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EFFECT OF DEICING AGENTS ON THE WATER STABILITY OF ASPHALT CONCRETE UNDER FREEZE-THAW CYCLES

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Abstract. Asphalt concrete pavement, as the main form of high-grade roads today, occupies an important place in modern road construction due to its advantages such as low noise level, ease of repair and short construction period. This road type is widely adopted worldwide and provides a reliable foundation for road networks in cities and villages. In cold regions, snowy weather tends to cause ice on the road surface, posing a serious safety hazard for vehicle travel. The problem of road accidents in winter is relevant both for regions with extremely cold climatic conditions and for the temperate continental climate that prevails almost throughout Ukraine. To solve this problem, deicing agents are widely used to improve the safety of road travel. The application of deicing agents effectively reduces the impact of snow and ice on roads and ensures the safe passage of vehicles in adverse weather conditions. However, while deicing agents play an important role in improving traffic flow, their widespread use has also brought some problems that should not be ignored. The chemicals in deicing agents may have adverse effects on pavement materials, especially on asphalt concrete roads.

For studying the effect of deicing agents on asphalt concrete, this paper presents an experimental investigation of the effect of deicing agents on the water stability of asphalt concrete under the conditions of freeze-thaw cycle test. The impact of deicing agents and freeze-thaw cycles on asphalt concrete was investigated by evaluating the variation patterns of three key parameters: stability, residual stability and air void content.

The experimental results showed that the stability and residual stability of asphalt concrete showed an overall decreasing trend with the increase of the number of freeze-thaw cycles, indicating that the asphalt concrete was damaged or degraded under the conditions of freeze-thaw cycles. The higher concentration of the deicer solution corresponded to the more pronounced changes in the test parameters, indicating a significant effect of the deicer on the asphalt concrete. At the end of 27 cycles, the average loss of stability, residual stability and void ratio were 29%, 22% and 73%, respectively. This indicates that the combined effect of freeze-thaw cycles and deicing agent is more significant for air void content.

Key words: asphalt concrete, deicing agent, water stability, freeze-thaw cycle, pavement performance.

Introduction. The problem of road accidents in winter is relevant both for regions with extremely cold climatic conditions and for the temperate continental climate that prevails almost throughout Ukraine [1-2]. In order to effectively deal with this problem, the extensive use of deicing agents has become an indispensable measure to ensure road traffic safety. The main function of deicers is to melt snow and ice as quickly as possible, improving the grip of vehicles and effectively reducing the number of traffic accidents [3-4].

However, while deicing agents play a key role in improving traffic flow, their long-term effects on road materials are a growing concern [5-6]. With the widespread use of deicing agents, especially chemical deicers like calcium chloride ($CaCl_2$) being used in large quantities, close attention is being paid to the potential impacts of these chemicals on road materials. In this context, asphalt concrete, a key material commonly used in road construction, has excellent compressive, shear and durability properties that make it the material of choice for road construction [7-8]. However, the long-term effects of deicing agents may lead to deterioration of the asphalt in asphalt concrete, crack generation, and overall structural damage, which can negatively affect water stability [9-10].

As a result, the widespread use of deicing agents has raised concerns about the long-term health of road materials. At the core of this concern are possible interactions between the chemicals in deicing agents and road materials, which can have potentially adverse effects on the durability, structural performance and overall stability of pavements [11-12]. In order to address this concern, it is important that we conduct in-depth research into the combined impacts of deicing agents on roadway infrastructure and develop a scientific and sustainable strategy for the use of deicing agents to ensure that the long-term health of roadway materials is not jeopardized while improving the smooth flow of traffic [13].

Analysis of recent research and publications. To identify the effect of deicing agents on asphalt concrete, some scholars have conducted some research. Wu [14] investigated the water sensitivity of asphalt concrete by dry and wet cycle tests, and the findings showed that the deterioration of asphalt concrete properties was mainly related to water and deicing agents. Hassan [15] compared the effects of sodium formate, potassium acetate, and urea on the durability of asphalt concrete, with the test results showed that urea caused the most damage, while the other deicing agents caused damage comparable to distilled water. Zhang [16] conducted an in-depth study on the reaction mechanism between asphalt and deicing salt solutions, suggesting that chloride ions in the deicers replaced hydrogen ions in the asphalt. However, these related studies on the influence of $CaCl_2$ on the water stability of asphalt concrete are currently incomplete, thus limiting its applicability as a regionally relevant reference for road design and maintenance.

