{,}14$$

Hence, $0.1 \le R_n < 0.25$ that corresponds to the moderate risk of the territory water-logging.

D. Winchester-type tunnel

There are also Winchester-type tunnels [17]. Tunnels of this type are quite typical of the European countries with high-density city development (fig. 4). The tunnel is called Winchester because traffic streams in the tunnel go at different levels one below another and the traffic moves along the streams in different directions. This kind of tunnel allows increasing traffic capacity without widening the roadway.

The first Winchester type tunnel in Moscow is being under construction at the crossing of Berzarina street and Narodnogo Opolcheniya street [18-21].

Let us evaluate water-logging risk of a Winchester-type tunnel.

The territory of a Winchester-type tunnel with area of 53.16 ha received a monthly norm of precipitation within 1 day. Top and bottom tunnels are located completely below zero level. Ground water is of high risk for the territory water-logging, ground water quality indices indicate medium risk of the territory water-logging. Water drainage system is designed in accordance with [4].

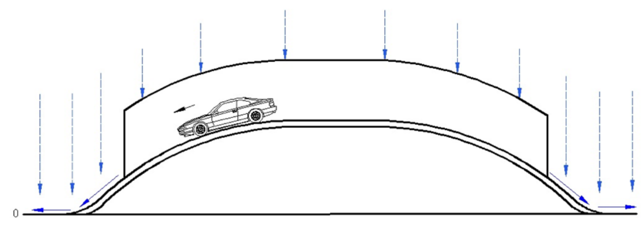

Fig. 3. The tunnel is located completely above zero level

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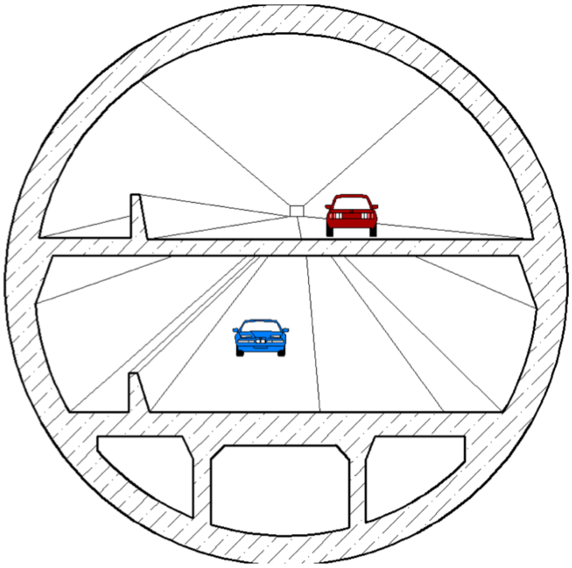

Fig. 3. The tunnel is located completely above zero level

Code of the territory for risk index is 12, risk factor λ_M = 0.7 (Table 1). In our opinion vulnerability of a Winchester-type tunnel is higher than vulnerability of a normal tunnel due to deeper position of the bottom tunnel. Code of the territory in terms of vulnerability is 3322, the bottom tunnel vulnerability factor ν_y =0.75 (Table 2).

Substituting the values in (1), we get:

$$R_n = \frac{0{,}7 \cdot 0{,}75 \cdot 53{,}16}{53{,}16} = 0{,}525$$

Hence, $R_n \geq 0.5$ that corresponds to the risk of critical situation. The results of the calculation suggest that there is a tendency of higher water-logging risk for a Winchester-type tunnel located below zero level as compared to a normal tunnel.

V. Conclusion

Preventive measures are necessary in order to reduce water-logging and flooding risk for tunnels. They may include:

1. Water drainage system, with water draining capacity exceeding one-time monthly precipitation norm.
2. Two lines of water drainage, one of which is an operational line and the second is a reserve line.
3. Construction of special purpose vehicles site in close vicinity to the tunnel for towing broken vehicles from the tunnel.
4. Introduction of a special alarm and signal system to warn about possible emergency in the tunnel.
5. Use of drained water as liquid for possible firefighting.

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