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Method for Assessing the Density of a Concrete Mix during Molding

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Abstract.
Introduction. Concrete mix compaction is one of the most pressing topics in modern construction. Vibration compaction is a key method used to ensure uniform distribution of concrete mix components and removal of air voids.
The process of manufacturing reinforced concrete products is complex and labor-intensive and requires significant responsibility and attention. The quality of compaction of mixtures affects the physical and mechanical properties of molded products, including strength, water resistance, frost resistance and other important parameters. A correctly compacted mix ensures uniformity of properties of finished products, accuracy of geometric shapes and good quality of its front surface. The aim of this article is to study the existing works of the authors and identify the development area in the method of assessing the density of concrete mixture during molding with the possible development of the device necessary for this.
Materials and methods. Concrete mix was chosen as the object of the study. Control of concrete vibration compaction parameters requires careful planning, taking into account the type of mix, the shape of the structure and quality requirements. This section covers the development of a fundamentally new device "Shar-1".
Research results. The results of the development of a device for measuring the density of concrete mixture have been successfully proved experimentally. The device makes it possible to evaluate the compaction of the mixture during the forming process, recording data in real time and allowing further analyses of the concrete mixture compaction process. This helps to improve the quality control of concrete mixtures at the stage of moulding, which is important for improving the reliability and durability of concrete structures. The use of "Shar-1" simplifies and speeds up the testing process, reducing the influence of subjective factors and increasing the objectivity of measurements.
Discussion and Conclusion. The section focuses on the difference between traditional research on control of concrete mixture compaction and with the use of the device "Shar-1", which allows to measure the density of concrete mixture in the process of moulding. The method allows to quickly obtain data on density, timely correct the technology if necessary. It is planned to improve the device with additional functions in the future.

Key words: concrete, reinforced concrete, concrete mixture, compaction, vibration compaction, vibration platform, vibrations

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Оригинальное эмпирическое исследование

Метод оценки плотности бетонной смеси в процессе формования

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Аннотация.

Введение. Уплотнение бетонных смесей является одной из наиболее актуальных тем современного строительства. Вибрационное уплотнение — это один из основных методов, используемых для обеспечения равномерного распределения компонентов бетонной смеси и удаления воздушных пустот. Этот процесс позволяет достичь более высокой плотности и прочности бетона, что, в свою очередь, улучшает его эксплуатационные характеристики. Процесс производства железобетонных изделий представляет собой сложный и трудоёмкий, требующий значительной ответственности и внимания, процесс. Качество уплотнения смесей влияет на физико-механические свойства формуемых изделий, включая прочность, водонепроницаемость, морозостойкость и другие важные параметры. Верно уплотненная смесь обеспечивает однотипность свойств готовой продукции, точность геометрических форм и хорошее качество его лицевой поверхности. Целью данной статьи является описание работы принципиально нового оборудования «Шар-1», направленного на совершенствование методов оценки плотности бетонной смеси непосредственно в процессе формованию.

Материалы и методы. В качестве объекта исследования была выбрана бетонная смесь. Управление параметрами вибрационного уплотнения бетона требует тщательного планирования с учётом типа смеси, формы конструкции и требований к качеству. Исследование выполнялось с применением принципиально нового прибора «Шар-1».

Результаты исследования. Результаты разработки устройства для измерения плотности бетонной смеси успешно доказаны экспериментальным путем. Прибор позволяет оценивать уплотнение смеси в процессе формования, фиксируя данные в реальном времени и позволяя в дальнейшем анализировать процесс уплотнения бетонной смеси. Это способствует улучшению контроля качества бетонных смесей на стадии формования, что важно для повышения надежности и долговечности бетонных конструкций. Использование прибора «Шар-1» упрощает и ускоряет процесс испытаний, снижая влияние субъективных факторов и повышая объективность измерений.

Обсуждение и заключение. Раздел акцентируется на различии традиционных исследований по контролю уплотнения бетонной смеси и с применением прибора «Шар-1», который позволяет измерить плотность бетонной смеси в процессе формования. Метод позволяет быстро получать данные о плотности, своевременно корректировать технологию при необходимости. В дальнейшем планируется усовершенствовать прибор дополнительными функциями.