Goals and objectives. To further study the effect of $CaCl_2$ on the water stability of asphalt concrete, this paper carries out freeze-thaw cycles on AC – 16 asphalt concrete after immersing in different concentrations of $CaCl_2$ solution in order to simulate the environment to which the pavement material is subjected on the actual road, and evaluates the damage rule of the water stability through the Marshall water immersion test and the air voids content test.

Research methods. In this study, five concentrations of $CaCl_2$ solutions, 2%, 4%, 6%, 8% and 10%, were selected to conduct freeze-thaw cycle tests on Marshall specimens (63.5 mm ± 1.3 mm in height and 101.6 mm ± 0.2 mm in diameter) of AC – 16 asphalt concrete. The test parameters for a single cycle were as follows: freezing temperature of -18°C±1°C, freezing time of 24h±0.5h, thawing temperature of 20°C±1°C, and thawing time of 24h±0.5h. A total of 28 cycles were conducted, and the Marshall water immersion test and air void content test were carried out at the end of 0, 3, 6, 9, 12, 15, 18, 21, 24 and 27 cycles, respectively. The parameters tested included stability, residual stability and air void content.

Table 1 – Stability of asphalt concrete after multiple freeze-thaw cycles

Number of freeze-thaw cycles	Stability, kN				
	2%$CaCl_2$	4%$CaCl_2$	6%$CaCl_2$	8%$CaCl_2$	10%$CaCl_2$
0	11.24	11.24	11.24	11.24	11.24
3	11.06	11.05	11.05	11.04	11.01
6	10.91	10.91	10.89	10.87	10.85
9	10.70	10.60	10.59	10.58	10.57
12	10.31	10.26	10.23	10.20	10.18
15	9.86	9.79	9.66	9.63	9.61
28	9.42	9.25	9.14	9.11	9.04
21	8.86	8.67	8.51	8.39	8.38
24	8.55	8.31	8.14	8.07	7.98
27	8.39	8.14	7.96	7.86	7.76

Results analysis and discussion. The Marshall water immersion tests were conducted on asphalt concrete after multiple freeze-thaw cycles. Results of the test for stability and residual stability are shown in Tables 1 and 2, and the corresponding loss rates are shown in Figures 1 and 2.

From the experimental data in Table 1, it can be observed that the stability of asphalt concrete gradually decreases as the number of freeze-thaw cycles increases. This indicates that the asphalt concrete was damaged or degraded to some extent under freeze-thaw cycling conditions. Meanwhile, it was observed that at each number of freeze-thaw cycles, the stability showed a different trend with the increase of $CaCl_2$ concentration, and this trend was more obvious with the increase of the number of freeze-thaw cycles. At the end of 27 cycles, the stability corresponding to different concentrations of $CaCl_2$ solutions were 8.39 kN, 8.14 kN, 7.96 kN, 7.86 kN, and 7.76 kN, respectively.It can be observed from Fig. 1 that the loss rate of stability shows a trend of slowly increasing at first, followed by an extremely rapid increase, and then finally a slow increase. At the end of 27 cycles, the loss rates of stability corresponding to different concentrations of $CaCl_2$ solutions were 25.38%, 27.62%, 29.17%, 30.06% and 30.95%, respectively.

