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HYDRAULIC CONCRETE COMPOSITION AND PROPERTIES CONTROL SYSTEM

Purpose. Scientific work aims at the development and testing of information system to meet the challenges of concrete composition design and control (for railway structures and buildings) based on the physico-analytical method algorithm for hydraulic concrete composition calculation. **Methodology**. The proposed algorithm of hydraulic concrete composition calculation is based on the physicochemical mechanics and in particular on the rheology of elastic–viscous–plastic bodies. The system of canonical equations consists of the equations for concrete strength, absolute volume, concrete mix consistency as well as the equation for optimal concrete saturation with aggregates while minimizing cement content. The joint solution of these four equations related to composition allows determining for the materials the concrete composition of required strength, concrete workability with minimum cement content. The procedure for calculation of hydraulic concrete composition according to the physico-analytical method consists of two parts: 1) physical, which is laboratory testing of concrete mix components in different concrete compositions; 2) analytical, which represents the calculation algorithm for concrete compositions equivalent in concrete strength and workability that comply with the specific conditions of concrete placing. **Findings.** To solve the problem of designing the concrete composition with the desired properties for railway structures and buildings it was proposed to use the information technology in the form of a developed computer program whose algorithm includes the physico-analytical method for hydraulic concrete composition determination. **Originality**. The developed concrete composition design method takes into account the basic properties of raw materials, concrete mix and concrete, which are pre-determined. The distinctive feature of physico-analytical method is obtaining of a set of equivalent compositions with a certain concrete mix consistency and required concrete strength, which allows to optimize the concrete composition by any optimality criterion, depending on the operation conditions. **Practical value**. Using the developed method will expand its functionality when applied in the form of the composition calculation computer program for the construction and repair of surface and underwater structures. The use of physico-analytical method at production site will simultaneously solve the economic problems of construction and maintenance cost reduction, component saving and ensure obtaining the concrete with the set properties for specific operation conditions of transport engineering structures.

Keywords: concrete composition; physico-analytical method; hydraulic concrete

Introduction

Over recent years there is the tendency to modernize the transport system of Ukraine, in particular the railway network, and therefore consumption and operational requirements for transport infrastructure have increased, resulting in extending use of modern high-quality construction and repair materials, the most popular of which is concrete. The concrete constructions of artificial transport structures face new higher requirements connected with increased train speed, district electrification, introduction of new permanent way designs, new technologies of structure and building erection, the need to save energy and material resources in structure fabrication.

The modern manufacturing process of concrete, concrete products and structures is characterized by expanded application field and therefore varies due to different requirements for concrete mix and

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concrete. The operational feature of transport facilities is constant or periodic contact with aqueous environment. Therefore these facilities require the special concrete type – hydraulic concrete, characterized by a set of properties to ensure concrete stability in specific conditions.

Concrete for hydraulic and transport facilities should provide reliable, durable and safe operation of buildings and structures in aquatic environment, and therefore should be characterized by complex of technological and operational properties such as workability, viability, connectivity, density, strength, water resistance, frost resistance, waterproofing, mechanical crack resistance, low cement heat liberation (only for massive structures), corrosion resistance, etc. These requirements are achieved by the correct concrete composition analysis.

Making concrete, whose properties comply with the project requirements, is a complex multistage process, each stage of which forms the final quality. The most important step that forms the design properties of concrete and allows adjustments for changes in the properties aimed to obtain a quality product is the concrete composition design – an important technological task accounting for the success of all the following stages. Today the information management systems are successfully used to solve this task. However, the existing systems do not take into account a set of specific requirements for concrete of hydraulic and transport structures and buildings; hence development of such a system is an actual scientific problem.

Purpose

The purpose is the development and testing of information system to meet the challenges of concrete composition design and management for engineering transport structures based on the physico-analytical method algorithm for hydraulic concrete composition calculation.

