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WAVES OF INNOVATION AND SUSTAINABLE DEVELOPMENT OF INDUSTRY ON AN EXAMPLE OF CONSTRUCTION

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Abstract

On the 25th Anniversary of the Russian Engineering Academy (REA), a historic retrospective review is presented, to show development of applied technological novelties in construction industry, waves of innovation, and Sustainable Development of industry. The proposed analysis makes it possible to obtain a deeper understanding of the principles of gaining, by countries and peoples, of technological leadership in resource saving, energy efficiency, independence from import, and all types of technological and eco-technological safety.

KEYWORDS: sustainable development, wave of innovation, technologies of reinforced concrete, resource saving, energy efficiency, technological leadership

Waves of innovation: characteristics

Historical sequence of waves of innovation is characterized by cyclicity (50-60 year period), peculiarities of development (improvement of knowledge, and periods of implementation of new technologies), predominant branches of industry, progress in materials science, system of production and consumption of energy, type of power machines, technological novelties.

First wave of innovation belongs to the period of the First Industrial Revolution, from 1780 to 1840. Richard Arkwright creates first spinning frame, later called “Water frame”, and builds textile factory in Cromford. Britain’s leadership was followed by France and Belgium. The wave of innovation is characterized by development of textile industry, new scientific discoveries in physics and mechanics, mastering of technologies of cast iron making and iron processing, building of channels, creating machines with use of water and power energy, organization of assembly-line production. Among the features of this period are development of competition, and cooperative uniting of cottage industry capital, founding of scientific-engineering, and inventor communities, early stages of professional education.

Second wave of innovation is related to the era of steam, from 1825 to 1890. Steam Engine Locomotion № 1 was made, Stockton-Darlington Railway was built. Leadership of Great Britain, France, and Belgium was followed by Germany and USA. This wave of innovation is characterized by

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accelerated development of railway and water transport on the basis of steam machines, their wide implementation into industrial production, new scientific discoveries in physics and thermal technologies, development of coal mining, machine building, and machine-tool building, *electric power engineering, inorganic chemistry,* mastering of ferrous metallurgy, use of steam energy, production of concrete.

Stock concentration of production and capital on the principles of limited liability, forming of research institutes, national and international systems of professional education and protection of intellectual property, high social status of engineering professions.

Third wave of innovation relates to the era of steel, and the period of the Second Industrial Revolution from 1880 to 1930. Invention of Bessemer process, creation on the basis of Bessemer converter of Edgar Thomson Steel Works in Pittsburgh. Germany's leadership leaves behind USA, Great Britain, France, Belgium, Switzerland, and Netherlands. The wave of innovation is characterized by industrial production of electric power, development of heavy machine-building and electrical engineering industry, emerging of new scientific discoveries in chemistry, spreading of radio and telegraph, development of automotive industry and railway transport, invention of dynamite, mastering of non-ferrous metallurgy and inorganic chemistry, oil processing

The wave of innovation is characterized by attraction of scientists and engineers to the industry, general elementary education.

Fourth wave of innovation correlates with Oil era, from 1930 to 1980. The wave of innovation is characterized by development of power engineering with use of hydrocarbons, new scientific discoveries in organic chemistry, oil-and-gas pipeline transport, serial production of wide range of armaments, including nuclear, development of aviation, defense, automotive industry and non-ferrous metallurgy, mass production of cars and tractors, conveyor production, development of petrochemistry and new synthetic materials, computational equipment and software products, radiolocation and wire communication, production of consumer goods, beginning of use of atomic energy in military and peaceful purposes.

The wave of innovation was marked by implementation on Ford factories of belt conveyor, beginning of production of Ford Model T cars. Leadership of USA, Western Europe, and USSR.

Fifth wave of innovation relates to the period of Scientific-Technology revolution and Computer and telecommunications era from 1975 to 2040. The wave of innovation is characterized by use of information technologies and achievements in microelectronics, informatics, biotechnology, genetic engineering, new scientific discoveries in computational mathematics and nanotechnologies, use of new types of energy, materials, developing projects in outer space and

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satellite communication, creation of flexible production structures, processing centres, and telecommunication systems, fiber-optic equipment, development of nuclear power, airspace transport, electronic industry, and robot-building, mastering of composite materials, and microelectronic components, fine chemical and biological technologies, wide use of oil and natural gas energy.

International horizontal integration of scientific research and planning with use of computational networks in joint research, state support for new technologies, and university-industry cooperation. The Silicon Valley becomes a symbol of emerging of first microprocessor Intel 4004, which started the era of computer technologies, network communications, and artificial intellect.

Sixth wave of innovation is related to the Era of nanotechnologies and cognitive knowledge, from 2010 to 2060, and is based on technological instruments of nanotechnologies and cell biotechnologies, laser technologies, molecular and nanophotonics, built-in intellect, construction laser materials and systems, biological tissues and organs with given and controlled properties, quantum-wave cybertechnologies for control of states, development of compact and super-efficient power industry with integration into local “smart” power supply and consumption networks, environmentally pure hydrogen energy carriers and bio-fuels with refusal of hydrocarbon ecological problems.

