Special Features of Using Universal Technological Sets of Small-sized Equipment for Renovation of Buildings

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Abstract. Nowadays, old utility lines are the most critical issue of society. Emergency condition of these utility lines results in their destruction and pollution of ecosystem and imposes threat to life of people residing within risk area. This article offers variants of mobile universal sets of small-sized equipment that allows restoration of destructed and emergency buildings through wet-mix shotcreting process. The universal nature of these sets of equipment allows performance of entire scope of renovation works from preparation of damaged surfaces to applying anti-corrosive coatings. Upon the use of such sets of equipment, it is possible to prepare and lay construction mixtures of different purpose directly at the place of works. Combination of process operation in time enhances the efficiency of equipment and reduces power consumption.

1. Introduction
Ukraine faces urgent concern of renovation and reconstruction of emergency construction facilities. In Ukraine, the problem of repair and reconstruction of objects with increased environmental and social risk is acute. The most urgent issue is old sewage systems of cities. Their worn state due to corrosion is evidenced by incident rate. On average, there are 300 accidents per 100 km of networks per year, resulting in pollution and destruction of urban infrastructure. The same holds for emergency bridges. Among 6 thousand bridges, maintained by Ukravtodor, one thousand is in emergency state and 2.5 thousand require total renovation. Problematic facilities of high social threat include buildings on the slopes and coastal zones etc. Currently, there are no uniform approaches and sets of equipment for quick response in emergency cases. This article describes sets of small-sized equipment for carrying out works at emergency facilities.

2. Review of the latest discoveries and publications
The issue of destruction of buildings of high human-induced risk is critical not only in Ukraine but also abroad. Works [1-3] are devoted to study of the behavior and methods of renovation of concrete sewerage conduits subject to wear due to biogenic sulphuric acid. Authors consider that shotcreting of surfaces with concrete mixtures and application of anti-corrosion polymeric coatings or the use of acid-resistant pipes (spools) with further injection of annular space are major methods of renovation. A considerable attention is paid to study of the design of hydraulic engineering works and methods of their strengthening [4]. The most commonly used method for casing of cast reinforced concrete under complicated conditions of construction is shotcreting technology which is widely used in the world due...
to its high efficiency [5]. Research papers [6, 7] are devoted to study of design of concrete mixers and improvement of the quality of concrete mixtures [6, 7]. Equipment for transportation of concrete mixtures is studied in research papers [8, 9]. It should be noted that there are many equipment for preparation of concrete mixtures, their transportation, casting, including is shotcreting. This equipment is manufactured by such leaders as Graco (USA), ASF Thomas (Germany), Watson-Marlow (UK), Welco (Japan), Brightwell (Canada), Tornado (Ukraine), StroyMechanics (Russia), Kyokuto (Japan), Monolithic Equipment (USA). Machines specified in review are considered as individual equipment, which may be included into composition of multi-functional process set. Studies devoted to creation of equipment sets that allow entire process cycle of renovation of emergency facilities is little known in foreign practice.

Specifics and basis for creation of sets of small-sized equipment for construction site are represented in research paper [10]. Authors consider the use of this equipment allows manufacture of multi-component modified mixtures at construction sites, which is very important in view of complexity of centralized delivery of special repair mortars from plants as this the case in conventional construction. The results of the analysis suggest that the creation of multifunctional mobile sets of small-sized equipment for carrying out renovation works is an urgent task, which is aimed at solving the problem of reconstruction of buildings of high human-induced risk.

3. Main part
The creation of high-tech small-sized equipment for renovation of emergency buildings is a very critical issue at this time. These facilities were built on average 40-50 years ago, operated in aggressive environment and are in a pre-emergency or emergency condition, which poses an increased risk to the environment and human life. The destruction of sewer pipelines is becoming more and more frequent, which results in penetration of impurities into groundwater, destruction the pavement and sinking of foundations. Collapses of bridge structures and other structures are less frequent. This requires a comprehensive approach, including the involvement of efficient equipment and qualified personnel.