Ключевые слова: бетон, железобетон, бетонная смесь, уплотнение, виброуплотнение, виброплощадка, колебания

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Introduction. Vibration started being used for compacting concrete mixtures using pneumatic and ratchet vibration devices in 1890. There had been no new scientific data on the topic until 1915. In 1915, studies of vibro-compacted concrete and hand-made masonry accompanied with their comparative evaluation got underway causing new publications for comparative analysis to emerge. The effectiveness of vibration forming of concrete products depends on whether vibration modes and equipment parameters are chosen wisely. Telichenko V.I. and Vasiliev V.G. described a vibrating table, which is a movable platform on spring-loaded supports with two vibrators creating directional vibrations transmitted to the form and mixture [1].

However, lots of traditional concrete compaction methods might fail to provide the required quality, particularly while working with rigid concrete mixtures, since these are most often either destructive or insufficiently fast, which restrains their use in mass production. It is to be noted that the quality of concrete directly depends on the degree of its compaction, since this impacts the strength, durability and operational characteristics of structures.

In order to create strong and reliable concrete, it is critical to compact a concrete mix properly. This can be done by using vibration, a movement that assists concrete particles in fitting tightly together.

Vibrating setups have a major role to play in compacting concrete mixtures, ensuring the removal of air and voids from the mass of concrete, which causes a considerable increase in its strength and durability. If a mixture is sufficiently liquid, even a slight vibration, for example, might be sufficient due to its own weight. For thicker mixtures, more powerful vibration and, possibly, additional pressure are needed. Methods for optimizing the parameters of vibration setups, such as the frequency and amplitude of vibrations, to maximize the efficiency of machines, as well as the analysis and improvement of designs of electric vibration machines with a longitudinal gap of a magnetic core were elaborated on in [2].

If a mixture is sufficiently liquid, even a slight vibration, for example, might be sufficient due to its own weight. For thicker mixtures, more powerful vibration is needed. Owing to modern research, it is known that only 20–30 seconds is enough for the initial compaction of concrete. During this time, the concrete particles are redistributed by gravity, forming a solid and stable structure. As a result, the air is removed from a mixture, and eventually is not over 3–4% [3].

In the next stage, only a small combination of components is performed as some of the air is removed. The duration of the second stage of technological conversion is longer than that of the first one and is 2–3 minutes on standard vibrating pads. The end of the second stage is based on that of compaction of a concrete mixture. Once it is over, the freshly laid concrete can be considered ready to be processed further, as additional vibration causes no significant increase in the density, strength or quality of its surface [4].

Vibration plays a major role in forming concrete, but its efficiency depends on a whole host of factors. Although the vibration intensity might decrease as he source is moved away from due to the material properties and internal friction, this opens up avenues for optimizing the process [5, 6].

The quality and strength of concrete directly depend on a proper technology of laying and compacting a concrete mix, as these affect the uniformity of the material structure. By understanding how vibration waves propagate and interact in a concrete mix, one is able to develop more effective compaction methods. Although vibration attenuation at a distance from the source is a natural phenomenon caused by material properties and internal friction, it is not something impossible to deal with. All of this would enable us to achieve a uniform concrete structure even in complex shaped products. Research in this area is ongoing and we are sure that in the future the quality and efficiency of concrete products production will be increased further [7–9].

Investigating the interaction of vibration with reflected waves and natural vibrations of concrete will allow one to create optimal conditions for compaction even in complexly shaped products. The development of new vibration control methods paves the way to increased production efficiency as well as life cycle of equipment, and creation of high-quality concrete products [10].

Along with the modernization of equipment, scholars are working hard on a new method for assessing the quality of a concrete mix which relies on its ability to resist delamination. This method makes use of a special coefficient that shows how effectively cement is distributed in concrete. It is assumed that in a high-quality concrete mix, where all the components are evenly mixed, water will wash out more cement with a slow flow than with a fast one. This will allow one to quickly and precisely identify the quality of concrete and guarantee its strength and durability [11].

During the vibrational compaction of a concrete mixture, there are some mechanical effects leading to the permanent destruction of the bonds between its constituent particles. This, in turn, helps to reduce the forces of friction and adhesion. Due to its special consistency, a concrete mix is evenly distributed under the influence of gravity resulting in a homogeneous mass. In order to obtain the ultimate strength and durability of reinforced concrete products made from heavy mixtures, high density must be attained. Scientists are striving to ensure that the actual density of concrete is almost perfect. This is determined by the compaction coefficient, which should be at least 0.98, and preferably closer to a unit. This method ensures the reliability and durability of reinforced concrete products [12].