Previous studies analysis

Determination of the rational material content in the concrete mix to achieve the project properties, as a crucial stage of hydraulic concrete technology, has been constantly within the field of leading specialists' interest. Full attention is given to the problem of concrete composition design in scientific, industrial and educational publications [1…15] at the domestic and foreign conferences and seminars. On the one hand, it confirms the relevance of the problem, on the other hand, the existence of a number of outstanding issues in the concrete design methodology, as well as expanded application of concrete for special construction.

However, the complexity of multi-component concrete structure led to empirical nature of the known methods of concrete proportioning.

Today there is a significant amount of methods for concrete component calculation, but they are distinguished by numerous factors and amendments, herewith only one concrete composition is obtained that meets the specified requirements [2, 5, 6, 11]. The main drawback of these methods is their isolation from the basic sciences, and therefore unilateral account of the raw material properties. Instead, the proposed method considers the concrete composition determination based on physically reasonable theory of the composition of concrete mix and concrete, developed by prof. Punahin V. M. and for hydraulic concrete by prof. Pshinko O. M. [10].

To reduce the cement content and thus heat liberation and cubic deformation while maintaining the required concrete consistency and density there are used chemical and mineral supplements that allow to increase remarkably the composition effectiveness, to achieve significant changes of certain properties and so on.

The properties of the concrete mix and concrete, particularly workability, non-segregation, fluidity, strength, frost resistance, thermal crack resistance, non-pressure water penetration depend on the structural characteristics of each level of the structure, i.e. the quality of primary components and their physical and mechanical characteristics, coarse aggregate spreading factor in cement-sand mortar, fine aggregate spreading factor in cement paste (gravel), water-cement ratio, crystalline and gel hydration products ratio.

The physico-analytical method for hydraulic concrete composition calculation [10] developed in Dnipropetrovsk National University of Railway Transport named after acad. V. Lazaryan is based on physical testing of concrete mix components in various concrete compositions and analytical calculation of compositions equivalent by concrete strength and workability, which meet the specific conditions of concrete placing.

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A large number of input parameters in the design of concrete (characteristics of components, characteristics of concrete mix and concrete at project stage, special properties such as frost resistance, water resistance, sulfate-, acid-resistance, etc.), the complexity of calculation methodology and the importance of immediate optimal results generate a need for the use of modern information technologies for solving the concrete design tasks, including those for hydraulic concrete.

The feasibility and relevance of the proposed approach is proved by the existence of software, both domestic [1, 4, 6, 8, 9, 7] and foreign [13-16] one, to solve such tasks, its active development and improvement, and the authors' positive experience in the development of such projects.

Methodology

The vast majority of requirements for concrete and methods of its composition design are based on the structure operation conditions. When designing concrete and reinforced concrete engineering structures it is necessary to meet the requirements relating to the their operation specificity: in the conditions of high humidity, corrosive environment, with variable temperature characteristics and so on. In this case, the basic requirements for concrete are its compressive strength, frost resistance, water resistance, crack resistance, electrocorrosion resistance.

To preserve the integrity of this system, despite the significant amount of the concrete components and the dependence of its properties on multiple input parameters, it is useful, when developing the theory of the concrete mix, to apply a systematic approach. It allows compiling and using of the available fundamental knowledge about the elastic-viscous-plastic bodies.

The developed theory is based on the physicochemical mechanics and in particular on the rheology of elastic-viscous-plastic bodies. Herewith it was able to apply a systematic approach in deriving composition equations. Furthermore the used fundamentals of basic sciences made it possible to obtain practically important, and most significantly, very simple correlations, which are easily used as for determination of concrete compositions equivalent by set properties, and for solving the tasks of hydraulic concrete technology.

Based on the systematic approach the properties and the relationship of input elements of concrete are described. This allowed in the development process to obtain analytical correlations that express the technological properties of the concrete mix, namely its consistency as the function of composition and main component properties. The obtained correlations, expressing the general laws of the system structure, manifested themselves in all range of real components of hydraulic concrete.

It is particularly important to effectively use the developed method of concrete composition design in the integrated production management system programs for concrete works in the process of construction and repair of various transport engineering structures.