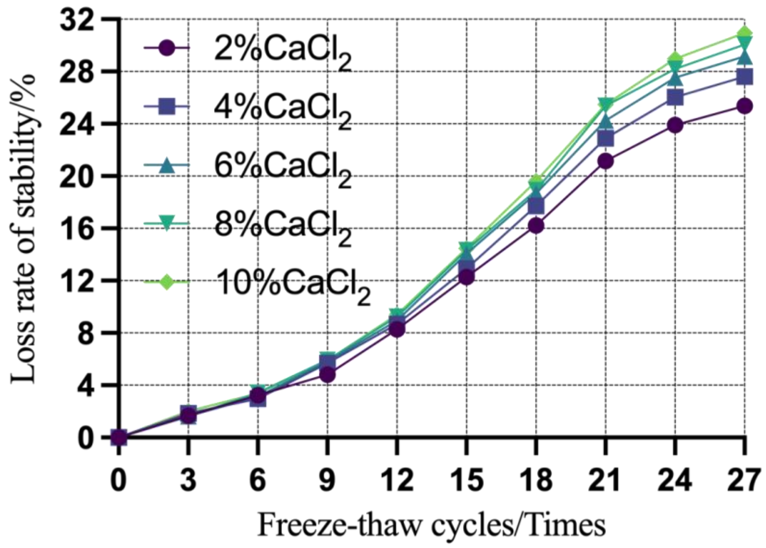

Fig. 1. Loss rate of stability of asphalt concrete after experiencing multiple freeze-thaw cycles

Table 2 – Residual stability of asphalt concrete after multiple freeze-thaw cycles

Number of freeze-thaw cycles	Residual stability, %				
	$2\%CaCl_2$	$4\%CaCl_2$	$6\%CaCl_2$	$8\%CaCl_2$	$10\%CaCl_2$
0	85.70	85.70	85.70	85.70	85.70
3	84.72	84.65	84.44	84.35	84.17
6	83.73	83.67	83.50	83.24	83.20
9	82.65	82.05	81.85	81.34	81.12
12	80.83	80.66	80.04	79.71	79.44
15	78.52	77.55	76.82	75.83	75.61
28	75.79	74.29	73.78	72.67	71.61
21	72.65	71.33	70.65	68.95	68.25
24	71.12	69.44	68.35	66.82	65.64
27	69.78	68.11	67.30	65.25	64.40

From Table 2, it can be observed that there is a gradual decrease in residual stability as the number of freeze-thaw cycles increases. This is in line with the expectation since freeze-thaw cycles usually lead to deterioration and decrease in the stability of the material. Meanwhile, it was observed that the value of residual stability corresponding to the higher concentration of $CaCl_2$ solution was smaller for the same number of freeze-thaw cycles, indicating a remarkable effect of deicing agents on the water stability of asphalt concrete. At the end of 27 cycles, the residual stability corresponding to different concentrations of $CaCl_2$ solutions were 69.78%, 68.11%, 67.30%, 65.25% and 64.40%, respectively. It can be observed from Fig. 2 that similar to the loss rate of stability, the loss rate of residual stability also showed a trend of slowly increasing at first, followed by an extremely rapid increase and finally a slow increase. At the end of 27 cycles, the loss rates of residual stability corresponding to different concentrations of $CaCl_2$ solutions were 18.58%, 20.52%, 21.47%, 23.86% and 24.85%, respectively.

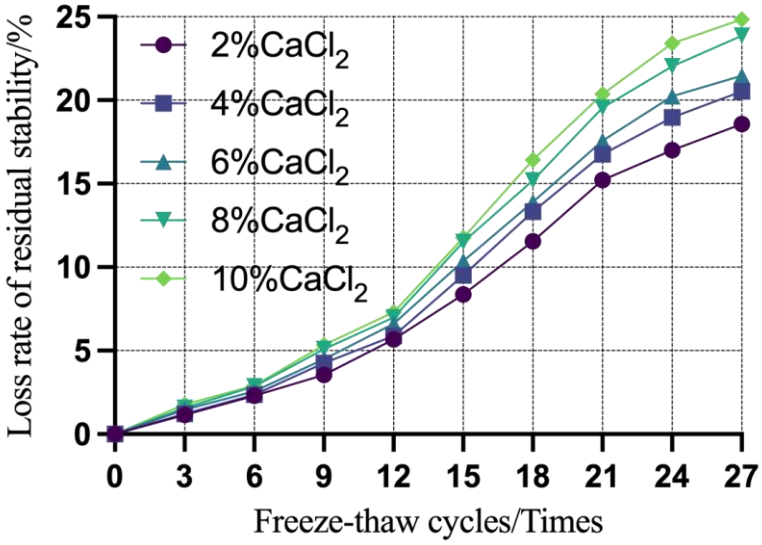

Fig. 2. Loss rate of residual stability of asphalt concrete after experiencing multiple freeze-thaw cycles

A comprehensive comparison of the experimental data on stability and residual stability revealed that at the end of 27 cycles, the average loss rate of stability was around 29%, while the average loss rate of residual stability was around 22%, indicating that the combined effect of freeze-thaw cycles and deicing agents is greater for stability. Meanwhile, at the end of 27 cycles, the loss rate of stability corresponding to 10% $CaCl_2$ solution was 21.9% higher than that corresponding to 2% $CaCl_2$ solution, and the loss rate of residual stability corresponding to 10% $CaCl_2$ solution was 33.8% higher than that corresponding to 2% $CaCl_2$ solution, which indicates that the effect of deicing agent is more important for residual stability.

