БУДІВНИЦТВО ТА ЦИВІЛЬНА ІНЖЕНЕРІЯ

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EXPERIMENTAL AND THEORETICAL DETERMINATION OF THE DURATION OF SURFACE RUNOFF FORMATION

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Abstract. *There are theoretical and experimental results of the study of the duration of surface runoff formation presented. The prospects of application of this method are defined at designing of sanitary technical measures on highways of public use and artificial constructions. There is prospective direction of increase of efficiency of sewerage rain network designing and local treatment facilities on highways defined. The issue of increasing the accuracy of hydraulic calculation has been studied. The main advantages of implementation of modern drainage solutions are investigated. It is proposed to use a monogram to determine the duration of the formation of surface concentration, in accordance with climatic characteristics.*

Key words: *highway, slope, pavement, surface runoff, precipitation intensity.*

Introduction

When designing highways, the traditional method is used for calculations of determining the duration of surface concentration, which is designed for planar catchments. This method significantly distorts the results and promotes inefficient use of sanitary measures on the highways.

The urgency of the problem

Design of sanitary measures: According to the method there is closed and open rain drainage, local wastewater constructions and oil separators in Ukraine [1].

One of the typical disadvantages of this method for use on highways is the lack of calculation to determine the duration of the formation of surface concentration. In accordance with [1], this parameter can be determined by the criterion of the presence or absence of intra-quarter networks: the time of surface concentration of rain runoff should be calculated or taken in settlements in the absence of intra-quarter closed rain networks such as 5–10 minutes. but if any – 3–5 minutes.. When calculating the intra-quarter drainage system, it is recommended to take the surface concentration time equal to 2–3 minutes.

The standard does not specify the method of calculating this parameter. Overestimation or underestimation of the parameter of rain duration in the subsequent affects the accuracy of calculations, which in turn can manifest itself in irrational or ineffective sanitary measures, or in the use of economically unreasonable measures.

Objective. Materials and methods

Objective. Check the feasibility of the results obtained in a theoretical way, by comparing with experimental data and existing methods. To determine the effectiveness of the studied method for the design of sanitary measures on highways. Materials and methods. Analysis of information sources on methods for determining the duration of surface concentration. Experimental research. Analytical research of the effectiveness of the proposed method.

Analysis of recent research and publications

The formation of rain runoff depends on the intensity and duration of precipitation: low-intensity precipitation is not threatening, characterized by the formation of small but long-term surface runoff and has small effect on traffic safety, and heavy rainfall is characterized by short duration and peak surface runoff, which threatens road safety (Fig. 1).

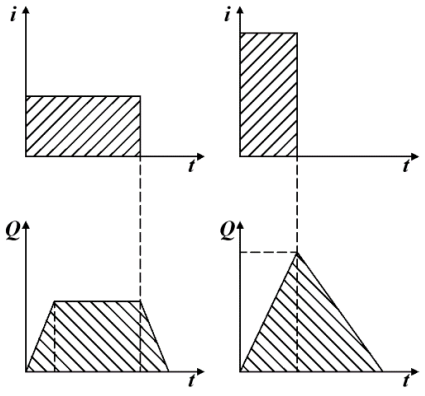

Fig. 1. Dependences of runoff formation on rain intensity [2]

In hydrometeorology, there are five main types of rainfall: with a maximum of intensity at the beginning, with a maximum in the middle, with a maximum at the end of the rain, with a uniform intensity and with a minimum in the middle [3]. Most often there are rains with the maximum intensity in the beginning, therefore they are accepted as a basis in all hydraulic calculations. However, when determining the impact on road safety, the most dangerous is the rain with a maximum at the end, as the wetting of the surface is a low-intensity part of the rain, and road surfaces are waterproof [1], the runoff will correspond to the intensity.