Humanitarian integration of man and society environment through development of biomedical, education, intellectual, social, communication, and economical technologies of nature management with support of cognitive sciences, and convergence of nano-, bio-, info-, and cognitive technologies.

Special feature and advantage of this wave of innovation in sharp reduction of power and material consumption of production and consumption, in designing of materials and organisms with given and controlled properties.

Table 1 presents generalized matrix of the waves of innovation [1].

In our opinion, sustainable development of society is being estimated as progressive development of technologies without harm for ecology and human activity. The articles presents the main areas of development of construction industry, and, first of all, the industry of precast concrete, and technological platforms on implementation of these directions in USSR, CIS countries, and South-East Asia [2, 3, 4, 6].

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The article pays attention to development of reinforced concrete industry; production volume of reinforced concrete amounts about 4-5 billion m3 per year. First of all, sustainable development of construction, in our opinion, is characterized by the development of precast concrete and main technological processes for its production, as well as creation of highly-mechanized and automated production lines [5, 6].

Table 1. Generalized matrix of the waves of innovation

Periods of the waves of innovation. Historical peculiarity	**I WAVE 1780-1840 Handicraft industry**	**II WAVE 1825-1890 Steam era**	**III WAVE 1880-1930 Industrial production**	**IV WAVE 1930-1980 Oil era**	**V WAVE 1975-2040 Information technologies**	**VI WAVE 2010-2060 Cognitive knowledge**
Leading industries	Textile	Steam machine building	Rail transport	Automotive and tractor industry	Electronics and robotization	**Robotized complexes**
Spheres of progress	Making of cast iron	Ferrous metallurgy	Electrification	Chemicalization	Informatization, telecommunication	Intellectual systems
Materials science	Iron	Steel, Concrete	Concrete, Steel	Metals, Plastic	Composites	**Nanomaterials Biomaterials**
Energy carriers	Water, Wind	Steam	Coal	Oil	Natural Oil and Gas	**Renewable energy**
Sciences	Physics, Mechanics	Physics, Thermal technologies	Inorganic chemistry	Organic chemistry	Nanotechnologies, Computational mathematics	Biotechnologies
Education	Mastering of professions	Professional education	General elementary education	Secondary education	Higher education	Inter-industry education
Wave measurements - Analysis methods	Qualitative - Empirical	Scalar - Comparative	Quantitative - Averaged	Spectral - Parametric	Amplitude-phase-frequency - Vector-phase	**Trajectory - System analysis**

In design and creation of highly mechanized and automated production lines it was taken into account that in the total volume of precast concrete, approximately 80% are flat and linear elements, what makes it possible to provide specialization and concentration of production. In developing of such lines there appeared some problems connected with certain technological operations, and suggestions have been made for each technological operation in the production of precast concrete [6].

The making of concrete mix is one of the most important technological operations, which may be completely automated. Currently it is necessary to improve concrete-mixing units with the use of new mixers, including high-speed ones, batchers with strain-gauge sensors, components of the preparation and activation of additives and cement slurries.

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In carrying out reinforcement works it is reasonable to widely application of welding equipment. Reduction the labour capacity of reinforcement works can be achieved through the following measures:

- unification of reinforcement products with decrease of the number of sizes of precast concrete products (decrease of sizes of concrete products by 2-3 times will reduce the number of sizes of reinforcement products by 10-15 times);

- automation of reinforcement works in production of all types of welded reinforcement meshes and cages, as well as embedded parts;

- automation of production of prestressed structures using reinforcement-winding machines, particularly with the use of steel wire rope with small diameter 7-6 mm, and a spiral reinforcing by wire (Fig.1).

For compaction of concrete mixes, there were created technological bases, and developed low-frequency equipment in 10-25 Hz frequency range. In manufacturing of road structures from fine-grained concrete the equipment with vibro-pressing mode is the most perspective.

An alternative automation approach is the development and use of Self-Compacting Concrete (SCC) without any vibrating during placing of concrete. This type of production can provide a silent working environment and is especially good for concrete element with digested reinforcements and massive volume. SCC mixture contents usually contains the replacement of cement by granulated blast furnace slag (GGBS) and fly ash up to 45~55%, which is regarded as a low carbon and sustainable material [7].

The most efficient method of intensification of concrete hardening is considered electric thermal processing for areas with severe continental winters. In areas to the South of 50° Northern latitude, during the reconstruction of precast concrete enterprises, it should be widely applied technological schemes of production with the use of solar energy and combined technology with the reserve source, namely, electrical energy. Technical re-equipment of precast concrete enterprises should be implemented through the establishment of production lines, providing production at least 550 m^3 of precast concrete per 1 person per year. First of all, these are highly mechanized and automated lines of conveyor type: cassette-conveyor and rotor-conveyor.