The system of canonical composition equations consists of the equations for concrete strength, absolute volume, concrete mix consistency as well as the equation for optimal concrete saturation with aggregates while minimizing cement content. Canonical equations, forming a complete system, at the same time reflect the current state of physicochemical mechanics of concrete, which allows to use them for description of the basic material properties.

The joint solution of these four equations related to composition allows determining for the materials the concrete composition of required strength, concrete workability with minimum cement content.

In practical terms it is appropriate to obtain not just one composition, but a set of equivalent compositions that for these primary materials comply with two conditions: the necessary concrete strength and the desired concrete consistency. To achieve this it is necessary to set the values of sand and cement ratio and conduct the calculation of compositions with the desired consistency and strength. The resulting compositions will include the optimal formula for cement content.

Herewith the obtained compositions, with the given project properties, are characterized by different ratios of various components and technological properties, such as non-segregation, crack resistance, etc.

This fact opens the possibility of optimizing the concrete composition by the complex of requirements that are most widely used in the

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technology practice for construction and repair of local damage on the engineering structures.

Based on the above, the procedure for the concrete composition design according to the physico-analytical method consists of two parts:

a) physical, which is laboratory testing of concrete mix components in different concrete compositions;

b) analytical, which represents the calculation algorithm for concrete compositions equivalent in concrete strength and workability that comply with the specific conditions of concrete placing.

PC-based concrete design allows to fully automated the definition of tables determining the equivalent components of concrete on the basis of experimental data related to material, concrete mix and concrete testing. The use of PC in the concrete design process is especially effective as it gives the opportunity not only to find the right composition with a minimum content of binding substance but also to obtain the adjacent equivalent compositions, setting different sand-cement ratios. This makes it possible to optimize the composition by any optimality criterion.

The definition aalgorithm for the table of equivalent components is developed based on solving four concrete equations, including the correlation (1).

$$f_0 \cdot \frac{\rho_{\blacksquare\blacksquare}}{\gamma_{\blacksquare\blacksquare}} \cdot (1 + Y_0 \cdot \frac{\theta^*}{f_0}) \cdot (1 + Y_0 \cdot \frac{m_{\blacksquare\blacksquare}}{f_0}) = \frac{\blacksquare}{\blacksquare} \cdot (\rho_{\blacksquare\blacksquare} + \blacksquare_0) \quad (1)$$

This allows following the determination of the main concrete composition with binder content $C_{\min}$, setting a certain deviation from the value x_{opt}, to build the entire table of components.

Block diagram of determining the equivalent components of concrete strength and concrete workability for machine-oriented concrete design method is shown in Fig. 1.

Concrete properties management can be realized by optimal combination of concrete composition with adding of optimum amount of superplasticizers, curing accelerators, micro-disperse network modifiers that previously had limited use for the concrete of transport structures and facilities. The optimal amount and type of these additives can provide in due time the optimal balance between crystalhydrate and gel hydration products, the minimum capillary porosity, that is to improve operational performance and technological properties of concrete – for concrete mix [7].

The developed concrete composition determination method is added with the possibility of additive action control of superplasticizer and mikrofiller and is taken as a basis of computer program algorithm.