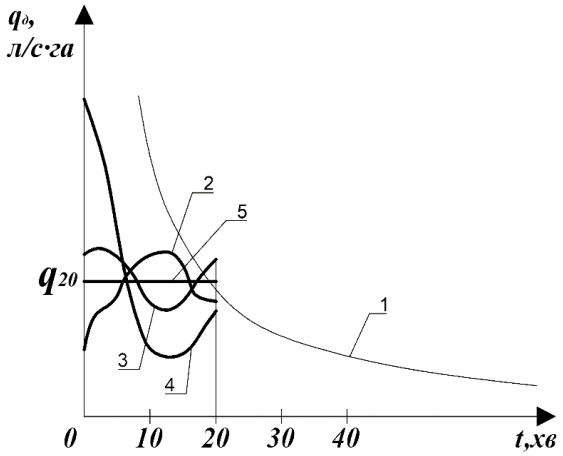

Fig. 2. Correlation between time average rain intensity and marginal intensity [3]: 1 – curve of maximum intensity; 2–5 – graphs of changes in time of rainfall intensity with qд=q20

As a result, flooding will occur on sections of roads with absent or deficient drainage (Fig. 3).

There is a typical direct relationship between the duration of rain and its intensity. The work of Soviet and Ukrainian scientists [3–13] and international research [14–21] are devoted to determining the flow rate of rainwater that enters the estimated cross section. However, all research is limited to the empirical determination of the volume of estimated rain runoff. Among the dependences for finding the time of surface runoff formation, the most famous is the Abramov-Shigorin formula [7]. It is obtained for rains with a decreasing power law of intensity change over time:

$$t_{con} = \left(\frac{1.5 \cdot n_m^{0.6} \cdot L_{con}^{0.6} \cdot 166.7^{0.5}}{Z_{mid}^{0.3} \cdot i_{n.кв}^{0.3} \cdot A^{0.5}}\right)^{\frac{1}{(1-0.5n)}}, \quad (1)$$

where n_m – roughness coefficient of drainage basin coverage; L_{con} – length of drainage basin, m; Z_{mid} – surface coefficient of drainage basin; $i_{n.кв}$ – surface slope of drainage basin; A, n – empirical coefficients describing the power law of change in rain intensity ($q = A / t_n$) and depend on the climatic features of the region.

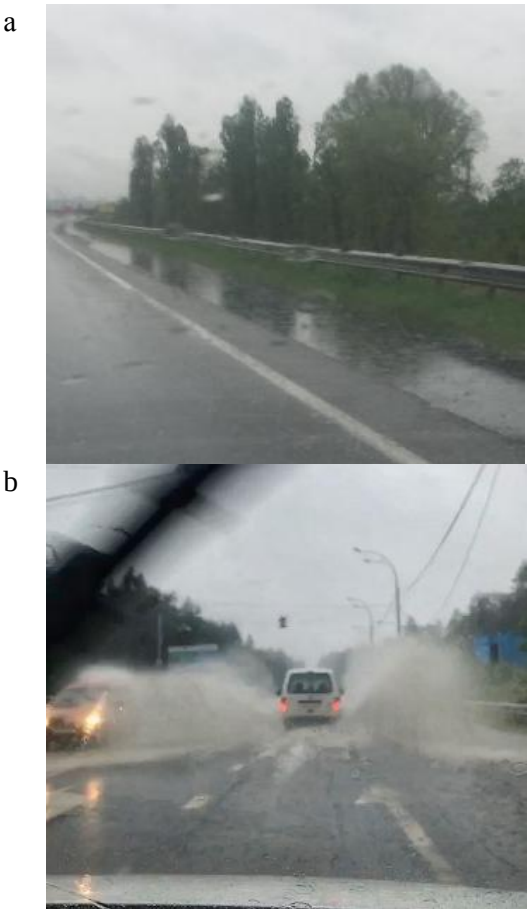

Fig. 3. Sections of roads with improper drainage: a – section of the highway R-69; b – section of the highway R-02

When determining the flow rate, the coefficient of the surface of the basin, which is actually decisive for the coefficient of runoff, which, like the coefficient of roughness of the coating should not be taken into account. The introduction of data into the calculation characterizes the percentage of runoff retention, which does not reach the drainage elements. They give a general idea of how much the amount of rain runoff will decrease as a whole, rather than per unit time.