The air void content test was carried out on asphalt concrete after undergoing multiple freeze-thaw cycles, the experimental data on air void content are shown in Table 3, and its corresponding loss rate is shown in Figure 3.

Table 3 – Air void content of asphalt concrete after multiple freeze-thaw cycles

Number of freeze-thaw cycles	Air void content, %				
	2%$CaCl_2$	4%$CaCl_2$	6%$CaCl_2$	8%$CaCl_2$	10%$CaCl_2$
0	4.12	4.12	4.12	4.12	4.12
3	4.24	4.25	4.27	4.29	4.30
6	4.42	4.46	4.47	4.49	4.56
9	4.59	4.64	4.65	4.74	4.76
12	4.79	4.87	4.88	4.94	5.02
15	5.10	5.13	5.22	5.31	5.33
28	5.40	5.53	5.59	5.70	5.80
21	5.78	5.99	6.04	6.19	6.33
24	6.27	6.44	6.61	6.81	6.91
27	6.74	6.94	7.09	7.33	7.51

From Table 3, it can be observed that the air void content of asphalt concrete shows an overall increasing trend with the increase in the number of freeze-thaw cycles due to the fact that the freeze-thaw cycles may lead to the deterioration of asphalt concrete materials, which increases the air void content. Also, it was observed that for the same number of freeze-thaw cycles, the air void content showed an overall increasing trend with the increase in $CaCl_2$ concentration, which indicates that the deicing agent had a certain effect on the air void content of the asphalt concrete. At the end of 27 cycles, the air void content corresponding to different concentrations of $CaCl_2$ solutions were 6.74%, 6.94%, 7.09%, 7.33% and 7.51%, respectively. It can be observed from Fig. 2 that the growth rate of air void content shows a trend of slow increase at first and then a rapid increase afterwards. At the end of 27 cycles, the growth rates of air void content corresponding to different concentrations of $CaCl_2$ solution were 63.58%, 68.47%, 72.04%, 77.86% and 82.16%, respectively. The average growth rate was about 73%, which was significantly higher than the loss rate of stability and residual stability, indicating that the air void content was greatly affected by the freeze-thaw cycle, which indirectly indicated that the freeze-thaw cycle caused the destruction of the asphalt membrane inside the asphalt concrete.

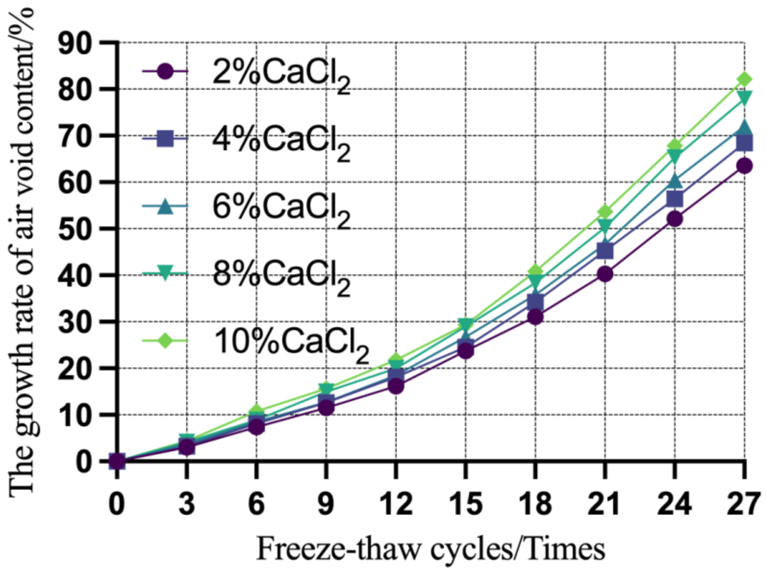

Fig. 3. Growth rate of air void content of asphalt concrete after experiencing multiple freeze-thaw cycles

Conclusion. In this paper, the following conclusions can be drawn by comparing and analyzing the experimental data of stability, residual stability and air void content of AC-16 asphalt concrete by conducting freeze-thaw cycle tests:

1. As the number of freeze-thaw cycles increased, the stability and residual stability of asphalt concrete showed an overall decreasing trend, indicating that asphalt concrete was damaged or degraded under freeze-thaw cycle conditions.

