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Loaders for Concrete Compaction

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The article presents a comprehensive analysis of load applicator designs used in the compaction technologies of stiff and lightweight concrete mixtures. The role of loading is revealed as one of the key factors influencing the effectiveness of forming products made from concrete with a low water-to-cement ratio. The main operating principles of load applicators are described, which apply additional force to the concrete mixture in combination with vibrational loading. A classification of load applicators is provided based on design features and energy source: inertial, non-inertial, pneumatic, and vibratory load applicators. Special attention is given to combined devices that integrate vibrational and impulse action on concrete. The study summarizes research findings that confirm the advantages of combined compaction, particularly when using pneumatic load applicators with adjustable pressure. It has been established that the use of active load applicators allows for a reduction in cement consumption by up to 30%, a decrease in product forming time by up to 50%, improved compaction uniformity along the height, and enhanced surface quality. An original design of an active load applicator with a vibration exciter and impact elements is proposed, providing impulse compaction with adjustable pressure and frequency. The main unresolved aspects of the problem are identified — the lack of unified methodologies for calculating loading parameters, insufficient adaptability of designs to changes in product geometry and concrete mixture properties. The feasibility of developing intelligent controlled load applicators capable of adapting to forming conditions is substantiated to improve the efficiency of reinforced concrete product manufacturing.

Keywords: concrete mixture, compaction, load applicator, vibration, combined compaction, vibratory load applicator, pneumatic loading, lightweight concrete, energy efficiency.

Привантажувачі для ущільнення бетонів

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У статті виконано комплексний аналіз конструкцій привантажувачів, які застосовуються в технологіях ущільнення жорстких і легких бетонних сумішей. Розкрито роль привантаження як одного з ключових факторів, що впливає на ефективність формування виробів із бетонів з низьким водоцементним відношенням. Описано основні принципи дії привантажувачів, які реалізують додаткову силову дію на бетонну суміш у поєднанні з вібраційним навантаженням. Наведено класифікацію привантажувачів за конструктивними ознаками та джерелом енергії: інерційні, безінерційні, пневматичні, вібропривантажувачі. Особливу увагу приділено комбінованим пристроям, які поєднують вібраційний та імпульсний вплив на бетон. Узагальнено результати досліджень, що підтверджують переваги комбінованого ущільнення, зокрема з використанням пневматичних привантажувачів із регульованим тиском. Встановлено, що застосування активних привантажувачів дозволяє зменшити витрати цементу до 30 %, скоротити час формування виробу до 50 %, покращити однорідність ущільнення по висоті та підвищити поверхневу якість. Запропоновано оригінальну конструкцію привантажувача активної дії із вібророзбуджувачем та ударними елементами, що забезпечує імпульсне ущільнення із регульованим тиском і частотою. Визначено основні нерозв’язані аспекти проблеми — відсутність уніфікованих методик розрахунку параметрів привантаження, недостатня адаптивність конструкцій до змін геометрії виробів та властивостей бетонних сумішей. Обґрунтовано доцільність розроблення інтелектуальних керованих привантажувачів з можливістю адаптації до умов формування для підвищення ефективності виробництва залізобетонних виробів.

Ключові слова: бетонна суміш, ущільнення, привантажувач, вібрація, комбіноване ущільнення, вібропривантажувач, пневмопривантаження, легкі бетони, енергоефективність.

Introduction

Loaders as elements of vibration equipment play a key role in the compaction process of stiff and low-workability concrete mixtures, which are widely used in the production of precast reinforced concrete products. Compaction is the factor that determines the main physical and mechanical properties of the final product—strength, density, frost resistance, crack resistance, and durability. Under construction conditions, where quality requirements and the productivity of technological processes are constantly increasing, the need arises for more efficient compaction methods than traditional vibration techniques [1, 2, 5].

The use of loaders in combination with vibrational loading is particularly relevant, as it allows the water-cement ratio to be reduced, prevents segregation of the mixture, and ensures uniform compaction throughout the entire volume of the form. Due to the additional static or dynamic pressure, loaders facilitate the active expulsion of air and compaction of the granular structure of the mixture, which, in turn, improves the quality and strength of concrete products [3].

