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CONCRETE PROPERTIES IMPROVEMENT OF SLAB TRACKS USING CHEMICAL ADDITIVES

Purpose. On the Railways of Ukraine a very large number of slab tracks are operated with cracks. Many scientific works of previous years are dedicated to improving the design of slab tracks. The main causes of defects are: poor exploitation of the track; insufficient physic-mechanical characteristics of concrete; poor quality of initial materials. It is therefore necessary to develop an optimum concrete mix for the manufacture of these concrete products. **Methodology.** To assess the impact of individual factors and effects of their interactions on properties of concrete mix and concrete method of experimental and statistical modeling was used. At this, methodological fundamentals of mathematical experiment planning in concrete technology and modern methods of optimization of composite materials were taking into account. Based on the obtained data during the planned experiment conducting, including 15 studies and using the computer program MathCad, were obtained the regression equations, which describe the relevant physical and mechanical properties of concrete. On the basis of the equations with the help of computer program MATLAB R2012b the graphs were drawn, illustrating the dependences of system response from the changes of two factors at a fixed value of the third factor. **Findings.** Firstly was the analysis of cracks that occur in the process of operation in the constructions of slab tracks. Further reasons of possible occurrence of these cracks were presented. In the process of the conducted research the author has concluded that for rational concrete mix development it is necessary to conduct the planned experiment with the use of quality materials. It was established that to increase the strength, chemical additives should be added in to concrete mix, it will let reduce cement amount. **Originality.** Experiments proved the usage of modern chemical additives in order to improve the properties of concrete. Models were developed, reflecting characteristics of concrete strength. With their help one can optimize concrete composition. **Practical value.** Research proved that the usage of more sustainable concrete mix for production of slab tracks will increase their strength, and with it the reliability of these designs mechanical properties.

Keywords: slab tracks; deck of bridge; concrete sleepers; durability; crack strength; optimal concrete composition; damages; impact factors; stress; deformation; response model of system

Introduction

Durability of slab tracks (concrete sleepers, slabs of ballastless bridge deck (BBD) depends on many factors.

The main defects of slab tracks are cracks, located in different places and directions. Therefore it is necessary to determine the primary causes of their occurenece and make recommendations concerning the possible elimination of these defects.

The analysis of research materials and publications indicates that significant increase of concrete surfacing frost resistance can be achieved by formation of a certaine material structure: to minimize the number of pores and achieve their anisotropic location; reduce internal stresses in the concrete through the use of non-shrink technologies, which will reduce the level of cracking growth. Experience examinations and tests of BBD, conducted at Ukrzaliznytsia existing lines, shows that the slabs, which are produced nowdays are not reliable and durable. During a short operation period (approximately 5 years) they can get massive damages. Thus, there is a problem of insufficient crack resistance of slab tracks.

Purpose

To analyze previous experience regarding the occurrence of defects in slab tracks during the operational phase. To set forth results of the planned experiment. To improve the properties of concrete with specially matched complex chemical additives PLKP (ПЛКП).

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Methodology

To assess the individual factors impact and effects of their interaction on the properties of the concrete mixture and concrete, the method of experimental and statistical modeling was used. At the same time methodological basis of experiment of mathematical planning in concrete technology and modern methods of composite materials optimization was taken into account**.** Based on the obtained results during the planned experiment, which included 15 experiments using the computer program MathCad, was received the regression equation, which describes relevant physical and mechanical characteristics of concrete. Based on the obtained equations, using a computer program MATLAB R2012b, graphics were drawn that reflect dependences of system response from two impact factors change at the fixed value of the third factor.

Statement of base line. The main defects, identified in concrete sleepers and BMP slabs are cracks, located in different places and directions.

As it shown in [3] the most common type of defect is split of sleepers along through longitudinal crack that runs through reinforcing bars (approximately 25% of the total detected ones), which, in turn, caused by insufficient physical and mechanical characteristics of concrete, both at the manufacturing stage of a slipper and at the stage of laying it in to the permanent way. The main causes of defect for this type is «culture» of sleeper manufacture; insufficient thickness of the protective layer of concrete; poor quality of materials, used for the concrete mix production; imperfect choice of the concrete; low quality of mixing, installation and vibration of concrete mix and the wrong choice of steam curing mode. Quality control of all these factors will significantly reduce the emergence of defects of this type.