Modern sets for small-sized equipment have modular design, which makes them flexible and suitable for using for wide range of purposes. The modular principle allows making special or universal sets of equipment from individual machine modules. Sets of small-sized equipment for certain types of work could be used according to the following schemes:

- for shotcreting works with the use of wet-mix shotcreting process: “metering unit → concrete mixer, operating in cascade mode → double-piston and flexible hose pump → nozzle with ring tip → concreted surface”.

- for off-form concreting by wet-mix shotcreting method with the use of fiber-concrete mixtures for manufacture of reinforced-concrete structures of complex geometric shape: “automatic fiber cutter → metering unit for complex concrete mixtures → three-shaft concrete mixer → piston-free hose concrete pump → shotcrete nozzle with ring tip → frame of concreted structure with embedded parts”

- for preparation of concrete mixtures and construction mixtures of different purposes: “metering unit for complex concrete mixtures → three-shaft or gravity concrete mixer”.

Proposed sets of equipment will allow the following in case of their full mechanization and automation:

- creation of conditions for quick preparation to repair works in case of accidents at buildings due to mobility of equipment;
- disassembly of destructed elements of structures and preparation of surfaces that are subject to repair by means of additional tools on the basis of sets;
- preparation of construction mixtures by special recipes, including fast-curing mixtures, directly at the construction site, when they cannot be manufactured at the factory;
- minimization of dust formation from dry components upon wet-mix shotcreting at small scopes of work instead of dry, which creates a favorable working environment for builders and reduces the risk of their occupational diseases;
- application of protective anti-corrosion layers, in spite of basic concrete mixtures by means of nozzle with set of special nozzles;
- increase of efficiency of equipment up to 30% and reduction in power consumption up to 15-20% due to combination of all operation of process cycle in time;
- simplification of staff training and more qualified performance of works due to operation of one plant;
- creation of conditions for obtaining of high quality protective coatings, which have significant effect on durability and protection of support structures against corrosion.

Principal diagram of one of universal sets of small-sized equipment for renovation works at construction site is shown on figure 1.

![Figure 1. Modern universal sets of small-sized equipment for construction site.](image)

1 is metering unit for multi-component concrete mixtures: 1’ – gravel, 1’’ – sand, 1’’’ – cement, 1’’’’ – water; 2 is intermediate hopper; 3 is concrete mixer; 4 is ribbon shaft of mixer; 5 is charging chute; 6 is universal hose concrete pump; 7 is frame; 8 is hydraulic distribution unit; 9 is automatic switchboard; 10 is shotcreting nozzle with ring tip

Machine module and component assemblies that ensure performance of entire scope of works at construction site upon construction of the buildings of different purpose are mounted on general frame. This set allows performance of all process operations, including batching of components for preparation of construction mixtures, their transportation and sputtering by wet shotcreting upon casting of monolithic reinforced concrete. If necessary, the set allows plastering works. Metering unit 1 is fitted with three hoppers with slide gate valves for: gravel (1’), sand (1’’), cement (1’’’). Batched components from respective hoppers covered with slide gate valves enter into intermediate hopper 2, from which certain volume and weight of these components enters the housing of forced mixer 3. Concrete mixer is fitted with actuating element in the form of bonnet shaft 4 that ensures preparation of construction mixture with high degree of uniformity. Finished mixtures enters charging chute 5, from which it is transferred to shotcreting nozzle with ring tip through pipeline by means of universal hose concrete pump 6. Shotcreting process is performed by wet-mix method that ensures casting monolithic reinforced concrete provided that there is a reinforcing frame that is under construction. All these process operations are combined in time, which results in enhancement of efficiency of construction works by 15-20. This set could be used in cyclic and continuous concreting. Hydraulic device with electric control and possibility for fully automated PC-based operation process is one more advantage of this set.
Universal, pistonless, hose concrete pump or concrete forced mixer may be used as basic machine of set small-sized equipment. In this case, the performance of process set will be determined by performance of basic machine.