In foreign engineering practice, the Overton-Meadows formula is widely used specifically to calculate the time of film flow formation [22]:

$$t_{con} = \frac{5.476 \cdot (n_1 \cdot L)^{0.8}}{P_2^{0.5} \cdot i^{0.4}}, \quad (2)$$

where n_1 – effective surface roughness coefficient; L – flow length, m; P_2 – the height

of the precipitation layer of 24-hour rain with a frequency of 2 years, mm; i – geodetic slope of the area, m / m.

In the engineering practice of Ukraine there is also possible usage of the method, which is covered in [23] and SNiP 2.05.08-85 «Aerodromes»:

$$t_{con} = \left(\frac{2{,}41 \cdot n_* B_{роз}}{\Delta^{0{,}72} \Psi^{0{,}72} J_{роз}^{0{,}5}}\right)^{\frac{1}{1{,}72-0{,}72n}}, \quad (3)$$

where n_* – roughness factor; $B_{роз}$ – the estimated width of the catchment area, m; Δ – parameter equal to one-minute rain intensity adopted repeatability, mm / min, determined by the formula (5):

$$\Delta = \frac{20^n \cdot q_{20}(1+ClgP)}{166{,}7}, \quad (4)$$

Ψ – runoff ratio; $J_{роз}$ – estimated slope of the catchment area.

In all the above formulas, one of the defining characteristics is the effect of coating roughness.

The purpose of the work. To analyze the feasibility of applying the method of determining the duration of surface runoff formation experimentally. To conduct a comparative analysis of known theoretical methods proposed and obtained from experimental data. To determine the impact of the studied indicator on the efficiency of designing sanitary measures on highways.

The main material research. Drainage – a set of sanitary measures that ensure the drainage of wastewater from settlements or industrial enterprises. In fact, surface drainage on the highway is part of a complex for the clean up of contaminated surface runoff. The calculation of rainwater drainage is based on the typical conditions of general construction design principles, without taking into account the features of linear objects. A characteristic difference in this case is the parameter of the estimated duration of rain, namely the duration of the surface runoff concentration.

In the work «Mathematical model for the duration of runoff formation determining from the road surface» the authors solve the inhomogeneous differential equation of the second order is fulfilled and receives the solution:

$$l = e^{-nt}\left(2n \cdot \frac{q}{k^4} cosw_1 t + \frac{V_0 + 2n^2 \cdot \frac{q}{k^4}}{w} sinw_1 t\right) + \frac{q}{k^2} t - 2n\frac{q}{k^4}. \quad (5)$$

The authors conduct theoretical research to determine the duration of surface runoff formation.

Based on formula 5, get the graphical dependence (Fig. 4).

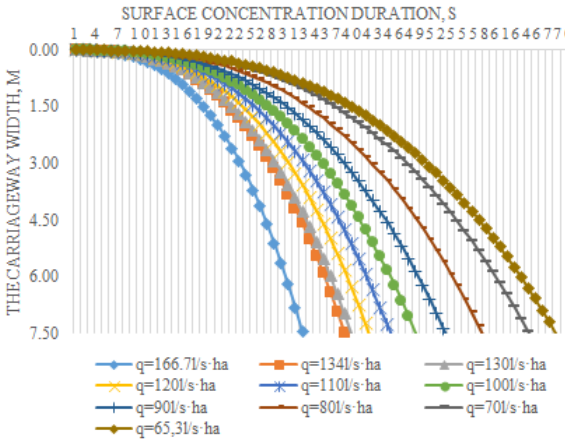

Fig. 4. Graphic dependence of the formation of surface runoff concentration

Curve length runoff formation characterized by degree dependence.

To verify the accuracy of the obtained theoretical data, experimental studies were conducted. In accordance with the requirements of [24], a study of the duration of surface runoff formation under different conditions of precipitation. The formation of surface runoff and its movement was recorded by staining the runoff. Precipitation was recorded under different conditions of rain intensity (Fig. 5, Fig. 6) and at the same time the practical determination of the duration of surface runoff formation was performed in sections for one lane with a width of 3.75 m and for two lanes with a width of -7.5 m.