The second most common operating defect is split of a slipper on a through longitudinal crack with the opening of more than 3 mm, passing through a hole for insert bolts (approximately 17% of the total detected ones). This defect can be ranged to those, arising from the poor-quality operation of a track. To prevent the occurrence of defects of this type one should regularly to carry out diagnostics and continuous insert bolts tightening.

The third and fourth types by the number of defects is fracture of the sleeper in the middle part with concrete destruction, opening of transverse cracks or reinforcement break and fracture of the sleeper in the slab track with the destruction of concrete, opening of transverse cracks or reinforcement break (respectively 15% and 11% of the total detected ones). These defects of sleepers may arise as during the new construction and through the operating deficiency of the track.

Also common type of defect is the longitudinal crack with opening up to 3 mm, that comes through reinforcing bars at the ends and middle of sleepers (approximately 10.5% of the total detected ones). This defect occurs because of the same reasons that the split through longitudinal crack, so it is fair to say that preventive methods of this type of defect for them have to be identical. Other defects are less common.

So one can confirm that main causes of defects are poor operation of the track and insufficient physical and mechanical properties of materials for railway sleepers production.

Ballastless bridge deck (BBD) on the railway slabs has great stability of elements set. It protects upper chord of traffic areas and links between them from pollution and corrosion, ensure safety passage of wheel set across the bridge in case of derailment and it is economical by total value of production and laying. All this means massive use of BBD on concrete slabs in the construction of new bridges and reconstruction of railway ones that are operated. At the same time, during the examination many of the bridges, was found a large number of cracks in the concrete slab with shrinkage and power character.

There is typical sequence of cracks development and formation. Usually shrinkage cracks appear first on the lower or upper surface of the slab. Then under temporary load and depending on support conditions, shrinkage cracks on the slabs soffit grow in strength longitudinal or transverse ones relative to the axis. Further, due to the variable nature of slabs loads, cracks become through and are being developed along the axis from end to end or across the axis from high-strength pins to the ends of slabs. Also a large number of defective slabs with cracks was registered that pass diagonally through technological holes (for pins, counterangles) that significantly reduces longevity of bridge deck, and consequently, its reliability, increase operating costs [3, 9, 10, 11].

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From the literature review it can be seen that many constructive solutions to improve the reliability of slabs of BBD were offered. But very little attention is paid to such problems as imperfect concrete, from which these slabs are produced, namely: the use of poor-quality aggregates, concrete mix heterogeneity, inadequate strength, frost and crack resistance of concrete.

As a result of all the above noted it can be concluded about the need to develop the optimal concrete composition for the manufacture of slabs both BMP (БМП) and concrete sleepers to improve their durability.

Results of the planned experiment. As the cement binder was used Amvrosiivskyi PTs I-500 N H that meets State Standard of Ukraine B.V.2.7-46: 2010 requirements «Building Materials. Cements for general purposes. Specifications».

As the aggregates were used the following materials: river sand with a fineness modulus of 1.28, which meets the requirements of State Standard of Ukraine B.V.2.7-32-95 «Fine aggregates for construction materials, products, structures and works. Specifications» and sand with fineness modulus of 2.8 according to All-Union State Standard B.V.2.7-210: 2010 «Sand from screenings of crushing igneous rocks for construction works. Specifications» and gravel, fractions 5-20 mm in accordance with All-Union State Standard B.V.2.7-75-98 «Building materials. Crushed stone and gravel are dense natural for building materials, products, structures and works. Specifications».

Experimentation let reduce the amount of experimental research and gain, at this, quite probable model system behavior.

Implementation of the planned experiment is conducted in the following sequence [2]:

- formulation the problem, main indicators choice of quality control of system functioning (outputs Yi);
- the main factors choice influencing the system and the range of their changes by prior information;
- conducting the experimental studies by a fixed algorithm of a plan;
- statistical analysis of the results.

The factor is pacing to form certain characteristic or it has a significant positive effect. It does not have an extreme nature within reasonable variations, and, at the same time, affect negatively other characteristics. Impact analysis change of this factor is necessary to establish its rational value, i.e. negative impact limit at maximum possible maintenance of positive one.

In the case when dependence of impact factor on fundamental characteristic of its action is extreme or close to it nature, at additional negative impact on other characteristics, stabilization of the factor in the extremum area is rational.

Determining the factors of the experiment and levels of their varying are presented in Table 1.