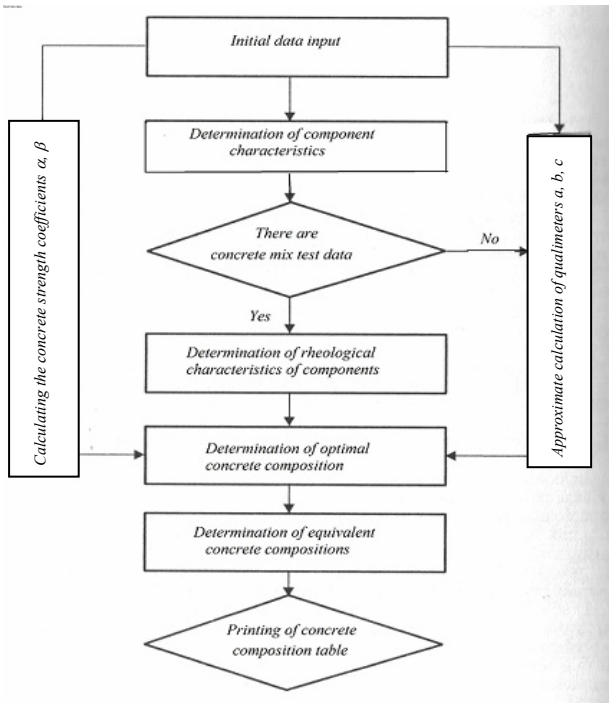

Fig. 1 Block diagram of determining the equivalent components of concrete

The developed for the software methodology of concrete composition and properties information management system has the following advantages:

– Adjustability for Windows operating system (XP or later versions);

– Availability of advanced graphical user interface (client side);

– Possibility of formation of accounting records in the form of text editors with the possibility of further editing;

– Providing affordable compact software.

Available services and functionality of the developed information system fully comply with the requirements of operational management of

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hydraulic concrete composition and properties when used in the process of repair and construction of transport infrastructure facilities.

Fig. 2 shows a common interface of the developed software to calculate the hydraulic concrete composition table.

The computer program is adapted to implement the intellectual decision support system that allows in interactive and convenient form to solve the problem of hydraulic concrete composition design with desired properties, taking into account the characteristics of the concrete mix components.

Fig. 2 Interface of developed software

Назначение составов бетона для строительства и ремонта транспортных искусственных сооружений	Application of concrete compositions for construction and repair of transport engineering structures
Приднепровская железная дорога	Near-Dnipro Railway
Служба путевого хозяйства	Railway Track Maintenance
Отдел искусственных сооружений	Engineering Structures Department
Днепропетровский национальный университет железнодорожного транспорта им. В. Лазаряна	Dnipropetrovsk National University of Railway Transport named after V. Lazaryan
Главная страница	Home page
Характеристики компонентов бетона	Concrete component characteristics
Вычисление квалиметров	Qualimeter calculation
Данные испытаний для уточнения квалиметров	Test data for qualimeter refinement
Вычисление коэффициентов прочности бетона	Concrete strength factor calculation
Проектные характеристики бетона	Design parameters of concrete
Таблица составов бетона	Concrete composition table
Нормативные документы	Normative documents

The program algorithm for concrete mix includes such properties as workability (a user sets cone slump or hardness), for concrete – strength in project stage, concrete component qualimeters *a, b, c,* concrete strength characteristics – coefficients *A* and *B*, as well as takes into account the types of the structure, in which the concrete will be used and the conditions of its operation.

The calculation results are submitted in a report that can be saved in several formats (*.pdf, *.doc, *.xls) or printed on the printer (Fig. 3).

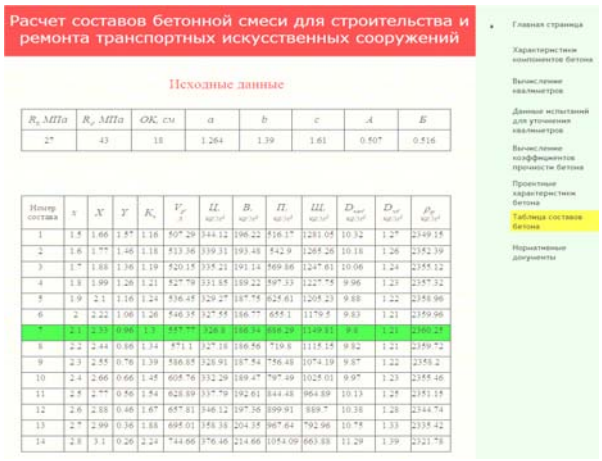

Fig. 3. Example of the table of equivalent components in hydraulic concrete

Расчет составов бетонной смеси для строительства и ремонта транспортных искусственных сооружений	Calculation of concrete composition for construction and repair of transport engineering structures
Исходные данные	Initial data
Номер состава	Composition №
Главная страница	Home page
Характеристики компонентов бетона	Concrete component characteristics
Вычисление квалиметров	Qualimeter calculation