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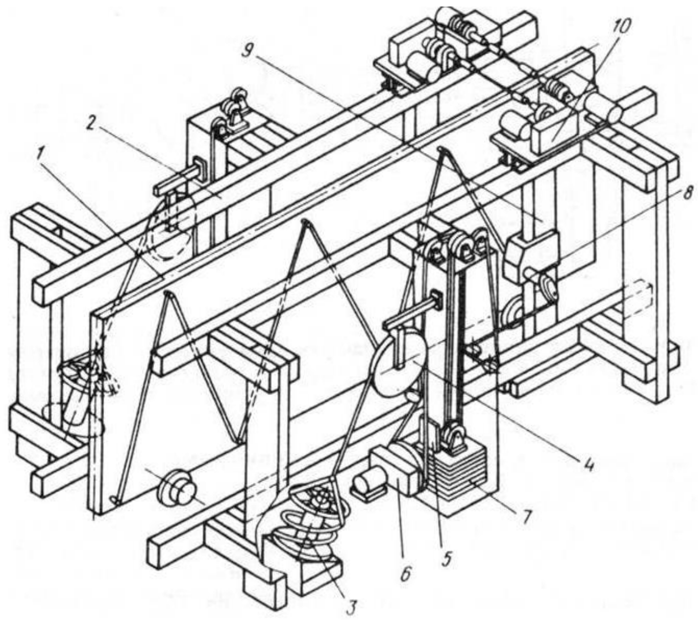

Fig. 1. Installation of prestressed continuous reinforcing

1 - mould; 2 - upper guide beam; 3 - coil-unwinding machine; 4 -lead block; 5 - stops; 6 - axis drive system; 7 - wire bridling installation; 8 - tail spindle; 9 - traverse beam; 10 - traverse beam move mechanism.

For such a large-scale industry as precast concrete, the technological platform was prepared with involvement of a large number of construction and machine-building ministries. The table 2 presents the tasks for the engineering ministries of the USSR for provision with equipment for production of precast concrete.

Table 2. Tasks for engineering ministries of USSR for the creation and supply of equipment for precast concrete industry

Name of the product, material, short technical specification	*Ministry-manufacturer*	*What equipment is to be produced*	*Approximate demand per year*
1. Automatic weighing machine on strain-gage sensors, *in composition of: weighing batchers, including volumetric for light aggregates, batchers for cement and liquids, and special additives, as a unit with control systems	Ministry of the instrument-making industry of USSR	Automated concrete-mixing installations with mixers 750 and 1500 litres (l)	600 sets
2. Special elevator with wear-proof chains, with productivity up to 400 tons/hour by the aggregate with coarseness up to 40 mm with power supply unit	Ministry of heavy engineering of USSR	Automated concrete-mixing installations of various power capacity	600 units
3. Conveyer belt with transverse ribs for belt conveyors 800, 1000, 1200 mm wide	Ministry of Oil and Chemical Industry of USSR	Automated concrete-mixing installations with mixers 1500 litres	100 thousand running meters
4. High-strength kapron-based rubber belt 1000 and 2000 mm, 10-12 mm thick	Ministry of Oil and Chemical Industry of USSR	Concrete pavers for paving concrete into mould	9000 running meters
5. Vibration-proof roller-bearings for vibratory plates 3000 oscillations/min	Ministry of Automotive Industry of USSR	Vibratory plates with load capacity from 10 to 24 tons	

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6. Assemblies of modular equipment with diameter of aperture = 6 mm; Consumption 12 l/min; pressure 32 MPa; diameter of aperture = 10 mm; Consumption 40 l/min; pressure 20 MPa	Ministry of Machine-Tool Construction Industry of USSR	Hydraulic jacks	1000 sets
7. Motors-reductors with built-in brake, power capacity 2-5 kW	Ministry of Machine-Tool Construction Industry of USSR	Travel drives	2000 units
8. Regulating and switch board hydraulic equipment with high pressure hoses	Ministry of Machine-Tool Construction Industry of USSR	Pipe-molding machines	2000 units
9. Hydraulic motor wheels with load capacity 50 kT, D 300 mm, 6…30 rpm	Ministry of Machine-Tool Construction Industry of USSR	Travel drives	2500 units
10. Controllable drive engineering package ET-3 with rotation frequency 10…1000 rpm, 5 kW	Ministry of Electro-Technical Industry of USSR	Drives of self-propelled machines	1500 units
11. Electric drive cylinders for belt conveyors for belts with width 800,1000, 1200 mm	Ministry of Electro-Technical Industry of USSR	Belt conveyors	2000 units
12. Electric engines series 4, 3000 rpm of various power capacity in protected construction	Ministry of Electro-Technical Industry of USSR	For vibratory plates	3500 units
13. Metal-roll of “rectangular pipe” type with dimensions 300x200x6, 270x190x6, 300x200x6, 270x190x6, 240x180x5, 160x130x4 mm	Ministry of Ferrous Metallurgy of USSR	Metal constructions for workshop, stationary, and self-propelled machines and equipment	At least 10 thousand tons only for Ministry of Road Construction of USSR
14. Roll-formed sections of channel type, angle (from 40x40 to 270x100 mm, thickness of sheet 3...6 mm)	Ministry of Ferrous Metallurgy of USSR	Metal constructions for workshop, stationary, and self-propelled machines and equipment	At least 10 thousand tons only for Ministry of Road Construction of USSR
15. Welding machines and equipment MTM-I60, MTM-88, MTM-I66, MTM-35. MTM-207, MTM-103, PDF-502, K-724A, ADF-200-I (modernized) MTP-1110 with tongs, KTP-8-6 (KTP-8-7) MPP-1111 with tongs, KTG-8-2 (by special order)	Ministry of Electro-Technical Industry of USSR	Systems and complexes of equipment for reinforcement works	Demand in units 150, 10, 60,100, 100,10 400,100, 100, 1700, 200, 200.