Table 1

Factors	Indexes	Levels of variation and natural values of factors		
		-1	0	+1
Cement content of, kg / m3	X_1	350	400	450
Screening content, % by weight of fine aggregate	X_2	0	50	100
The content of additive PLKP, % by weight of binder	X_3	0	0,55	1,1

Obtained mathematical model in the processing of experimental results of interconnection between factors X_i, influencing the system, and system output Y_i, that are response on impacts, at checking its adequacy with sufficient probability reflects equation of objectively existing system state.

In this paper polynomial and experimental-statistical model of general form is used

$$\hat{Y} = a_o + \sum_{i=1}^{k} a_i X_i + \sum_{i \langle j}^{k} a_{ij} X_i X_j + \sum_{i=1}^{k} a_{ii} X_i^2$$

where, a_0 – value of system response at base level of factors; a_i – linear effect of factor X_i, which characterizes the average rate of system response change when factor control X_i in the range -1 ≤ X_i ≤ +1; a_{ii} – quadratic effect of factor X_i, which characterizes the acceleration system re-

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sponse change when factor control; a_{ij} – interaction effect, changing the average rate of system response change when factor control X_i, depending on level of the factor $X_{i+1.}$.

Based on data, obtained at the planning experiment, which included 15 experiments with help of the computer program MathCad, was received regression equation, which describes relevant physical and mechanical characteristics of concrete.

Regression equations, obtained after models statistical analysis, allow observing individual and common impact factors on under study output parameters of the system.

Analysis of the resulting equations system of basic parameters changes twill determine the permissible values of individual components content in the mixture and optimize the concrete mix.

The regression equation, which reflects the average compressive strength of samples after thermal and humidity treatment:

$$Y_1 = 399{,}773 + 50{,}045 \cdot X_1 - 9{,}829 \times \times X_2 + 55{,}033 \cdot X_3 - 8{,}142 \cdot X_1^2 + 17{,}372 \cdot X_2^2 - 5{,}682 \times \times X_3^2 - 18{,}704 \cdot X_1 \cdot X_2 - 1{,}061 \cdot X_1 \cdot X_3 - 16{,}276 \cdot X_2 \cdot X_3.$$

The regression equation, which reflects the average compressive strength of samples, at age of 7 days at hardening in natural environment:

$$Y_2 = 432{,}725 + 47{,}776 \cdot X_1 + 4{,}825 \cdot X_2 + 25{,}316 \cdot X_3 - 13{,}263 \cdot X_1^2 - 15{,}018 \cdot X_2^2 + 7{,}197 \cdot X_3^2 - 18{,}951 \cdot X_1 \cdot X_2 - 3{,}631 \cdot X_1 \cdot X_3 + 2{,}731 \cdot X_2 \cdot X_3.$$

The regression equation, which reflects the average compressive strength of samples at age of 28 days at hardening in natural environment:

$$Y_3 = 516{,}448 + 50{,}289 \cdot X_1 - 2{,}801 \cdot X_2 + 23{,}266 \cdot X_3 - 7{,}893 \cdot X_1^2 - 12{,}733 \cdot X_2^2 + 30{,}122 \cdot X_3^2 - 14{,}475 \cdot X_1 \cdot X_2 - 0{,}193 \cdot X_1 \cdot X_3 - 4{,}412 \cdot X_2 \cdot X_3.$$

Based on the obtained regression equations, using the computer program MATLAB R2012b, were constructed graphics that reflect system responses dependences from changes of two influencing factors in the fixed value of the third factor.

The strength of concrete is an important characteristic that determines its quality as a building material and the ability to resist destruction from internal stresses, that arise as a result of external loads. Therefore, was paid attention to concrete strength primarily at the planned experiment.

Compressive strength of concrete depends directly on activity of a binder (cement) and on its quantity in the mixture. However, high cement content affect the strength of concrete surface to some extent, after which it remains unchanged. In this case, shrinkage will increase and change the consistency of the concrete mix, increase the heat emission and temperature and shrinkage cracks will start appearing.