2. The loss rates of stability and residual stability corresponding to 10% $CaCl_2$ solution were 21.9% and 33.8% higher than those corresponding to 2% $CaCl_2$ solution, respectively. This indicates that the effect of high concentration of $CaCl_2$ on residual stability is more significant.

3. The higher concentration of deicer solution corresponded to the more significant changes in the test parameters, indicating the significant effect of deicer on asphalt concrete.

4. At the end of 27 cycles, the average losses of stability, residual stability and air void content were 29%, 22% and 73%, respectively. This suggests that the combined effect of freeze-thaw cycles and deicing agent has a more significant effect on air void content.

References

[1] H. R. Vignisdottir et al., "A review of environmental impacts of winter road maintenance", *Cold Regions Science and Technology*, vol. 158, pp. 143–153, 2019.

[2] M. O. Rivett et al., "Highway deicing salt dynamic runoff to surface water and subsequent infiltration to groundwater during severe UK winters", *Science of the Total Environment*, vol. 565, pp. 324–338, 2016.

[3] J.-S. Chung, B.-H. Kim, and I.-S. Kim, "A case study on chloride corrosion for the end zone of concrete deck subjected to de-icing salts added calcium chloride", *Journal of the Korean Society of Safety*, vol. 29, no. 6, pp. 87–93, 2014.

[4] C. D. Johnston, "Deicer Salt Scaling Resistance, Chloride Permeability and Code Requirements for Air Content, Spacing Factor", *Concrete International*, vol. 16, no. 8, pp. 48–55, 1994.

[5] Y. Meng et al., "Deicing characteristics and pavement performance of eco-friendly de-icing asphalt mixture", *Construction and Building Materials*, vol. 360, p. 129565, 2022, doi: 10.1016/j.conbuildmat.2022.129565.

[6] J. B. Shanley, "Effects of Ion Exchange on Stream Solute Fluxes in a Basin Receiving Highway Deicing Salts", *Journal of Environmental Quality*, vol. 23, no. 5, pp. 977–986, 1994, doi: 10.2134/jeq1994.00472425002300050019x.

[7] L. Wang, Li. Gong, and Y. Xing, "Influence factors of salt freeze-thaw cycle on asphalt mixture properties", *Journal of Functional Materials*, vol. 47, no. 4, pp. 88–93, 2016.

[8] Z. Zhou, H. Li, X. Liu, and W. He, "Investigation of sea salt erosion effect on the asphalt-aggregate interfacial system", *Int. J. Pavement Res. Technol*., vol. 13, no. 2, pp. 145–153, 2020, doi: 10.1007/s42947-019-0095-2.

[9] F. Jin, G. Zhang, Y. Jin, Y. Watanabe, A. Kishita, and H. Enomoto, "A new process for producing calcium acetate from vegetable wastes for use as an environmentally friendly deicer", *Bioresource Technology*, vol. 101, no. 19, pp. 7299–7306, 2010, doi: 10.1016/j.biortech.2010.04.081.

[10] R. Chang and P. Hao, "Effect of salt freeze-thaw cycle on low temperature performance of asphalt mixture", *Journal of Building Materials*, vol. 20, no. 3, pp. 481–488, 2017.

[11] Y. Cui, J. Han, Z. Li, S. Zhang, and Z. Liu, "Effect of salt-freezing cycle on properties and microstructure of asphalt", *Journal of Functional Materials*, vol. 46, no. 18, pp. 18037–18042, 2015.

[12] Z. Liu and W. Hansen, "Freezing characteristics of air-entrained concrete in the presence of deicing salt", *Cement and Concrete Research*, vol. 74, pp. 10–18, 2015, doi: 10.1016/j.cemconres.2015.03.015.