In creation of technological platform of development of precast concrete in the USSR, and later, in Russian Federation, CIS countries, and other countries [5, 6, 8], the following tasks were solved:

1. Supposed the methodology of research of stressedly-deformed state of concrete and structures, including beams with variable section (patent[1]), two-axially reinforced flexible reinforced concrete plates, helically-reinforced pipes and columns. These structures are presented on Fig. 2, 3.

[1] Gusev B.V. Patent of Russian Federation № 2014148693, 2015

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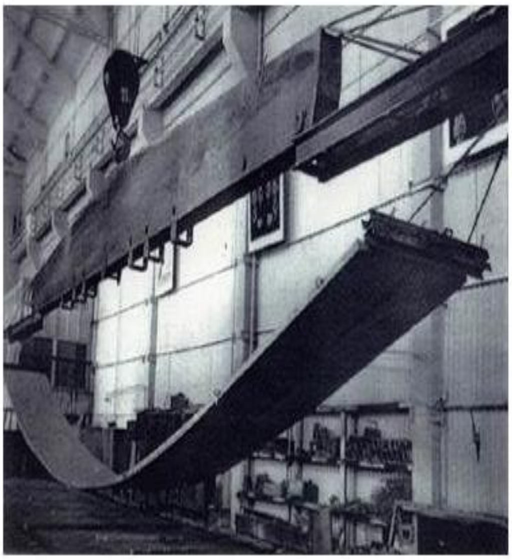
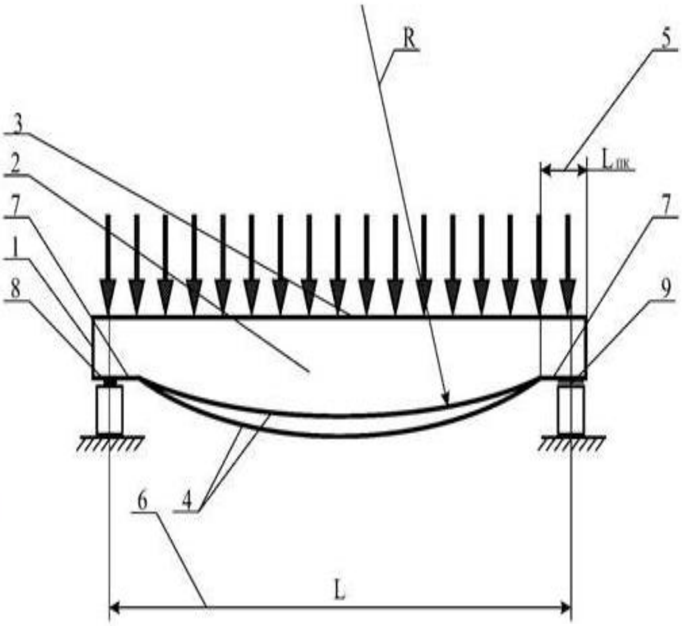


Two-axially reinforced prestressed plate 24 meters in length, 5 centimeters thick

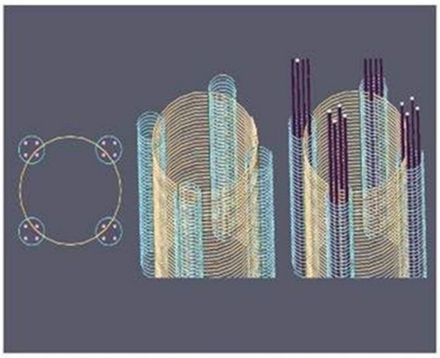


Beam of variable section

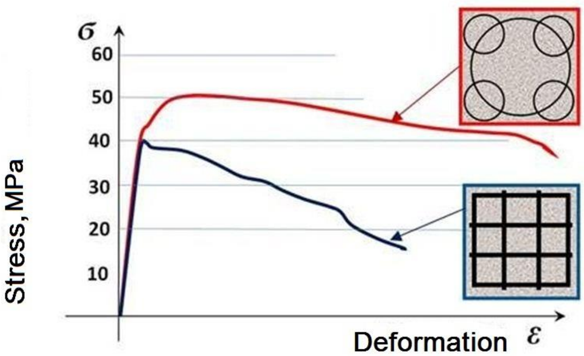
1 - beam, 2 - wall, 3,4 – upper and lower belts, 5 – supporting points; 6 –span, 7 - end parts of structure, 8 – rotation hinge, 9 – sliding hinge

Fig. 2. Efficient types of structures

2. Obtained discovery on the phenomena of self-organization of solidification processes of binders (cements), which implemented in the creation of nanobinder (patent[2]), which recommends to fill cement concretes with mineral particles of certain dispersibility. The research have proved reduction of cement consumption by 1.5-2.0 times, what reduces environmental harmfulness due to decrease of total volume of cement production.