Fig. 5. Research of the duration of surface runoff 24.09.2020

In the first case, the measurement results were performed at a precipitation intensity of -0.9 mm / min on 24.09.2020. The intensity was determined only for the period of surface runoff formation.

Otherwise, observations were performed at an intensity of -0.32 mm / min 27.09.2020 (Fig. 6).

The results at the end of experimental research are comparable with the results of calculations obtained by known methods, formulas (1)–(3) and research results.

Fig. 6. Research of the duration of surface runoff 27.09.2020

As a result of fixing the duration of runoff formation at the calculated sections of 3.75 m (Fig. 7).

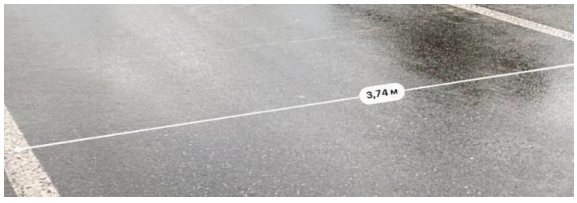

Fig. 7. The research area - 1 lane

and 7.5 m (Fig. 8)

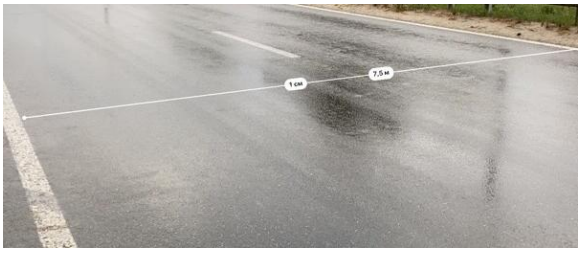

Fig. 8.T he research area - 2 lanes

The obtained data are summarized in a comparative calculation table by various known methods (formulas 1, 2, 3), the data obtained by calculation using formula 5, and the experimental data of table 1.

Table 1 – The results of the duration of the surface concentration at a precipitation intensity of 0.9 mm / min

Length of	Methods				
	Abramov-Chigorin	Overton-Meadows	Calculation	SNiP 2.05.08-85 "Aerodromes"	Experimental
	time, seconds.				
3.75m	13	25	29	17	27
7.50m	25	44	36	29	35

Taking into account the obtained results, the average deviation of the calculated indicators is determined from the experimentally researched table 2.

Table 2 – Deviation of the duration of the surface concentration of theoretical methods from experimental at a rainfall intensity of 0.9 mm / min

Deviation, %			
Abramov-Chigorin	Overton-Meadows	Calculation	SNiP 2.05.08-85 "Aerodromes"
51.85	7.41	7.41	37.04
28.57	25.71	2.86	17.14

A similar comparison was performed at a precipitation intensity of 0.3 mm/min (Table 3).

Table 3 – The results of the duration of the surface concentration at a precipitation intensity of 0.32 mm/min

Length of	Methods				
	Abramov-Chigorin	Overton-Meadows	Calculation	SNiP 2.05.08-85 "Aerodromes"	Experimental
	time, seconds.				
3.75m	31	50	68	32	64
7.50m	58	87	86	56	84

Table 4 – Deviation of duration of surface concentration of theoretical methods from experimental at precipitation intensity of 0.32 mm /min

Deviation, %			
Abramov-Chigorin	Overton-Meadows	Calculation	SNiP 2.05.08-85 "Aerodromes"
51.56	21.88	6.25	50.00
30.95	3.57	2.38	33.33

In the method of calculation of local treatment plants according to [1], it is allowed to take the indicator of the duration of the surface runoff concentration from 2 to 10 minutes. In fact, increasing the duration of the estimated rain, which in turn leads to flooding of roads (Fig. 3).