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Данные испытаний для уточнения квалиметров		Test data for qualimeter refinement	
Вычисление коэффициентов прочности бетона		Concrete strength factor calculation	
Проектные характеристики бетона		Design parameters of concrete	
Таблица составов бетона		Concrete composition table	
Нормативные документы		Normative documents	
Мпа	MPa	*Ц*, кг/м^3	*C*, kg/cm^3
ОК, см	*CS*, cm	*В*, кг/м^3	*W*, kg/cm^3
$K_н$		*П*, кг/м^3	*S*, kg/cm^3
$V_р$, л	V_{gr}, l	*Щ*, кг/м^3	*G*, kg/cm^3
$D_{нап}$		D_{gk}	

Findings

To solve the problem of designing the hydraulic concrete composition with the desired properties for railway structures and buildings it was proposed to use the information technology in the form of a developed computer program whose algorithm includes the physico-analytical method for hydraulic concrete composition determination.

Originality and practical value

The developed concrete composition design method takes into account the basic properties of raw materials, concrete mix and concrete. Its distinctive feature is obtaining of a set of equivalent compositions with a certain concrete mix consistency and required concrete strength. The composition calculations can be conveniently carried out using PC.

Conclusions

1. It is established that while developing the methods for determining the concrete components amount for construction and repair of transport facilities it is necessary to use an integrated approach: to take into account the quality and quantity of the concrete components with the set technological and operational characteristics of concrete mix and concrete in specific operation conditions of hydraulic and transport facilities.

2. The physico-analytical method for determining the concrete components amount for construction and repair of transport engineering structures was developed and presented. It provides preliminary laboratory tests of materials, concrete mix and concrete (physical part) and the calculation of concrete compositions, equivalent by strength and consistency of concrete mix (analytical part).

3. The integrated management system for hydraulic concrete composition and properties was developed; it is presented as the concrete component calculation software, implemented through information technology on PC.

4. Application of the developed integrated system at the production site will fully automate the definition of tables determining the equivalent components of concrete on the basis of experimental data related to material, concrete mix and concrete testing.

5. Implementation of physico-analytical method at production site will simultaneously solve the economic problems of construction and maintenance cost reduction, component saving and ensure obtaining the concrete with the set properties for specific operation conditions of transport engineering structures.

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СИСТЕМА УПРАВЛІННЯ СКЛАДОМ ТА ВЛАСТИВОСТЯМИ ГІДРОТЕХНІЧНОГО БЕТОНУ

Мета. Наукова робота має за мету розробку й апробацію інформаційної системи для розв’язання задач проектування та управління складом бетону (для конструкцій і споруд залізниць) на основі алгоритму фізико-аналітичного методу розрахунку складу гідротехнічного бетону. **Методика.** Запропонований алгоритм розрахунку складу гідротехнічного бетону базується на положеннях фізико-хімічної механіки та, зокрема, реології пружно-в'язко-пластичних тіл. Система канонічних рівнянь складається з рівнянь міцності бетону, абсолютних об'ємів складових, консистенції бетонної суміші та рівняння оптимального насичення бетону заповнювачами при мінімальній витраті цементу. Сумісне вирішення чотирьох перерахованих рівнянь складу дозволяє визначити для даних матеріалів склад бетону заданої міцності, необхідної легкоукладальності бетонної суміші з мінімальною витратою цементу. Порядок розрахунку складу гідротехнічного бетону за фізико-аналітичним методом поділяється на дві частини: 1) фізичну, що представляє лабораторне випробування компонентів бетонної суміші в різних складах бетонів; 2) аналітичну, яка представляє алгоритм розрахунку складів бетону, еквівалентних за міцністю бетону