[13] N. Buss, K. N. Nelson, J. Hua, and R. A. Relyea, "Effects of different roadway deicing salts on host-parasite interactions: The importance of salt type", *Environmental Pollution*, vol. 266, p. 115244, 2020, doi: 10.1016/j.envpol.2020.115244.

[14] Z. Wu, C. Shi, P. Gao, H. Zhang, and X. Hu, "Moisture Susceptibility of Asphalt Mixture Subjected to Chloride-Based Deicing Salt Solutions under Simulated Environmental Conditions", *Journal of Materials in Civil Engineering*, vol. 35, no. 5, p. 04023052, 2023, doi: 10.1061/(ASCE)MT.1943-5533.0004713.

[15] Y. Hassan, A. O. Abd El Halim, A. G. Razaqpur, W. Bekheet, and M. H. Farha, "Effects of Runway Deicers on Pavement Materials and Mixes: Comparison with Road Salt", *Journal of Transportation Engineering*, vol. 128, no. 4, pp. 385–391, 2002, doi: 10.1061/(ASCE)0733-947X(2002)128:4(385).

[16] X. Zhang, H. Chen, and I. Hoff, "The mutual effect and reaction mechanism of bitumen and de-icing salt solution", Construction and Building Materials, vol. 302, p. 124213, 2021.

ВПЛИВ ПРОТИОЖЕЛЕДНИХ РЕЧОВИН НА ВОДОСТІЙКІСТЬ АСФАЛЬТОБЕТОНУ В УМОВАХ ЦИКЛІВ ЗАМОРОЖУВАННЯ-ВІДТАВАННЯ

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Анотація. Асфальтобетонне покриття, як основна форма високоякісних доріг, займає важливе місце в сучасному дорожньому будівництві завдяки своїм перевагам, таким як низький рівень шуму, простота ремонту та короткий термін будівництва. Цей тип доріг широко застосовується в усьому світі і забезпечує надійну основу для дорожніх мереж у містах і селах. Проблема дорожньо-транспортних пригод взимку актуальна як для регіонів з досить холодними кліматичними умовами, так і для помірно-континентального клімату, який переважно характерний майже для всієї території України. Для вирішення цієї проблеми широко застосовуються протиожеледні речовини, що сприяють підвищенню безпеки дорожнього руху. Застосування протиожеледних реагентів ефективно зменшує вплив ожеледі та снігу на дороги і забезпечує безпечний проїзд транспортних засобів за несприятливих погодних умов. Однак, незважаючи на те, що протиожеледні суміші відіграють важливу роль у поліпшенні транспортного потоку, їх масштабне використання також створює певні проблеми, на які варто звернути увагу. Хімічні речовини, що входять до складу протиожеледних реагентів, можуть мати негативний вплив на матеріали дорожнього покриття, особливо на асфальтобетонних дорогах.

З метою вивчення впливу протиожеледних речовин на властивості асфальтобетону проведено експериментальне дослідження стосовно дії протиожеледних речовин на водостійкість асфальтобетону в умовах циклів заморожування та відтавання. Вплив протиожеледних речовин при циклічному заморожуванні-відтаванні на асфальтобетон досліджується шляхом оцінки закономірностей зміни трьох ключових параметрів: стабільності, залишкової стабільності та залишкової пористості.

Результати експерименту показали, що стабільність і залишкова стабільність асфальтобетону мали загальну тенденцію до зниження при збільшенні кількості циклів заморожування-відтавання, що вказує на часткове пошкодження або розшарування асфальтобетону в умовах циклів заморожування-відтавання. Вища концентрація розчину протиожеледної речовини характеризувалася більш вираженими змінами параметрів дослідження, що свідчить про значний вплив протиожеледної речовини на властивості асфальтобетону. Після 27 циклів випробувань середні показники втрати стійкості, залишкової стійкості та залишкової пористості становили 29%, 22% та 73% відповідно. Це свідчить про те, що вплив протиожеледного реагенту при циклічному заморожуванні-відтаванні має вагоміший вплив на показник залишкової пористості.

Ключові слова: асфальтобетон, протиожеледна речовина, водостійкість, цикл заморожування-відтавання, експлуатаційні характеристики дорожнього покриття.

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