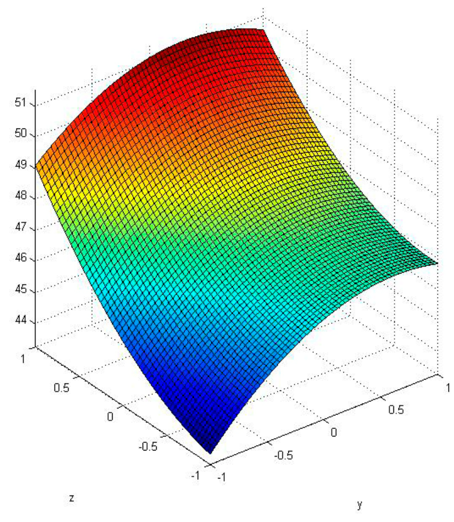

Fig. 1. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_2 (% screening) and X_3 PLKP (ПЛКП) at fixed index X_1 (Ц) = -1.

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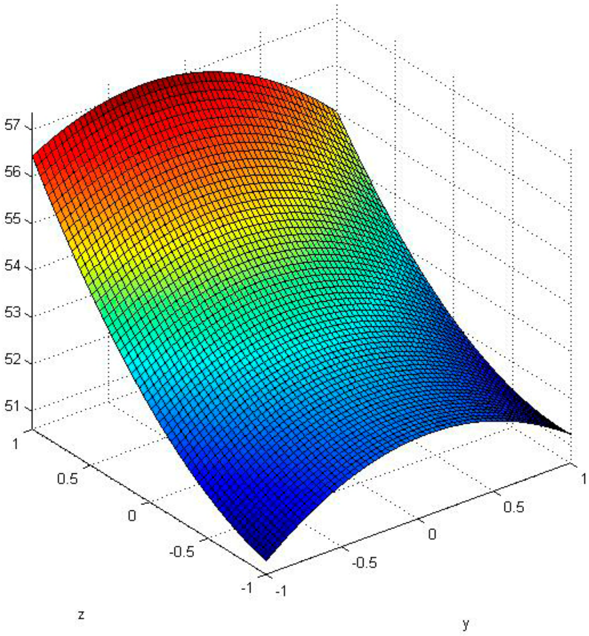

Fig. 2. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_2 (% screening) and X_3 PLKP (ПЛКП) at fixed index X_1 (Ц) = 0.

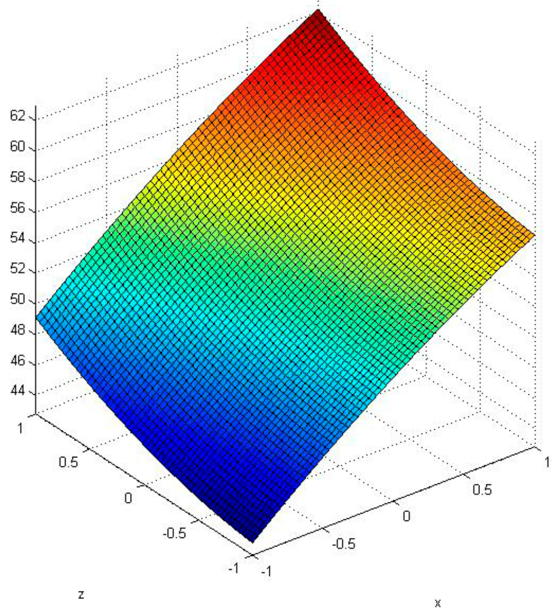

Fig. 4. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cement) and X_3 PLKP (ПЛКП) at fixed index X_2 (% screening) = -1.

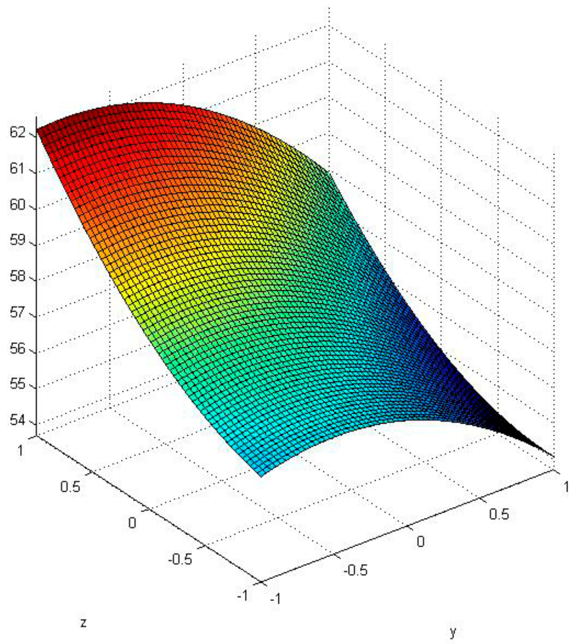

Fig. 3. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_2 (% screening) and X_3 PLKP (ПЛКП) at fixed index X_1 (Ц) = 1.