Depending on their structural design and operating principle, loaders are classified into inertial, non-inertial, pneumatic, and vibratory types, among others. Each type has its own application features, advantages, and limitations, which necessitate a thorough analysis in the context of forming technologies. Combined compaction modes, in which vibration is combined with active loading—pneumatic, mechanical, or impulse—are especially effective.

Given the diversity of product types, the properties of concrete mixtures, and performance requirements, a systematic analysis of existing loader designs and their impact on compaction efficiency is of significant importance.

Definition of unsolved aspects of the problem

Despite the availability of various technical solutions for loading concrete mixtures during compaction, there remain a number of unresolved issues related to both the structural improvement of loaders and their classification by operating principle, type of loading, and intended function.

A significant portion of existing loader designs feature fixed geometric and load parameters, which limits their applicability for products of varying shapes and sizes. Adaptive, modular, or universal designs capable of automatically adjusting the force, direction, or point of load application have yet to become widespread or standardized in serial production.

Many existing designs also lack technical solutions for precise synchronization between the loader's action and the operation mode of the vibration exciter (in terms of frequency, phase, and direction). This limits the effectiveness of combined compaction modes, where the synchronization of impact and vibration is critically important for forming a homogeneous concrete structure.

Basic material and results

One of the key stages in the production of reinforced concrete products is the compaction of the concrete mixture. Particular attention must be paid to low-workability and stiff concrete mixtures, for which traditional compaction methods based solely on vibration often prove to be insufficiently effective [4, 7]. In such cases, it is advisable to combine vibrational impact with additional static pressure, which is implemented through the use of loaders. This approach significantly increases the degree of mixture compaction, reduces forming time, and improves the uniformity of the product structure.

Loaders perform the function of applying additional pressure to the concrete mixture during vibration. This promotes the intensification of the compaction process by reducing viscosity, preventing segregation, and accelerating air expulsion. Critical parameters in this context include the magnitude of the pressure applied to the mold surface, the frequency and amplitude of vibrations, all of which must correspond to the physical and mechanical properties of the concrete mixture.

Studies show that the application of combined effects—vibration and loading—can increase the early (24-hour) strength of concrete by 130–200% compared to traditional pressing. This improvement is attributed to denser particle packing, reduced void content, and enhanced development of molecular bonding forces. In particular, vibropressing technology with a loader is successfully used in the production of paving slabs, curb stones, and wall blocks made from stiff concrete mixtures with workability of 40–50 seconds under a pressure of 5–10 kPa.

Depending on the compaction conditions and the properties of the concrete mixture, loaders can serve various functions—from stabilizing the mixture's position in the mold to initiating additional particle movement. For example, in the case of heavy stiff concrete, loading facilitates intensive air expulsion, while in the compaction of lightweight concretes with porous aggregates, it helps prevent segregation. Therefore, it is a relevant task to adapt the type of loader to the specific technological process and material type.

In the compaction of polystyrene concrete, which exhibits high damping properties, the effectiveness of traditional vibrocompaction is significantly reduced. Under such conditions, the use of combined loaders (e.g., pneumatic loading in conjunction with vibration) enables a substantial increase in density and strength while reducing cement consumption. Research findings indicate that the application of variable pressure throughout the compaction cycle not only ensures uniform mixture distribution but also reduces internal stresses in the product after hardening.

Given the wide range of concrete products, the universality of loaders is also of great importance. Modular designs with easily replaceable sections, variable shield geometries, universal mountings, and adjustable stiffness of elastic elements allow for rapid reconfiguration of equipment for new products without significant time and resource costs. This is especially important for small and medium-sized manufacturers, where equipment flexibility directly affects production efficiency.

An important criterion for selecting a loader remains the energy efficiency of the compaction process. It has been established that, at the same degree of compaction, energy consumption for systems with vibratory loading can be 20–30% lower compared to traditional vibration-only methods, particularly when compacting heavy or low-workability mixtures. This is due to reduced energy losses from oscillations of massive formwork elements and stabilization of vibration modes.