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і легкоукладальністю бетонної суміші, що відповідає конкретним умовам бетонування. **Результати.** Для розв'язання задачі проектування складу бетону із заданими властивостями для конструкцій та споруд залізниць запропоновано використання інформаційних технологій у вигляді розробленої комп'ютерної програми, в алгоритм роботи якої покладено фізико-аналітичний метод визначення складу гідротехнічного бетону. **Наукова новизна.** Розроблений метод проектування складів бетону враховує основні властивості вихідних матеріалів, бетонної суміші та бетону, які попередньо визначаються. Відмітною рисою фізико-аналітичного методу є одержання набору еквівалентних складів із заданою консистенцією бетонної суміші та потрібною міцністю бетону, що дозволяє оптимізувати склади бетону за любим критерієм оптимальності в залежності від умов експлуатації. **Практична значимість.** Використання розробленого методу дозволить розширити його функціональні можливості при застосуванні у вигляді комп'ютерної програми для призначення складів для зведення та ремонту надводних і підводних споруд. Застосування фізико-аналітичного методу на виробництві дозволить одночасно вирішити економічні питання зменшення собівартості будівництва та ремонту, економію складових бетону та забезпечити отримання бетону із заданими властивостями для специфічних умов експлуатації транспортних штучних споруд.

Ключові слова: склад бетону; фізико-аналітичний метод; гідротехнічний бетон

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СИСТЕМА УПРАВЛЕНИЯ СОСТАВОМ И СВОЙСТВАМИ ГИДРОТЕХНИЧЕСКОГО БЕТОНА

Цель. Научная работа своей целью имеет разработку и апробацию информационной системы для решения задач проектирования и управления составом бетона (для конструкций и сооружений железных дорог) на основе алгоритма физико-аналитического метода расчета состава гидротехнического бетона. **Методика.** Предложенный алгоритм расчета состава гидротехнического бетона базируется на положениях физико-химической механики и, в частности, реологии упруго-вязко-пластических тел. Система канонических уравнений состава состоит из уравнений прочности бетона, абсолютных объемов составляющих, консистенции бетонной смеси и уравнения оптимального насыщения бетона заполнителями при минимальном расходе цемента. Совместное решение четырех перечисленных уравнений состава позволяет определить для данных материалов состав бетона заданной прочности и необходимой удобоукладываемости бетонной смеси с минимальным расходом цемента. Порядок расчета состава гидротехнического бетона по физико-аналитическому методу разделяется на две части: 1) физическую, представляющую лабораторное испытание компонентов бетонной смеси в разных составах бетонов; 2) аналитическую, которая представляет собой алгоритм расчета составов бетона, эквивалентных по прочности бетона и удобоукладываемости бетонной смеси, отвечающую конкретным условиям бетонирования. **Результаты.** Для решения задачи проектирования состава бетона с заданными свойствами для конструкций и сооружений железных дорог предложено использование информационных технологий в виде разработанной компьютерной программы, в алгоритм работы которой положен физико-аналитический метод определения составов гидротехнического бетона. **Научная новизна.** Разработанный метод проектирования составов бетона учитывает основные свойства исходных материалов, бетонной смеси и бетона, которые определяются предварительно. Отличительной особенностью физико-аналитического метода является получение набора эквивалентных составов с заданной консистенцией бетонной смеси и прочностью бетона, что позволяет оптимизировать составы бетона по любым критериям оптимальности в зависимости от условий эксплуатации. **Практическая значимость.** Использование разработанного метода позволит расширить его функциональные возможности при использовании в виде компьютерной

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программы назначения составов для возведения и ремонта надводных и подводных сооружений. Применение физико-аналитического метода на производстве позволит одновременно решить экономические задачи уменьшения себестоимости строительства и ремонта, производить экономию составляющих бетона и обеспечить получение бетона с заданными свойствами для специфических условий эксплуатации транспортных искусственных сооружений.

Ключевые слова: состав бетона; физико-аналитический метод; гидротехнический бетон

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