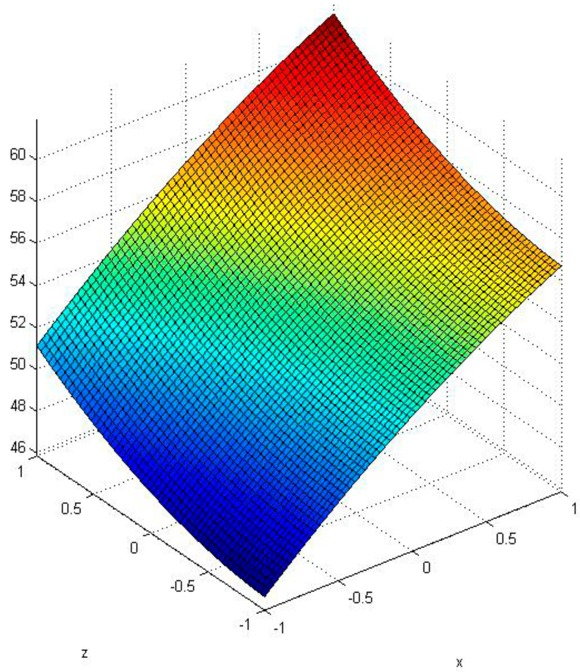

Fig. 5. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cement) and X_3 PLKP (ПЛКП) at fixed index X_2 (% screening) = 0.

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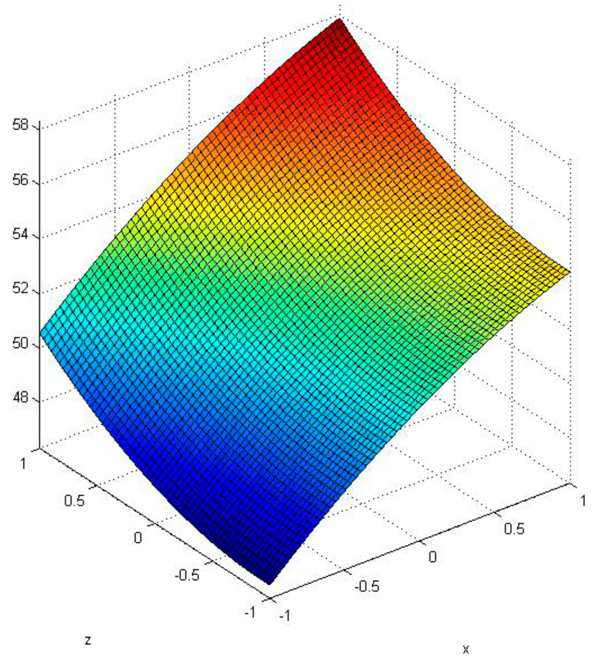

Fig. 6. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cement) and X_3 PLKP (ПЛКП) at fixed index X_2 (% screening) = 1.

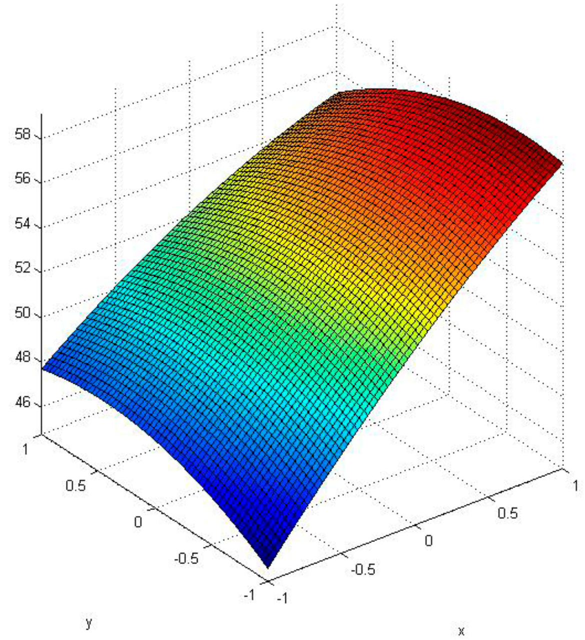

Fig. 8. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cement) and X_2 (% screening) at fixed index X_3 PLKP (ПЛКП) = 0.