Structurally, loaders can be implemented as movable frames, loading plates, or mechanical or pneumatic systems that provide controlled pressure on the surface of the concrete mixture. The most common are vertical loaders, which act on the top part of the form, ensuring uniform pressure distribution across the surface. When combined with vibrating platforms or vibrating tables, loaders may be integrated into a common kinematic scheme.

In industrial conditions, the effectiveness of loaders is determined not only by the pressure applied but also by the precision of synchronization with the vibration mode. The best results are achieved using multi-frequency compaction, where the vibrating table operates at 55 Hz and the loader at 75–150 Hz.

Such a mode contributes to reduced energy consumption, improved uniformity of compaction, and significantly shortened forming time.

Despite the widespread adoption of loaders in production, a unified methodology for calculating their parameters is still lacking. Existing theoretical approaches show significant discrepancies in assessing the optimal pressure, creating difficulties in implementing such systems in new technological lines. This highlights the need for further research aimed at harmonizing loader parameters with the characteristics of the concrete mixture, the product geometry, and the vibration compaction modes.

In the practice of manufacturing concrete and reinforced concrete products, loaders have gained widespread use due to their ability to provide additional force on the mixture during vibrocompaction. They can be designed as devices that replicate the shape of the product in plan view and operate based on mass, elastic elements, or controlled pressure. According to their mode of action, they are classified as passive or active.

Passive loaders, which do not have built-in sources of oscillation, apply pressure using gravity or elastic systems. The simplest type is the inertial loader, in which compaction occurs under the weight of the structure itself. These are effective for small-batch production, for example, in the manufacture of cinder blocks or wall stones. However, their disadvantages include limited productivity, manual feeding, and the inability to precisely control the applied pressure.

Another type is the non-inertial loader, in which the additional pressure is applied by a mass that does not participate in oscillations but transmits the load through elastic elements.

These systems may use either rigid or pneumatic springs. In such two-mass systems, periodic impact between the loader components is possible, which further enhances the compaction effect. However, to achieve stable impacts, it is necessary to precisely adjust the spring stiffness according to the height of the product and the nature of oscillations.

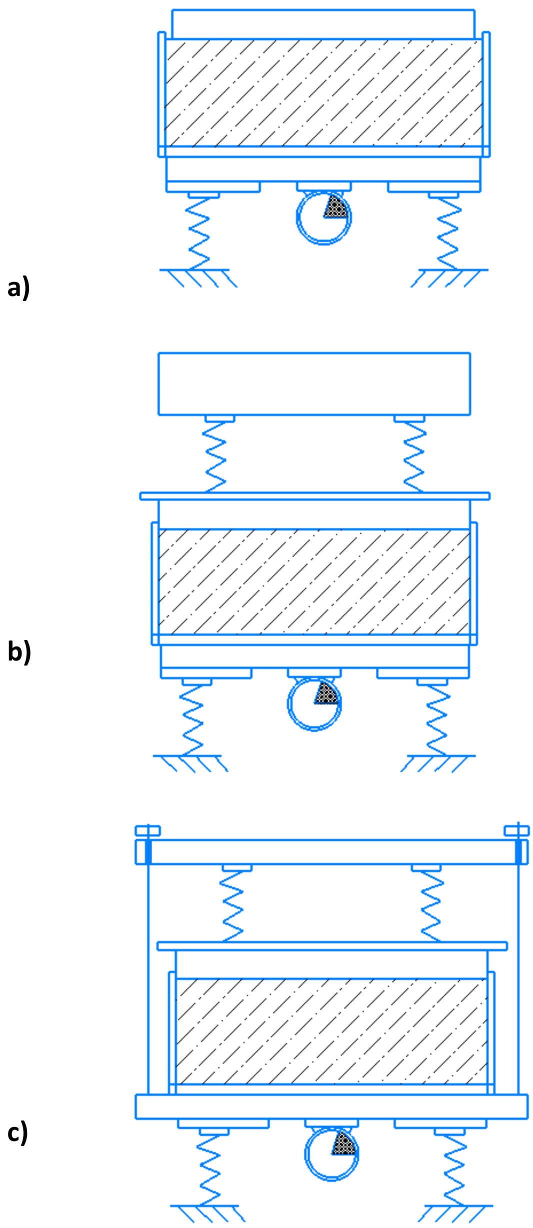

Figure 1 – Passive Loaders:
a) inertial loader; b) inertial loader with an additional spring-loaded mass; c) inertial loader with a spring-loaded pressing system

Active loaders are equipped with vibration exciters and provide not only static pressure but also dynamic action (vibrational or impact) on the concrete mixture. This allows for a significant intensification of the compaction process and improved structural uniformity, particularly for products with complex geometries.