The process of process set is determined by performance of universal hose concrete pump according to the following relations [11]:

$$P_{\text{concrete pump}} = 3600 \cdot S_{\text{hose}} \cdot v_{avg} \cdot k_1 \cdot k_2 \cdot k_3 \tag{1}$$

where $S_{\text{hose}}$ is cross section of hose in concrete pump, m$^2$; $v_{avg}$ is average flow of concrete mixture along flexible hose, m/sec; $k_1$ is coefficient that considers gradual increase in the force created by the clamping rollers of the rotor, which press hose in the working part of the pump; $k_2$ is coefficient that considers reliability of horse part of pump, considering tension and ultimate tensile strength; $k_3$ is coefficient that considers conditions for feeding mixture by concrete pump through flexible hose, considering its properties.

If basic machine is concrete mixer, the performance of set is determined as:

$$P_{\text{concretemixer}} = 3600(z_1 + z_2)V_{avg1} \cdot \theta \cdot \cos \alpha(R - r)K_{vol} \tag{2}$$

where $z_1$ is a number of tuning of ribbon screw on mixer shaft; $z_2$ is number of blades of shaft; $V_{avg1}$ is an average rotation speed of mixer shaft, m/sec; $\theta = (\theta_1 + \theta_2)$ is blade width and ribbon width, respectively; $R, r$ are maximum and minimum radiiuses of ribbon shaft, respectively; $K_{vol}$ is volumetric efficiency of concrete mixer.

One of conditions for efficient use of above-mentioned set of equipment in wet-mix shotcreting process is maximum possible use of working space of basic mixer for preparation of necessary mixture, considering certain conditions for repair of building directly at construction site.

Working volume of mixer body is estimated by coefficient $K_{vol}$.

Volume coefficient $K_{vol}$ is determined, considering that the performance of concrete pump and concrete mixer modules should be equal in process set. This this case $P_{\text{concrete pump}} = P_{\text{concretemixer}}$.

In this case, volume coefficient for offered process set is determined as follows:

- **For cyclic operation**

$$K_{vol1} = \frac{S_{\text{hose}} \cdot v_{avg} \cdot t_c \cdot k_1 \cdot k_2 \cdot k_3}{V} \tag{3}$$

where $S_{\text{hose}}$ is cross section of hose in concrete pump; $v_{avg}$ is average flow of concrete mixture along flexible hose in concrete pump body; $k_1, k_2, k_3$ are coefficients that consider availability of pressure pulses upon discharging of mixture by concrete pump, conditions of mixture feeding, reliability of operation of concrete pump; $V$ is volume of working part of mixer body (charging hopper); $t_c$ is time of operation cycle of concrete mixer;

- **For continuous operation**

$$K_{vol2} = \frac{S_{avg} \cdot v_{avg1} \cdot t_c \cdot k_1 \cdot k_2 \cdot k_3}{v_{avg2} \cdot (\theta_1 + \theta_2)(z_1 + z_2) \cos \alpha(R - r)} \tag{4}$$

where $v_{avg2}$ is an average rotation speed of working element of mixer of ribbon shaft; $z_1, z_2$ is number of tuning of shaft ribbon and blade, respectively; $(\theta_1 + \theta_2)$ is a width of working part of ribbon shaft turn $(\theta_1)$ and shaft blade $(\theta_2)$; $R, r$ is maximum and minimum radiiuses of ribbon shaft, respectively; $\alpha = \alpha_1 = \alpha_2$ are installation angles of ribbon turns and blades on shaft against its horizontal axis.
Thus, volume coefficient of mixer depends on design parameters of modules of process set and their operation speeds, which should be considered upon development of process sets of small-sized equipment.

Total power consumption for transportation of concrete mixture through pipeline by means of hose concrete pump as basic machine are determined by the following dependency [12]:

\[
P_{\text{conc.pump}} = k_s \cdot \left( \frac{3.45 \left( G_{\text{conc.mix}} k_{\text{fric}} + F_{\text{press}} \frac{k_{\text{roll.frinc}}}{r_{\text{roll}}} \right) n R_{\text{avg}}}{30 \eta_{\text{avg}}} + \frac{S_{\text{hose}} \Delta p v_{\text{avg}} k_{\text{length}}}{\eta_r} \right) \quad \text{Pa.s/m^3},
\]