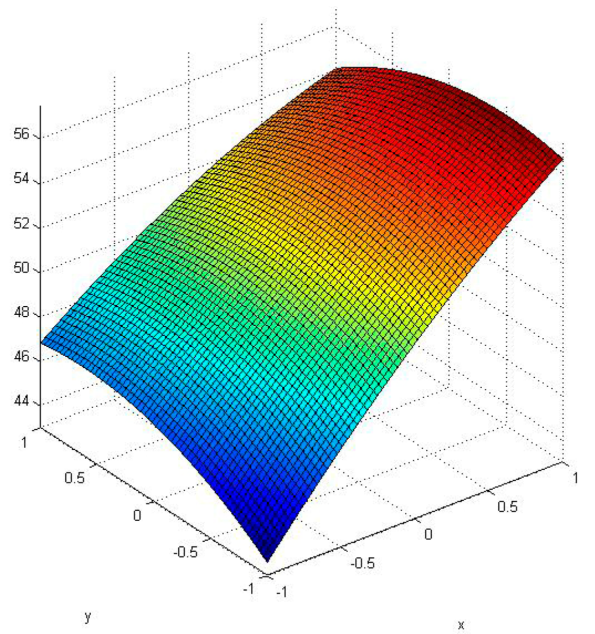

Fig. 7. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cement) and X_2 (% screening) at fixed index X_3 PLKP (ПЛКП) = -1.

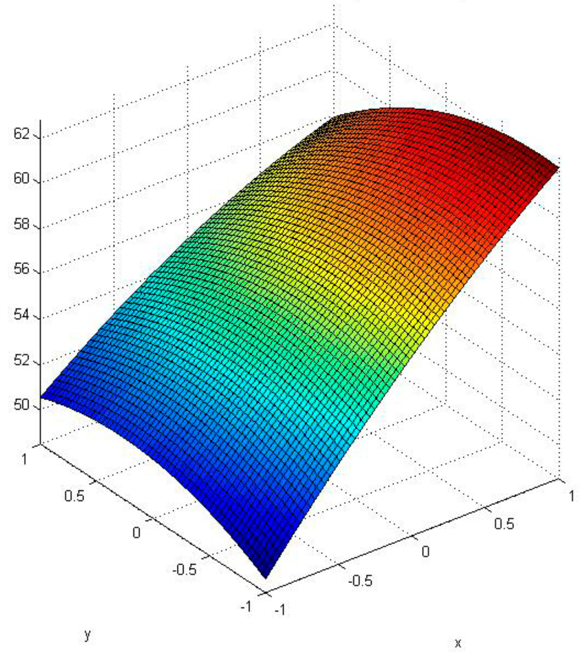

Fig. 9. Dependence model of system response (strength of concrete at the age of 28 days, MPa) on changes of influencing factors X_1 (% cementy) and X_2 (% screening) at fixed index X_3 PLKP (ПЛКП) = 1.

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Originality and practical value

Models were obtained that represent characteristics of concrete strength depending on change in each of three selected impact factors.

The practical value is to develop rational concrete mix for implementation the production of concrete sleepers and slabs of ballastless bridge deck.

Conclusions

In research it has been found that use of screening of 50% from total mass of fine aggregate is optimal, since at this ratio one can get optimal concrete mix placing and provide increased durability of concrete, compared with the use of fine sand.

In the experiment was used PLKP (ПЛКП) complex chemical additive, which has changed slightly the cement stone structure. It led to properties improvement of concrete. Composition of additives were chosen specially for use in the concrete preparation of slab tracks.

In the future conduction of more detailed experiment in order to get such concrete mixture is planned. It will have the necessary characteristics of strength, water resistance, frost resistance, crack resistance, and which can be recommended for the production of concrete sleepers and BBS slabs.

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ПОКРАЩЕННЯ ВЛАСТИВОСТЕЙ БЕТОНУ ПІДРЕЙКОВИХ ОСНОВ ЗА ДОПОМОГОЮ ХІМІЧНИХ ДОБАВОК