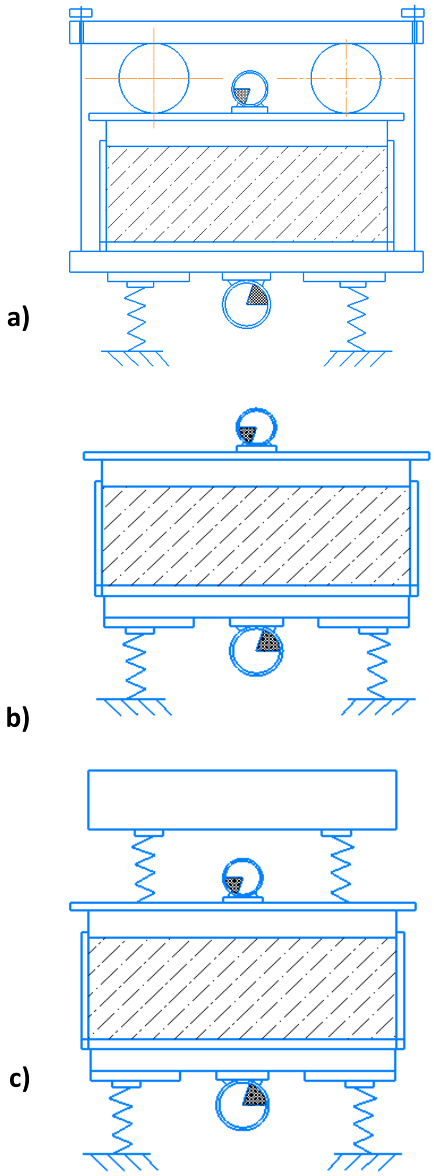

Figure 2 – Active Loaders:
a) pneumatic loader with vibration exciter;
b) inertial active loader with vibration exciter;
c) inertial active loader with additional spring-loaded mass and vibration exciter

Among active-type designs, special attention is given to pneumatic loaders, in which pressure on the mixture is generated by inflatable rubber bladders filled with air. Such systems enable effective compaction of both the external and internal surfaces of the product. For example, in the production of pipes or hollow elements, the bladders are installed on internal core formers, creating uniform pressure on the concrete from all sides. According to research, this technology can reduce cement consumption by up to 25%, cut hardening time nearly in half, and decrease the need for thermal curing.

Particular mention should be made of combined compaction systems, where pneumatic loading is used in conjunction with vibration applied both from the top and the bottom [5]. This ensures uniform compaction throughout the entire volume, reduces the risk of segregation, and enables efficient processing of stiff mixtures with a low water-cement ratio.

The design of an active loader equipped with a vibration exciter and impact elements (Figure 3) enables the generation of additional impulses on the compacted mixture. This design is based on the results of the study [8].

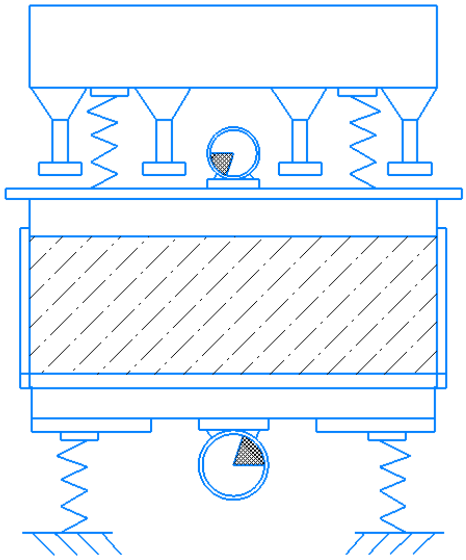

Figure 3 – Active loader with vibration exciter and impact elements

Thus, concrete compaction loaders offer a wide range of structural solutions, each oriented toward a specific product type, concrete mixture properties, and production conditions. The most promising among them are combined systems that integrate vibrational impact with controlled loading. Their implementation enables improved strength and density of products, reduced cement consumption, increased productivity, and consistent product quality with significantly lower energy consumption.