Helical reinforcement



Carrying capacity of column fragments

Fig. 3. Helical reinforcement of columns

[2] Gusev B.V. and others. Patent of Russian Federation №2412919, 2011.

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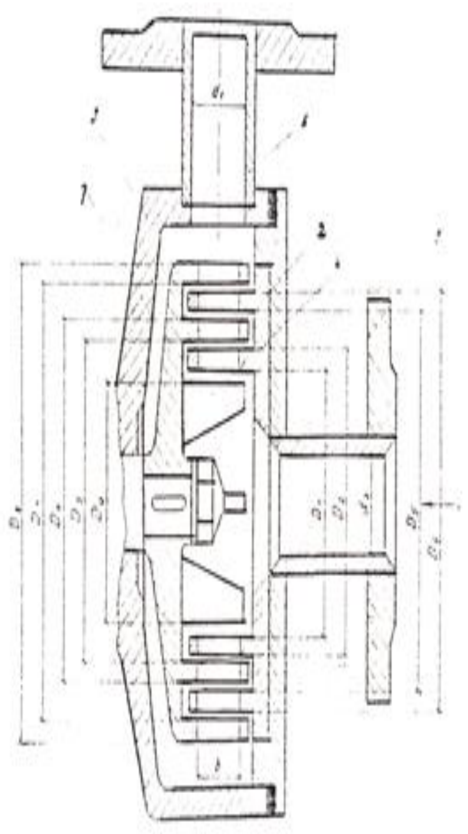
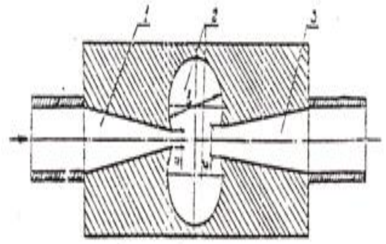
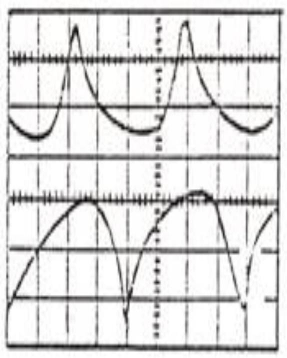
3. Proposed technologies and equipment for mechanical-chemical dispersion and activation under cavitation effects and new low-frequency vibration compaction methods. It provided a significant acceleration of preparation and compaction processes of concrete mixtures, as well as the reduction of cement consumption by 20-30% in production of any mass-produced structures. Fig. 4, 5 presents hydrodynamic emitters and the general view of the cavitator-disperser.





Hydrodynamic system

1 – input nozzle; 2 – resonating chambers; 3 – discharge nozzle



Impulse (rotor-pulse) devices
1 – rotor; 2 – stator; 3 – hull;
4 – impeller; 5 – flange; 6 - connection

Type of impulses of pressure, forming in the medium in two resonant chambers of hydrodynamic and impulse

Fig. 4. Hydrodynamic and impulse radiating elements

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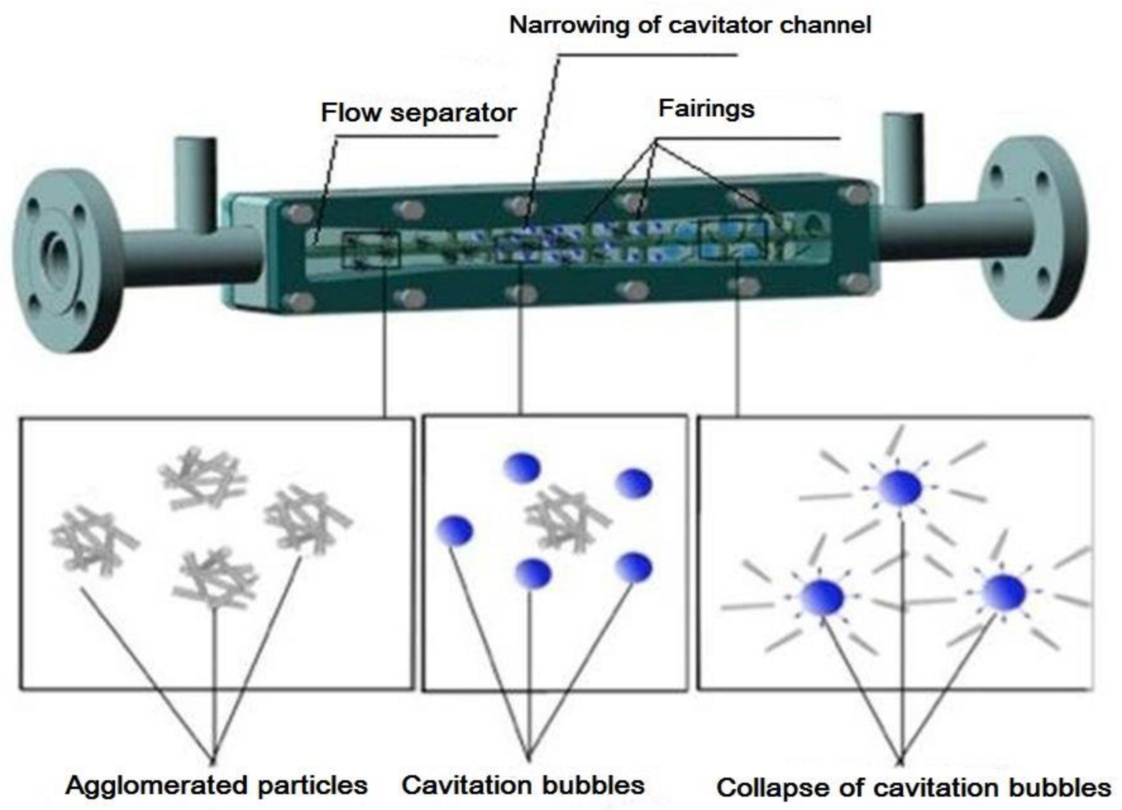