For a long time, the effectiveness of concrete vibration compaction was believed to reach its maximum when the particles of the concrete mixture are resonantly coupled to the vibration source. However, each fraction of the filler has its own unique oscillation frequency. This implies that the optimal sealing effect can be attained via a multi-frequency effect bringing all of the particles of a mixture into resonance. Self-synchronization is actually observed in a concrete mixture due to the binding effect of the cement paste uniting the individual grains of the aggregate. Therefore the efficiency of vibration compaction can be increased by optimizing the operating mode of the vibrator, which helps to synchronize the natural vibrations of the entire volume of a concrete mixture with the frequency of its operation [13].

The oscillation frequency determines the speed of movement of the particles of a concrete mixture. Changing the frequency allows the speed and intensity of compaction to be controlled. For example, for denser concrete mixtures, a higher oscillation frequency can be applied [14, 15].

Over the recent years, there has been a growing interest in optimizing vibration sealing parameters for increasing production efficiency and reducing costs. There is thus a need for system analysis and control of vibration parameters (frequency, amplitude, duration and exposure modes). In the future, this quality control method can be achieved by means of developing an effective and accurate method for estimating the density of a concrete mixture directly during molding improving the product quality and optimizing the production costs. This article looks at the main approaches to measuring the compaction of concrete mixtures experimentally using the "Shar-1" device developed by the authors.

Materials and Methods. The control of vibration seal parameters calls for careful planning and control. It is necessary to consider the type of a concrete mix, size and shape of the structure, as well as the requirements for the quality of concrete. The use of a variety of methods and approaches makes it possible to attain the optimal results and ensure the durability of concrete structures [16].

Vibration duration describes that of compaction. Time optimization makes it possible to achieve an even distribution of a concrete mixture and eliminate voids and irregularities. An exposure to vibration which is excessively long might cause the concrete mixture to separate, therefore a balance might be struck. Fig. 1 clearly shows the effect of the duration of compaction on the strength of concrete. The strength does not increase over a short-term and long-term compaction time, i.e., it is necessary to identify a point in time when the maximum compaction is recorded.