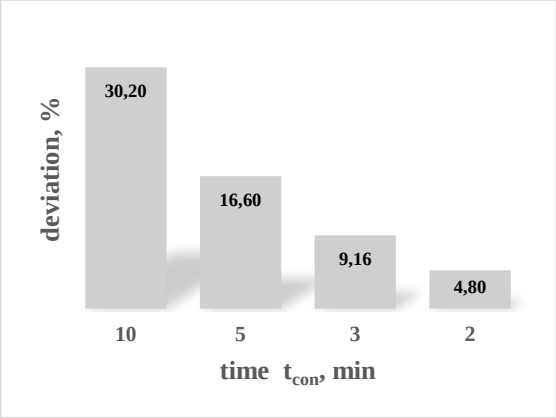

Fig. 9. Deviation of the results of the estimated duration of rain in percent at the values of the duration of the surface concentration taken for [1]

As a result of theoretical research, experiments and analytical calculations, the magnitude of the absolute error in determining the magnitude of rain runoff using various methods for calculating the duration of the formation of surface concentration. With the size of the calculated section of 1000 m and the width of the carriageway - 7.5 m of received deviations in determining the estimated flow in the range of 0.09 % to 38.65 % (table 5).

Based on the research, it is recommended to use a monogram (Fig. 4) to determine the duration of the surface concentration of runoff depending on climatic zoning [1] on highways of category 1 [25].

Table 5 – The results of calculations of rain runoff and the actual deviation by different methods from the experimental

Calculation method	Duration, tcon, min	General calculations from the catchment basin, l / s	Calculation results, l / s	deviation ,%
Abramov-Chigorin	0.42	129.47	15.54	-0.76
Overton-Meadows	0.73	127.59	15.31	0.70
Calculation	0.6	128.37	15.4	0.09
SNiP 2.05.08-85 "Aerodromes"	0.48	129.1	15.49	-0.47
DBN B.2.5-75: 2013	2	120.79	14.5	5.99
	3	113.82	13.66	11.42
	5	100.41	12.05	21.85
	10	78.79	9.46	38.65
Experimental	0.58	128.49	15.42	0.00

Conclusions

The analysis of known methods of calculation of duration of formation of surface concentration of runoff is executed in this work. The results of experimental studies of the duration of the formation of the surface runoff concentration are presented. The value of the absolute error in the design of the drainage systems and local wastewater constructions on public roads of the 1st category is determined.

It is proposed to use the monogram (Fig. 4) to determine the estimated duration of surface runoff, increasing the accuracy of calculations in the range from 5 to 39 %.

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Експериментальне та теоретичне визначення тривалості формування поверхневого стоку

Анотація. *Представлено теоретичні та експериментальні результати дослідження тривалості формування поверхневого стоку. Визначено перспективу застосування даного методу при проектуванні санітарно-технічних заходів на автомобільних дорогах загального користування та штучних спорудах.* ***Проблематика.*** *При проектуванні автомобільних доріг, для розрахунків застосовують традиційну методику визначення тривалості поверхневої концентрації, яка розроблена для площинних водозбірних басейнів. Застосування даного методу суттєво спотворює результати та сприяє застосуванню неефективних санітарно-технічних заходів на автомобільних дорогах.* ***Мета.*** *Перевірити доцільність результатів отриманих теоретичним способом, шляхом порівняння з експериментальними даними та існуючими методами. Визначити ефективність досліджуваного методу для проектування санітарно-технічних заходів на автомобільних дорогах.* ***Матеріали та методи.*** *Аналіз інформаційних джерел, щодо методів визначення тривалості поверхневої концентрації. Експериментальні дослідження Аналітичні дослідження ефективності запропонованого методу.* ***Результати.*** *Визначено перспективний напрямок підвищення ефективності проектування дощової мережі каналізації та локальних очисних споруд на автомобільних дорогах. Вивчено питання підвищення точності гідравлічного розрахунку. Досліджено основні переваги впровадження сучасних рішень з водовідведення.* ***Висновки.*** *В роботі виконано практичну перевірку ефективності запропонованого методу визначення тривалості формування поверхневого стоку. В результаті підвищується точність розрахунків мережі дощової каналізації та очисних споруд в межах від 5 до 39 % в залежності від вихідних умов. Запропоновано до застосування монограму з визначення тривалості формування поверхневої концентрації, відповідно до кліматичних характеристик [1].*

Ключові слова: *автомобільна дорога, похил, покриття, поверхневий стік, інтенсивність опадів.*

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