Fig. 5. General view of general hydrodynamic dispenser

4. Developed the basic principles of automation of precast concrete production. This allowed in terms of large-scale production of concrete products to formulate and implement two main types of automation: cassette-conveyor and rotor-conveyor, which enhanced production of 1 worker by 5-7 times in comparison with average industry standards. Fig. 6, 7 presents the main highly mechanized production lines.

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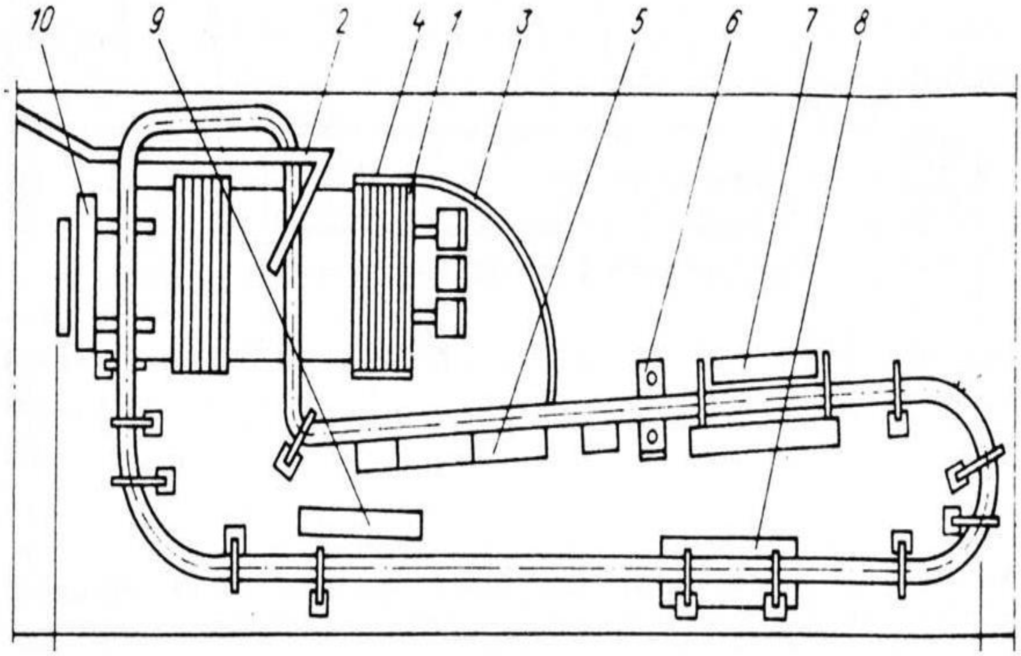


Fig. 6. Cassette-conveyor line Kamensk-Uralsky construction factory

1 - cassette; 2 - concrete placing boom; 3 - cart for waste collection; 4 - rammer; 5 - stripping trolley; 6 - post of mechanized cleaning; 7 - post of manual cleaning; 8 - post of lubrication; 9 - post of installation of reinforcing cages; 10 - pushing trolley