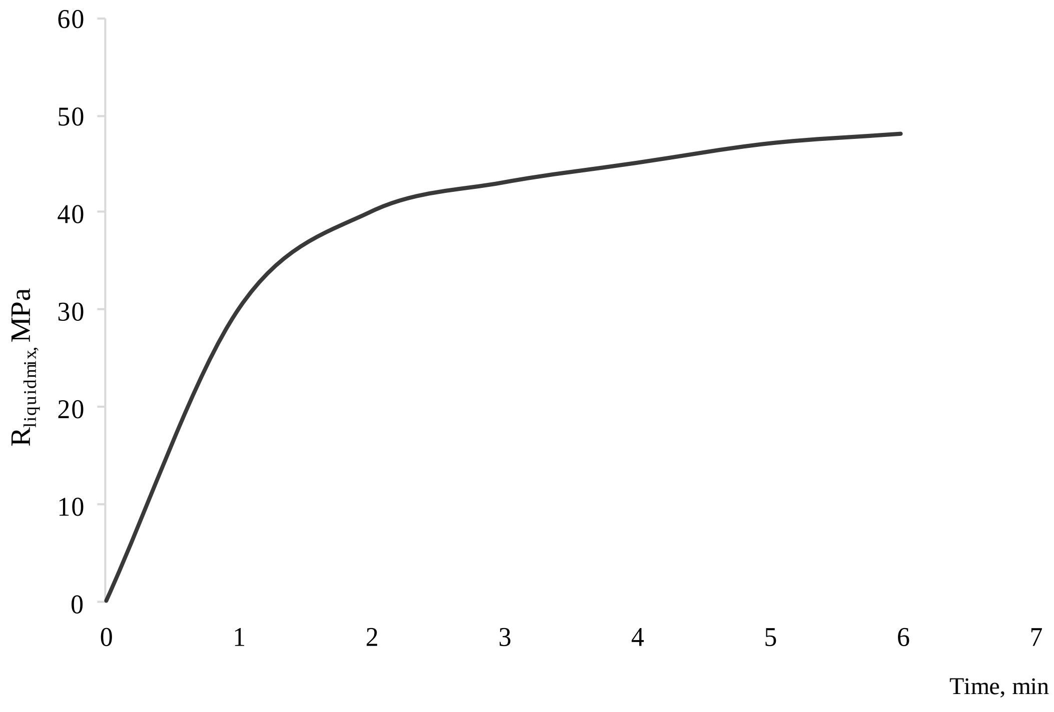

Fig. 1. Effect of the duration of compaction on the strength of concrete

To understand the processes occurring in the concrete mixture during its compaction, we have developed a fundamentally new device "Shar-1" (Fig. 2, 3).

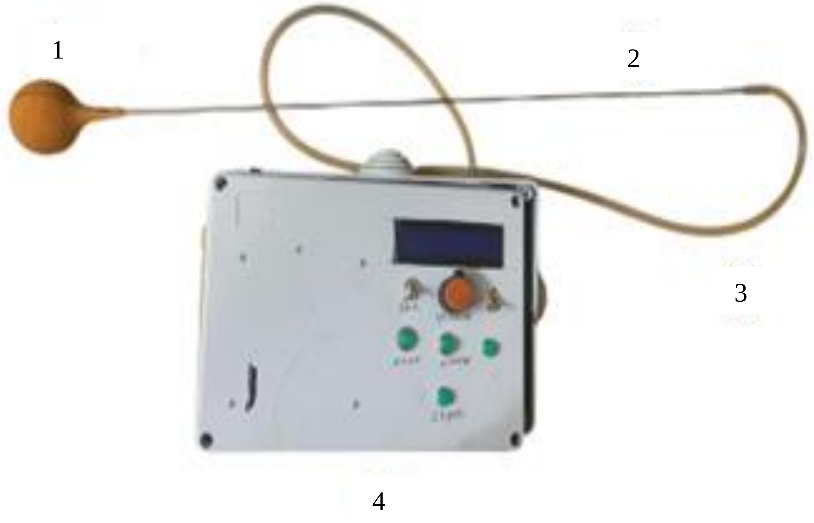

Fig. 2. Main parts of the "Shar-1" device: 1 — rubber ball; 2 — metal tube; 3 — rubber tube; 4 — control panel

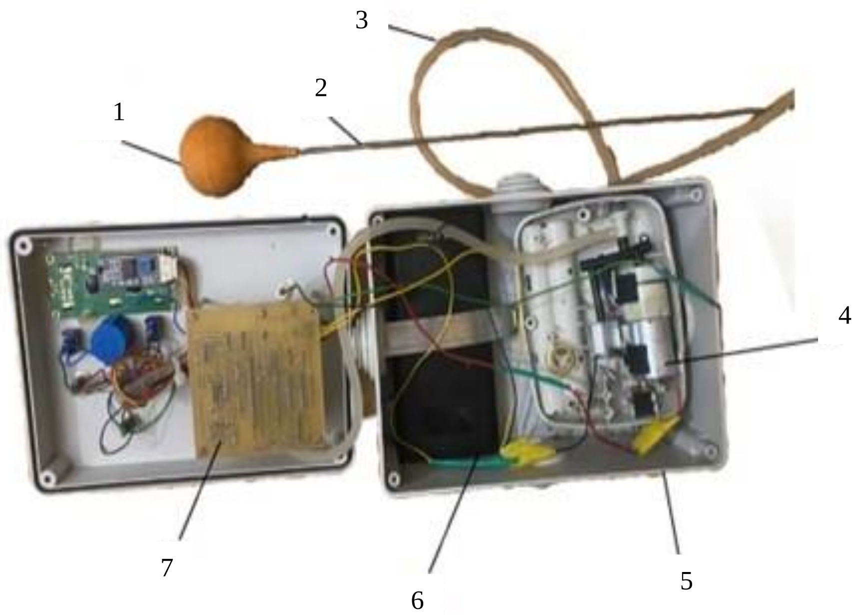

Fig. 3. Internal components of the “Shar-1” device: 1 — rubber ball; 2 — metal tube; 3 — rubber tube; 4 — control panel; 5 — body; 6 — battery, 7 — power board

The main working body of the device is a rubber ball under pressure connected through a metal hollow tube and a rubber tube to a pump in the control panel. Inside the rubber ball are a pressure sensor; a real-time clock; a vibration sensor measuring amplitude and vibrations. The case contains an SD drive for recording parameters on a power board; a battery for autonomous operation; a pump generating pressure in the ball for testing.