In the context of compacting stiff and lightweight concrete mixtures, pneumatic loaders hold a special place due to their high efficiency enabled by continuous pressure adjustment during the forming process. Studies [5, 6] have shown that when compacting lightweight concrete using pneumatic loading for 30–40 seconds, the strength increases initially, then stabilizes, and eventually begins to decline. This indicates the necessity to optimize both the duration and dynamic control of pressure during compaction, especially at the final stage of forming.

Experimental results [5] also indicate a significant increase in strength (up to 50%) when combining variable vibration modes with non-inertial loading, compared to compaction without loading. The main advantages of pneumatic bladder-type loaders are reduced structural metal consumption, quick adjustment of compaction modes, and minimized human influence. This is particularly important for serial production of components with varying heights or complex geometries.

Active vibro-loaders equipped with autonomous vibration exciters are widely used and operate in coordination with vibrating platforms. These systems provide a dual-factor effect on the concrete mixture: bottom vibration (via vibrating table) and top vibration (via loader), with the ability to independently adjust the frequency of each vibration source. As a result, so-called dual-frequency compaction is achieved, which, according to research [3, 8, 9], is the most effective method for attaining maximum concrete density and strength.

The practical implementation of such solutions is realized in serially produced vibro-loaders of the SMZh-849 and SMZh-852 types, used both in automated lines and stationary posts. However, one of the drawbacks of these systems is the fixed geometry of the contact surface, which limits their versatility. To overcome this limitation, some designs [9] include shields composed of independent sections, each of which can move separately. This allows the loader to adapt to the shape of any product without replacing the main unit.

We propose a design of an active-type loader equipped with a vibration exciter, impact elements, and an additional mass.

This loader consists of two plates:

1 – the lower plate, which rests on the concrete mixture and has a vibration exciter (3) mounted on it;

2 – the upper plate, connected to the lower plate through guide elements (4) with spring elements (5).

On the underside of the upper plate, impact elements (6) are installed with threaded height adjustment.

Additionally, the system allows for adjustment of the added weight (7) to fine-tune the loader's operating mode.

Summarizing the advantages of active vibro-loaders, the following key points should be noted:

– Capability to form products from stiff concrete mixtures without the need for excessive pressure;

– Implementation of dual-frequency compaction to enhance efficiency;

– Reduced energy consumption through localized vibrational impact;

– Improved uniformity of compaction and surface quality of products.

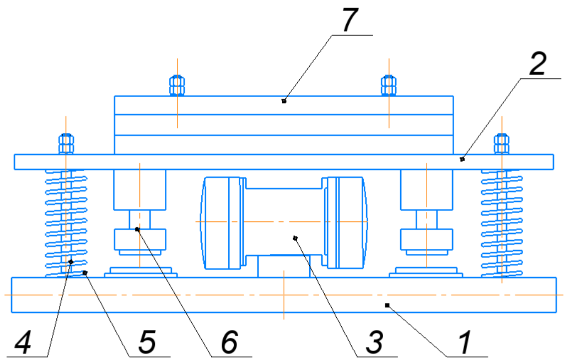

Figure 4 – Design of active loader with vibration exciter, impact elements, and additional mass

Conclusions

The designs of loaders used for the compaction of concrete and lightweight concrete mixtures were analyzed, and it was established that the most effective are combined devices that integrate vibrational impact with controlled loading on the mixture.

It was determined that active vibro-loaders particularly pneumatic and impact-vibration types provide enhanced homogeneity of the concrete structure, reduce cement consumption by 15–30%, and shorten the compaction cycle duration by up to 50%.

A design of an active-type loader equipped with a vibration exciter, impact elements, and adjustable mass was proposed. This design allows for the compaction mode to be adapted to specific types of concrete mixtures and product geometries.

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