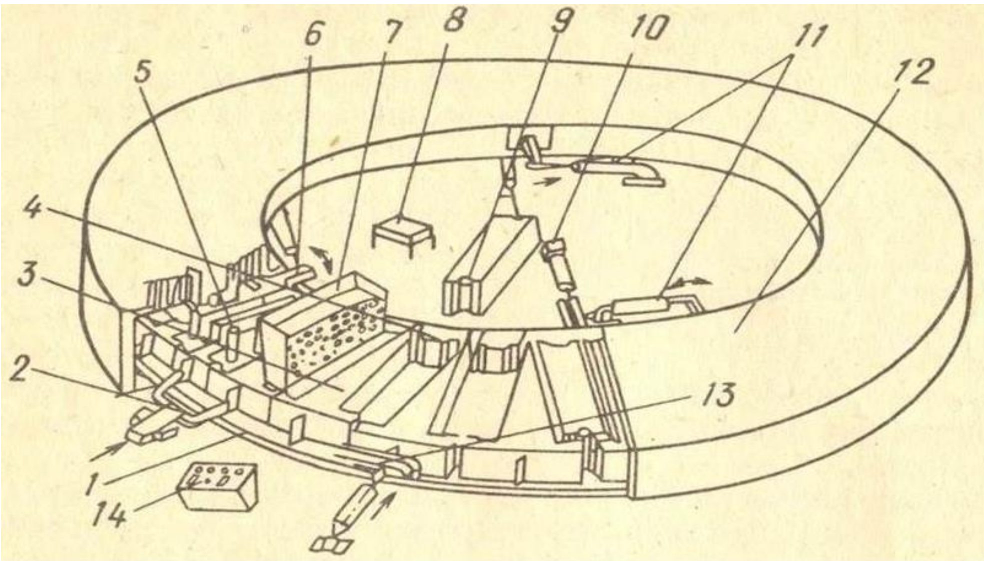
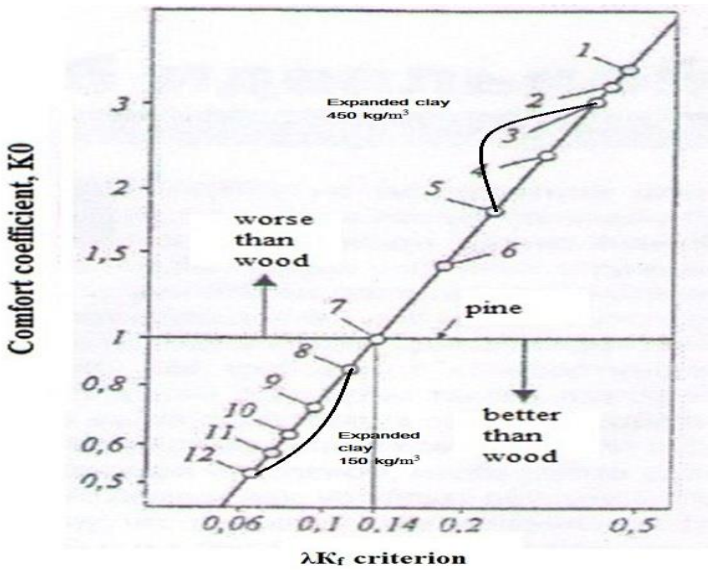


Fig. 7. Rotor-conveyor line

1 - ring turning drain pan; 2 - fixation mechanism; 3 - wedge formwork; 4 - box-formwork of butt-end; 5 - vibropackage; 6 - mechanism for installation of hinges; 7 - accumulative bunker; 8 - hydrostation; 9 - mechanism of pick-up of blocks; 10 - mechanism of stripping of formwork; 11 - lever drive of sweep drive of drain pan; 12 - ring chamber of heat processing; 13 - mechanism for assembly of formwork; 14 - control panel.

5. For the first time it was formulated and solved the ecological problem of the perfect comfort of premises and materials, introduced the concept of comfort coefficient, which made it possible to create lightweight design solutions for thermal insulation of walls of buildings, and increase thermal resistance of walls up to 3 times. This founded the establishment of ecological approach to the creation of an internal microclimate during construction and operation of buildings. Fig. 8 and 9 present the basic concept about the comfort coefficient and heat consumption for wall insulation.



Material of inner layer
1. Cellular concrete ρ = 600
2. Polystyrene concrete 400
3. Expanded clay concrete 800
4. Expanded clay concrete 700
5. Expanded clay concrete 600
6. Perlite concrete 600
7. Pine-tree 500
8. Expanded clay ceramics 500
9. Expanded clay foam concrete 255
10. Expanded clay perlite concrete 400
11. Expanded clay ceramic vermiculite 260
12. Expanded clay ceramic perlite 200

Fig. 8. Values of comfort coefficient for various materials

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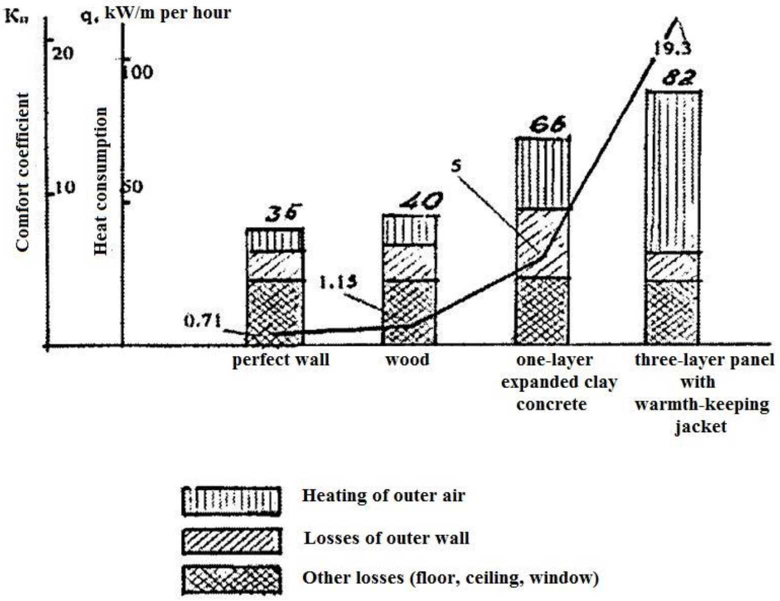

Fig. 9. Values of comfort coefficient of rooms for various types of walls with thickness 350 mm

6. Discovered a new energy effect during obtaining low-grade cement during the firing process of crushed concrete at a temperature 2 times lower than in the production of ordinary Portland cement. Fig. 10 shows a plant for producing crushed stone from substandard concrete.