where \( k_s \) is safety factor; \( G_{\text{conc.mix}} \) is a weight of concrete mixture affected by clamping rollers, H; \( k_{\text{fric}} \) is a coefficient of friction due to constant effect between inner wall of flexible hose and concrete mixture during its movement; \( F_{\text{press}} \) is a force of pressing rollers to outer surface of flexible hose in working space of pump, H; \( k_{\text{roll.frinc}} \) is a coefficient of roller friction on hose surface, m; \( r_{\text{roll}} \) is roller radius, m; \( n \) is rotor rotation rate, min\(^{-1}\); \( R_{\text{avg}} \) is an average distance between rotor axis and roller face, m; \( \eta_{\text{cp}} \) is an efficiency of concrete pump; \( S_{\text{hose}} \) is cross section on inner diameter of hose, located in body of concrete pump, m\(^2\); \( \Delta p \) is pressure differential at the ends of transport pipelines, Pa; \( v_{\text{avg}} \) is an average speed of movement of concrete mixture through flexible hose, m/sec; \( k_{\text{length}} \) is a coefficient that considers the length of transport pipeline; \( \eta_r \) is a coefficient of hydrodynamic loss in transport pipeline.

Upon the use of concrete mixer as basic machine, the performance of process set would be determined by the following dependency:

\[
P_{\text{conc.mixer}} = \left[ \omega_s h + \omega_{\text{fric}} \cdot V_{\text{abs}} \cdot z_1 \cdot \frac{c \rho_0 S_{\text{avg}} \omega_{\text{sh}} m \kappa_s \gamma_{\text{screw}} (D^2 - D_{\text{in.screw}}^2)}{32 \pi^2 \kappa_s} \right] + \frac{\pi c \rho_0 S_{\text{avg}} \omega_{\text{sh}} f_1 \gamma_{\text{screw}}^{\gamma_{\text{screw}}} \sin \alpha_{\text{avg.screw}} (D_{\text{in.screw}}^5 - D_{\text{out.screw}}^5)}{80 \kappa_s} \cdot \frac{1}{1000 \eta_{\text{shaft}} \eta_{\text{screw}}},
\]

where \( \omega_{\text{sh}} \) is angular rotation of blade shaft, c\(^{-1}\); \( M_s \) is torque of blade shaft, Nm; \( F_{\text{fric}} \) is friction force that arises upon movement of particle of concrete mixture along blade surface, H; \( z_1 \) is number of blades on shaft; \( V_{\text{abs}} \) is absolute speed of movement of mixture particles along shaft blades, m/sec.; \( c \) is coefficient of resistance to movement of blade upon mixing of concrete mixture in direction to its movement in circle; \( S_{\text{avg}} \) is screw pitch along its average diameter, m; \( z_{\text{screw}} \) is number of screw turns; \( D_{\text{in.screw}} \), \( D_{\text{out.screw}} \) is outer and inner diameter of screw, m; \( \rho_0 \) is average density of concrete mixture, kg/m\(^3\); \( f_1 \) is a coefficient of friction of mixture upon movement of particles of concrete mixture along mixer body; \( \alpha_{\text{avg.screw}} \) is lifting angle of flight auger along average diameter, m; \( \kappa_s \) is return factor of mixture; \( \eta_{\text{shaft}} \), \( \eta_{\text{screw}} \) is efficiency of drive of blade shaft and ribbon screw.

Thus, process sets are assembled from machine modules, which, due to their mobility, allow renovations works with complete mechanization of separate operations and possibility for automated control of production process at small time consumption, depending on certain conditions of renovation works.

4. Conclusions

- Detailed analysis of emergency buildings within Ukraine was carried out.
- Using of modern construction technologies upon renovation of emergency buildings requires the development of respective equipment. For this purpose, new sets of equipment for renovation works based on modular principle were represented.
- Principal diagram of one of the variants for process set of small-sized equipment was proposed,
and its operation mode was described.
- Respective dependencies for calculation of basic parameters of operation of process sets were provided.
- Analytical dependencies for calculation of the basic parameters of technological sets operation are given.

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