Мета. На залізницях України дуже велика кількість підрейкових основ експлуатується з тріщинами. Багато наукових робіт попередніх років присвячено вдосконаленню саме конструкції підрейкових основ. Основними причинами виникнення дефектів є: незадовільна експлуатація колії; недостатні фізико-механічні характеристики бетону; низька якість вихідних матеріалів. Тому в роботі необхідно розробити оптимальний склад бетону для виготовлення цих залізобетонних виробів. **Методика.** Для оцінки впливу окремих факторів та ефектів їх взаємодії на властивості бетонної суміші та бетону використовувався метод експериментально-статистичного моделювання. При цьому враховувались методологічні основи математичного планування експерименту в технології бетону та сучасні методи оптимізації композиційних матеріалів. На основі даних, отриманих в результаті проведення планованого експерименту, котрий включав у себе 15 експериментів за допомогою комп’ютерної програми MathCad, було отримано рівняння регресії, за якими описуються відповідні фізико-механічні характеристики бетону. На основі отриманих рівнянь за допомогою комп’ютерної програми MATLAB R2012b було побудовано графіки, які відображають залежності відгуків системи від зміни двох факторів впливу при фіксованому значенні третього фактору. **Результати.** Спочатку було проведено аналіз тріщин, які виникають у процесі експлуатації в конструкціях підрейкових основ. Далі надано причини можливого виникнення цих тріщин. В процесі проведених досліджень автором зроблено висновок, що для розробки раціонального складу бетону треба провести планований експеримент із використанням якісних матеріалів. У результаті цього встановлено, що для підвищення міцності необхідне введення хімічних добавок до складу бетону, що дозволяє знизити кількість цементу. **Наукова новизна.** Експериментально встановлено використання сучасних хімічних добавок для покращення властивостей бетону. Розроблено моделі, що відображають характеристики міцності бетону, за допомогою яких можна оптимізувати склад бетонної суміші. **Практична значимість.** Дослідженням встановлено, що використання більш раціонального складу бетону для виготовлення підрейкових основ дозволить підвищити їх міцність, а разом із цим і надійність цих конструкцій.

Ключові слова: підрейкові основи; мостове полотно; залізобетонні шпали; довговічність; тріщиностійкість; оптимальний склад бетону; дефекти; фактори впливу; напруга; деформація; модель відгуку системи

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УЛУЧШЕНИЕ СВОЙСТВ БЕТОНА ПОДРЕЛЬСОВЫХ ОСНОВАНИЙ С ПОМОЩЬЮ ХИМИЧЕСКИХ ДОБАВОК

Цель. На железных дорогах Украины очень большое количество подрельсовых оснований эксплуатируется с трещинами. Много научных работ предыдущих лет посвящено совершенствованию именно конструкции подрельсовых оснований. Основными причинами возникновения дефектов являются: неудовлетворительная эксплуатация пути; недостаточные физико-механические характеристики бетона; низкое качество исходных материалов. Поэтому в работе необходимо разработать оптимальный состав бетона для изготовления этих железобетонных изделий. **Методика.** Для оценки влияния отдельных факторов и эффектов их взаимодействия на свойства бетонной смеси и бетона использовался метод экспериментально-статистического моделирования. При этом учитывались методологические основы

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математического планирования эксперимента в технологии бетона и современные методы оптимизации композиционных материалов. На основе данных, полученных в результате проведения планируемого эксперимента, включающего в себя 15 исследований с помощью компьютерной программы MathCad, были получены уравнения регрессии, по которым описываются соответствующие физико-механические характеристики бетона. На основе полученных уравнений с помощью компьютерной программы MATLAB R2012b были построены графики, отражающие зависимости откликов системы от изменения двух факторов при фиксированном значении третьего фактора. **Результаты.** Сначала был проведен анализ трещин, которые возникают в процессе эксплуатации в конструкциях подрельсовых оснований. Далее предоставлены причины возможного возникновения этих трещин. В процессе проведенных исследований автором сделан вывод, что для разработки рационального состава бетона нужно провести планируемый эксперимент с использованием качественных материалов. В результате этого установлено, что для повышения прочности необходимо введение химических добавок в состав бетона, что позволяет снизить количество цемента. **Научная новизна.** Экспериментально установлено использование современных химических добавок для улучшения свойств бетона. Разработаны модели, отражающие характеристики прочности бетона, с помощью которых можно оптимизировать состав бетонной смеси. **Практическая значимость.** Исследование доказало, что использование более рационального состава бетона для изготовления подрельсовых оснований позволит повысить их прочность, а вместе с этим, и надежность этих конструкций.

Ключевые слова: подрельсовые основания; мостовое полотно; железобетонные шпалы; долговечность; трещиностойкость; оптимальный состав бетона; дефекты; факторы влияния; напряжение; деформация; модель отклика системы

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