The pressure ball is at half the height of the metal mold, and this is when the process of compaction of a concrete mixture gets underway. Based on the physics of concrete compaction, it is known that during vibrations large particles tend to go down, and small ones go up respectively, which is called stratification. A ball under a certain pressure of 100 units placed in a mold starts contracting due to the pressure of a large fraction of a concrete mixture and reaches its maximum value. The maximum value of the Shar-1 device is considered to be the one when there is an equilibrium during compaction of a concrete mixture in the system, i.e., there will be no stratification. If there is one, theindices will start declining rapidly, as there is no more the equilibrium in the system , and a large proportion of a concrete mixture will be at the bottom, and a small (cement dough) fraction will be at the top. This indicates that the density between the upper layer and the lower ones differs, i.e., aconcrete mixture has experienced stratification.

Research Results. The development of the new "Shar-1" device is aimed at identifying the optimal quantitative indicator reflecting the full degree of compaction of a concrete mix while maintaining its strength characteristics. In order to identify this indicator, the working body of the "Shar-1" device is installed in a mold with a concrete mixture sequentially intorduced. As compaction gets underway, the device identifies the pressure on the working body over time and records the maximum values indicating the peak value of compaction of a concrete mixture.

The graph in Fig. 4 shows what the point of maximum compaction of the concrete sweep looks like through the course of the experiments.

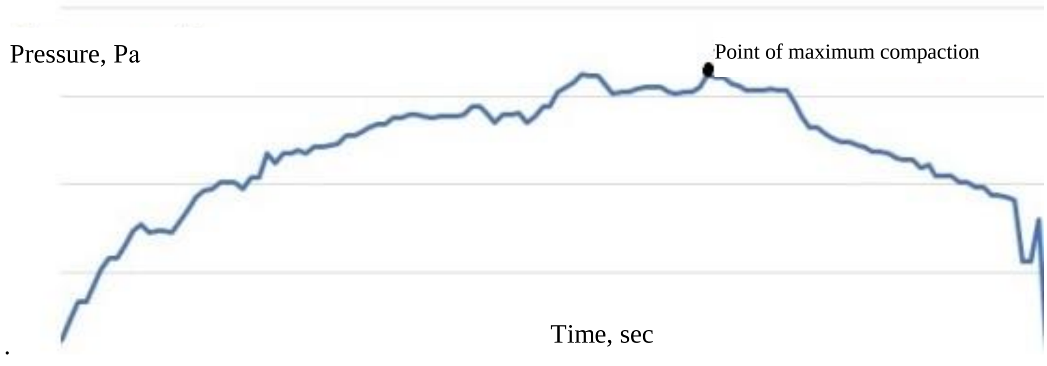

Fig. 4. Point of maximum compaction of a concrete mixture

The device is currently being tested and debugged. It is to be stressed that the use of devices capable of measuring the degree of compaction of a concrete mixture is currently restrained. However, the introduction of this method and the "Shar-1" device will be a breakthrough in concrete production technology with a positive impact on the economic growth of enterprises.

Discussion and Conclusion. Ensuring high-quality compaction of a concrete mix is an important step in construction, which is of paramount importance for the strength of future structures.

While working on the manuscript, we investigated the work of lots of authors and found a promising field of development, i.e., the development of a method for controlling the compaction of a concrete mixture during molding, which was the inspiration behind a completely new device "Shar-1". This method of density estimation using the developed device makes it possible to quickly obtain density data and allows for timely correction of compaction technology improving the quality and durability of concrete products, as well as reduces test time as well as the cost of preparation and measurement compared with traditional laboratory methods.

The mass use of this development in precast concrete production plants would involve an increase in the quality of products, a reduction in the human factor, and thereby in the likelihood of frequent errors as well as the production costs.

We are planning to refine the device to a more ergonomic appearance and as it is tested further, additional functions will be introduced to create an even more comprehensive and multifunctional device.

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KhS Yavruyan: scientific supervision, formulating the main concept, refining the text, correcting the conclusions.

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