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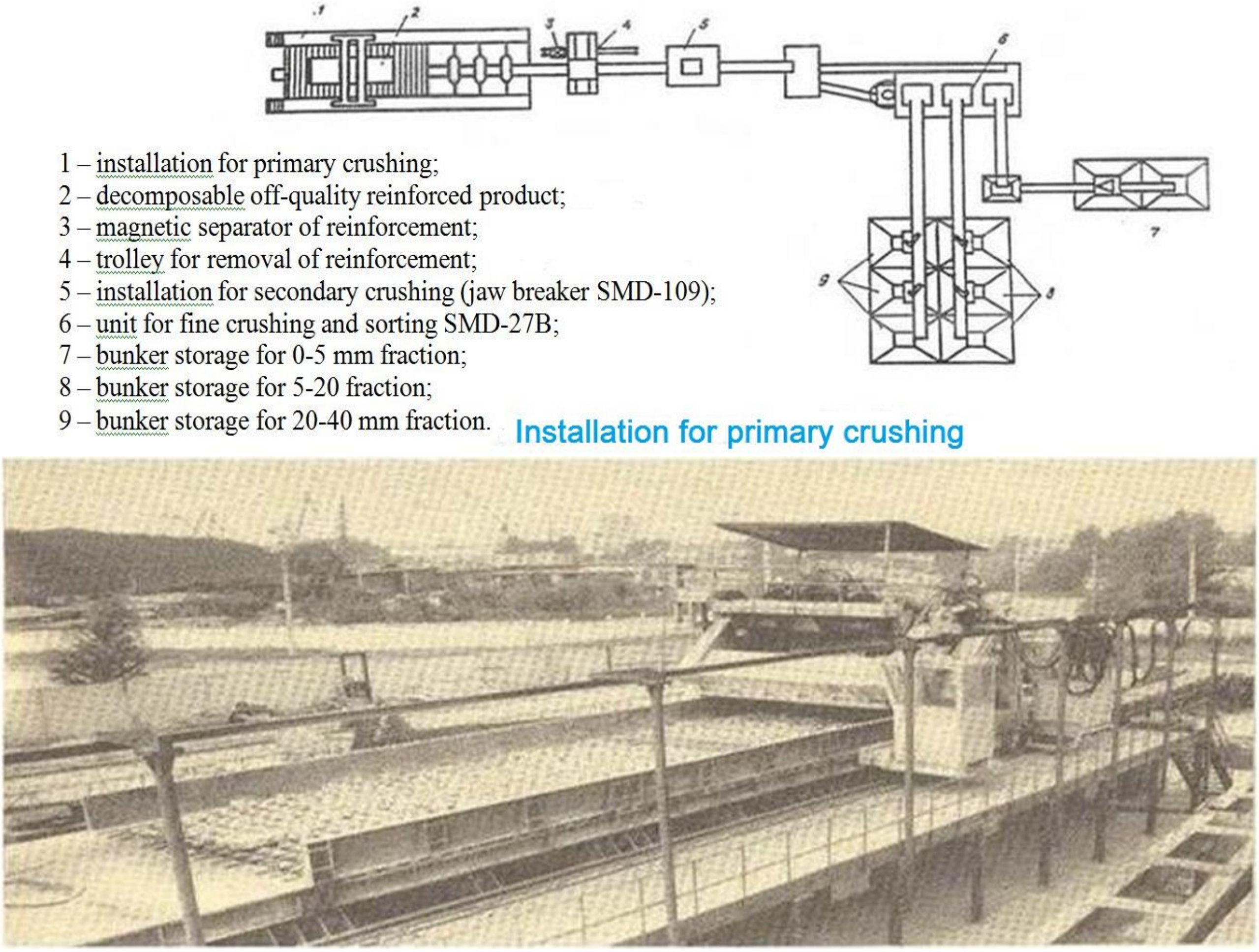

Fig. 10. Technological line for production of fractionated secondary aggregate

7. Developed a comprehensive theory of concrete corrosion under various types of atmospheric, chemical and other effects in 3D space taking into account phase transfers in the formation of corrosion products that makes it possible to make calculations and to increase the service life of structures from 30-50 up to 100 years and above [9].

On the proposed technologies, there were adopted over 15 regulation and recommendation documents in Belarus, Georgia, Kazakhstan, Russian Federation, Ukraine, and Uzbekistan. Work on broader use of efficient technologies in the production of concrete and reinforced concrete continues successfully in the Russian Federation, CIS countries, Central European and Scandinavian countries [10].

Efforts on the creation and implementation of technological platform for the development of the construction industry are presented in the references.

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